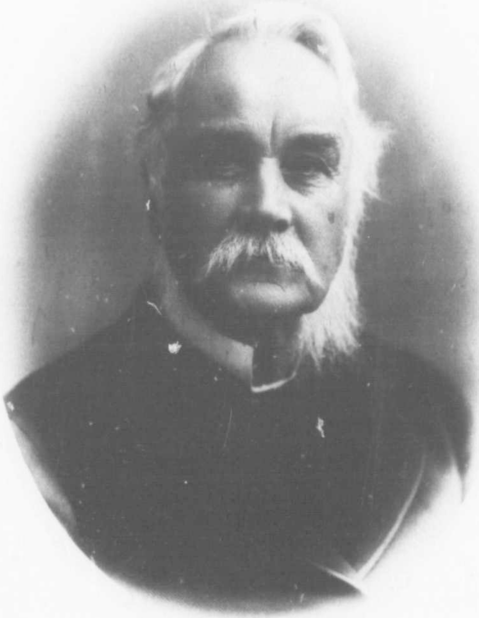


C. S. Gzowski
Colonel. A.D.C.

PRESIDENT, CAN. SOC. C.E.
1889.

TRANSACTIONS

OF

The Canadian Society of Civil Engineers.

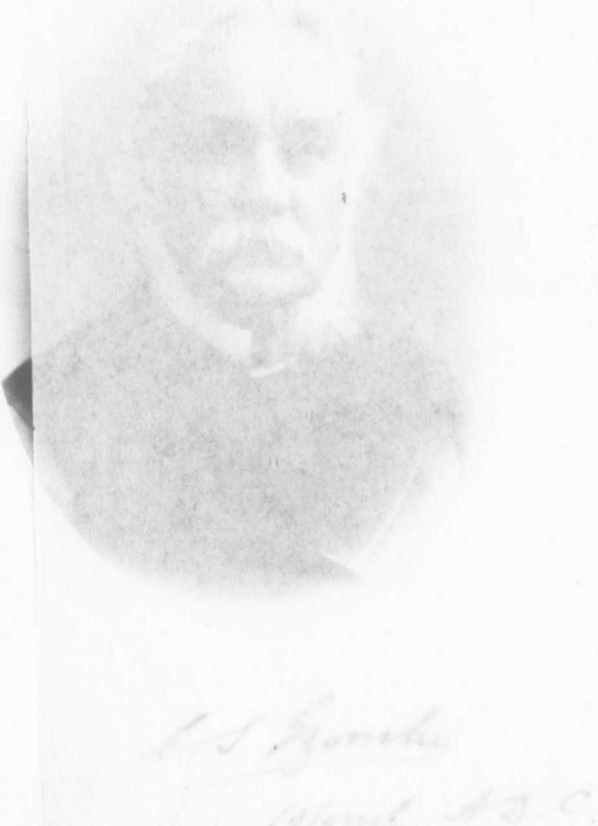
VOL. IV.

JANUARY TO DECEMBER,

1890.

Montreal:
PRINTED FOR THE SOCIETY
By John Lovell & Son.

1891.



PRESIDENT, CAN. SOC. C.E.
1889.

TRANSACTIONS

OF

The Canadian Society of Civil Engineers.

VOL. IV.

JANUARY TO DECEMBER,

1890.

Montreal:

PRINTED FOR THE SOCIETY

BY JOHN LOVELL & SON.

1891.

CONTENTS.

ERRATA.

Vol. IV.

Page	17,	Line	35,	*for*	" citizens deserve "	*read*	" company deserves."
"	25,	"	34,	"	" 2 "	"	" 3."
"	171,	"	31,	"	" wire "	"	' were."
"	267,	"	16,	"	" I and II "	"	" VIII and IX."
"	269,	"	40,	"	" I "	"	" VIII."
"	271,	"	15,	"	" I and II "	"	" VIII and IX."
"	271,	"	25,	"	" I "	"	" VIII."
"	272,	"	39,	"	" II "	"	" IX."

INSTRUCTIONS FOR PREPARING PAPERS, ETC.

In writing papers, or discussions on papers, the use of the first person should be avoided. They should be legibly written on foolscap paper, on one side only, leaving a margin on the left side.

Illustrations, when necessary, should be drawn on tracing paper to as small a scale as is consistent with distinctness. They should not be more than 10 inches in height, but *in no case* should any one figure exceed this height. Black ink only should be used, and all lines, lettering, etc., must be clear and distinct.

When necessary to illustrate a paper for reading, diagrams must be furnished. These must be bold, distinct and clearly visible in detail for a distance of thirty feet.

Papers which have been read before other Societies, or have been published, cannot be read at meetings of the Society.

All communications must be forwarded to the Secretary of the Society, from whom any further information may be obtained.

The attention of Members is called to By-laws 39 and 40.

CONTENTS.

CANADIAN SOCIETY OF CIVIL ENGINEERS.

LIST OF OFFICERS FOR THE YEARS 1887 TO 1890.

	1887.	1888.	1889.	1890.
President	T. C. Keefer.	S. Keefer.	C. S. Gzowski.	C. S. Gzowski.
Vice-Presidents	C. S. Gzowski. J. Kennedy. W. Shanly.	C. S. Gzowski. E. P. Hannaford. H. F. Perley.	E. P. Hannaford. H. F. Perley. P. A. Peterson.	E. P. Hannaford. J. Kennedy. H. F. Perley.
Members of Council	F. N. Gisborne. E. P. Hannaford. W. T. Jennings. S. Keefer. L. Lesage. H. D. Lumsden. A. Macdougall. H. F. Perley. H. Peters. P. A. Peterson. H. S. Poole. H. N. Ruttan. P. W. St. George. C. Schreiber. H. Wallis.	H. Abbott. F. R. F. Brown. F. N. Gisborne. J. Hobson. W. T. Jennings. J. Kennedy. L. Lesage. A. Macdougall. H. A. F. McLeod. M. Murphy. P. A. Peterson. H. S. Poole. H. N. Ruttan. P. W. St. George. C. Schreiber.	G. F. Baillairge. J. D. Barnett. K. W. Blackwell. St. G. J. Boswell. F. R. F. Brown. G. C. Cunningham. E. Gilpin. F. N. Gisborne. W. T. Jennings. G. A. Keefer. J. Kennedy. M. Murphy. B. D. McConnell. E. Wragge. J. E. Vanier.	W. P. Anderson. J. D. Barnett. F. R. F. Brown. K. W. Blackwell. C. E. W. Dodwell. W. T. Jennings. G. A. Keefer. H. G. C. Ketchum. T. Monro. G. H. Massy. P. A. Peterson. H. N. Ruttan. P. W. St. George. J. W. Trutch. E. Wragge.
Past Presidents and Hon. Councillors	....	T. C. Keefer.	T. C. Keefer. S. Keefer.	T. C. Keefer.
Secretary Treasurer	H. T. Bovey.	H. T. Bovey. H. Wallis.	H. T. Bovey. H. Wallis.	H. T. Bovey. H. Wallis.
Librarian	....	F. Chadwick.	F. Chadwick.	F. Chadwick.

Canadian Society of Civil Engineers.

Session 1890.

TRANSACTIONS.

Thursday, 2nd January.

P. A. PETERSON, Vice-President, in the Chair.

VANCOUVER WATER WORKS.

DISCUSSION.

Mr. E. Mohun. The author, in his very interesting and comprehensive paper, gives the average velocity of the Capilano River for the first seven miles from its mouth at five feet a second. A difficulty has been frequently encountered,—notably in the precipitous mountain ranges of the Pacific Coast,—in maintaining impounding reservoirs in somewhat similar situations. In these torrential streams it has been found that the boulders and gravel washed from the banks and bed above the dam are liable to be swept down and gradually fill the reservoir. A velocity of five or six feet a second will move good sized boulders, and less than half that velocity will move gravel. From the author's description of the bed of the stream, it would appear that the velocity has been great enough to remove most of the gravel from the channel, except at points where from the formation of the banks slack water was encountered. On the other hand, as even the most sanguine Vancouverites do not anticipate a population of four or five millions requiring a daily supply of 440 millions of gallons, a storage reservoir, as such, is not an essential, provided means are adopted to keep the entry conduit clear.

The steel mains which were built and laid by the Albion Iron Works Company of Victoria did not when first laid give satisfaction. Many were leaky, and considerable damage was done to the streets.

These defects have, it is believed, been since remedied, and the writer is informed that the same Company subsequently laid a similar main with complete success for the Victoria Water-Works. The writer understands that the Iron Works Company was solely responsible for making and laying the steel mains in Vancouver.

On the 15th November, 1889, a serious accident happened to the submerged main, by which the city was deprived of its water supply for eight days. One of the 12 in. cast iron pipes, lying in 40 feet of water, was badly fractured, and it can hardly be doubted, from the position of the pipe, that the break was caused by a water ram. The writer understands that Mr. G. A. Keefer had recommended automatic blow offs at each end of the submerged main, to guard against just such an accident; but unfortunately his advice had been neglected. The blow offs referred to by the author are not automatic. The break was repaired by a diver, who covered the fracture with a wrought iron sleeve, in two parts bolted together and lined with vulcanite. In justice to the Water-Works Company, it should be added that it did all in its power to reduce the inconvenience to a minimum, bringing water across the Inlet, and delivering it free to its customers by cart.

Having been resident in Vancouver at the time of the discussion of the rival water-works schemes, the writer is aware that the main objections raised to the Capilano project were based upon the supposed difficulty of crossing the Narrows. One party said that it could not be done, because no similar work on the same scale had yet been attempted. It is to be hoped that there are but few engineers with whom such a reason would have weight. The more reasonable opponents of the work did not dispute the practicability of laying the pipe, but thought that, in only having a single main, in the event of an accident to it, the safety of the city would be imperilled, putting on one side the terrible inconvenience of a short water supply. From Mr. Smith's paper it appears that the duplicate submerged main was a part of the general plan which hitherto the company has failed to carry out.

The writer has always believed in the feasibility of laying the submerged main, and has never hesitated to express this opinion to the opponents of the scheme. Looking, however, to the vast interests at stake, the has always insisted upon the necessity of the submerged main being in duplicate, and is glad to learn that since the accident the company has taken active steps towards laying on additional main across the Narrows. From the reports of the divers it would seem that the pipe has not been moved by the current from the position in which it was first laid.

With regard to the dangers to be apprehended from vessels' anchors, the writer is inclined to think they have been exaggerated; nevertheless, were he responsible for the maintenance of a single line of pipe across the Narrows, upon the integrity of which the very existence of the city might at any moment depend, he would be very uneasy until all human precautions had been taken to secure its safety. A simple mode of obviating any risk from ships' anchors would be to cover the pipe with concrete in sacks laid by a diver. This if done properly would also add greatly to the strength of the pipe; and if the diver's report, that the pipe was lying in a groove in the sandstone rock, is correct, the pipe, by the means suggested, would be completely incased in a shell of rock.

The unfortunate accident referred to has, for a time, put a stop to submitting to the ratepayers, a scheme for the purchase of the Water works by the city; and though the vast majority of the citizens are agreed that the city should own its water supply, no by-law approving of the purchase would pass, unless it was felt that such another failure was practically impossible. The burnt child dreads the fire. Vancouver has once been wiped off the face of the earth, and it cannot be wondered that her citizens should refuse to purchase a system, which, under the same circumstances as occurred a month or two ago, would leave them at the mercy of a conflagration which might occur at any moment.

Mr. P. Summerfield.

The conception of the Capilano Water-Works for the supply of the city of Vancouver was of its very nature one of the best examples of hydraulic engineering to be met with on the Pacific Coast of the Dominion. The great difficulty to be encountered was the crossing of an arm of the sea under conditions entirely unparalleled in water-works engineering, and in some respects the pipe line across the Narrows of Burrard Inlet is almost without an equal.

The design of Mr. G. A. Keefer, M. Can. Soc. C. E., for the Capilano Water-Works was not the only design for Water-Works for the city of Vancouver.

The Coquitlam Water-Works, designed by Mr. E. A. Wilmot, M. Can. Soc. C. E., was also under consideration at the same time that the Capilano Water-Works was being matured, and as both projects received a great deal of consideration at the time, their merits and demerits being frequently discussed both in the press and elsewhere, it may not be out of place for an outsider to present the features of both schemes to the Society of Civil Engineers. The data before the writer are the reports by Col. W. R. Eckhart, of San Francisco, on the Capilano River Scheme, and which is now constructed, and the Coquitlam Lake Scheme, which is now being matured for the supply of the city of New Westminster, reported upon by Mr. H. Schussler, chief engineer of the Spring Valley Water-Works of San Francisco.

The elevation of the pipe inlet as given by Mr. Eckhart for the Capilano was 422 ft.

The elevation of the pipe inlet, as given by Mr. Schussler for the Coquitlam, was 435 ft., so no important difference obtained between the elevations of the two proposed systems.

The entire length of the Capilano scheme, as given by Mr. H. B. Smith in his valuable report, is 52,741 ft. from the dam to the centre of the city, or very nearly 10 miles.

The entire length of the Coquitlam scheme as given by Mr. Schussler is 105,600 ft., or 20 miles.

It will thus be seen that the laying of the submerged pipe across the Narrows of Burrard Inlet was the direct means of saving 10 miles of piping so far as Vancouver water supply was concerned.

Mr. Thomas C. Keefer, C.M.C., Past President of the Society, reported upon the Capilano scheme; and looking now upon the accomplished work, the only feeling is one of admiration for the design of so bold an engineering feature as the submerged pipe line across Burrard Inlet Narrows. For a country or carrier main, mild steel enables the engineer to undertake works of magnitude, that, if he were compelled to use cast iron mains, would almost render the cost of such works prohibitive.

At present ruling prices, a steel main of equal dimensions can be laid complete in the trench for about the same figure that a cast iron main could be landed on the wharf in Vancouver or any other port on the Pacific Coast; thus shewing clearly that it is possible to effect a saving of nearly 40 per cent. in the cost of the pipe line. But valuable as mild steel is for mains of large dimensions, there appears to be a tendency among engineers to exact too much from it.

Thus in the Vancouver Water-Works system, the ultimate strength of the 16 inch main, allowing a tensile strength of 60,000 lbs. per inch for plates, and .7 for strength rivetting, would be 580 lbs. per sq. inch, and the same data for the 22 inch would permit of 420 lbs. per sq. inch. Now, according to Mr. Smith's report, the 22 inch main has to sustain a head of water equal to 164 feet in height or a pressure of 71.17 lbs. per sq. inch, as a maximum. The factor of safety in this case is therefore 6.

In the case of the 16 inch main, the head of water sustained is equal to a column of 415 feet, and equal to a pressure of 180.11 lbs. per sq. inch as a maximum. The factor of safety in this case equals a little over 3 or nearly $3\frac{1}{4}$. It is apparent therefore that no very great amount of corrosion can take place without very materially reducing the factor of safety, and that moreover the workmanship and material must be the best obtainable.

From Mr. Smith's report there is a flush valve on the 22 inch main, and likewise one air valve in the tunnel. On the 16 inch main there is a flush valve on the north side and another on the south side of the Inlet, one air valve located between the Inlet and Coal Harbor, and two flush valves on opposite sides of Coal Harbor.

The total number of vertical and horizontal bends are given by Mr. Smith at 179. It would be interesting to know how many of these are horizontal and how many vertical bends; for no matter how free from sediment the waters of the Capilano may be, there are certainly a great number of elevations and depressions without either air or flush valves, and doubtless there will be a great difference of opinion as to the capacity of the 16 inch main after accumulations of air and silt have taken place.

From the description of the turning on of the water, it is very evident that water-ram and air compression were treated as a myth, and it would afford a great deal of valuable information if Mr. Smith would give a detailed account of the behaviour of steel mains, having a factor of safety ranging from 3 to 5, a large number of angles of elevation and depression along the pipe line, few air valves and very few flash valves, with a full head of water flowing with a velocity of 1.4 feet per second. The water seems to have taken $3\frac{3}{4}$ hours to traverse 19,320 feet from the tunnel to the north shore of Burrard Inlet. That something occurred may be inferred from the last two paragraphs of Mr. Smith's paper.

It appears that a tank is now placed on the north side of the Inlet at an elevation of about 230 feet above tide water mark, thus reducing the pressure upon the lower portions of the system by 200 feet of head, and likewise reducing the pressure upon the upper portion of the system by the difference between the velocity and static pressures, as the tank is allowed to flow over and to discharge the surplus water into the river. Some kind of provision is made for inserting a plug so as to utilize the full head of 430 feet in case it should be required.

Taking Mr. Smith's description of the Vancouver Water-Works, one cannot help feeling that there can be no difference of opinion about the works as projected by Mr. Keefer, for they are without a doubt unrivalled in this section of country; but there is a wide field for discussion relative to the manner in which Mr. Keefer's plans have been carried out. Doubtless other engineers who are conversant with the question will give us the benefit of their extended and valuable experience on this very important branch of engineering,—water-works construction.

Mr. D. J. Russell Duncan. The writer has read the advance proof of Mr. H. B. Smith's paper on the Vancouver Water-Works with very great interest, and as copious extracts have been made from a small pamphlet, which the London Steel Pipe Co. published a few years ago, and the joint referred to in that pamphlet is described on page page 338 (Vol. III) of the author's paper as a *cumbersome arrangement,* the writer desires to bring under the notice of the Society some particulars with reference to this joint.

The advantages of a single socket, as compared with the Moore & Smith joint, are the great reduction in the quantity of lead consumed, the adaptability of the joint to overcome angular deviations in the pipe track, and the increased strength of the spigot, which must be of sufficient firmness to resist the strains due to caulking by inexperienced workmen.

The Moore & Smith joint, although it has no doubt been very largely employed, is inferior to the joints referred to, because the nipple reduces the internal diameter of the pipe, and tends to create an increased velocity of the flow of water through the pipe and the joints; whereas the joint now referred to is so constructed, that the pipe is actually larger in internal diameter wherever the joints occur, and this system of construction is of decided advantage by reducing the friction of flowing water.

It cannot be fairly said by the author that the joints to which the writer refers have been entirely discarded on the Pacific Coast, for the simple reason that they have never yet been employed there, with the exception of the pipe line constructed by the Steel Pipe Company, Limited, London, for the water supply of the town of Mazatlan, Mexico. This is the first pipe line on the Pacific Coast fitted with the improved joints, and is a line 20 miles in length and 14 and 12 inches internal diameter.

With regard to the 22 inch and 16 inch pipes, it is a matter of some surprise that these pipes were specified so thin. The pressure upon the pipe line is about 400 feet near to the Burrard inlet, and the pipes at this point are 16 inches diameter, and .11 of an inch in thickness. So far as the writer's investigations go, the ordinary working pressure on a Californian wrought iron pipe of this thickness and diameter would not exceed about 265 feet head, and according to the practice of this company, pipes of this thickness would not be made of mild steel for a higher pressure than 285 feet. It is clear therefore that the pipes laid by the Vancouver Water-Works Company are subject to much higher strains than is customary, and there is every reason to believe that the life of the pipe will thereby be injuriously affected. The paper gives no information regarding the test pressures imposed upon the steel pipes, indicating that the cast iron connections only were tested to a pressure of 300 lbs. per square inch.

It is unfortunate that the author has not given details of the rivetting. On the 2nd of May, 1889, this Company received a long letter from him, indicating that the pipes leaked to such an extent that when the water was turned on it was found impossible to stop them. In his letter dated April 13th, 1889, he says: "In two days time it was discovered that the leaks were enlarging, and the plates being actually cut by the jets of water forced out between the laps. The holes made in this manner are just beyond the edge of the outside lap, and are of all shapes, some being circular and nearly half an inch in diameter. After the pressure the appearance presented by the pipes was as if they had been acted on at several points by a sand blast." He then goes on to state that attempts were made to repair the leaks by cast iron rings; but on again subjecting the pipes to pressure, new leaks were developed, and at the date of his letter 5,700 feet of the pipes were leaking so badly that their removal was ordered and new pipes decided upon.

It is somewhat misleading to read in the latter paragraphs of the paper that the leaks discovered at the seams were speedily repaired by steel rings four inches wide, made in halves, which were made to go round the pipes, in the face of the information contained in the letter of the 13th April, to which reference has been made, and the writer would suggest that the author should correct the latter part of his paper.

In replying to the author's letter about the leaks, the following questions were asked, and it is very desirable that the information should be communicated to the Society :

Were the rivets put in hot or cold ?

Were they closed by power, and if so by what power ?

How were the longitudinal seams distributed round the circle ?

What was the length of the rivets ?

Were any sections of pipe rivetted up and tested by hydraulic power in excess of the working pressure, to prove the quality of the rivetting, and was any test whatever made of the rivetting ?

With what were the pipes coated, and how was the coating applied?

How were the pipes jointed together?

The length of pipes being 23 feet, $9\frac{3}{4}$ in., seven plates was a very large number to employ. Four would have been preferable, thus saving a number of rivetted seams.

The rivetting was apparently faulty and the plates not properly laid together at the seams, and possibly burrs were left at the rivet holes which prevented the perfect contact of the surfaces.

Although a rivetted joint may be made strong enough to resist the strain brought to bear upon it by a tension testing machine, and may be proved to be very nearly equal in tensile strength to the original plate, yet the rivets may not be close enough to secure water tightness under pressure. Experience has proved that there is considerable difference between pipes being strong enough to resist a certain tensile strain across the joint, and being water-tight under fluid pressure, which may exert no greater tensile strain across the joint than that for which it was designed. The evidence submitted at the time, led this firm to the opinion that the defects in the pipe were due to faulty workmanship and inexperience on the part of the contractors.

No information is given in the paper as to the means adopted for letting off air in the pipe, and possibly the leakages which were found were aggravated by the accumulation of air in the mains before the pipes were properly filled with water. Neither is any evidence given as to the hydraulic tests upon specimens of the pipes to prove the tightness of the rivetting.

The writer considers it bad practice to make up the pipes of so many small plates. It is found much more satisfactory to make the plate cylinders in lengths of from 6 to 8 feet; and if this system had been adopted for the steel pipes described by the author, there would have been a great reduction in the number of circumferential rivetted seams.

Caulking, in the manner described by the author, tends rather to aggravate leaks than to prevent them whenever mild steel plates are employed. A better system for preventing leakages and to make perfectly water-tight joints is to employ suitable plate closing apparatus upon the rivetting machines, the effect of which is to close the plates perfectly together, so that the laps are thoroughly overlaid and the surfaces brought into close contact before the rivets are inserted; then when the rivets are closed by hydraulic pressure there is no liability to leakage, and caulking is entirely dispensed with.

The description of the method in which the lead joints were made is such as to indicate that the work of making a Moore & Smith joint is at least twice as much as that of making the patent socket joint recommended by the writer. The great care which has to be taken in making the Moore & Smith joint in a perfectly straight line is a very serious disadvantage. A particular feature in an efficient joint should be its facility for overcoming angular deviation in the pipe line, and thereby reducing the number of bends.

It may be mentioned that a 9 inch steel pipe, which was laid by this firm in the Tay Viaduct some years ago, was laid round a very sharp curve on the bridge, without any special connections whatever, the flexibility of the joint permitting the curvature of the pipe line. The joints were made above ground, and 360 feet of jointed pipe in a single curved line lowered into the trench.

Nor is there any necessity in a joint such as is recommended for the caulkers to be cautioned with regard to the packing of the lead. The spigot ends of the pipes are welded into cylinders, and made about 50 p.c. thicker than the pipe, so that any pressure the caulker imposes upon the lead will not indent the pipe, or in any way cause it damage. The sockets for pipes up to 24 inches diameter are stamped by hydraulic pressure on the system invented by Mr. James Riley, General Manager of the Steel Company of Scotland, Limited. This is known as the Riley Patent Socket. This socket has an external lip or flange which adds very greatly to its strength, and with this joint it is not found that the shell of the pipe is bent inward nor the mouth of the socket bent outward, as is the case with the Moore & Smith joint, described by the author on page 339 (Vol. III) of his paper.

With regard to the system of constructing pipes with inner and outer courses, this method is entirely discarded by this Company on pipes of all diameters made of plates under .2 of an inch in thickness. A much more correct and reliable method of making perfect circumferential seams is obtained by the use of suitable machinery for expanding the circumferential lap at one end of the plate cylinder, after the plates have been punched and bent into cylinders; all the circumferential seams are carefully punched by multiple punching machines precisely to the same pitch, and the increase in pitch due to the enlarged diameter of the overlap is obtained by stretching the plate in the manner described.

For pipes made of plates exceeding .2 of an inch thick, the circumferential seams of the outer course are punched when the plate is flat, by dividing machines which divide the pitch into the most minute fractions necessary to overcome the irregularities between the diameter of the outer and the diameter of the inner course of plates. The system described by the author, of leaving one end of the plate cylinder to be punched while the pipe is rivetted up in the pipe track, is not only one which causes enormous delay in the execution of a pipe contract, but one which is liable to very great inaccuracies of workmanship. The method described of fitting the pipes together in a trench, drawing them apart, punching the holes, putting them together again, and rivetting them up is most unsatisfactory.

With regard to the distribution of the longitudinal or straight seams, a pipe made of very thin plates, such as those employed for the Vancouver Water Works, is made stronger and better by a uniform distribution of the longitudinal seams of the several courses around the circumference, instead of having them all in one straight line. Sometimes in constructing pipes with the longitudinal seam all in one line along the pipe, much greater care has to be taken in straightening the pipe, as there is a tendency to curvature.

The paper is one of very great interest to all engineers interested in water-works, and the author has displayed conspicuous ability in the execution of the works under his charge.

Mr. G. H. Henshaw.

Mr. Henry Badeley Smith's able paper on the construction of the dam and pipe line of the Vancouver Water Works leaves little for the critic to say, beyond expressing admiration for the successful manner in which difficulties both novel and otherwise have been met under exceptional circumstances. The moderate height of the dam no doubt permitted the foundation (in the absence of puddling clay) to be laid with safety in the manner described; nevertheless, the accident to the "lean to," and one of a similar nature that occurred previously to another part of the structure, would seem to be a warning in case it should be proposed at any future time to increase the height of the dam.

With regard to the objections and answers to the plan of laying the pipe across the Narrows of Burrard Inlet, a few remarks may be in order.

The first objection begs the question by claiming as known a force that is not known, while the answer claims a mathematical demonstration not given, but doubtful in its fundamental basis, as all calculations of the forces of the sea must be without actual previous experiment.

The true reply to the objection is philosophical not mathematical. The bed of the inlet at the point of crossing is stated to be composed of soft sandstone, partially covered with mud, gravel and cobble stones. Now a stream with no friction on the bottom, other things being equal, would flow with equal swiftness at every depth, hence the difference in speed between the bottom and top would be a measure of the friction at the bottom. But the present case is one of a tidal current, whose efflux and reflux are governed by so many and complicated conditions, extending even to the existence, occasionally at least, of an outward current at bottom and an inward current at top, that even the most careful observation would fail in producing reliable formulæ. It is plain then that where the erosive force is actually unable to remove mud, gravel and cobble stones, a 12 in. metal pipe would lie undisturbed, quite independent of its self-made trench. This argument also answers the second and sixth objections. The third has a little more in it, and is more weakly replied to. It is decidedly doubtful whether such a pipe could resist the direct impact of a falling anchor, or that any engineer would invite a trial; nor is it likely that he would be free from anxiety should a vessel, whose anchor fluke embraced the pipe, be caught in a violent gale. It would be interesting to see what mathematicians would make of the problem. The wisest course would seem to be to protect those parts which are not sufficiently trenched already in the bottom. The fourth and fifth are speculative, and need facts capable of clear verification in their support before they have a right to claim notice. The seventh and eighth are mathematical, to which a very decided practical answer has been given. The ninth objection is of unascertained antiquity, and is still voiced wherever old settled habits of thought are disturbed by new ideas. "Who ever heard of such a thing?" "Don't take much stock in these new fads," etc.

It is true that it is sometimes difficult, without giving more attention than is convenient, to decide whether a certain scheme is the work of a "crank" or of a scientific mind, but if it is worth considering at all, it is surely the duty of critics to meet arguments with something more than mere assertion, and to support their own statements on facts and premises which are undisputed or capable of ready proof. Mr. Smith is to be congratulated on having contributed such an interesting paper to the Society.

As the paper is a long one, it will be better to discuss that portion relating to the dam this evening. If the paper is all read through at once, the points relating to the dam will probably be forgotten by next evening. Mr. Peterson.

Was there not some mistake about the size of the tree? It would be hard to get the stumps out. Mr. Blackwell.

The author was perhaps a little misleading. The tree must have Mr. C. L. Smith.

been one badly formed at the root. He did not think there was a tree of that size solid right through.

Mr. C. E. Goad. It was a rare thing to see a tree solid right through there. The paper is well written and the subject elaborately gone into. There seemed to have been great difficulty in regard to the carriage of material, etc., but this matter could not be followed out properly without being able to see how the plans were adapted to the peculiar formation of the ground.

Mr. Peterson. It would have been much better had a large sketch been made showing the most important points of the dam, etc., and the methods taken to prevent the water following through the longitudinal timber, which is a great source of trouble in all works of this kind. As he understood it, in this case the water was kept back by sheet piling. Then there was the question of getting round the end, also a difficulty that had been overcome by a brush and gravel bank, but he did not understand how the concrete was put in. It would be a good plan to make a rule, such as was in force in the Institution, that all papers should be accompanied with large drawings which could be hung on the walls. This would very materially tend to aid the discussion.

Prof. Bovey. In reading the paper over, it would seem that some of the concrete had been made by mixing a certain amount of cement with gravel, out of which stones over a certain size had been eliminated. This was contrary to the practice recognized by many eminent authorities, who said that the best concrete was made of stones of irregular sizes—not limited to $1\frac{1}{2}$ inches.

Mr. Gower. The material was different from what we had here. Take the London gravel, which was similar to that they had in Vancouver, and the practice was the same. All big gravel was taken out. It was more of a sea gravel than anything else, and generally it ran $1\frac{1}{2}''$ to $\frac{3}{4}$,'' and with a fine kind of grit was mixed six to one with Portland cement. This plan was invariably adopted by engineers in the south of England.

Prof. Bovey. The best concrete was made of gravel of different sizes—the more irregular the sizes the better. As to limiting the size of the gravel, some engineers say that large blocks of stone can be put in without injuring the concrete in the least.

Col. Hayward, City Engineer of London, in his specification for gravel, specifies for a small gravel nothing larger than $1\frac{1}{2}$," mixed in proportion of six to one. Mr. Gower.

The idea of having stones larger than $1\frac{1}{2}$" taken out was probably because the concrete had to go into a small space and had to be rammed. In filling large spaces there was no question but that large stones, two or three feet square, might be put in. In the Lachine bridge they put large masses of concrete—20′ × 40′ × 15′—in the middle of which they might have put large stones and filled in all round them, and in many cases stones larger than $1\frac{1}{2}$" were put in. In the case under discussion, however, they were quite right in taking out everything over $1\frac{1}{2}$," for the reason that they had to pack the cement, and it would be much easier to ram and make a much better job with small stones than with large ones. Mr. Peterson.

The timber in Burrard Inlet would in all probability be affected by worms. He did not know to what extent the Teredo Navalis had appeared on the Pacific coast. Some member present might be able to say whether any information had been obtained on this subject. Prof. Bovey.

Had seen specimens in the Library of the House of Commons at Ottawa, showing the effect of the "Teredo Navalis" on the timber of the Pacific coast, which is very disastrous. It had occurred to him what a fortunate city Vancouver was as compared with other towns having the average system of water-supply and cost of same. In Vancouver they had an abundant supply of cold, clear, running water for almost nothing. He imagined that if these works had been economically carried out, there would be a supply of water for all time at a cost of from one to two dollars per head per annum. There was a pressure of 80lbs. at the highest part of the town, which was remarkable. Mr. Blackwell.

In the harbour of Vancouver, on Burrard Inlet, piles of 18" diameter are eaten through sometimes in a year, and in a sawn section one can scarcely find half a square inch in any one place of solid wood. The holes are $\frac{1}{2}$" in diameter, and some probably larger. The wood is just as if it had been perforated with a series of auger holes. He felt certain the teredo would never reach the dam, there is a great elevation with a very heavy current. They did not find them even where the water was brackish. Mr. Peterson.

Prof. Bovey. It had been stated that good cast-iron would resist the action of salt water, but he did not know of a case on record in which it had been found to do so. In a case that had come under his own notice columns taken up from foundations in salt-water were just like sponge.

Mr. Blackwell. He had not had much experience with cast-iron in salt water, but had seen cast-iron taken out of columns or piers just like cheese. That was the ordinary gray cast-iron of foundry casting. He would like to know something more about these pipes, which he believed were made in Glasgow. The sheet steel pipes had ends rivetted on which were described as "white cast-iron." There must be something more than that, because if simply white cast-iron they would be of no use at all; they would be like glass, having no tensile strength. In Glasgow there were several firms which made a specialty of producing a metal called "McCaffie's metal"—a sort of white metal. In the first place when cast it was like white pig, and was then decarbonized in a furnace, which converted it into a kind of semi-steel. If simply white metal they would not be fit for the purpose. It might be assumed that these joints were made of a material superior to ordinary "white pig" or "white cast-iron." A little more information regarding these joint castings would be interesting.

Mr. Peterson. Plenty of white metal water pipes could be obtained from Scotland and the north of England. He had got some out of pure white metal, which were nearly useless.

Mr. Blackwell. White metal was useless, as it had so very little tensile strength.

Mr. Peterson. When in Vancouver last year he saw this cast-iron pipe, a portion of the wrought-iron pipe, and also the valve that was placed between the cast and wrought iron pipe. There was a very heavy stream of water pouring out, and he was told that the wrought-iron pipe was not sufficiently strong to stand the pressure. Its thickness was less than $\frac{1}{4}''$—about $\frac{3}{16}''$, and the rivets, he imagined, were about 4″ or 5″ apart. It was a very thin plate, and the water was flowing in little streams out of nearly all the joints of the sides. He believed that they had since put straps round the pipe to hold it together, but they had reduced the pressure by means of a safety valve. He was astonished to see the small size of pipes which had been put in for mains, viz.:—4″ and $2\frac{1}{2}''$, and he thought this was a mistake. He considered streets should have nothing less than 6″ pipe, that is in places where there was to be fire protection.

A 4″ pipe was not large enough, and a hydrant on a 2″ pipe, in the case of a large fire with three streams going, would be utterly useless—there would be no water. It was, however, a case where the water supply was furnished by a company, which he thought should never be done. There can be no possible reason why every city or town should not build and own its water works. The corporation can certainly borrow money at a lower rate of interest than any company, and can afford to put in just such distribution of pipes as are wanted, and the corporation will then have complete control of its own streets. He knows of no instance where corporations have been supplied by water companies in which the supply has not been unsatisfactory, or in which the cost to the citizens has not been greater than if they had had a much more liberal supply under their own control.

In reply to the remarks of Mr. Mohun, the bed and banks of the Capilano having been, for ages past, swept by flood currents of great velocity, all loose boulders have long since been carried away, leaving the larger boulders so interlocked that it is rarely, and only in extreme floods, that one is loosened and carried down stream. In the course of years, it is probable that detritus from the banks may lodge itself in front of the dam; but, should this accumulate to any inconvenient extent, it can be readily removed, and at small expense. In the ordinary quiescent state of the river, when the current does not exceed 5 miles per hour, it is not probable that stones or good-sized boulders, as suggested by Mr. Mohun, are in motion along the bed of the stream. Smeaton's observations go to prove that a velocity of 11½ feet per second will not derange quarry rubble stones not exceeding half a cubic foot. Mr. H.B. Smith

The considerations which decided the construction of a dam and reservoir at the point of supply were as follows:—A pressure as nearly uniform and invariable as possible would be obtained. There would be a direct gain of 11 feet of head, which would allow the system to be carried through the rock bluff at the end of the 22 inch main, by means of a tunnel of moderate length. To obtain the same head without a dam, the 22 inch main would have to be extended at least 1,500 feet further up stream, under conditions which presented features especially unfavourable for pipe laying, and for the permanency of the pipes when laid. By reference to plate XVI., it will be seen that, at a point 1,500 feet above the present dam, the channel of the river is not confined to one permanent position. Moreover, as the eastern branch, at the present period, is dry at low water, and the island between the channels is invariably flooded at high water, an extension of the 22 inch main above the dam must necessarily cross the western branch to its western side, and following that side, where the banks are high and rock in situ is exposed, reach a point where works for an entry conduit of a safe and reliable character, during all stages of the river, would be of a costly nature.

Finally, as the Capilano is a stream which has only become known since the construction of the water works, reliable data as to the lowest possible stage of water are still wanting. It is impossible to say with certainty what changes in its volume may occur in the future; more especially when it is taken into account that its banks may be denuded of timber by forest fires and the improvements of settlers, and that at any season the snowfall in the mountains, on which its very existence depends, might be very much less than it has ever been known to be. Giving due weight to these considerations, no doubt Mr. Mohun will acquiesce in the opinion that the dam is a very valuable addition to the system.

Several lengths of steel main in the low lying parts of the system subject to full head, when first laid, developed leaks more or less annoying. These leaks were, however, overcome in the usual manner, by means of cast-iron lugs, leaded and caulked, and by the substitution of new lengths where the originals were leaky enough to warrant this step. The Iron Works Company, who furnished the pipes, under contract for manufacturing, laying, and maintaining the line of mains for two months after completion, were solely responsible for the leaks; and it is worthy of note that the substituted lengths, made by them from the same design as the original leaky ones, were found to be entirely satisfactory, showing that the leaks in the original lengths arose, not from the character of the pipes used, but from some fault in the construction of these lengths. The Victoria Water-Works, for which the same company subsequently made and laid a main exactly similar in all its details, is no parallel case, the total head of that system being under 200 feet.

When the break in the submerged main occurred, the writer was in England, and can give no account of it from personal knowledge. All the evidence in his possession goes to prove that it was a break pure and simple, due to a severe water ram created by a too sudden closing of the hydrants, and acting upon a defective pipe casting. The outer and inner skins of the metal at the point of rupture were found to be as perfect as on the day of immersion, 15 months previously, proving conclusively that the action of the salt water had had no deteriorating effects. There appeared, however, in the centre of the fracture, a globular mass, showing a check by cooling or some other cause, which had prevented a proper fusion of the metal during the process of casting. The fracture beyond the flaw showed the hard, close-grained, white surface of a casting of good quality.

Inasmuch as there has been a great diversity of opinion, and so much has been written and spoken as to the possibility of repairing a break in the submerged main, it is fortunate that this accident occurred at the time it did, as it has demonstrated beyond question, even to the most sceptical mind, that this part of the system can be got at and repaired almost as readily as any other part. Although, on this occasion, the city was deprived of its water supply for a period of eight days, this was not due to the difficulty of effecting actual repairs, but to the unusually stormy weather which unfortunately prevailed at the time of the occurrence, preventing the company's divers from locating the leak. As soon as this was done, the necessary repairs were accomplished within 24 hours. Under the ordinary summer and winter conditions appertaining to Burrard Inlet, any similar leak can be repaired in the same or possibly a less period of time.

There can be no doubt that had Mr. Keefer's recommendation (that automatic blow-offs be placed at each end of the submerged main) been adopted, the possibility of a break from water ram, even under the conditions described, would have been greatly lessened; and had the general plan of the system been carried out in its entirety before the works were put in operation, such a break would have caused no inconvenience whatever to the city. It is even doubtful whether the citizens would have been aware of its occurrence. By referring to plate XVIII, it will be seen that the general plan provides for duplicate mains at the Narrows—one of cast-iron (laid) and one of steel (to be laid). Without presuming to criticise the action of the company in not having completed the crossing of the Narrows, as designed, up to the time of the break, there can be no doubt that it would have been well had they done so. At the same time, it must be conceded by all disinterested parties, that, as Vancouver is a young city, with as yet a small population, the citizens deserve every credit for the energy already displayed, and for the confidence they have expressed in the future progress of the city, by risking so much private capital in completing the system all but this one link, the more so as the chance of a break was infinitesimal. Since the occurrence of the accident, pipes have been ordered and tenders invited for the laying of the duplicate main.

The method proposed by Mr. Mohun, for protecting the single submerged main from ships' anchors, is not a new idea. From the inception of the scheme, it was intended, should circumstances render it advisable, to insure the safety of the pipes by a covering of concrete in sacks. In the present instance, however, the pipe shell being of great strength, and to a large extent imbedded in the soft sandstone bottom of the Narrows, it is a matter of opinion whether such a costly addition to the works would have been advisable; the more so, as the author is not aware that this or any other protection has been adopted in the case of the submerged mains of other systems.

Mr. Summerfield is labouring under a misapprehension when he quotes the Vancouver Water Works system as an example of the tendency amongst engineers to exact too much from mild steel. To make good this assertion, he has endeavoured to show that the factors of safety of the 22 inch and 16 inch mains are respectively 6 and $3\frac{1}{4}$, assuming the ultimate tensile strength of mild steel at 60,000 lbs. per square inch, with a loss of 30 per cent. for double rivetting, and that, with these factors of safety, no great amount of corrosion can take place.

The tensile strength of the mild steel employed in the construction of the mains in question is, as per contract, 72,000 lbs. per square inch; 60,000 lbs. being little more than is ordinarily allowed for rolled wrought-iron plates of the best quality. The double rivetting of the horizontal seams has been so designed that 75 per cent. of the full strength of the plates has been retained. The ultimate strength of the 22 inch main $\frac{11}{100}$ of an inch thick is, therefore, 540 pounds. This main, being subject to a maximum pressure of 71 lbs. per sq. inch, has consequently a factor of safety against rupture at the horizontal seams of $7\frac{6}{10}$ instead of 6.

The ultimate strength of the 16 inch main, $\frac{11}{100}$ of an inch thick, is 743 pounds. The maximum pressure it is called upon to withstand at its lowest levels (which it may be here mentioned form but a small part of its whole length, and are so situated as to be easy of access both for inspection and repairs) is 180 pounds per sq. inch. Its factor of safety against rupture at the horizontal seams is, therefore, $4\frac{13}{100}$, instead of $3\frac{1}{4}$.

These calculations refer to the ultimate strengths of the mains at their weakest part, namely, the double rivetted horizontal seams. As far as corrosion is concerned, and this is what Mr. Summerfield more particularly refers to, the seams, being of two thicknesses of metal, are the strongest parts of the pipe. The shell will be the first to give way under this cause; and, in calculating factors of safety with reference to corrosion, the full strength of the plate must be allowed.

These factors may readily be ascertained to be 10 and 5½ for the 22 inch and 16 inch mains, respectively. The author is of opinion that these results give satisfactory evidence of the permanent safety of the mains, and in support of this opinion would mention, that in the Pacific States of the Union long systems of rivetted wrought-iron pipes have been in constant and satisfactory use for many years, under pressures sometimes as great as one-half their ultimate strength.

In connection with this subject, the following table, showing the strengths and pressures in the various parts of the Virginia City, Nevada, supply main, 11½ inches diameter and 37,000 feet in length, may be of some interest.

VIRGINIA CITY, NEVADA, RIVETTED WROUGHT-IRON SUPPLY MAIN.

Ultimate strength 55,000 lbs. per sq. inch, less 30 p.c. for double rivetting.

Head in feet.	0 to 200	200 to 330	330 to 430	430 to 570	570 to 700	700 to 950	950 to 1050	1050 to 1250	1250 to 1400	1400 and over
Extreme pressure in lbs. per inch............	87	143	187	247	304	412	456	543	608	750
Thickness in inches....	.065	.072	.083	.109	.120	.148	.180	.220	.259	.340
Ultimate strength in lbs. per sq. inch..........	435	482	556	724	803	991	1205	1473	1734	2276
Factor of safety........	5	3.4	2.96	2.93	2.64	2.40	2.64	2.71	2.85	3

It may be here incidentally mentioned that, in a recent publication of the London Steel Pipe Company, issued under the auspices of Messrs. Russell Duncan and H. C. Mylne, Associate Members Inst. C.E., it is stated: "Wrought-iron pipes have been extensively used in the States, and it has been proved that no risks are run from fear of corrosion. Hundreds of miles of wrought iron pipes have been used for periods extending to over 30 years, and no indications are shown of injurious oxidation. In some cases the pipes have been used without coating of any kind, in others they have been coated with natural asphaltum, which is the common method of coating pipes in the United States. Under ordinary conditions, the coating of natural asphaltum is not affected by water, earth, or atmosphere."

In May of this year, 1890, 14 months after the opening of the Vancouver system, an official examination of the steel mains was made for the purpose of ascertaining to what extent corrosion had taken place. The earth covering was removed at numerous points along the line, and the pipes and castings closely examined without an indication of oxidation being found.

The number of horizontal bends in the 22 inch main is 33, and in the 16 inch main 103. Of vertical bends the 22 inch main has 20, none of which exceed 10 degrees deflection; and the 16 inch main 23, none exceeding 15 degrees deflection. As is the case in all properly constructed systems, every elevation of any magnitude is tapped by an air-cock; a fact, which, though not mentioned in the paper on the Vancouver Water Works, was so obviously necessary, that it might have been taken for granted. The profile of the 22 inch main from the dam to the blow-off at the tunnel, a distance of 2½ miles, is very uniform. Naturally the greater part of any sediment brought down from the well chambers will be deposited in this main. The 8 inch blow-off is amply sufficient to flush it when required.

The greater number of the vertical bends in the 16 inch main are located in the first 8,000 feet beyond the tunnel, where the pipe line passes over unavoidable sidehill. Whatever small proportion of sediment may be carried past the deep depression, where the blow-off at the tunnel is situated, into the 16 inch main, will be of minute particles, and will have little opportunity to settle in the bends, inasmuch as the velocity of flow in that main is $5\frac{6}{10}$ feet per second, a velocity amply sufficient to keep fine particles in a constant state of progression towards the 8 inch blow-off at Burrard Inlet. However, should an accumulation of silt from some unexpected cause take place at any of these bends, the deposit may readily and with reasonable expense be removed by the ordinary means adopted in such cases, such as self-acting scrapers, spring gouges, etc.

Mr. Summerfield unhesitatingly states that it is very evident, from the description given of the turning on of the water, that "water ram and air compression were treated as a myth." This is, to say the least, a hasty and ill-considered assertion, in no wise warranted by the account given. It is evident that, in this instance, he has pictured to himself a system of water works, being opened for the first time with a full velocity of water flowing, and every air-valve and blow-off closed. This portion of the paper was necessarily brief, and did not contain details minute enough to give a full and complete description of how the work was accomplished. Moreover, Mr. Summerfield, although he makes no mention of the fact, may have been led somewhat astray by a clerical error which appears to have crept into the manuscript or print. In the latter it is stated—"at 9.45 p.m. the water reached the closed 12 inch valves on the north shore of Burrard Inlet." For "valves" should be read valve. If this faulty paragraph had anything to do with the misunderstanding which seems to have occurred, it is to be regretted. But, in any case, in order that a clear conception be obtained of the manner in which the mains were first filled, the following more minute description is given.

When it was decided to make a test trial of the line of mains, the gate at the well chambers of the dam was lifted high enough to expose a segment of the 22 inch main 3 inches deep; the 8 inch blow-off at the tunnel and all the air-valves being wide open. By means of these, the air was expelled, the incoming water occupying its place, and very gradually filling up the main until it was discharging freely through the blow-off. The 22 inch main was allowed to continue in this state for a period of 48 hours. No breakage or sign of leakage having taken place, the gate at the well chambers was lifted from time to time, until, on the 5th day from the first partial opening, it was opened wide, the water in the main discharging freely through the 8 inch blow-off.

This trial being so satisfactory, it was then decided to test the 16 inch main. The 8 inch blow-off, before mentioned, was partially closed, and the water allowed to rise up the steep incline to the tunnel, until that part of the 22 inch main passing through the tunnel, and connecting with the 16 inch main, was filled one quarter full. How very slowly this was accomplished will be understood from the fact that, although the 22 inch main was nearly full up to the 8 inch blow-off, it required two hours from the time of partially closing that blow-off to reach the floor of the tunnel. The 22 inch main was not allowed to exceed about one-quarter full, but was maintained at this level, slowly and uniformly filling up the 16 inch main, until it was discharging freely by means of one of its 12 inch valves and the 8 inch blow-off at Burrard Inlet, the other 12 inch valve being kept closed in order to prevent the water entering the 12 inch main under the narrows. As in the case of the 22 inch main, all air-valves were kept wide open, allowing free vent for the escape of air, and affording absolutely no opportunity for air compression or hydraulic ram.

It is much to be regretted that Mr. Summerfield cannot be gratified in his desire for information as to the behaviour of the 16 inch main, under such (very contradictory) conditions as "*a full head of* water flowing with a velocity of 1.4 feet per second." As Mr. Summerfield calculated the velocity with which the water in this main travelled during the test trial, using the time and distance given in the paper, it is somewhat surprising that he did not also calculate the velocity due to the head and length, and thus avoid the error into which he appears to have fallen. From the data at his disposal, he might readily have deduced, that, under a full head of water, the velocity of discharge at the termination of the main in the city is $5\frac{6}{10}$ feet per second. But, as the portion referred to in the present instance is only that between the tunnel and Burrard Inlet, if a full head of water had been allowed to enter the 16 inch main at the tunnel, the velocity of out-flow would have been found to greatly exceed $5\frac{6}{10}$ feet per second, using as data the total fall 388 feet, and total length 19,320 feet, between these two points.

Had Mr. Summerfield ascertained these facts, he could not have fallen into the rather extraordinary belief that water ram and air compression had been treated as a myth; and it may be here mentioned, that, had both 12 inch valves been closed, and only the air-valves along the line and the 8 inch blow-off at Burrard Inlet been open, these latter would have been amply sufficient for the discharge of air and the prevention of hydraulic ram.

The day following the turning on of the water, a thorough examination of the whole line of mains from Burrard Inlet to the dam was made. Throughout the whole distance, no sign of leakage was apparent. Mr. Summerfield's inferences that "something occurred" are without foundation.

The reducing tank referred to is entirely temporary, having been built solely to relieve the pressure on certain defective pipe lengths in the lower levels of the system, until new lengths could be manufactured and substituted.

With reference to the remarks of Mr. Russell Duncan, in a comparison between steel pipes jointed by the Moore and Smith joint, and those jointed by means of faucets and spigots attached to the shell, the word "cumbersome" was used in reference to the latter. This was a general expression, and not intended to particularize any individual joint, such as the Riley patent referred to by Mr. Duncan, and it may have been used without due consideration.

It is merely a matter of opinion, which is the simpler joint of the two; but on comparing them, it certainly seems that a joint consisting of a plain nipple and ring is simpler and more easily handled than a joint made in imitation of ordinary cast-iron joints.

Without details of the particular joint referred to by Mr. Duncan, it cannot be determined whether it requires a less quantity of lead, as he avers, than the Moore and Smith joint; but it is open to question, whether any safe spigot and faucet joint can be designed for 16 inch or 22 inch pipes, which will require less lead than $27\frac{3}{10}$ lbs. and $37\frac{4}{100}$ lbs., respectively, the amounts used in the Vancouver water works for these diameters. In the pamphlet issued by the London Steel Pipe Company, it is claimed that the steel spigot and faucet joint of a 24 inch pipe requires $9\frac{1}{2}$ per cent. less lead than the joint of a cast-iron pipe of the same diameter. (See author's paper, page 337.)

According to American practice, a cast-iron joint for a 24 inch pipe would require not less than 50 lbs. of lead; consequently, Mr. Duncan's joint for the same diameter would require 50 lbs. less $9\frac{1}{2}$ per cent., or $45\frac{1}{4}$ lbs. But it can be easily calculated that a Moore and Smith joint for a 24 inch steel main $\frac{11}{100}$ of an inch thick with $\frac{5}{16}$ inch thickness of lead, the usual allowance, would require only $39\frac{1}{2}$ lbs. It appears, therefore, that in the case of a 24 inch pipe, according to the London Steel Pipe Company's pamphlet, as applied to American practice, the Moore and Smith joint requires $5\frac{3}{4}$ lbs. less lead than the spigot and faucet joint recommended by them.

As for great flexibility at the joints, it is not advisable in any system of water works to make with large mains much angular deviation, without special castings. It is not necessary, however, with the Moore and Smith joint to lay the pipes in a perfectly straight line, as claimed by Mr. Duncan, contrary to the description given. It will, on occasion, admit of deflection to the extent of one degree per length. In the case of 24 feet lengths, this would form an 8 degree curve of 716 feet radius. Without actual knowledge of such curves having been put in practice, it would be unwise to express an opinion as to their suitability; but there can be no question, that by means of this joint, such a curve as that on the Tay Viaduct, alluded to by Mr. Duncan, round which his 9 inch spigot and faucet pipe was laid, can be easily overcome, it being only a 4° 10′ curve with a radius of 1386 feet.

The nipple of the Moore and Smith joint in the Vancouver Water Works pipes does not decrease the internal diameter of the pipes at the joints; but in thickness of pipe shell over $\frac{11}{100}$ of an inch actually increases it. Had careful consideration been given to the drawing (Plate XX), there could have been no misconception on this point. It is there plainly shown, that the end courses of each pipe length are large or outer courses. The nipple being inserted in the end of a large course must, therefore, when of the same thickness as the shell, have the same inside diameter as the inner or small course, which, it is unnecessary to state, is the governing diameter of the pipe. The nipple adds greatly to the stiffness of the shell at the joint, but having no water pressure to withstand is, for economy sake, usually made of thin material, so that, in the case of a thick pipe shell, the inside diameter at the joint is greater than the governing diameter.

The reply given to Mr. Summerfield fully answers Mr. Duncan's doubts as to the strength of the 16 and 22 inch mains in comparison with ordinary Californian practice. When he reviews this subject, it would be well to bear in mind that there is no equality of strength between wrought iron and steel.

The omission of mention of the test pressures imposed on the mains was an oversight. The engineer's specification, and the company's agreement with the contractors for supplying and laying the steel mains, provided that the pipes should withstand safely and without leakage a column of water 600 feet high or 260 lbs. pressure to the square inch; and in order to insure the application of proof tests by the contractors, a special clause bound them to maintain and keep the whole system perfectly tight for two months after completion. So far as the engineers are concerned, these are the terms of the contract to this day. It will be admitted that no more stringent agreement for the laying of properly tested pipes could have been entered into.

Full details of the rivetting of the 12 inch, 16 inch, and 22 inch mains in the form of a table headed, "Details of Rivetted Steel Mains," accompanied the paper under discussion, when forwarded to the Society. That this table did not appear in the advance proof is to be regretted. However, it has now been embodied in the appendix to the paper, Vol. III., page 361.

Mr. Duncan's inferences and quotations from the author's letter to him are liable to mislead.

Immediately after the successful turning on of the water, the concluding portion of the paper, in which the account appears, was written, and the whole forwarded to the Society. There is nothing in this account at variance with the facts contained in the letter of April 13th. The primary leaks which were discovered up to the time of forwarding the paper to the Society were being readily repaired in the manner described. But, on the second day after the main had been put under *full pressure*, leaks developed themselves in the low-lying parts of the system, of an altogether different nature, and too numerous to be economically repaired in the same manner. The extracts quoted by Mr. Duncan were not intended by the author to reflect in any way on the character of the mains, as would be plainly seen were the latter given in full. The information afforded him was to serve as data on which to answer the questions, whether in his experience he had ever known a jet of water forced out between the laps of a rivetted pipe to actually cut the shell of the pipe beyond the laps, and, if so, what remedies were adopted by him? This was what had occurred in the Vancouver system, after the paper had left the author's possession.

Mr. Duncan in his reply could state no similar case; but very kindly advanced many theories, among which were the following:—"That an hydraulic ram had occurred; that the rivetting of the seams was faulty; that the plates were not laid flat together at the seams; that there may have been burrs left at the rivet holes; that in caulking, the edge of the plate may have been upset so as to spring one plate more than another; and that the rivets may have been pitched too far apart." Any one of these causes would have been sufficient reason for leakage between the laps, but would not account for the cutting of the steel plates beyond the laps, which was the point upon which information was desired. The most probable explanation of this phenomenon, of a water jet apparently cutting steel, is that, in rivetting the plates together, too much power was used, the effect being to compress the plates at the rivets, and to buckle them in the intervals between, thus allowing the water when under full pressure to be forced out with great velocity. As the soil in which the injured pipe lengths are laid is nearly pure sand, the sand particles mixed with the escaping jets, and being kept in constant motion, acted as sand blasts at the points where the jets struck the shell just beyond the laps. This theory is supported by the fact, that the pipe shells were not cut where the excavations were in earth or clay, and that part of the 12 inch steel main which was uncovered, though leaking at several laps, showed no sign of abrasion. It has since been learned that similar occurrences have taken place in eastern cities, where the practice is, either to box the mains, or remove the sand and substitute clay.

Answers to the queries proposed by Mr. Duncan as to rivetting, coating, etc., etc., are to be found in the paper.

With reference to the statement that the pipe lengths being 23′ 9¾″, four courses would have been preferable to seven in the manufacture of each length, it may be briefly replied, that four courses would not have answered in the kind of pipe used. In order to admit of a nipple which would not lessen the governing diameter of the main, it was necessary that a large or outer course should be at each end of each length. This could only be (see Plate XX.) when each length consisted of 2, 5, or 7 courses. The "preferable pipe" of 4 courses would have had a small course at one end, which would not have received a nipple, except of lese diameter than itself. If a nipple were dispensed with, and the smaller course forced into the larger, this latter, overlapping the other, would make the thickness of lead, at each side of the junction, unequal.

As to its being bad practice to make up each pipe length of 7 courses of so-called small plates, this is a matter of opinion, and not warranted by custom on the Pacific Coast. The pipes of the Vancouver system have been endorsed by the best authority in California, and as a notable example of similar design, the 36 inch wrought iron main of the Spring Valley Water Works, Cal., may be cited. The specification of this pipe calls for plates 116″ × 44″.

It is a questionable statement, and unsupported by proof, to say that caulking the seams as described tends to aggravate leaks. Experience on this coast has shown that, to obtain perfectly tight seams, chipping, caulking and split caulking are necessary. A reference to the specification of the Spring Valley Water Works, California, and the Portland Water Works, Oregon, will give further information on this point.

The spigot and faucet joint, having only one surface to be caulked, requires less labour in laying than the Moore and Smith joint, which, owing to its simple construction, has two surfaces. This advantage, however, is more than counterbalanced by the original labour of making the spigots and faucets, and attaching them to the shell. Had the cost of these details been given, a satisfactory comparison could have been made, which might not have been unfavorable to the Moore and Smith joint.

The statement made, that in the Riley patent socket joint it is not found that the shell is bent inward by caulking, as is the case with the Moore and Smith joint described in the paper, is misleading. The paper merely says: "That if the lead is beaten between the ring and the pipe too tightly, the shell of the latter will bend inward; and that it is necessary to caution inexperienced caulkers with regard to this." But in the hands of caulkers who have learned their business, the Moore and Smith joint is as free from liability to defective workmanship as any other joint; an assertion which is amply proved by the fact that in the Vancouver Water Works system, after the pipes had been subjected to a full pressure for several weeks, no joint in the whole length of 10 miles was found to leak.

Mr. Duncan claims that owing to the spigot end of the socket joint pipe being made 50 per cent. thicker than the shell, no pressure imposed in caulking will indent it. This is somewhat strange, seeing that he admits the possibility of the shell of the Moore and Smith joint pipe being bent, where the extra thickness exposed to the pressure of caulking is often, as in the case of the Vancouver mains, 100 per cent. In the latter joint, a nipple or ring 5 inches wide, and of the same thickness as the pipe shell, is closely fitted to the interior surface of the pipe, directly under the 4 inch ring of lead to be caulked, thus doubling the thickness of metal exposed to the pressure of caulking.

Mr. Duncan's concluding observations afford very valuable information as to the manufacture of pipes by the London Steel Pipe Company. When in London some months ago the author had the pleasure of seeing various specimens of these pipes, and was much struck by their excellence. For finish and workmanship, they are not likely to be surpassed; and it is very desirable that full information regarding them should be well known.

In reply to Mr. Henshaw, as to the question of an anchor falling on the submerged main, it is conceded that it would be undesirable to invite a trial; but in the event of such a test being made, it is by no means certain that the disastrous effects hinted at would take place. In any case, such an occurrence is a very remote possibility, even with one submerged main; while, that an accident should happen to two at the same time is almost an impossibility.

With reference to the remarks of Messrs. Blackwell, Smith, Goad, Peterson, Gower and Bovey, there is no mistake about the dimensions of the Cedar in question. Should Messrs. Blackwell, Smith and Goad care to visit British Columbia, they can have the pleasure of verifying the measurements. The Cedar is dead, but is very uniform from the ground upwards, and has no abnormal enlargement at the base. Such trees are rarely solid, and this is no exception. In trenching for pipe lines, it is not usual to extract such stumps, it being much more economical to tunnel under them.

A working plan of the dam, drawn to the scale of 8 feet to the inch, accompanied the paper on the Vancouver Water Works. It was considered that this would, if hung on the wall, have afforded all necessary information.

As the whole front of the dam is protected by double sheet piling, overlapping, with the ends imbedded in a trench of concrete sunk in the bottom of the river, and the shore connections protected on the south side by a hand-laid stone wall with a well rammed gravel and earth backing, and on the north side by a gravel embankment of picked material, the chance of water percolation through the body of the dam, and seepage round the ends, has been reduced to a minimum. Certainly, none has taken place during the two years of the dam's existence. The trench in which the sheet piling is imbedded, owing to the shallowness of the river, was filled with concrete in a simple manner. The concrete was wheeled over gangways extending along the face of the dam, within a few inches of the water, was then deposited over the sides, and allowed to settle in the trench. Twenty-four hours after the trench had been filled, the concrete was firm enough to resist moderate probing.

The definite object in view in the manufacture of the concrete was imperviousness and a thoroughly secure connection between the foundations of the dam and the bed of the river. The space in which it was to be placed was very confined, being a narrow trench, not exceeding at any point a depth of 3 feet; and being for the most part entirely under water, it would not permit of the filling being packed and rammed. These objects could only be obtained by making the concrete of such small materials that the whole would form as nearly as possible a homogeneous mass.

The author's experience in the manufacture of concrete is not extensive enough to permit of his expressing an opinion as to the advisability of employing large stones. But it is worthy of note, that the specifications for the water works systems of Gosport, Lambeth, Bideford, Halifax, and Aberdeen distinctly require that either sharp gravel be employed, or that all stones shall be broken so as to pass through a ring $1\frac{1}{2}$ or 2 inches diameter. Also, Trautwine (page 680, edition 1886) states "that broken stone for concrete is generally specified not to exceed about 2 inches on any side; but if well freed from dust, all sizes from $\frac{1}{2}$ inch to 4 inches on any side may be used."

It is therefore apparent that if eminent authorities advocate the use of large stones, many quite as eminent do not.

The Teredo Navalis, not being gifted by nature with the acrobatic powers of the salmon, is not likely to ever find a home in the timbers of the dam.

Corrosion of metal exposed to the action of salt water is a subject of great importance; and it is a matter for surprise that really reliable information with regard to it is difficult to obtain. But experience, so far, goes to prove that steel and wrought or cast iron of proper quality resist this action for long periods. Trautwine says "that certain cast iron sea piles of hard white metal showed no deterioration after 40 years immersion." (page 218, edition 1886.) The double 8 inch cast-iron pipes laid across Shirley gut nearly 20 years ago are in active operation to this day. In the discussion on the Avon Bridge, published in the last volume of the Society's Transactions, Mr. Uniacke in reply to Mr. Blackwell (page 286) says: "That bolts and plates used in the construction of the old bridge, 50 years ago, and exposed to salt water at different stages of the tide, showed not the slightest corrosion." Also, in constructing the new steel dock gates of Limerick Floating Dock, the pintles of the old gates were found to be so little affected by their 38 years' exposure to salt water, that they were used again.

It is to be noted that the cast-iron in the Vancouver submerged main is of the quality approved of in Trautwine; and, also, that there are many instances of similar mains submerged in salt water, designed by eminent engineers; as, for example, the aforementioned Shirley gut pipes, the Bournemouth storm outfall, the San Francisco Bay mains and the San Diego Bay main. Full information as to the manufacture, specification, quality, and proof tests of the submerged main are given in the paper on pages 344, 348, 351.

It is difficult to believe that Mr. Peterson's remarks relating to his observations when in Vancouver are uttered in any other than a jocular spirit. No one can suppose that because an irresponsible individual volunteered the information that the steel mains (wrought iron, he calls them) were not sufficiently strong to withstand the pressure, he credited that statement without investigation. It is hard to understand his imagining the rivets to be 4 or 5 inches apart, seeing that this is nearly 4 times the extreme distance. The round seam rivets of the 12 inch and 16 inch mains, referred to by him, are 1.2 inches and 1.08 inches apart, from centre to centre, respectively; and the straight seam rivets, which are in double rows, 1.3 inches and 1.4 inches. It is impossible he can believe that any steel or wrought iron pipe, which had so yielded to pressure that water was flowing in little streams out of nearly all the joints of the sides, could be held together and rendered serviceable by straps placed round it. All new rivetted pipes weep more or less at the laps, when first put under pressure. The great majority of the leaks he observed, being on the south side of the Inlet, where there was little or no sand to cut the plates, "took up" of their own accord, without special repairs.

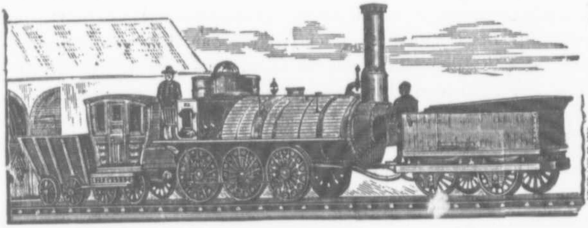
The submains are 8 inches, 6 inches, and 4 inches in diameter; not 4 inches and 2½ inches. 2½ inch welded wrought iron tubes have been laid for short distances, as a temporary means of supply for certain buildings. No hydrants are connected with 2½ inch pipes.

The distribution system was designed by the most eminent authority on water works in Canada, Mr. T. C. Keefer, C.E., C.M.G.

In the case of Vancouver, there is a very substantial reason why the water works should be in the hands of a private company. They were projected before the city had an existence, and constructed at a time when the city's resources were being fully employed in making absolutely necessary improvements, and it is doubtful whether even at this day the city would care to incur the expense of water works construction.

Thursday, 16th January.

K. W. BLACKWELL, Member of Council, in the chair.



THE SAMSON.

Paper No. 36.

ONE OF THE OLDEST RAIL ROADS IN CANADA.

By H. S. Poole, M. Can. Soc. C. E.

In 1818, when coal mines were first opened on the East River of Pictou, a tram road was made from the pits to the head of the tide, above where the iron railway bridge now spans the river; but shipments were small until a transfer of the property took place in 1827, when a new site for the wharves was selected lower down the river.

As the trade grew and the inconvenience of shipping in shallow waters was more and more felt, other sites still lower down were found, and so it came about that in the course of ten years four moves were made.

The tram road was of the now standard gauge, 4′ 8½″, and was worked by horses. Sidings were placed about half a mile apart, and each horse went his half mile or so with a full load, and, leaving it on the main line for the next horse to take on, returned with empty wagons from the siding.

When, in 1834, it was found that much improved facilities were required to meet the growing trade, the final site was selected opposite the loading ground, some four or five miles further down the river from the shipping place in use, at a point where there was ample water for vessels of the largest size then engaged in the coal trade.

The extension then decided on was subsequently built in a more substantial manner than the upper part of the road had been made. It was finished in 1838, and in that year the first locomotive ran over a rail road in Nova Scotia.

For half a century this rail road was in operation, and for many years carried passengers as well as freight; it was finally abandoned last autumn, and the shipping of coal transferred from the loading ground where this South Pictou Rail Road terminated, to wharves at the mouth of the harbour, access to which is obtained over a branch of the Intercolonial Railway to Pictou Landing. These newer wharves will accommodate any vessel that can cross the bar at the harbour's mouth, they are accessible earlier and later in the season than those at the loading ground, and from them loaded vessels can sail at any time of the tide day or night.

When the tram road gave place to the rail road, the line to the pits was also changed, and the whole length of seven miles came under new surveys.

The President of this Society has spoken of the desirability of recording the names of those who were pioneers in the several branches of the profession of engineering, and the writer would now name Mr. Peter Crerar as one of the earliest railroad engineers in Nova Scotia, if not in Canada.

Mr. Crerar was born in 1785 at Breadalbane in Perthshire, and came to Nova Scotia in 1817. He first taught in a school and then became deputy land surveyor, in which latter capacity he laid out several of what are now the main roads in Pictou County. He died in 1857.

Mr. Crerar* had had no experience in railroad surveying and building prior to the time when he was engaged to run the trial lines of the extension of the South Pictou Rail Road; yet when his plans and specifications were laid before the Board of Directors "at home," they were so well satisfied with them that they wrote out, saying: "What need is there of our sending you an engineer when you have Mr. Crerar in the country? Let him supervise the construction." This was accordingly done, and several of the sections he prepared to show the progress of the work have been preserved. One of these sections the writer is, by the kindness of Mr. Clendenin, the President of the Acadia Coal Company, the present owners of the property, enabled herewith to send for preservation in the archives of the Society. (See Plates I to III.)

A glance at Mr. Crerar's section is arrested by the unusual uniformity of the grade for a road passing through a country so uneven as there shown, so different from that ordinarily met with on colliery railways built in the present day. The road starts from the pits with a falling grade of one in 437 feet for a distance of 3500 feet, thence it is practically level for 18,770 feet, a slight incline of one in 578 feet then follows

* In some papers he signs himself "Geographic Engineer."

for 2,500 feet, succeeded by a level piece of road for 5,810 feet; a grade of one in 360 feet for 1,500 feet then takes the road to the timber structure, in connection with the wharf 16½ feet above ordinary high tide.

It will also be noticed on the plan of the road that in the matter of curves great caution has been shown; as, even when it entailed extra cutting of considerable amount, nowhere is there a curve of over 4 degrees radius.*

The cuttings and embankments were both made with a slope of one and a half to one; the former being made 18 feet wide at the bottom, and the latter of the same width at the top.

Among the papers relating to the construction of the road is the following memorandum, connected with the first line in England intended for general traffic :—

"The Liverpool and Manchester Rail Road.

"Iron Rail Road account £67,912.0.0.

"The above expenditure comprises the following items : Rail for a double way from Liverpool to Manchester, with occasional lines of communication and additional side lines at the different depots, being about 35 miles of double way = 3,847 tons, at prices averaging something less than £12.10.0. per ton."

In addition to the interest which this memorandum has as a statement of cost, the author would specially draw attention to the use in it of the words "depot" and "rail road." Their use here makes it probable that these words were common in England at the time in question, although they have been there abandoned and replaced by "station" and "railway."

It would appear probable that these terms were at the same time adopted in America, but, in contradistinction to the English practice, they were retained there just as philologists tell us many words and expressions, which are distinctive of New England to-day, are recollections of Puritan times, and are not indigenous to the soil. Only the other day, a reviewer, writing on the great American language, gave "depot" as an adaptation from the French direct by the people of America; but it would seem that the use of that word in the foregoing memorandum points to its having had at least a temporary resting place in England on its way to America.

It may be noted that in all the papers connected with the South Pictou road the invariable practice is to speak of it as a "rail road," never as a "railroad" or "railway," and this spelling the writer has retained in this paper.

The road has, as already mentioned, a gauge of 4′ 8½″, as was the practice in England at the time of its building. The rails were of several sections, of which pieces have been sent to the Museum of the Society. The earliest form was scalloped to sit in metal chairs spiked to sleepers placed 3 feet apart. The turnouts are made with tongues or split points of the form now required by the British Board of Trade, and one which has of late grown more in favour in America than the facing points ordinarily seen.

Locomotives:—The first engine to run on the road was the Samson, which is still in working order, and was in use until 1884. This engine led in the procession of locomotives at the Chicago exhibition in 1883, and was driven by George Davidson, who came out with it from England in 1838.

The John Buddle and the Hercules were imported at the same time, and were similarly constructed; they were followed by the Albion and Pictou, which have inclined cylinders and tubular boilers, and subsequently in 1853 by the Vulcan, which has the cylinders placed horizontally.

The boiler of the John Buddle is now used to drive a stationary engine, and the others are not beyond repair if use could be found for them. The veteran Samson is waiting for a purchaser* who will preserve it as a relic of past practice. It was built by Timothy Hackworth of Newcastle, weighs 16 tons, 19 cwt., 0 gr., 20 lbs., and with duplicate wheels and other parts cost £2140 cy.

The cylinders are 15¼″ diameter, with a stroke of 16″ and a valve area of 2¼ sq. ins. They sit vertically over the hind driving wheels, and have Watt's parallel motion instead of crossheads and slides. The wheels are 4′ in diameter, six in number, with a wheel base of 8′ 8″; they are made in two pieces, the annular portion is kept in position round the central hub by twelve circular keys of wood.

The boiler with a capacity of 540 gallons is 54″ in diameter, has a length of 13′ 4″, and carried a pressure of 60 lbs. on the square inch. It has a single return flue of ⅜″ plate, single rivetted, 26½″ in diameter round the fire, and diminishing to 18″ where it enters the smoke box. Another novelty lies in the exhaust pipe passing from the cylinders through the shell to the smoke stack. As constructed the tender goes behind, and the stoker alone attends to the firing, while the driver sits in an iron chair in front of his engine, and has an uninterrupted view along the line.

---

* Price asked $500

The writer, among the notes of his father, who managed the Albion Mines for the General Mining Association for fourteen years, finds a careful record of the work done by each locomotive; and between the years 1840 and 1853, the Samson on an average in each year was out 113 days, ran 4721 miles a year, and hauled 21,913 chaldrons of coal, at an average annual cost of £61 9s. 6d. cy.* for repairs, and £227 13s. 2d. cy. for working expenses.

Cost of material and work.—The writer has come across a few items of cost with which material and work of to-day may be compared, *e. g.*, The actual cost of earth cuttings per yard ranged from tenpence to one shilling and threepence, 62,297 yards costing £3247 7s. 5d. In later work the rate paid was even lower, and down to 5¾d. per cubic yard for levelling a coal floor. At the present time, cuttings through the same class of ground, stiff boulder clay with embedded rocks and pebbles, could not be made under thirty cents per cubic yard.

Spruce 1½″ and 2″ boards were bought for 22 shillings per thousand; hemlock at nineteen and sixpence.

Hemlock logs not less than 15″ diameter as follows:—

27	logs	36	feet	long	each	at	4s. 6d.
297	"	25	"	"	"		3s.
54	"	24	"	"	"		2s. 10d.
567	"	19	"	"	"		2s. 5d.
1356	"	13	"	"	"		1s. 9d. in all £233 0s. 9d.

Cedar sleepers from New Brunswick were delivered at 2s. each in 1846, and at from 1s. 9d. to 2s. 6d. in 1847.

Iron rails, 21,149 yards, weighed 617 tons 14 cwt., and required 258 tons 2 cwt. of metal chairs and 35 tons 17 cwt. of pins and wedges.

As an example of stone work take the cost in 1850 of a culvert 4 feet in diameter, 143 feet long, under an embankment 35 feet high.

Finding and hauling stone 9 miles at................	10s. 6d.	per c. yd.
Building same..	4s.	" "
Face dressing inside of culvert and including reducing the stone to the mould of the arch 18″ thick, stones 7″ at face, 11″ at back at..........	12s. 6d.	" "

Then a retaining wall 90 feet long by 24 feet high, 7 feet thick at the bottom, and 4 feet 3 inches wide at the top, was built, the stone found and the face chisel dressed for 12s. 6d. per cubic yard.

The writer has not been able to make out the actual first cost of the road, but in after years the valuation, inclusive of land damages and engines, stood at £76,700 1s. 0d.

---

* The £1 cy. was worth 16s. stg.

The following, however, is the estimate by Mr. Crerar of the probable expense of completing the Albion Mines Rail Road, from its commencement at the foundry to its termination at the Loading ground :—

	Currency.
Excavating 135,980 cubic yards @ 1s. 2½d.	£8,882 2 6
21,600 tons prepared stones laid on @ 6s. 6d. per ton	7,020 0 0
10,560 sleepers @ 1s. 3d. each	660 0 0
Laying down same and rails, etc	660 0 0
A bridge at Simon Fraser's Cove, stone abutments, each averaging 30 ft. high, wooden tops supported by wooden piers or pier poles, etc., etc.	447 0 0
A bridge across Cove Brook, etc., etc	579 0 0
A bridge from Dunbar's Point to Loading ground, one stone abutment, etc	1593 0 0
15 bridges and passing places, stone abutments, wooden tops, averaging 20 ft. high and 15 ft. span, at £180 each	2,700 0 0
Drains and culverts	800 0 0
600 tons iron rails, chairs, etc., @ £15 per ton	9,000 0 0
	32,341 2 6
Ten per cent. contingencies	3,234 2 3
	£35,575 4 9

Having located the line, the next step was to obtain the right of way, and as in those days there was no Railway Act, it may be of interest to note what proceedings were actually taken.

First, application was made to the General Sessions of the county, and then, in accordance with the authority there obtained, there was issued the following notice and in due course the Jury's award :—

NOTICE is hereby given that pursuant to an order of the Justices of the General Sessions of the Peace for the County of Pictou, dated the 4th day of January instant, made upon the application of the General Mining Association, which Association are the sublessees of His Majesty's mines in the Province of Nova Scotia, by Joseph Smith, Esquire, their agent and attorney, a precept in writing has been issued, directed to the Sheriff of the county of Pictou, or his deputy, commanding him to summon certain persons being freeholders to appear at the house of James Fraser, innkeeper, in the town of New Glasgow, on Tuesday, the 4th day of April next ensuing, at 11 o'clock forenoon, for the purpose of laying out and setting off within the lands of any person or persons owning the same, or in possession thereof, so much of the said land as may be required for the purpose of altering the line of rail road, now in use at the Albion Mines on the East River of Pictou, in the county aforesaid, the whole way from the shafts or pits at the said mines, down the west side of the said river to some convenient point opposite to what is generally called the " Loading Ground," and for assessing the damages to the owner or owners, tenant or tenants of such lands, according to their several interests, for being deprived of the use and benefit thereof; and for the expense of making fences or ditches, and also for fixing and ascertaining the annual rents for the use and occupation of the said lands, in accordance with the laws of the Province in such case made and provided.

(Signed,) JAS. MINNESTER,
Clerk of the Sessions.

Pictou, January 6th, 1837.

At the house of James Fraser, Innkeeper, in the Town of New Glasgow, this sixth day of May, one thousand eight hundred and thirty-four.

A list or panel of the names of twelve of the freeholders summoned and in attendance, under and by virtue of the precept hereto annexed, who on the list of freeholders to the said precept annexed being called over first appeared and answered thereon, and who were thereupon sworn by me the subscriber, John W. Harris, the deputy of John J. Sawyer, Esquire, sheriff of the County of Halifax, as a jury to the faithful discharge of the duties required of them by the laws of the Province, touching the several matters and things in the said precept mentioned and set forth namely :—(Alexander McDonald and others.)

VERDICT OR FINDING OF THE ABOVE JURY.

We whose names are hereto subscribed, being the jurors named in the above list or panel, do hereby certify, that being first duly sworn we proceeded to the discharge of the duties imposed on us, and having traversed the line proposed by the agents of the trustees of the General Mining Association, as an extension of the rail road from the shafts or pits at the Albion Mines on the East River of Pictou, the whole way from the said shafts or pits down the west side of said river, to a point in said river opposite to what is called the loading ground, as shown to us by the said agents of said trustees, and having heard all such parties interested therein, as well for as against their several proofs, opinions, plans, estimates and suggestions as appeared before us, and having again by ourselves, separate and apart from all interested therein, given the whole business referred to us our most mature deliberation, do say that in our judgment it is needful and requisite to extend the said line of rail road the whole way from the said shafts or pits, to a point or place in the said East River of Pictou, opposite to the said loading ground, that being the nearest sea water navigable for loaded ships or vessels of any size in the said river; and that for the purpose of so extending the said rail road, it is needful and necessary to open and make the same across and in front of the lands lying on the west side of the said river, between the said shafts or pits and the said loading ground, on the several courses as shown upon the plans hereunto annexed, which plans are made and signed by Peter Crerar, deputy land surveyor and civil engineer, and thereupon for that purpose we do hereby lay out and make as the same is now marked and staked on the ground, and shown upon the said plan, through, over and within the lands following, that is to say, commencing at or near the foundry, that being a short distance from the said shafts and pits, and to which place the said rail road has been previously laid down and established as we are informed, and running from thence through, over, and within the lands now in the possession of the said General Mining Association, one John Duff, one William Fraser "Ogg," one William Blair, the widow and heirs of the late Donald Smith deceased, and then again of the said Association to the bridge at New Glasgow, and passing under the western end of the said bridge, thence to run through, over and within the lands of the said Association, one Donald Fraser, mason, one Thomas Fraser, one Edmund Walter Remdell, one Donald McKenzie, one William McIntosh, Messrs. Simon James and John Fraser, again other land of the said Association; Messrs. George and John Fraser, one William McRay, again more land of the said Association; one Alexander McDonald, one Donald Fraser, the widow and heirs of the late Colin Fraser deceased, and Messrs. Robert and William Dunbar, and from the said Robert and William Dunbar's lands into the said East River, to a point opposite the said loading ground, according to the said plan, allowing for the purpose of opening and making the said rail road so much of the land on each side of the said line not exceeding more than five nor in any case less than three rods in the whole breadth thereof, clear of fences and ditches, except at such places as the said line shall or may pass into or out of the waters of the said river, as may be requisite and necessary for the formation of a proper rail road, when so extended as aforesaid, and we have assessed the damages to be paid by the said trustees of the said Association to the owner or owners, tenant or tenants of the said lands, according to their several interests therein, or to such other person or persons as may be lawfully entitled to receive the same, for being deprived of the use and benefit of such land, and for the injury that may be done thereto, and for the expense which may be imposed on them for making fences or ditches, for the purpose of separating all the lands so laid off as aforesaid from other parts of the tracts of land, within which the lands so laid off are contained as follows: that is to say, for damages and fencing on and over the land now in the possession of the said Robert and William Dunbar, seventy-three pounds ten shillings, and for the like, etc., etc., all which said sums are to be lawful money of Nova Scotia, and to be paid to the person or persons entitled thereto as aforesaid by the said trustees of the said Association, when and so soon as the said line of railroad is commenced and the fences put up in a lawful manner.

And we have also fixed and ascertained the annual rent for the use and occupation of the said lands, laid off as aforesaid as follows, that is to say, for so much thereof clear of any fences or ditches as shall be requisite and necessary for the purpose of the said rail road, when so extended as aforesaid, the same to be ascertained by actual measurement by a sworn deputy surveyor of land when the said rail road is formed, which is now in possession of the said Robert and William Dunbar, etc., etc., the annual rent of four pounds for each and every acre and so in proportion for any lesser quantity that may be requisite, etc. (N.B.—Other lots are at two pounds, two pounds ten shillings, three pounds, five pounds), which said sums hereby fixed for rent, being also of like lawful money as aforesaid, and to be paid by the said trustees in twelve months from and after the time when the proceedings had or to be had under the said precept shall have been confirmed, and soon yearly and each year thereafter, so long as they continue to occupy the said rail road. Provided always that such owner or owners, tenant or tenants, or such other person or persons entitled to receive such annual rent as aforesaid, do and shall from time to time, and at all times hereafter, so long as the said line so laid off and marked as aforesaid shall be held and occupied as aforesaid, at his or their expense, cost and charges, repair and keep in repair all such fences as he, she, or they are bound to put up in manner aforesaid, and in default thereof the said Association shall be at liberty to repair and keep in repair all such fences, and retain out of the annual rent aforesaid the reasonable expense and cost of the same. * * * And we have further considered that there shall be made at the expense of the said Association, either across or under the said rail road, when the same is formed and completed, suitable and commodious places for the owner or owners, tenant or tenants respectively of the several tracts of land through, over or within which the said line for the said rail road has been laid off and marked as aforesaid, to pass and repass from one part of the said tracts of land to the other, the said passing places to be in such part of the said line as will admit of their being made by a bridge at least fourteen feet above the level of the rails to be laid on the said road, or at such other part thereof as will admit of their being made to pass under the said line of rails, and to be at least ten feet clear, at the option of the owners, of the soil opposite thereto, and in case there shall not be on any of the said tracts of land an embankment of sufficient height or cutting of a sufficient depth, to admit of a passing place to be made as before described, then there shall be made as aforesaid one at such place on the said line, as there shall be neither a cutting nor embankment of more than three feet, such place to be pointed out by the owner opposite, and we further consider the number of said passing places shall be as follows, etc.

In witness we have hereto subscribed our names at the house of James Fraser, Innkeeper, at New Glasgow, this eighth day of May, one thousand eight hundred and thirty-four, having been three days engaged in this business, to us referred as aforesaid, in the presence of the said John W. Harris, who has subscribed his name hereto.

(Signed) Alex. McDonald.
his
George x Gratto.
mark
John Adamson.
Peter McLauchlan.
Joseph Trinniman.
his
James x Perrin.
mark

William Wylie.
Donald McGilveray.
Duncan McDougall.
John Lippincott.
Edward Patterson.
Jas. Purvis.
John W. Harris.
Depy. Sheriff.

From the drawing accompanying this paper Plates I, II and III have been prepared.

DISCUSSION.

Mr. Hannaford. Mr. Poole is mistaken in stating that the first locomotive in British North America ran on the Pictou Coal Mines tramway in 1838.

The first locomotive used on a railway in British North America was the "Dorchester" on the Champlain and St. Lawrence Railway, St. Johns, P. Q., to Laprairie, sent out in 1836, and operated regularly in 1837. This engine was built by George Stephenson & Co., Newcastle-on-Tyne, and was used for some years on the Liverpool and Manchester Railway before coming to Canada.

Mr. Blackwell. The speaker believes that the first locomotive in Canada ran on the old Champlain Road, and was called the "Dorchester." He remembers the matter being spoken of while serving his apprenticeship in the Grand Trunk shops 25 years ago. He did not know whether anyone remembered, but he thought that the conception, plans and carrying out of the old Champlain Road were all prior to the coal road in Nova Scotia now under discussion.

Mr. McNab. The Charter for the Champlain and St. Lawrence Railway was granted in February, 1832. The line was completed in 1834. In 1835 the locomotive "Dorchester" was brought out from England, as Mr. Hannaford said, and was running in 1836. The speaker understood that the Dorchester" was still in existence, driving a sawmill somewhere down East, having been sold several years ago for $300.00.

Mr. Macdougall The practice in Britain of distinguishing between "tramways" and "railways" is as carefully maintained at the present day, as the terms "tramway" and "railroad" were in the earlier days of the century.

Street railways are not known in Britain, they are specially designated street tramways.

The speaker can remember when the term "depot" was much more commonly used than "station," which is now the common term. The expression railroad was dropped in the early history of the movement. Many parliamentary plans he had seen of proposed lines early in the "forties" always have railway on the title of the bill.

Relative to the existence of the veteran "Sampson," he would mention a curious conjunction of the past and present. On the North

British Railway, the passenger, after stepping out of a train which travelled at sixty miles an hour for a considerable portion of the distance from Edinburgh to Carlisle, at Silloth Junction stepped into one of the original horse-coaches used on the first railroad from Edinburgh—the Edinburgh and Dalkeith—and was drawn by a horse for a distance of two miles.

Mr. Poole's paper is one of great historical interest, and the writer regrets that he was unable to be present during the reading of the paper and the discussion which followed. Mr. Chadwick.

In the first edition of "Civil Engineering in North America," by David Stevenson, published in 1838, the author makes a short reference to the "Champlain and St. Lawrence Railway" as the only one in Canada at that date, stating that the line was 16 miles long, and was constructed of plate rails laid on wooden sleepers. Two locomotives, one built in England and the other in the United States, were used, but the names are not mentioned.

In the same work there is a description of what would appear to be the prototype of the "cow-catcher," but which was then called a "guard," and it is stated to have been first used on a short line, the Quincy Railway, Mass. It consisted of a sort of framing, attached to the front axle of the engine, from which it sloped to within an inch or two of the rails, upon which it ran, supported on a pair of small wheels five or six feet in front of the leading wheels of the locomotive. In the Transactions of the American Society of Mechanical Engineers, Vol. X., page 509, 1889, there is a paper by Mr. D. W. Robb, of Amherst, N.S., M. Am. Soc. M.E., on "The Old Locomotive Sampson." The paper is illustrated with drawings of this interesting old locomotive. The plan of carrying the exhaust pipe from the cylinder inside the shell of the boiler is very curious.

Thursday, 23rd January, 1890.

ANNUAL GENERAL MEETING.

COLONEL C. S. GZOWSKI, President, in the Chair.

MORNING SESSION.

The Secretary having read the notice convening the meeting, and also the minutes of the last annual meeting,

It was moved by Mr. John Kennedy, seconded by Mr. K. W. Blackwell, and resolved :—

"That the minutes as read be approved."

The following Annual Report was then read by the Secretary:

ANNUAL REPORT.

In resigning its charge at the expiry of another year, the Council has again much pleasure in reporting a year of progress.

ROLL OF THE SOCIETY.

During the past year the membership of the Society has steadily increased. The elections comprised *seven* honorary members, *fifteen* members, *eleven* associate members, *twenty-eight* associates, and *twenty-three* students, while from various causes *twenty-nine* have been removed from the list, the net increase for the year being *fifty-five.*

The total number on the list at the present date includes *seven* honorary members, *two hundred and sixty-five* members, *one hundred and two* associate members, *sixty-two* associates, and *one hundred and fifty-two* students, or *five hundred and eighty-eight* in all.

The resignations were :

Member—J. J. Collins,

Associate Member—H. Wilson.

Associates—John Taylor, N. N. Evans, G. M. Dawson.

Students—W. W. Baillairgé, W. S. Belcher, J. C. Burns, D. Cator, M. L. Hersey, T. R. Henderson.

The deceases have been:

Members—L. Lesage, E. E. Gilbert, C. B. Franks.

Student—W. H. Lough.

In this list will be observed the names of Mr. Louis Lesage and Mr. E. E. Gilbert. Mr. Lesage was an incorporator of the Society, and served on the two first councils. He was widely known, and was one of the most respected engineers in the country. Mr. Gilbert was amongst the earliest of the mechanical engineers of Canada, and was the inventor of many valuable improvements. Only the other day, members of the Society heard of the death of our second President, the late Samuel Keefer, who might be considered one of the fathers of engineering in the Dominion. In him the Society has lost an ardent supporter and well-wisher. Still more recently we have received the sad news of the death of T. T. Vernon Smith, a pupil of Robert Stephenson's, and one of the last remaining links connecting our profession here with the early engineers of England. These losses will be severely felt, as the Society can ill afford to do without the advice and support of men of such long experience. Their memoirs will appear in due course in the Transactions.

The honorary members who have been elected are:—

His Excellency The Right Honourable LORD STANLEY OF PRESTON, G.C.B., P.C.

Sir John William Dawson, *Kt.*, C.M.G., LL.D., F.R.S.

Sir Charles Augustus Hartley, K.C.M.G., F.R.S.E.

Sir Frederick Joseph Bramwell, *Bart.*

Sir William Thomson, F.R.SS.L.&E., LL.D.

Sir John Fowler, *Bart.*

Sir John Hawkshaw, F.R.SS.L.&E.

The answers from the above accepting their elections are herewith appended:—

GOVERNMENT HOUSE,
OTTAWA, January 17th, 1889.

DEAR SIR,

Allow me, in acknowledging your letter, to ask you to be good enough to express to the President and Members of the Society of Civil Engineers my high appreciation of the compliment which they have paid me, by proposing that I shall be an Honorary Member, and my sense of the honour of belonging to such a distinguished body.

I remain, my dear Sir,

Yours very faithfully,

STANLEY OF PRESTON.

PROF. H. T. BOVEY, M.A.,
Sec. Can. Soc. C.E.

MCGILL COLLEGE,
January 5th, 1889.

DEAR PROF. BOVEY,

Kindly convey to the Canadian Society of Civil Engineers my sincere thanks for the honour they have done me in my election as an Honorary Member, and which I can assure you I very highly value. Any services that I can render to the Society are merely those of a worker in collateral and educational matters, but these I shall be always ready to render.

Sincerely yours,

J. WM. DAWSON.

---

26 Pall Mall,
LONDON, 18th April, 1889.

DEAR SIR,

I beg to acknowledge the receipt of your letter of the 5th inst., informing me that, at an ordinary meeting of the Canadian Society of Civil Engineers, I was unanimously elected an Honorary Member of the Society, and calling my attention to By-Laws 14 and 19.

I beg to tender my grateful thanks to the Canadian Society of Civil Engineers, for the very distinguished honour they have conferred upon me by unanimously electing me an Honorary Member of the Society.

I have the honour to be,

Yours faithfully,

CHAS. A. HARTLEY.

HENRY T. BOVEY, Esq.,
Honorary Secretary.

---

5 Great George Street,
WESTMINSTER, S.W., 21st June, 1889.

DEAR SIR,

I beg leave to acknowledge the receipt of your letter of the 3rd inst., in which you inform me that, at a meeting of the Society on the 23rd May, I was unanimously elected an Honorary Member of the Canadian Society of Civil Engineers.

I shall be glad if you will kindly convey my best thanks for the honour which the Society has thus done me, and say that I have great pleasure in accepting the election.

I am, dear Sir,

Yours truly,

FREDERICK BRAMWELL.

PROF. BOVEY, M.A., Hon. Sec.

THE UNIVERSITY, GLASGOW,
June 15th, 1889.

DEAR MR. BOVEY,

I have to-day in London received your letter of the 3rd, announcing that I have been elected an Honorary Member of the Canadian Society of Civil Engineers, and I write to you in reply to ask you to communicate to the Society my hearty thanks for the honour it has done me, and to say that I accept the appointment with much pleasure. Believe me,

Yours very truly,

WILLIAM THOMSON.

2 Queen Square Place,
WESTMINSTER, Dec. 2nd, 1889.

DEAR SIR,

I have received your letter of the 15th November, conveying to me the gratifying intelligence that the Canadian Society of Engineers have unanimously elected me an Honorary Member of the Society.

I beg you to communicate to the Society my appreciation of the high distinction they have conferred upon me.

Yours very truly,
JOHN FOWLER.

H. T. BOVEY, Esq.

BELGRAVE MANSIONS, S.W.,
Dec. 2nd, 1889.

DEAR SIR,

I have to acknowledge the receipt of your letter of the 18th ult., informing me that the Canadian Society of Civil Engineers had elected me an Honorary Member of the Society.

I beg to return my thanks for the honour that has been conferred upon me, which I assure you I greatly appreciate.

I am, dear Sir,
Yours very truly,
JOHN HAWKSHAW.

PROF. BOVEY, M.A.,
Sec. Can. Soc. C.E.

The Council again feels it an imperative duty to direct the attention of members to the qualifications required for admission into the several classes. As regards the *Student* class, it is considered that a candidate should have a good general education. He should be able to express himself clearly and grammatically, should have a knowledge of elementary mathematics and mechanics, in fact should be capable of undergoing an examination equivalent to that required for the matriculation into the Arts or Science Department of a University, as specified in the By-Laws.

The qualifications for admission into the classes of *Members* and *Associate Members* are still more important, and should be rigidly exacted. Corporate members, before attaching their signatures to a form of application for admission into the Society, should make it a rule to verify the accuracy of the statement of the candidate's professional career, and should further satisfy themselves that, if admitted, he would prove a fit and proper member of the Society. This is especially necessary, as, in many cases, the applicant is personally unknown to the members of Council. It would also greatly aid the Council in coming to a decision, if the proposers would, in *every case*, communicate, through the Secretary, their views as to the proper classification of the candidate.

A careful adherence to these principles will do much to maintain that high standard which *esprit de corps* and patriotism alike demand should be jealously guarded in a national society.

The same motive which leads to the exclusion of ineligible applicants will induce members to take every method to secure men who will be worthy of the Society, and who will be likely to contribute to its permanent advancement. There seems to be ample opportunity for this kind of effort, in filling the ranks of the class of Associates, which offers a means of gaining the co-operation of men distinguished in the kindred sciences, or interested directly or indirectly in the development of the material resources of the country.

BRANCHES.

The Council notes with much satisfaction that a branch has been established in the City of Toronto. This result has been largely due to the efforts of Mr. A. Macdougall, who, from the first, has taken a deep and practical interest in the welfare of the Society. It is greatly to be desired that the example of Toronto should be speedily followed in other leading centres, as the discussion of the various papers at such centres will much enhance the value of the Transactions, while the holding of meetings will necessarily call out more practical interest in the working of the Society.

The Council is also still convinced of the truth of the principle which led the original framers of the constitution to provide for the establishment of branches, viz., that the national character of the Society would be best preserved by giving it a local hold in different parts of the Dominion.

ANNUAL MEETING.

The Third Annual Meeting was held on the 17th January, 1889. The morning session was devoted to the transaction of the business of the Society, and in the afternoon the retiring President, the late Samuel Keefer, delivered an address on the Progress of Hydraulic and Railway Engineering, referring also to the present condition of Electrical and Sanitary Engineering.

As in previous years, the Annual Meeting was concluded by a conversazione held at McGill College. The Society was honoured by the presence of His Excellency the Right Honourable Lord Stanley of

Preston, to whom an address was presented by the President, Colonel Gzowski, A.D.C., in the name of the Society.

A large number of guests were entertained on this occasion.

ORDINARY MEETINGS.

During the year 1889, sixteen ordinary meetings of the Society have been held, at which the following papers were read:

On "The Panama Canal," by E. Deniel; on "Cantilever Bridges," by C. F. Findlay; on "The Development of the Locomotive," by the late T. T. Vernon Smith; on "Work-shops, their Design and Construction," by J. Davis Barnett; on "The Colonial Government Dry Dock, St. John's, Newfoundland," by H. C. Burchell; on "The Esquimalt Graving Dock Works, B.C.," by W. Bennett; on "Bridge Calculations," by H. E. Vautelet; on "The Design and Construction of the Avon Bridge (N S.)," by R. F. Uniacke; on "The Cornwall Canal," by the late S. Keefer; and on the "Vancouver Water Works," by H. B. Smith.

The discussions have been animated and well sustained, but there is always room for improvement in this direction. The Council cannot too often remind members that their duty to the Society requires them to contribute any information they may possess on the subjects under consideration.

STUDENTS' MEETINGS.

There have been four students' meetings, at which papers were read on "Locomotive Construction," by J. P. Tuplin, B.A.Sc.; on the "Grand Trunk Ry. Double Track," by A. W. Strong, B.A. Sc.; and on "Wood Fibre for Paper-making," by F. A. Bowman.

Of these, Mr. Tuplin's Paper and Mr. Bowman's Paper have been considered by the Council worthy of record in the Transactions.

ACCOMMODATION.

During the past year, the meetings of the Society have again been held in rooms at McGill College, for the use of which the Society is much indebted to the Board of Governors. The Council, however, has long considered that the growing requirements of the Society, and the need of a library, in which the books could be consulted with convenience, rendered it most desirable that the Society should possess rooms of its own. This has now been made possible through the liberality of your President, Colonel Gzowski, and the Council has therefore secured the lease of the first floor of the new Bank of Montreal building, at the corner of St. Catherine and Mansfield streets, for a term of five years. It will be observed that the rooms are in a good central position, and it is hoped that the natural result will be an increased attendance at the regular meetings.

It is expected that the rooms will be ready by the 1st of May, and that such arrangements will have then been completed as will make them at all times available for the use of members.

LIBRARY.

A number of donations to the Library have been received, and of especial value are:

Fifteen volumes of various works on Engineering, from Colonel Gzowski, President.

A complete set of the Tenth Census of the United States, consisting of thirty-four volumes, through your President, from the U. S. Government.

Eight volumes of Van Nostrand's Magazine (1869-76), and *seven* volumes of Reports of Commissioners of Public Works and Public Works Reports (1844-1870), from the late Samuel Keefer.

Volumes I. to VII. of the Transactions of the American Society of Mechanical Engineers, from the Council of the Society.

Nine volumes of Specifications of Government Buildings, alphabetically arranged, from G. F. Baillairgé, Esq., Member of Council.

Mr. Baillairgé's donation is to be supplemented at an early date by additional volumes of specifications relating to Harbors and other works.

The collections are in bound volumes, and have been carefully arranged to meet the requirements of the engineer, to whom they will prove of the utmost value for purposes of reference.

The Council has also much pleasure in stating that your President has given a further proof of his interest in the Society, by intimating his intention of presenting to the Library a valuable collection of engineering works, as soon as the rooms shall be ready for their reception.

Donations to the Library have also been received from Messrs. H. Wallis, F. R. F. Brown, H. F. Perley, C. Schreiber, John Kennedy, M. Murphy, C. M. Odell, J. B. Francis (of Lowell), W. McNab, R. Hering, S. Fortier, R. P. Cooke, G. Lindenthal, etc.

Exchanges of publications, in addition to those previously announced, have been arranged with each of the following Societies:—

The Society of Civil Engineers, Paris, France.

The Liverpool Engineering Society, Liverpool, England.

The Manchester Association of Engineers, Manchester, England.

The Midland Institute of Mining, Civil and Mechanical Engineers, Barnsley, England.

The North-East Coast Institution of Engineers and Shipbuilders Newcastle-on-Tyne, England.

The Royal United Service Institution, London, England.

Another donation of historic interest has been presented to the Society by the late Samuel Keefer, viz., a painting of the Suspension, Bridge, which he designed and erected at Niagara.

It is also of interest to note that Mr. Keefer built the first suspension bridge on this continent, over the Chaudière at Ottawa.

The Society is also fortunate in possessing large portraits of its Presidents, and it is hoped that future Presidents will be able to leave the Society like pleasant mementos.

BUILDING FUND.

The Building Committee reports that, in response to the two appeals made to the members of the Society for aid to the Building Fund, it has received subscriptions to the amount of $3,323.00, as per annexed list. This amount has been contributed by 37 members, 13 associate members, 1 associate, and 21 students. From these statistics it is evident that the Society, as a body, has, so far, taken little interest in the movement. It is, however, very satisfactory to find that so high an average as $46.20 per subscribing member has been reached. Had all the members contributed in like proportion, the Building Fund would now have amounted to not less than $25,000. Members should bear in mind that no entrance fee is required on admission into our Society, so that an extra effort is necessary to meet emergencies such as the present.

Your President, Colonel Gzowski, has generously given $300.00 a year, for five years, towards the rental of rooms for the Society, but the Building Committee feels that no time should be lost and no efforts spared in raising the sum required for the purchase of a site and the erection of a building, so as to give a more permanent basis to the Society.

New subscription lists will be immediately issued to all who have not yet subscribed, and the Committee hopes, at the end of the present year, to report that there is no one on the rolls of the Society who has not done something towards aiding in a work so important to its well-being.

FINANCES.

The income for the year ended on 31st December, 1889, amounted to $3629.92, and the general expenditure reached $3075.95, leaving a balance of $553.97, which, together with the balance of $1948.92 brought forward from the year 1888, gives a total balance of $2502.89 to be carried forward.

CANADIAN SOCIETY OF CIVIL ENGINEERS.

ABSTRACT OF RECEIPTS AND EXPENDITURE FOR THE YEAR ENDING DECEMBER 31st, 1889.

Balance from Dec. 31, 1888			$1948 92	
General Receipts.				
Subscriptions:—				
Arrears	$78 00			
Current	2711 00			
Advance	619 00			
Extra on local cheques	3 54	3411 54		
Repaid by Building Fund for stationery		9 75		
Extra "Transactions," &c., sold		122 98		
Donations to the Library		20 00		
Bank interest to Dec. 31st		65 65	3629 92	5578 84
Building Fund.				
Balance from Dec. 31st, 1888			1249 70	
Additional subscriptions		1420 25		
Bank interest to Dec. 31st		56 58	1476 83	2726 53
				$8305 37

HERBERT WALLIS,
Treasurer.

General Expenditure.			
Cost of printing "Transactions"		$1358 93	
Advance proofs of papers		124 60	
Extra copies of papers for sale		79 85	
Printing and stationery		382 78	
Postage, messengers, telegrams, cabs		322 09	
Expenses of Secretary		573 00	
Stenographer		105 00	
Janitor		39 50	
Furniture, books and rent of chairs for annual meeting		48 46	
Rent of telephone (6 months)		12 50	
Bank commission on local cheques		8 91	
Express charges, etc., on library books		20 [illegible]	3075 95
Building Fund.			
Stationery and Bank commission			11 05
Balance.			
General Fund	2502 89		
Building Fund	2715 48		5218 37
			$8305 37

Examined with books and vouchers and found correct.

P. A. PETERSON,
K. W. BLACKWELL,
Auditors.

SUBSCRIPTIONS TO BUILDING FUND, TO NOV. 21st, 1889.

NAME.	CLASS.	PROMISED.
Armstrong, J. S.	M.	$20 00
Barlow, J. R.	"	50 00
Blackwell, K. W.	"	80 00
Brown, F. R. F.	"	60 00
Drury, E. H.	"	20 00
Duffy, A	"	20 00
Dodwell, C. E. W.	"	20 00
Dawson, W. B	"	10 00
Evans, E. A	"	50 00
Garden, G. H	"	20 00
Harris, W. D.	"	20 00
Hill, A.	"	25 00
Harkom, J. W	"	20 00
Howard, S	"	10 00
Hannaford, E. P.	"	100 00
Jennings, W. T.	"	100 00
Keefer, S	"	100 00
Lloyd, J. Y.	"	20 00
Leduc, D	"	20 00
MacLeod, M. H	"	40 00
Massy, G. H	"	15 00
Macdougall, A.	"	25 00
Murphy, M.	"	40 00
McWood, W	"	100 00
McMillan, D.	"	24 00
Pim, J. P.	"	12 00
Poole, H. S.	"	20 00
Peterson, P. A.	"	100 00
Page, John	"	100 00
Ross, James.	"	500 00
Schreiber, C	"	100 00
Tate, R. F.	"	25 00
Trutch, Sir J. W.	"	100 00
Vallée, L. A.	"	20 00
White, J. H.	"	100 00
Webster, G. H.	"	20 00
Wallis, Herbert.	"	100 00
		$2206 00
Allison, J. L.	A.M.	20 00
Bannister, H.	"	40 00
Davis, W. M.	"	20 00
Hooper, G. R.	"	40 00
Irwin, H.	A.M.	$20 00
Lesage, T. W.	"	20 00
Mackenzie, H. J.	"	20 00
Odell, C. M.	"	20 00
Ostler, C. H	"	20 00
Smith, C. B.	"	40 00
Thompson, R.	"	20 00
Vanier, J. E.	"	30 00
Warren, J.	"	4 00
		$314 00
Reid, R. G.	A.	500 00
Ball, J. P.	S.	$4 00
Brooks, N. E.	"	10 00
Cartwright, C. E.	"	4 00
Childs, A. E.	"	20 00
Denison, W. S.	"	5 00
Dimock, A. H.	"	20 00
Gibbons, J.	"	5 00
Hopkins, M. W.	"	1 00
Haultain, H. E. T.	"	15 00
Jonah, F. G.	"	12 00
Kilgour, W. H. A.	"	10 00
Loignon, E.	"	20 00
Loignon, A.	"	20 00
Mickle, G.	"	10 00
McColl, R.	"	12 00
McGregor, J. H.	"	20 00
Redpath, P. W.	"	10 00
Rinfret, R.	"	20 00
Shillinglaw, W. H.	"	25 00
Sargent, C. D.	"	20 00
Williams, M. L.	"	40 00
		$303 00

RECAPITULATION.

Members	2206 00
Associate Members	314 00
Associates	500 00
Students	303 00
	$3323 00

It was moved by Colonel Gzowski, seconded by Mr. P. A. Peterson, and resolved :—

"That the Report of the Council be received, approved and printed in the Transactions."

It was moved by Mr. John Kennedy, seconded by Mr. L. A. Vallée, and resolved :—

"That the Society has learned with the deepest regret of the death of its past President, Samuel Keefer, in whom it has lost an ardent friend and supporter, and that the members of the Society desire to convey to his widow and relatives their sincere sympathy with them in their bereavement, and their hearty appreciation of the work of Mr. Keefer during a long, active and useful life."

The Secretary next read the following resolution from the Branch at Toronto :—

Resolution adopted by Toronto Branch at meeting 9th January, 1890.

"That this branch desires to express its sorrow on learning of the death of our late President, Mr. Samuel Keefer, to whom the Society is greatly indebted for his services as President and his contributions to the Proceedings of the Society.

"Mr. Keefer, during his long and honourable career of over half a century, had, at various times, carried out several of the largest public works of the Dominion, which stand as monuments to his memory and engineering skill, and this branch desires to send a message of sympathy to the parent society on the loss we have all sustained."

It was moved by Prof. McLeod, seconded by Mr. K. W. Blackwell, and resolved :—

"That the scrutineers of the ballot for the election of officers and members of Council be instructed to prepare their report in such a manner as to be able, in the event of amendment *d* to by-law 7 being carried, to give the information required by said amendment."

Letters having been read by the Secretary from Messrs. John Page and C. Sproatt, signifying the wish of these gentlemen to withdraw their names from nomination on the Ballot Lists for the election of officers and members of Council for the year 1890,

It was moved by Mr. E. P. Hannaford, seconded by Mr. P. A. Peterson, and resolved :—

"That the scrutineers of the ballot for the election of the officers and members of Council be instructed to make no returns as to Messrs. John Page and C. Sproatt."

Upon the instructions of the President, the following legal opinion had been obtained and was read by the President :—

23rd January, 1890.

HENRY T. BOVEY, Esq.,

Sec. Can. Soc. C. E.

DEAR SIR,

The case submitted for our opinion we understand to be as follows:

The nominating committee of the Canadian Society of Civil Engineers, acting under the authority of by-law No. 6, issued to the members a list, Mr. Page being nominated by them as President. Mr. Page has since notified the committee that he withdraws his acceptance of such nomination. In view of the probability of there being no ballot cast for any other person as President, you desire to know what course of action the Society should follow in order to a valid election of a President at the annual meeting of the Society to be held to-day.

We should suggest either of the following courses of action:

1. The sealed letter ballots are, we think, by the terms of the by-laws under the control of the respective members (owners thereof) of the Society, until they are in the hands of the officer or scrutineer appointed at the meeting to open them. We would suggest that certain of these ballot papers be withdrawn, and the names of one or more members eligible for election to the office of President be substituted for that of Mr. Page on such ballot papers. This can be legally done, the nomination list being simply for guidance and not exclusive.

It being made known to the meeting before the sealed letter ballots are opened that Mr. Page has withdrawn his acceptance of nomination as president, the votes cast for him would be inoperative, and the choice of candidates would then be limited to these candidates having the greatest number of votes, and the voting upon such candidates could then be proceeded with in the usual way in terms of by-law No. 7.

2. If the remedy above suggested is not availed of by further nomination, than that of Mr. Page, we are of opinion that, as the by-laws do not provide any legal solution of the difficulty, the members of the Society may proceed to ballot for, and elect, any member eligible for the position of president in the usual way without reference to the by-law, and such election will be legal.

We remain, yours truly,

ROBERTSON, FLEET & FALCONER.

The meeting having resolved to adopt the course recommended by the above opinion, the corporate members withdrew their ballots and returned them, after having made such alteration therein as seemed advisable to the several voters.

It was moved by Mr. P. W. St. George, seconded by Mr. W. E. Gower, and resolved:—

"That Messrs. C. H. McLeod, J. M. Shanly, H. Irwin, G. H. Duggan, C. Leprohon and C. B. Reed be scrutineers of the ballot for the election of officers and members of Council for the year 1890."

It was moved by Mr. P. A. Peterson, seconded by Mr. H. D. Lumsend, and resolved :—

" That Messrs. A. P. Low, W. Whited, and E. A. Stone be scrutineers of the ballot for the amendments to the By-Laws."

The following were balloted for and elected the Nominating Committee for the year 1890 :

F. L. Wanklyn, Montreal.
C. Schreib r, Ottawa.
A. Macdougall, Toronto.
M. Murphy, Halifax.
P. Summerfield, Victoria, B. C.
T. C. Keefer, Past President, Ottawa.

The following Report of the Committee, anent the Summer Convention, was read by the Secretary of the said Committee, Mr. W. McNab :—

MONTREAL, 22nd January 1890.

PROF. H. T. BOVEY,
Sec. Can. Soc. C. E.,
Montreal.

Re Proposed Summer Convention.

DEAR SIR,

I have much pleasure in enclosing you the Report of the Summer Convention Committee, and in attaching a letter from Mr. Alan Macdougall of Toronto, dated Jan. 11th.

I may add that of the opinions received from members of the Society in regard to location for a Convention

57	per cent. were in favour of	Toronto.
12	" " " " " "	Montreal.
12	" " " " " "	Niagara Falls.
6	" " " " " "	Quebec.
6	" " " " " "	Ottawa.
3	" " " " " "	Lower Provinces.
3	" " " " " "	Western Pacific points.
1	" " " " " "	New York.

And in regard to the time of year :—

For month of May	7	per cent.
June	48	" "
July	13	" "
Aug.	14	" "
Sept.	17	" "
Oct.	1	" "

Yours faithfully,

W. McNAB,
Secy. to Committee.

30 Adelaide Street East, Toronto,

11th January, 1890.

Re Can. Soc. C. E. Summer Convention.

W. McNab, Esq., C. E.,

G. T. Ry., Montreal.

Dear Sir,

The following resolution was passed on the 9th :—

That this branch do now invite the members of the Society to meet in Toronto, not later than the third week in June of this year, and hold their Convention in this city under the auspices of this branch.

I have much pleasure in personally indorsing this. When you bring it before the Society, say that June is in every way the best month for the Society to come here. I have had to arrange for the visits of British Association, American Public Association and American Association for the Advancement of Science, all of which took place in the end of August and first week of September, and it has been very hard work to "do" the thing properly. In the early part of June everybody is in town, and visitors will be much better entertained.

Faithfully yours,

(Signed), ALAN MACDOUGALL.

Montreal, 22nd January, 1890.

To the Council and Members of the Canadian Society of Civil Engineers:

Your Committee, appointed at the regular meeting of the Society held on, the 5th ult. to take into consideration, and report at the Annual Meeting upon the advisability of holding a Summer Convention, and to make recommendations as to time, place, etc., beg to submit the result of their deliberations and enquiries as follows :—

1st. That in order to promote closer professional relations and more intimate personal acquaintance amongst the members, resident and non-resident and to more largely extend the influence and sphere of the Society, a Summer Convention should be held.

2nd. That in regard to the time of the year for holding such, the third or fourth week in June is recommended as the most suitable.

3rd. That the first Convention should be held in Toronto, that city affording special advantages, and being more centrally situated, besides having a branch of the Society already established there; but that the time and place of subsequent Conventions should either be determined by a vote of the members at the Annual Meeting immediately preceding it, or arranged by the Council with reference to the convenience of members connected with the place selected.

4th. That the Presidential Address be not made a feature of the Convention, but reserved, as at present for the Annual Meeting. It is recomended, however, that short papers might be prepared specially for the occasion, read and discussed, and visits of the Society be made to such points of engineering or scientific interest as exist in the section of the country where the Convention may be held.

The whole respectfully submitted.

Per W. McNab, under authority

John Kennedy, Chairman.
Alan Macdougall.
W. P. Anderson.
W. McLea Walbank.
F. Came.
G. A. Mountain.
W. McNab, Secretary.

It was moved by Mr. R. Surtees, seconded by Mr. P. W. St. George, and resolved :—

"That the Report of the Committee anent the Summer Convention be received and adopted, and that the Council be requested to take the necessary steps to carry out the recommendations therein contained."

Notice was given of the following proposed amendment to By-Law 6 :—

Line 7.—Strike out the words "who are neither elective officers nor candidates for office."

Proposed by W. L. Scott, G. H. Garden, W. Skaife, H. D. Lumsden, P. A. Peterson, P. W. St. George, R. Forsyth, John Kennedy, St George Boswell, W. J. Sproule.

The scrutineers of the ballot for the amendments to By-Laws reported as follows :—

(*a*) By-Law 6, line 13, etc.—Instead of "The list shall contain twenty-six names," read, "The list shall contain at least twenty-six names." *Carried by* 76 *per cent.*

(*b*) By-Law 6, line 16, etc.—Following "nineteen for councillors," insert "It shall be the duty of the nominating committee to accept as nominated for any office, any eligible candidate whose name is submitted on or before October 30th with his consent, by five or more members ;" and instead of "such names shall be forwarded to the Council," read. "all names nominated shall be forwarded to the Council."

Carried by 75 *per cent.*

(*c*) By-Law 6, line 21.—Instead of "The nomination list shall be signed by a majority of the nominating committee," read "The list of names nominated by the nominating committee shall be signed by a majority of that committee. *Carried by* 91 *per cent.*

(*d*) By-Law 7.—Following the words "declared at the Annual Meeting," add "and the report of the scrutineers shall give all names that have received five or more votes and the number of votes cast for each." *Carried by* 67 *per cent.*

(*e*) By-Law 38, line 9.—After the words "31st December preceding," add "also a list of the meetings held by the Council, and the names of those present at each meeting." *Carried by* 76 *per cent.*

(*f*) By-Law 16.—Instead of the last paragraph commencing "In every case" and ending "works," substitute "In every case the candidate must have held a position of professional responsibility for at least two years." *Carried by* 90 *per cent.*

(*g*) By-Law 21, line 10.—After "promoted," insert "This statement shall not be required from Associates." *Carried by* 87 *per cent.*

The scrutineers of the ballot for the election of officers and members of Council for the year 1890 reported that the following had been duly elected as:—

President.

Casimir S. Gzowski (*re-elected*), Toronto.

Vice-Presidents.

Edmund P. Hannaford, Montreal.
John Kennedy, Montreal.
Henry F. Perley, Ottawa.

Treasurer.

Herbert Wallis.

Secretary.

Henry T. Bovey, M.A., F.R.S.C., Montreal.

Librarian.

Francis Chadwick, Montreal.

Members of Council.

William P. Anderson, Ottawa.
John D. Barnett, Stratford.
Kennet W. Blackwell, Montreal.
Francis R. F. Brown, Montreal.
Charles E. W. Dodwell, Montreal.
William T. Jennings, Toronto.
George A. Keefer, Vancouver, B.C.
H. G. C. Ketchum, Amherst, N.S.
George H. Massy, Montreal.
Thomas Munro, Coteau Landing.
Peter A. Peterson, Montreal.
Henry N. Ruttan, Winnipeg.
Percival W. St. George, Montreal.
Sir Jos. W. Trutch, Victoria, B.C.
Edmund Wragge, Toronto.

It was moved by Mr. J. H. Taylor, seconded by Mr. R. Surtees, and resolved:

"That the thanks of the meeting be tendered to the scrutineers, for the able manner in which they have performed the duties entrusted to them, and that the ballot papers be destroyed."

It was moved by Mr. E. P. Hannaford, seconded by Mr. F. R. F. Brown, and resolved:—

"That the meeting grants the Council power to incur the necessary expenses of rental, to enable the new rooms of the Society to be furnished and the Library to be properly catalogued, together with the expense required to make provisions for such attendance at the rooms as will render them available to members."

The meeting then adjourned until three o'clock.

AFTERNOON SESSION.

At three o'clock the meeting reassembled in the Lecture Hall of the Peter Redpath Museum, and Colonel Gzowski, President, delivered the Annual Address.

At the conclusion of the Address it was moved by His Excellency the Right Honorable Lord Stanley of Preston, seconded by Sir William Dawson, and unanimously resolved:—

"That the best thanks of the Society be presented to our President, Colonel Gzowski, for his untiring efforts in the interests of the Society during the past year, for the practical aid he has generously given towards its establishment on a firm foundation, and for the very able and interesting Address he has this day delivered."

It was moved by Mr. H. D. Lumsden, seconded by Mr. J. S. Armstrong, and resolved:—

"That the thanks of the Society be presented to Mr. Herbert Wallis for his services as Treasurer during the year 1889."

It was moved by Mr. St. G. Boswell, seconded by Mr. A. J. Lawson, and resolved:—

"That the thanks of the Society be presented to Prof. Bovey for his services as Secretary during the year 1889."

It was moved by Mr. J. H. Taylor, seconded by Mr. J. E. Vanier, and resolved:—

"That the thanks of the Society be presented to Mr. Francis Chadwick for his services as Librarian during the year 1889."

Messrs. Wallis, Bovey and Chadwick made appropriate replies, thanking the Society for its expressions of approval.

On the motion of Mr. Hannaford, seconded by Mr. Kennedy, a cordial vote of thanks was presented to His Excellency Lord Stanley, for having consented to be present at the Society dinner on the 23rd inst. and at the delivery of the President's Address.

The President, in closing the proceedings, thanked Sir William Dawson for the kindness he had shewn the Society in giving it a home in McGill University during the last three years.

The meeting was then adjourned.

PRESIDENT'S ADDRESS.

The established custom of the Society being for the retiring President to deliver an Address, I shall make an effort to follow the example of my predecessors. Before entering upon the subjects to which I hope to secure your brief attention, I must express my grateful appreciation of the cordial manner in which I was offered the highest position in the gift of the Society, and my warmest thanks for the unanimity with which you called on me to preside over it. The progress of the Society since its recent organization has been very gratifying. The Roll of Members, as you will have observed from the report of the Council, is as follows:—

Honorary Members	7
Members	265
Associate Members	102
Associates	62
Students	152
	588

A number of original, interesting, and valuable papers on Engineering subjects have been read and discussed at the regular meetings, which have been fairly attended. As this has all been achieved in the first three years of the life of our Society, I submit that it furnishes unquestionable and encouraging evidence of its usefulness and popularity. Our Honorary Members are all men of such marked distinction as to do honour to the Society. The first who accepted election was his Excellency Lord Stanley of Preston, G. C. B., Governor General of the Dominion of Canada. His Excellency's acceptance of Honorary Membership of our Society is a valuable and gratifying compliment to, and affords evidence of appreciation of, the Engineering profession. The next was Sir William Dawson, C. M. G., the learned President of McGill University, to whom the Society is under great obligations for the generous hospitality he extended by giving our Members a home within the University Buildings, which proved a great advantage in the formative period of the Society's existence.

As those Honorary Members who belong to our Profession have all joined our ranks since my accession to the office of President, I may be permitted to make a brief reference to their record and distinctions.

Sir Frederick Bramwell, besides his eminent talents as an engineer, has won unrivalled fame from his faculty for technical exposition, combined with oratorical powers of illustration—he is indeed one of the brightest lights of the Profession.

Sir Charles Hartley, the distinguished hydraulic engineer, is famous not only in England, but on the continent of Europe, having been selected by England, Austria, and Russia to act as chief engineer on the Commission for the improvement of the navigation of the River Danube.

Sir John Fowler's name is honourably familiar to the Profession as that of the designer of many important and difficult engineering works, more especially the one approaching completion—the great Bridge over the Forth. This unique and magnificent monument of scientific genius and engineering talent, daring, and skill has carried the art of spanning wide spaces much further than was heretofore conceived as practicable.

Sir John Hawkshaw is one of the oldest and most eminent members on the roll of the Mother Society. The Severn Tunnel, just completed, bears striking evidence of his great engineering skill. It is well expressed in the dedication to him of the late Mr. Walker's book on the Tunnel in the words, "To Sir John Hawkshaw's professional skill and indomitable perseverance, the Severn Tunnel will ever remain a lasting monument."

I must not pass by the name of Sir William Thomson, who enjoys a world-wide reputation as an eminent scientist. He is especially famous as the electrician by whose exhaustive experiments the exact measure of electric power was arrived at, which enabled the submarine cables to be as effective as they now are. Indeed we owe to his researches and skill the marvellous facility for almost instantaneous communication enjoyed with all parts of the world. The Society has every reason to be congratulated upon, and take pride in, the representatives of Engineering talent on her roll of Honorary Members.

The Addresses of my two predecessors have so exhaustively treated the different branches of the Profession with reference to men and the works with which they were associated in Canada, that I find it difficult to say anything new and interesting about them, for although Canada has not ceased to make progress, nor her Engineers to design and carry out works which evidence their ability, one or two years is too short a measure of time to allow of sufficient development of new projects for the text of an Address, or any extended notice of such enterprises. At a meeting of the British Association last year, after being introduced by Sir Henry Roscoe and inducted into the President's Chair, Sir Frederick Bramwell commenced his brilliant address by saying: "The late Lord Iddesleigh delighted an audience for a whole evening by an address on 'Nothing.' Would that I had the talents and could discourse to you as charmingly as he did to his audience, but I dare not try to talk about 'Nothing'." In the same spirit I may say: "Would that I had the literary gifts of Sir Frederick, and could discourse to you as charmingly as he did to the British Association."

But lacking those powers for which he is so famed, I will ask your indulgence while I offer some observations, first, upon a work of considerable magnitude, to which my predecessor, the late Mr. Samuel Keefer, made a very brief allusion in his Address,—I refer to the Railway Tunnel under the River St. Clair. That interesting work was then in but a very early stage of progress. Since that time it has advanced very rapidly. This tunnel is the first important engineering work of that description in Canada. It contains some novel features of much interest to our Profession.

The work is in charge of, and is carried on by a Canadian engineer, who is a Member of our Society, Mr. Joseph Hobson, Chief Engineer of the Great Western Division of the Grand Trunk Railway. The Tunnel under the River St. Clair is designed to connect the Grand Trunk Railway system in Canada with that portion of its organization which is in the United States, extending as far as Chicago. The object of the tunnel is to do away with the necessity of the present costly ferry for passengers and freight at Point Edward, at the foot of Lake Huron, which during the winter occasions much delay from accumulations of ice. The organization under which the undertaking is carried on is a chartered company under the laws of the State of Michigan and of the Dominion of Canada.

About the year 1884 Mr. Walter Shanly, a member of our Society, reported upon the project. He recommended locating it below Sarnia, very near the spot where the tunnel is now being constructed, but he made no survey. Under instructions from Sir Joseph Hickson, the President of the Tunnel Company, Mr. Hobson made the necessary survey in 1884, and finally located the line along which the tunnel is now being driven. An arrangement was made by the Tunnel Company with the well-known Engineer, General William Soy Smith, drive a temporary adit as a trial to ascertain the nature and quality of the material likely to be encountered, especially under the River St. Clair. This adit had only been partially carried out when a flow of gas was met, which caused the work to be abandoned. The Tunnel Company subsequently decided to carry out the work themselves under the direction of their Engineer, Mr. Hobson.

Learning of the decision to drive a full-sized tunnel for a single line of rails, work for which was to be commenced and pursued at both ends, and that the tunnel was to be lined with cast-iron flanged plates, a novel mode of lining in America, and only used in two tunnels of small dimensions in England, I decided to personally examine the work. I waited, however, until it was sufficiently advanced to enable me to see it in full operation. Having visited the tunnel, it occurred to me that an account of the progress already made, with other particulars in connection with this large work, would be of interest.

The total length of the tunnel with approaches will be 2 miles and 1145 feet. The length, from face to face of the portals, is 6.000 feet. The depth of open cutting at the East or Canadian side of the tunnel is 62 feet; at the West, or United States end, 52 feet. The length of that part which is under water will be 2310 feet, with a gradient to the West rising one foot in one thousand. The greatest depth of the River St. Clair on the line of the tunnel is forty and one half feet. The minimum thickness of the roof is 16 feet. The bottom of the tunnel is about 10 feet above the rock underlying the clay. This has been ascertained by very accurate soundings and borings taken near the line of the tunnel at each 20 feet. It may be well to say that the flow of gas was found immediately above the rock, indicating that its source was in or below that strata, the gas escaping through fissures in the rock. Locating the bottom of the tunnel above the rock, and yet securing sufficient thickness of material to support the roof, was in order to avoid meeting with gas.

The material through which the tunnel is driven is clay, with pockets of wet sand and gravel. Large boulders are occasionally encountered. The clay varies in quality, changing from hard to soft so abruptly, that one side of the shield works sometimes in hardpan while the other side is in material of the consistency of putty, so soft as to flow under the pressure of the superincumbent weight. The borings that have been made in the bed of the river parallel to the axis of the tunnel indicate that the material as described will be found throughout. The tunnel in cross section is circular with an inside diameter of 19 feet 10 inches. It is a circular tube, lined throughout with flanged plates of cast-iron two inches thick, five feet long, bolted together. The ends of these plates are planed to make a close joint, and before being used they are heated and soaked in tar. The lower half of the lining is encased outside in three inches of grout, formed of the best Portland cement and coarse sharp sand. Holes are made in the upper part of each plate through which the grout is poured in. Under the river the whole of the outside of the cast-iron lining will be covered in this way.

In the prosecution of the work an iron shield is used, under the protection of which the excavation is carried on and the cast-iron lining is put together. The shield is just large enough to enclose the cast-iron lining, and as the excavation in front of it is advanced, it is moved forward just far enough to put together one section of the tunnel lining. As the width of these sections or rings is only 18 inches, and as the rear portion of the shield which encloses the lining overlaps it 39 inches, the forward end of the lining is always within the shield. To ensure safety as far as possible in the event of a sudden strong flow of quicksand or water, an iron diaphragm or bulkhead is built across the shield 48 inches from the rear of it, with two sliding doors which can at once be closed. To give an intelligible description of the shield would require drawings, but it may be said that it differs in many respects from Barlow's, Greathead's and Beache's shields, the construction of each having been carefully examined. It is made entirely of steel, its weight being about 80 tons.

Close to its circumference, and just outside the outer shell of the shield, there are placed 24 hydraulic jacks, so that the rams can be worked against the finished iron lining of the tunnel when the shield has to be moved forward. These rams are operated by steam force pumps, and can be used singly, in groups, or altogether. The cocks controlling them are so placed that one man can work 12 of them without changing his position. The aggregate power of the 24 jacks in the shield is 3,000 tons, which is immensely in excess of what is required to move it. But it has been found during the progress of the work that, when a nodule of extremely hard material is met with, the work has to be done by a small group of jacks at the point where the hard clay is encountered. Although, as I have already said, the shield differs materially from all other shields, its circular form and mode of propulsion by jacks is common to other shields. An ingenious arrangement is provided, to show whether the position of the shield is maintained in the direct line of the tunnel. Deviation from the right line is ascertained by measurement, and is marked on a diagram prepared for this purpose, which is kept as a record. One of these measurements for record is made daily, after placing the last section of the lining for that day's work. Any deviation is corrected next day by working the shield to the right or left, lifting it or lowering it as may be necessary. Thus far, the deviations have been very trifling, not exceeding two inches in any direction. The average rate of progress at the two ends of the tunnel has for some time been 15 feet per day of 24 hours. The rate is wholly dependent upon the character of the material met with. On a face of twenty-one and a half feet in diameter, the size of the shield, only 16 men can excavate at a time. The removal of the clay, after it is cut out, as well as putting in the lining, appears to be done without any difficulty or delay. The men have already become so expert in the work of excavation, as well as in placing together the cast-iron segments forming the lining, that, under ordinary circumstances, they can complete a full ring in one hour, sometimes in a less period. I found the tunnel quite dry. Provision is made during construction to catch the rain water that falls into the open cutting at each end of the tunnel, into wells at the portals, from whence it is pumped by steam power into channels at the top of the slopes. It is also thoroughly ventilated. Fresh air is supplied by blowers with a capacity of 600,000 feet of air per hour.

The total length on both sides of the river of the completed tunnel to the 22nd of January is 2006 feet, in Canada 844 feet, in the United States 1162 feet. In a work of this character it is very difficult to make a reliable estimate of cost at so early a stage of progress, but it is believed that the cost of the tunnel completed with approaches and permanent way will be about $2,500,000. Future difficulties, particularly under the river from gas and water, also the system of ventilation, have been very carefully considered, and provision is made to meet them. The time named for the completion of the tunnel is July, 1891.

In the Address of my predecessor, the late Samuel Keefer, a short reference is made by him to the great cantilever bridge across the Forth, constructed by Sir John Fowler and Mr. Benjamin Baker. Having been engaged in the construction of an important railway bridge across the Niagara River, the International Bridge, more especially in the treatment of sub-aqueous foundations, where I made a novel use of well-known appliances, anchors and chains, in accurately locating and founding the caissons for piers, I became very much interested in the construction of the Forth Bridge. That gigantic monument of engineering skill, which has upset all former theories on the dimensions of rigid spans for bridges, deserves, I think, a more extended notice to be placed among the records of our Society. With that object in view I obtained from Mr. Baker information with permission to use it, which enables me to give a brief account, free from technicalities, of this great work, that may prove interesting and instructive.

The bridge across the Frith of Forth is at this date a bridge with the largest spans in the world. Its total length is 7098 feet 6 inches, made of two spans, each 1700 feet in the clear, the remaining distance is covered by iron lattice girders on stone piers. Its construction was the outcome of railway competition. The Frith of Forth at Edinburgh being from one to five miles wide blocks the direct line of the East Coast railways. Traffic must either be diverted many miles, or cross the stream in ferry boats. The Forth Bridge will make the line of which it forms a part continuous. Its construction was long delayed, owing to the great width and depth of the Forth. It is not easy to realize how vast is the difference between a bridge with a 1700 ft. span and the largest span of a railway bridge hitherto constructed. The height of the steel work is also exceptionally great, being equal to that of the golden cross at St. Paul's, 360 feet, while the total height of the bridge is just equal to that of the Great Pyramid, 460 feet. As regards the principle of design, "Cantilever" is a 200 year old term for a "Bracket," and the Forth Bridge spans are made up of two brackets and a connecting girder. On these brackets there is a horizontal pull of 10,000 tons, and on their bases rests a weight of 100,000 tons. The principle of bracket and girder construction is as old as the hills, as it lends itself particularly to timber construction, which preceded masonry. A wooden bridge built 230 years ago in Thibet, with a span of 182 feet, was the true prototype of the Forth Bridge, which only became possible when Bessemer steel was invented. One of the advantages of the cantilever system is facility and safety of erection, as such bridges can be built by commencing at the piers and adding successive bays of the cantilever right and left until the whole is completed. There is thus no moment when the safety of the whole structure is dependent upon the integrity of some temporary staging. At first glance one might think that a cantilever or bracket was not adapted to carry great weights or for long spans. But in long spans the dead weight of the structure itself is the most important element, and since a bracket requires to be the strongest at the root, and lightened out towards the point, it follows that the main weight of the cantilever lies towards the support and acts at a relatively small leverage. The cantilevers or brackets of the Forth Bridge are enormously strong. Mr. Baker says that half a dozen iron-clads might be hung upon them.

The works of the bridge were commenced in 1883. Mr. Arrol, of Glasgow, was the contractor. A start was made with the pier work simultaneously with the erection of shops and machinery for the manufacture of the superstructure. Each main pier consists of a group of 4 cylindrical masonry piers about 70 feet diameter. These are founded on rock or hard boulder clay at depths ranging up to 90 feet below high water. Six of the cylindrical piers were put in place by the use of compressed air. The piers were floated into position by building them hollow in the first instance, and filling them with solid masonry subsequently. The whole was enclosed in a bottom placed about 7 feet above the external cylindrical skin, so that a huge diving bell, 70 feet in diameter and 7 feet high, constitutes the bottom of each pier. When in position the water was driven out of the chambers by forcing in compressed air. Workmen then entered through air-locks, and carried on the excavation 90 feet below the waters of the Forth.

Mr. Baker describes the fixing of one of the piers thus:—"A huge iron caisson, 70 feet in diameter and about 50 to 60 feet high, was built on launching ways like a ship. The bottom of the caisson was set up 7 feet above the cutting edge, and so constituted a chamber 70 feet in diameter and 7 feet high, capable of being pumped full of compressed air." The iron work weighed about 500 tons, and when towed out into position the concrete and brick work added brought the total weight up to 2700 tons. Additional concrete was then filled in, and when the weight reached 3300 tons, the caisson grounded on the sea bottom, where a bed had been prepared for it with sand bags. The workmen then entered through air locks, and the excavation work proceeded in an electrically lighted chamber. The barometer is considered high at 31 inches, but in the working chamber it often stood at 72. It may be interesting to remark that when Coxwell, the aeronaut, made his high ascent, the barometer fell to 7½, or about one-tenth of the height named, which illustrates how marvellously the human body is adapted to sustain wide variations of atmospheric pressure. The superstructure of this gigantic bridge required the manufacture on the spot of 50,000 tons of steel girders and other work. As a rule the *compression* members consist of tubes, and the *tension* members of lattice girders; and this arrangement from an architectural point of view proved most effective. The central connecting girder was erected in two halves temporarily connected with the projecting ends of the cantilevers. The bottom members of the two halves, at the centre of the 1700 ft. span, had large holes bored in them, for the insertion of pins to connect the two projecting halves of the bridge, each of course 850 feet long. These holes had to be watched so as to seize the right moment when the varying temperature and consequent expansion of the steel brought them opposite each other, so that the pins could be dropped in. The next thing was to release the temporary ties holding the top members of the central girder to the cantilever. These were steel bars three feet wide and two inches thick ; to cut through such section of steel would have taken a long time. Mr. Arrol, the contractor, arranged portable oil furnaces by which the ties could be made white hot in a short time, and so the strain on the ties was relieved as effectually as by cutting them. Mr. Baker admits that the cost of the bridge exceeded the estimates. He claims that this was not an exceptional thing, and says that if such a bridge had to be built again, time and money might both be saved. It is expected that trains will begin to run over the bridge in March next. Before concluding a reference to this great bridge, I may add that last year a charter was granted for a 2800 feet span bridge at New York.

This year, Messrs. Schneider & Company of Creusot, in conference with Sir John Fowler and Mr. Baker, as consulting engineers, have designed the steel work of a bridge over the English channel, and Messrs. Hersent & Co., of Suez and Panama Canal fame, have designed the piers. The total length of the projected bridge is 24 miles, the number of piers 120, the width of the openings from 328 to 1640 feet, the clear headway for ships 180 feet, the greatest depth of water 180 feet, and the height from the foundations to the top of the steel work 600 feet. It is calculated that a trifle less than a million tons of steel would be required for this stupendous structure. The estimated cost of the bridge is £34,000,000 sterling.

The Forth Bridge is not only a lasting monument to the designers and constructors, but verifies and most forcibly illustrates the fitness of the motto adopted for the profession of civil engineer: "Whereby the great sources of power in nature are converted, adapted, and applied for the use and convenience of Man."

ELECTRICAL ENGINEERING.

Electricity as a science and electrical engineering are making very rapid progress to control that wonderful power in nature, for the use and convenience of man, which was so graphically described by Mr. Thomas Keefer, in his address to the Society, as "that force like steam, and like it chiefly known by its effects ; its range is universal in the heavens above and the earth beneath, and apparently in all things living, in all animal and vegetable life." It is not my intention to enlarge at present on the numerous improvements in the production and use of electricity for giving light and motive power. But it may be of interest to know that its use as a motive power is being very rapidly developed. One of the early practical satisfactory results of electrical power transmission was at Virginia City, Nevada, on the celebrated mining property, "The Comstock Lode," where water power from streams in the Sierra Nevada Mountains was found to be insufficient to work the stamp mills. A tunnel is driven into the mountain to a point at which a chamber is excavated out of solid porphyry, for the reception of dynamo electric generators and water wheels. This chamber is 50 feet long, 25 feet wide, and about 12 feet high. From the tank above the tunnel at an elevation of 1650 feet, containing waste surface water, two wrought-iron pipes are led to this chamber which supply water to wheels that drive the large dynamo generators, each of 130 horse power capacity, with sufficient numbers of them to generate in the aggregate 800 horse power which is transmitted to the stamp mills, and by this means they are doubled in number, and worked at 70 per cent. less cost.

As Chairman of the Commissioners of the Victoria Niagara Falls Park, I am in negotiation for the use of Niagara Falls to generate electricity in sufficient quantity and power to be transmitted to Buffalo, Lockport, Rochester, Hamilton and Toronto, there to be used as a motive power for working stationary engines at a greatly reduced cost per horse power. The project is to drive a tunnel under the Falls at a point about 165 feet below the upper level of the river, and at its termination excavate a large chamber for placing water wheels and dynamos. The supply of water to be from pipes leading into the tunnel, with a fall of about 160 feet. That an almost unlimited electric power can be generated by the use of Niagara Falls is not doubted. The transmission of that power to contemplated distances in an effective form is maintained by some electrical experts as quite practicable; there are others again who place a much shorter limit to the power of transmission. However that may result, there can be no doubt that the science of electricity and its uses is still in a very early stage of development.

Allow me to close my Address with a short reference to my own personal engineering experience in Canada. The very great progress Canada has made in the development of her canals, railways, and other public works within the last half century induces me to ask you to bear with me for a few moments, while I make some references to the condition of public works, more especially those in Upper Canada, now the Province of Ontario, in the year 1841, requiring the services of engineers. I do this for the purpose of contrasting the beginnings at that period with the magnitude of works accomplished with the aid of engineering skill as they are to-day. During the administration of the Government by the late Sir Charles Bagot, Governor General, I was appointed in 1841 in charge of construction of all kinds of roads, plank, macadam, etc., harbours, light-houses and bridges, not including the Welland canal; that work was under charge of my predecessor as President of the Society, the late Mr. Samuel Keefer, who at that time occupied the position of Chief Engineer of Public Works in Upper and Lower Canada, with the late Hon. H. H. Killaly as Chairman of the Board of Works. It was a period immediately after the negotiation of a loan for £1,500,000 stg. by the united provinces of Upper and Lower Canada. The proceeds were to be applied for the construction of public works in both provinces. The district containing works placed under my charge extended from Kingston on the east to Toronto, Hamilton, and the southern shore of Lake Erie on the south, Amherstburg and Sarnia on the west, Owen Sound and Penetanguishene on the north, in all containing 41 district works. A list of these will be found in the report of the Commissioner of Public Works for the year 1848, on page 50, accompanied by my reports on each. The amount expended on each of them varied materially, but in the aggregate amounted to about $2,000,000, which in those days was considered a very large sum.

The location, laying out, and supervision of this number of scattered works, with very limited assistance from willing and hard working men, in most cases with very little engineering knowledge or experience, was no easy task. The work was rendered more difficult by the impossibility of rapid communication, for from 35 to 40 miles a day, whether on wheels or in the saddle, sometimes for the greater part on foot, was considered a good day's journey. The existing roads in those days were in the occasionally cleared portions of the country, formed only with the material thrown out of small ditches and placed in the centre of the road allowance, without any regard to form; while in the uncleared portions of the country, which were by far the largest, the roads were made by cutting down trees for a certain width on each side of the centre line, but only blazing those standing on or near the boundaries of the 66 feet road allowance,—the statutory width for roads. The setting out of these allowances for roads was done with ordinary compass by amateur surveyors who practised in those days.

The act respecting land surveyors, requiring them to pass an examination before being allowed to practice, was not passed until 1849. Drainage, which by that eminent authority, McAdam, is considered to be the primary and most important condition in making a road, was not understood, and therefore altogether ignored. Where there was a wet spongy depression, it was filled with logs covered with a small quantity of earth that soon disappeared, leaving the logs bare. Such portions of a road were called "Corduroy," and were the dread of all who were obliged to travel over them. The length of time required for a journey and the discomfort of travelling over such roads can only be understood and appreciated by those who were compelled to go over them. I make this allusion to show the physical effort and endurance that were needed to visit the different works sufficiently often to see that they were being properly carried out. There were in all about 600 miles of varied classes of roads.

To show the novelty in those days of engineering works, I may be allowed to narrate an incident: I had to build a bridge across the River Thames near London, now within the limits of that city, on the road to Sarnia, to replace a temporary structure then in use. The new bridge was on the Howe truss plan with the roadway on the bottom chord, one span of 160 feet. When this bridge was completed ready for traffic, and just before the removal of the temporary one, I was waited upon by several leading citizens of London, who inquired if I had absolute confidence in the stability of the bridge to carry the heavy traffic that the improved condition of the road would bring upon it? They thought it too light and spidery. Fortunately batteries of Royal Artillery were quartered in London. I asked the commanding officer to take them across the bridge to test its strength. He replied, "Yes, if you will agree to stand under it." The batteries crossed the bridge at a walk, then at a trot, without even disturbing the camber. That established confidence in the bridge.

The introduction of plank and McAdam roads gave rise to a desire for better means of communication, as their construction gave such striking evidence of great saving of time by the ability to carry heavier loads more rapidly, with reduced wear and tear of horses and vehicles, hence with greater economy of carriage. This practical, beneficial evidence pioneered the way to the construction of railways, towards which counties, cities, towns and townships voted subsidies in the form of bonds towards the cost of building them. While plank roads were considered a novelty, investigation proved that the system was very ancient. The Prussian Minister of Education, having learned that Prof. Knoke found traces of old Roman plank roads in Lower Hanover, had the matter fully investigated. Two plank roads were traced built across a moor. One of them showed signs of having been demolished by force, the boards, that originially were fastened to the bearers with trenails, having been violently torn away and buried in the bog. The other road seemed to have fallen into decay, but it appears to have been repaired during the Roman period. Those repairs, apparently, were done hastily, for in one place, a mallet, probably used to drive home the trenails, was found on the track. The local archæologists feel assured that they have here the "Pontes Lougi" which were used A. D. 15 by the Roman commander in his retreat from Germany to Ems. In addition to the 600 miles of roads, such as I have referred to, six bridges were built which in those days were considered important structures; and six harbours, with lighthouses, four on Lake Erie and two on Lake Ontario, including the Burlington Bay Canal. The building of these harbours was a strong incentive to the movement for obtaining still more rapid communication to these points for shipment of agricultural products. Railways now extend to all of them. All these roads and works were completed about the year 1846. These references to the earlier stages of work for facilitating traffic, and to the condition of the country when in course of development, are given with the view of supplying some historic reminiscences, for the purposes of comparison with the present advanced state of public works, as well as those of private enterprise, accomplished by the aid of civil engineers.

After 1841 and 1842 there was a rapid development throughout Canada of large enterprises undertaken by the Government and private organisations. The first enlargement of the Welland Canal to 9 feet of water on the mitre sills was commenced in 1842. The earliest railway in Canada, the Laprairie and St. Johns, was built in 1836. The Montreal and Lachine Railway was opened and worked with imported English equipment in 1847. The St. Lawrence and Atlantic Railway (now the Grand Trunk), of which I was chief engineer, was opened for traffic to St. Hyacinthe in 1849. The first deepening of the straight channel in Lake St. Peter, upon which I reported with Sir William Logan, General McNeil, and Captain Child of the U. S. Engineers, was begun in 1850. The Byetown and Prescott Railway, known as the St. Lawrence & Ottawa, now part of the Canadian Pacific Railway, was commenced in 1851, and in the same year, the Northern Railway from Toronto to Owen Sound, as was also, about the same time, the Great Western Railway from the Niagara River to Windsor (now Grand Trunk). I will not enter into further details.

These improved means of communication, not only within the boundaries of the Dominion, now extending from the Atlantic to the Pacific, but with the neighboring Republic, have had a marvellous effect in accelerating the material progress of Canada by developing her natural resources in soil, forest, and mine, by stimulating manufacturing industries, and creating those commercial enterprises which have added so greatly to the stability and wealth of the Dominion. The canals of Canada, as a system of internal navigation, have not their equals in the world. As they add so largely to the carrying conveniences of the country, they reflect much honour on the engineering skill displayed in their construction. The St. Lawrence and Niagara Rivers are spanned by bridges that demanded engineering skill to design and erect. Canada has now in operation within her borders no less than 13,410 miles of railways, representing a capital of $727,180,448. In this vital necessity of rapid locomotion, the Dominion with its five millions of people is as fully and favourably equipped as the States with sixty-five millions.

It is interesting to mention that in a book published a few months ago, entitled "The Railways of England," by W. M. Acworth,—a work evidently popular, for I quote from the 2nd edition,—the year 1843 is named as marking the period of stable equilibrium and development of railways in Great Britain. At that date there were only 1829 miles in operation, nine-tenths of that mileage was in England. The capital authorized at that date was about £70,000,000, about 300,000 passengers were carried every week, and the total weekly receipts from all sources were somewhat in excess of £100,000. To-day there are nearly 20,000 miles of railway lines in Great Britain, seven-tenths of them in England and Wales. The paid up capital exceeds £800,000,000, and the annual receipts are greater than all the capital in 1843. The number of passengers has increased forty fold.

But vast as has been the development of Canada's capacities for meeting the needs of agricultural, mineral and industrial enterprises, and for providing the conveniences of ever enlarging commerce and of domestic life, the future will see even greater strides made in the material progress of our country. The works that have signalized the past only foreshadow those enlarged opportunities for usefulness and distinction which the future will open up to the civil engineer.

Permit me in conclusion to say a few words about our Society. The report of the Council shows a considerable increase in our numbers, This no doubt is highly satisfactory, from my own point of view, not only because of this increase, but as a proof that the Society is doing work that is appreciated by engineers, and that the work is good, for were it otherwise they would not have joined us. During the year of my office as your President, I have to regret that owing to my residing at so great a distance from the head-quarters of the Society, and for other reasons beyond my control, I have done but little towards promoting the interests of the Society. This failure to do more has been from inability and not from earnest good-will towards or interest in the welfare of the Society. Allow me, however, to say that any effort of your President alone will not suffice to ensure success. He is powerless unless aided by members. Pardon me if I say that it is the duty of each one of you to help. Each member should bring before the Society every subject of interest connected with our profession of which he has experience in the course of his practice. He ought to attend the meetings for the reading and discussion of papers as frequently as possible. You will forgive me for these words of personal advice to every member. Although they come from one who was your nominal head but for the short term of twelve months, he is not wanting in age in other ways, and let me assure you that they are inspired solely by a desire that the transactions and papers selected by the Council for discussion should be worthy of the Society. They are the proper medium by which the Society's usefulness is to be maintained. By the printing and distribution of those papers our work becomes known, and by their merits new members are attracted. Accept the assurance that I will do all in my power to further the interests of the Society, and I shall watch its progress with anxious desire to see it prosper.

I cannot sit down without making an allusion to the death of my predecessor in the Presidency of the Society, Mr. Samuel Keefer, who was my warm personal friend, and the earliest professional colleague I had in Canada. During the period of my service in the Department of Public Works from 1841 to 1846, Mr. Keefer was my superior officer. I always found his advice sound and most valuable. He was devotedly fond of his profession to which he did honour. He left important engineering works, with which his name will always remain associated. His irreproachable life reached almost fourscore years, the limit allotted to man, leaving a good example to be followed by all members of our profession.

Thursday, 30th January.

JOHN KENNEDY, Vice-President, in the Chair.

Paper No. 37.

STAND-PIPES.

By R. S. Lea, Stud. Can. Soc. C.E.

In many systems of water-supply where the reservoir and the pumping station are at a considerable distance apart, a stand pipe is placed upon the force mains, to equalize the resistance against the pumps. The stand pipe, when used for this purpose, serves as a partial substitute for relief valves, acting in combination with tall and capacious air chambers. It is the office of the stand-pipe or of the air vessel to take up the excess and to compensate for the deficiency of delivery by the pump pistons, plungers, or buckets, and they are more effective the nearer they are placed to the pump cylinders.

The forward stroke of the piston of the single acting pump forces the water, not only along the pipes, but also into the lower part of the air vessel or into the stand-pipe, compressing the contained air in the one case and raising the column of water in the other. The energy stored up in this way is given out, during the backward stroke of the piston, to the advancing water in the main, sustaining its motion until the next forward stroke. The air vessel on the force main is practically a shorter closed-top stand-pipe containing an imprisoned body of air under pressure, instead of a heavy column of water; and neither of them is of so much importance where a double-acting pump is employed.

Tall, open-topped stand-pipes of wrought iron or steel are very generally employed, without reservoirs, in the construction of waterworks in the Western States, where the level character of the ground makes them necessary. They are also very often built in locations where the necessity for their use is not so evident. In such cases the choice between a reservoir, a tank, or a stand-pipe is often one which requires careful calculation, combined with judgment and experience. An earthen reservoir is always to be chosen where practicable, on account of its durable and permanent character. Where the site is just a little too low to enable an embankment for a reservoir to be constructed, at a reasonable cost, a mound of earth is made artificially, and upon this foundation an iron tank is built, which maintains the surface of the water at the required elevation.

But in flat countries, or in situations where the nearest elevation is at too great a distance, some other method must be employed to get the requisite head. This may be done either by building a steel or iron stand-pipe high enough for the purpose, or by constructing an iron tank of large diameter compared with the stand-pipe, and supporting it at the proper elevation by a well braced iron tower. One advantage urged in favour of the elevated tank method is, that by making the diameter say 75 per cent. greater than that of the stand-pipe, a much larger quantity of water at a high pressure is always in readiness. This is of importance in case of fire, and this after all is just when pressure is most needed. The delay in pumping up, when the level of the water has been allowed to fall considerably, is one of the strongest arguments against stand-pipes. However, this disadvantage may be obviated by the use of a device for automatically disconnecting the stand-pipe from the distributing main in cases of emergency, several of which have been invented.

There are many rules for finding the thickness of the plates of which the shell is made.

The following one, which is sometimes used for steam boilers, allows for rivetted joints, and assumes a net strength of 6000 lbs. per sq. inch, and reads :—

"Multiply the diameter in feet by the pressure in lbs., divide the product by 1000, and the quotient will be the thickness in decimals of an inch." This not very explicit rule, however reliable it may be in the case of boilers, does not work very well in the case of stand pipes and tanks, with their extreme range of pressures and proportions. For example, the stand-pipe in Sandusky, Ohio, is 25 feet in diameter and 208 feet high; this rule would make its lower sheets $2\frac{1}{4}$ inches thick, while in reality it has stood for years with a thickness of $\frac{7}{8}$ of an inch. And again, in the case of a stand-pipe 5 feet in diameter, the sheets near the top, when the pressure is only 1 lb., would be $\frac{5}{1000}$ of an inch thick, *i.e.*, thinner than the thinnest tin plate.

The following formula, in which a constant is introduced, is simple and seems fairly reliable :

$$\frac{h \times d}{10000} + .2 = t$$

in which h = head of water in feet, d = diameter of pipe in feet, and t = thickness of iron in decimals of an inch. The thickness may decrease in half a dozen or more changes until the top is reached, and each successive change can be calculated by the same formula, using the distance of the lowest part from the top of the pipe. The thickness of the bottom may be made the same as that of the sides half way up, unless it is to be laid on some kind of a foundation requiring special strength, as when supported by beams like the floor of a house.

Whatever formula is used, the greatest load which comes upon the lower rings in a stand-pipe is the pressure due to the column of water when the stand-pipe is full; and if they are proportioned to meet this, they will be quite able to bear all other strains. But the *upper* rings, while of a sufficient thickness for the hydrostatic load, may be so light as to collapse under moderate wind pressure, should the water be below the ring, and an extra thickness must be provided to meet this condition.

The ordinary size of sheet used is 5′ × 12′. The vertical joints should be double-rivetted for at least two-thirds of the height, while the horizontal ones need only be single-rivetted, the strains in them being far less than those in the vertical.

The bottom is usually connected to the shell by an angle iron. The top of the pipe may be trimmed on the outside with a flat iron band or hoop; but trimming on the inside is apt to interfere with ice floating in the stand pipe in winter.

The anchor bolts and foundation should be proportioned in accordance with the assumed wind pressure. It is the practice of a writer in the *Engineering News* to use $1\frac{3}{4}$ inch bolt for each 16 feet of height, with masonry foundation 8 feet deep and stepped out $3\frac{1}{2}$ feet on each side beyond the stand pipe, each bolt passing through a strap lug attached to the lower part of the pipe by six or eight rivets. For example, if the pipe is 160 feet high by 10 feet in diameter, the use of 10 bolts going through a foundation 17 feet in diameter is a good approximation This arrangement of base gives great stability to resist wind pressure.

The best form for a stand pipe is the cylinder, because a tapering one costs more for the same cubic capacity, has less storage capacity at the top where it is most required, weighs more for equal strength, and its shape prevents the ice, which forms in cold weather, from moving up and down with the variations in height of the water, which causes severe strains in the material of the plates. It has been found that the proportions of the lightest tank to hold a certain quantity of water are two in diameter to one in depth.

In calculating the contents in U. S. gallons, the following rule is convenient; also if the quantity measured in this way is assumed to vary in temperature 10°, it will cover all discrepancy in volume from the results of the most elaborate calculation :—

Let h = height of tank in feet.
" d = diameter " in inches.
" g = capacity " in gallons.

Then

$$\frac{.17g}{d^2} = h,$$

$$\frac{.17g}{h} = d^2$$

$$g = \frac{h \times d^2}{.17}$$

The following description of a stand-pipe lately completed at Malden, Mass., will give some idea of the details of construction :—

Malden is one of the many suburban towns of Boston, Mass., and has a population of about 20,000. Its original situation was in a valley around the base and in the vicinity of an elevation known as Wales Mountain; but within the last few years it has been extending up the slopes of the hill, in consequence of which this newer portion of the town was left without sufficient water pressure in time of fire. The water supply until the present year was taken by gravity from a pond 3 miles distant, and was fairly sufficient for most purposes, while the area covered by the town was confined to the valley. But the demands of the elevated portion of the city for increased pressure made some form of high service necessary, and it was therefore decided in this connection to construct a reservoir or stand-pipe on the top of Wales Mountain. This was evidently the best location for the storage reservoir, being situated almost in the centre of the town and of sufficient height to give the requisite pressure.

The ordinary "core wall and earth embankment" reservoir was out of the question, owing to the character of the hill, which was composed almost entirely of an igneous granite rock, the greater part of which was exposed.

It was therefore decided to construct a stand-pipe or tank of wrought iron, with a capacity of about 1,000,000 gallons, the latter name being in this case more appropriate on account of the dimensions, viz., 75 feet in diameter and 35 feet high.

The foundation for the stand-pipe was constructed on a solid ledge which forms the summit of the hill. Fig. 1, Plate IV., shews a cross section through this ledge with the foundation finished, the original line of the surface being represented by the dotted line.

The exact site having been chosen, it was next laid out, in squares and cross-sectioned, and then a certain elevation was determined upon—200 feet above city datum—as that of the bottom of the stand-pipe when finished, which was such that it left part of the summit above grade and part below. That portion of the rock which was too high was removed by blasting, while the remainder was brought up to grade by first cutting steps in the sloping sides of the rock to get a firm footing, and then building it up with masonry laid in cement mortar.

There was also considerable blasting required in forming the pipe chamber through which the supply main passes into the tank.

This pipe chamber is situated as shown in Fig. 1, and is 10 feet long, 5 feet wide and 6 feet deep. It is roofed over with a 12 inch brick arch through which at the inner end there is a circular opening $2\frac{1}{2}$ ft. in diameter, to allow the supply main to enter the stand-pipe. Across this hole at each side of the main are placed two 5 inch I beams to support the bottom of the tank. The portion of the chamber outside of the foundation is covered with a large piece of North River flagging 5 inches thick, with a manhole 2 feet in diameter cut in the centre and fitted with an iron cover. When the base had been brought to an even grade, a granite underpinning 12 inches wide and 16 inches high was laid around the outside. This underpinning, which has a 3-inch wash-cut, secures the foundation from the effects of the frost and also gives it a finished appearance.

The foundation having now been completed, the next step was the erection, directly over and upon it, of false works three feet high, upon which to put together the bottom of the tank. This bottom is built of plates 10 feet long, 6 feet wide and $\frac{5}{8}$ of an inch thick, rivetted together by a single row of $\frac{3}{4}$ inch rivets spaced $3\frac{1}{4}$ inches apart centre to centre. The plates around the outside were made of a softer metal than the others, to allow of the formation of a 5-inch flange around the entire circumference. To the flange the first row of side plates was rivetted.

The bottom of the tank was put together and the first row of side plates attached on the false works above referred to, so that the next process was to lower it into its position on the foundation.

The specifications required that there should be a four-inch layer of Portland cement mortar (one of fresh ground cement to two of clean sharp sand) over the whole foundation, in order to give the bottom a perfectly uniform bed to rest on. These constituents, after being well mixed, were put in dry, the moisture from the foundation, bottom, etc., being considered sufficient to set it.

The bottom was lowered by means of jacks beginning at the centre and working outwards. As fast as the false works were removed the cement was drawn in in bags and spread in place. When the false works had all been taken away, the outside edge of the tank was lowered on to a number of 6″ × 8″ spruce blocks about a foot long, placed at intervals of 10 or 12 feet. The jacks were then removed, leaving the tank resting on these blocks, the bottom being already down, having sagged a foot. After seeing that everything was clear, the blocks were broken to pieces by sledge hammers, letting the bottom perfectly true with the foundation in every way.

The process of construction was now continued, the plates for each course being hoisted into place and fastened with temporary bolts until the rivet holes were all in line, the use of a drift pin not being allowed. The first or lowest course is connected with the flange (the flange being inside) by a triple row of $\frac{7}{8}$ inch rivets spaced $2\frac{1}{2}$ inches apart centre to centre, the rivets in the several rows occurring alternately. The first two courses are made up of plates 6 × 10 feet and $\frac{3}{4}$ of an inch thick, the vertical seams being triple rivetted and the horizontal ones double rivetted. The triple rivetted laps are 5 inches wide and the double rivetted $3\frac{3}{4}$ inches.

The plates of the next two courses are of the same dimensions as those mentioned, except that they are $\frac{1}{2}$ inch thick, and all the seams are double rivetted. The two top courses are composed of plates $5\frac{1}{2}$′ × 10′ and $\frac{5}{16}$ of an inch thick, and all the seams are single rivetted with a lap of $2\frac{3}{4}$ inches. All the seams were carefully caulked by hammering or welding the edge of the plate (planed at an angle for the purpose) into the one over which it is lapped. In one of the lower side plates there is an oval-shaped manhole—24″ × 18″—fitted with an iron cover on the inside and proper bolts and yokes on the outside. By means of nuts bearing upon these yokes, the cover is firmly drawn up against a rubber seat, making it tight and secure.

Twenty-eight feet from the bottom, the stand-pipe is encircled by a balcony. It is made up of $2\frac{1}{2}$″ × $2\frac{1}{2}$″ × $\frac{5}{16}$″ angle iron with a floor of hard pine, cut rightways and well oiled, laid radially with the tank, and fastened with $\frac{1}{4}$ inch carriage bolts. The whole is supported on brackets, made of 3″ × 3″ × $\frac{3}{8}$″ angle iron rivetted to the sides of the tank. The balcony is reached by means of a staircase built of angle-iron with cast-iron steps, which is supported on angle-iron brackets bolted to the sides of the tank.

The stand-pipe is covered by a slate roof with twelve sides, supported by 12 iron trusses of the form and dimensions shown in Fig. 2.

Between the trusses the roof is supported by five rafters of channel and angle iron, and across these, $10\frac{1}{2}$ inch centre to centre, are placed the purlins, which are made of $1'' \times 1\frac{1}{2}''$, 6 lb. per yard T iron. The roof is covered with the best of Eastern slate which is fastened to the purlins by "Farquhar's Patent Clasp"—a very neat and effective arrangement for the purpose; it consists of nothing more than a small bolt and a piece of wire bent into a particular shape. (See Fig. 3.)

The roof was designed and built by the Boston Bridge Company, and put in place by them, for the total sum of $5000. The specification required the roof to be able to sustain the following vertical loads. On the purlins 45 lbs. per sloping square foot of roof surface; on the rafter 50 lbs. per sq. ft., etc.; on the trusses 55 lbs. These loads not to strain the iron in tension more than 12,000 lbs. per sq. in., nor in compression more than 10,000 lbs. per sq. inch. The iron used was the best American bridge iron. The trusses are all tied together in the centre by 1 inch iron rods.

The roof is surmounted by a galvanized iron ventilator or cupola of a neat and ornamental design.

When all the iron work had been completed, the inside of the stand-pipe was given three coats of black asphalt varnish, while the outside was painted with the same number of coats of white lead and linseed oil. The pipe has a capacity of 1,180,000 gallons, and the elevation of the water when full is 235 feet above city datum. It was pumped full about the 1st of August last, and proved perfectly tight, there being no sign of any leakage beyond a slight exudation or "sweating" for a short time.

The cost of the foundation was $1500, of the roof $5000, and of the stair $500. The stand-pipe itself was built by the Cunningham Iron Works of Charlestown, Mass.

The total cost of the structure when completed, including that of the foundation, was $22,440. It was built under the direction and according to the specifications of M. M. Tidd, C.E., of Boston, Mass.

From the drawings accompanying this paper Plate IV. has been prepared.

Thursday, 13th February.

JOHN KENNEDY, Vice-President, in the Chair.

Paper No. 38.

THE SCREENING OF SOFT COAL.

By J. S. McLennan, B.A., A. Can. Soc. C.E.

Coal comes from the pit to the surface as the miner has broken it down. He loads into the tubs the lumps and fine coal made by his pick in holing or undermining his shot, or in breaking up the large mass which is tumbled over as its result. In mines where a layer of stone adheres to the top of the seam, he is bound under a penalty to clear this off. But with other foreign matters found in the coal he has no concern. Roughly speaking, few seams are absolutely free from such impurities, and, to bring the coal to its best merchantable condition, these must be removed as far as possible. When this has been done the coal is "run of mine" in the commercial sense. Round coal is that which passes over a screen, the bars of which have between them apertures of $\frac{1}{2}$ to $\frac{3}{4}$ of an inch. Slack is the coal which falls through these apertures, and it is often passed through a secondary screen and divided into nut and duff.

The desiderata in screening are therefore:—

I. Effective separation of sizes; so that slack may not be carried among the lumps into the round coal, or so that, in avoiding this by wide openings between the bars, too large coal may not pass into the slack, a consideration of some importance in shipping slack to the United States, where an excessive size would render the cargo liable to a higher rate of duty.

II. An opportunity for the removal of mechanical impurities as stone or pyrites, which occur in some mines as "balls," or elsewhere in laminations so thickly grouped, as to be easily visible.

III. The minimum of breakage in the transit, from the pit tub to the railway car, the vertical distance between the levels of which is from 15 to 25 feet.

The ordinary method of screening is by a fixed screen about 20 feet long and 6 feet wide, inclined at an angle of about 25°. The effective screening surface is reduced in many cases, by the use of cast-iron bars about $\frac{3}{4}$ inch thick. The tub is commonly provided with an end door, and, when run on a tumbling cage, it is tipped into contact with the upper end of the screen. The door is opened automatically or by the attendant, and the coal slides down the screen. As there are no means of regulating its speed, it very imperfectly fulfils all the conditions of screening coal, except rapidity, as it is obvious that coal can be sent down it as rapidly as tubs can be tipped; but it is not separated effectively, no opportunity for picking is given, and the breakage of the lump coal and also of railway cars is excessive.

The method of screening adopted by Mr. Poole, at the Acadia Colliery in Pictou county, is effective and economical. He describes it as follows:—

Coal is drawn from the mine up an incline of 24° to 28° in boxes holding a ton each. The boxes have end doors, and are run forward on the bank head, 28 feet above the main railway, to a rocker. The loaded box tilts up, the door is released, and the coal slides out on to a dead plate at the head of the screens.

The dead plate, 3 ft. wide, dips at an angle of 40°. From its ower edge proceed two sets of bars which we may call A and B. A is 5 ft. long, and is made of 2 in. bars placed 6 in. apart. It inclines at an angle of 12°. To the far end is hinged an apron 12 ft. long, ordinarily lying at the same inclination. The free end of the apron is sustained by a counter weight. When the weight is down and the apron up, the passage over its upper surface is closed by a fixed stop suspended from above, at a point two-thirds of the distance from the near end.

The "B" set of screen bars are 12 ft. long, 1 in. sq. iron and $\frac{3}{4}$ in. apart; they start from the dead plate under the heavy bars at an inclination of 45°, being continued at a lessening inclination until an angle of 21° is reached, at which inclination the screen then remains. A hopper under these bars collects the "slack" coal that has fallen through, at the lower end of this screen; a short fixed screen 2 ft. 6 in. long with $2\frac{1}{2}$ in. openings separates out the "stove" size. Thence onward the screen is lined with perforated plates, and terminates in a counterbalanced apron 4 ft. wide, which, as required, checks the flow of coal over the screen and enables stony coal, etc., to be seen and removed; or entirely stops the flow, and allows coal to accumulate while cars below are being shifted.

The object of the coarse screen A is to separate out "furnace" coal, and the separation of very large lumps from the run of mine enables a more thorough screening of the remainder to be effected. The furnace coal slides forward on the apron and collects against the fixed stop. When the apron is full, the screenman lifts a brake from the counterbalance, the apron then descends until the point rests on the regular screen; and while it is descending, the coal upon it is slowly sliding forward, and thence passes quietly on without a drop into the car below.

The slack collected in the hopper under the screen drops into a well, from which it is elevated to the level of the bank head, and dropped into a revolving screen 12 ft. long by 4 ft. diameter, covered with wire cloth of $\frac{3}{8}$ in. mesh. This screen separates the slack into "nut" and "culm."

The above will make clear the arrangement at Westville; at the other pits the ordinary screen is in use.

The arrangements at "Acadia," which are thoroughly effective, require a high bank head to give space for the screens, and thus were not available as models, when the writer decided to change the screens he found in place at the International mines. Notwithstanding Mr. Poole's kind assistance, some other device had to be used, which could be placed in a bank head only 21 feet high. No other screens are in use in Nova Scotia, and the apparatus known as Riggs Patent Curved Balance Screen was imported from England. It is shown in Plate V, Figs. 1 and 2, and consists in the tipping cage shown in Fig. 2, in the position in which the loaded tub is pushed into it. The tub is retained in position by angle irons, which project beyond and slightly above its edges. The lever shown in the sketch which operates the hand brake is partially released, and the whole cage turns over slowly until it reaches the position shown in Fig. 1; the coal slides out of the tub on the screen, and by gravity the cage assumes its former position. The tubs are "solid," that is without end doors, and thus save a good deal in repairs, the doors being the parts most liable to get out of order.

The screen is 6 ft. wide and 11 ft. long from the top to the journal shaft which supports it, and thence to the mouth 13 ft. in length. To the journal shaft is keyed a large brake wheel, the band brake on which is controlled by a bell crank lever indicated in both sketches. The angle of inclination of the upper part is 25°, and of the lower 8°. The momentum of the coal from the tub carries it forward to the lower part of the screen, where it lies until it is inspected, and, if necessary, cleaned; then, on the release of the brake, its weight causes the screen to tilt downwards to the position shown in Fig. 2, until the coal slides gently into the car. When the weight is removed the screen returns to its former position.

It will be seen that, in giving a chance for cleaning the coal and saving of breakage, it is perfect, and very good for separation of sizes. It is, however, slow, and by requiring more screens is thus more expensive for a given output than the old type. Its first cost is high, and, consequently, a modification, suggested by Mr. John Johnston, the underground manager, has been adopted. This is shown in Figs. 3 and 4. The screen is the same length, but is 7 ft. 6 in. wide. The upper part is fixed at an angle of 28°.

The lower part rests on a journal at X, and is supported by a counter-weight W, controlled by a brake B around which the connecting wire rope passes. The Rigg's cage is used with this screen. When the coal is ready to be deposited in the cage, the brake is released, and the point of the screen descends as in Fig. 4. When the coal is off, the counter-weight brings the screen back into the position in Fig. 3. In Figs. 1 and 2 is shown the box in which slack is caught and deposited in a car. In the other is indicated at E an endless chain conveyor, which carries it to an elevator to the subsidiary screen on the bank head, where the nut coal is taken out.

While this system is more costly than the normal type, its efficiency more than compensates for the cost in giving a cleaner and larger coal than was formerly obtained.

The Old Sydney and Victoria Mines employ an apparatus known as the Billy Fairplay which Mr. Brown, the manager, has kindly described for this paper. He says:—

The "Billy Fairplay" system is in use at the Sydney mines of the General Mining Association, Limited.

By this method the coal is not riddled in the pit by the colliers, but is filled by them just as it is cut, into the tubs or boxes, the large and small or slack coal all together. On arrival at the surface, the tub of coal is weighed, and the gross weight of the coal it contains is recorded. It is then dumped into the screens; the screened large coal passes over the bars of the screen into the cars, and the slack coal passes through the spaces between the bars of the screen into a hopper.

From this hopper the slack coal falls into a tray which hangs suspended on pivots from an indicating dial overhead. When all the slack from a tub of coal has thus gone into the tray, its weight is ascertained by the dial, and the tray is then capsized by a string pulled by a small boy stationed at the screen for the purpose, and the empty tray resumes its original position ready for the next tub of coal.

The gross weight of the coal that was in the tub is placed to the credit of the collier who sent it up, and the weight of slack that has been screened from that tub is placed to his debit; he is paid a certain price per ton, only on the difference, that is, the screened large coal.

The advantages of this system are, that the colliers are saved the labour of riddling their coal by hand, and that it discriminates in favour of the skilful workman, who hews his coal with a view to make as little slack as possible, and gives him, as he deserves, better pay than the careless miner, who breaks up an undue proportion of the coal which he produces.

The slack coal is emptied by the capsized tray into a small tub. This tub, when full, is drawn up a steep incline by means of a small engine and wire rope, and when arriving at the top it automatically empties itself.

The slack coal from the tub falls upon an oscillating screen composed of wire netting of half inch square mesh, which separates it into nut and duff, each of which passes through a shute into a car of its own on the railroad below. If slack coal is at any time desired in the cars instead of nut and duff, then the wire netting screen is not used.

The Billy Fairplay system is largely used in Wales and in the north of England.

It may be noted that, while the "Billy Fairplay" is a very valuable incentive to the miner to reduce the slack to a minimum, the practice of riddling coal in the pit to which Mr. Brown refers has been abandoned by all but one or two mines in Cape Breton and Nova Scotia. The English practice is very elaborate at the best collieries. Screens having bars with reciprocal motion carrying the coal along, circular screens revolving horizontally, so that different bands of coal can be sorted into different cars, are in use, all of them elaborately explained in Percy's Mechanical Engineering of Collieries. In the Pittsburg region, the screening appliances are good. In many cases a very high bank head allows enough assorting of the different sizes through a succession of screens into different cars; but while it may not be true of other departments of the industry, the best practice in screening in this province is abreast of the times.

From the drawings accompanying this paper Plate V has been prepared.

DISCUSSION.

Mr. McLennan said that only the two mines mentioned of the General Mining Association paid the miners for large coal; at all the other mines the colliers were paid per ton of run of mine, and the coal was screened as the company chose. Mr. McLennan.

Mr. H. Wallis said that he had listened to Mr. McLennan's paper with much interest. The process of screening described was one which would, no doubt, turn out coal in excellent condition. At the same time he was not greatly impressed, having regard to the commercial value of coal at long distances from the mines, with the necessity of screening it at all. The Grand Trunk Railway Company used run of mine coal only, after an extended experience with the various grades of lump and nut, the reason being that the expenditure for screening, some 20 cts., added to the cost per ton, did not ensure the delivery of the coal, after much handling and long haulage, in the condition expected. The company paid for lump coal and received apparently the run of the mines, the grade having been lowered in the manner named, but the difference was not so apparent under the present system of purchasing. He would, however, prefer the lump coal if it could be delivered as contracted for. There was a difference of 8 or 10 per cent. in its favor, varying as a rule in accordance with the hardness of the coal. He was aware that it ought to be cheaper to the consumer to use long distance coal as lump rather than of a lower grade, and so it would but for the objections mentioned. It was true that recent improvement in locomotive practice, including what are known as extended smoke boxes, together with largely increased grate surface and the introduction of the compound principle, had rendered possible a steady if softer exhaust, and therefore reduced the tearing action on the fire to an extent which had in some cases permitted of good results having been obtained from slack. He desired to ask what percentage of culm and slack was left over after screening. Mr. Wallis.

Mr. Dodwell enquired whether the damage which the coal sustained in transit was due entirely to handling or in part to disinte- Mr. Dodwell.

gration, and also whether the author had had any experience with lime cartridges and did he coke the slack. In 1870 or 1871 he spent a month or two at the Albion Mines, and the slack coal was then looked upon as a nuisance. The loading ground was ballasted with it, and it struck him as being singular that it should be considered valueless when it might have been used for coking or making briquettes.

Mr. St. George. Mr. St. George said he thought a screen necessary as an incentive to good mining. He considered clean coal necessary to good steaming in stationary boilers, particularly with forced draught, and the experience of engineers on the ocean steamers was that their speed had been increased by the cleaner condition of the coal. He was aware that in Virginia, especially West Virginia, in the Alleghany Range, they coked all the coal now. He would like to know how it would answer to ship coal to a large market and screen it there. In Belgium the practice was to cover the slack coal with earth and to plant it with trees.

Mr. Wanklyn. Mr. F. L. Wanklyn enquired what experience the author had in the use of powder, also had he used hydraulic rams with long buckets for breaking down the coal.

He thought it would suit them better to simply clean the coal instead of separating it into different sizes. There seemed to be a larger percentage of dirt and shale in the Lower Province coal than in that from the United States.

He would like to know the difference in price at the pit's mouth between lump and run of mines coal, and if it is the custom to dress the cars conveying run of mine coal, that is, to place the lumps at the top? He had noticed cars apparently loaded in this way.

He believed that briquettes were used in Europe when coal was carried long distances, because in this form it did not deteriorate so much from exposure to the atmosphere, and they could be more readily slacked, although owing to the pitch used in their manufacture, such coal gave off more smoke in combustion. The system adopted in England of firing factory boilers by mechanical means had rendered possible the burning of small coal with satisfactory results. The regularity with which the furnaces were fed, in relation to the quantity of air supplied, prevented loss through the tubes, and the percentage of ash was inconsiderable.

Mr. John Kennedy enquired whether coal could be cleaned without screening so as to save the cost of as well as the loss by screening. Mr. Kennedy.

In buying cargoes of coal it often appeared to him to be all slack, and at times he found it hard to persuade himself that it had been screened at all. He supposed that the better draught obtained in all sorts of boilers, especially on board steamers, and to some extent in locomotives, enabled them to use more slack or run of mine coal than formerly. Ten years ago enormous quantities of Scotch coal were used in Montreal, because it was thought that nothing else would give satisfaction, until the price rose so high that steam users had to purchase Lower Province coal, and now scarcely any Scotch coal came into the market.

Mr. Rhodes said he would be glad to have some information as to the manufacture of slack into briquettes. Large supplies of these were manufactured at the Taff Vale collieries in Wales, and shipped to Continental railways. They were made from the pure washing of the slack coal pressed into shape with hot pitch. There was a large and increasing trade done in these briquettes, principally with French railways. Mr. Rhodes.

Mr. McLennan remarked that Mr. Wallis had spoken from the standpoint of the consumer, and what he had said was undoubtedly correct from that as well as from his own standpoint. They endeavoured to persuade their customers to use "run of mine" coal, especially in markets reached by vessels, on account of the damage to the coal caused by dropping into the vessels and afterwards from the vessels into the dumps. If the handling could be reduced so that coal could be simply cleaned and sold as run of mine, it would be an advantage to everybody concerned except householders. His company had not sold to the Grand Trunk Railway Co. for a long time past, but he did not think that company had ever received from them unscreened coal. He remembered distinctly the impression made on him by the appearance of a cargo of coal in Montreal which had been loaded in Cape Breton. It was absolutely unrecognisable, and if he had not known the ship, he would have doubted its being the same coal that he had seen in Cape Breton five or six days previously, the destruction in handling had been so great. Mr. McLennan.

With reference to the percentage of culm and slack coal, it averaged from 25 to 30 per cent. over $\frac{5}{8}$ inch apertures. At one mine it was as much as 35 per cent. Mr. Routledge claimed to get 18 per cent. only but he riddled in the pit at that time. The average might be taken as from 22 to 28 per cent. It depended to some extent on whether the screens were double or not.

Their miners were paid by the ton on the run of the mine which was supposed to be cleaned from stone, slate and roof. They could do this in their mine where there was only one band in it, and that about one inch thick. The lump was cleaned out and a proportion had to be afterwards broken in order to get out the slate before shipment. When the coal was riddled in the mine the refuse was left there. In some mines this practice would be a source of danger. If there was a demand for slack it would be taken out by bags. It was thought that the "Billy fair-play" system, mentioned by Mr. Brown, would make the miners more careful, but when they found that the slack for which they were not paid was being sold, objection was raised to the system.

In reply to Mr. Dodwell, the damage to the coal was not so much due to disintegration, which did not take place until some months afterwards. Coal that had been badly mined or shaken with powder would break sooner, but no doubt all coals commenced to disintegrate slowly from the time they were mined. His experience with lime cartridges had not been satisfactory. One man lost an eye through some which had been sent out to the Sydney Mines to try. With regard to the slack they coked merely what was required for local purposes. Cape Breton coal coked tolerably well, but was a little high in sulphur for iron working.

As to the necessity for screening as an incentive to good mining, it was customary to pay for each ton of coal sent up if it were reasonably clean. It would hardly pay to screen coal at the point of delivery, which would cause double handling and therefore increase the cost, but it might be done if the market at that point were large enough for pick coal.

Replying to Mr. Wanklyn, the hydraulic rams had not been tried in Canada, and were only useful when the coal made a clear parting from the roof. If the roof parted badly the coal had to be picked over. It depended upon the strata next the roof. He had thought sometimes of obtaining a few wedges to try. In every seam were one or more bands. He believed that in the case of the Pittsburg coal—perhaps the cleanest coal in the United States—the band was very much broken up. They mined out six feet and actually sent to lump four to four and a half feet, while the rest of the coal, between six and seven feet in height, was thrown away. The difference between the value of lump and run of mine coal at the pit's mouth would probably be twenty cents or a little over, it would depend upon the price obtained for slack. In the Newfoundland market the domestic consumers wanted lump coal entirely. He did not think it was usual to dress coal cars in the manner suggested.

Referring to Mr. Kennedy's remarks, the cost of cleaning coal included the screening. In reality considerable labour was expended beyond that actually engaged in screening. The slack was worth from 50 to 60 cents a ton.

It was quite as painful for the coal owner as for the purchaser to see the condition in which the coal very often arrived at ports of delivery. Shippers took a pride in sending it away in good condition, and the damage which took place in transit was most discouraging to them. Vessels to be economically worked should be about twenty feet deep in the hold, and it would be in the interest of the consumer if the system of discharging could be improved. The method of hoisting a tub of coal by a whip and turning it over into a car caused more breakage than the loading of the vessel.

With reference to the manufacture of briquettes, at the Gowrie Mines they had Yeadon's apparatus, and they made tolerably good bricks, but the practice did not seem to be much favoured. Moreover, they had not any great excess of slack in Cape Breton or Nova Scotia, and there was not the same pressure now as years ago to get rid of it. He had been surprised to see how small was the export of bricks at Cardiff; the trade did not seem to have kept pace at all with the coal trade from that city, although he was aware that the French railways were rather large consumers.

Referring to the burning of slack coal, there was, as had been remarked by Mr. Wanklyn, some difficulty with a high forced draught, much of the coal would, under such conditions, pass through the tubes and up the smoke stack unburnt. One of their steamers carrying coal to Montreal some years ago and burning slack ran under such conditions with an excessive consumption, he thought, of about 25 per cent. He believed, however, that quite a number of colliers were running on the east coast with slack coal entirely, and with a different arrangement of grate; they could probably do the same.

The maximum evaporative results would probably be obtained from the use of nut coal. Slack was more likely to heat spontaneously, but it would part with the volatile carbons more readily even although there might be no actual heating.

CORRESPONDENCE.

Mr. Leonard.

Mr. R. W. Leonard said that in Spring Hill, all stone or other impurities must be separated in the pit by the loader employed by the coal cutters, and boxes of dirty coal are "docked" at the bank head, *i.e.*, the miner is not paid for them.

The form of the bars has much to do with the successful screening of soft coal. Cast-iron bars are rough, and are apt to cause much trouble in cold weather by freezing up; square bars set on edge are very well adapted for the work, but it is necessary to clean them continually with a hoe, as certain sized pieces will stick between them. Flat top bars $\frac{3}{4}''$ wide on top, $\frac{1}{4}''$ at bottom, and $1\frac{1}{2}''$ deep are not so subject to this trouble, but do not screen as efficiently, unless the screen is made in two sections with bars in second section opposite space in first part.

The "ordinary method" described by Mr. McLennan is used in screening in Spring Hill, and is found to suit our requirements very well. Two of our bank heads are too low (18 ft. and 22 ft.) to adopt the admirable system described by Mr. Poole.

The output of these mines is very large, and 1300 boxes of 1650 lbs. have been passed over two screens in ten hours. The screens are six feet wide, and are fixed at an angle of about thirty degrees. The bars are ten feet long, of one inch square iron set on edge, and spaced three-quarters of an inch apart. The speed of the coal sliding over the bars is regulated by a stop door above the screen bars, hinged at the top, and held by a lever by which the door can be opened as much as is necessary to run the coal over the bars at the required speed. By keeping the shute full above the stop door, the coal is not broken much by being stopped in that manner. Below the bars is a long apron running out to a flat angle on which the coal rests, where it is thoroughly picked by men handling it over with hoes. With careful work Spring Hill coal can be well screened without much breakage, although it is one of the tenderest coals in the Province. The slack is run into cars, and is then taken to a large revolving screen if required to be further separated into nut and culm.

This screen was erected last year and has a capacity of over 400 tons in ten hours (it has screened 516 tons in that time); it is 20 ft. long and 5 ft. in diameter. The coal is hoisted by an endless chain of buckets 40 ft. from a hopper under the track, and may be separated into four different sizes if required. The different sizes drop into separate bins, and are thence run into cars as required. The cost of screening at the Rotary is about 6 cts. per ton, including shunting of cars.

The modified Rigg's system of screening finally adopted by Mr. McLennan is essentially identical with a system in common use at the collieries on the Kanawha River, West Virginia.

In that district the Mount Carbon Coal Co. has a most ingenious "coal transfer" or wharf for loading their coal (which is very easily broken) into barges, at the greatly varying heights of water in the river. This wharf, which is very cheaply and substantially constructed, has a capacity, it is stated, of about 400 tons per hour. It breaks the coal less than any other system the writer has seen, and is a very cheap one for even small shipments. It is fully described in the Transactions of the American Institute of Mining Engineers, 1888, but a short description of it will not be out of place here. It is a simple application of a flexible steel belt 4 ft. wide, with 6 inch flanges, and of the required length between sprocket wheels to suit different heights of vessel or water without being so steep as to allow the coal to move on it. The motive power is a small stationary engine, and the belt virtually draws the coal from the open hopper of the car and carries it to the vessel. The outer end of the belt is raised or lowered (being pivoted at the inner sprocket wheel) to suit varying stages of the water. This system is being rapidly adopted in the "New South," where coal is required to be handled without breakage. The Cumberland Railway and Coal Company are preparing to erect a similar wharf at Pugwash, for loading into all classes of vessels for the St. Lawrence trade.

Mr. E. Gilpin said that in Nova Scotia for many years the distinction between round and slack coal was an arbitrary one. The screens at all, or nearly all, the collieries being made with bars $\frac{3}{4}$ of an inch apart, in order that the requirements of the royalty clauses of the Mines Act might be most readily complied with. The law required a payment of 6d (9.7 cents) per ton of 2240 lbs. on all unscreened or round coal, *i.e.*, coal that had not passed between the bars of a screen placed $\frac{3}{4}$ of an inch apart. In the earlier days also nothing but lump coal was considered marketable for general purposes. In the Block House pit, Cape Breton, gas coal was riddled in the pit through riddles having $\frac{1}{2}$ inch meshes, and passed without the formal screening direct to the vessel, the saving in time and expense compensating for the increased amount of royalty paid. At other Cape Breton mines Mr. Gilpin.

riddled coal was banked out during the winter, and when screened in the spring was found to have made nearly as much more slack. The result of the adaptation to market purposes of the size of $\frac{3}{4}$ inch, as distinguishing slack from round coal, has been that hundreds of thousands of tons of nut coal, equal to round for nearly every purpose, have been thrown away and irrevocably lost.

His experience has been that at Nova Scotia collieries, under ordinary circumstances, steam can be as quickly raised and as readily maintained by slack coal as by the more costly fuel. The Provincial Insane Asylum, under the charge of the Works and Mines Department, has for a number of years used culm from Pictou for boilers, for pumping and steam heating, with the most satisfactory results. Several plans have been tried with more or less success for screening, in addition to those referred to by Mr. McLennan. Doors are put across the screens, so that the coal can pass over them at the speed and in the amounts desired by the screeners. A flat plate at the foot of the screens often receives the coal which undergoes a final cleaning, and then the plate, turning by a lever, falls into the coal car.

Underneath the round coal screen, attempts have been made to separate the nut and culm by means of square-meshed iron wire screens having a lateral shaking motion. At Spring Hill a separation into three classes of small coal has been satisfactorily effected by a revolving screen taking the coal from an endless bucket rope. Great trouble is experienced in screening wet or damp coal, especially when the operation is performed while the temperature is several degrees below freezing point. The shape of the small pieces into which the coal of any particular seam breaks is also an item to be observed, for with some coals longitudinal screens will take out more slack than square-meshed screens of relatively greater area.

He believes that, at the present stage in the preparation and use of coal, a good nut coal gives the greatest satisfaction to buyers for all steam and domestic purposes. The great object of coal producers is the introduction of a satisfactory system of burning slack coal. At the mine the object should be to ship all the coal that is raised for the market as well cleaned as possible. At the market the lumps could be separated down, say, to stove size, and sold for domestic grates, etc. Then the resulting coal could be separated into nut for ranges, small stoves, etc., and pea and culm for factories, etc. If this could be done the problem of screening would be immensely simplified, and the sale of the small coal, now thrown away, would represent, in many cases, a handsome profit, and lessen the inroads on the solid coal reserves of the mines.

Mr. H. S. Poole said that Mr. McLennan almost implied that the credit of one of the designs he described is due to him, but that he cannot claim anything more than the simplification of a few details, *e. g.*, the removal from the outer end of the A screen apron of a door, which on descending is opened by a catch striking a projection. As contrived the latch did not always close, and the improvement consisted in substituting and so adjusting a fixed stop over the apron, that the increased distance for the coal to slide from the stop outwards, allowed sufficient time for the apron to descend and come in contact with the main screen before the released coal could pass over the end. Another minor detail was in substituting curved bars, at the bottom of the receiving dead plate, for straight bars which were liable to be choked by fragments of coal falling on them vertically and wedging between them. And yet again, by controlling the movement of the aprons by friction merely instead of by rack and pinion. Mr. Poole.

The objects of the arrangements described are, as Mr. McLennan says, to size the coal and separate the good from the unsaleable bone coal and stony shale, etc.; and yet the more complicated must appear very simple to any one familiar with the elaborate structures and appliances known as "breakers" in the anthracite region of Pennsylvania, erected for the same purposes. The anthracite being hard withstands the excessive handling necessary to effect the perfect sizing, and justifies the great expenditure incurred in its preparation for market, while the friable nature of most of the varieties of bituminous coal does not permit of the same treatment being extended to them. Nor would careful sizing be of use in any variety that agglutinated under the boiler, and required after this change has taken place the use of the slice to open up the fires.

It may even be questioned whether, in some cases, it is not useless to extract the small coal and dust made in mining and in handling in the pit, since the coarser portion separated by screening is immediately after exposed to still greater abrasion and pulverization by falling, first some 5 or 6 feet into wagons or cars, and from them into the holds of ships, dropping, it may be, 20 or even 30 feet, shovelled over by the trimmers, shovelled into tubs at the port of discharge, dumped into carts, thence into heaps and the subsequent handling familiar to consumers. Those varieties of soft coal, however, which do not possess the property of caking under heat, and are compact, and which are in demand for grate purposes, may justify greater care in preparation. With ordinary soft coal it may be doubted whether screening beyond so much of the process as consists in picking out the mixed stone and inferior coal is worth the cost, at least when the coal is subsequently to be exposed to several rough handlings before it reaches the consumer.

To clean the coal more thoroughly than the ordinary screen permits of, mined coals are in some localities crushed and washed, the separation being effected by a pulsating upward current. Or the cleaning is attained by hand picking from tables, either circular, which are made to slowly rotate, or in the form of continuous bands which slowly pass before the pickers.

Mr. Routledge. Mr. Routledge said that from what he has seen of the Billy Fairplay system of screening coals, adopted at Sydney mines, he believes it is the most perfect and honest system for lessening the quantity of slack in working coal which has yet been adopted. The employer pays only for large merchantable coal; the honest and careful miner, by keeping his working low, sheaving it narrow, and studying the proper application and quantity of powder to use, makes considerably more large coal than his careless fellow-workman, and, what is more, the less powder used the more merchantable will coal be delivered at its destination. His knowledge of Billy Fairplay screening goes back for a period of perhaps 28 years, when he saw it first adopted by the present Sir George Elliott at the old Durham collieries in England.

Paper No. 39.

THE MANUFACTURE OF NATURAL CEMENT,

As carried on at the Napanee Mills, Ontario.

By M. J. Butler, M.Can.Soc.C.E.

The Geological Report of the State of New York, 1839, contains an analysis of "Manlius Hydraulic Limestone," stating at the same time: "This stone belongs to the same bed which yields the hydraulic cement obtained near Kingston, Upper Canada." As the only bed of hydraulic limestone found near Kingston is the one at Napanee Mills, there can be no doubt but that it is the one referred to.

It was not, however, until the year 1867 that anything was done towards working the bed, when Mr. H. M. Wright, a lumber merchant, acquired the quarry and had one or two kilns built at the quarry site. The mill for grinding the stone and the cooperage works for the manufacture of the barrels were built at Napanee, six miles distant, where convenient facilities for shipping by boat or rail were to be had, the burnt rock being teamed from the quarry to the mill. Messrs. Wright & Co. produced a fairly good quality of cement, supplying the local demand for a cement for cellar floors, cisterns, dams, etc.; they sold out to George Lasher & Co. in 1874, who carried on the cement and lime business for six years.

In 1880 the Napanee Cement Co. (Lmtd.) was incorporated, buying the mill and cooperage works at Napanee, and arranging with Mr. Lasher to supply the burnt rock to the mill at a stated price per ton. This arrangement proved very unsatisfactory to the Cement Co. In 1883 the cement was so very bad, that it was felt that something had to be done to improve the quality.

The writer was requested by the manager to make an examination of the quarry, mill, method of burning, grinding, etc. On examination it was found that the stripping (consisting chiefly of a loose shale) and all other rock, just as it came handy, without regard to size, quality or anything else, was alike dumped into the kilns to be burned for about 24 hours. At the mill the grinding was loosely and carelessly done, one burrstone alone turning out 130 barrels per day.

A report was made setting forth the facts and advising a careful test of each layer in the quarry by itself; some to be underburnt, some to the point of vitrification, some intermediately. Attention was particularly requested to getting the grinding as fine as possible so as to retain not more than ten per cent. on a 2,500 mesh. The purchase of a testing machine was advised. It was thought that in this way the best cement might be had that the quarry was capable of producing. Some time in 1884 the manager died; after which the company was re-organized. A new manager of works was secured, and the work of real improvement was energetically taken in hand, and is still being carried on.

In 1886, owing to the construction of the Napanee, Tamworth and Quebec Railway, which passes close to the quarry, it was thought best to build a new mill at the quarry site. Before doing so, however, the Cement Co. had a series of careful and thorough tests of every layer in the quarry made by an expert in the cement business from the United States; his report advised the using of certain layers aggregating some 5½ feet in depth.

The mill is built of stone 40 × 80 feet, three stories in height with an engine and boiler room 40 × 40 feet, also of stone, one story in height, containing an engine of 40 H. P. and two horizontal tubular boilers. South of the main building and 70 feet distant is the stave preparing mill 30 × 80 feet, built of brick. One hundred feet to the east of the main building is the barrel factory 30 ft. by 50 ft., also of brick. The kilns, of which there are three, lie about 200 ft. north of the main building. They are of the continuous burning type, with two doors for firing purposes and one door for withdrawing the charge.

Process of Manufacture:—The rock is broken into pieces of tolerably uniform sizes, averaging about $\frac{1}{10}$ to $\frac{1}{12}$ of a cubic foot each, loaded into carts, hauled to the top of the kilns and dumped into them. There are three continuous kilns fired on two sides; each kiln holding sufficient rock to make about 150 barrels of cement. The charge is withdrawn about every eight hours, depending somewhat on the weather, the foreman and attendant judging from the appearance of the stone the sufficiency of the burning. It requires about half a cord of soft wood to each ton of cement. As fast as the charge is withdrawn at the base of the kiln, it is loaded into an iron car, and hauled by a wire rope up an incline to the third floor of the building. Here it is dumped into a conical box which feeds by gravity into a rock breaker, and slowly tumbles down to the second floor where it reaches the grinders, about the size of beans. The grinders are the ordinary French burrstones. It is then ground and passed to bolters that are at present 1,600 meshes to the square inch. A finer bolting cloth 2,500 meshes was tried, but was found to clog with the finer particles attaching themselves to the wire. The residue from the bolters is returned to the stones and reground. Numerous tests show that a 2,500 mesh standard sieve will retain barely 10 per cent. After leaving the grinders the cement drops on the first floor, where it is allowed to cool on an average for about two weeks before being barrelled. A series of tests are made from each burning, the procedure in preparing the samples being that recommended by the Committee on cement testing of the American Society of Civil Engineers, the object of the tests being to insure a uniform article.

For convenience of reference and comparison tables of analysis and strength are appended, see pages 102 and 103.

It is not quite such a simple a matter as it appears to prepare briquettes properly for the testing machine. To begin with, the quantity of water used exercises a most important influence,the mortar should be very stiff and be firmly pressed into the mould so as to exclude all air, the operations should be performed quickly, the sample should rest on an impervious plate, glass being probably as good as anything. When the mould is filled, it should be struck off evenly with a trowel, and be left quietly for a short time before attempting to remove the sample from the mould, the slightest disturbance at this stage materially interfering with the proper setting of the briquette. After the sample has set in air, usually one hour being required, it should then be carefully removed from the mould and placed in water, where it should remain until the expiration of the time fixed for breaking.

Once it is placed in the testing machine the load should be applied steadily, quietly, and without jerking up to the breaking limit. Although every care may be exercised in the preparation and manipulation of the samples under test, it will be found that they do not break with uniformity, and it is only by taking the average of a number of samples that anything like a correct result can be arrived at.

Having secured a high tensile strength, as evidenced by the testing machine, the question is, have we a cement that is going to prove itself reliable when subjected to the test of time and the elements? Is there any connection between high tensile strength and good reliable wearing properties? Have the cements that show a high tensile strength proved themselves better under use than the natural cements? Is it not a fact that the cements which give such a high tensile strength grow brittle with age, and crack and peel off? Witness the cement walks wherever laid, the pointing in any old bridge with the higher testing Portland cements, they will be found full of cracks and scales which can be readily picked off. Although it is very hard, it is brittle, whereas when we come to examine any old work laid up with the natural cements, we rarely find cracks or other signs of disintegration. The variety and extent of the works in existence, built entirely with the natural cements, show their good lasting qualities; witness the Erie Canal, the high bridge on the Croton Aqueduct, and innumerable other works of great magnitude. The writer has used in one season over 10,000 barrels of natural cement from Louisville, Milwaukee and Utica, on foundations in caissons, on well work and in other trying situations without an instance of failure.

At Napanee Mills, the Napanee Paper Co., Limited, put in some three or four tanks of large size, and lined them with the Napanee cement, about ten or twelve years ago, which are perfectly water-tight, the cement having set as hard as limestone rock. At Gananoque the dams and canals of the Gananoque Water Power Co. are all grouted with Napanee cement, some of it having been in use eight or nine years.

In 1883 the writer was present at the tearing down of an old head gate which had partially rotted out, and it became necessary to cut away some posts that had been grouted in. It actually took two good men one day to pick out a post 8″ × 8″ × 7 feet, showing how hard the cement had become. These dams are all water-tight, and the cement is very hard.

At Deseronto, about five years ago, the foundations for a heavy gasometer, requiring to be perfectly water-tight, were, with much misgiving on the part of the superintendent, put in with a concrete composed of two parts sand to one of Napanee cement and three parts broken limestone. Not one cent has ever been expended for repairs, and the concrete is now in first-class order without a crack. On the Grand Trunk Railway bridges, on the canals and other public works of the Government, many thousand barrels have been used, all giving great satisfaction. If too much water or sand is used the mortar will of course be weakened, but when such a record as the above can be shewn from the old cement, there is no doubt but that the cement now being turned out is a first rate reliable natural cement, as good as can be ordinarily secured in any of the quarries in use.

E. J. De Smedt, chemist to the District of Columbia, U. S., says: "A limestone such as dolomite, containing 46 per cent. of magnesia, has been pronounced unfit for making good cement; but when the percentage of magnesia is not too large, it becomes in time just as hard as a cement containing no magnesia, with this difference, that it is somewhat slow in setting. In sea water containing magnesia such cement should be preferred, for the reason that it does not disintegrate in that water."

TABLE OF ANALYSIS OF VARIOUS NATURAL AND ARTIFICIAL CEMENTS.

NAME OF BRAND. By whom analyzed.	Akron, N.Y. E. C. Boynton.	Buffalo, N.Y. E. F. Cox.	Milwaukee, Wis. E. F. Cox.	Utica, N.Y. G. Bode.	Louisville. E. F. Cox.	Fayettville. E. F. Cox.	Rosendale. E. C. Boynton.	A Perfect Cement.
Silicic Acid	54 77	32 86	28 11	35 43	20 66	18 22	43 11	32 00
Alumina	6 42	8 38	27 62	9 92	27 11	26 76	3 64	8 00
Lime	29 64	52 60	37 18	33 67	50 52	51 99	40 09	54 00
Magnesia	9 17	6 16	7 09	20 98	1 71	3 03	13 16	6 00
Total	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00

NAME OF BRAND. By whom analyzed.	An Eng. Portland. Ext'd. from Henry	A good Portland. Reid's Treatise on	A Ger. Portland. Portla'd Cement.	Manlius. Dr. Manlius Smith	Napanee. of Syracuse, N.Y.
Lime Ca.O	56 68	60 05	58 03	45 00	39 73
Magnesia Mg.O	0 57	1 17	2 93	18 55	18 02
Oxide of Iron $Fe^2 O^3$	....	....	11 30 } (Oxide of Iron and Alumina)	{ 11 97 } (Oxide of Iron and Alumina)	10 50 } (Oxide of Iron and Alumina)
Alumina $Al^2 O^3$	7 74	10 84			
Silicia Si O^2	22 74	24 31	21 11	19 60	26 35
Alkali Na Ho K.Ho	0 63	1 54	0 71	Trace.	....
Sulphate of Lime So_4 Ca	1 66	....	0 51	2 04	0.935
Carbonic Acid Co^2	3 50	....	0 83	2 70	2 95
Undissolved Residue	0 53	....	0 49	....	....
Water H^2O	1 90	....	0 54	0 70	....
Total	99 65	97 91	99 81	100 62	98.485

TABLE OF TENSILE STRENGTH OF VARIOUS BRANDS OF NATURAL AND ARTIFICIAL CEMENTS.

ALL SAMPLES ARE UNIFORMLY OF ONE SQUARE INCH SECTION.

Age of specimens, after being allowed 1 hour in air, balance of time in water.

Name of Brand.	1 Dy.	2 Dys.	1 Week.	2 Weeks.	1 Month.	6 Mths.	1 year	2 yrs.	3 yrs.	Authority.	Remarks.
Louisville	72.2	78.7	....	....	....	150.6	....	....	....	Journal Assoc. Eng. Societies, page 187, Vol. V.	
Rosendale..	49.0	......	73.0	....	156.0	286.0	....	....	....	Journal Assoc. Eng. Societies, page 187, Vol. V.	
Average of 25,000 samples of American cements..	71.	......	92.0	....	145.0	282.0	290.0	....	....	Eliot C. Clark, Boston Main Drainage Works.	
Napanee..............	50.	.....	90.0	....	140.0	280.0	300.0	315	....	M. J. Butler, the two year old samples were from a lower grade of cement, thence do not show as great strength in proportion to age.	
Artificial *.	......	......	280. not	broken	at 1 year	8 mos.	275	broke	it.	These two briquettes were composed of common lime and clay burned together and ground finely.	
" *......	......		390. "	"	"	"	290	"	....		
Portland Cement.	102.	......	303.	....	412	468	494	....	....	Eliot C. Clark, Boston Main Drainage Works.	
Alsen & Co., Portland................	170.	......	275.	340	467	561	690	....	....	E. J. De Smedt, Foreign, Portland.	Rep'rt District Columbia, 1885.
J. B. White	95.	......	200.	268	364	400	....	....	....	" " " "	
Giant................	150.	......	335.	....	416	673	700	....	....	" " American "	
Egypt	100.		270.	....	355	"	....	....	....	" " " "	

NOTE—The two samples of artificial cement shew that it is quite possible in short time tests to get a high result from an inferior article, as these samples deteriorate with age.

DISCUSSION.

Mr. Hannaford. Mr. Hannaford said his experience with natural cements was not so favourable as with artificial cements, and that with the former the bulk was often inferior to the samples. In explanation of this, it may, and no doubt does, arise from the fact that the stone from which natural cement is manufactured is in beds, adjacent and mixed with ordinary limestone, and that the assorting of the one from the other, and the selection of the natural cement stone, even within its own compass, requires the most careful attention of experts, and that when a demand is made upon natural cement works for a large supply, it is reasonable to suppose that the selection of the stone is apt to be hurried; but be that as it may, his experience has been that as a rule natural cements do not hold their character throughout bulk, like artificial cement, and hence in carrying out works (especially under contract) this element affords much anxiety.

But assuming that the difficulty above mentioned may be overcome by care in selection and systematic manufacture, this process means additional cost; still, even so, can the output of natural cement meet the market demand, and is it equal to the artificial cements?

He was unable to give a reply to the first query. There are several natural cement works in Canada, and all alike praise their output; but in regard to equality with artificial cements, his experience has been that none of them are to be relied upon in bulk for doing work equal to artificial cement. Artificial cement (Portland) has the qualities of quick setting, great cohesion, and resistance of sea water beyond all others, whilst it can be used freely with water to form "grout," which natural cements cannot be, and whilst water may be used freely with artificial cement, it must be used sparingly with natural cements.

In the way of concrete his experience has been that artificial cement was preferable to natural cement, and that he had failed to obtain results of hard setting in water from natural cement, whilst in sea water it refused to set. He had used natural cement in concrete but invariably laid in air.

Mr. W. E. Gower thought that Mr. Hannaford's claim as to the unreliability of the cement was fully borne out by the figures given by Mr. Butler, who gave 7 days' test at 90 lbs., one month's at 140, and 6 months' at 280. The figure given by Mr. Bravender showed a 7 days' test at 135 lbs. and a 27 days' test at 200 lbs.; but on referring to a paper read before the Society by Mr. Rust, on the Construction of Sewers in Toronto,* he found the results of tests of Napanee cement showed for a 6 days' test 39 lbs. per sq. in. only, and a 30 days' test 76 lbs. only; these figures were considerably less than 50% of those given by either Mr. Bravender or Mr. Butler. He thought there was no doubt that Canadian cement could be made to stand a very high test, although he had not arrived at the figures given by the gentleman who said that he had tested the Hull cement and had attained the result of 676 per sq. inch for 7 days. He understood that the highest test cements known at present were German cements, and for a 7 days' test these did not attain the figures of the Hull test. In February, 1889, he tested four briquettes of artificial cement, and the result was from 325 to 219 lbs., one giving a very low test, the average being 292 lbs. for a 7 days' test. **Mr. Gower.**

Mr. Reid said it would not be prudent for him to say much about the quality of cement made in different parts of Canada. There could be no doubt that there was an abundance of suitable material here. The first Portland cement he made was in 1869 in Halifax, N. S. Material there was abundant and fuel cheap. A quantity of cement was then being sent out by the British Government for the harbour fortifications, and he made some native cement and subjected it to a test made by the Royal Engineers, then stationed there. At that time—21 years ago—Portland cement was scarcely known in Montreal, and comparatively little of it was used in New-York. He commended Mr. Thos. Arnold's method of testing samples:—Each of his small briquettes contained 135 grammes of cement compressed into a dry mould by screw pressure, which were then treated in water. **Mr. Reid.**

Mr. Dodwell considered that one of the most important features in the cement discussion was the desirability of a uniform system of testing. The want of such a system has been one of the great defects and difficulties in comparing tests of one cement with that of another, the systems of testing having been dissimilar, and anything **Mr. Dodwell.**

* "Construction of Toronto Sewers," by C. H. Rust. Transactions, Vol. II, page 302, November, 1888.

that would tend towards uniformity in the testing of cement would be of very great advantage.

Prof. McLeod. Professor McLeod asked if in the method mentioned by Mr. Reid the pressure was uniform?

Mr. Reid. Mr. Reid said the pressure was uniform, because the plunger was made precisely to fit the briquette, and when pressed down level it left exactly the space of one inch.

Prof. McLeod. Professor McLeod understood the pressure was measured in that way by the volume which the powder occupied.

Mr. Reid. Mr. Reid said that a briquette mould would contain 135 grammes under certain pressure, and that this could not be overdone or overstrained so that there was uniformity in every briquette; a little tray filled with water was used in which the briquettes were placed.

Prof. McLeod. Professor McLeod thought different cements would have different gravities, and it could not be expected that the same weight would always occupy the same volume.

Mr. Dodwell. Mr. Dodwell did not think the Arnold system was quite free from objections in some points, but the great point was that if it could be universally introduced as a standard of cement tests, that would be sufficient, as results would then be comparable, and the objections would be of no moment.

Mr. Hopkins. Mr. Hopkins considered that if there was a good deal of material containing iron ore it was better by not being tested in amounts of 135 grammes as the density would not be as great. That seemed to him to be the chief objection, because of the testing by the same unit of weight instead of volume.

Mr. Reid. Mr. Reid asked if that would not be apparent in the result of the briquette test?

Mr. Irwin. Mr. Irwin said in any case cement was sold by the barrel, and its value determined by volume instead of by weight. He considered a good testing machine was much required.

Professor McLeod said he had asked the question because he thought that possibly there was some arrangement in Arnold's test, whereby a uniform pressure was obtained independent of volume. If, for example, the pressure were exerted against a spring, it would always be the same, and the briquette subjected to the same pressure. He could easily imagine some little adaptation for measuring pressure which would overcome the difficulty mentioned. Prof. McLeod.

Mr. Dodwell said the result of the method of compressing a briquette into a certain size would favour a light and a finely ground cement. A higher tensile strength would be obtained with a fine rather than with a coarse cement. The more a cement was compressed into a briquette the greater would be the tensile strength resulting. Mr. Dodwell.

Mr. Reid did not agree with this. When cement was in rougher particles it possessed some solidity, and when it was pressed in by the mechanical process mentioned there was a tendency to give it a uniform density. Mr. Reid.

Mr. Blackwell considered the machine would insure the briquette being filled at a certain pressure. Mr. Blackwell

Mr. Gower said it also insured the pressure being distributed all over the briquette, which was not accomplished by the use of the trowel. If it was required to increase the tensile strength per square inch, hammering was resorted to, and the more it was hammered the greater the result obtained. Mr. Gower.

Professor McLeod mentioned another objection to this method of testing. He thought that material should be tested as far as possible under conditions similar to that under which it was going to be used. It did not seem to him that this was a condition similar to that under which the cement would be used; the old method of testing was more in acordance with what the cement would be called upon to do in actual work. Prof. McLeod.

Mr. McLea Walbank did not understand what the method was of testing the special brands of cement for comparison; but in his opinion cement should be tested barrel by barrel as used. Mr. Reid's test would be a fair one, because the same brand would in nearly every Mr. Walbank.

case be used throughout the works, and the consistency or specific gravity would be practically the same. It would be cumbrous to transport a testing machine as large as six feet square.

Mr. Irwin. Mr. Irwin understood Mr. Reid's method was for getting the cement into shape, and not with regard to the form of the testing machine.

Mr. Walbank. Mr. Walbank considered that every barrel should be tested.

Mr. Gower. Mr. Gower observed that to do this with a 7 days' test all the shipment would be used up before obtaining the result. He said that tests of Thorold cement gave 42 lbs. 6 days in water, 85 lbs. in 30 days.

Mr. Dodwell. Mr. Dodwell said the tests recorded in the paper and in the discussion varied very much, from 39 lbs. to 90 and 135 lbs. He considered cement that varied so widely to be unreliable.

Mr. Irwin. Mr. Irwin said his experience with Thorold cement was that it contained an excess of lime.

Mr. Hopkins. Mr. Hopkins stated that he had seen cement used in very cold weather on bridge masonry, the low temperature making no difference so long as the cement did not thaw out.

Mr. Dodwell. Mr. Dodwell observed that he had often used Portland cement for masonry, when the temperature was 10° below zero Fahr., the cement and the joints proving as hard as if laid in summer. If it should thaw before setting then the cement would be impaired.

Mr. Walbank. Mr. Walbank said he had used Portland cement at the Grande Mare Falls on the St. Maurice river at 20° below zero Fahr. There was a very heavy wall over 20 ft. wide at base to dam a 40 ft. head of water, and they built it in a hurry during the winter. Portland cement was used, the sand used with the cement was heated, and a little salt was put into the water used in mixing the cement. Experiments showed that alternate freezing and thawing did not produce any appreciable effect.

Mr. Dodwell. Mr. Dodwell considered there was not enough known about the action of frost upon cements. He had noticed but few instances of failure of cement owing to frost. He did not refer to "face" work. The question of Canadian cements was one worthy of discussion. If cement *could* be made here it should be manufactured and used. All the material was here, and it only required men who understood manufacturing it. He thought that as a rule natural cements were poor substitutes for artificial cements, as they could not be guaranteed, and their reliability could only be ensured by frequent tests.

Mr. St. George observed with regard to Canadian cements, that it had been mentioned by the author that their strength increased with age, while Portland cement, it was stated, deteriorated. He had prepared a table giving particulars of tests for one year of different brands of cement, (see page 110), which the Quebec Government had embodied, with a report on cements, in the Annual Report of the Minister of Public Works. **Mr. St. George.**

A German, whose name he had forgotten, had gone thoroughly into this question, and had made one series of tests altogether in water and another series altogether in air, differing from the English practice of testing cement by first allowing it to set for 24 hours and then putting it into water. The speaker had experience with many brands of cement,—English, German and Canadian,—and after a test of 7 days (one in water) with pure cement he found that the German (Dyckerhoff) cement had a tensile strength of 445 lbs. per square inch. Some of the English cement (Johnson's) reached 330 lbs. Of the Canadian cements, the Quebec stood the highest, being 110 lbs., Thorold 80 lbs., Napanee 65 lbs., and Hull 50 lbs., all mixed neat. With one of cement and one of sand the German reached 220 lbs., Johnson's 130 lbs., Quebec 35 lbs., Thorold 30 lbs. The Napanee showed no result. With one of cement to two of sand there was a gradual decline, the German showing 110, Johnson's (English Portland) 60, Quebec 20, Thorold, Napanee and Hull no result.

Referring to the 7 days' test, 24 hours in air and 6 days in water, the speaker remarked that Johnson's (neat) showed 260 lbs., the Quebec no result at all, and the Thorold 40 lbs.; and with equal parts of cement and sand there was no result with Canadian cements. The other results gradually lowered, 180 lbs. for the German down to 90 lbs. for Johnson's Portland with a 30 days' test.

The author of the paper had stated that foreign cements did not improve with age, but the speaker found that the German ran up to 520 as against 460, and taking the English cements,—Johnson's or

Table of Tests of Cements.

	Name of Maker or Brand.	7 Days Test Dry.			7 Days Test Wet.			30 Days Test Dry.			60 Days Test Dry.			100 Days Test Dry.		
		Neat C. Cement Lbs.	1 of C to 1 of S, Lbs.	1 of C to 2 of S, Lbs.	Neat Cement Lbs.	1 of C to 1 of S, Lbs.	1 of C to 2 of S, Lbs.	Neat Cement Lbs.	1 of C to 1 of S, Lbs.	1 of C to 2 of S, Lbs.	Neat Cement Lbs.	1 of C to 1 of S, Lbs.	1 of C to 2 of S, Lbs.	Neat Cement Lbs.	1 of C to 1 of S, Lbs.	1 of C to 2 of S, Lbs.
Foreign.	Dyckerhoff...	445	220	110	373	180	102	588	285	200	850	345	215	885	355	245
	Josson	440	210	106	360	175	95	......	......	......	......	......	......	......	......	......
	Farrick	363	235	108	......	......	......	......	......	......	[illegible]	205	150	535	238	175
	Alsen	340	160	110	275	173	125	560	283	180	635	320	210	700	330	215
	Zung	320	140	90	......	......	......	445	170	112	460	195	120	585	280	195
	Vicat	340	118	80	......	......	......	......	......	......	......	......	......	......	......	......
	Talbot	305	125	65	295	110	45	345	130	80	370	135	90	392	180	125
	Excelsior.....	305	165	90	......	......	......	......	......	......	......	......	......	......	......	......
	Delbende.....	240	133	90	......	......	......	......	......	......	515	233	118	650	250	155
British.	Johnson	330	110	63	260	95	55	......	......	......	390	160	70	585	268	112
	Robins........	325	177	100	......	......	......	406	200	108	420	215	115	......	......	......
	Knight, B & S	325	75	35	......	......	......	......	......	......	......	......	......	......	......	......
	Frances	300	115	60	255	90	55	395	173	112	418	245	130	450	270	148
	Burham	300	150	90	300	170	73	......	......	......	......	......	......	......	......	......
	Jarrow.......	195	80	45	......	......	......	200	100	68	285	125	75	375	170	85
	White	280	143	55	260	118	55	395	150	60	475	200	100	538	210	128
	Union	275	120	55	260	65	25	400	163	105	500	180	110	538	245	148
	Bull.........	265	133	105	210	100	63	......	......	......	430	210	155	520	256	175
	Brooks.......	240	90	65	338	165	70	......	......	......	......	......	......	......	......	......
	Hoyle-Robson	240	125	70	......	......	......	......	......	......	......	......	......	......	......	......
	Gillingham...	335	65	35	......	......	......	......	......	......	......	......	......	......	......	......
Canadian.	*Point Claire.	345	130	45	325	165	80	......	......	......	......	......	......	......	......	......
	Wright.......	275	No sa	mples	......	......	......	......	......	......	......	......	......	......	......	......
	Quebec	110	38	20	No	result	......	168	110	60	187	120	85	268	125	85
	Thorold......	85	33	No res	45	No	result	108	50	10	125	75	60	155	100	68
	Napanee......	55	No res	ult	......	......	......	......	......	......	......	......	......	......	......	......
	Hull.........	50	No res	ult	......	......	......	......	......	......	......	......	......	......	......	......

N. B.—The average of three bricquets was taken in all cases, and the results arrived at indicate the tensile strength per square inch.

***Laboratory test.**

White's,—they went up in the same manner. The Quebec cement neat increased from 110 to 170, the Thorold being only 82 lbs.

With one of cement to one of sand they had also all increased, the Quebec with only 48 lbs. increased after 30 days to 110 lbs. With the test of 60 days it was found German cement reached 850 lbs. (neat), the Quebec increasing after 30 days 170 lbs. to 185 lbs., a gradual increase; but when the natural cements were mixed with sand they did not stand at all except after 60 days, the Canadian cements taking a long time to set.

Cements were made for a certain purpose, viz., to enable works to be constructed in as short a time as possible. The Craig street sewer, Montreal, built in 1840, with plain lime, was taken out in 1885, when the mortar and brickwork were a solid mass. He desired to state as his experience that artificial cements improved and did not deteriorate by age, as Mr. Butler's paper describes.

Mr. J. Kennedy observed that the paper mentioned the time as after three or four years. **Mr. Kennedy.**

Mr. St. George thought that if 60 days' test showed that the artificial cements increase in the ratio stated, it was not probable that they were going to fail. This was not the case in any works he had seen, nor did he think Mr. Kennedy had ever had such experience with Portland cements. White's cement (Portland) pure showed, with a test of 7 days in air, a tensile strength of 280 lbs. **Mr. St. George.**

The figures tabulated were the highest that could be obtained here, and the Quebec test of some hundred samples gave results very near the figures.

Mr. K. W. Blackwell said that some of the table books gave results as high as 1200 lbs. **Mr. Blackwell.**

Mr. Kennedy asked Mr. St. George how it was known that the mortar in the old Craig street sewer was common lime, because at that time Canadian cement was generally well known. His recollection made it difficult to tell whether the mortar was made from natural Canadian cement or common lime. **Mr. Kennedy.**

Mr. St. George replied that when the Craig street sewer was broken down, the mortar was quite white and colorless. In those days in Montreal lime was slacked a long time in advance of being used, as is **Mr. St. George.**

now done in Germany, where lime is slacked in large vats and sold according to its age.

With regard to high tensile strength of cements, he found that in Belgium, in order to obtain these results, the water was extracted from them. In that way a higher tensile strength could be obtained, but tests should be made under circumstances similar to those under which it was to be used. In his opinion the best way to make a test so as to obtain the actual quality of the cement was not only to take the pure cement, but to mix it with sand, one to one and two to two. It had been seen that some cements could not stand sand at all, and that although good when pure, they would not work with sand. The crushing of the cement was another important factor. At some factories he had seen cement come from the kilns quite black. Such had not been properly burnt, and should be raked on one side, recrushed and reburnt. Last year he had experience with a good brand of imported artificial cement. It did not set well, and whilst in that state spewed up a black oily substance with a scum on the top, and under the scum ($\frac{3}{16}$ of an inch thick) it was quite soft and had not set at all; this was owing to not being properly burnt. Robin's cement was good, but the charges were from 5 to 8 per cent. higher than for any other make.

Mr. Ruttan. Mr. Ruttan said he was glad to see from the paper that there was a prospect of their having a good Canadian cement, that makers of these cements had pressed their use with engineers, and the latter had been censured by the makers for not using them. But the fact was, experience had proved that Canadian cement was not satisfactory. The chemical constituents of the cement were said to be all that is required, and if this were so he was led to believe that the fault must be in the manufacture. He thought the sooner Canadian manufacturers were brought to realize the fact that their cement was not what is required, the sooner they would endeavour to improve. The quality of cement was not a matter of opinion, but the result of tests. Engineers would be glad to use the native cements if they came up to requirements. Canadian cements are cheaper than the imported cements, and he thought that there would be no greater demand for the former until the quality equalled that of the latter.

Mr. St. George. Mr. St. George stated that there was a cement he had omitted to mention, manufactured at Point Claire. He had not yet tested it, but he had given Mr. Reid's (the manager) laboratory test in the table.

Mr. Ruttan said it might interest the members to know that within the last year a natural cement manufactory had been established in Manitoba. No practical test had yet been made, but the laboratory tests were said to be very good. **Mr. Ruttan**

Mr. F. E. Came asked if the tests of the Hull cement were made recently or some time ago? **Mr. Came.**

Mr. St. George replied they were made in 1889. **Mr. St. George.**

Mr. Came said the Hull manufacturers claimed to have made recent improvements in their cement. **Mr. Came.**

Mr. St. George said he was of opinion it could be improved by proper mixing, burning and crushing, and also by keeping it dry when made. **Mr. St. George.**

From a diagram, showing results of Cement Tests, exhibited by Mr. St. George, Plate VI has been prepared.

CORRESPONDENCE.

Mr. Macdougall

Mr. Alan Macdougall said that the paper dealt with a valuable native industry. It was to be regretted that in the early efforts to manufacture this cement more care had not been taken in selecting the rock. Mr. Butler brings this out in his paper; the result has been that the industry has suffered. The cement is well ground, as the samples produced by Mr. Rust show, and with age the test results are good. It is a slow setting cement. The speaker believed there was a market for it in the province. He hoped the present management would exercise prudence, and not try to place it on the market till they had satisfied themselves as to the quality of the rock, and had brought the manufacture of the cement to a sufficient stage of perfection to produce a reliable article.

Mr. Gauvreau.

Mr. L. P. Gauvreau of Quebec said that the only natural cement of Quebec is manufactured from the black stone adjacent to the city. The method of burning and grinding this cement is similar to that used for other natural cements. The analysis of the stone made by Mr. Delesse, one of the jurors of the Paris International Exhibition, 1855, was:—

Water and carbonic acid	52.49
Magnesia	traces
Silica	27.40
Alumina and oxide of iron	12.16
Sulphate of lime	7.95
	100.00

He stated that Quebec cement has been largely used for public and other works in Canada, and with satisfactory results.

Mr. Evans.

Mr. E. A. Evans said Mr. Butler's paper suggests the question: Are the natural equal in quality to the best Portland or artificial cements? In the speaker's opinion, all quick setting and other natural cements are considerably inferior to the slow setting Portland and other artificial cements. Are they then so inferior as to be entirely condemned for use on all public works? He believed not (at any rate for works above ground), provided that the bulk supplied is equal to the approved sample. Here is the difficulty in the way of the general use of the Canadian cements, viz., their varying quality—utterly bad, inferior and fairly good cement, all being supplied by the same manufacturer as first class hydraulic cement. Mr. Butler admits that it is not at all a simple matter to quickly and satisfactorily test the quality of cement, and until some better and more practical method of testing than at present available is devised, Canadian cements cannot be recommended for any foundation or hydraulic works. He did not admit that the cements showing a high tensile strength grow inferior with age, crack and peel off, as stated by Mr. Butler, but that in his experience such failures refer only, in certain instances, to surface work generally imperfectly done.

Mr. H. H. Killaly said that previous to last August, Napanee cement had not been used upon any of the works under his charge; that recently a small quantity of this cement was used at Lock 21 on the Cornwall Canal enlargement; that for concrete it was very slow in setting, and for this reason its use was discontinued; that subsequently Napanee cement was used in building some of the masonry of the same Lock; but that he was not then able to say how this cement had behaved when used for concrete. **Mr. Killaly.**

Mr. C. H. Rust said that during the last seven years he had frequent opportunities of testing Canadian cement in the construction of sewers in Toronto. The tests were all made with a Riéhlé testing machine. The results so far with Canadian cement have not been satisfactory, and owing to the unreliability of these cements, the use of both Thorold and Napanee have been nearly discontinued in favor of Portland. The great fault of the Canadian cements is their tendency to "blow." This was not so pronounced in the Napanee as in the Thorold, but in tensile strength both are deficient. He considered this deficiency largely due to the fact of the manufacturer not using sufficient care in selecting the stone. He is glad to see that Mr. Butler calls attention to this important feature. He stated that the City Engineering Department of Toronto used 12,000 to 15,000 barrels of cement annually on its sewers alone. It will be seen by the table of tests on pp. 116-117 that no such result as that mentioned by Mr. Butler has been reached with Napanee cement, the highest tensile strength, after being 6 days in water, being 40 lbs. per square inch. He considered the method of making tests of sample briquettes open to objections, his experience **Mr. Rust.**

being a much lower result than claimed by some cement agents. According to his experience in the use of natural Canadian cements the mortar should not be weaker than 1 to 2.

TESTS OF NAPANEE CEMENT MADE IN CITY ENGINEER'S OFFICE, TORONTO, 1886 TO 1889.

TIME IN WATER.	TENSILE STRENGTH PER SQ. INCH.	PROPORTIONS.
1 Year	180	Neat
1 "	200	"
30 Days	76	"
6 "	40	"
1 Year	150	"
30 Days	25	"
	1888-9	
6 Days	12	
6 "	18	
15 "	22	
28 "	53	
500 "	275	
150 "	130	
6 "	25	
18 "	40	
6 "	20	
6 "	10	
6 "	10	
35 "	12	
26 "	50	
100 "	80	
8 "	6	
5 "	6	
150 "	113	
135 "	135	

The two last tests are from a batch, the rest of which went to pieces when first placed in water.

MARCH, 1890.

AGE OF BRIQUETTE.	TENSILE STRENGTH PER SQ. INCH.	REMARKS.
190 Days	174 lbs.	Sent from Napanee by E. Bravender.
289 "	636 "	do
24 "	120 "	do
400 "	222 "	do
2 Yrs. 90 Dys.	109 "	do
2 " 227 "	151 "	do
3 "	123 "	do
2 " 212 Dys.	151 "	do
2 " 242 "	150 "	do
2 " 242 "	101 "	do
2 " 273 "	140 "	do
170 Days	421 "	Sent from Napanee by Mr. Terry
1 Year	275 "	" " do
1 "	297 "	Moulded by do
1 "	204 "	" " do

THOROLD CEMENT.

TIME KEPT IN WATER	AVERAGE STRENGTH	
6 Days	30 lbs.	
30 "	75 "	
100 "	200 "	
	Buffalo, U. S.	
6 Days	50 lbs.	
30 "	75 "	
100 "	200 "	
	Syracuse, U. S.	
6 Days	200 lbs.	American Portland
30 "	400 "	" "
100 "	446 "	" "

Mr. Gray said that Mr. Butler, after stating that the cause of the failure of the Napanee cement is owing to the mode of manufacture, says that under his instruction and advice tests were made of the several layers of the quarry by graduating the intensity of the heat in the roasting or burning. It appears to him that this is just the reverse of what is necessary to obtain the qualities for a good cement. He considered that the proper method to insure a good cement being manufactured is to have the raw material of stone chemically analyzed *before* being roasted and ground. It is found indispensable to do this with the raw materials of iron and steel. The value of the manufacture depends more on the obtaining and selecting of the raw material which contains the least amount of deleterious elements, than in the elimination of such elements. It is easy to understand how iron and other manufactures would suffer if their make depended upon the very scant knowledge applied to the manufacture of cements. The result is that the contractor or engineer receives as cement a substance of undetermined composition, varying in quality with every circumstance of its manufacture and every condition of its storage and preservation, and from this by the addition of sand water, etc., he must compose a material, the strength of which he is to determine, although every method in combining the ingredients will affect the results. **Mr. Gray.**

Mr. M. J. Butler stated in reply that it was not his intention in the paper to convey the impression that good Portland was inferior to natural cements. An instance was given when two samples of an artificial cement prepared from common lime and clay, without regard **Mr. Butler.**

being had to any particular proportion, gave on short time test a high tensile strength which they afterwards lost. The object being to record a mild protest against the present tendency of calling for a very high tensile strength on a seven days test.

Over-clayed cements set quickly; hence, if specifications, require a high tensile strength in short periods of time, manufacturers will endeavor to comply with this demand by every means available, among which are over-claying, the addition of sugar or molasses, and extremely fine grinding (this latter being doubtless a permanent benefit). The ultimate effect of over-claying cements is to weaken them. Eliot C. Clark, M. Am. Soc. C. E., in his paper read before the American Society of Civil Engineers, describes a new brand of cement which was made by some patent process, which at the end of 7 days tested neat 184 pounds, in a month it reached 267 pounds, but in six months the briquette fell to pieces. He also makes the instructive remark that absolute uniformity in breaking need not be looked for, as he expressed it, "the sample declined to break by formulæ."

Mr. Hannaford points out very clearly the causes that have led to lack of uniformity in natural cements. That cements containing magnesia are best for sea water constructions is generally admitted. It does not seem necessary to quote from the various recognized authorities on the point. The proof contains an analysis of Quebec cement, it is thought worth while to point out the fact that as given the elements to make a cement are not present, and doubtless there is an error in the reading.

Since the paper was prepared the writer has paid particular attention to the examination of the exposed parts of old works laid up in Portland cement. The pointing being usually the only part visible, he has not yet seen one place where it has not been cracked and where it could not be picked out by a little effort. The cement is very hard and brittle, and would under tensile test doubtless show a high resistance to breaking. Under water the cracks do not appear.

With regard to the remarks of Mr. Killaly, the writer is informed that Napanee cement was delivered to the works at Cornwall under his charge about two years ago, that all of the concrete has been made with Napanee cement, that the bulk of the masonry, including the pointing, has been done with Napanee cement, and that the work is in first class condition.

Mr. Rust's table of test samples is interesting, the date given by the writer is based on about 200 samples, and that given by Mr. Bravender is based on upwards of 1,000 samples.

The manner of preparing the briquette, the temperature of the air and water, the quantity of water used, and the method of treating the briquette after and before filling, are all factors in determining the final result, and but emphasize the fact that a uniform method is most desirable. The writer begs to suggest that a committee of the Society be appointed for the purpose of recommending a uniform system of testing and to prepare a specification for quality. The fact is that natural cements should never have more than two parts sand to one cement, and in important work one and one-half sand to one cement.

Mr. St. George is mistaken in assuming that the writer claimed that Portland cements deteriorate with age, so far as the *tensile testing machine would show.* Under water there is no doubt that they are practically everlasting (so far as our knowledge goes), but in air or sea water there is, to say the least, some doubt of their lasting properties. Common lime will never stand in water, even if mixed for centuries, when placed in water it will go to pieces; hence, if the sewer in question has stood, the lime must have been an hydraulic lime. The quotation from Mr. Clark and the writer's own tests show that even after sixty days a cement may fail, and fail badly.

Mr. Gray thinks the writer erred in directing the cement manufacturers as he did; if so, he was in good company. It is precisely the method followed in all of the natural cement works in the world. It is the method advised by Gilmore in his "Limes, Cements and Mortars."

As the paper shows, frequent chemical analyses were made both of the rock and of the cement, for the chemists are by no means agreed on what constitutes a first class cement, and it is only by practical test on a large scale that a reliable result can be hoped for. The chemical analysis is a useful guide to show us that we are not trying to work against natural laws, but no laboratory work can supersede the actual test on a large scale.

Thursday, 27th February,

C. E. W. DODWELL, Member of Council, in the Chair.

The following candidates having been balloted for were declared duly elected as :—

MEMBERS.

MOSES BURPEE,
A.B. IMSHENICK KONDRATOVITSH,
NICHOLAS KROUGLICOFF,
RODMAN M. PRICE,
JAMES HENRY EDWARD SECRETAN,
ANTOINE ZDZIARSKI.

ASSOCIATE MEMBERS.

WILLIAMS BURNS,
JAMES JOHNSTONE,
CHARLES D. MAZE.

ASSOCIATES.

F. W. CRAM,
ALEXANDER MACLEAN,
JEAN ZEPHIRIN RESTHER,
J. C. ROBERTSON,
CHARLES E. SAUNDERSON,
JAMES TRAILL SHEARER,
THOMAS TAIT.

STUDENT.

ALFRED JAMES STEVENS.

The following were transferred from the class of Associate Members to that of Members :—

GEORGE HERRICK DUGGAN, JAMES MOORE SHANLY.

The following were transferred from the class of Students to that of Associate Members :—

JAMES MARMADUKE MCCARTHY, CHARLES DANIEL SARGENT.

The following was transferred from the class of Associate Members to that of Associates :—

GEORGE R. HOOPER.

The discussion of Mr. M. J. BUTLER's paper on "The Manufacture of Natural Cement" occupied the evening.

Thursday, 13th March.

E. P. HANNAFORD, Vice-President, in the Chair.

Paper No. 40.

COLUMNS.*

By Charles F. Findlay, M. Inst. C. E.

In the whole range of subjects with which the art of engineering is concerned, there are few in which theory has contributed less to the advance of intelligent practice than in this. The reason cannot be found in any want of importance in the subject itself, for, of the materials used in construction, a much greater part is used in compression than in tension, and a very considerable part is used in the form of columns or struts. Until recently the experiments on compressive strength were very few in number and narrow in range, compared with the multitude of tensile experiments that have been made. Even now, many of the laboratories with expensive and elaborate apparatus for tensile tests have no means of making compressive tests. Of late years, however, American experimenters have done a great deal to remedy this state of things, among whom Mr. Christie, Mr. Bouscaren, and Messrs. Clarke, Reeves & Co. may be mentioned in particular.

What is now wanted even more than experiments, is a theory of the subject which will enable us to interpret their results in a general way, and also to indicate the kind of experiments desirable. We shall therefore attempt here to give a treatment of the subject somewhat more rigourous than is usually found in text books.

A column differs from a beam or girder in the nature of the forces it is intended to resist, a beam being used to resist forces transverse to its length, a column to resist forces directed between its two ends. Of course, the same material may be used to resist forces of both kinds at once, but for the sake of clearness we shall neglect transverse forces altogether in treating of the column. The leading feature in the behaviour of a loaded column is that it bends, the deflection constantly

* This investigation coincides in certain parts with papers by Professors Ayrton and Perry, in the *Engineer* (London), December 10th and 24th, 1886, and by Professor Krohn in the Proc. Am. Soc. C.E., 1887.

increasing with the load. The stress which might at first be almost uniformly distributed in the column, becomes thus more and more unequal at the outer and inner edges as the load increases. With a tensile stress on the other hand, although a small flexure undoubtedly must result from the same causes that give rise to flexure of columns, the direction of the flexure is opposite, and therefore tends to produce a more uniform distribution of stress. The difference between the two cases may be illustrated by that between stable and unstable equilibrium.

The equation which forms the basis of all investigations into the flexure of beams and columns is

$$(1) \qquad M = EI\left(\frac{1}{R} - \frac{1}{R_{\circ}}\right)^{*}$$

where M = moment of external forces at a cross section of the beam or column, whose moment of inertia about an axis through its centre of gravity at right angles to the plane of flexure is I;

R = radius of curvature of axis of beam or column at same cross section, and $R_{\circ}$ = initial value of R when $M = 0$;

E = modulus of elasticity of material.

By the axis of a column we here and hereafter mean the axis of figure and not the neutral axis (which for columns generally lies at a considerable distance outside the column).

It will be well here to call attention to the assumptions on which (1) rests, because it has often been applied to circumstances in which it is not true, and most misleading conclusions have been drawn in consequence. Equation (1) supposes:

First, that every plane section of the beam or column normal to the axis in the unstrained state remains plane and normal to the axis throughout. This is probably approximately true for homogeneous beams or columns formed out of one mass of uniform material, as, for instance, a log of timber, a cast iron column, or a rolled joist, but it is very doubtful how far it can be relied on for a framework built up of a number of separate pieces.

Secondly, that the value of E is constant throughout the cross section. This is approximately true in most cases, and it can be shown

---

* This equation is usually given as $M = \frac{EI}{R}$, thus assuming the initial form of the axis to be a straight line. For a beam, although the assumption cannot be true in fact, it does not affect the distribution of stress in the beam. With a column, however, the correction is of vital importance, as we shall see.

that the variations of E occurring in practice cannot largely affect the strength of iron columns, though some writers have attached an exaggerated importance to this point.

Thirdly, that the fibres of the beam or column are all strained in accordance with Hooke's Law. As soon as the most strained fibres pass the limit of elasticity, equation (1) ceases to express the condition of equilibrium, and all conclusions based on it cease to have any application. When therefore, as is sometimes done, a comparison is made between the stress in the extreme fibres of a beam as deduced from equation (1), when M is the moment causing fracture, and the direct tensile stress the same fibres will bear in a testing machine, it should cause no surprise that there is an enormous discrepancy. Equation (1) is based upon a supposed distribution of stress throughout the various parts of the cross section which is utterly wide of the truth when the moment of flexure is such as to cause rupture.*

Equation (1) being the equation of moments at any section of a column, we have also an equation between the sum of the applied forces parallel to the axis and the sum of the internal stresses at the same cross section which will be found to be:

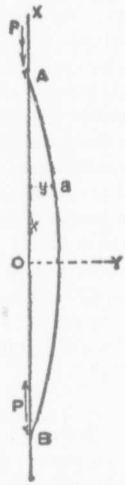
$$(2) \qquad p = \mathrm{E}y_1\left(\frac{1}{\mathrm{R}}-\frac{1}{\mathrm{R}_0}\right) \text{ whence by (1) } y_1 = p\,\frac{\mathrm{I}}{\mathrm{M}}$$

where p is the total applied force per unit of area of cross section, and y_1 is the distance of the neutral axis from the axis of figure at the same section.

In order to determine M we must know the form of the bent column under a given load, and in order to ascertain that, equation (1) must be solved. Now the essential difference between a beam and a column as regards this solution is, that for a beam M is independent of the deflection, while for a column it depends directly on the deflection. In other words, if x and y be rectangular co-ordinates defining the position of any point on the axis of the column, x being measured parallel to the length of the column, M is for beams a function of x only, while for columns it is a function of y. This entirely alters the character of the differential equation to be solved, and makes it quite inadmissible to assume, as is frequently done, that the deflections of a column will be governed by the same laws as are deduced from equation (1) for beams.

*For a full discussion of the question of the relation of transverse to direct strength of iron, v. Etudes sur l'Emploi du fer et de l'acier, by M. Considère, Paris, 1886.

Let AQB be the axis of a column bending under the action of a load P. Take AB as axis of x, its middle point O as origin, and let $AB = l$. Since the equilibrium of the column as a whole requires



that the forces acting on its two ends should be reducible to two equal and opposite forces P, let the line of action of these forces be at a distance a from O and we shall suppose it parallel to AB, because it is found that the principal effect in producing flexure is due to the mean value of the eccentricities of the loads at the two ends. Of course a is small since the intention is supposed to be to load the column so far as possible centrally. Let a be the cross section of the column at Q, and let $pa = P$. Let y_0 be the initial value of y for the unstrained column. We shall suppose $x_0 = x$, thereby neglecting the elastic shortening of the column. Let $\rho =$ radius of gyration at Q, $= \sqrt{\frac{I}{a}}$; then since $\frac{1}{R} = \frac{d^2y}{ax^2}$ as long as R is very large; similarly $\frac{1}{R_0} = \frac{d^2y_0}{dx^2}$; and since $M = -pa\,(y + a)$, (1) becomes

$$- p\,(y + a) = E\rho^2 \left(\frac{d^2y}{dx^2} - \frac{d^2y_0}{dx^2}\right)$$

write for brevity k^2 for $\frac{p}{E\rho^2}$ and suppose k to be constant throughout the length of the column, *i.e.*, suppose the column to be uniform in section and in material.

$$\text{Then } \frac{d^2y}{dx^2} - \frac{d^2y_0}{dx^2} = -k^2(y+a)$$

To solve this equation we must know what $\frac{d^2y_0}{dx^2}$ is in terms of x, or, in other words, what the unstrained form of the axis is. It being supposed that the column is initially as straight as the ordinary conditions of manufacture permit, the actual form of the axis will be an irregular curve departing very little from the line AB. We shall assume that the curve is the curve of sines $y_0 = \delta_0 \cos \frac{\pi x}{l}$. This assumption can be justified by the fact that the curve, whatever its form, can be expressed by equating y_0 to an infinite series proceeding by sines and cosines of multiples of $\frac{\pi x}{l}$ of which $\delta_0 \cos \frac{\pi x}{l}$ may be considered the first term. If this be done, it will be found that in ordinary cases the effect of the successive terms of the series on the resulting solution rapidly decreases.

$$\text{We have then } \frac{d^2y_0}{dx^2} = -\delta_0 \frac{\pi^2}{l^2} \cos \frac{\pi x}{l}$$

$$\text{and } \frac{d^2y}{dx^2} = -k^2(y+a) - \delta_0 \frac{\pi^2}{l^2} \cos \frac{\pi x}{l}$$

The solution of this equation with the conditions that $y = 0$ when $x = \frac{l}{2}$ or $-\frac{l}{2}$ is:

$$(3) \quad y + a = a \frac{\cos kx}{\cos \frac{kl}{2}} + \frac{\delta_0}{1 - \frac{k^2l^2}{\pi^2}} \cos \frac{\pi x}{l}$$

Before proceeding to obtain from this equation the stresses in the column, it will be well briefly to point out the relation it bears to the theory of flexure given in most text books, and known by the name of Euler's theory from the name of its author, who published it in the middle of last century. In that theory δ_0 and a are neglected, so that the differential equation is $\frac{d^2y}{dx^2} = -k^2y$. The direct solution of this is $y = A \cos kx + B \sin kx$, and the terminal conditions require $kl = \pi$ and $B = 0$, while A is indeterminate. In other words $p = \pi^2 E \left(\frac{\rho}{l}\right)^2$, and p having that value y may be anything. The same result may be deduced from (3), for if a and δ_0 vanish, y must always be zero except when $kl = \pi$, and in that case $\frac{a}{\cos \frac{kl}{2}}$ is an indeterminate fraction for which an arbitrary constant A may be substituted.

This theory is not only inconsistent with facts, which might be expected from the assumption of ideal conditions that cannot be realized in practice, but in the form given above (which is that usually published) it evidently contains some other serious error; for while it is quite conceivable that under the ideal conditions supposed, no flexure can occur until p reaches a certain limit, it is not conceivable that the flexure, when it does occur, should be independent of the load, so that the same load which first causes flexure will bend the column double. The error lies in neglecting the elastic shortening of the column. In the theory here given this is permissible, but in Euler's theory, a and δ_0 being neglected, a different order of small quantities is dealt with and the contraction of the column becomes important. If this be taken into account, and p is the load for which flexure first becomes possible, or $\pi^2 E \left(\frac{\rho}{l}\right)^2$ then the deflection δ_1 for a given load p per sq. in. greater than p_1, is given by

$$\delta^2 = \frac{4\,E}{p}\rho^2 \left\{ \sqrt{\frac{p}{p_1}} - 1 \right\}$$

It must also be observed that although by Euler's theory flexure cannot take place until p reaches the value p_1, it does not follow that it will then occur. For every value of p greater than p_1, there will be two positions of equilibrium for the column, one straight and one curved. The former will be unstable, and the chord of the arc of the bent column will be shorter than the straight column under the same load by an amount $\frac{\pi^2\,\delta^2}{4l}$.

The difference in results between Euler's theory and equation (3) is strikingly shown by observing that if either a or δ_0 has any finite value, however small, equation (3) shows that y is infinite for the value $kl = \pi$, where Euler's theory first allows flexure to become possible. It should also be observed that for ordinary proportions of columns p_1 approaches the limit of elasticity of the column, so that at ordinary working loads no flexure would ever occur if Euler's theory applied. For instance, with wrought iron having an elastic limit of 12 tons, the length of a column would have to be more than 100 times its radius of gyration in order that any flexure should occur with a load of 12 tons per sq. in., and 400 times to bend with a load of 6 tons per sq. in. We have given so much space to Euler's theory only because it has been so widely spread in treatises on engineering subjects and for its historical interest.

We will now return to equation (3), and, before going further, it becomes necessary to distinguish between the various ways in which the ends of the column may be constrained since the value of a depends upon the nature of the constraint.

i. The ends may rest in hinges in which the friction is insufficient to prevent rotation. In this a is independent of p.

ii. The ends may be rigidly attached to fixed objects, in which case a is a determinate function of p. (Flat-ended columns are another variety corresponding mechanically neither with i nor ii, and presenting great elements of uncertainty. As it does not represent any column used in practice we shall not consider it here. The same remarks apply to round-ended columns.)

iii. The ends may be rigidly attached to objects which themselves change in position as the load varies. This is a very common case and is that of the struts of a rivetted bridge, but we shall not deal with it, as it would require a very lengthy investigation. We only call attention to the fact that the conditions vary from those of case ii, and that a rivetted bridge strut has in consequence less strength than a similar strut whose ends are really fixed. Not only does it endure secondary stresses arising from the bending moments applied to its ends by the booms of the bridge, but its axis is thereby thrown out of line, by which its strength is impaired for bearing the direct load. We can refer students who wish to pursue the subject (which is one of great complexity) to Dr. Winkler's treatise, "Theorie der brücken," Vienna, 1886.

Considering case i, we must first remark that a hinged strut differs in no way from a fixed-end strut so long as the friction of the hinges is below its limiting value, or if the circumstances are such that the flexure takes place in some other plane than that normal to the axes of the hinges. Presuming that rotation of the hinges actually occurs, let h be the radius of the hinge, a_0 the distance of the centre of the hinge from the axis of the column, φ the angle of friction;

then $a = a_0 \pm h \sin \phi$, where the sign of $h \sin \varphi$ depends on the values of a_0 and δ_0, the direction of friction being always opposite to the tendency to rotation at the end. For iron on iron without lubrication $\sin \phi =$ about $\frac{3}{20}$, and $h \sin \phi$ will usually be much greater than a_0.

In equation (3) it is permissible to expand in powers of kl and neglect the higher powers because $kl = \frac{l}{\rho}\sqrt{\frac{p}{E}}$ and must always be small for such values of p as would constitute a safe working load. This may be verified by calculating the values of y direct from equation (3) for certain cases, and comparing them with the values given by the approximation. If this expansion be made, we obtain

$$(4)\quad y+a = a\left(1+\frac{k^2 l^2}{8}\right)\cos kx + \delta_0\left(1+\frac{k^2 l^2}{\pi^2}\right)\cos\frac{\pi x}{l}$$

$$\text{when } x=0,\ y=\delta_0 + k^2 l^2\left(\frac{a}{8}+\frac{\delta_0}{\pi^2}\right)$$

so that the central deflection is $\frac{p}{E}\left(\frac{l}{\rho}\right)^2\left(\frac{a}{8}+\frac{\delta_0}{\pi^2}\right)$

Let r be the distance of the innermost or most strained fibres of the column from the axis and f the stress per sq. in. in them, then, so long as Hooke's Law holds, the moment of resistance of the column may be expressed by $\frac{a\rho^2}{r}(f-p)$ which must therefore be equal to $ap\,(y+a)$.

Therefore $\frac{\rho^2}{r}(f-p)=p\,(y+a)$.

f is greatest where y is greatest, *i.e.* at the middle of the column. Substitute from (4) for $y+a$ and write b for $\frac{a+\delta_0}{r}$ and c for $\frac{1}{r}\left(\frac{a}{8}+\frac{\delta_0}{\pi^2}\right)$. We have then $\frac{\rho^2}{r}(f-p)=p\left\{br+cr\frac{p}{E}\left(\frac{l}{\rho}\right)^2\right\}$

The reason for introducing r into the values of b and c is that a and δ_0 are likely to vary roughly with the size of the column. We have seen that the principal part of a generally will arise from friction and be proportional to the radius of the hinge, and δ_0 is likely to increase with the length of the column with respect to which the diameter is generally fixed. At any rate $\frac{\delta_0}{r}$ will more nearly be independent of the dimensions of any particular column than δ_0 simply.

Rearranging the terms, $f=p\left\{1+\left(\frac{r}{\rho}\right)^2\left(b+\frac{cp}{E}\left(\frac{l}{\rho}\right)^2\right)\right\}$

This is a quadratic to obtain p in terms of f, but b and c being small, we may, as a first approximation, write f for p in the last term inside the bracket, the error so committed being in the direction of safety, and we thus obtain

$$(5)\quad p=\frac{f}{1+\left(\frac{r}{\rho}\right)^2\left\{b+\frac{cf}{E}\left(\frac{l}{\rho}\right)^2\right\}}$$

Case ii. Fixed ends.—Here the terminal conditions are that $\frac{dy}{dx}$ when

$x = \frac{l}{2}$ or $-\frac{l}{2}$, must be constant, whatever the value of p may be. If the same assumption as before with regard to the initial form of the axis be made, these conditions give

$$a = -\delta_0 \frac{\frac{kl}{\pi}}{1-\frac{k^2l^2}{\pi^2}} \cot \frac{kl}{2}$$

or expanding in powers of kl as before $a = -\frac{2\delta_0}{\pi} - \delta_0 k^2 l^2 \frac{12-\pi^2}{6\pi^3}$

The maximum bending moment is in this case at the end of the column and equal to $p\,a$. Proceeding as before to equate $p\,a$ to $\frac{\rho^2}{r}(f-p)$ we obtain a result of exactly the same form as (5), but in this case $b = \frac{2}{\pi}\,\frac{\delta_0}{r}$ or nearly $\frac{2}{3}\frac{\delta_0}{r}$ and $c = \frac{12-\pi^2}{6\pi^3}\,\frac{\delta_0}{r}$ = nearly $\frac{1}{87}\,\frac{\delta_0}{r}$.

The central deflection will be found to be $\frac{12-\pi}{12\,\pi^2}\,\delta_0 k^2 l^2$ or nearly

$$\frac{3}{40}\delta_0 \frac{p}{E}\left(\frac{l}{\rho}\right)^2$$

It might, however, perhaps be a fairer assumption for a fixed-end column to suppose the initial form of the axis to be the reversed curve $y_0 = \frac{\delta_0}{2}\left(1+\cos\frac{2\pi x}{l}\right)$, having the same central ordinate δ_0 but tangent to the line AB at both ends. On this assumption a will be found to be equal to $\frac{\delta_0}{2}\left(1+\frac{k^2\,l^2}{4\,\pi^2}\right)$

and the equation to the curve of the axis will be

$$y = \frac{\delta_0}{2}\left(1+\frac{k^2\,l^2}{4\pi^2}\right)\left(1+\cos\frac{2\,\pi x}{l}\right)$$

giving a central deflection due to the load of $\delta_0\,\frac{k\,l^2}{4\pi^2}$ or nearly $\frac{p}{40\,E}\left(\frac{l}{\rho}\right)^2$. The relation between f and p is of the form of (5) as before, only that now $b = \frac{1}{2}\frac{\delta_0}{r}$ and $c = \frac{1}{8\,\pi^2}\,\frac{\delta_0}{r}$ = nearly $\frac{1}{80}\frac{\delta_0}{r}$

The following conclusions may be drawn from the investigation which has resulted in this formula.

First, the actual strength of any column depends partly on known facts with regard to its dimensions, material, etc., and partly on accidental circumstances which can neither be predicted nor observed. This is true in some measure of all constructions, but with columns these accidental circumstances do not merely require corrections in the calculations of strength that would otherwise be true, but are governing factors in the calculations themselves. It follows then that any formula such as (5), supposing the constants determined, should express, not the strength which may be expected from a particular column of certain dimensions and material, but the *minimum* strength which experiments show may fairly be expected with ordinary care and skill in manufacture. The strength of a number of columns apparently alike and loaded alike may be expected to vary widely without apparent cause, and a formula for practical use should express the minimum and not the average of the results given by a very wide and numerous range of experiments.

Secondly, experiments on the crippling or destruction of columns cannot be expected to give coherent results when applied to the determination of the constants in any formula such as (5). The reasons for this have been fully indicated already. The constants can only properly be determined by experiments within the limits for which the column is perfectly elastic, and unfortunately very few experiments have been made of that kind. One method of determining the constants would be to measure the variations of deflection for given increments of load. If δ be the increase of deflection for an increase of load p, we have for a hinged column $\delta = cr\,\frac{p}{E}\left(\frac{l}{\rho}\right)^2$ and $b =$ nearly $9c$.

For a fixed-end column (on the second hypothesis, which is probably the truer) $\delta = 2cr\,\frac{p}{E}\left(\frac{l}{\rho}\right)^2$ and $b = 40c$.

Another method of determining b and c is to observe the limit of elasticity of the column as a whole and assume that this corresponds with the stress in the extreme fibres, f being the limit of elasticity of the material under direct stress. In Mr. Christie's experiments (Proc. Am. Soc. C. E., 1884) there are some observations which enable the first method to be applied. In Mr. Bouscaren's experiments (Proc. Am. Soc. C. E., 1880) are some which enable the second method to be applied. Unfortunately the majority of experiments are made on flat-ended columns, and no deduction can be made for our present purpose from them.

According to the experiments mentioned above, it would seem safe to place c for hinged columns at .05, and b at .45. If then we take E to be 13,500 tons and f (limit of elasticity in direct stress) 15 tons, which figures would apply to mild steel, and if, further, we allow the working load to be half the elastic load, we shall have as the working in lbs. per sq. in. of a mild steel hinged column

$$(6)\ p = \frac{16{,}800}{1 + \left(\frac{r}{\rho}\right)^2 \left\{.45 + \frac{1}{16{,}000}\left(\frac{l}{\rho}\right)^2\right\}}$$

For fixed-end columns it would seem that c might be put at .0075 and b at .3, and the safe load on a fixed-end column in lbs. per sq. in. would then be

$$(7)\ p = \frac{16{,}800}{1 + \left(\frac{r}{\rho}\right)^2 \left\{.3 + \frac{1}{120{,}000}\left(\frac{l}{\rho}\right)^2\right\}}$$

These determinations cannot, however, be recommended with any confidence on such a narrow basis of experiment. They would give higher working loads for long columns relatively to short ones than the formulæ and tables now in use. The fact that they disagree with present practice we do not regard as a condemnation, because present practice judges of the strength of a column for ordinary working loads solely by its ultimate strength, which we regard as a false principle, but at the same time so radical a departure as is now advocated could not prudently be made until a sufficient experimental basis is found for it as well as full theoretical justification.

The method chiefly used by engineers now is to make the working load a definite fraction of the load of rupture as determined by experiments for a similar section, and this is the best plan available; but it must not be supposed that it secures anything like a definite limit of working stress in the column. The term "crippling load" means different things with different experimenters. "Crippling" occurs in various ways with different columns, and the ratio of the crippling load to the elastic load varies very greatly with different proportions of columns. Further, the stress in the innermost fibres of a column at its point of failure is not the ultimate stress of the fibres, or any constant amount whatever.

Thirdly, since f (or more strictly p) is a coefficient of $\left(\frac{l}{\rho}\right)^2$ in the denominator of (5), the question is raised as to whether f should be made the elastic limit of the material in direct compression, and the working load made a definite fraction of the value of p so derived from (5), or whether f should be made the permissible working stress in the extreme fibres, and the working load p derived directly by (5) from it. The two methods would give different working loads which would agree for short columns and diverge more and more as $\left(\frac{l}{\rho}\right)$ increased, the first method giving the higher load. The first seems, however, the more logical plan, and has been followed in the tentative formulæ (6) and (7). By it the working load is made a definite fraction of the load at which the column, as a whole, ceases to be perfectly elastic. As we have before said, the margin between this elastic limit of the column and its failing point may vary enormously for different proportions of columns.

Fourthly, comparing hinged and fixed-end columns, we see that the strength of hinged columns may be expected to be much more variable even than that of those with fixed ends, because it depends on two variable elements a and δ_0, while the fixed end gets rid of a. For a hinged column accurately centered $a_0 = o$, and $a = \pm\ h \sin \phi$ being opposite in sign to δ_0, unless the hinge were very small indeed, b and c would then be negative. The meaning of this is that the friction would never rise to its limiting value, and the column would behave exactly as if its ends were fixed. The moment at the end of a fixed column under a load p is nearly $p\,\frac{\delta_0}{2}\left\{1+\frac{p}{40\,E}\left(\frac{l}{\rho}\right)^2\right\}$, and while p is within the elastic load, the moment of friction in a hinge of ordinary size will be greater than this. When p reaches such a magnitude that the friction is not sufficient to resist rotation, we may expect the column suddenly to spring into a new position of equilibrium.

We see, then, that according to formula (5) an accurately centered pinned column will safely bear as great a load as if its ends were fixed, and would be much weaker if it rested on knife edges. It is possible, however, that in structures the vibration which usually accompanies increase of load may destroy the friction to a great extent, and, if so, it would largely diminish the strength we might otherwise allow for in pinned columns well centered, and besides that a_0 may in practice have a very appreciable value.

The above conclusions, which are strictly deduced from our investigation, agree in general with the observations made by Mr. Christie on his experiments referred to above.

At first sight it might seem an objection to formula (5) that when $\frac{l}{\rho}$ becomes very small p does not approach the value f as a limit, but a definite quantity less than f. A little consideration, however, will show that any theory which takes into account the variations from ideal conditions on which the flexure of columns really depends ought to give that result. It must be remembered that f is not the safe load per sq. in. on a short column uniformly loaded, but the stress per sq. in. in the extreme fibres, and this will always be greater than the average stress, except under the ideal conditions of a and δ_0 being zero, which lead to Euler's theory.

The formulæ hitherto used to express the strength of columns have been empirical, that is, have been framed so as to agree as nearly as possible with the results of experiments. One of them has practically displaced all others, and is known as Gordon's formula, having been first made widely known by Professor Lewis Gordon, although it was put forward originally by Tredgold. Using the same symbols as hitherto it is as follows:

$$p = \frac{f}{1 + c\left(\frac{l}{\rho}\right)^2}$$

[and is sometimes given in a less correct form as:

$$p = \frac{f}{1 + c\left(\frac{l}{r}\right)^2} \quad]$$

We see that for columns of similar section in which $\frac{r}{\rho}$ is the same, this is practically the same formula as (5), for the second term in the denominator of (5) could then be got rid of by using a different value for f, viz.: $\dfrac{f}{1 + b\left(\frac{r}{\rho}\right)^2}$, the safe load per square inch on a short column of the section in question. It may be regarded as a confirmation of the truth of the principles on which we have proceeded that we have arrived at a similar formula in the main to that which is usually accepted as the nearest possible expression of experimental results. The agreement of Gordon's formula with experiments on the destruction of columns is, however, only comparative, and, as we have pointed out, could only be expected to be so. It would appear *a priori* that the introduction of $\left(\frac{r}{\rho}\right)^2$ into Gordon's formula, or some similar correction, ought to be an improvement, because, of two sections having an equal radius of gyration, that one with a smaller external diameter would have a higher elastic limit per square inch. The results of experiments also have shown that Gordon's formula requires a different value of c for different sections of column.

In designing a column it is clear that, according to formula (5), a given cross-section A will give the greatest strength: first, when $\frac{A}{\rho^2}$ is as small as possible; secondly, when $\left(\frac{r}{\rho}\right)^2$ is as small as possible. We therefore give a table of the values of $\frac{A}{\rho^2}$ and $\left(\frac{r}{\rho}\right)^2$ for some simple forms of cross-section.

Form of Cross-section.	Plane of flexure.	$\frac{A}{\rho^2}$	$\left(\frac{r}{\rho}\right)^2$
1. Solid circular.........	Immaterial......	4π or $12{\cdot}5$	4
2. Solid square..........	Bisecting sides...	12	3
3. do do	Through diagonal	12	6
4. Hollow circular (thin shell of radius r and thickness d)........	Immaterial......	$\frac{8\pi^2 d^2}{A}\left(\text{or } 79\frac{d^2}{A}\right)$ or $\frac{2A}{r^2}$	2
5. Hollow square (thin shell of side $2a$ and thickness d)........	Bisecting sides...	$\frac{96d^2}{A}$ or $\frac{3A}{2a^2}$	$\frac{3}{2}$
6. do do	Through diagonal	$\frac{96d^2}{A}$ or $\frac{3A}{2a^2}$	3
7. Square, side $2a$, in which material is concentrated in the four angular points......	Bisecting sides...	$\frac{A}{a^2}$	1
8. do do	Through diagonal	$\frac{A}{a^2}$	2
9. Square, side $2a$, in which material is concentrated along two opposite sides of thickness d................	Bisecting closed sides..........	$\frac{16d^2}{A}$ or $\frac{A}{a^2}$	1
10. do do	Bisecting open sides.	$\frac{48d^2}{A}$ or $\frac{3A}{a^2}$	3
11. do do	Through diagonal	$\frac{24d^2}{A}$ or $\frac{3A}{2a^2}$	3
12. Angle bar, side a, (small) thickness d..	Through root of angle.........	$\frac{24A}{a^2}$	3

Nos. 7 and 9 are the ultimate forms of built up square columns with four sides latticed and with two plated and two latticed respectively. It appears doubtful, as was said before, however, how far the flexure of built up columns can be expected to follow the same laws as those of solid columns.

The table contradicts common impressions in one or two respects. It is commonly supposed that a square column is weakest for flexure in a plane bisecting its sides, but, since the moment of inertia of the cross-section is the same for all axes, the moment of resistance for a given curvature will be the same for all planes of flexure, and accidental circumstances will determine the plane in which flexure actually occurs. For a plane through a diagonal of the square, however, $\left(\frac{r}{\rho}\right)^2$ is twice as great as for a plane bisecting the sides, and therefore the diagonal plane is the one in which the column would soonest reach its limit of elasticity. For this plane a solid square column is therefore weaker than a solid circular column of equal length and weight, while, if the plane of flexure bisecting the sides of the square were alone regarded, the square column would be the stronger, ρ being almost the same for both. If hollow square and circular shells be compared, similar remarks apply, only in this case the circle has the advantage also of a larger radius of gyration nearly in the ratio of ten-ninths. If square columns of equal length and weight be compared, in which the material is in the first case distributed in a uniform shell, in the second along two sides of the square only, and in the third concentrated in the four angular points only, and taking for each case the most unfavorable plane of flexure $\frac{A}{\rho^2}$ varies in the three cases as $3:6:2$ and $\left(\frac{r}{\rho}\right)^2$ as $3:3:2$, showing that the last form has a considerable advantage in both respects over the others, and that the fully closed square is more economical than that latticed on two faces.

DISCUSSION.

Prof. Collignon

Professor Collignon said he did not propose to discuss Mr. Findlay's calculations in detail, but would refer to a pamphlet on the subject which he himself had written in January, 1889, and which seemed to throw some light on the question of struts loaded at the ends.

It at least shows that the indeterminate result of the analytic solution of the problem is due to the approximate method employed in solving the equations, and that it will disappear when the solution is more complete and rigourous. He would also beg to remark that the theory of struts loaded at the ends does not, in his opinion, aim at determining what takes place when the strut bends and is going to break, but rather at investigating the conditions which it must satisfy in order that it may neither tend to bend nor break. Engineers are nowadays very nearly in accord on this last practical question, and the formulæ which they employ, very different according to the country and customs, lead to the same results, excepting as to the degree of safety adopted.

Prof. Burr.

The subject of long columns has probably received as much analytical consideration as any one construction with which the engineer has to deal, and yet it is a little singular that most of the latest purely mathematical treatments of this problem are radically in error in the assumptions on which the mathematics of the subject are based. Unless the writer quite misapprehends its scope, this paper is not an exception to the last observation. Euler and the eminent mechanicians from his time down to the present, with Saint Venant and Clebsch pre-eminent among the later ones, saw and promised that the common theory of flexure could only be applied with even approximate accuracy to columns whose lengths were very great as compared with their lateral dimensions in the plane of flexure. Just what these lengths are it is perhaps impossible to exactly determine, but we know that with wrought iron, for which the coefficient of elasticity in compression may be taken at 28,000,000 lbs., and the ultimate resistance to compression in short locks at 60,000 lbs., the lengths will considerably exceed 140 and 70 times the radius of gyration for fixed and rounded ends, respectively, thus excluding the greater part or all of the columns used in railroad bridges. In fact a considerable number of Mr. Christie's tests of very long angle iron struts indicate with strong probability that these limits should not be taken lower than 250 and 125 times the radius of gyration, which would leave nothing in the field of bridge columns to be even approximately covered by the theory. Such experimental results constitute by the process of exclusion a most interesting confirmation of the common theory of flexure in its own proper field, but demonstrate the hopeless futility of any and all attempts to force from it a column formula for bridge members. This erroneous impression regarding the applicability of the common theory of flexure to ordinary compression members is probably due to the fact that, with one or two exceptions only, writers of authority in the English language assume either the theory itself, or such imaginary and erroneous conditions as enable some of its chief features to flow from them in a very simple manner, and thus utterly fail to discover its true scope. If the theory were deduced from the fundamental conceptions of the mathematical theory of elasticity in solid bodies, as it should be, engineering authorities would fall into much fewer errors regarding its use, and, among others, the statement that it requires normal sections plane before flexure to remain plane during flexure. The theory shows, in fact, that such sections, in the general case, cannot possibly remain plane when flexure takes place.

But, returning to Mr. Findlay's paper, the writer thinks that it will impress most experienced structural engineers that his assumption of the eccentricity (a) of the line of applied load is very far, in most cases, from representing actual column conditions. If the columns are with flat ends, it is scarcely probable, and much less possible, that the line joining centres of pressure at their ends will be exactly parallel to its axis. In fact those centres are as liable to lie on opposite sides of the column axis as to occupy other positions, if not far more so. If the columns are with pin ends the assumption of a mean eccentricity of appreciable value is still more liable to be erroneous, for the centres of pressure are then essentially, if not exactly, at the pin centres in the column axis at each end. The matter of pin friction is too indeterminate to make it other than dangerous to attempt to definitely represent it in an analytical column formula, either by means of eccentricity or otherwise. These considerations in connection with the rough analytical approximations, by which Mr. Findlay causes a and δ_0 to be displaced by measurable elements, make it a matter of very serious doubt whether his formulæ are as exact, in the end, as theoretical expressions, as Euler's. The assumption of a mean value of eccentricities conduces to simplicity in analytical treatment, and is certainly justifiable on that ground ; but there is equally good reason for going a short step further and making the "mean value" zero, as is done in Euler's formula. In reality, as Mr. Findlay observes, his formula is in no way different from Euler's, except in the fact that the latter makes the former's a equal to zero. Hence the main features of both expressions, as column formulæ, must be essentially the same, and as it has been shown that both involve about the same degree of approximation, it is reasonable to conclude that neither will, on the whole, give actual column resistances much nearer than the other. This conclusion is confirmed by results of tests on full-sized columns.

These latter also confirm the conclusion reached in this discussion as to the impossibility of establishing any column formula for ordinary bridge members by the use of the common theory of flexure.

In 1879 Messrs. Clarke, Reeves & Co. tested to destruction sixteen full sized Phœnix Columns with flat ends, in the large testing machine at the U. S. Arsenal at Watertown, Mass. Each of these columns had a sectional area of a little over 12 square inches, and their lengths varied from 7 to 28 feet. Between the values of 28 and 112 for the ratio of $l \div r$ (length divided by radius of gyration) the following simple formula gives values of the ultimate resistance in pounds per square inch far more closely than any form of expression that can be deduced from the common theory of flexure:

$$p = 39640 - 46\frac{l}{r} \qquad (1)$$

It is believed that this experimental form of column formula was first given by the writer in a discussion of these tests, as published in the Transactions of the American Society of Civil Engineers for 1881. It has since come into quite common use.

During the years 1880, 1881, etc., a series of 70 tests of full sized latticed channel columns was completed at the U. S. Arsenal at Watertown, Mass., and the results were published in various "Ex. Docs." by the U. S. Government. These columns had $3\frac{1}{2}$ inch pin ends with 6 to 12 inch channels having areas from 4.65 square inches to 21.00 square inches, and lengths from 10 feet to 30 feet. Between values of 30 and 130 for $l \div r$ the formula:

$$p = 40{,}000 - 110\,\frac{l}{r} \qquad (2)$$

gives ultimate resistance in pounds per square inch nearer to the test results than any formula derived from the theory of flexure, although the following is tolerably satisfactory :

$$p = \frac{39,000}{1 + \frac{1}{30,000}\left(\frac{l}{r}\right)^2} \qquad (3)$$

Three inch square solid wrought iron columns, varying in length from 30 to 179.5 inches, and tested in the same machine, with $1\frac{1}{2}$ inch pin ends, yielded the following very close formula between $l \div r = 30$ and 210:—

$$p = 32,000 - 80\frac{l}{r} \qquad (4)$$

The full sized tests by Mr. James Christie, mentioned by Mr. Findlay, gave the following very close expressions for ultimate resistances in pounds per square inch :—

Flat and fixed end iron angles and Tees :—

$$p = 44,000 - 140\frac{l}{r} \qquad (5)$$

Round end iron angles and Tees :—

$$p = 46,000 - 175\frac{l}{r} \qquad (6)$$

Flat end mild steel angles:—

$$p = 52,000 - 180\frac{l}{r} \qquad (7)$$

Flat end high steel angles :—

$$p = 76,000 - 290\frac{l}{r} \qquad (8)$$

Equations (5), (6), (7) and (8) are to be used only between $\frac{l}{r} = 40$ and 200.

Flat end iron channels and I beams for $\frac{l}{r} = 20$ to 240 :—

$$p = 40,000 - 110\frac{l}{r} \qquad (9)$$

It has not been thought necessary to reproduce here either the mass of numerical results showing a comparison between the experimental resistances and those derived from Equations (1) to (9), or the scale diagrams showing the same thing, but they may be seen in all detail and consulted in the writer's "Resistance of Materials," pages 450 to 462.

None of the above Equations except Equation (3) can be established either in form or type by the common theory of flexure, nor does Equation (3) or any other formula similar to it or to Euler's give results agreeing nearly as well, with full sized tests, as those of the above equations between the limits indicated, which, it is important to observe, are both below the theoretical limits of applicability of Euler's formula. The crucial test of actual experience, therefore, shows only what the true theory establishes with equal clearness and certainty, viz., that no formula based on the common theory of flexure can be devised which will satisfactorily represent the ultimate resistances of ordinary bridge columns.

Mr Moulton. Having carefully followed Mr. Findlay's demonstration of the formula he presents for the permissible stress in columns, it seems to the writer that he has produced one which gives proper expression to the factors which should be recognised and used as the basis of working data in proportioning structures.

The main trouble, however, is, as he clearly states, that experimenters have not given us sufficiently complete data, in the reports of their tests, to enable us to judge accurately when in the tests the elastic limit was passed, and at what points actual crippling of the piece as a whole occurred.

The writer has never doubted that if we could determine with certainty, in compressive tests on columns, the stage at which the elastic limit is passed, it would be found to vary with much more regularity than that at which crippling takes place.

Could we have a sufficient number of reliable experiments, conducted according to a proper system, and covering the ordinary range of lengths and forms of cross section, so as to obtain the elastic limit for each case in a similar manner, there would result much more rational data from which to determine our working values than those on which our present formulæ are based.

There is, however, little likelihood of such experimental work being done for some time, hence the question arises whether we can improve our formulæ with our present data.

For determining the modulus of elasticity of a built column, the best way would of course be to test one like it, otherwise we must determine the compressive moduli of the component parts, either by direct compressive tests, requiring much care in preparation, or by approximations from the tension moduli, and assume that the resultant is like that of the whole column.

The writer has little faith in the latter method, as he has seen, in steel, so much variation in the modulii of the parts composing a certain built member, and has also observed, in the case of a very few steel posts, where he has had accurate data for comparison, the further variation of these modulii from that of the post as a whole.

If we could refer our permissible stress to the elastic limit, the factor or ratio would be, of course, much less than we now use when referring to the ultimate crushing strength, and consequently we should have to deal very carefully with the circumstances tending to vary the elastic limit.

Mr. Findlay makes an excellent point when he introduces the factor $\left(\frac{r}{\rho}\right)^2$ into his formula, and were Gordon's (or Rankine's) a more rational formula, the writer would agree that it would be well to introduce it there; but, as far as our practice in the United States is concerned, the tendency is to forsake the formula as it stands for simpler forms which represent straight lines, and seem to fit in between the experiments about as well, and any further complication or rather addition to the formula would be about as hard to introduce with us as an entirely new formula.

The disturbing element in railroad structures, which has always seemed to the writer to tend to vitiate any deductions drawn from quiescent tests in the physical laboratory, is the vibration during the passage of rapidly moving loads.

We are of course trying to arrange our formulæ to take account of this, but when we get down to bottom facts what have we for data on which to base our changes?

Fresh in mind is a discussion on a set of formulæ presented to the Am. Soc. C. E., which embodied the ideas brought out by the experiments of Wöhler and Spangenburg; and it was argued, and the writer thinks maintained, by the majority of our most prominent experts, that the experiments and the data afforded by them were not sufficient to warrant us in accepting and applying the theory in the form then presented.

Such being the case with a long series of experiments in evidence, how little direct and conclusive testimony may we be said to have regarding the effect of vibration on the resistance of the compression members in a railroad bridge? None attempt to ignore its influence, and the theory most accepted with us now is to make the permissible working stress for live loads equal to one half that for dead loads. Necessarily, there must be a starting point for the formulæ, and that is taken so that the old units obtain for a structure wherein the dead load is about one half the live load. This would occur with the American type of construction in a span of about 150 feet single track, with a live load of two consolidation engines each weighing about 83 net tons on 50 feet, followed by a train of 3000 lbs. per lineal foot.

The first advance was in using Rankine's formula expressed in the present paper

$$p = \frac{f}{1 + c\left(\frac{l}{\rho}\right)^2}$$

in which the constant "c" varied with the form of section as before, and the constant "*f*" was made 8000 lbs., increased in a certain ratio as the span exceeded 150 feet—all applied to the combined live and dead stresses.

As before mentioned, the form most in present favour is a formula of a straight line, and is applied to the live and dead load stresses separately, giving the permissible unit stresses for the former just one half of those for the latter.

The writer has preferred to retain the "Rankine" form, giving as it does a somewhat greater range, varying the constant "*f*" in a similar manner for live and dead loads separately, and has found it quite acceptable to a number of engineers of prominence.

It is his belief that the next move in experimental work of value, to determine the working strength of columns, will have to be made by applying some form of self-registering dynamometer to columns in existing bridges during the passage of trains, and by systematic experiment with known loads and velocities ascertain what our compression members already constructed and in constant use are doing under their daily conditions, and from such data, together with full knowledge of the parts when unloaded, ascertain the state of our practice in designing columns, and wherein it should be improved.

Mr. Whited. The author speaks of Euler's theory of columns as being unsound. It is a fact that a long column shows no notable deflection until it is loaded very nearly up to its ultimate strength, and although it may be difficult to understand how the same load that first produces flexure is sufficient to bend the column double, experience shows that the increase of load necessary is slight, and it is quite possible that that slight increment may be accounted for by the internal stresses, the want of uniformity, and the eccentricity of the column.

He also says that the length of a wrought iron column must be about 100 times its radius of gyration in order that it may fail by bending under a load equal to its elastic limit, and about 140 times its radius of gyration—not 400 times, as the author states—in order that it may fail under $\frac{1}{2}$ its elastic limit according to Euler's theory, while columns much shorter than this actually do fail by bending. These facts may be accounted for by the fact, that some portion of the shorter column is strained beyond the elastic limit before Euler's limit is reached, and therefore no rational theory will hold, and experiments prove very little. It may be assumed that whenever any portion of a column is strained beyond its elastic limit, bending will take place provided $\frac{l}{s}$ exceeds a certain very moderate amount. Euler's theory is based upon conditions that are not realized in practice, but that is the case with a great many other physical theories.

With regard to the values of f and c, they seem to depend very much upon circumstances, and that the engineer has an excellent chance to use a little good judgment in his assumptions. For example, rolled wrought iron is made sometimes from special and sometimes from miscellaneous scrap, but in any case it is liable to be far from uniform. Mild steel is rolled from the ingot, and is much more nearly homogeneous. Cast iron is very liable to hidden defects, and allowance must be made for that fact. The closing of the rivets in rivetted columns is liable to produce quite serious internal stresses, the cold straightening of rolled metal has a similar effect. In columns for buildings the settlement or yielding of something may change the manner of loading very materially. Such things as connecting rods and other working parts of machinery that are machined all over are much more accurately made and loaded than any class of structural iron work. In bridges the speaker is in favour of specifying a certain maximum eccentricity, perhaps about one-half inch for ordinary bridge work, and insisting upon that rule being observed. To be sure some engineers specify that compression members for bridges shall be perfectly straight, but any manufacturer will tell them that he does not expect to make anything perfect in his establishment until the millennium. If engineers will bear this fact in mind, and write specifications that can be carried out at a price they are willing to pay, insist on their being strictly carried out, and make their calculations accordingly, substituting the corresponding values for the constants in the author's modification of Euler's formula, making due allowance for accidental circumstances, they will have their columns as well proportioned as the present state of science and art will permit in all cases where the author's formula is available.

The speaker's experimental knowledge of columns is very limited, but the tests that have been carried out were very carefully made with the Emery testing machine, and the results were as follows:—

TEST NO. 1.

$3\frac{1}{8}'' \times 3\frac{1}{8}'' \times \frac{1}{4}''$ I beam, square ends 86.3″ long, deflections measured from points 84″ apart. Area 2.448 sq. in., moment of inertia 1.3604, radius of gyration .7455″, $\frac{l}{\rho} = 116$ failed at $91100 = 37214$ per sq. in. Elastic limit in tension 41356 per sq. in., so that in view of the fact that the elastic limit in tension may differ considerably from that in compression, and also owing to various causes mentioned above, the stress may not have been uniformly distributed over the section of the column, and it is fair to assume that some part of the column was strained beyond the elastic limit before failure took place, and therefore no column formula has any legitimate application. When the load reached 53,000 it was removed, showing no permanent compression and very slight permanent deflection, and the deflection did not reach its previous amount until the load reached 88,000, and was not notably increased till the load was within 1 per cent. of the ultimate strength, and after the ultimate strength was reached the load diminished while the column continued to deflect. This was owing of course to the outer fibres being strained beyond the elastic limit.

TEST NO. 2.

$5\frac{1}{8}'' \times 4\frac{3}{4}''$ I beam, 112.26″ long square ends, deflections measured from points 108″ apart. Area = 4.854 sq. in., moment of inertia = 4.97074, radius of gyration 1.0119″. This was tested transversely on 35″ bearers with the load in the centre showing a deflection of .0265″ at 5390, whence, by the equation of the elastic curve, the modulus of elasticity = 36630000. This column did not fail under the greatest load the machine was capable of applying, and is only given to show how rapidly the deflection takes place as the ultimate strength is approached. It was not so rapid in this case as in the preceding one, doubtless owing to internal strains in the metal. It will also be seen that the column was strained very little beyond its elastic limit.

TEST NO. 3.

Another piece of the same I beam from which 2 was cut. This was tested on pin bearings, pins 2.92″, length centre to centre 111.17″, $\frac{l}{\rho}$ about 110; failed at 149600 by crippling. The diagram shewed that the deflection was almost *nil* until the load had nearly reached the maximum, when it increased very rapidly, in the present case with a bound, probably because the friction of motion on the pin was less than the friction of rest. If we substitute the value of the modulus of elasticity as given above = 36630000 in Euler's formula, we shall obtain 145100 as the ultimate strength of the column, which agrees sufficiently nearly with the experimental result. It is to be understood, however, that this fact does not prove Euler's theory to be applicable in practice, it only tends to indicate that the conditions of the test were very nearly those on which Euler's theory depends.

Thursday, 27th March.

H. T. Bovey, Member of Council, in the Chair.

The discussion of Mr. M. J. Butler's paper on "The Manufacture of Natural Cement" and of Mr. Findlay's paper on "Columns" occupied the evening.

Thursday, 10th April.

C. E. Goad, Member, in the Chair.

The following candidates having been balloted for were declared duly elected as:—

MEMBERS.

IRA ABBOTT, ALEXANDER LAUDER HOGG.

ASSOCIATE MEMBERS.

ARTHUR THOMAS KELLY EVANS, CHARLES THOMAS SYMMES.

ASSOCIATES.

WALTER REGINALD BAKER, HON. DONALD McINNESS,
J. PHILIP SCOTT.

STUDENTS.

FRANKLIN M. BOWMAN, HENRY ROBERTSON LORDLY,
JOHN ANDREW DUFF, JAMES R. PEDDER,
JOSEPH H. LEFEBVRE, THOMAS HENRY WIGGINS.

The following has been transferred from the class of Associate Members to that of Members:—

CHARLES LE BARON MILES.

The following has been transferred from the class of Associates to that of Associate Members:—

GEORGE BROKITT ABREY.

The following has been transferred from the class of Students to that of Associate Members:

RODERICK MACCOLL.

41.

IRRIGATION IN BRITISH COLUMBIA.

By E. Mohun, M. Can. Soc. C. E.

The art of irrigation may claim to have been practised by the oldest branch of that profession which seeks to direct the great sources of power in nature for the use and convenience of man. Its origin is lost in the mists of antiquity, but the skill and knowledge of hydraulic laws possessed by the first civil engineers are attested by the ruins of the gigantic works constructed by them in Egypt and Assyria. In the former we find the artificial Lake Mœris, two hundred and twenty-five miles in circumference, according to Herodotus, supposed to have been constructed by Amenemhat III. about 2380 B.C., the great Canal Bahr-Yoosup, 350 miles long, constructed under the Pharaohs, and repaired by Saladin, and the Sweet Water Canal attributed to Sesostris about 1400 B.C. In Assyria, Khammuragas, probably about 2000 B.C., is credited with the construction of numerous canals and the embankment of the Tigris.

About 600 B.C. Nebuchadnezzar embanked the Euphrates; cut canals to carry its overflow into the Tigris; excavated a reservoir, forty miles square and thirty-five feet deep (Herodotus) to receive the waters of the former river, while its channel was being lined with brick; and constructed the far-famed Hanging Gardens of Babylon, on a series of arches at least 75 feet high and 400 Greek feet square. It is said that the water for their irrigation was raised from the Euphrates by an Archimedean screw. In China its history appears to be coeval with that of the Chinese Empire. In India in modern times the Imperial Government spent in ten years on irrigation no less a sum than £10,457,702 sterling. Of this amount £5,673,401 was expended in the North West Provinces, including the great works of the Ganges, the Eastern Jumna, the Agra, and the Lower Ganges canals; the area irrigated in the North West Provinces being 1,461,428 acres.

One of the most gigantic of modern irrigation schemes is proposed in Southern Idaho, and includes the construction of two great canals 300 and 280 miles long respectively, for the purpose of irrigating an estimated area of 4,500,000 acres. At the present day irrigation is in systematic use on every continent, and has proved of inestimable value in adding to the food supplies of the population of the globe.

In 1878 the author received instructions to report upon irrigation as practised in British Columbia for the information of the Dominion Government, and this paper is principally based upon the notes then taken. He would also bespeak the indulgence of the older members, when entering into details with which they are familiar, but to which, it may reasonably be assumed, some of the younger members have not probably devoted much attention. The main objects of the investigation were to ascertain how much water was required for crops, and whether the existing supplies were properly utilized.

THE MINER'S INCH.

As there will be frequent occasion to refer to the Miner's Inch, the standard measure of water both for mining and agriculture, it may be well before proceeding further to define it.

In California, the inch varies in different localities, and it means the amount which will pass through an orifice one inch square in a two inch plank with a certain head; the usual head is six inches above the top of the orifice. As, however, the depth of the orifice is sometimes made two inches, with a head varying from five to eight inches above it, it is obvious that the inch in California is not a fixed quantity in practice, and the writer believes there is no State law regulating it. Mr. Melville Attwood, a well-known mining engineer in San Francisco, informed the author that the inch recognized by the profession generally was 92 lbs. a minute. About sixteen years ago Mr. Amos Bowman, now of the Geological Survey of Canada, then in California, made a practical and admirable suggestion, namely, that an inch of water should mean 100 cubic feet an hour, or 2400 cubic feet a day. Had his suggestion been adopted, the matter would have been much simplified.

In 1878 the Mining Laws of British Columbia permitted the orifice to be ten inches or less in depth, with any head not more than seventeen inches above the *bottom* of the orifice. A few years later the author brought the matter to the notice of the Provincial Government; the following is now the definition according to the Land Act:—

"In measuring water in any ditch or sluice, the following rules shall be observed:—

"The water taken into a ditch or sluice shall be measured at the ditch or sluice head. No water shall be taken into a ditch or sluice except in a trough placed horizontally at the place at which the water enters it, and which trough shall be extended two feet beyond the orifice for the discharge of the water. One inch of water, or any multiple of one inch, shall mean half the quantity that will pass through an orifice two inches high by one or more inches wide, with a constant head of seven inches above the upper side of the orifice."

These dimensions and head were adopted as being as nearly as possible in accordance with the customary measurement. It is believed that this standard has since been adopted by the Dominion Government.

Taking the value of c. at 0.645 (Greenhill & Unwin):—
one inch $= 0.645 \sqrt{29h} \times 0.01389 \times 43200 = 2536$ cubic feet a day. And for orifice of different depths with other heads the number of inches $= C \sqrt{h} \times 273.4 \times a$.

The construction of gauges has for a long time occupied the attention of the hydraulic engineers of Northern Italy; and the researches and experiments made by them, for the purpose of establishing a simple self-acting instrument of that description, led to the discovery of the following curious law of hydrodynamics, upon which is based the principle of the gauges used in Piedmont and Lombardy.

"It was ascertained that, in a vase constantly supplied, but divided into two portions by a diaphragm susceptible of being moved vertically, with a discharging orifice on one side of the vase, a constant difference of level existed in the surfaces of the respective portions of the reservoir so long as the water flowed; and that this difference of level was greater in proportion as the opening of the diaphragm was less compared to that of the orifice. And it was also observed that if, by any change in the direction of the supply or the flow, the level were made to alter on either side of the diaphragm, the corresponding variations in the level upon the two sides continued always to be proportional to the respective difference of level first established." (Burnell.)

A sketch of one of these modules is shewn in Plate VII, Figure 1, in which the water is admitted into the regulating chamber A by the movable sluice b. The water is maintained at the proper height in the regulating chamber when discharging through the orifice O, by raising or lowering the sluice b. The chamber A is covered with a ceiling at the exact level of the required head (which is indicated by a gauge) to still the agitation of the entering water. The unit of measurement varies in different localities as follows:—

	Height of Orifice. ft.	Width of Orifice. ft.	Head above top of Orifice. ft.	Discharge i cubic feet a second.
Canal Lodi........	1.12	0.12416	0.32	0.61655
Canal of Cremona.	1.31816	0.131	0.131	0.722
Sardinian Module.	0.6562	0.6562	0.6562	2.046
Oncia Magistrale of Milan.........	0.655	0.3426	0.3294	0.866

In Spain a module giving very good results is in use on the Madrid Canal, Figure 2. Its construction, however, involves a serious loss of level between the canal and the irrigation ditch. This module consists of two chambers, one above the other. To the upper one the water has free access from the canal, in its floor, which is also the roof of the lower chamber; there is a circular sharp-edged orifice in a bronze plate, in which hangs a circular plug of varying diameter suspended from a float. The plug is so shaped that as the water in the upper chamber rises and falls and the float and plug with it, the free passage in the orifice is diminished or enlarged, so that the quantity discharged is uniform, though the head may vary. From the lower chamber the water is discharged through a culvert into the irrigation ditch.

An ingenious method of measurement has been proposed in England. In this module the orifices are in a sliding metal plate, connected by a link to a lever, attached at one end to a float in the regulating chamber, and so proportioned that the plate rises and falls with the float, maintaining the top of the orifice at a uniform depth below the surface of the water. Mr. Appold has also invented a module in which the water passes through a pipe having an enlarged chamber, in which swings a heavy pendulum, so proportioned that the discharging orifice diminishes as the pendulum under increased pressure approaches a horizontal position.

The general rules for irrigating crops, laid down by DeCandolle, are thus briefly enumerated by Dempsey:—

1st. That the water should be well ærated; the presence of atmospheric air is good, but that of carbonic acid gas much better; and it is desirable that the water should contain fertilizing matters.

2nd. In the winter there should be little irrigation, because the plants are then dormant, and water is then superabundant. In spring water is usually abundant. In summer it is wanting; and at that time the water should be given in the evening.

3rd. The quantity of the water to be applied should be varied according

a. To the object of the culture:—When for leaves, more water should be given than when for flowers; less water should be given when for grains or fruits.

b. To the depths of the roots:—The application should be more frequent to the plants of which the roots are superficial; less frequent to deeper roots.

c. To the structure of the foliage:—Those which evaporate much (such as plants with large leaves) more frequently than perennial, or plants with thick leaves.

d. To the consistence of the stalks and of the roots:—Roots with fleshy fibres do not thrive if too abundantly watered; at the same time they are injured by dryness. Tuberculous or bulbous plants, or plants with fleshy leaves, can bear a long-continued dryness, and therefore infrequent, yet abundant, watering suits them well.

e. To the stage of vegetation:—It is important to bear in mind that young germinating plants require light and frequent waterings; those that are in the height of growth abundant waterings; and when the fruit or seed is being matured the waterings should be infrequent.

Those that have been transplanted require abundant watering.

f. To the nature of the soil, according to which the rules must be modified:—The lighter the soil the more frequent and plentiful must be the waterings. If it is a compact and clayey soil, less watering will be required.

g. To the state of the atmosphere:—It will be readily conceived that the watering must be more frequent when the temperature is high, the sky clear, and the air dry, and during drought.

Quantities necessary in Europe, Africa and Asia.

In connection with the subject it will be well to consider the quantities estimated to be necessary in different localities, when irrigation on an extensive scale is carried on; and Mr. Burnell gives the following figures:

Grau d'Arles........................	932	cubic feet per acre a day.
Haute Garonne........................	622	" " " " " "
Algeria........................	244	" " " " " "
Eastern Pyrenees........................	205	" " " " " "
East Indies........................	400	" " " " " "
South of France........................	1200	" " " " " "

The first and last of these quantities Mr. Burnell (and probably the reader will agree with him) considers excessive. He also states that the successful cultivation of rice is estimated to require 1440 cubic feet a day; but as rice is an essentially aquatic plant, requiring to be constantly immersed in water during its growth, while it cannot be cultivated with success north of the 46th parallel, its irrigation need not now be taken into consideration.

In that part of the Sahara which is contiguous to the French possessions in North Africa, much has been done in the way of irrigation, during the last few years, by means of artesian wells. Throughout the low-lying portions of the Algerian Sahara, there appears to be an abundance of subterranean waters, which only require an outlet to the surface to cause the wilderness to blossom as the rose. The first French well was bored in 1856, which yielded about 82 inches; and by the 1st October, 1885, there were in the Oned Rir, a valley about one hundred and twenty miles long, one hundred and fourteen artesian wells, and four hundred and ninety-two natural springs, yielding about 5,100 inches. Nor has this large flow affected the yield of the older wells. The "Société de Batna et du Sud Algerien," formed in 1881, in the first five years of its existence, sank seven wells yielding 527 inches, reclaimed one thousand acres of desert, planted more than fifty thousand date palms, constructed twenty-five miles of irrigation ditches, and built houses for the cultivators and company's agents, and have already derived a revenue in round numbers of $100,000. (Chambers' Journal.)

SYSTEMS OF IRRIGATION.

In Lombardy the bedwork system of irrigation is generally adopted, in which the land to be irrigated is thrown up into ridges, the more compact the soil the wider the ridge. On the summit of the ridge is the shallow feeder or floating trough, from which the water is shed over the gently sloping sides of the ridge. The usual dimensions of the floating troughs are about 20 inches wide at their junctions with the conductors, decreasing in width to about 12 inches at their lower ends, while they are generally about 70 yards long. The main conductor, from which the floating troughs are supplied, is usually but not necessarily at right angles to them, and the water is commonly turned off by closing the upper end of the floating trough with a sod. Between the ridges are small drains in which the superfluous water is collected and conveyed to a main drain, from which it is either again used to irrigate lower lying lands, or returned to the stream from which it was originally taken.

Figure 3 shews how with favourable natural contours a comparatively small amount of water can be of very considerable service.

In the Figure AA is the main conductor, BB the main drain, a a are the floating troughs, b b the drains, c c are either conductors or drains according to circumstances, D, E, F, G, H & L, being hatches or sluices for the direction of the water. It is obvious that by opening or closing the hatches as circumstances dictate, the whole or any portion of the water can be directed to any particular section, and the superfluous water from one division used upon a lower one. In mountainous districts the main conductors have frequently a fall of 1 in 500; in the plains the fall usually is from 1 in 1500 to 1 in 3500.

In the catchwater system, extensively used in the water meadows of England, though generally considered inferior to the bed work, the water is conveyed along the side of a slope in a nearly level ditch without an outlet. As soon as the ditch is full, its contents begin to flow over the lower bank; at distances of about 30 feet, other level ditches on contour lines without outlets are formed, which collect and redistribute the water over the next lower area, when it is again caught and redistributed, until it finally reaches the lowest ditch, which is a drain.

A third method, that of sub-irrigation, has been employed both in England and in the United States, generally for the purpose of utilizing and disposing without offence of liquid sewage. It has been received with favour by some persons, and has been adopted on free soils with apparent success, but as the liquid is distributed through the subsoil by underground pipes which are out of sight, the process is liable to objections which sanitarians cannot fail to recognize and appreciate.

The foremost of these objections is the fact that the distributing pipes must sooner or later become choked with the minute solid matters held by the liquid refuse in suspension, and when this is the case an "excrement sodden" condition of soil is produced. A stoppage can only be detected by positive signs of wetness on the surface, and not until the evils produced by exhalations from excrementitious matter may have gained an ascendency. Mr. Rogers Field has done much to overcome these objections. The drains by which he effects the distribution of the liquid consist of common agricultural drain pipes, laid some 10 or 12 inches below the surface upon a continuous bed of larger half pipes. This bed is not disturbed when the pipes are taken up to be cleaned, which ensures their being readily re-laid in true position. The sewage flows out of the joints into the soil and feeds the vegetation, and the concentrations of the flow, effected by the sudden discharge of a regulator or flush tank, with which the pipes are connected, forces the liquid rapidly along them.

In deference, however, to the wide experience of Mr. Rogers Field, and to the practical results obtained by Mr. Waring of Newport, U. S. A., who has adopted this means of sewage utilization in various instances in America, it is only right to append an extract from one of this last-named gentleman's letters on this subject.

In it he says: "I am carrying out the principles of sewage utilzation here to some extent, not, however, in surface irrigation, but in the distribution of screened sewage by means of flush tanks of larger capacity, and of sub-irrigation by draining tiles laid about 10 inches below the surface of the ground. Some of this work dates back to 1869, and in one instance I have disposed in this manner of the sewage of a village of about 1500 inhabitants, and in another of the outflow of a prison producing about 30,000 gallons per day.

"In every instance the result has been most satisfactory, and I have large works of the same character now on hand." (Bailey-Denton.)

The sub-irrigation of drained land is also accomplished by closing the outlets of the drains, when the surface becomes too dry, and thus holding back the water in the soil, a very convenient method in land which has been over-drained. This system is in use to a considerable extent in Switzerland, and has been common in Persia for a great length of time. A system of irrigation known in England as "warping" is common in many countries; under this the land is flooded with water, having a large amount of mineral substances in suspension, the water being retained upon the land until the fertilizing matter has been deposited.

In British Columbia it has not been found practicable in many instances, owing mainly to the high price of labour, to properly prepare the surface for the reception of the water, and it is obvious that were such preparations made, a smaller quantity of water than is now in such cases used would be required, as we more nearly approached to its most economical distribution. In this province neither the bed-work nor catchwater systems have been adopted in their integrity. The more general method in use appears to be derived from the former. The ground is frequently formed in narrow ridges, and the water is carried in the hollows between them, instead of as in the bedwork system proper on top of them, and finds its way to the higher portions of the ridge by capillary attraction, so that in effect the lower part of the ridge is watered by surface and the upper part by sub-irrigation; a curious example of a combination of different principles. The method, however, appears a successful one. Grass crops are generally flooded to a depth of a few inches at each period of irrigation; the depth varies, and depends mainly on the amount at the disposal of the agriculturist.

In California, where irrigation, under somewhat similar conditions of climate and soil as those which obtain in this province, has proved most successful, it is customary among the ditch companies to charge the farmer for one cubic foot of water a second,—34 inches,—for each one hundred and sixty acres under cultivation, equivalent to 540 cubic feet per acre a day, or a monthly rainfall of $4\frac{1}{2}$ inches, of which it is estimated that not more than about $\frac{1}{3}$ is actually absorbed.

The managing director of a company, engaged in extensive irrigating operations, stated in answer to enquiry: "In the San Joaquin Valley in the beginning of the farming season, a furrow is turned up all round the track, thus forming a check, and the water is turned on until the land is so thoroughly saturated that it will absorb no more. This, with the few inches of rain that fall in the spring, is often enough to mature a crop of wheat, barley, etc. If not, then as the heads begin to fill out, that is six weeks or two months before maturity, the necessary amount of irrigation has to be applied."

It is obvious that such a method as this is only applicable to very level land. It is also to be remarked that there is no special irrigation season for grass in that state, the climate permitting this crop to be irrigated all the year round or nearly so.

Mr. Amos Bowman remarks as follows:

The quantity of water required to irrigate an acre varies considerably, depending chiefly upon the crop. Vines require very little; none after they are rooted. Other fruit requires irrigation. An inch of water running night and day will irrigate from one to ten acres for some products. For grass and clover, 10 inches, running three days in the week (of 24 hours each), would irrigate ten acres. Perhaps a constant flow of five inches to every ten acres would be near the mark, in other products one half an inch to the acre.

The few results obtained by the writer, as examples of the quantity of water required to irrigate an acre, may be stated as follows:

For hay, one inch to half an inch per acre, running night and day.

For berries and newly planted vines, one half to one quarter inch per acre, running night and day.

For trees, one quarter to one tenth of an inch per acre, running night and day.

About eleven years ago a Mr. Pike sank an artesian well in the San Joaquin Valley, 268 feet deep, which it is stated cost between $400 and $500. The flow from this well was estimated at about 18,000 cubic feet a day, between 7 and 8 inches, and it was claimed to have successfully irrigated about 10 acres of barley, 5 acres of wheat, 5 acres of English peas, 2 acres of Chinese sugar cane, 4 acres of oat hay, $1\frac{1}{2}$ acres of corn, besides a small orchard and vegetable garden, in all say from 28 to 30 acres; or approximately that one inch irrigated four acres of land. In California the extensive tracts of land which can be cultivated with the aid of irrigation encourage the formation by joint stock companies of irrigation ditches on too large a scale, and generally of too costly a character, to be undertaken by individuals.

Among them may be mentioned:

The Rodes Ditch............	length	about	10	miles,	cost	about	$10,000
Lower King's River Ditch.	"	"	13	"	"	"	28,000
Last Chance Ditch..........	"	"	20	"	"	"	60,000
Mussel Slough Ditch........	"	"	60	"	"	"	60,000
The People's Ditch..........	"	"	45	"	"	"	100,000
The Settlers Ditch....	"	"	20	"	"	"	30,000
The Lake Side Ditch.......	"	"	30	"	"	"	50,000

The foregoing are some only of the larger ditches. Since the date at which these notes were taken several very costly ones have been constructed, of which the author cannot give any details. During the past ten or twelve years considerable additions to the water supply for agriculture in California have been obtained from artesian wells.

IRRIGATING DISTRICT OF BRITISH COLUMBIA.

The district in this province in which irrigation is required may be roughly described as the elevated plateau lying between the Cascades and the Rocky Mountains. It is broken by smaller mountain ranges and spurs from the main chains; its elevation varying from about 800 to 3000 feet above the sea. The soil of the benches and terraces and irregular slopes of some of the valleys, which were once probably the bed of a large lake, is extremely fertile when cultivated, and has been described as composed of modified or redistributed drift, modern alluvium, etc., and is chiefly the product of the disintegration and rearrangement of the boulder clay, though mixed also with the detritus from local rocks since the glacial period, which has been carried down by rivers, when flowing at a higher level as they seem here to have flowed in the past. (See Report Geol. Sur. of Canada.)

It appears that, at a greater elevation than about 2000 feet, summer frosts prevent successful cultivation as a general rule; though in some instances, owing to favourable local conditions, cultivation has proved remunerative of greater elevations. A curious instance of the uncertainty of obtaining a crop occurs at Douglas Lake, Nicola Valley; the Lake is 4 or 5 miles long at an elevation rather over 2000 feet, the soil at its head and foot appears identical, and the conditions seem precisely similar, yet both Whites and Indians agree that the crops at the head of the Lake are very uncertain, while at the foot they rarely fail.

IRRIGATION ESSENTIAL.

It must be understood that in the section of country referred to, with a few notable exceptions, such as the Spellamcheen Valley, cultivation cannot be successfully carried on without irrigation. This is usually applied three or four times in the season, commencing in April, at intervals of from twenty to thirty days.

SOURCES OF SUPPLY.

The main stream of the Fraser and Thompson Rivers lie too far below the fertile benches in their valleys to render their boundless resources available except by pumping; this is unfortunate, for their waters contain an enormous amount of fertilizing matter in suspension. The principal supplies are derived from the smaller mountain streams, which generally attain their greatest volume in May, the month in the commencement of which the largest quantity is required; during the two succeeding months they fall very rapidly, and in dry summers there may be a scarcity towards the latter end of the irrigation season.

When it is practicable, to select from different sources of supply, which is rarely the case in British Columbia, the broad rule would appear, to be that the water which has been longest exposed to the air is the best for the purpose, and it is on this ground that it is advisable to construct the main conductors wide and shallow; and though this form leads to a greater loss by evaporation, it also diminishes to an appreciable extent the lateral pressure on the banks. Water from lakes and large streams is generally of such a temperature as to be permitted to run without cessation; but when obtained from cold springs and short snow-fed streams, it is sometimes necessary to shut it off during the night. Authorities on this subject appear to consider that the best water for irrigation is obtained from artesian wells of considerable depth, on account of its temperature, and also on account of the mineral elements usually contained in it.

The artesian wells of Dakota are, perhaps, the most remarkable examples of their kind which have ever been opened, both as regards the pressure and the volume of the escaping water. More than one hundred wells, from 500 feet to 1,600 feet deep, are at present in successful operation in the district north of Yankton, and they yield a constant stream of water which is apparently never affected by any of the surrounding influences. The pressure of the water is abnormally high in many instances, and up to 180 lbs. per square inch has been registered by the gauges. (Industries.) Artesian wells have not yet been sunk in this province; the Provincial Government, however, last year commenced an experimental bore in the valley of the South Thompson River.

Mr. Bailey-Denton says:

In the "conclusions" arrived at by the "Rivers Pollution Commissioners," the average composition of "unpolluted waters" is given in the following form:

Results of analysis expressed in parts per 100,000.

Description.	Dissolved Matters.								Hardness.			No. of samples taken.
	Total solid impurities.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as nitrites or nitrates.	Total combined nitrogen.	Previous sewage or animal contamination.	Chloride.	Temporary.	Permanent.	Total.	
Rain water	2.95	.070	.015	.029	.003	.042	42	.22	.4	.5	.3	39
Upland surface water.	9.67	.322	.032	.002	.009	.042	10	1.13	1.5	4.3	5.4	195
Deep well w't'r	43.78	.061	.018	.012	.495	.522	4,743	5.11	15.8	9.2	25.0	157
Spring water...	28.20	.056	.013	.001	.383	.396	3,559	2.49	11.0	7.5	18.5	198
Average	....	.127	.019	.011	.222	.250	....	2.24	......	......	......	....

Without venturing to express an opinion upon the precise meaning of "previous sewage or animal contamination," the heading of one of the columns, these figures shew an exceptionally large amount of fertilizing matters in the waters from deep wells.

Temporary hardness is hardness due to calcic or magnesic carbonates, and can be got rid of by boiling the water. Permanent hardness is hardness due to calcic or magnesic sulphates, and cannot be got rid of by boiling. One grain of bicarbonate or sulphate of lime in a gallon of water is expressed as one degree of hardness per gallon.

It must not be inferred from previous remarks, that the table land of which we are speaking is badly watered for purposes other than those of irrigation. On the contrary, the whole surface of the country is dotted with lakes and traversed by streams, varying in size from the Fraser River to the tiniest rivulet, though frequently, from their positions and the large outlay required before they can be utilized, they are practically excluded from being classed among the available sources of supply.

RAINFALL.

The following table shews the rainfall in the irrigating and non-irrigating districts of British Columbia, during the irrigation season of 1877.

IRRIGATING DISTRICT.

Place.	April.	May.	June.	July.	Total.
Spence's Bridge	0.38	1.41	0.75	1.25	3.79
Cache Creek	1.03	1.10	1.35	1.22	4.70
Kamloops	0.78	1.42	1.67	0.59	4.46
Okanagan	0.22	1.75	2.15	1.42	5.54

NON-IRRIGATING DISTRICT.

Place.	April.	May.	June.	July.	Total.
Spellamcheen	1.38	1.84	1.65	1.82	6.69
Hope	1.71	1.84	2.20	1.38	7.13
New Westminster	1.55	1.62	2.65	1.03	6.85

The above table shews an average in the irrigating district of 137, and in the non-irrigating district of 205 cubic feet per acre a day, or half as much again in the latter case as in the former.

The years 1877 and 1878 were, however, dry seasons in the non-irrigating, though fully up to the average rainfall in the irrigating district. The mean rainfall in New Westminster for 14 years was for the above months, 3, 18, 2.41, 2.42, and 1.67 respectively, equivalent to 288 cubic feet per acre a day. The rainfall in May, 1878, at Kamloops was 1.85 inches, equivalent to 216 cubic feet per acre a day, and it appeared to be the general opinion that with a similar rainfall during the season irrigation might, at all events to a very great extent, be dispensed with.

It must be remembered, however, that as art cannot compete with nature in the equable distribution of water, a larger quantity is required for artificial irrigation than would constitute an abundant rainfall. And it may further be observed that the rainfall which would constitute an ample supply for the generally retentive soils of the lower, would possibly prove inadequate for some of the soils of the upper country.

Further, in the irrigating district, a heavy precipitation is often the esult of sudden and violent storms, the effect of which is sometimes more injurious than beneficial. An instance of this occurred on the 20th July, 1878, when a sudden storm burst on the Bonaparte Valley, with the result that several acres of cultivated land were covered with wash gravel, the crops destroyed, and that portion of the farm rendered worthless. It is obvious that such a storm would largely increase the registered rainfall, though its effects were simply disastrous. In the farming lands of the non-irrigating district, storms of this description are almost unknown, the rain falling more frequently and less violently, and with a corresponding increase of beneficial effect.

LOSSES OF WATER.

There are three principal heads under which the losses of water after leaving the reservoir or stream may be classified, namely :—

Loss by evaporation,

Loss by leakage in transit, and

Loss in distribution.

As regards the first there are no data derived from experiments in this province from which to deduce any conclusions. In California loss by evaporation does not appear to be taken into consideration.

On this point the following are the opinions of some eminent English engineers :—

Mr. Bateman places the loss by evaporation at from 9 to 16 inches, with an average of 12 inches.

Mr. Hemans allows from 12 to 14 inches.

Mr. Duncan estimates 11 or 12 inches as the constant loss at Liverpool, and found the loss varied little, even with considerable difference of rainfall.

Mr. Hawksley says: "Evaporation is more nearly 15 inches than any other quantity."

Careful experiments, extending over a period of 25 years, made in Hertfordshire, England, shewed that with a mean annual rainfall of 26.609 inches, the mean percolation was 8.227 inches, and the mean loss by evaporation 18.382 inches.

Mr. Dempsey quotes the following results of experiments made in Yorkshire during five consecutive years: mean annual rainfall 24.6, mean annual percolation 4.82, which gives double the loss by evaporation recorded in Hertfordshire.

Dr. Dalton gives the following results: mean annual rainfall 33.56 inches, mean evaporation 25.158, and mean percolation 8.402.

By another set of observations, quoted by Dempsey and also by

Haskoll we have: mean annual rainfall 26.614, mean percolation 11.294, mean evaporation 15.32 inches.

To tabulate them we have

	Rainfall.	Evaporation.	Percolation.
1st	26.609	18.382	8.227
2nd	24.6	19.78	4.82
3rd	33.56	25.158	8.402
4th	26.614	15.32	11.294

The mean of these various independent observations would give rainfall 27.846 inches, evaporation 19.66, percolation 8.186, or in round numbers the loss by evaporation would be about seven-tenths, leaving about three-tenths of the whole rainfall for percolation.

These results, however, are for the entire year; during the summer months the evaporation is probably much greater.

The amount lost in transit by leakage and evaporation has, in some cases, been estimated at 50 per cent. of the amount entering at the head of the ditch. It is obvious that the quantity lost through these causes depends upon the construction, the length and exposure of the ditch. The loss by filtration may often be reduced by the construction of timber flumes when the soil is porous, and by throwing into the ditch at intervals small quantities of soil, which being first carried along in suspension, and then gradually deposited, assist the consolidation of the bottom and banks.

The main conductors are often necessarily carried along steep side hills, and around bluffs and across ravines in timber flumes. These ditches and flumes have generally been set out and constructed by their owners, and as a rule most successfully, though in some instances too great a gradient having been adopted, overfalls have been found necessary at intervals to reduce the velocity which threatened serious damage. In one or two instances when the water refused to disobey the laws of gravity and flow up hill, heavy losses have been the result to the unfortunate projectors.

The loss in distribution may be reduced to a minimum by the proper preparation of the surface for the reception, and by making adequate provision for the distribution of the water. No hard and fast rules can be laid down by which to estimate these losses, each case must be treated on its individual merits.

QUANTITY OF WATER.

It has been customary in this province to record and claim one inch of water per acre, or 2536 cubic feet per acre a day. As to the amount necessary, one cubic foot a second, or 34 inches, will cover four acres to a depth of over six inches in a day, which certainly appears to be a not unreasonably low estimate of the quantity required at each period of irrigation.

On this assumption, and that the land requires irrigating once in 25 days, 34 inches will irrigate one hundred acres of land, and 34 inches on 100 acres is equivalent to 864 cubic feet per acre a day. Judging from the quantities given by Mr. Burnell as required in Europe this amount should prove ample.

It is generally considered by engineers that from one-half to two-thirds of the whole quantity delivered is lost or wasted. Now the amount delivered at each period of irrigation on one four acre tract is 86,400 cubic feet, or 21,600 cubic feet per acre a day; deducting three-fourths of that amount for all losses, we have 5,400 cubic feet per acre at each period of irrigation, or a daily average throughout the irrigation season of 216 cubic feet per acre per day actually utilized, equivalent in round numbers to a monthly absorption of 1.8 inches of rain. As, however, it is doubtful if more than one-third of any rainfall is actually absorbed, this amount may fairly be taken as equivalent to from 5 to 6 inches of rainfall. With such a rainfall it is certain that irrigation would be unnecessary. If the superfluous water be utilized on lower lying lands, the result will be found to be an approximation to the Californian standard of one cubic foot a second for each one hundred and sixty acres under cultivation.

In the author's opinion 34 inches delivered upon the land will be found ample to irrigate from 100 to 150 acres of cereals or roots according to position and soil.

It is generally considered that grass requires a larger supply of water than grain, and in estimating that quantity we are again confronted by a total want of data in this province; but since it is known that rice needs 1440 cubic feet per acre a day, it would appear reasonable to assume an approximate mean, say 45 inches delivered on the ground, for each hundred acres of grass under cultivation.

In assuming these quantities it is thought that an ample margin has been left for all losses in distribution, and the author, though anxious not to under-estimate the quantity required, feels considerable doubt as to whether, with proper construction and handling, two-thirds of the amount would not prove sufficient.

To give an example of the enormous quantities supposed by some to be required: on a certain farm it was found that the main conductor close to the land to be irrigated had a velocity of 2.35 feet a second, with an area of 1.25 square feet, equal to a daily discharge of 253,800 cubic feet or 100 inches. It was stated that the season lasted ninety days, that the irrigated area comprised about 50 acres of grass and 30 acres of grain, that during sixty days the grass received the water and during thirty days the grain. We have then the astounding result, that throughout the season the grass received an average of 3,384, and the grain 2,820 cubic feet per acre a day, equivalent to over 26 inches of rainfall a month, or enough in ninety days to convert the whole area into a lake over 6½ feet deep. Probably not more than one-tenth was of actual service, and when compared with other results, it will appear that in this case at least the supply exceeded the legitimate demand.

DRAINAGE.

In this province but little has been done, and in most cases, from the natural contour of the land and the character of the sub-soil, but little requires to be done for the purpose of removing the surplus irrigation water. When, however, it does not naturally and rapidly flow off, its drainage is as essential as its original introduction.

FALL OF MAIN CONDUCTORS.

It is apparent that the main conductors are frequently constructed with too heavy grades, and it is suggested that the velocity should not be greater than from 1 to 2 feet a second through earth, and 3 to 4 or 5 feet in timber flumes.

With regard to flow in open channels, Colonel Waring calls attention to a result he has observed in the flow of sewers in the following words :

"One principle is very apt to be disregarded in regulating the size of sewers ; that is, that after water has once fairly entered a smooth conduit, having a fall or inclination towards its outlet, the rapidity of the flow is constantly accelerated up to a certain point, and the faster the stream runs the smaller it becomes ; consequently, although the sewer may be quite full at its upper end, the increasing velocity soon reduces the size of the stream, and gives room for more water. It is found possible, in practice, to make constant additions to the volume of water flowing through a sewer by means of inlets entering at short intervals, and the aggregate area of the inlets is thus increased to very many times the area of the sewer itself."

The author has on two or three occasions observed results confirmatory to a certain extent of this statement, and would be glad to learn whether the point has attracted the attention of others, and how far it is available in practice. Except by Colonel Waring, he has never seen the matter referred to in any works of reference to which he has access, and though probably of not much practical importance in the construction of such channels as drainage and irrigation ditches, he would submit that it may prove a serious point for consideration in designing such costly subterranean works as sewers.

From the drawings accompanying this paper Plate VII has been prepared.

CORRESPONDENCE.

Mr. M. J. Butler said that he believed the subject of irrigation to be one of the most important in this country, applicable not only to the regions of slight rainfall, but largely to the whole of Ontario and parts of Quebec. With irrigation and proper drainage, for the two should go together, a certain crop is insured year after year. Mr. Butler.

In Italy, where the rainfall is quite equal to our own, viz., about 39 inches, enormous sums of money have been spent in irrigation works.

"In France, Italy and most of India the rainfall is ample for ordinary crops, irrigation is adopted to prevent the failure of crops by droughts. These reasons apply equally as well to all other countries; the general impression that irrigation is only necessary and useful in dry countries is entirely incorrect." See valuable paper in Vol. XVI Transactions Am. Soc. C. E., by E. B. Dorsey.

It is to be regretted that the so-called Miners' inch as a measure of volume has been permitted in British Columbia. This measure has been aptly defined as a "nondescript inch which can scarcely be credited with a remote approximation to correct measurement," and it seems to vary in volume with the state or place where it is used. In Idaho it is "partly by custom, partly by statute, the quantity of water which will flow through an inch square orifice in an inch board, with a head or pressure of four inches above the centre of the orifice, but is in reality the quantity of water which will flow through an inch square orifice in an inch board, with a head or pressure depending upon the care used in adjusting the gate which admits the water to the orifice." In Colorado on one occasion he saw a description which read "The lessee is entitled to six inches of water," and he endeavored to find out how many cubic feet it was intended to cover, but could not do so until he hunted up the engineer who had prepared the lease.

The description of what constitutes an inch in British Columbia, or a multiple of one, does not specify the thickness of the plate, nor how made. When it is considered that the co-efficient for construction depends upon the kind and size of the orifice, it will be seen that a not very accurate measurement will be the result. An admirable, cheap and simple device has been designed by Mr. A. D. Foote,

M. Am. Soc. C. E., and is described in Vol. XVI, Paper No. 355, Transactions Am. Soc. C. E.

The subject of loss of water in conduits by evaporation is an important one, on which but little data are available in this country, and the writer knows of no authority so good as that of Mr. Desmond Fitzgerald, who has carried out an extensive series of experiments at Boston, and which are described in Transactions Am. Soc. C. E., Vol. XI.

Thursday, 24th April.

E. P. HANNAFORD, Vice-President, in the Chair.

Paper No. 42.

THE SAULT STE. MARIE BRIDGE.

By G. H. Massy, M. Can. Soc. C.E.

The completion of "The Sault Ste. Marie Bridge" adds one more to the number of great International bridges joining Canada with the United States, and forms the connecting link between the Canadian Pacific Railway and the network of roads traversing the Western States.

In the autumn of 1885 it was decided, by the Sault Ste. Marie Bridge Co., to build a bridge across the Ste. Marie River at "The Soo," and a party was organized to make the preliminary surveys, from the results of which it was decided to construct the bridge at the upper end of the Ste. Marie's Rapids, where the smooth water of the Lake commences to break away over the rocky bed of the river. The bottom is formed of smooth, level sandstone of the Potsdam formation, perfectly bare of gravel or *debris*, with the exception of Pier No. 1, where a considerable deposit was formed. In the winter of 1886-7 the contract for the construction was awarded to R. G. Reid, who the year before completed the St. Lawrence Bridge. Early in May the contractor and the engineering party arrived at "The Soo," and the work of triangulation commenced, and here it may not be out of place to go a little into the general detail of accurately determining the position of the piers.

The first operation was the measurement of a base line and the calculations of angles. The most scientific and practical method of setting out piers is by means of angles from a measured base, direct measurement by a long wire has been advocated by some engineers, but the experience of the author on this method has not been satisfactory. It may appear a very simple matter to measure 700 or 800 feet on a wire, and then transfer this distance between two points supported only at the ends, but the result of such is often unreliable, as was experienced by the engineers at the Forth Bridge. For distances of 400 or 500 feet, with great care, accurate results can be obtained, as the sequel will show.

In setting out by angles, the instruments used will first be discussed; these are three in number,—a transit, steel tape and picket. The transit should not be less than 8" diameter, reading to 10 seconds. The one used at the St. Lawrence Bridge and "The Soo" was of this description, made by Hammersly of London, being furnished with a very powerful glass and long sensitive level underneath the telescope. There was no vertical arc, but simply the ordinary clamp screw; on this instrument five seconds could be estimated. For distances over 3,000 feet the author would recommend a 12 inch instrument, such as that used at the Forth Bridge, or better a 16 inch reading to five seconds. The author also thinks it would be an advantage to have the upper plate moved by a wheel attached to it, working into teeth set near the outer rim of the lower plate, thus ensuring a relative motion between the plates, and avoiding the danger of moving the lower plate when the upper plate is moved round, as this is one of the most serious causes of error in taking angles. The glass should be such as to show an ordinary picket clearly at a distance of one mile, so that the hairs can be set on an object to one inch at that distance. Accuracy of graduation is also one of the essentials. The transit above mentioned weighed about 40 lbs., and when not used on a fixed pedestal, was attached to a heavy wrought iron tripod weighing 80 lbs.

The next instrument is the steel tape. At the suggestion of the author the company ordered from Chesterman, England, a tape of heavy steel 500 feet long, and the result shows the accuracy of the work done with it.

Thirdly, we come to the picket, or centre used. These were designed by the author for the "Soo Bridge." They were made of 2 inch gas pipe, about seven feet long; the lower end being screwed into a socket formed like a fork, the two prongs of which rested on the hub, the centre of the pipe being placed accurately over the nail by means of a plumb bob and line, the line being fastened to the centre of the upper end and the plumb bob swinging in the fork below, thus ensuring the centre to be both exactly vertical and on the nail. The picket was then secured by four wires fastened to the upper end and to stakes driven into the ground; these wires could be adjusted for length by swivel screws, such as are used to tighten the ordinary buck-saw frame. The pickets were painted white, and a black board placed at a little distance behind to make them more distinct.

Now, in selecting a base, it is preferable to have one on either side of the river; one half of the piers being laid out from one and their positions checked from the other; a most satisfactory check on the work being to calculate one base from the other.

Of course the more level the ground is the better, and if at all possible each end of the base should be visible from the other, but it often happens that level ground cannot be had. The base for the St. Lawrence Bridge was measured with an ordinary 100 foot steel tape, laid on strips of board supported by hubs driven in about ten feet apart, and the ends cut off to a level. Where the ground fell away a lower set of levels were taken, and the distance plumbed down at each break. This was done with great accuracy, considerable time being spent at it. By careful measurement the error should not exceed $\frac{1}{1,000,000}$. This base was measured before the author took charge of the St. Lawrence Bridge. The plan adopted at "The Soo" was to drive in stakes 1″ × 2″ ten feet apart, exactly in a straight line along the base from a point 25 feet above the centre line of the bridge to the point at which the transit was to be placed. A line was taken along the stakes, regardless of levels, from one point to the other, and large nails driven into the stakes to support the tape. At every 500 feet a firm staging was built, on which the exact 500 feet was marked, and the tape moved on to its next position, and so on till the base was measured. This was repeated three or four times, the tape being always stretched by a spring balance under a tension of 50 lbs. The 500 foot tape while under this tension was checked with a 100 foot standard tape, the latter having been previously compared with the standards used by the company who were to build the superstructure of the bridge. The temperature was also carefully noted, and the length of the base reduced to a normal temperature of 60° Fahr. and also corrected for slope. At the St. Lawrence Bridge a good base was obtained on both sides of the river, and the accuracy of the triangulation and measurements checked by calculating one base from the other, but at "The Soo" the two bases had to be measured on the south side. When the base was fixed, a solid oak post was placed at one end and a hub let into the rock at the other. The large transit was set on this post, and all the angles to the several piers laid off from it. An ordinary transit was set over the other, this point being, as was stated, 25 feet above the centre line of the bridge, and a corresponding centre set up on the opposite side of the river, also 25 ft. above the centre line of the bridge on which the cross hairs of the transit were set. All the piers were laid off from this upper line. The object of keeping this line 25 ft. above the bridge was to clear all derricks, scows, etc., at the same time admitting of a point being fixed on the upper end of the caissons.

The distance across the river at "The Soo" was about 3,000 feet. This being calculated from two entirely independent sets of data, the results checked *to the tenth of an inch*, the whole of the work, including measurement of basis, taking of angles and calculations, did not occupy one week. This calculated distance agreed with the taped distance, after the construction of the bridge, to 1½ inches. The author may add that the calculated distance and the measured distance on the St. Lawrence Bridge agreed to 2½″ on a distance of 3,700 feet. The base used for setting out the piers at "The Soo" was about 1,900 feet long. A small shanty was built at either end to protect the instruments, and on the roof of these, exactly over the centres, two pickets were set, of the kind previously described. These were checked from time to time by means of the plumb bob. The instrumental work required much care and patience. All the angles had to be repeated several times to eliminate all eccentricity in the centering of the transit. It was found that the lower plate of the transit was liable to slip while moving the upper plate; thus after taking the three angles of a triangle, the sum was usually less than 180° by some seconds. To avoid this error the following method was adopted: Zero of the transit was first set on the far end of the base, and the upper plate moved till the hairs intersected the picket on the far side of the river. The angle was then noted, and the upper plate moved round in the same direction till the hairs intersected the first picket. Now, if the vernier did not read zero, it was evident the lower plate had shifted, and the operation had to be repeated. When this angle was satisfactorily recorded, the vernier was set at 10°, the hairs set on the first picket and the upper plate moved round to the second picket, the angle read, then moved round to 10° and checked to see if the hairs were on the first picket, and so on, increasing by 10° each time, when the average was taken. By this means great accuracy was attained, any small discrepancy of a second or two being distributed between the three angles in proportion to their size. In setting out the piers the same precautions were taken. In reading the verniers, a sheet of white paper was placed close to the plate, and the reading taken through a small hole cut in the paper. This paper threw a shade on the vernier, and the graduations could be seen with great distinctness. Close beside each of the shanties, a signal was erected, which could be worked by the man at the transit, without taking his eye from the instruments. As the caisson approached its proper position, a man on board held up a picket, which was immediately signalled into its exact position by the transitman, and by this means the men who guided the caisson were enabled to see which way it had to go without any confusion or mistake. When the caisson was placed by the transits, its position was verified with a steel wire of given length, usually the length of a span. This wire was about $\frac{1}{8}''$ diameter, the exact length marked on it by a loop soldered on at each end; one loop of the wire was brought exactly over the starting point by means of a long adjustable screw arrangement, the other was carried in the boat to the caisson and strained to 200 lbs. and the exact distance marked. Very correct measurement can be made in this way, but it is necessary constantly to check the wire under strain with the standard tape, and also when not in use to roll it on a reel made specially so as to prevent the wire getting bent. At the St. Lawrence Bridge, the 408 ft. cantilever spans were measured in this way, and when the iron work was connected, the measurements agreed exactly on one of the 408 feet spans, and on the other there was a discrepancy of only $\frac{1}{4}$ inch.

In setting out piers from a base line, the question will arise as to the length of base which will give the most accurate results, assuming that the transit reading may be liable to an error of (*a* seconds) when (*a*) may be 1 to 5. It may be shewn mathematically that this length should be equal to the length from the base to the pier measured along the base, or that the angle below the base line and a line from the transit to the pier should equal that between this line and the bridge line. This would shew that theoretically the best results are obtained by having a separate point on the base for setting off each pier. The author believes that this was carried out at the International Bridge at Buffalo.

The next operation was to level across the river. This was done by placing three of the best levels on each side of the river, and reading on a large rod graduated to $\frac{1}{10}$ of a foot held up on the opposite shore; when the three readings were taken the rods were held up at as nearly as possible equal distances, but on the same shore. Thus the errors of curvature and refraction were neutralized by these equal sights. The error in levelling by this method should not exceed $\frac{5}{100}$ in 3,000 feet, when the levels were transferred across two stands for the large transit wire set up just above the bridge line, one on either side of the river, and opposite each a target placed, whose centre was exactly on the same level as the cross hairs of the transit when set on the opposite stand. Thus by setting up the instrument and directing its cross hairs on this target, a correct level was ensured The only source of error was in certain states of the weather, the refraction being so great as to cause an error of $\frac{1}{10}$ of a foot in the line of levels; but slight errors in levels, except in the case of continuous girders, are of little consequence, much less than errors of distance, as the appearance of a bridge not sitting fair on the centre of the piers has a very bad effect. During the time occupied in triangulation, the contractor was employed building a temporary wharf for landing stone and other material and excavating foundations for abutments. Most of the plant used in the construction of the St. Lawrence Bridge was shipped to " The Soo," and comprised two tugs, 22 scows, three of which were furnished with steam derricks, two pumps, six large anchors, two clam shell dredges, and other but less important implements used on such work. The depth of the water on the site of the bridge varied from 2 to 12 feet.

Although the extreme rise of the river, except after a westerly gale, does not exceed $2\frac{1}{2}$ feet, it is at any time liable to $1\frac{1}{2}$ feet rise in less than an hour, due to some wave motion of the Great Lakes. The swiftest current is where the water is deepest towards the Canadian side, and attains a velocity of 9 miles per hour. The shallowness of the water rendering it impossible to bring the tugs within less than 300 feet of the piers, the scows and caissons had to be lowered down by ropes.

The plan of foundation is similar to the St. Lawrence Bridge, namely, caissons with water-tight sides of 12″ × 12″ timber, without any bottom, the sides scribed to fit the rock. The caissons were so designed as to allow a space of 4′ 6″ between the timber and the sides of the piers. A curtain of canvas was nailed round the inside of the caisson to check any current while depositing the concrete.

The concrete was formed of sand and Portland cement in equal quantity, to which was added as much broken stone as the mortar thus made would take. This concrete was deposited by the same boxes as were used at the St. Lawrence Bridge, and described in a paper by the author.* The depth of the concrete was never less than half the depth of the water with a minimum depth of two feet. The second day after the concrete was deposited the caisson was pumped dry, the bottom levelled, and masonry commenced. In building with timber caissons and concrete bottoms, the depth of the latter should not be less than $\frac{1}{3}$ the depth of the water with a minimum depth of two feet. Less concrete than this is apt to cause troublesome leaks, and the concrete box should hold two cubic yards. The masonry of the small bridge on the Canadian side was commenced June 9th; and the north abutment of the main bridge on June 2nd, but no masonry was laid in the river piers until August 9th; as much time was lost in negotiating with the United States Government as to duty on plant and material, etc. The last of the masonry of the Main Bridge was laid October 7th.

The work proceeded rapidly and smoothly without serious mishaps or accidents of any kind, the experience gained on the St. Lawrence Bridge

---

* Transactions Can. Soc. C. E. Vol. I., Part I., page 39.

by the men employed proving of great service. No. 1 Pier was the most tedious, as a large quantity of gravel had to be dredged off by means of a large rake attached to a long handle, operated from scows anchored over the foundation, any remaining gravel being cleared off after the caisson had been placed. The most troublesome and costly foundation was the centre pier of the Swing Bridge. This had to be carried down 22 feet below water level through seamy rock, in anticipation of the enlargement of the canal at some future date. The pier was circular, with a diameter of 30 feet, the excavation being several feet wider; leaving only about 20 feet of rock between the pier and the canal, through which the water poured like a river, requiring the constant use of two large rotary wrecking pumps until the masonry reached the water level. The stone used in the swing bridge and the bridge at Canal Street was Ohio sandstone, the remainder being white limestone from the Owen Sound Quarries. The general plan of piers and abutments are similar to those of the St. Lawrence Bridge, the piers of the Main Bridge all being 10 feet wide on top.

The following is a brief outline of the bridge: Commencing on the Canadian side, the approach to the bridge is a timber trestle 1500 feet in length, with two spans of iron crossing a small branch of the river, then 1900 feet more of trestle to the main bridge consisting of 10 spans of 242 feet each, pin connection through girders: then 350 feet of bank which reaches the north abutment of the swing bridge over the Ste. Marie canal. The swing has a total length of 396 feet, crossing the canal at an angle of about 60°, then another bank of 200 feet, and a plate girder over Canal Street reaches the southerly limit of the Bridge Co.'s property.

DISCUSSION.

Mr. Blackwell. Mr. K. W. Blackwell asked if the author had noticed any change in levels in Lake Superior to correspond with tidal movements. He had seen it stated that there was a slight movement twice in the 24 hours in the waters of the Great Lakes, occasioned by the same physical influences which caused tides.

Mr. Hannaford. Mr. E. P. Hannaford said the author had gone to a great deal of trouble to give the profession every information interesting and valuable in regard to laying out piers, leaving little for discussion.

Mr. Irwin. Mr. H. Irwin said the author had mentioned the advisability of constructing the transit with gearing attachments connecting the upper and lower plates, so as to avoid the movement of the lower plate when moving the upper, and wished to know if the author knew of the "reiterating transit," that is, a transit with only one spindle, the lower plate being a fixture. It was not quite so handy since the vernier could not be set to zero before pointing the telescope at the back sight, but it practically did away with the slipping. These transits are used by Dominion land surveyors in running the outlines of townships. He did not think a rack and pinion connection would work satisfactorily. He knew of a very expensive instrument with the rack and pinion movement, but it did not prevent slipping. In the North-West, reiterating transits were much used on account of their accuracy.

With regard to levelling across the river, he suggested setting up the instrument first on one side of the river, and reading a bench mark close by and also reading a bench mark on the other side of the river, and then going to the other side of the river and reading the same bench marks similarly. In this way there was a good check upon the curvature and refraction. He had tried this method across the Richelieu River, P. Q., but the distance there was not greater than 900 ft.

Mr. Goad. Mr. C. E. Goad said the author had apparently experienced the same difficulty as he had on a bridge upon the Montreal & Ottawa Railway, where the river was about 700 feet across. A steel wire could not be depended upon for accuracy; and triangulation was resorted to.

Mr. H. Irwin remembered reading, that in building the Forth Bridge a steel wire was found to be satisfactory as a check measurement. It was strained by known weights, and the difference from the calculated length was small in the distance of about 1700 feet. Mr. Irwin.

Mr. E. P. Hannaford said that reference had been made by the author to the International Bridge at Buffalo. This bridge was built by the present president of the Society, the speaker being the engineer, and Mr. Joseph Hobson, M. Can. Soc. C. E., the resident engineer. On the Canadian side a base line was laid out at an angle of about 90 degrees with the line of the bridge, and its length checked by rods and a steel tape, then another or check base was established on the American side. The position of the piers was given by a fixed transit in the line of the bridge and another transit at the end of the base line. The Niagara River at the site of the bridge is very deep with a strong current and bad anchorage. Mr. Hannaford.

The working out of the position of the piers and placing them by triangulation was eminently successful. There was no error due to calculation, and what little there was in exactly centering the inner and outer caissons of each pier was owing to the trouble in getting the caissons in their right position, because although a liberal allowance was made for lee-way, the depth of water—45 feet—and the rapid current caused the caissons to sway, or surge, although every precaution by means of side and bottom anchorage was resorted to. (See book on International Bridge, 1873, by C. S. Gzowski.)

He could not conceive how anyone could rely on wire for distances; it seemed to him a most erratic and unreliable method. He had never seen concrete boxes used as large as those mentioned by the author, containing two cubic yards.

Mr. C. E. Goad said such boxes would be heavy, but he certainly thought they are a step in the right direction. Mr. Goad.

Mr. P. W. St. George understood these boxes were lowered into the water, so as to get as near the river bed as possible before depositing the concrete. Mr. St. George.

Mr. Massy. Mr. G. H. Massy explained that the concrete boxes were constructed with the bottoms above the lower edges and opening at the centre, so that when the box rested on the foundation, the bottom could be opened from above, allowing the concrete to slip out gradually.

He considered the larger the concrete box the better; but of course this necessitated strong derricks and large scows. The contractor had found it difficult to handle boxes containing two cubic yards, but it was undoubtedly better to deposit concrete in large quantities.

Mr. St. George. Mr. P. W. St. George asked if, after depositing concrete from the boxes, the author had an opportunity of seeing how the concrete was left on the bottom, and whether the cement and sand had separated from the stone?

Mr. Massy. Mr. Massy replied that when the caissons were pumped out, there was every opportunity of observing how the concrete lay on the bottom, and there was generally about three inches of loose stone which could be shovelled off before reaching the solid concrete. It was more than probable that the next box of concrete would mix with and consolidate this loose stone. As to the state of the concrete along the sides of the caisson, he had watched the construction of a concrete abutment built on dry land, and when the planks were removed the concrete presented a solid face on which the mark of the grain of the timber could be seen.

Mr. St. George. Mr. St. George remarked that the sides would not have the same opportunity as the bottoms from which the stones would be heaved up, as was the case in road-making.

Mr. Hannaford. Mr. Hannaford asked what were the proportions of the concrete?

Mr. Massy. Mr. Massy replied that the proportions were about one of cement, one of sand, and four of broken stone. The object in making the concrete so rich was to allow for any loss due to the cement washing away from the sand during the process of submersion. He thought for this class of work the concrete could best be prepared by gangs of men sufficient to keep one box employed constantly.

Mr. St. George. Mr. St. George referred to the Aberdeen harbour and docks, in the construction of which concrete consisting of ten of stone to one of sand and one of cement was used; and to the Manchester canal, the concrete used in the main wall of which was in the proportion of twelve to one, except the face work, which was four to one. This showed that in England an apparently much weaker concrete was used than in this country, which he said was because there the cement could be obtained fresh. Here such high tensile strengths were not obtained.

Mr. Massy thought the reason stronger cements were not imported was because engineers as a rule did not specify such, and manufacturers would not exceed the specifications. Mr. Massy.

Mr. St. George thought Mr. Massy was in error, as he understood there was no special method of making cement in England for exportation. He has visited the English factories, and considered the difficulty was in the fact that cement was held by for a time and then shipped to this country, so that they got old instead of fresh cement. His observation was similiar with tile pipes, agents often sending an inferior article to this country to that used in England. Mr. St. George

Mr. Hannaford said he had always understood that there was little difference in the various brands of standard manufactures of English Portland cement. His experience with concrete was that he should hesitate to use any weaker than one in six—one of cement to six of sand and stone. He preferred one in five—weak concrete was dangerous. He generally specified for two of sand and two of broken stone to one of Portland cement. It was better to be on the safe side when letting the work, as when tendering contractors were ready to bid the same for strong as for weak concrete. Mr. Hannaford.

Mr. Irwin said that some of the barrels of cement imported were smaller than those used in the United States and England, where they were $3\frac{3}{4}$ or 4 cubic feet. He had once tested the capacity of barrels of English cement, and found the average to be only $2\frac{1}{2}$ cubic feet. Mr. Irwin.

Mr. St. George said barrels of English cement weighed 370 to 375 lbs., German 400, and American 240 lbs. The city of Montreal purchased cement per 100 lbs., not by the barrel, and every tenth barrel was weighed. There were cements in the market that had been rebarrelled here; some in fact were reground here, having being injured by the voyage. Mr. St. George.

Mr. Massy said in reply to remarks, that he had not answered that the general weight of English cement was seven barrels to a ton. Mr. Massy.

He had noted the rise and fall in Lake Superior, but could not discover any law governing it, as the movement at times was most erratic. A movement towards higher water would often occur twice in a few hours, and then not for days. He did not think the effect of a tide was noticeable.

With reference to the rack and pinion attachment to the transit, he had never used such an instrument as mentioned by Mr. Irwin.

With regard to levelling across a river, he had never tried the method mentioned. The simplest way that occurred to him was to take two equal sights, and then eliminate every kind of error due to curvature, refraction, etc. He had read an article on the Forth Bridge by one of the assistant engineers, in which it was stated that the errors made by measuring with a wire amounted to 6½ inches, which they did not appear to be able to account for.

With respect to measuring distances by wire, he thought the simplest method was to suspend the wire on land, measure the length, then suspend the wire under identically the same circumstances over the points to be measured afterwards, again testing the wire on land. He had found on several occasions, with these precautions, that the wire had undergone a change in length.

Mr. Fairman.

Mr. F. Fairman said he agreed with the remarks as to the unreliability of measurements made by wire. His experience as a manufacturer was that wire made out of crucible cast steel and of high tensile strength was the only wire that could be at all depended upon, and even then the difficulty of annealing such wire, so as to render it the same throughout, was such as to prevent its being absolutely reliable for measurements.

Thursday, 8th May.

F. R. F. BROWN, Member of Council, in the Chair.

Paper No. 43.

GENERATION, DISTRIBUTION AND MEASUREMENT OF ELECTRICITY FOR LIGHT AND POWER;

APPLIANCES THEREFOR, AND PARTICULARS OF CANADIAN INSTALLATIONS.

By A. J. Lawson, M. Can. Soc. C.E., A.I.E.E.

Introduction.

Although hardly fourteen years have elapsed since the first application of electric arc lighting on a commercial scale, and only about nine years since the practical introduction of incandescent electric lighting, yet the production of electric currents by mechanical means had long before that time been successfully solved by men to whom our indebtedness is too often ignored. They were not patentees but inventors, and the splendid results of their labours were often freely given for the public benefit without thought of personal advantage. First among these disinterested discoverers and benefactors was Michael Faraday, who in 1831 discovered the law of induction of currents and the principles of magneto electricity, and who published to the world his researches with the remark, "I have rather been desirous of discovering new facts and "new relations than of exalting those already obtained, being assured "that the latter would find their full development hereafter," a prophecy now most amply fulfilled.

Profiting by the knowledge obtained from Faraday's researches, Pixii of Paris constructed in 1832 the first appliance embodying the principle of magneto-electric induction, and for several years thereafter many inventors worked on the same subject, but it was not until 1860, just 30 years ago, that Dr. Antonio Paccinotti, of Florence, invented the first generator of electricity, having an electro-magnetic field and an annular armature, — a machine which may be justly described as the prototype of all the dynamo-electric machines now known as Gramme armature dynamos. The exciting current, however, was not obtained from the machine itself, as is now the common practice in all continuous current generators, but was derived from a battery connected to the wires forming the field winding.

In 1866, the idea of a self-exciting dynamo suggested itself, almost simultaneously, to Mr. S. A. Varley of London, England, and to Dr. Werner Siemens of Berlin, Germany. Mr. Varley patented his machine towards the close of that year, and the publication of the patent took place in July, 1867. In January, 1867, Dr. Siemens described publicly for the first time the dynamo-electric machine which he had invented the previous year. Sir Chas. Wheatstone also invented, about that time, a machine which was self-exciting, and which he had had constructed in the workshops of Mr. Augustus Stroh of London.

In 1870, Mr. Z. T. Gramme, of Paris, invented the armature winding which bears his name, and the commutator and connections thereto— one of the most important improvements in the development of dynamo-electric machinery.

In 1876, Mr. C. F. Brush, of Cleveland, Ohio, invented his arc light dynamo with cast-iron field magnets and cast-iron armature, a type of machine of which the first constructed is still running in Baltimore, and which, while closely resembling the Paccinotti and Gramme machines, had its distinctive peculiarities. From this machine and the series arc lamp, invented by Mr. Brush, may be said to date the commercial development of arc lighting; and it is probably to the interest evoked by the success which attended Mr. Brush's inventions that the present success of electric lighting generally is due.

In 1879, Mr. T. A. Edison, who had been engaged for some months in experimental work, produced a lamp, which gave rise to great expectations and much speculation. His experiments did not indeed result at that time in a commercial article, but they were the foundation of his success the following year, when he abandoned the attempt to use filaments of platinum-iridium wire and resorted to carbon as the light-giving medium. But it was not until 1881, when he succeeded in obtaining a really durable incandescent lamp, that the application of electricity to domestic lighting became a possibility, and its adoption only a question of time.

Mr. J. W. Swan of England and Mr. W. E. Sawyer of New York, who had been experimenting on the same lines for probably a much longer period than Edison, both invented, about the same time, lamps embodying the elements of the success which afterwards attended their endeavours; but whilst to the three distinguished inventors mentioned is due the credit of the production of really efficient commercial incandescent lamps, the fact that they were simply perfecting the ideas of other investigators, who had long previously experimented on the same lines, seems to have been generally forgotten.

On September 4th, 1882, the Edison station for the distribution of current to supply incandescent electric lights, located in Pearl Street, New York, the first permanent station of its kind, was put into operation.

In 1870, not a single horse-power, whether produced by steam or water, was used for electric lighting, or for the manufacture of electric lighting apparatus, yet now it is estimated that out of a total of five and a quarter millions horse-power developed by steam engines and water wheels on this continent, half a million horse-power, or nearly ten per cent., is used in the production of electric current for the distribution of light and transmission of power, and in the manufacture of electrical machinery and appliances.

At the beginning of 1886, there were in the United States and Canada 450 local electric lighting companies operating central stations. At the beginning of 1887, the number had increased to 750; and at the beginning of 1889 to nearly 1,200; while in January, 1890, there were 1185 different companies operating central stations in the United States, 147 in Canada and 25 in Central America and Mexico, besides 266 gas companies, etc., engaged in electric lighting, making a total of no fewer than 1623.

At the end of 1886, there were 1,000 incandescent and nearly the same number of arc isolated plants. The number of private plants now in the United States is 3,925; in Canada and miscellaneous 196, and in Central America and Mexico 200; making a total of 4,300 isolated electric lighting plants, large and small.

The following was the condition of the arc lighting business at the beginning of the years mentioned:

Year.	Arc lamps in use.	Year.	Arc lamps in use.
1882	6,000	1886	96,000
1883	12,000	1887	115,000
1884	24,000	1888	150,000
1885	48,000	1889	210,000

while in 1890 the lamps in use number 235,000. Of these about

68,000 are of the Thomson-Houston manufacture, and 49,000 have been made by the Brush Electric Company.

Between November, 1886, and January, 1889, the number of incandescent lights in America more than quadrupled, increasing from 525,000 to 2,500,000. At the present time, there are fully 2,800,000 incandescent lamps in use, of which 808,500 are supplied from alternating current plants, and of these 408,350 with the necessary apparatus, including 25,000 converters, have been furnished by the Westinghouse Electric Co., 208,760 by the Thomson-Houston Co., 111,500 by the Fort Wayne Electric Co. and the majority of the remainder by the Brush Electric Co. since September last. In addition to these the Thomson-Houston Company has furnished plant for direct current distribution of a total capacity of 144,000 lamps, the Brush Company for nearly 200,000 lamps, and the Westinghouse Company for 45,000 lamps. The estimated total capitalization of electric lighting and electric manufacturing companies in America at the present time is $250,000,000.

ELECTRIC LIGHTING IN CANADA.

Being one of the pioneers in construction of electric lighting plant in Canada, and the manufacturer or constructor of nearly 30 per cent. of the total capacity of incandescence lighting installations now in operation in the Dominion, the writer submits the following brief history of the progress of the electrical industry in this country.

Ten years ago there was not one electric light plant in operation in Canada. The first plants erected were Brush arc plants of small capacity. About the end of December, 1882, some Thomson-Houston arc lights were placed on exhibition in Montreal by the Thomson-Houston Electric Co. of Canada (afterwards merged into the Royal Electric Co. of Montreal), lighting St. James Street, Beaver Hall Hill, and part of Dorchester street, but the first permanent installation for street lighting in the city was that supplied from a Brush dynamo owned by the Harbour Commissioners, who by this means lighted the harbour, wharves and approaches.

In the Fall of 1883, some 50 arc lights of the Hochhausen and Vandepoele systems were placed in the streets of Toronto, and Winnipeg also had some arc lights put into operation about the same time. In May, 1885, Ottawa adopted the Thomson-Houston arc light for its streets, replacing thereby both gas and oil, and in 1887 Quebec followed its example, and Halifax and other places followed.

In 1889, Montreal gave a contract for the electric lighting of the whole of its streets to the Royal Electric Co. for a period of five years, a portion of the city having been lighted by the same company since 1886. Hamilton also is now lighted by the arc light, and St. John, N.B., has recently contracted for the lighting of the whole city, dividing the work between the companies operating the Thomson-Houston and the Brush systems, so that the following cities may be said to have adopted exclusively the arc light in place of gas or oil:—Montreal, Ottawa, Quebec, Hamilton, London, Winnipeg, Victoria, Vancouver, Halifax, St. John, N.B., St. John's, N.F., Moncton and Sherbrooke, besides the majority of the towns throughout the Dominion, so that comparatively little work remains to be done in arc lighting; incandescent lighting for residences and stores being the principal field remaining unoccupied, and there can be no question that the large majority of this work will be done on the alternating current system, which is so admirably fitted for the lighting of our widely-built cities and towns, and for the utilization of our numerous water powers for this purpose.

In 1882, two private installations of incandescent lights were made in the city of Montreal. The system employed was the Maxim, which was put into the St. Lawrence Hall and the Bank of Montreal. So crude was the construction of these plants that they proved unsatisfactory, and after a very short time both were discontinued. In the St. Lawrence Hall only one lead was carried from the dynamos to the lamps, the return being made through gas and water pipes, a method which, it need hardly be pointed out, would not now be permitted by the Board of Fire Underwriters. The wire used in the Bank of Montreal for mains did not even have the coating of paint which would have gained for it the misnomer of "Underwriters wire," but was merely single cotton-wound magnet wire. This is not pointed out as reflecting in any way on the Maxim Co.: all companies' systems at that time were about equally crude.

In the Fall of 1882, a contract was made for lighting the Canada Cotton Co.'s mill at Cornwall with the Edison light. A plant of 500 16 c. p. lamps capacity, constructed under the superintendence of Mr. Byllesby, now Vice-President of the Westinghouse Co., was started on the 28th day of February, 1883. In June, 1883, an exhibition Edison incandescence plant was placed in the "Mail" building, Toronto, but was discontinued a few months later.

The Montreal Cotton Co.'s mills at Valleyfield were next lighted in September 1883, 800 lights being placed: which number was subsequently increased to about 1100. The Canada Cotton Co.'s plant was also increased at the end of the year to 1200 lights, and it is now the largest private installation in Canada. In January of 1884, two competitive plants of small capacity were placed in the Parliament Buildings at Ottawa, for the lighting of which the writer furnished, in 1886, Edison machinery of a total capacity of 1000 lights.

The first incandescence electric light station in Canada was started at Victoria, B.C., in January, 1887, and was followed by that at Vancouver, B.C., completed in September of the same year. The distribution from both stations is on the three-wire system.

The station at Calgary, N.W.T., was completed and started in October, 1887, and in January, 1888, the station at Valleyfield, with overhead conductors—at that time the best constructed of all the Edison stations in Canada—was put into operation. For these four stations the writer supplied and erected all the machinery, and remodelled the stations originally constructed in the two first-named places.

The Cornwall station on the Westinghouse A. C. system, completed the same year, was the first A. C. station in Canada.

Toronto is the only place in which underground wires have yet been placed, but the Edison station, from which they are fed, has only lately been put into operation. It is the intention of the older Toronto Electric Light Co. to put under ground the wires for arc lights and for the alternating current plant about to be installed.

The Barrie central station, which the writer has constructed, is the latest completed central station plant, and the only one in the Dominion on the A. C. system carrying 2000 volts in the primary wires and nearly 100 volts in the secondaries, and it is one in which the highest quality of insulation, both of primary mains and house wiring, has been used.

At the present time there are 13,530 arc lights and about 70,765 incandescent lamps in use throughout the Dominion. There is hardly a village in Ontario, having a population of over three thousand inhabitants, which has not an electric light station of some kind in operation, and few of the important towns of the other Provinces are without electric lighting. Most of these, it is true, are arc lighting stations, but about a dozen supply the incandescent light only, chiefly to stores and public buildings, the lighting of residences being yet scarcely entered upon. Several of the local companies which have hitherto supplied the arc light alone, or with a few incandescent lamps in series with their arcs, or in series multiple with them, have recently purchased and put into operation incandescence A. C. plants; and the various lighting companies formed for the supply of incandescent lights only, have also found it necessary in most cases to add arc lighting to their business, it having been sufficiently demonstrated that the incandescent light is unsuitable for street lighting, the public demanding from electric lighting, whether arc or incandescent, a much better illumination than is usually obtained from gas lighting, and in this respect the incandescent light has failed to meet the expectations of its advocates. The Edison municipal system was used for street lighting on the Lachine Canal, and at Vancouver, B. C., Valleyfield, Que., and Chatham, N. B., but has been replaced by arc lights in the two first-named places.

The principal electric lighting stations in Canada of which the capacity is 100 arc lamps of 2,000 nominal candle power or over, or 1,000 incandescent lamps of 16 candle power or more, are :—

Place.	No. of Arc Lights.	Inc. Lights 16 c. p.	System.
Barrie, Ont.	75	1,200	Ball Arc, Brush A. C. Incandescence.
Brockville, Ont.	105	1,000	Ball and Reliance Arc, Slattery A. C. Incandescence.
Cornwall, Ont.		1,300	Westinghouse A. C.
Gazette Printing Co., Montreal, Que.		1,350	Edison.
Halifax, N.S.	200	1,950	Thomson-Houston and Fuller-Wood Arc, Slattery Incandescence.
"	250	1,400	Thomson-Houston and Ball Arc and Westinghouse A.C. Incandescence
Hamilton, Ont.	394	2,000	Thomson-Houston Arc, Westinghouse A. C. Incandescence.
Joliette, Que.	30	1,500	Thomson-Houston Arc and A. C. Incandescence.
London, Ont.	100		Thomson-Houston.
"	150		Ball.
Montreal, Que.	1,440	2,000	Thomson-Houston.
Ottawa, Ont.	522		Thomson-Houston.
"		4,000	Westinghouse A. C. and Weston multiple-series.
Peterboro, Ont.	137		Thomson-Houston.
Quebec, Que.	692	1,000	Thomson-Houston.
St. Catharines, Ont.	105	215	Thomson-Houston Arc, Weston multiple-series Incandescence.
Sherbrooke, Que.	167	500	Ball and Thomson-Houston Arc, and T.-H., A. C. Incandescence.
St. John, N.B.	325	1,000	Thomson-Houston.
"	205		Brush.
Toronto, Ont.	750	1,000	Hochhausen-Wright Arc, and T.-H. series Incandescence.
* "		10,000	Edison.
Truro, N.S.	60	1,800	Thomson-Houston Arc, Mather Inc.
Valleyfield, Que.		1,200	Edison.
Vancouver, B.C.	100	1,150	Thomson-Houston Arc, Edison Inc.
Victoria, B.C.	50	1,200	Ball Arc, Edison Incandescence.
Winnipeg, Man.	200	1,000	Brush and Thomson-Houston Arc, and T.-H. Incandescence.
* "		3,000	Edison.
Yarmouth, N.S.	100		Fuller Wood.

* The two stations marked thus have the nominal capacity given here, but actually run at present about 20 per cent. of the number of lights at which they are rated.

The private installations for incandescence lighting in Canada, having a dynamo capacity exceeding 600 lamps of 16 c. p., are:—

Name of Owner.	No. of lamps 16 c. p.	System.
Canada Cotton Co., Cornwall, Ont.	1,250	Edison.
Montreal Cotton Co., Valleyfield, Que.	1,000	"
New York Life Ins. Co., Montreal, Que.	1,000	Brush.
Parliament Buildings, Ottawa, Ont.	1,000	Edison.
Stormont Cotton Co., Cornwall, Ont.	850	"
Gibson Cotton Co., Marysville, N.B.	850	"
Canadian Pacific Railway Station, Montreal.	800	Thomson-Houston.
Magog Print Co., Magog, Que.	700	Edison & Thomson-Houston.
W. Bell & Co., Guelph, Ont.	600	Brush.

The following is a summary of the number of lights of the various systems now in operation in the Dominion:—

System.	Arc Lights.	Incandescent Lights.
Thomson-Houston	6,105	14,600
Edison	......	23,500
Ball	3,529	1,660
Brush	615	3,300
Hochhausen (Wright's improved)	750	......
Reliance	1,780	......
Westinghouse	......	6,850
Slattery	......	5,850
Craig	......	4,515
Mather	......	3,125
Weston	180	5,365
Fuller Wood	425	......
Other systems	150	1,500

ENGINES.

Whether the system to be employed be the low tension incandescence, the alternating current incandescence, or the high tension continuous current arc system, the three which are to-day practically the only ones operated to any extent in America, one of the chief points to be considered in the construction of a station is the economical generation and application of the prime power. Unfortunately in a great many cases where steam power is used, it was assumed in the early stages of electric station construction that any kind of steam plant would answer. Old slide-valve engines, which drove machinery as antiquated as themselves in machine shops, saw mills, woollen factories, and like places during the day were used at night for the running of electric light machinery, and very good reason naturally existed for the complaints made of the unsteadiness and unsatisfactory character of the lights supplied.

High-speed engines belted direct to the dynamos were next tried, and having been found to give much better results in point of steadiness, a number of builders, who had had no experience in such work, undertook the manufacture of this class of engines, and evidently tried to combine the old designs for agricultural engines, upon which their previous practice was based, with some of the principles embodied in the best class of engines sold in the United States for electric light purposes. The product was a mechanical curiosity, and a failure. It is safe to say that in not one of the Canadian shops building these engines in the early history of electric lighting in Canada was there a proper equipment for the manufacture of high-speed machines of any kind. No parts were made to gauge so that in the event of a break-down the broken part could be duplicated without sending it back to the shop as a model. A reaction soon afterwards set in in favour of slow-speed engines, especially for arc lighting, and at the present time, with few exceptions, engines of the Brown and Wheelock types are used in all arc light stations in Canada operated by steam power. For the running of incandescence plants, however, high-speed engines, mostly of American manufacture, have obtained the preference to which their excellent qualities and performance entitle them.

Brown engines furnish the motive power for the Central Stations in Montreal, Toronto and Winnipeg, both Brown and Wheelock engines are used in Halifax and London, and Wheelock engines in Hamilton, while Armington and Sims engines are the prime motors in the stations in St. Johns, N.F., St. John, N.B., Calgary, Alta., Vancouver and Victoria, B.C., and in the Parliament Buildings at Ottawa.

14,750 H. P. generated by steam engines is used for electric lighting and electric railway working in Canada.

The economy of many stations could be increased by the intelligent use of the indicator, instead of trusting to the valves of engines being properly set by guess work, as is now so frequently the case.

BOILERS.

With the exception of the Royal Electric Co.'s east end station in Montreal, the ordinary horizontal fire-tubular steam boiler has been used in every station. In that case the Babcock and Wilcox water-tubular boiler is employed. In some cases the Jarvis setting has been adopted, but not to any considerable extent.

WATER POWERS.

At Quebec, power is obtained at the Falls of Montmorency, nine miles distant, to drive the Thomson-Houston arc dynamos and Thomson-Houston A. C. incandescence machines.

At Peterboro, water power is used to drive Thomson-Houston arc dynamos, from which 137 arc lights and a number of Bernstein incandescent lamps in series are supplied. At Barrie, Ont., a stream five miles distant from the town furnishes the power for both the arc and Brush A. C. incandescence plants.

Also in Ottawa, Cornwall, Smith's Falls, St. Catharines, Welland, Dunville, Thorold, Sault Ste. Marie, Sherbrooke, Joliette, Valleyfield, Almonte, and some other places, for both factory and central station lighting, water furnishes the motive power, the total H. P. from turbines used for electric lighting and power transmission in the Dominion being 4520, or more than one fifth of the whole power utilized for this purpose.

ATTACHMENT OF DYNAMOS.

The dynamos are not coupled direct to engines in any of the Canadian stations. Ordinary double leather belting, made without seams or rivets, is generally used. In a few cases link leather belting has been tried, but the results have so far justified the opinion that this belting has been invented chiefly to find a market for scrap leather. Belting should not be overtaxed. One inch width of double leather belting running at a speed of 750 feet per minute will easily transmit one horse power, and at this tension will last a long time. Some dynamo manufacturers, in order to impose the belief that their machines use but little power, are in the habit of providing a much smaller margin than this per horse power. The only advantage, of which the contractor receives nearly the whole benefit, is that the first cost is decreased. The disadvantages, which affect the purchaser, are the necessary excessive tightness of the belt, and the consequent heating of journals, rapid wear of the belt, and large oil consumption. Rope driving may eventually be used as it has many advantages, but so far, with one exception in an isolated plant, the method has hitherto not been tried in Canada.

ARC LIGHTING SYSTEMS.

The arc lighting systems in use in Canada are the Thomson-Houston, Ball, Brush, Reliance, American or Fuller Wood, Hochhausen (Wright's improved) and Weston. The large majority of machines and lamps is of the Thomson-Houston and Ball systems.

In the Thomson-Houston, in the Brush and in the Fuller Wood or American systems a current of 9.6 amperes is used, with a pressure varying according to the number of lamps in circuit. In the Ball system a current of 8 to 8½ amperes has been the standard, but lately that company have supplied several plants having a current of only four amperes, the lamps for which are nominally of 1,000 candle power each. In the Hochhausen-Wright system, a current of 10 amperes is used. In the Weston system the current is about 18 amperes, and the P. D. between the terminals of each lamp 25 volts. On account of the short arc and the consequent hissing the Weston lamp has not found general favour in this country. The regulation of the Thomson-Houston machine is excellent. The lamp also has the merits of simplicity of construction and steadiness in running. The feed is purely gravitational like the Brush feed, controlled by electro-magnetic action, there being no clock-work or gearing. It is not, however, quite so steady as some clock-work arc lamps, and requires the feed rod to be kept very clean in order to secure the proper working of the clutch. With the rack and pinion lamps this point is not of such importance, and the difference in the running of the two kinds of lamps sometimes observed may, to some extent, be due to the cleaning of the clutch lamp rod having been neglected.

In regard to the rating of arc lamps some change seems to be desirable. At present lamps taking 48 volts and 9.6 amperes, lamps of the same voltage taking 10 amperes, and lamps of 50 volts and 8 amperes, are all compared the one with the other, and each is called 2,000 candle power, which is manifestly absurd. The current and pressure, or watts per lamp, should be given in all specifications, tenders and contracts.

STREET WIRING FOR ARC LIGHTS.

In wiring for arc plants, as is generally known, one wire of uniform section is carried from the machine to the lamps, where it is cut, one end being placed in the first binding post and the other in the second binding post, and so continued, the pressure falling on an average about 48 volts for each lamp in circuit, where the lamps, as is the general practice on this continent, are always run in series.

For lamps of 2,000 nominal candle power No. 6 and for lamps of 1,200 nominal candle power No. 8 wire American gauge, is used for the leads. Up to within the past two years, the insulation known as "Underwriters wire" was used, but lately this has given place to much superior quality. Unfortunately, there is still room for improvement even on the best which has yet been supplied in Canada.

SYSTEMS OF DISTRIBUTION FOR INCANDESCENCE LIGHTING.

In the distribution of current for incandescence lighting from central stations the multiple arc two-wire system with low tension continuous currents was first used during 1882 and 1883.

In private installations at that time the tree system of wiring was usually followed, and it has not yet been entirely abandoned, although used in very few installations at the present date. In one station in the Maritime Provinces wired on this principle, the pressure varies from 125 volts at the lamps nearest the dynamo to 110 volts at the furthest point of distribution. But since 1884, very few stations indeed and few isolated plants of more than moderate size have been constructed on other than the feeder system.

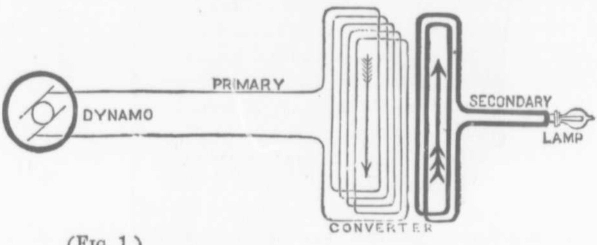
A very short experience of distribution on the multiple-arc system proved that lights singly controlled could not be furnished economically by it at a greater distance from the central station than a quarter of a mile radius. The three-wire system, invented by Dr. John Hopkinson, and elaborated by Mr. Edison, was a temporary and partially successful solution of the difficulty, but this system, although it greatly reduced the quantity of copper necessary, only increased the radius of distribution on a paying basis by another quarter of a mile, and, while satisfactory for thickly populated towns, still left the distribution of light in suburban districts or openly built country towns as far from attainment as ever. The adoption of the alternating current system of distribution solved the difficulty.

The method of regulation first employed for the maintenance of equal pressure at the ends of the feeders in the three-wire system consisted of placing adjustable resistances or feeder equalizers in each circuit, more or less resistance being inserted by hand, according to the indications of the pressure indicators. Where the frames of such equalizers were made absolutely fireproof, such a system of regulations in small stations having only three or four sets of feeders radiating from it was in a measure unobjectionable, but when it came to the distribution of several hundreds, perhaps thousands, of amperes of current, through dozens of sets of feeders, the loss in these equalizers became a serious matter, and perfect regulation was difficult of attainment. In several cases also the heating of the equalizers was the origin of fires which resulted in the burning down of the stations, the destruction of the Edison stations in Boston and New York being cases in point. In recent practice these equalizers have not been used, but a method of interlacing the feeders as well as the distributing mains has been adopted, necessitating a somewhat larger outlay in conductors, but not involving, as in the other case, a loss of energy by the heating of useless resistance. With this interlacing the pressure at the lamps is much more nearly constant than under the old method.

At the price of labour and fuel and the selling prices current in this country, it may safely be said that the economical distribution of light or power, on the three-wire system, is limited to half a mile radius from the station in our most thickly populated towns. In both the United States and Canada, distribution by this system has been carried out on a much wider area for a limited number of lights and under special circumstances; but it is doubtful if there is a single city in Canada which will return any dividend on the necessary investment to a company placing low tension wires carrying a pressure of even 300 volts underground, and there are not more than six cities in the whole Dominion which will yield any return on this system with overhead wires, unless the charges for electric lights be at least 50 per cent. more than the current prices for gas.

ALTERNATING CURRENT DISTRIBUTION.

In the method of distribution by high tension alternating currents, the converters, indicated by Fig. 1, are placed in parallel circuit. As shown,



(Fig. 1.)

the high tension current from the dynamo does not enter the premises of the consumer but merely passes through the fine wire in alternately opposite directions, and generates, by induction, a low tension current in the secondary or thick wire of the converter or transformer, which induced current is carried into the houses and through the lamps.

There are at present no alternating current motors in use developing large powers, but probably before many months have elapsed machines will be supplied which will convert the electrical energy of alternating current into power with high efficiency. Ganz & Co., of Buda Pesth, have indeed

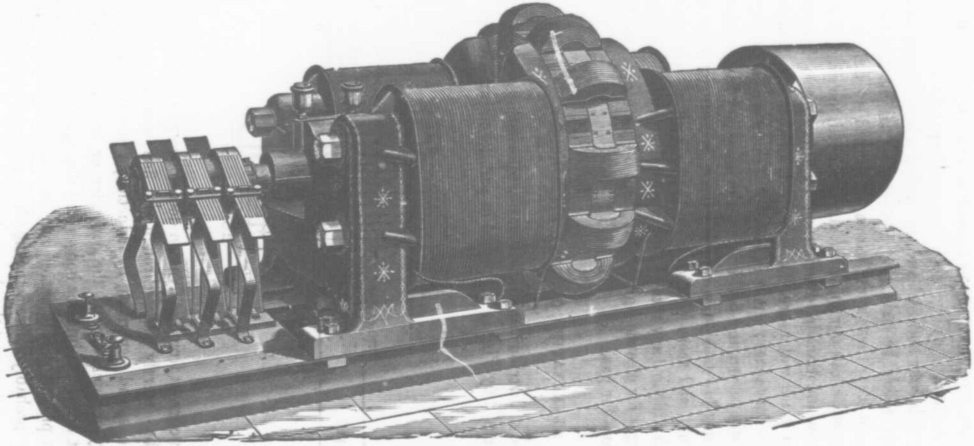


Fig. 2.

BRUSH ARC DYNAMO.

nearly completed a station from which to distribute power by A. C. motors, and the Westinghouse Company are just completing a contract for A. C. motors for mine working. It is also the case that the A. C. system will not easily lend itself to the charging of storage batteries, without a complication of commutators and other apparatus; but there does not appear to be any demand for the charging of storage batteries except what can be supplied from continuous current stations or isolated plants now n operation, or for which special dynamos would not be best use separate and distinct from any other circuit.

ARC LIGHTING DYNAMOS.

Brush Arc Lighting Dynamo (Fig. 2).

This machine was first made with both armature and field cores of cast iron; but for some years past the armature has been built up of laminated hoop iron of good quality, a simple modification which has raised the efficiency greatly, enabling the output to be increased 50 per cent. while running at the same speed as formerly. Upon the ring so formed the copper coils are wound. The 18-light machine weighs 1500 lbs., the 30-light machine 2500 lbs., and the 65-light machine 4800 lbs. complete. The P. D. at lamp terminals is the same as in the Thomson-Houston system, 48 volts, and the current is 9.6 amperes. The output of the first two sizes is 5.53 watts per lb. gross weight, and is 6.2 watts per lb. gross weight for the large machine. The respective speeds at full load are 1050, 950 and 805 revolutions per minute. In the 65 light machine the copper wire on the armature weighs 1340 lbs. and on the fields 1264 lbs., so that the output is 11.5 watts per lb. of the total weight of copper wire on the machine, and 22.35 watts per lb. of the copper wire on the armature.

Thomson-Houston Arc Dynamo (Fig. 3).

In the Thomson-Houston dynamo the field is composed of two massive iron castings upon which the magnetising coils of copper wire are wound, and these castings are of such shape that they nearly completely encircle the armature, being fastened together over it by wrought-iron bolts, which form the yoke or keeper. The armature core is a spheroid built up of soft iron wire. Upon this core three coils of copper wire are wound, these being connected together at their inner ends, their outer ends being carried out and fastened to a three segment commutator. The regulation of the current, which in all arc lighting machines should be maintained constant, is performed by an electro magnet which shifts the position of the brushes on the commutator, as fully described

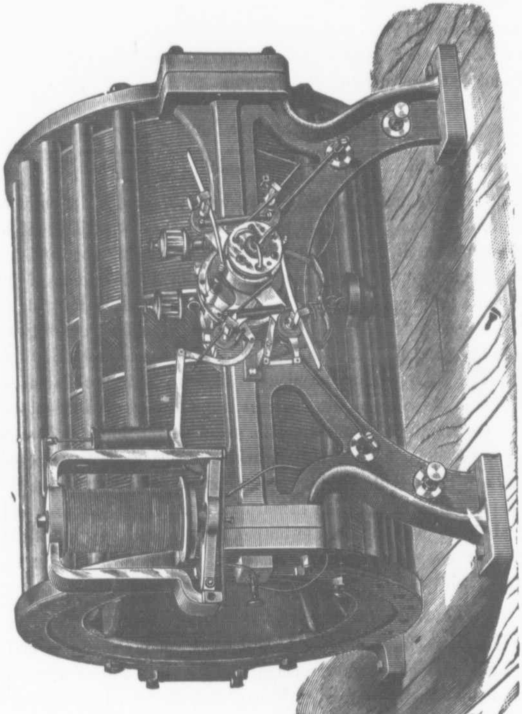
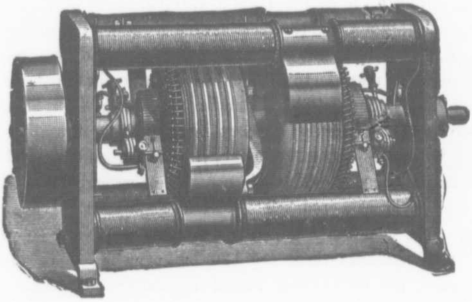


Fig. 3

THOMSON-HOUSTON ARC DYNAMO.

in Silvanus Thompson's "Dynamo Electric Machinery." The magnetism of this machine leaks outwardly to a considerable degree, which, of course, is a bad fault. There is also the objection to the form, that it is necessary, in case of breakdown of the armature, to dismantle the whole of the machine before the armature can be removed, and that that being done, should a coil be burned out it is necessary to completely rewind the armature—in itself the work of several weeks.

The nominal 50-light Thomson-Houston machine will run 60 arc lamps of 2000 nominal candle power on a short circuit of wire; and speeded at 850 revolutions per minute, has a working E. M. F. of 2700 volts with a current of 9.6. amperes. Its total weight is 6200 lbs. The iron in the armature weighs 340 lbs., and the two cast-iron field cores weigh 2710 lbs. The weight of copper wire on the armature is 378 lbs. and on the fields 820 lbs. The output is 4.18 watts per lb. of gross weight; 21.6 watts per lb. of copper wire on the machine; and 76.25 watts per lb. of armature wire.



Ball Arc Dynamo (Fig. 4).

The Ball arc light dynamo has a Gramme ring armature, or rather two armatures, running between blocks peculiarly placed one above one armature and the other under the other armature, and it has wrought-iron fields and pole pieces: in fact the whole machine frame is made of wrought-iron. It weighs much less therefore than other machines in which cast-iron is used, the 25-light machine weighing 990 lbs while the 35-light machine weighs 1180 lbs. complete. The current is $8\frac{1}{2}$ amperes, and the voltage per lamp 48. The output is 10.3 watts per lb. gross weight of the first machine and 11.97 watts per lb. of the 35-light machine. The weight of copper wire on the armatures of the 35-light dynamo (there being two in each machine) is 102 lbs., and on the fields 150 lbs. The output is thus 56.6 watts per lb. of copper on the machine and 140 watts per lb. of copper wire on the armature. The speed of the two machines mentioned is 1365 and 1275 revolutions per minute respectively. The resistance of the field winding of the 35-light machine is 13 ohms, and of the winding of the two armatures 15 ohms.

The Ball Co. have recently made a machine intended for 80 arc lamps, of which the following are some of the particulars: Weight of the machine complete 3200 lbs.; current 10 amperes; E. M. F. 3750 volts; speed 940 revolutions per minute; wire on field 362 lbs. No. 10; on armatures 222 lbs. No. 15 B. & S. gauge; iron in each armature core 137½ lbs. The output of this machine is 11.66 watts per lb. gross weight: 63.21 watts per lb. of copper wire on the machine, and 168.83 watts per lb. of copper wire on the armature.

Toronto Arc Dynamo.

The machines made by the Toronto Electric Light Company for use in their own station are of the Hochhausen type, modified and improved by Mr. J. J. Wright, the company's electrician and manager. The company do not manufacture machines for sale, but make all their own arc light dynamos. Their standard type is a 40-light machine 10 ampere current, average P.D. at binding posts of lamps 48 volts. The field is laid horizontally, being, it may be said, a Hochhausen machine laid on its side. The field cores are of wrought-iron, the frame and pole pieces of cast-iron. The cast-iron weighs 1200 lbs. in each machine. The field winding consists of 700 lbs. of No. 9 copper wire, and on the armature there are 180 lbs. of wire. The armatures are sectional, the coils being wound separately on moulds. Each armature has 18 coils with Gramme connections. The commutator consists of 18 segments, and is mounted on slate with an air space between the sections. The weight of the completed machine being 2400 lbs., the output is at the rate of 8 watts per lb. gross weight; 21.8 watts per lb. of wire on the dynamo, and 106.6 watts per lb. of the copper wire on the armature. Mr. Wright in a communication on the subject sarcastically states: "Unlike all other systems our armature "coils sometimes burn out, and I have adopted the sectional style to "facilitate repairs. The power required I have not accurately determined, but it is nearly ¾ horse power per light—rather over than "under—when working to full current and voltage. I adopt a few coils "on armature rather than many, for while the spark at brushes is "larger, the increased simplicity of all parts more than compensates."

Westinghouse A. C. Arc Dynamo.

This dynamo, recently put upon the market, embodies several novel features. The frame of the 60-light arc machine is cast off the same patterns as the ordinary 750-light Westinghouse incandescence dynamo; and the only difference in the field windings is that the iron cores project through the coils to a greater extent than in the incandescent machine, the coils being shorter. The principal feature of the machine is the armature winding, which is almost entirely enveloped by the laminated iron discs forming the core, and is connected to two collecting collars as in the Westinghouse incandescence machines. The speed is 600 revolutions per minute, the periodicity being 60 cycles.

The lamp has two laminated wire cores, somewhat similar to the core of the Westinghouse ammeter, hung on a swinging arm, one of which plunges into the coarse wire series coil and the other into the fine wire shunt coil. One carbon rod only is used, and the carbon itself is about $2\frac{1}{4}''$ wide by $\frac{7}{16}''$ thick. The lamp runs for 42 hours with one set of carbons. The P. D. at lamp terminals is 50 volts and the current 10 amperes. For lamps for inside use a converter is attached to the high-pressure street wires which transforms the current to 50 volts and 10 amperes, so that 50 volts is the maximum pressure entering a building. With the 60-light machine the lamps when required for street lighting only, may be run in series without the use of these converters. In the 125-light machine the current is 30 amperes and the total E .M. F. 2100 volts, and, with this size, converters are used for all the lamps (whether for street or interior lighting), which raise the voltage from 17 volts per lamp to 50 and reduce the current from 30 to 10 amperes. These are made to carry one, three, or five lights each.

The machines are started upon short circuit, and when fully excited a switch is opened and the lamps thereby thrown into circuit. During a recent visit of the author's to one of the Westinghouse stations with a sensitive ampere meter attached, the total change in the current when the lamps were thus placed in circuit was less than two amperes, and this was only temporary. Provision is made by attachments on the dynamo and on the wires in the station to prevent the opening of the circuit.

LOW TENSION INCANDESCENCE DYNAMOS.

The Edison Dynamo (Fig. 5).

The type of low tension machines which has found most favour on this continent is the Edison as modified and improved by Dr. Hopkin-

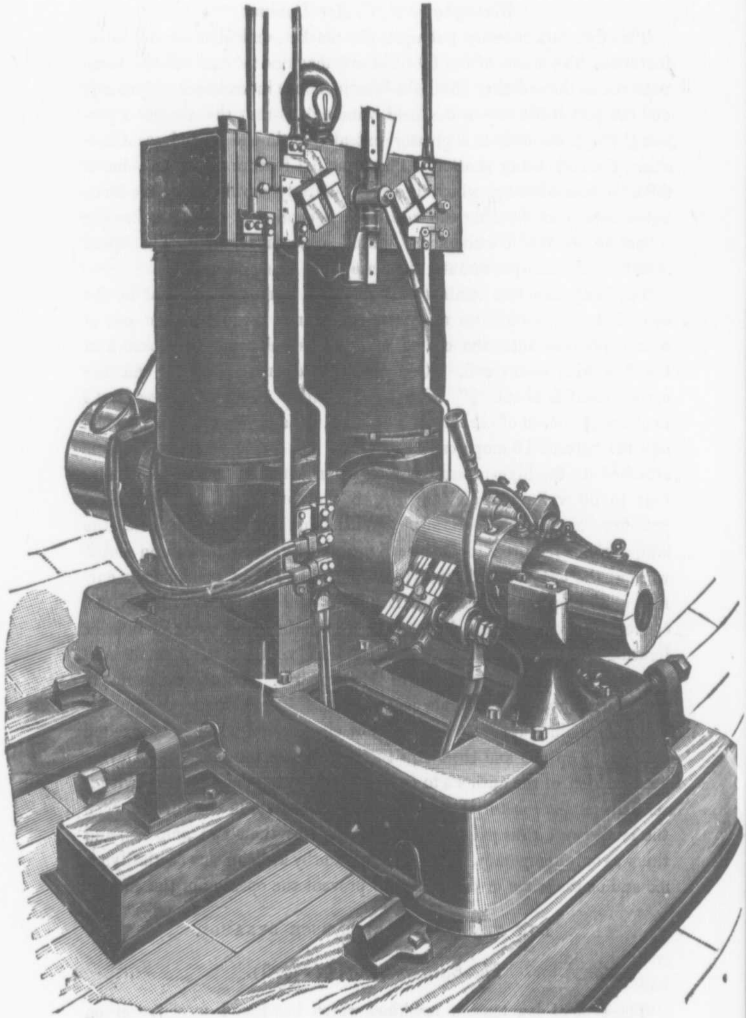


Fig. 5.
EDISON COMPOUND-WOUND DYNAMO.

son, and further perfected at the Edison Machine Works. Between the machines made by the Edison Co. in America and the Edison-Hopkinson machine made by Mather & Platt of Manchester there is this difference: the field cores of the Edison machine are made cylindrical and the armature core is still built up of iron discs bolted together; while the Edison Hopkinson machine has field cores, the section of which is a square between two half circles, and the armature discs are held together by nuts at each end of the core screwed on the shaft, thus giving the core a greater sectional area.

The Edison machines known as Nos. 10, 12 and 16 will serve to illustrate the general construction of Edison dynamos, and their relative proportions and weights. The No. 10 machine is made for an E. M. F. of 125 volts and a current of 200 amperes, but is hardly ever run at more than 200 amperes and 110 volts except for central station work. The total weight of this, the best running of all the Edison dynamos, is 3570 lbs. The two cast-iron field blocks weigh 600 lbs. The field cores which, as in all Edison machines, are of wrought-iron, are each $10\frac{1}{8}''$ diameter by $16\frac{1}{8}''$ long, and are connected by a massive wrought-iron keeper $10\frac{1}{8}''$ wide by $8''$ deep by $26\frac{1}{4}''$ long. The field cores are wound with 220 lbs. of copper wire—110 lbs. on each limb. The wrought-iron in the armature weighs 220 lbs., the dimensions of the armature shell before winding are $8\frac{3}{4}''$ diameter by $16\frac{1}{2}''$ long, and the winding is a modified Siemens, taking 60 lbs. nett weight of copper wire. The diameter of the completed armature outside the bands is $9\frac{11}{16}''$ and the bore of the fields being $9\frac{15}{16}''$, there is a clearance of $\frac{1}{8}''$ all round. The speed of the machine is 1300 revolutions per minute. The resistance of the shunt coils is 37 ohms, and of the armature about .017 ohm cold, the shunt being thus about 2200 times the resistance of the armature. The output of this machine at 110 volts and 200 amperes is 6.13 watts per lb. gross weight, 77 watts per lb. of copper wire on the machine, and 333 watts per lb. of wire on the armature. There are 66 bars in the commutator.

The next two sizes will serve as a basis of comparison with the Royal Electric Co.'s Thomson incandescence machine and the two Brush incandescence machines, of which the particulars are hereafter given.

The weights and dimensions of the No. 12 Edison dynamo are as follows:—complete machine 4340 lbs.; the cast-iron field blocks weigh 800 lbs.—400 lbs. each. The field cores are $20\frac{3}{4}''$ long by $11\frac{1}{8}''$ diameter. The keeper is $27\frac{1}{2}''$ long, $11\frac{1}{8}''$ wide and $8\frac{3}{4}''$ deep. The armature core is $9\frac{11}{16}''$ diameter, and $18\frac{1}{4}''$ long. When wound the armature is $10\frac{15}{16}''$ diameter over bands, and the bore of the fields is

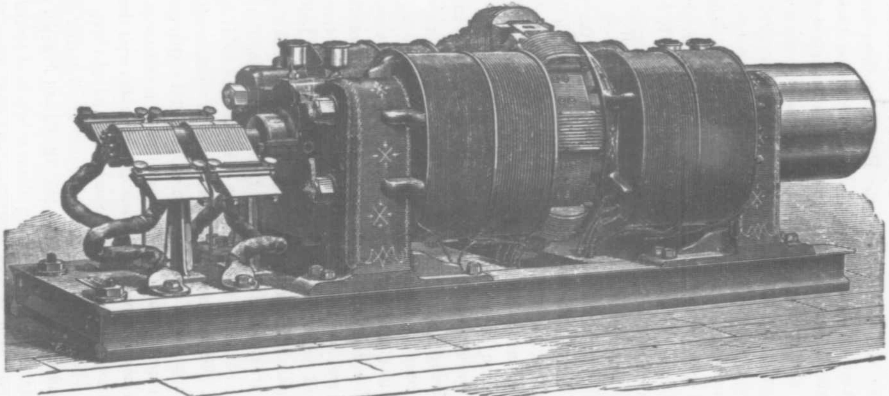


Fig. 6

BRUSH INCANDESCENCE DYNAMO. (Old Type.)

1'$\frac{1}{4}$, the clearance being $\frac{5}{32}$". 248 lbs. of wire are wound on the fields, and 84 lbs. of wire on the armature. The resistance of the shunt is 28.5 ohms and the resistance of the armature .011 ohm, the ratios being as 2600 to 1. At 110 volts and 240 amperes the output per lb. gross weight is 6.08 watts; for each lb. of copper on the machine it is 79.5 watts, and for each lb. of copper on the armature 314.3 watts. The speed is 1200 revolutions, and there are 58 segments in the commutator.

The No. 16 machine made for a current of 320 amperes weighs 6800 lbs. The field cores are 12$\frac{3}{4}$" in diameter by 23$\frac{1}{2}$" in length. The keeper is 12$\frac{3}{4}$" wide × 10" deep by 32$\frac{1}{2}$" long. The two cast-iron pole pieces weigh about 600 lbs. each, and are 28$\frac{1}{2}$ inches in length, parallel with the shaft. The bore of fields is 12$\frac{7}{16}$" diameter; the armature core is 11$\frac{1}{16}$" diameter by 20$\frac{1}{2}$" long, and when wound the finished armature is 12$\frac{1}{4}$" over the bands, the clearance being thus $\frac{3}{32}$" all round. The weight of iron in the armature core is about 400 lbs., the number of commutator segments is 52, and the speed is 1000 revolutions per minute. Each field limb is wound with 160 lbs. of copper wire—320 lbs. on both. The armature is wound with 133 lbs. of copper wire, one-third the weight of the iron disc core. The resistance of the shunt is 22.7 ohms, cold, and of the armature between opposite bars .009 ohm, the ratios being as 2500 to 1. As a shunt wound machine run at 110 volts and 320 amperes the output is 5.18 watts per lb. gross weight: 77.7 watts per lb. total copper wire, and 264.66 watts per lb. of wire on the armature. When compound wound the series winding of this machine is composed of 10 wires in parallel, making 5 complete spirals round each limb outside the shunt winding. Its resistance is .001 ohm.

The armature cores in all the Edison machines are built up of the softest disc iron .006" thick, separated by thin manilla paper, and every fifth disc is more widely separated from the next by several thicknesses of the same paper. In the three machines above mentioned there are two layers of wire on the armature, of which each section is wound once around the core.

Brush low tension Incandescence Machines (Fig. 6).

The Brush incandescence machines are much lighter than the Edison for the same output. The new type which is being put upon the market has closed Gramme ring armatures connected to 60 segments in the commutator, the old type of machine, with only eight armature seg-

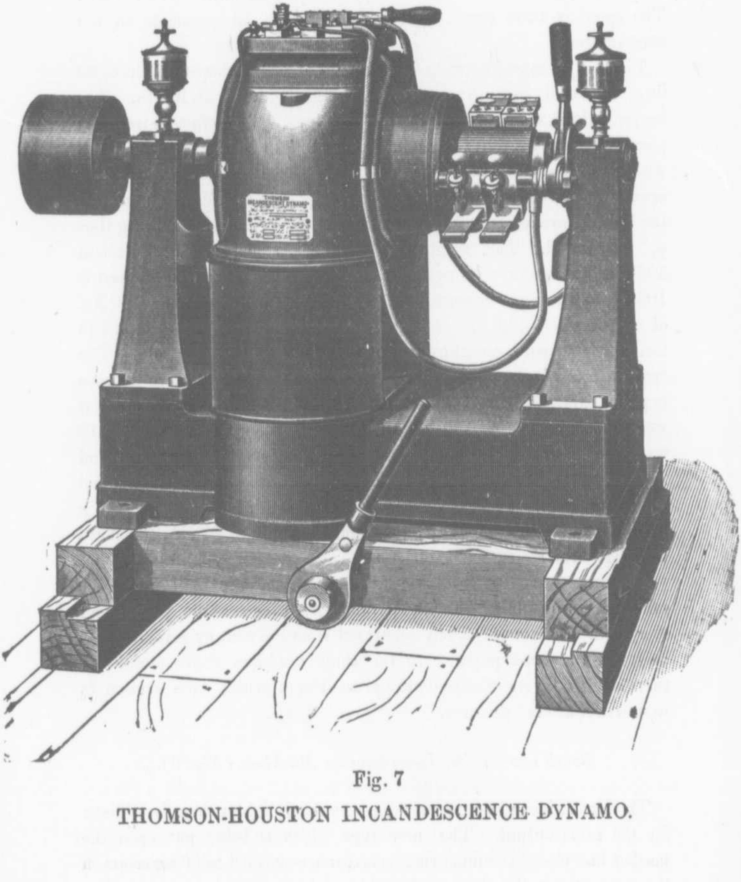


Fig. 7

THOMSON-HOUSTON INCANDESCENCE DYNAMO.

ments, as in the arc light machine, having been recently abandoned. Of this new type of machine particulars have not yet been given. The old 250 ampere machine weighs 2300 lbs ; the weight of iron in the armature, which is composed of laminated hoop iron, is 178 lbs., and the weight of iron in the fields is 400 lbs., the weight of copper on the armature is 148 lbs., shunt 360 lbs. and series coil 346 lbs. The gross weight of the 360 ampere machine is 3200 lbs; the weight of iron in the armature is 258 lbs. and the weight of copper is 184 lbs: on the fields there are 444 lbs. of copper in the shunt and 460 lbs. in the series coils. The output of the 250 ampere 105 volt machine is 11.4 watts per lb. gross weight: 30.73 watts per lb. of the total copper wire, and 177.36 watts per lb. of wire on the armature. For the 360 ampere 105 volt machine these figures are 11.81 watts per lb. gross weight; 41.81 watts per lb. of copper on machine, and 205.43 watts per lb. of copper on the armature. The speeds are 1200 revolutions and 1100 revolutions per minute respectively.

The largest Brush machine, first made for the Cowles Smelting Co. of Lockport, N. Y., is equally adapted for the smelting of aluminum or the production of current for incandescent lights. Its capacity is 3200 amperes at 86 volts. It has 5424 lbs. of copper on the fields and 1600 lbs. of iron and 825 lbs. of copper in the armature. The total weight of the machine is 22,000 lbs., and the output 12.51 watts per lb. gross weight; 44 watts per lb. of the total copper wire, and 332 watts per lbs. of wire on the armature.

Thomson Incandescence Dynamo (*Fig.* 7).

This incandescence machine, which is made in Canada by the Royal Electric Co., is very similar to an inverted Edison dynamo. The wrought iron keeper is dispensed with, the bed casting forming the yoke between the field cores. The armature is built up in the same manner as in the Edison machine, of wrought-iron discs, but thicker, and instead of paper insulation between them, vulcanized fibre is used. The 250 ampere 110 volt Thomson machine weighs 5260 lbs. complete. The armature core is $14\frac{1}{2}''$ long by $11\frac{1}{2}''$ diameter, and is wound with $130\frac{3}{4}$ lbs. of No. 4 wire to $12\frac{3}{4}''$ diameter over the bands. The bore of the fields is 13", thus allowing a clearance of $\frac{1}{8}''$ all round the armature. There are 76 segments in the commutator. The field cores, which are of wrought iron, are $10\frac{3}{4}''$ diameter by $12\frac{3}{4}''$ long, and are wound with $120\frac{1}{2}$ lbs. of No. 15 wire, and the series coil of four No. 8 wires weighs 62 lbs. The speed of the machine is 1300 revolutions per minute.

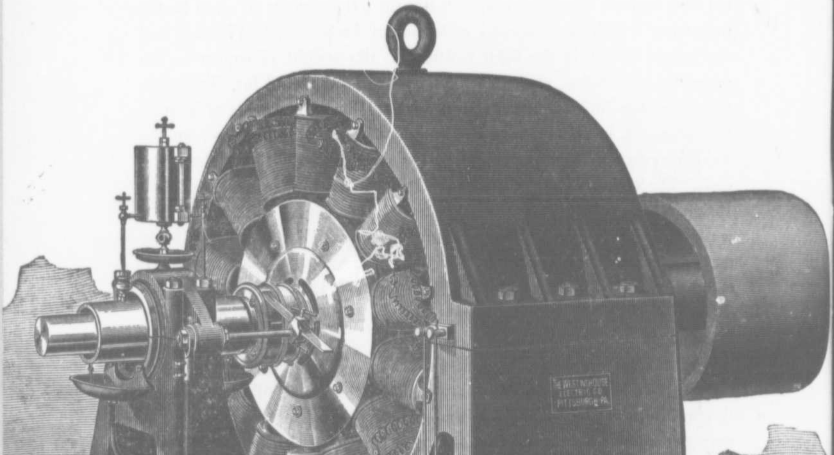


Fig. 8.

WESTINGHOUSE A. C. DYNAMO.

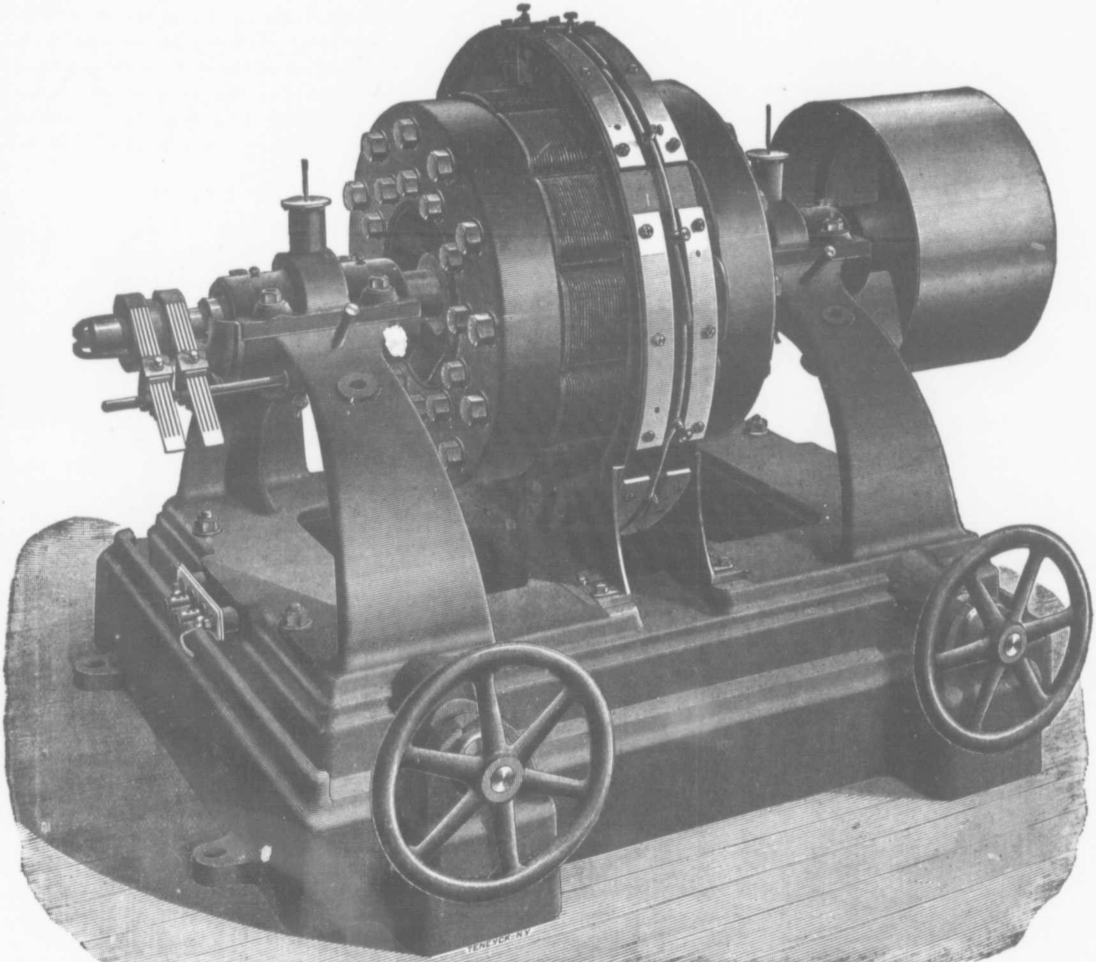


Fig. 9.

BRUSH A. C. DYNAMO.

The output is, therefore, at full load 5.23 watts per lb. gross weight; 87.79 watts per lb. of copper wire on the machine and 210.3 watts per lb. of wire on the armature. One peculiarity of this machine is the manner in which the series coils are wound over the armature itself and not over the field limbs as in other dynamos. The regulation of the machine is not perfect, but is fully equal to that of the compound-wound Edison dynamos.

ALTERNATING CURRENT DYNAMO MACHINES.

Westinghouse Dynamo (Fig. 8).

In a description of alternating current apparatus, the first place is due to the Westinghouse Electric Co., of Pittsburgh, organized in 1886, the pioneers on this continent in the supply of the A. C. system of distribution of electricity.

The Westinghouse 1500-light machine weighs 9750 lbs. complete. The armature, which is built up of laminated discs of soft iron, is in the form of a hollow cylinder, $20\frac{7}{8}''$ in diameter and 21″ long, and weighs 1440 lbs. It is wound with 30 lbs. of No. $10\frac{1}{2}$ B. & S. gauge wire, and its weight complete is 1600 lbs., including the shaft. The total weight of the castings in the field and bed plate is 6838 lbs. The weight of copper wire on the field bobbins, which are twelve in number, is 1257 lbs. The current from the machine at full load is 75 amperes, and the pressure 1050 volts. The output is thus 7.7 watts per lb. of gross weight: 58.27 watts per lb. of copper wire on the machine, 2500 watts per lb. of wire on the armature. The speed of the machine is 1375 revolutions per minute, and the periodicity 136. The exciting current is 14 amperes at 110 volts pressure, equivalent to 1540 watts, or nearly 2 E. H. P.

Brush A. C. Dynamo (Figs. 9 and 10).

This dynamo and the other details of the Brush Company's alternating current system are the invention of Mr. Gustave Pfannkuche, who, as will be observed, has made a radical departure from the usual construction of dynamos and converters hitherto adopted in this country, and obtained results in point of efficiency and general excellence of design, not surpassed, if equalled, in any other system.

The machine shown in the engravings is the 1000-light alternator. Like all the Brush A. C. dynamos, it is intended to be run at from 2000 to 2200 volts. This machine delivering 30 amperes at that pressure runs at 1100 revolutions per minute at full load, at

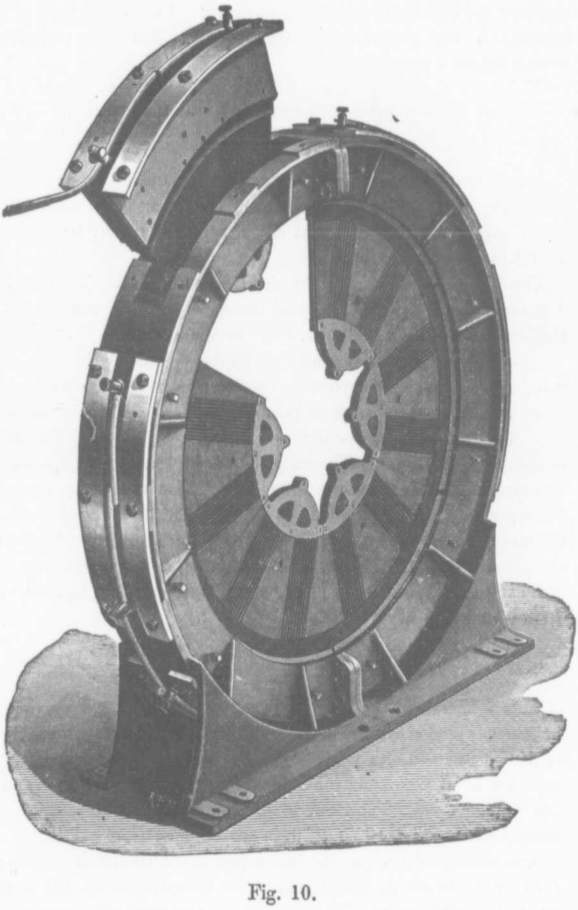


Fig. 10.

ARMATURE OF BRUSH A. C. DYNAMO.

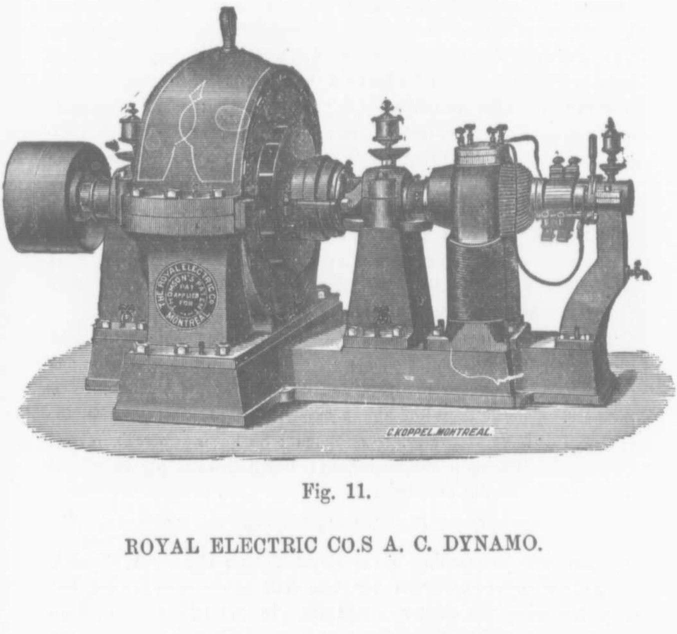


Fig. 11.

ROYAL ELECTRIC CO.S A. C. DYNAMO.

which it takes 100 H. P. to drive the alternator and exciter. The exciting current of 22 amperes and 135 volts is supplied by a small Brush arc light dynamo. The regulation is effected by sending part of the current from the exciting dynamo through a shunt box of varying resistance operated by hand. Very little regulation, however, is required, as the machine is nearly self-regulating from no load to maximum load. The armature (Fig. 10) is stationary and the fields revolve, this being the only A. C. machine in America so constructed. Such a construction has many advantages: in the first place the revolving part has only a low tension current passing through its coils, and being heavy and perfectly balanced acts as a fly wheel and regulator when from any cause there is a tendency in the prime motor to slacken speed. The wires from the switchboards are permanently attached to the ends of two coils of the armature. The armature coils are light and independently bolted to the ring which holds them in position between the field bobbins. Should an accident happen to one of the armature sections, the latter may be replaced in five minutes by one man, the weight being only a little over 20 lbs. The armature core is composed of fibre in segments on which are wound copper ribbons insulated by silk and shellac. The total weight of the armature ribbon is 63 lbs., and of the complete machine 5120 lbs.

There are 12 cores of alternating polarity on each side of the field wound with 618 lbs. of copper wire. These cores are of wrought-iron bolted to two iron plates, and the weight of the twelve is 456 lbs. The output of the machine, 60,000 watts, is at the rate of 11.71 watts per lb. gross weight: 88.1 watts per lb. of the total copper on armature and cores, and over 952 watts per lb. of the copper ribbon on the armature.

The Royal Electric Co.'s Dynamo (Fig. 11).

Sometimes the machines of the Royal Electric Co. for A. C. work are made with the exciter on the same shaft as shown in the cut, but more frequently the exciter is separate. In the 1200-light dynamo with separate exciter, the active iron in the fields weighs about 3400 lbs., and the iron rings of the armature (which is a hollow cylinder built up of laminated wrought iron) weigh 1250 lbs. The radial depth of these rings is 5″. When turned up ready for winding the armature is $24\frac{5}{8}$″ diameter and $18\frac{1}{2}$″ long. The diameter when wound is $25\frac{1}{8}$″ over the bands, and, as the internal diameter of the field bobbins is $25\frac{1}{2}$″, there is a clearance of full $\frac{3}{16}$″ all round. The fields are wound with 845 lbs. of No. 8 B. & S. gauge wire; the armature winding con-

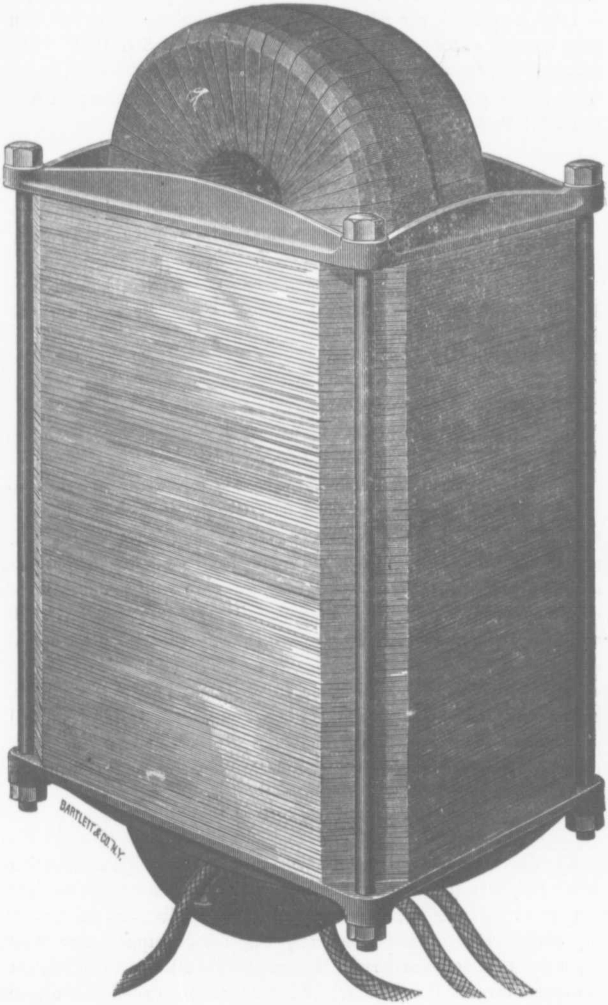


Fig. 12.

CORE OF WESTINGHOUSE CONVERTER.

sists of 32 lbs. of No. 11 B. & S. gauge wire. The speed of the machine is 1200 revolutions per minute, and the exciting current at full load is 24 amperes and 90 volts—say 2160 watts or nearly 3 E. H. P. The standard output of the machine is 70 amperes and 1020 volts, or 7.5 watts per lb. gross weight: 81.41 watts per lb. of the total copper wire and 2231 watts per lb. of the wire on the armature.

RATE OF ALTERNATION OR PERIODICITY.

In the Brush dynamo the periodicity is 110, while in the Fort Wayne, Westinghouse and Thomson-Houston machines the periodicity is from 125 to 136.

The European practice as to the rate shows considerable variation Messrs. Ganz & Co., of Buda Pesth, in the Zipernowsky system use 42 cycles; Mr. Ferranti uses 68; Lowrie-Parker work their machines at 80; and Mr. Mordey runs his at 100.

CONVERTERS.

Westinghouse Converter (*Figs.* 12 *and* 13).

The Westinghouse converter is of the shell type. In the 40-light converter, the core is built up of plates .017 inch thick, of which the total weight is 81 lbs. The primary winding of No. 16 wire weighs 10½ lbs., and the secondary wire is No. 3 gauge, 13¼ lbs. in weight. At 50 volts and 40 amperes this converter gives an output of 19.09 watts per lb. of active material. The P. D. required between primary terminals is 1000 volts, developing an E. M. F. of 50 volts at the terminals of the secondary coil.

Recent tests by Dr. Louis Duncan, of John Hopkins University, show 95 per cent. efficiency in a 40-light converter at full load, and only 84 watts loss with no load, and 90, 87.6, 83.3, and 70.7 per cent. efficiency in a 20 light converter at full, three-quarter, half and quarter loads respectively.

Brush Converter (*Figs.* 14 *and* 15).

The Brush converters are of the core pattern, with the exception of the two of smallest size. The iron wire in the core of the 50 light converter weighs 92 lbs., the primary wire weighs 20 lbs., and the secondary winding 11 lbs. At 100 volts and 30 amperes its output is thus 24.39 watts per lb. of active material. The case weighs 100 lbs. The 75-light converter core of iron wire weighs 115 lbs., primary winding of copper wire 21 lbs., and secondary winding 15 lbs. At 100 volts and 45 am-

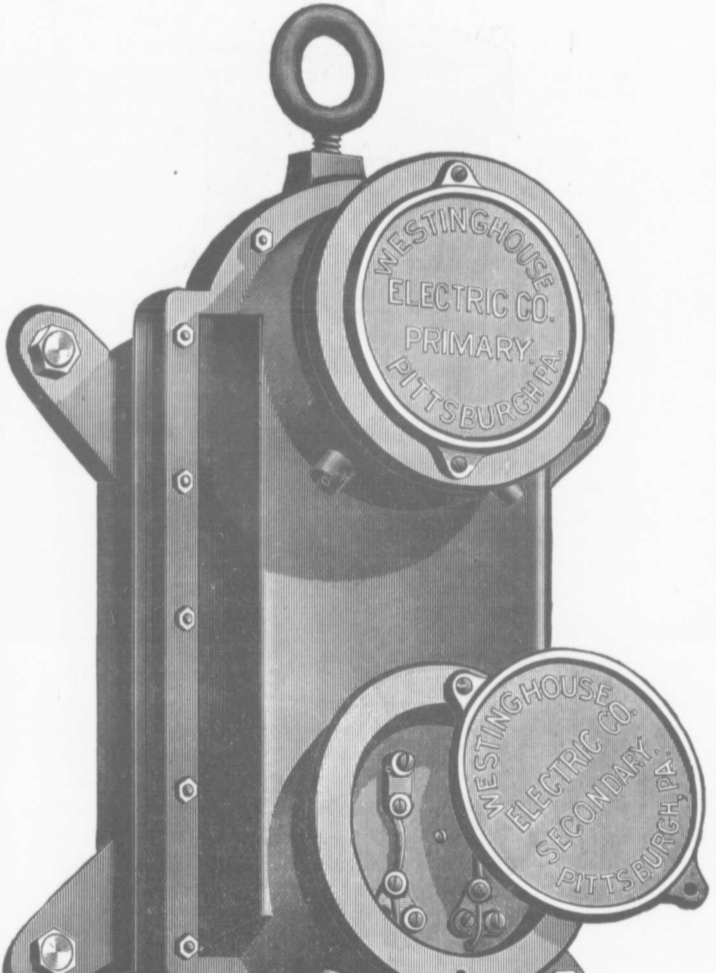


Fig. 13.
WESTINGHOUSE CONVERTER IN CASE.

Fig 14.

20 LIGHT BRUSH CONVERTER IN CASE.

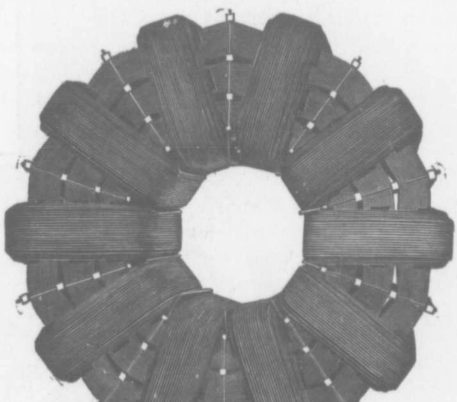


Fig. 15.

LARGE SIZE BRUSH CONVERTER (Case removed).

peres the output is 29.8 watts per lb. of active material. The case weighs 110 lbs. These converters are made in standard sizes of 5, 10, 20, 30, 40, 50, 75, 125, 250 lights and up to 1000 lights capacity. They are also made for primary circuits of 1000 volts pressure with a ratio of conversion of 10 to 1 or 20 to 1. The core consists of the finest Swedish iron wire, insulated by cotton winding or braiding wound into an octagon form, by having pieces of wood placed under and through the coils, as shown. The secondary wires are then wound over the sections between the wood blocks with insulated pads between them and the iron wire at the corners. Over the corners of the secondary winding are placed other insulating pads, over which are then wound the fine primary wires. There is thus an air space for insulation all round the different coils except at the corners where the wires lie on the insulating pads. The efficiency of a 75-light converter varies from 98 per cent. with 75 lights attached, to 93 per cent., with 38 lights.

THOMSON CONVERTER.

The Thomson converter, manufactured by the Royal Electric Company in this city, is similar in construction to the Westinghouse. The following are the particulars of the 30-light size: Iron discs, 108 lbs. primary wire, 920 feet No. 18 B. & S. gauge, $4\frac{3}{4}$ lbs.; secondary wire, 44 feet No. 8 B. & S. gauge, two in parallel, 4 lbs.; total active material, $116\frac{3}{4}$ lbs. with an output of 13.20 watts per lb.; case, $59\frac{1}{2}$ lbs.; weight complete, 176 lbs.

METERS.

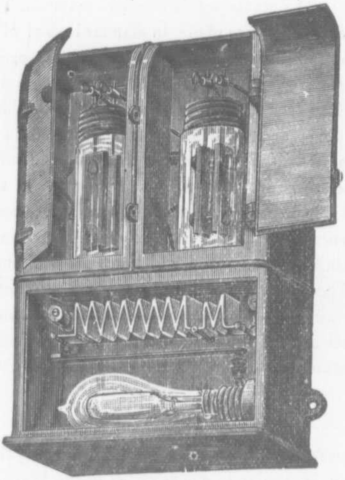
Edison Meter (*Figs.* 16 *and* 17).

In the Edison system of distribution an electrolytic meter has been employed. A disadvantage connected with its use is that nobody except an employee of the company can find out what the meter has registered, and even he has to take every precaution in the washing and drying of the electrodes, and in their accurate weighing in a chemical balance. This meter has been very extensively used, and has evidently given fair satisfaction, but the following statements from some of the superintendents of Edison stations show that satisfaction is not general:

"The confidence is fully as great as in gas meters."

"They [the customers] have as much confidence in the Edison meter as in the gas meter, and probably a little more."

"The meter to our customers is a blank, and it becomes a question of confidence in the meter man."



E DISON METER. Fig. 16.

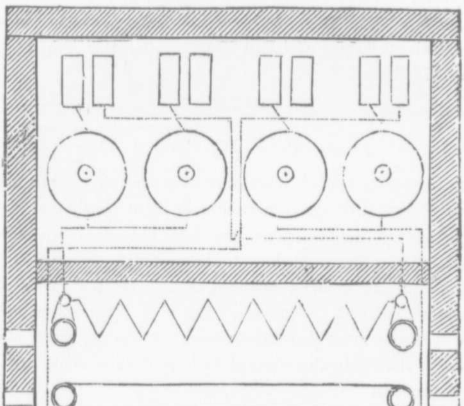


Fig. 17.

CONNECTIONS OF EDISON 3-WIRE METER.

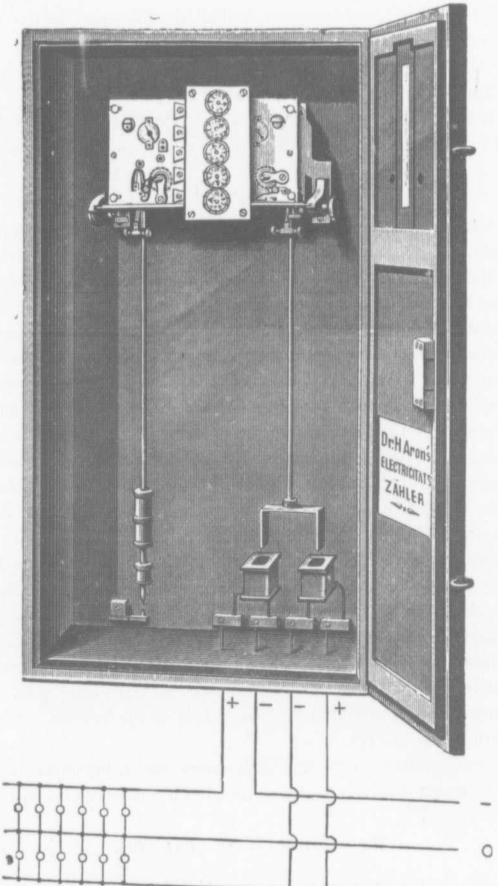


Fig. 18.

ARON'S 3-WIRE METER.

"Our meters here are a great deal of trouble owing to the number we have in use, but still we could not get along without them."

Sir D. Salomons, in the last edition of his work on electric lighting, describes the Edison meter as a thing of the past.

It is but fair to the Edison Company to say that they do not recommend their meters being used in stations of less than 1000 lights capacity.

Aron Meter (Figs. 18 *and* 19).

The Aron three-wire meter (Fig. 17) is used in all the large Edison stations, and by some other companies in Germany. It is a most admirable and reliable instrument, and it is one from which the consumer himself can learn what he is using. The one shown in Fig. 18 is applicable to the two-wire direct and A. C. systems. The registering apparatus consists of two sets of clockwork which will run forty days with one winding, but which it is intended to wind up every thirty days, when the readings are taken. The pendulum on the left is an ordinary pendulum uninfluenced by the current, but that on the right consists of a coil of very fine wire, which is connected direct to both the positive and negatives wires of the system, while one of the main wires, either the positive or negative, forms a solenoid through which the main current passes, enveloping the fine wire pendulum core.

Before any current is passed through the meter, it should be tested in place to see that the pendulums swing synchronously. If they do not, the indications of one pendulum will gain upon those of the other. The exact adjustment to perfect synchronism is obtained by raising or lowering the weight on the left hand pendulum. If found correct the current is passed through the meter, and the right hand pendulum's movement being accelerated by the action of the current, causes the registering gear to work.

The chief obstacle in the way of the more general employment of this meter is its comparatively high first cost, but it appears to be well worth the money.

Shallenberger Meter (Fig. 20).

The Shallenberger meter is the one which has been most extensively used in America for the measurement of alternating currents, having been exclusively used in the Westinghouse stations, and being now largely used in those of other companies. About 12,000 are now in use. It is simply a small alternating current motor with registering gearing, and attached vanes placed on the shaft to retard the movement to a degree necessary for adjustment and regulation. Its chief

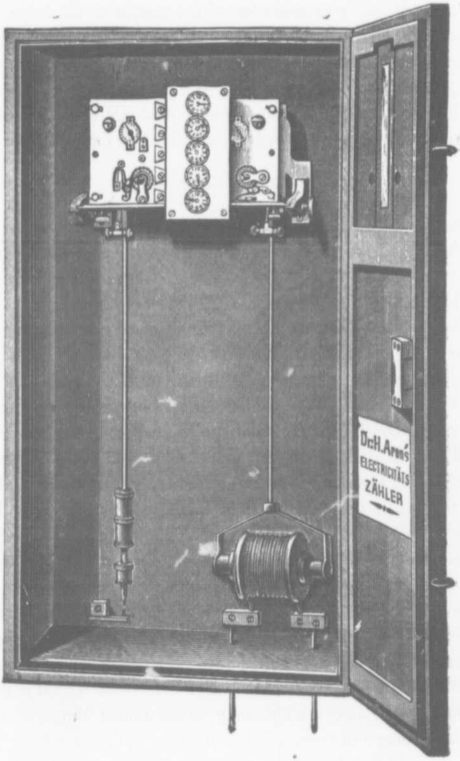


Fig. 19.

ARON'S A. C. METER.

disadvantage is that it does not work readily with a small current, but as this tells against the company and not against the consumer, the latter will not probably have any objection to it. This meter will be better understood by examination of the sample on the table.

Alternating current meters have also been made by the Fort Wayne Electric Co. and the Thomson-Houston Electric Co.; but the latter is not yet on the market, and as the author has no experience of either he prefers not to describe them, but would refer members to the "Electrical World" or "Electrical Engineer" for full particulars.

STORAGE BATTERIES.

Storage batteries have not been applied on this continent to any such extent as they have been in Europe. Wherever they are employed except for propulsion of about a dozen street railway cars, perhaps fewer, it has been for the purpose of securing light after engines and dynamos have been stopped at night, and for railway car lighting. For the latter purpose they have not hitherto been a success, and have been discontinued on the Pennsylvania Road, on the Canada Atlantic and on the Grand Trunk Railways, the Julien battery having been used in these cases. On the Intercolonial Railway a great number of cars have been fitted up with these batteries, and it is said several additional charging stations are to be erected, it having been found that the two at present in operation, one at Levis and the other at Moncton, together with such current as may be obtained at Halifax, N.S., and Montreal, have been insufficient, or otherwise expressed, the capacity of the batteries supplied has not been enough to last during the runs between the various stations. The fact that the coal oil lamps, which were wisely left in position, are used on nearly every trip, proves the inadequacy of the batteries which have been supplied for this work.

Outside of these plants storage batteries have been used in five or six places in Canada, among which may be mentioned McGill College, the lights there being run from a Gibson battery in the basement. The battery is charged from a small shunt wound dynamo driven by an Otto Gas engine made by Crossley Bros. of Manchester.

A PRIVATE INSTALLATION.

The same kind of plant and the same kind of battery are used in the residence of Mr. F. R. Redpath, the arrangement of which is shown in Figs. 21–24. The plant is in the basement of the house. The gas engine is an Otto made by Messrs. Schleicher, Schumm

Fig 21.

Fig. 22.

Mr. F. R. REDPATH'S INSTALLATION.

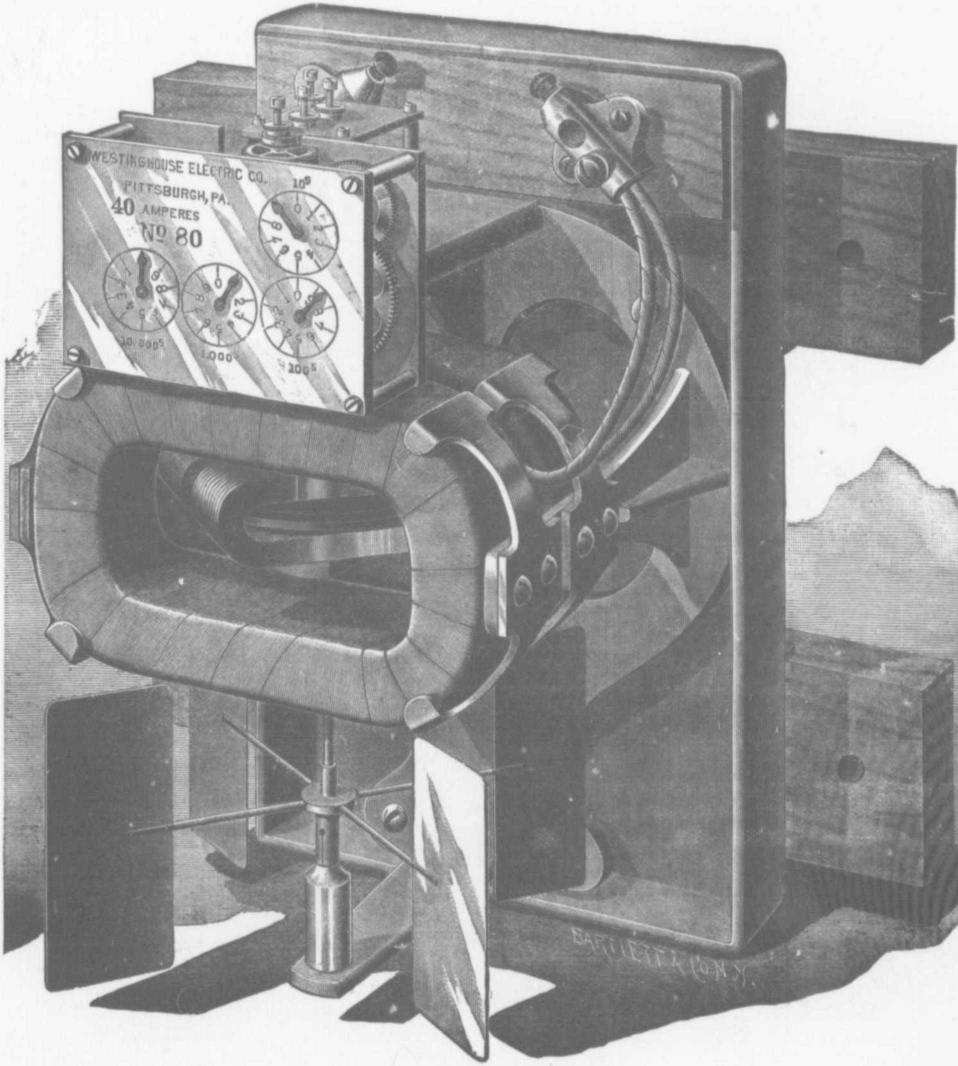


Fig. 20.

WESTINGHOUSE A. C. METER.

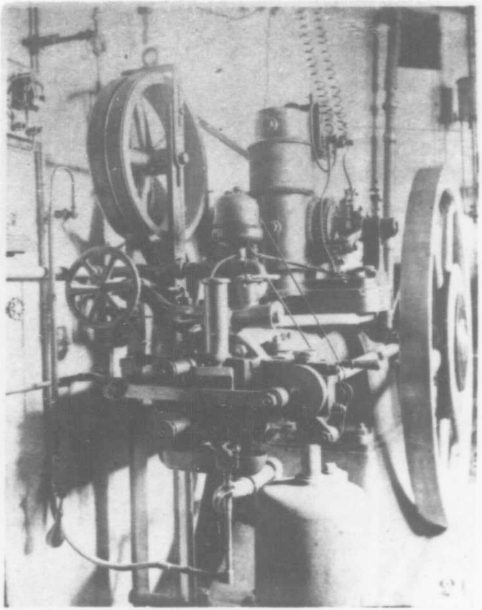


FIG 21.

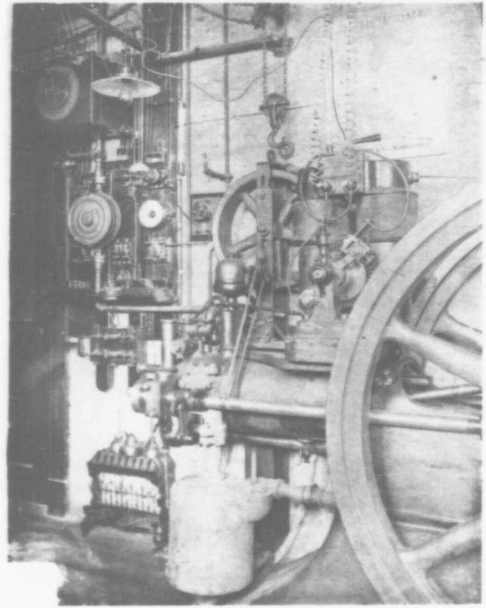


FIG. 22.

Mr. F. R. REDPATH'S INSTALLATION.

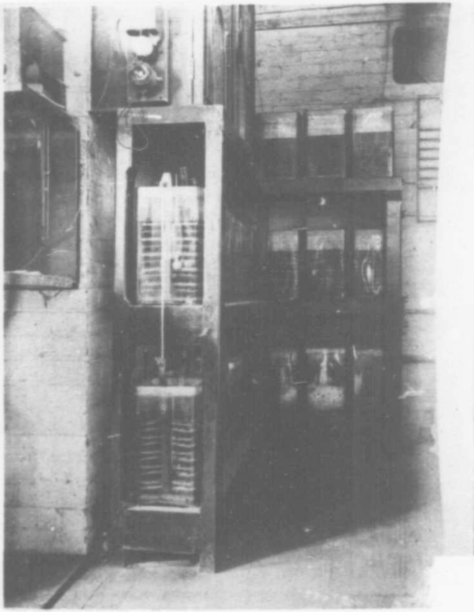


Fig. 23.

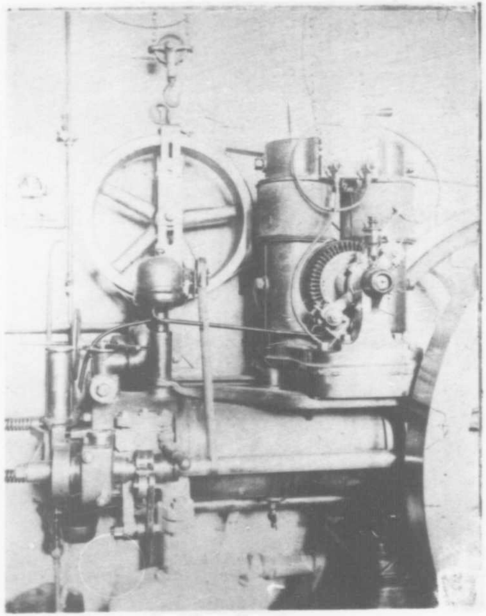


Fig. 24.

Mr. F. R. REDPATH'S INSTALLATION

& Co., of Philadelphia, and is the steadiest running gas engine in Canada. Its weight, with two 54-inch fly wheels, is about 3200 lbs. It indicates 3.9 H. P., with a gas consumption of 26 cubic feet per H. P. per hour. Over the cylinder is a cast-iron saddle, on which the dynamo, a shunt wound machine made by Holmes & Co., of Newcastle-on-Tyne, England, is placed, there being just one quarter of an inch clearance between the rims of the fly wheels and the ends of the dynamo bed. Behind the dynamo and attached to the bed of the engine are two wrought-iron adjustable arms carrying the countershaf and idler pulley. The dynamo pulley is therefore between the idler and the fly wheel of the engine, is double crowned and is lapped over nearly the whole circumference by two belts as shown. The slip is less than 2 per cent. The speed of the engine is 180 revolutions per minute. The dynamo weighs 430 lbs., and the idler pulley and countershaft 100, so that the total weight of engine, dynamo and driving gear is 3800 lbs. A box 7′ 4″ × 2′ 8″ × 5′ 2″ would cover engine, dynamo, belting, idler pulley and countershaft, and the whole might be thus shipped to any distance completely set up ready for connection of gas and exhaust pipes. The arrangement of the plant was designed by Mr. Redpath, and is most compact and ingenious.

There are 42 cells of Gibson battery, capacity 150 ampere hours, and they are connected in two sets of 21 each in parallel, the changing current being 33 amperes at from 45 to 55 volts pressure. These cells are ranged on shelves in the engine room. The plates in this battery are placed horizontally instead of vertically as in other batteries, and have thus the advantage of being less liable to short circuiting through paste falling between them as it does in vertically arranged plates. A slight disadvantage is that the internal resistance is higher than some other forms of battery owing to the plates being further apart; but this is compensated for by the longer life of the Gibson, the makers guaranteeing to keep it in order for ten per cent. per annum of the first cost. The electrolyte used is dilute sulphuric acid with the addition of sulphate of soda, the density of the combined solution being 1.220. This battery will stand heavier charging than any other, and has frequently been charged with a current of 75 amperes; but the most economical practical charging rate is about 30 amperes. In charging the current is measured by Weston ammeter and the pressure by a Weston voltmeter. There is also another Weston voltmeter in the library upstairs, and underneath it a resistance switch of German silver in series with the battery, by which the pressure in discharging is regulated, as the battery, when first connected to the lamps after charging, is higher in E. M. F. than when nearly discharged, the lamps used being of course of such voltage that they will give their full light at the lowest pressure to which the battery in practice is reduced. The maintenance of perfectly uniform light is thus under control from Mr. Redpath's arm chair.

This is the first and only complete private installation for residential lighting in Canada, and was first started five years ago, shortly after the visit of the British Association to this country.

VALLEYFIELD AND BARRIE CENTRAL STATIONS.

Let us describe briefly and compare these central stations, both constructed by the writer, and good samples of their respective classes. Both have water power, but the first is on the Edison three-wire system and the second is a Brush A. C. plant. In Valleyfield the power is in the heart of the town and in the centre of distribution, so that it is in the most favourable position for economical distribution by low tension, and the wire used is as small in area as consistent with even voltage at the lamps and greatest efficiency of the plant. Both stations were built with rooms for the man in charge over the dynamo room. The running expenses are the same or about the same in both places. Probably no other stations of similar capacity in the world cost less to run, the total annual expense in each being less than $1600. The capacity of both stations is about the same, say 60,000 watts. The Valleyfield station complete cost $40,000, including building, water-wheels and flume. The Barrie station, with the same items, cost less than $22,000, including over $3000 for the wire leading into town from the station, five miles distant. In the Barrie plant heavily insulated wire is used throughout the 24 miles of street wiring, and rubber-covered wire in all buildings, whereas bare wire is used at Valleyfield for street wiring, and fire and weatherproof wire for inside work. House wiring in Valleyfield is all cleat work: most of that at Barrie is concealed, the lights in the latter place being principally in private houses and placed on brass fixtures, whilst at Valleyfield drop cords are used exclusively. The pressure in the houses in Valleyfield is generally 220 volts, the three wires being carried in in all cases where this system is used, in order to maintain as even a load as possible on both sides of the circuit. In Barrie the pressure is 93 volts on the lamps in the houses, and nothing higher than 98 volts can ever enter them. The charge for current averages at Valleyfield $9 per light a year, and at Barrie $7.50. This means that, making due allowance for all contingencies in both cases, the

Barrie plant will pay its shareholders better than the Valleyfield plant will, while the customers pay $1.50 per light a year less. In the Barrie station Westinghouse meters are used on the premises of the largest consumers, and these can be read by the consumer as well as the meter man, the cost of operating the station is not increased, the man who attends to the wiring of the buildings in town and to collection of accounts taking the readings; while if the Edison meter be used at Valleyfield, another man will require to be employed to attend to the meters solely, and his wages will have to be added to the operating expense and thus reduce the net revenue.

The respective sizes of wire used in both stations is worthy of study. At Barrie the loss in the feeder is $14\frac{1}{2}$ per cent. at full load, nearly the same as at Valleyfield. The length of feeder at Barrie is 10 miles for the complete circuit, and the size of wire No. 4 B. W. G. At Valleyfield the feeders are three in number and three in a set; the longest is less than two miles for the complete circuit, and the size of the outside wires No. 000 B. W. G. The No. 4 wire used at Barrie weighs 985 lbs. per mile, including insulation, and the No. 000 bare wire at Valleyfield weighs 2886 lbs. per mile.

It may be and has been said that in the one case there is a perfectly safe low tension system, while in the other, to use the pet phrase of the paid advocate of low tension, the New York State Electric Executioner there is the "Deadly Alternating Current." That is admirable as a trade trick, but even the Edison Company now advertise that they are prepared to supply A. C. plant to all who desire it. Either there is less danger in the A. C. system than they would have the public believe, or they are ready to subordinate principle to pocket in the contest. To alter slightly a phrase from Dickens' "Holiday Romance," the Edison people have been advising the public to "Prohibit the use of the alternating current system on the ground of humanity as it makes ours too expensive." In an article on the subject, Sir William Thomson, the greatest living authority on electrical matters, says :

"*In passing I may remark that* 100 *volts in the house is perfectly* "*safe to the user, whether the current be alternating or continuous, as* "*is proved by large and varied experience in England.*"

It must be freely admitted that the accidents reported from New York were real and not invented for sensational purposes, but it must also be acknowledged that in no other city in the world is there such an organization as the Board of Electrical Control, to which appointments are made by political influence only, regardless of qualification, and one of whose advisers is, or was, an individual whose business it was for the past two years to discredit the alternating system, for which service he was well paid. In no other city in the States or Canada is there such bad construction of overhead conductors as there was in New York. The under-ground construction there is nearly as dangerous on account of existing grounds on the wires and leakage of current and the consequent liability to cause explosions of gas in subways, as has already been repeatedly done, besides turning the paving stones into "a molten mass."

Furthermore, the insulation of the overhead wires, which have been in use in some cases over eight years, had rotted off, being of the quality known as "Underwriters," or "Undertakers" if you will.

Four deaths have occurred in the whole history of electric lighting in Canada from shocks of electricity, and two of these were the result of bad insulation of wires and faulty construction by a purchasing company doing its own work, without employing anybody having any knowledge of the business, in order to cheapen the first cost of the plant, and which purchased a job lot of poorly insulated wire, and ran two dynamos in series with 100 arc lamps in circuit at a tension of nearly 5000 volts. The current used on that system was a continuous one, not a pulsating high tension current as stated in a circular which some of you may have received.

Reverting to the main subject: Thirty wires radiate from the Valleyfield station; one pair carry the current from the Barrie station. In the Barrie station the pressure of primary current is the highest which has yet been used in this country, being about 2100 volts average on the feeder. This pressure is raised or lowered by increasing or decreasing the exciting current according to the load shown on the central station ammeter, which is graduated to single amperes, and is indicated by a Cardew voltmeter, which, as elsewhere mentioned, is attached through a converter to the armature. Instead of having a compensator as is used in the Westinghouse system, a table of loads and the corresponding pressures to be carried at the station is used. This method, though of course not absolutely perfect, owing to the rise of current with increase of voltage and vice versa, answers very well. The Cardew voltmeter in the company's office in town, which is an excellent check upon the dynamo attendants' work, shows an average variation of two volts only in a night's run. The mains in town, which aggregate nearly 14 miles in length, are calculated for a loss of only 2 per cent. at full load, which gives a difference of $\frac{2}{3}$ of a volt per lamp up or down from the standard. The house wires, which are insulated with

Fig. 25.

WESTON VOLTMETER.

rubber and tape are calculated for one per cent. loss only at full load As most of the lights are taken in private residences, where the whole number are hardly if ever in use at one time, the loss of light through resistance of the house wiring is practically nil.

MEASURING INSTRUMENTS.

The Ayrton and Perry instruments have been used to a very considerable extent in this country, and until recently were the most accurate of all really portable electrical measuring instruments. There is a sample on the table before you. They are only suited for direct. currents, and are open to the objection that they have considerable friction and a high temperature error if kept in circuit, which they should never be except only for a few seconds when taking readings.

The Weston voltmeter is shown in Figs. 25 and 26. These voltmeters have the great advantage of extreme accuracy and very high resistance, averaging about 20,000 ohms, so that the quantity of current passing is extremely small. They may be kept continuously in circuit without any material variation in their readings. They require careful handling, of course, as do all electrical instruments, but they are the most accurate and reliable of all portable testing instruments for continuous currents. The voltmeters contain a calibrating coil by which their constancy can be at all times tested. The writer has used quite a number of these instruments which he has checked with each other, and has sometimes compared the higher and lower scale by taking the P. D. difference between terminals of single cells of secondary batteries, and then, putting the whole of the cells in series, compared the reading of total E. M. F. of the battery. Several tests of this nature have come out within one quarter of a volt. The calibrations are in single volts on the higher scale, and thirtieths, twentieths or tenths of volts on the lower scale. The ammeters read to tenths of amperes in the small sizes. In both the divisions of the scale are so wide that one quarter of these values can be read with perfect ease.

For the most perfect readings by these instruments they should be set quite level, and five feet away from any other instrument, or from any mass of iron or steel, and so placed that the index will point due west when at the centre of the scale, but these precautions are not necessary for ordinary testing of pressure in buildings, as the error can seldom be more than ½ volt, if otherwise placed.

The Cardew volt meter (Fig. 27) is used for both direct and alternating currents, and is made to be used either vertically or horizontally.

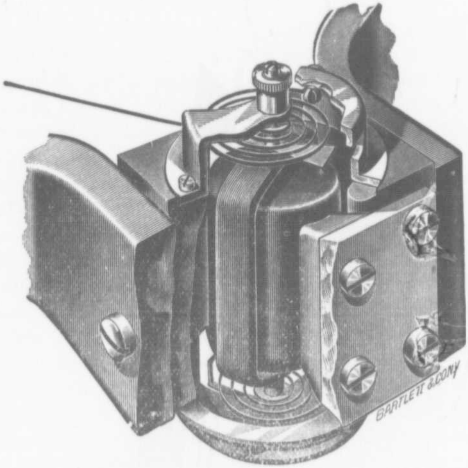


Fig. 26.
COIL AND MAGNETS OF WESTON VOLT-METER (Cover removed.)

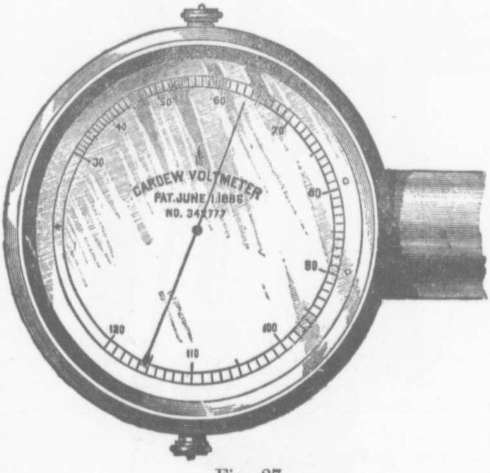


Fig. 27.
CARDEW VOLT-METER.

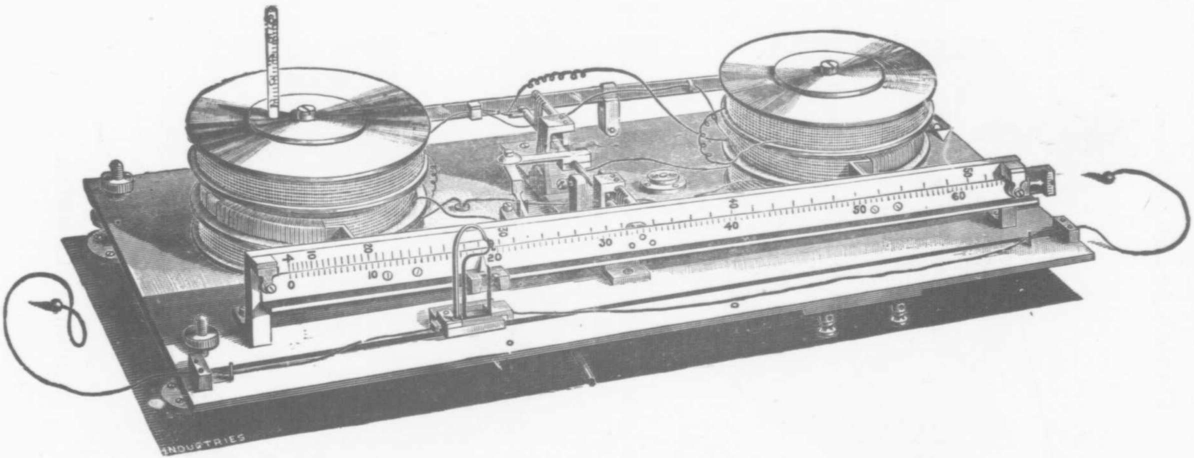


Fig. 28.

SIR WM. THOMSON'S ELECTRICAL BALANCES FOR DIRECT OR ALTERNATING CURRENTS.

The horizontal pattern has the advantage of being steadier than the vertical instrument owing to the disturbance caused by currents of air passing up the tube of the latter. All the more recent forms of this instrument have an adjusting screw outside of the case to bring the needle to zero, which should be done before the current is turned on. No adjustment should be made while the wire remains warm, as the section of the wire may be altered by any tension put upon it while in this condition and the calibration destroyed.

For alternating and direct currents Sir Wm. Thomson's latest instruments are the finest yet produced, but are more suited for standard or station use than as testing instruments. In the electrostatic-instruments no current passes through the instrument at all, and so the conditions of a battery or dynamo on open circuit can be found with perfect accuracy. The electrical balances (Fig. 28) are adapted for both alternating and direct currents. To any body desiring a fine standard laboratory or station set of large range, none are better than these instruments, expensive though they be. All stations for alternating current work should have a Cardew or Thomson voltmeter, a portable Thomson multicellular electrostatic voltmeter for testing pressure in consumer's premises, etc., and a Thomson ampere gauge. For direct current stations Weston or Cardew voltmeters for station work and line testing should be used, and Thomson ampere gauges for current measurement. The Westinghouse ammeter, an excellent instrument closely resembling the Thomson ampere gauge, is shown in Fig. 29, and the Edison ammeter in Fig. 30. For rough approximations the latter is a cheap and fairly accurate instrument.

TRANSMISSION OF POWER.

In his Address at the Annual Meeting, the President touched upon the subject of electrical transmission of power, mentioning the installation at the Chollar Mine, Virginia City, Nevada. There a Brush plant is used, as then stated, placed 1680 feet below the surface of the ground, in a chamber 50′ long by 25′ wide by 12′ high, hewn out of solid porphyry. The small stream of water, which drove the wheels at the surface of the mine,—was carried down through two iron pipes one 10″ and the other 8″ diameter, connected together at the bottom of the shaft by a Y into a single pipe 14″ diameter from which 6″ pipes lead to the Pelton water wheels' nozzles, there developing sufficient energy through the generators to transmit to the surface by well insulated cables 450 H. P. The waste water is conveyed away through the Sutro Tunnel, which pierces the side of the

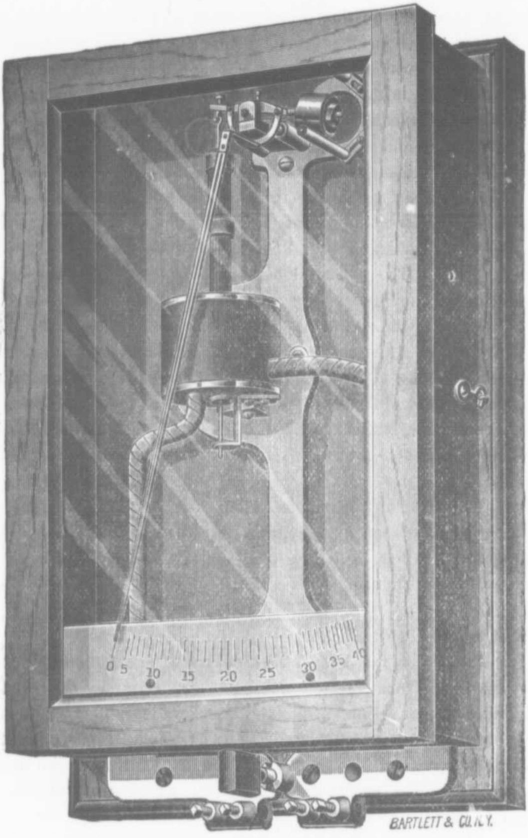


Fig. 29.

WESTINGHOUSE AMMETER.

mountain for the drainage of the mines—in itself a monument of engineering ability and Western enterprise. This is at present the largest installation in the world for transmission of power by stationary electric generators and motors.

About August last a generator and a motor of exactly the same type as those placed in the Chollar Mine were installed at Messrs. Barber & Co.'s Mills, Georgetown, Ont. The water of the Credit river was dammed over two miles below the mill, and a water wheel and shaft were placed in a building there along with the generator. A copper wire was carried back and attached to the motor, which develops 75 H. P. in the mill.

ELECTRIC RAILWAYS.

Four years ago there may be said to have been no electric railways in operation in America. Yet according to the most reliable sources of information there were 636½ miles of electrically equipped railways in operation and 700 miles under construction at the end of December, 1889: 1063 electric cars were then running and 771 cars were being equipped. The total number of completed roads was 107, and 85 were under construction. Of these roads two were running in Canada, their total length being 10 miles, and these were equipped with 10 motor cars. The first, at Windsor, Ont., with two miles of road and two cars, has now been at least four years in operation; the other is at St. Catharines, and the length of road is 8 miles, and it is equipped with 8 cars. Both roads use the Vandepoele system. The road at Victoria, B.C., is now running. The track is 4 miles long, with 6 motor cars. The Vancouver road, which is likewise 4 miles in length, and is to be equipped with 4 motor cars, will be running about the beginning of June. The Thomson-Houston system is used in both cities, and a contract for a short line in Toronto, on which two motor cars will be used, has lately been closed with the Thomson-Houston Company, which has done by far the largest amount of work in Electric railways, the Sprague Co. ranking next. The following table shows the amount of work done by various companies and that under construction in January last.

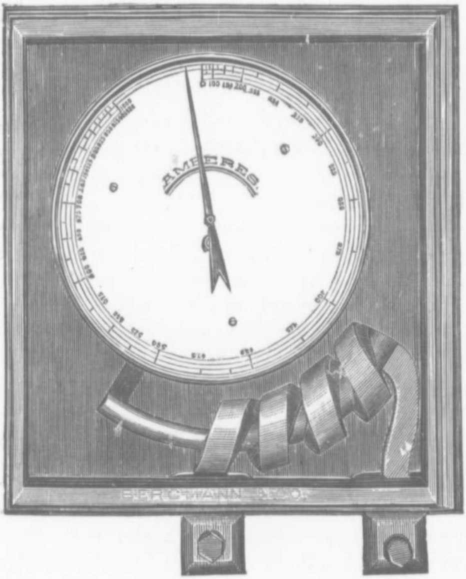


Fig. 30.

EDISON AMMETER.

ELECTRIC RAILWAYS.

In operation and under construction, Jan., 1890.

Name of System.	In operation.		Under construction.	
	No. of Roads.	No. of Cars.	No. of Roads.	No. of Cars.
1 Thomson-Houston	47	490	37	509
2 Sprague	35	408	33	218
3 Daft	10	66	5	15
4 Van de Poele	8	57		
5 Short	3	17	1	5
6 Bentley-Knight	1	6	1	20
7 National Electric Traction Co.	1	1	5	not given
8 Julien	1	10		
9 Fisher	1	4	2	not given
10 Henry	1	4		
11 Rae			1	4

Within the past few months great activity has existed in electric railways in the United States, and the two leading companies in this business have contracted for several hundreds of cars each; the lead of the Thomson-Houston Company having increased, while the Sprague Company has over 1200 motors cars in operation or in course of construction.

The largest electric street railway system in the world is that of the West End Railway of Boston, contracted for by the Thomson-Houston Company, of which the following particulars may be of interest: At the present time there are 150 cars running, and when completed there will be 600 in operation. Now there are 56 miles of road electrically operated, and 236 are to be equipped. In the power station from 3.30 till 7 p.m. the electrical plant, which is capable of developing, if called upon, 2500 H. P., usually furnishes from 1000 to 1500 H. P. The cars generally in use are 16 ft. closed cars, each carrying 30 passengers, and towing a similarly loaded car. Such a car, equipped with a single 15 H. P. motor, averages in speed 15 miles an hour on the level, and will pass a grade of 5½ per cent. at a rate of nine miles an hour. Such work is, however, rather severe for constant use, and for heavy work they are using two 15 H. P. motors. The potential used is 500 volts, and the average rate of speed is from 10 to 15 miles an hour. The weight of a motor car equipped is 6 tons. The cost of steam power is from one to four cents per car mile, taking 100 miles per car per day as a basis; the cost of operation and maintenance, four to six cents per car mile on the same basis; the cost of repairs to electrical apparatus is from one and a half to two cents per car mile; cost of management from one to two cents per car mile, and the average total cost of operation is nine and a half to sixteen cents per car mile, according to the number of miles operated.

Unfortunately the severe winters and heavy snow-falls of Montrea and other cities in Eastern Canada preclude the possibility of working electric railways the whole year on our present street roads, but it is a question worthy of the study of members of this Society, whether it would pay to operate our roads electrically during the seven months of open weather which we get, or if a system of overhead railways along our main traffic thoroughfares operated electrically, and which could be run the whole year round, would not be a good investment.

STREET WIRING FOR ELECTRIC LIGHTING.

First, on account of the dangers of break down from heavy sleet storms, and the variation in tension of wire caused by the extremes of temperature experienced in Canada, poles should be placed not more than 135 feet apart, or say 40 to the mile. They should all be good, sound, straight cedar, 7 inches diameter at the top, and not less than 35 feet long, and should be set in the ground to a minimum depth of 6 feet and securely tamped. The cross arms should be of sound timber $4\frac{1}{2}'' \times 3\frac{1}{2}''$, well painted, and fixed in gains cut in the poles and secured thereto by lag screws 8″ long, which would thus enter into the pole about $4\frac{1}{2}$ inches. They should never be attached by spikes only. Wherever telephone or telegraph wires run in the same streets, the poles should be of sufficient height to carry the electric light wires at least four feet above them. Bare wire for carrying either high or low tension currents in towns should be strictly prohibited. The insulation of the wire should be both fire-proof and weather-proof, and of such tough texture as to withstand abrasion should other wires by any means fall across the electric light wires. None but the best double petticoat glass insulators should be used.

For outside construction some of the English Board of Trade Regulations, which might be adopted with advantage in this country, are as follows, the numbers given being those of the Regulations:

1. An aerial conductor in any street shall not in any part thereof be at a less height from the ground than 20 feet, or when it crosses a street, 30 feet, or within six feet of any building for the purposes of supply.

2. Every support of aerial conductors shall be of durable material and properly stayed against forces due to wind pressure, change of direction of the conductors or unequal lengths of span, and the conductors and suspending wires (if any) must be securely attached to insulators fixed to the supports. The factor of safety shall be at least 6, and for all other parts of the structure at least 12, taking the maximum possible wind pressure at 50 lbs. per square foot.

5. Every aerial conductor shall be protected by efficient lighting protectors.

6. Where any conductor crosses a street, the angle between such conductor and the direction of the street at the place of such crossing shall not be less than 60 degrees, and the spans shall be as short as possible.

7. Where any aerial conductor is erected so as to cross any other aerial conductor, or any suspended wire used, for purposes other than the supply of energy, precautions shall be taken by the owners of such crossing conductors against the possibility of that conductor coming into contact with the other conductors or wire, or of such other conductor or wire coming into contact with such crossing conductor by breakage or otherwise.

11. The insulation resistance of any circuit using high pressure aerial conductors, including all devices for producing, consuming or measuring energy connected to such circuit, shall be such that should any part of the circuit be put to earth the leakage current shall not exceed $\frac{1}{25}$ of an ampere in the case of alternating currents. Every such circuit containing high pressure conductors shall be fitted with an indicating device which shall continuously indicate if the insulation resistance of either conductor fall below the conditions required by this regulation.

" 14. The owner of every aerial conductor shall be responsible for the efficiency of every support to which such conductor is attached.

" 15. Every aerial conductor, including its supports, and all the structural parts and electrical appliances and devices belonging to or connected with such conductors, shall be duly and efficiently supervised and maintained by and on behalf of the owners as regards both electrical and mechanical condition.

" 16. An aerial conductor shall not be permitted to remain erected after it has ceased to be used for the supply of energy unless the owners of such conductor intend, within a reasonable time, again to take it into use.

"17. Every aerial conductor shall be placed and used with due regard to electric lines and works from time to time used or intended to be used, for the purpose of telegraphic communication, or the currents in such electric lines and works, and every reasonable means shall be employed in the placing and use of aerial conductors to prevent injurious affection, whether by induction or otherwise, to any such electric lines or works, or the currents therein."

The author considers that rules 7, 13, 14, 15, 16 and 17 should be equally binding upon telegraph and telephone companies whose wires are often as carelessly constructed as those of any electric light company, and have in consequence been quite as blameworthy for fires originating from electric currents.

HOUSE WIRING.

In the interior wiring, none but high class rubber-insulated wire protected by an outer linen tape or other efficient covering should be used.

None but porcelain or slate base cutouts and switches should be allowed, and the sweating of drop wires for single lights on the main wires (such wires being afterwards twisted together and brought down to the lamp socket) should be prohibited.

Wherever lights are suspended by wires, stranded conductors, equal in area to No. 20 standard wire gauge, covered with a good solid rubber coating and protected on the outside by silk or cotton braiding, should be used, and where taken off from the main wires a porcelain rosette cut-out, such as the K. W. rosette, should in all cases be provided, or a wood base rosette may be used, provided it is rendered fireproof.

No switches should be used which do not break contact quickly and automatically, or in which spring copper makes a connection; such copper is heated by the passage of a large current, and by losing its hardness therefrom often fails to make good connection, and so may cause an arc to form. The Paiste switch is the only one at present made on this continent in which these objections are successfully met.

Fuses for cut-outs should not be interchangeable with others of widely different capacity. Over-loading of wires first designed for lighter loads would then be impossible.

The joints in wires are preferably made with connectors such as the MacIntyre wire joint, as soldered joints on which acid has been used frequently corrode through the excess of acid not having been removed on completion of the soldering, and it has been the author's experience that ordinarily wiremen will not take the time or trouble to make a good joint with rosin as a flux.

It must be remembered that a low tension continuous current is more liable to cause a fire in case of short circuit between the main wires than an alternating current, owing to the connection which exists directly between the dynamo and the house wires, permitting the entrance into the house of an enormous current, while with the alternating current system the short circuiting of the secondary house wires will only result in the immediate melting of the fine wire fuse in the primary circuit of the converter. There should be no relaxation, therefore, of adopted regulations in favour of low tension direct systems on account of supposed greater safety, a thing which does not exist in their case, but both direct and alternating current systems should be treated alike so far as the wiring of consumers' premises is concerned, and the present standard should be raised, not lowered.

It should not be forgotten, that one of the most important elements in the attainment of perfect safety to everybody concerned is the employment by supply companies of properly qualified and experienced labour both for the construction and for the running of plants. It will be found to be very poor economy to employ bell-hangers, plumbers and even shoemakers on work requiring considerable electrical and mechanical knowledge and clear judgment, as is done at the present time in some Canadian stations which might be mentioned, merely for the sake of saving two or three hundred dollars a year in wages, a sum which is much more than counterbalanced by the unsatisfactory results in the lighting and the additional cost of repairs. Nor should it be forgotten that a cheap and poorly constructed electric lighting plant is the worst of all possible investments.

To reassure the timid whose nerves have been so skilfully played upon by advocates of low tension systems, the following opinions of Sir William Thomsom, Dr. John Hopkinson, Mr. W. H. Preece, Professor George Forbes and Monsieur E. Fesquet, handed in at a recent meeting of the New-York Senate Committee on Electric Lighting, may be cited. These gentlemen, whose qualifications to speak authoritatively on the subject cannot be questioned, are practically unanimous in the opinion that the distribution by alternating currents can be and is safely carried out by underground or overhead wires at pressures of 2000 to 2500 volts; that absolute safety to the person can be and is obtained in the use of such currents; that there is less danger from fire from an alternating current system using converters than from a continuous low tension current connected direct from the dynamo to the consumers' premises (and the higher the tension in the primary the greater the safety in this respect); that on account of the small current and the consequently smaller area of copper wire required for its distribution, the alternating current has many advantages over all systems of low tension distribution; and that a properly constructed and mounted converter is in itself an effective protector to the user of electric illumination against danger from shock or fire.

In conclusion the opinion may be hazarded that within the next ten years three-fourths of the incandescent electric lighting on this continent, following the example now set in Europe, will be carried out on the alternating current transformer system at increased rather than lower pressures than at present used, and that a large proportion of our mills and factories situated within five or even ten miles of water powers will be run by electric motors either driven direct by high tension continuous currents or by low tension alternating currents obtained through converters attached to primary conductors carrying a high tension and small current.

The thanks of the author are due to the Westinghouse Electric Co. of Pittsburg, the Brush Electric Co. of Cleveland, the Thomsom-Houston International Electric Company of Boston, the Royal Electric Co. of Montreal, the Ball Electric Light Co. of Toronto, the Reliance Electric Light Co. of Waterford, Mr. J. J. Wright of the Toronto Electric Light Co., Messrs. J. W. Queen & Co. of Philadelphia, the Weston Electrical Instrument Co., of Newark, N.J., and to Mr. A. Barthmann of New York, representing Mr. W. Hackenthal of Berlin, for particulars of machine and instrument construction and loan of woodcuts. His thanks are also specially due to Mr. T. Commerford Martin, Editor of the "ELECTRICAL ENGINEER," New York, for statistics concerning the electrical industries of the United States, and to Mr. F. R. Redpath of Montreal for the photographs of the electric light plant in his residence from which the engravings thereof have been produced.

DISCUSSION.

Mr. D. A. Starr said the author had given correct information as to the weight and output, etc., of the Thomson-Houston incandescent dynamo, but had made a mistake in stating that the machine was not absolutely automatic. The author had referred also to the manner in which the series coils were wound, the winding being over the armature and not around the fields. This was an invention of Professor Elihu Thomson's, whose brother, Mr. F. Thomson, chief electrician of the Royal Electric Co., being present, would, he thought, be able to explain exactly how the automatic arrangement worked. Mr. Starr.

Mr. Thomson and he had recently tested, for delicate regulation, a machine of the kind under discussion, and the difference between full load and no load in cutting off the whole of the lights, on a 150 light machine, was nothing; it could not be seen on the lamp that the current had increased by cutting off the whole of the lights.

A volt meter was put in the circuit, and it was found that when the lamps, with the exception of one, were cut off the machine (150 light) the pressure dropped 5 volts out of the 110 (5 per cent.). The machine could be made to compensate either way by changing the series coils.

The advantage was that in wiring for a building that was to be wired for 5 per cent. loss with the full number of lamps burning on the circuit, if a number of lights were cut off the actual loss was nothing. The result, if there were no drop in gauge, would be that the lamps would brighten up that 5 per cent.; but instead, if there was a drop, it compensated for the loss in the wire, and the lamps were kept at their normal brightness all the time.

The speaker said he mentioned this machine because he knew it well, its perfect automatic regulation, and also that any loss could be made up and compensated for. He did not think Mr. Lawson had seen one of these machines running under the same circumstances, or he would be willing to alter his opinion and classify the machine in his paper as being absolutely automatic.

Mr. F. Thomson, referring to the Thomson incandescent dynamo, said that the reason the coils were placed on the machine in that peculiar manner was to make it perfectly automatic and to produce a neutral point, so that there would be no shifting of the brushes necessary when the load was charged. Mr. Thomson.

The machine could be made to increase or decrease, or to remain automatic without loss, according to the position of the series coil and the strength of the shunt.

When the machine was first constructed for 800 lights, some little shifting of the brushes was necessary on account of the wire taking effect on the fields in the front, the wire being so long ; but this is now corrected.

According to Mr. Lawson's remarks on the Brush machine, the exciting current was 22 amperes and 135 volts, equal to 2970 watts for 1000 lights. In the Thomson machine, manufactured by the Royal Electric Company of Montreal, the exciting current was 30 amperes and 90 volts, which would be 2160 watts for 1200 lights. In the Westinghouse machine for 1500 lights the exciting current was 14 amperes 110 volts, equal to 1540 watts.

There must be something wrong in this. By referring to the exciting current of the Brush and Thomson machines it will be seen that the Westinghouse requires just about half the watts ; in the Westinghouse machine the current passes through one coil on the field, then misses a coil, and again passes through a third coil, misses a fourth ; and then through the fifth, etc. In consequence, there are practically two branches of current, the second branch passing through the second, fourth, sixth, etc., so that the 1500 light machine has 12 fields, six in series and two in multiple, 14 amperes passing through six, and 14 amperes passing through the other six, making in all 28 amperes and 110 volts, equal to 3080 watts.

A machine described in Dredge on Electric Illumination, Vol. I., page 250, and invented by a Mr. Lachaussie of Liege, will be found to resemble the Brush alternating machine of to-day in almost every point. With regard to taking out a section of the armature while the Brush machine was running, the same thing could be done with the Lachaussie machine.

With reference to the Fort Wayne meter, he believed Mr. Edison had some very early patents on motor meters, and that these patents would include the above mentioned meter because they covered broadly all motor meters.

He was sorry the author had not compared transformers of the same size, as it was difficult to arrive at a conclusion when comparing various sizes.

Referring to the low tension dynamo : of course a machine that was perfectly automatic should keep the same voltage at any speed ; he did not claim that the Thomson machine would do that, but it would give any desired voltage required by changing the shunt and position of the series coils, so that if a place was shunt wired for a 10 per cent. loss, it could be made up at the dynamo, or any other loss could be made up in the same way. The series coils could be placed in a certain position and the machine would be perfectly automatic, or it could be made to drop its voltage when the lights were switched off up to 25 per cent. The series coils take direct action on the armature. He would like to see the paper correct; at present it was not.

He admitted the diameter of armature was a little too great in relation to length in some of the early large machines.

In these the armature should have been longer, but this has been rectified now. In machines of 100 to 500 lights the series coils would hold the neutral points in the centre. It was possible by moving the series coil back, if the lights were increased on the machine, to move the brushes farther back, not ahead. The series coils being placed over the armature, they took direct effect on the armature independent of the fields.

Mr. A. J. Lawson, replying to Mr. Kimball, said that the Brush alternating current system at Barrie had been in operation since January last. There had been no accidents there on account of the high voltage. The only accident had been the burning out of an armature coil one night before the station work was completed, on the fuses being put on the main wires, through an arc wire light coming in contact and crossing both wires out-going and return, and this would have occurred with any low tension machine. Mr. Lawson.

The Edison people had practically given up the use of equalizers in central stations, and were instead interlacing the feeders. Some stations lately constructed had them in use, but the present rule of the Engineering Department was to interlace the feeders at all points, especially the neutral wires. There was a Westinghouse arc light plant in operation in Boston in the City and Suburban Company's station, and there was another in the United States illuminating station in New York running about 125 lights. He had been informed there were about 10 or 12 plants installed since the one in Boston had commenced running.

Referring to Mr. Thomson's remarks about the Thomson machine, he would simply say that if the absolute perfection of regulation claimed had really been attained, there was a fortune in it both to Mr. Thomson and his Company, for many had been striving to attain perfect regulation hitherto without perfect success.

The over-compounding of five volts he thought excessive, as there was very little lighting done by isolated plants, which was not done between 4.30 and 6 p.m. in winter, and 5 per cent. loss he thought in that case was simply a waste of coal.

He did not make any special reflection on the Thomson machine in stating that it was not perfectly automatic, but simply stated what he believed to be the case, viz., that the machine was not perfectly automatic in regulation.

The paper was not confined to a description of the construction of dynamos, and he had not therefore gone into details of the reasons for winding in any particular way.

With regard to the Westinghouse machine, the particulars given had been obtained from the superintendent of the Westinghouse Electric Co., and he had found the figures given to be correct.

In describing the Brush machine as a departure from the ordinary types of machines constructed in America, he had said only what was correct. To call the Brush alternating current dynamo an old form of machine was wide of the mark. One might, with more reason, call the Thomson-Houston alternating machine simply a Westinghouse alternator, because the construction was practically the same. Another thing, there was no iron, and, therefore, entire absence of treating effect due to iron in the armature of the Brush alternating machines.

He had given the Thomson machine credit for being better regulating than the Edison, but he could not see that any machine was yet perfect; and as regards the construction of the machine, there were reasons occurring to him why there should be a waste of magnetism in the machine with the stationary coils in any position. Taking the larger machine, a change of brushes was necessary. In some of the later English machines, without placing the coils in such a manner as Mr. Thomson did, by particular attention to the relative dimensions of the armature and of the field, the position of the brushes did not require to be altered under large changes in load.

In the construction of the armature of the Thomson-Houston machine he thought Mr. Thomson would admit that the diameter of his armature was too great in relation to its length, especially in some of the larger machines.

In such construction there was a quantity of dead wire at the ends. With the same diameter and greater length the output could be increased while the speed would be somewhat lower.

Thursday, 22nd May.

J. KENNEDY, Vice-President, in the Chair.

The following candidates having been balloted for were declared duly elected as :—

MEMBERS.

OCTAVE CHANUTE, JOHN WILLIAMS.

ASSOCIATE MEMBER.

WALTER CONSTANTINE BROUGH,

ASSOCIATE.

LEONCE FRANCOIS LUDOVIC STEIN,

STUDENTS.

OSCAR ARCAND,
THOMAS ROSS DEACON,
JAMES ATKINSON DOUGLAS,
ANDREW LANE,
BARTLETT McLENNAN,
THOMAS McLEOD,
JOHN RANKIN, JUN.,
ARNOLD J. RYAN.

The following has been transferred from the Class of Associate Members to that of Members :—

REUBEN WELLS LEONARD.

The discussion of Mr. A. J. LAWSON'S paper on the "Generation, Distribution and Measurement of Electricity for Light and Power, etc.," occupied the evening.

Thursday, 9th October.

P. A. PETERSON, Member of Council, in the Chair.

Paper No. 44.

DEVELOPMENTS IN TELEGRAPHY:

WAY-WIRES MULTIPLEXED AND INTERCHANGEABLE.

By D. H. Keeley, A. M. Can. Soc. C.E.

The title of this paper is so comprehensive that it might be supposed the writer purposed giving a *résumé* of all that has been attempted in the way of signalling since the word *telegraph* was first coined and found place in our vocabulary. It may be well therefore to state at the outset that it is only intended to deal with the subject of telegraphy in its present stage, introducing just enough of retrospect to show the drift, so far, of successful research in lines that, if followed up, will carry us to the realization of perfection in the art; and that is nothing short of the complete utilization, with the utmost economy, of the capacity of a line wire for the transmission of electrical effects.

Telegraph apparatus, and systems of telegraphy, have been so rapidly multiplied that scores of volumes and text-books are extant devoted exclusively to their treatment, either specifically or generally, and the student in wading through them finds difficulty in reconciling the idea of advancement with the circumstance that, whereas indisputable and important properties of conductivity and electro-magnetism were early discovered, the inventions from time to time introduced, instead of aiming to more and more fully utilize these properties, appear to have been designed to do in different ways just what had already been accomplished in the absence of a clear recognition of the possibilities attainable.

Supposing, however, for the sake of convenience, that two well-established facts—the *celerity of conductivity*, and the *diverse properties of electro-magnetism*—were ever held in mind by the workers in this field, it will be possible to discriminate between the different systems that have been brought forward.

There are those, in that case, that have been designed to utilize the capacity of a line wire for the rapid transmission of electrical effects; they may be comprehensively designated *Simple Circuit Systems.* And there are those that have been designed to utilize the diverse properties of electro-magnetism, in which the use of auxiliary circuits is necessary; they may be described as *Complex Circuit Systems.*

With this division in mind, it will occur to those conversant with the subject, that whatever *progress* has so far been made in the field of telegraphy is referable to the Complex Circuit Systems, comprehending the various methods for duplex and quadruplex transmission; while the obviously more far-reaching province of the Simple Circuit, which embraces several automatic and synchronous systems, has been comparatively neglected, and, although extensively experimented in with splendid success, has never been developed in a measure to surpass the performance of its original arrangement constituting the ordinary Morse telegraph of forty years ago.

As this unique system, the Morse, is still universally in use, and a great deal depends upon its existence, it will be profitable to review it before proceeding further, for anything so old in the history of an art as this system is in telegraphy must have some remarkable features to recommend it.

Like the proverbial law that "holds good," the Morse has *nine points* that defies its dispossession of the field:—

1. The transmitter is a single contact key. The limit to speed is the physical possibility of an operator's manipulation, and the matter to be transmitted needs no special preparation.

2. The receiving instrument is simply an electro-magnet, the armature of which directly reproduces the movements of the transmitting key; and the immediate transcription of the operator is in proper shape for delivery.

3. The receiving instrument being electro-mechanical, an automatic repetition of transmitted signals from one circuit to another is readily obtained.

4. The circuit current is supplied from batteries at one or *both* of the terminal offices.

5. There may be any number of offices on a single wire, the only limit being the accommodation for traffic; and any number of the intermediate or way offices may be in or out of circuit without affecting the operation of the others.

6. The way offices are not called upon to contribute battery current to the main circuit.

7. The wire can be earthed at any point, thereby forming two separate circuits from earth to the respective terminal offices; each circuit being operative for all of the offices included in it.

8. At any way office, one wire can be switched to connect with another, the equipment of the lines being uniform.

9. The last and very important feature is, that in the act of transmission, substitution of messages or interruptions by the receiving operator, or by any other in the circuit, can be effected instantly.

These are the *nine points* of advantage that distinguish the slow old Morse, and these are the advantages that render it as yet pre-eminent and indispensable.

There is no other system possessing all of these features, consequently there is none other equally advantageous. And it is clear that if the usefulness of a wire is to be enhanced, its equipment should have in its composition the means for affording, in each separate line of communication, the facilities of the single Morse circuit.

It is found, however, on examination, that this great desideratum has not been secured in any of the various methods that have heretofore been invented for the purpose of increasing the practical utility of the wire. [*It is important to bear this circumstance in mind in following this paper to its conclusion.*]

In reviewing the field of telegraphy it will be convenient to consider first the

SIMPLE CIRCUIT SYSTEMS.

From time to time, dating from an early period in the history of our telegraphs, attempts have been made with more or less success to transmit signals by means of automatic *make* and *break* devices, perforated strips and the like, and to effect their reproduction by the action of the current impulses upon moving strips of chemically prepared paper. The speed attained has not unfrequently been marvellous and fairly incredible.

Without entering into a discussion of what may or may not have been the conditions of the circuits at times so successfully operated, it will suffice to state that the performance of these systems was not uniformly good and reliable.

Theoretically, any one of these systems would utilize the signalling capacity of a wire to its fullest extent. An almost inconceivably rapid succession of *makes* and *breaks* at the transmitting end of the line will produce a corresponding number of dots or dashes on the recording strip at the receiving end. And, since the current can effect chemical decomposition in a very much shorter time than it can produce the manifestation of magnetism, it is obvious that the same speed could not be attained by any arrangement of electro-magnets.

This will be understood in view of the fact that a telegraph line 300 miles long is capable of transmitting about 1125 distinct electro-chemical effects per second. By an *effect* is meant the manifestation at the receiving end of the application or the withdrawal of current at the sending end. In a Morse operator's fastest manipulation (40 words per minute), there are produced but 24 electro-magnetic effects, or an equivalent of 12 dot signals per second.

At first sight, then, it would appear that an automatic system of the kind described, made reliable, would fill every requirement, and afford us in a single circuit the accommodation for which we are accustomed to employ a score or more of wires. Such is not the case in practice, however, and it is the discovery of its innate shortcomings and comparative inutility that has caused attention to drift away from the electro-chemical circuit.

The characteristic and maybe inseparable conditions most palpably disadvantageous to all of the automatic systems are that:

The matter to be telegraphed must be translated or specially prepared for transmission, and on its reception has to be retranslated for delivery. The collective preparation of a large amount of matter precludes the practicability of giving precedence to any single despatch on occasion. The signalling current emanates from the sending end alone; consequently the corresponding offices must take turn about in transmitting, and there is no accommodation for way offices unless equipped as terminal stations, which they are in fact constituted when in operation.

Besides these drawbacks to the automatic systems, there is the unavoidable nuisance of the paper tapes used at both the transmitting and receiving ends of the line. When the Morse system was developed to that stage where the single tape at the receiving end was dispensed with, a sigh of relief went up from every quarter where the business was of sufficient volume to produce an accumulation of the stuff in the course of a few hours work. The automatic in this respect is a retrograde system; in its working the paper tapes form the most important feature; the perforated and the marked material rapidly accumulates, and if fyled for purposes of reference it is difficult to get at any particular despatch, and no part of one can be so readily recognized as the easily fyled manuscript of despatches sent or received by the Morse system.

In fine, it has been found that the automatic systems cannot be advantageously operated, and the extreme rapidity of the chemical apparatus is, therefore, rendered practically unavailable.

The nearest approach that has been made to a realization of the expectations reasonably entertained of the electro-chemical systems is the performance of the Wheatstone Automatic. This system is a sort of compromise between the electro-chemical and the ordinary Morse. Its transmitter is essentially the same as those employed in the other automatic systems, while its receiver is electro-magnetic. The speed attained is of course much lower than that of the chemical apparatus, yet it is remarkably high compared with the work of a directly manipulated Morse circuit. It has already been stated, that in the operation of an electro-chemical system, 1125 effects can be produced per second, and of the Morse system, 24; with the Wheatstone system the rate attainable is as high as 386 electro-magnetic effects per second. In common with the other automatic systems, however, it has the already defined drawbacks rendering its general application impracticable.

Several printing systems have been brought forward but have not scored any great success. The chief defect in these is that the signalling medium is necessarily idle during the time that the mechanism operates to present successively the characters called for by the transmitter. With these therefore only a part of the signalling capacity of the wire is utilized, and a very high speed is obviously unattainable.

Another phase of simple circuit operation is presented in the systems that have been devised to transfer the line wire from one apparatus to another successively at both ends of the circuit, and thus afford for each corresponding set an intermittent connection so rapidly recurring as to constitute a practically continuous one.

For a long time after the idea of these systems was suggested, it was considered impracticable, in consequence of the difficulty of obtaining the requisite perfect and continuous synchronous action of the machinery at either end of the line. In 1883, however, that difficulty was got over by the adaptation, in Mr. Delaney's synchronous multiplex, of the *phonic wheel*, a species of electro-motor; and more recently Lieut. Patten has succeeded in adapting an alternate current motor for the same purpose. (See the *Electrical World*, Vol. XIII, p. 106.)

Delaney's multiplex comprises the best features of all of the synchronous systems that preceded it. He has succeeded in getting with it six circuits suitable for the fastest Morse transmission. It is in operation on some lines in England and in the United States. The utility of this system, however, is limited in consequence of some very serious defects that will be specifically dealt with later on.

We now come to a consideration of the

COMPLEX CIRCUIT SYSTEMS.

The possibility of simultaneous transmission in opposite directions through a single wire was an early conception, but it was not until 1872 that the idea found practical application.

As soon as the principle became generally known and understood, the *Duplex*, as it is called, was introduced in multifarious forms. Its principle is a prolifically suggestive one, and in one form or other it is now found in operation wherever the traffic between any two stations is of considerable volume.

Of all the systems for duplex telegraphy that are in existence, however, there is but one—a somewhat recently introduced combination of telegraphic and telephonic apparatus—practically applicable to way stations. The reason for this is that the duplex depends for its operation upon devices for neutralizing the effect of outgoing currents in the receiving instruments, while leaving the latter free to respond to incoming currents. This necessitates the placing of main line batteries at each transmitting station, an arrangement that is, as already explained, impracticable for way offices, especially on lines of any considerable length.

The *Quadruplex*—an arrangement of apparatus for double transmission in opposite directions—first appeared in practicable shape in 1874. It is essentially an adaptation of the duplex principle; a combination, as it were, of two duplexes. There are, however, only four forms of the duplex susceptible of being so adapted. These are the Differential, Bridge, Split-battery, and Reciprocal (the last mentioned is described in the U. S. patent No. 331,975 granted to the writer conjointly with Mr. Aaron Garvey in 1885). For the exchange of business between centres where the wires are constantly occupied, the quadruplex, in one or other of its forms, is now extensively used all the world over.

The general features of the quadruplex may be stated to consist in means for neutralizing the effect of the outgoing currents in the receiving instruments, and for effecting the production of signals on one side by increase and decrease of current, and on the other side by reversals of this current; or, as in the Reciprocal system, by currents of a given strength on the one side and heavier currents of the same polarity on the other side.

Attempts have frequently been made to apply these means for the production of a *Sextuplex* system; but the greater necessity for special devices such as are used in the quadruplex to obviate interference of the effects of the current of one side with the other, involves so great an amount of complication and machinery as to render the idea impracticable.

The inherent defects of the several quadruplex systems consist in :—

1. The receiving instrument is in every instance dependent for its energization upon the battery at the transmitting station. This necessitates nice adjustment on the one hand and extraordinarily heavy currents on the other.

The fine adjustment of the receiving instrument exposes it to the influence of induction from strong currents transmitted from the same end in wires running parallel to its circuit. And the heavy currents transmitted to effect the receiving instruments occasion the same mischievous induction effects in other circuits adjacent.

Owing to these conditions it is a matter of considerable difficulty to keep the apparatus in working order.

2. There is no means for including intermediate offices in circuit.

3. One receiving operator is unable to interrupt his correspondent without interrupting the other two operating on the same side. That is what occurs in each of the duplexes; each of which has four operators,—a sender and a receiver at each end. Hence, of 4 or 8 operators at work on one wire, three are handicapped if the fourth be inexpert; and it has thus become necessary to detail the best available operators for duty on duplex and quadruplex circuits.

With these facts before us we can readily understand the fairness of its being estimated, that the value of a duplex *circuit* is about 90 per cent., and a quadruplex circuit about 75 per cent., that of a simple Morse line between any two stations. In other words, a quadruplex is only about as good as three straight Morse circuits. And we can see, too, in the light of these facts, how very far these multiple circuit systems have fallen short of the advantages of the simple Morse circuit set forth in the beginning of this paper. At the same time, it will be remarked that the work done in respect of these systems has been one of steady development and extensive application in practice; they have been brought to that stage where all but their inherent defects are eliminated, and we perceive, in view of the already mentioned signalling capacity of a line wire, that the principles underlying them are not the correct ones on which an *ideal* system can be based.

THE SYSTEMS COMPARED.

To get at a clear idea now of the comparative value of the different systems, we can admit a *maximum* of efficiency in each case—crediting the quadruplex, for example, with the full value of 4 Morse circuits —and set down the highest rates of transmission quoted in works in which they are specifically treated. By classifying them as hereunto we can readily perceive how they stand.

		Rate Per Minute.
Single Circuit—*Manipulated.*		
	Morse	40 words.
	Type Writing (Hughes or Phelps)	50 "
	Synchronous Multiplex (6 circuits × 40 =)	240 "
Single Circuit—*Automatic.*		
	Electro-Chemical	1500 "
	Electro-Magnetic (Wheatstone)	428 "
Complex Circuit—*Manipulated.*		
	Duplex............(2 × 40 =)	80 "
	Quadruplex.......(4 × 40 =)	160 "

Leaving aside the question of the practical availability of the electro-chemical method, we have seen that the value of its remarkably high speed is reduced by the necessity for dual translation of the matter transmitted; the same is true of the Wheatstone Automatic, the next highest in point of signalling capacity.

Of the systems operated by direct manipulation, the simple Morse is the only one of general utility. The others are, as has been pointed out, only adaptable to terminal stations; of these latter, however, the synchronous multiplex is shown to have the greatest efficiency. It is besides a simple circuit system, and the nearest of any akin to the simple Morse.

The indications are therefore very clearly defined, that the principle upon which the synchronous multiplex is based is the correct one to follow up, with a view to the full utilization of the line wire.

We can now with advantage revert to a consideration of that principle, and in due course it will transpire how, by properly applying it, we can create a perfect system of

MULTIPLE CIRCUITS.

If a moment's consideration is given to the fact, that the signals transmitted by an operator on a Morse wire are made up of dots, dashes, and spaces, it will be perceived that there are in these several conditions certain periods of rest. When the key is open (spacing for instance), the circuit is fulfilling no function. Can this period be taken advantage of, and the line wire for the time of its duration, however short, be transferred to complete a circuit with other sets of apparatus?

That is the question on which the operation of the synchronous multiplex hinged, and it has been answered affirmatively.

To get at an understanding of it, the action of the current upon the electro-magnet must be considered.

It is evident the magnetism developed in the iron core by the action of the current does not appear and disappear in its greatest strength abruptly; there must be a rise and a fall to it. Some time is taken for the magnetism to develop after the current is applied, and some time is taken for the magnetism to die away after the current is withdrawn. There is as it were a residual magnetism in the core for a brief period after the current is withdrawn. And it further appears that the stronger the current is the longer will the residual magnetism last. If the armature of the electro-magnet were arranged to respond to the effect of a weak current, and a strong current were applied, it is evident the armature would remain attracted for some time after the current was withdrawn. If the current were withheld for a brief space the armature would fall away; but if the current were re-applied very quickly, the electro-magnet would become re-energized before the armature would have had time to fall away. Hence, by alternately applying and withdrawing the current very rapidly, the electro-magnet would appear to be influenced by a continuous instead of an intermittent current.

Now, that being the case, it is evident that a number of points in a circle might be made the terminals of conductors leading to the electro-magnet, and a revolving arm successively touching these points might be the means of communicating the current to it. In that case it would only be necessary to apply the current to the arm in order to actuate the electro-magnet. And if between these several points another set of points is placed and put in connection with a second electro-magnet, this one would be actuated in like manner to the first, and so on, until the entire space of the circle were occupied and a considerable number of instruments could be actuated.

Now, if a similar arrangement of electro-magnets and contact points is placed at a distant station, and the revolving arms are synchronized and connected together by a line wire reaching from one to the other, the line wire becomes a practically permanent conductor common to all of the electro-magnets, and yet it is only in connection with the several pairs of them one at a time, so that signals might be exchanged between any two corresponding sets without any reference whatever to the others.

Whether this could be realized in practice, was what Mr. Delaney and others before him sought to ascertain in the working of their respective systems. We have seen the outcome of it in the synchronous multiplex, and the result is very satisfactory. It is, however, not nearly so efficient as it was expected to prove.

In the *Electrical World*, Vol. II., No. 18, of Dec. 29, 1883, and Vol. VI., No. 20, of 14th Nov., 1885, will be found illustrated articles fully explanatory of the original system and its improvements. These articles can be consulted for details; it answers our present purpose to have gleaned the following facts :—

1. The receiving instruments are actuated by currents emanating from the sending end alone. Hence the system is only applicable to terminal stations.

2. It is necessary to afford to each operator 34 contacts per second with the line wire, in order to enable him to transmit with the same facility as on an ordinary circuit. This is practically equivalent to 3 contacts, or 3 impulses of current per dot signal.

3. The operation is confined to lines not exceeding 100 miles in length.

With these facts before us we perceive that the synchronous multiplex, according to Mr. Delaney's invention, is deficient in two important respects; its application is limited, and it does not economically utilize the signalling capacity of the line wire.

We have not to go very far to ascertain the causes that produce these restrictions.

In several of the text-books the laws governing the transmission of currents are fully set forth. Take for instance the work of Geo. B. Prescott, 1885, Vol I, wherein it is shown (*see note page* 260) that the time required to actuate an electro magnet is about directly proportional to the length of the conductor and inversely proportional to its conductivity. An actual experiment is cited, p. 395, whereby it was ascertained that on a No. 8 iron wire 300 miles long, a Hughes (polarized) electro-magnet was actuated in $\cdot003 = \frac{1}{333}$ of a second; while for an unpolarized electro-magnet the time required is stated to be $\cdot01 = \frac{1}{100}$ of a second.

By calculation in accordance with these premises, it appears a length of 100 miles of No. 6 iron wire (the size generally used for multiple circuit lines) is capable of producing a signal in $\cdot0022 = \frac{1}{454}$ of a second on a receiver, † such as is used in the Delaney system. Here are the figures :—

	No. 8		No. 6		
Lengths	300	:	100	:: ·01	: ·0022 = $\frac{1}{454}$
Resistances	12·92	:	8·54		

† As the Hughes' apparatus already mentioned is not adaptable for general signalling purposes, and the polarized instruments in use, such as the Siemens relay, have practically about the same celerity of action as an unpolarized electro-magnet, the time required to produce a signal on an unpolarized magnet on the 300 mile line, viz., ·01 sec., is obviously, for purpose of comparison, the proper quantity to consider.

Now, on referring to the descriptive articles already mentioned, it is seen that Mr. Delaney's apparatus comprehends 7 circuits (six signalling, and one corrective of the synchronism) of 12 contacts each; in all ($12 \times 7 =$) 84 line contact points. These 84 line contacts are alternately disposed with an equal number of contact points connected to earth, which serve to partially discharge the line between the successive transmissions of current, so there is altogether 168 contact points or "plates," as they are generally called, in the circle traversed by the line brush.

Suppose the parts to be of the following demensions :—

	Inches.	Total.
Line plates, each	$\frac{1}{4} = .25$ in. $\times 84 = 21.0$	
Earth " "	$\frac{1}{4} = .25$ " $\times 84 = 21.0$	
Spaces between ditto	$\frac{1}{40} = .025$ " $\times 168 = 4.2$	$= 46.2$

The circumference of the circle is in this case 46.2 inches, and as it is traversed by the line brush $2\frac{5}{6}$ times in a second, it follows that a distance of ($46.2 \times 2.83 =$) 130.75 inches per second is covered.

Now, as the length of time occupied by the brush in passing over a given line plate is the exact measure of the duration of contact made with the battery, for the transmission of a current, it is evident that (since 130.75 : ·25 :: 1 : ·0019) the current is in each instance presented to line for only (·0019=) $\frac{1}{526}$ of a second.

Again, it will have been noticed in following these calculations, that with a given speed of rotation of the line brush, the width of the plates determines the length of time the current is put to line. This being the case, it is obvious that when the brush is passing over an earth plate, the line is fulfilling no function, it is idly discharging; consequently, with this arrangement the line is half of the time idle and its theoretical capacity is utilized to the extent of less than 50 per cent., the insulation wedges between the line and earth plates occasioning the slightly further loss.

That this disadvantage is inseparable from the system is evident, for the discharge of a line is always slower than the charge, and it is necessary in this system to obviate the possibility of an appreciable part of the charge due to the transmission of a signal between one pair of corresponding plates being communicated to the electro-magnets connected with the next succeeding pair.

There is in the foregoing figures, too, an explanation of the other deficiency of the system. The apparatus in operation transmits currents of only .0019 sec. duration; we have seen elsewhere that the time required to produce a signal (that is, to effect a full attraction and movement of the armature of the receiving instrument) on a line of 100 miles of No. 6 iron wire is, by calculation, .0022 sec. The difference is so small that the figures may be said to agree. However, it is evident the transmitted current is barely sufficient to produce an effect; and, as the length of time required to produce a signal increases with the length of the conductor, it can be readily understood why the operation of the system is confined to comparatively very short circuits.

With the synchronous multiplex before us, its deficiencies discovered, and the causes thereof traced to an arithmetical certainty, it is an easy matter to define what the requisites are to produce an *ideal* system :—

1. The receiving instruments should be made responsive to single pulsations of an ordinary strength of current, so as to be independent of intermittances. This would economize the signalling capacity of the line.

2. The necessity for discharging the line after each pulsation should as far as possible be eliminated, so as to admit of minimizing the earth-plates and thus afford space for additional line plates. This would secure the furthest utilization of the signalling capacity of the line.

3. The system should be applicable to intermediate stations. This would render every one of the several circuits as readily available and generally adaptable as a single Morse line.

Now, the attainment of this perfection is not only possible, it is the next thing to an accomplished fact, as will be seen in considering the results of the writer's personal research in this particular department. These results are comprised in a new system comprehensively designated,

THE INTERCHANGEABLE WAY-WIRE MULTIPLEX.

As this system is somewhat different from its predecessors in the principle of its operation, it may be best introduced for consideration by a general statement of its characteristics.

The conception of it is based like the other synchronous systems on the well-known fact that the manipulation of a key by the most expert Morse operator is very slow compared with the rapidity with which an electrical effect can be produced, and further, on the ascertained fact that when signals are produced by pulsations of alternate polarity, + closing and — opening, 24 *contacts per second* (12 corresponding to downward movements or depressions, and 12 corresponding to uprisals of the key) is all that is necessary for transmission at the rate of 40 words per minute.

According to this latter finding it is only necessary to make connection between any two corresponding sets of apparatus once in every $\frac{1}{24}$ of a second, in order to intercept every movement of a given key, and so produce precisely the same effect in the distant receiver as would obtain were the sending and receiving instruments continuously in circuit.

In order that this may be understood, the tape of a Morse register may be taken in an instance where signals have been embossed upon it at the rate of 40 words per minute. The length of a dot will be found to be $\frac{1}{24}$ of the length of tape passed over per second. Or, a sentence of 40 words may be written down in Morse characters on paper ruled with horizontal lines representing unit divisions, allowing 1 unit for a dot, 1 unit for the space between the elements of a letter, 3 units for a dash, 2 units for the space between letters, and 4 units for the space between words; it will be found that the entire sentence occupies 1440 divisions = 24 units per second, thus showing that *$\frac{1}{24}$ sec. is occupied in the formation of a dot or a space* in manipulation at the rate of 40 words per minute.

On the other hand, it is known that the time required for the production of a signal by electro-magnetism is extremely brief; only ·003 = $\frac{1}{333}$ of a second, with sufficiently sensitive yet practical apparatus, on an ordinary No. 8 iron telegraph wire 300 miles long, and in less time on a line of shorter length.

It is therefore obvious that the whole period ($\frac{1}{24}$ sec.) of each of 24 contacts that can be afforded in a second is not necessarily at the disposal of one operator.

Hence, if in every $\frac{1}{24}$ of a second the line wire is put in connection with a given key sufficiently long to produce one electrical effect, the balance of each $\frac{1}{24}$ of a second can be occupied in the production of electrical effects under other keys with which it can be successively connected. From this it follows that if the time required to produce an effect on a 300 mile line is only $\frac{1}{333}$ of a second, we can, theoretically, obtain in it as many as ($\frac{333}{24}$ =) 13 signalling circuits.

Now, it will have been seen in the description thus far, that the principal action hinges on the possibility of the brief transmitted current affecting the receiver, in such a way as to leave an impression upon it during the interval of the succeeding pulsations. That is, if a + pulsation is transmitted in the formation of a dot or dash, the armature of the receiver must be attracted and remain so until a − pulsation, transmitted in the formation of a space, reverses its position.

And it is also evident that the receiver must be extremely sensitive in order to afford the maximum number of signalling circuits on a given line.

To see how this is provided for, it will be remembered that in dealing with the other systems just now, it was shown that a signal can be produced on a Hughes' magnet in $\frac{1}{333}$ sec. against $\frac{1}{100}$ sec. required for electro-magnets of other forms. In other words, the Hughes is 3 times quicker in its action.

Now, it has been found in the course of experiments made with reference to this system, that if an ordinary polarized relay is operated through the medium of an induction coil, the relay is rendered responsible to a single brief pulsation of current; whereas, when operated directly, three successive pulsations are required to produce a full attraction of its armature. That is to say, the combination with the induction coil furnishes a receiving instrument equal in celerity with the Hughes magnet, and should therefore be capable of response to a signalling current of $\frac{1}{333}$ sec. duration on a 300 mile line of No. 8 iron wire. By means of an automatic device, the induced currents communicated to the relay operate in only one direction dependent upon the polarity of the transmitted pulsation. Consequently its armature remains at rest against one or other of its limiting stops, according to the direction of the last current presented to it, and is unaffected by successive pulsations of the same polarity.

Now, having an economical method of signalling and the requisite apparatus therefor, it is only necessary to associate it with means for transferring the line wire from one set of instruments to another simultaneously, at as many stations as desirable on a line, in order to produce a multiplicity of signalling circuits.

In the references that have already been mentioned in connection with previous systems (viz., *Electrical World*, Vols. II, VI and XIII), the means whereby synchronism can be obtained and maintained between stations connected together in circuit are set forth in a sufficiently clear manner, to obviate the necessity for explaining in detail the specific arrangements that have been devised for that purpose in this instance. It will suffice to state here that motors at the terminal stations of a line are brought into unison by correcting devices. Currents regularly alternating in polarity are concurrently transmitted to line from both terminals; these currents conjointly operate the motors at the intermediate stations, and the result is a perfectly synchronous action throughout the entire system.

By means of this synchronous mechanism, a brush in electrical connection with the main line is revolved about the circle of contacts connected with the signalling apparatus, at all of the stations in circuit, with sufficient frequency to put the line in contact with each of the corresponding sets of apparatus once in every $\frac{1}{24}$ of a second; and at each of the terminal stations the shaft that revolves the brush carries a commutator of a sufficient number of segments to produce 24 reversals per second of the main line battery which is connected with it.

The main batteries at the terminal stations are moreover reversely connected with the commutators, consequently + presented to line at one end is met by — presented at the other end; the currents combine in the line, and, as they are alternated by the revolving commutators, the line is traversed by regularly recurring + and — pulsations.

It will be seen, therefore, that the passage of the main line brush over the contact plates connected with the signalling instruments is concurrent with the presentation to line of any one phase + or — of the main line current. Hence, if the contact plates are arranged in series equidistantly, and corresponding to the segments of the commutator, certain of the contacts will regularly and invariably afford a path for the +, and the others for the — pulsations.

And, further, if the transmitting keys are provided with front and back contacts, respectively connected with the + and — series of the line plates, the levers of the keys being connected with the battery commutator, it is evident that when any given key is depressed or upraised it will, in its circuit, interrupt the path of one or other of the currents.

This being the case, the polarity of the current transmitted depends upon the position of the key in the case of each of the signalling circuits. And normally, when the key in any circuit is not being used, a circuit closing arm associated with it in the ordinary manner is closed and bridges both the back and front contacts, thus permitting both phases of the current to circulate.

Now, as the + and — phases of current are presented in each instance for $\frac{1}{24}$ of a second, during which time the line brush traverses one entire series of the contacts, it is clear that if the keys in some of the circuits were depressed and in others upraised, the current would be interrupted and re-established repeatedly, so that it becomes broken up in a succession of mere pulsations. The fact is, therefore, that each of the signalling circuits is operated by means of a single pulsation that recurs alternately + and —, every $\frac{1}{24}$ of a second, and the position of the key determines whether a given pulsation shall or shall not affect the receiving instruments that are in circuit with it.

It might appear at first sight that there is a chance of a movement of the key taking place between two successive pulsations, that would not be reproduced in the receiver; but a moment's consideration will show this to be impossible, since every movement of the key by the operator's hand occupies, at the very least, a period of time that is sufficient for the line brush to sweep over the entire series of the circuits. There is, however, this possibility, that in a case where + currents operate to close the receivers, and — currents to open them, the sending key might be depressed concurrently with the presentation of a — phase of the current, and upraised concurrently with the succeeding + phase. In such a case it is evident the movement of the key would be lost on the receiver; this possibility is, however, obviated by means of a semi-automatic transmitter through which the movements of the key are communicated to the line circuit. The operation is simply this: If the key is depressed to form a dot, the lever of an electro-magnet, in local circuit with the key, is depressed, and remains in that position, after the key is upraised, until a + pulsation transmitted to line releases it. The lever in its upraised position affords a path for the succeeding — pulsation. A dot is thus transmitted. If the key is again depressed, the same operation is repeated; so long as the key remains open only — currents go to line; and when closed, + currents are transmitted. As the successive pulsations recur with the same rapidity as the movements of the key, it is obvious the latter cannot get ahead of the former; consequently, every movement of the key is reproduced in the receiver, the operation being precisely the same as if the key moved in exact unison with the recurring alternations of current.

There now remains only one other important feature to point out: It is, that as in this system the receiving apparatus is positive in action and responsive to one full pulsation of either polarity, it is not in any given circuit susceptible to the influence of the tailings of the charge in the line due to the transmission of a signal in the circuit immediately preceding. It is therefore sufficient to put between the successive line plates a very narrow segment for earth contact. Between the separate series an earth plate, as large as any one of the line plates, is provided to fairly clear the line of the charge of one polarity before the other is introduced.

Reverting for a moment to the explanation given as to how signals are transmitted, it will be remembered that the current pulsations are regularly presented, and it is the position of the keys that determines their circulation in the respective circuits. It will therefore be readily understood how intermediate offices can be introduced on the line; they have circles of line contact plates and the rest of the apparatus excepting the main line batteries and commutators, which are not needed; the transmitted currents pass through them, each circuit having its own pulsations to which the receivers respond. As at the terminal stations so is it at the way offices, the position of a given key determines the circulation of the current. Normally, the circuit-closing arms of all the keys in a given circuit are closed, and the recurring + and — pulsations circulate in it. The opening of any one key, therefore, will affect all the receivers in the circuit, and they will follow its movements precisely as on an ordinary single circuit Morse wire.

The interchangeable feature of the system is also almost self-evident. Since the signalling currents emanate from both ends of the line, any one of the intermediate offices can ground a given circuit and work in either direction independently; or loop lines can be introduced and operated precisely in the same way as when let into a regular Morse circuit; or a number of offices may be regularly on one circuit while a certain other number may be on another, and these can interchange in the same way as if located on so many separate wires. Moreover, we have this very desirable feature, that in the normal condition the keys being all closed, the apparatus at an intermediate office presents no obstruction whatever to the passage of the currents; it may therefore be out of adjustment or otherwise disarranged without affecting the other offices in circuit, just as on an ordinary Morse line which is operative between offices whose instruments are adjusted and inoperative to those whose instruments are not adjusted or otherwise locally affected.

Now, from what has been stated, it is evident that we have here a system calculated to afford the highest possible degree of efficiency, and one that utilizes the capacity of the line wire to the fullest extent.

Of 13 circuits theoretically obtainable in a wire 300 miles long, we can count upon at least 9 for signalling purposes; we might do more than that, but recollecting that the number depends upon the length of the surface traversed by the line brush per second, the space equivalent to 4 circuit plates is only a liberal allowance to make for the synchronous circuit plate, the earth plate, and its minor segments and the insulation wedges. All these may be taken together and set down as *mechanical intervention*, and therefore a constant quantity; and in any calculation we make for a given line, we may subtract the equivalent of 4 circuits from the theoretical in order to determine its practical capacity. Thus, in accordance with the law of proportions elsewhere dealt with in this paper, we should obtain on an ordinary line 150 miles long as many as $(\frac{300}{150} \times 13 = 26, - 4 =)$ 22 signalling circuits.

How readily this can be done has yet to be ascertained. It will be remembered that in the remarks prefacing the description of this Way-Wire system, it has been stated that the perfection attainable in it is the next thing to an accomplished fact. What has been herein described is mainly an hypothetical fabric—to use a big phrase—but it is a theoretical construction that is based on the results of and inferences from sound laboratory experiments. It yet remains to be seen whether all that is claimed for this system can be realized in actual practice.

Note.—It is not stated so, literally, but it is in effect: It is stated on p. 397, that, "The rapidity with which successive signals can be transmitted depends essentially upon the time required to charge and discharge the line." [This time, it is shown on p. 393, is on a No. 8 iron wire 300 miles long, about ·018 sec., and on an equal length of No. 6 gauge (·20 in diameter), the time required is about ·013 sec].

It is stated on p. 395, that the time required to produce an effect on the No. 8 wire was found to be with a Hughes electro-magnet ·003 sec.; and ·01 sec. is set down for an unpolarized electro-magnet of the ordinary form.

It further appears, on p. 395, that on a given line with one class of apparatus, the time required to produce an effect is "nearly in proportion to the length of the line;" and with the other class of apparatus the time required "increases in a much greater proportion than the length of the line." These statements have reference to lines of 300 miles and over, and it is therefore very safe to assume that for lines under 300 miles the time is at the most directly proportional to the length.

The obvious interpretation of all this is, that the time required to charge a line is the index of its signalling capacity. If we know the rate of charge of any two wires and the signalling capacity of one of them, we can, by a simple sum in proportion, determine the signalling capacity of the other.

Whence it follows, taking the figures quoted, that the time required to produce an effect on an unpolarized magnet on the 300 mile No. 6 line is ·0072 sec.; the proportion being ·018 : ·013 : : ·01 : ·0072. And the time required on a 100 mile length of the same line is ·0024 sec.; the proportion being 300 : 100 : : ·0072 : ·0024.

This result is practically the same as the ·0022 arrived at by the other calculation given in the paper. Besides, the interpretation of the above text, upon which the last mentioned calculation is based—(viz., that the time required to actuate an electro magnet is about directly proportioned to the length and resistance of the conductor)—is supported by the statement, in Prescott, Vol. II, p. 1110, that "the speed (having reference to the synchronous multiplex) is inversely proportional to the length and directly as the size of the conducting wire"; this is of course assuming that *the size* of the wire has reference to its conductivity.

DISCUSSION.

Mr. W. J. Camp, of the Canadian Pacific Telegraph Co., said he had read Mr. Keeley's paper, and, as far as he could judge at present, the system appeared quite feasible. To give a decided opinion upon it he would have to study it more thoroughly. The principal trouble with the existing multiplex or quadruplex systems, which are the only ones in practical use, is that of battery power. Mr. Keeley's system overcomes that, as it reduces the battery power required to about one-third. Mr. Camp.

The Wheatstone automatic system, which is largely used in England, and to some extent in the United States, did not answer very well for America, the percentage of errors in telegrams being largely increased by its use. Although it may appear that automatic transmission would reduce the number of errors, experience has proved that by direct manual transmission and receiving by sound, the very best results as to correctness are obtained. Another objection to the automatic system is the time occupied in getting the despatch from one point to another. Although the actual transmission over the wire is very rapid, a great deal of time is lost in preparing the paper tape to transmit and in translating the characters at the receiving office. If Mr. Keeley's system can be worked, this will be overcome; and if his system will work between terminal offices, any way office can be worked as described.

Mr. J. Kennedy asked to what extent was the quadruplex system employed on the Canadian Pacific Telegraph? Mr. Kennedy.

Mr. Camp, in reply, stated that their quadruplex circuits were as follows:— Mr. Camp.

Canso, N. S., and St. John, N.B.	375 miles.
St. John, N.B., and Montreal	485 "
Montreal and Albany, N.Y.	350 "
Montreal and Toronto	350 "
Toronto and Buffalo	180 "
Montreal and Ottawa	125 "
Montreal and Sudbury, Ont.	450 "
Port Arthur and Winnipeg, Man.	430 "
Winnipeg and Swift Current, N.W.T.	515 "
Donald and Vancouver	450 "

Besides these they had a number of duplex circuits, the principal ones being Montreal and Chicago, Montreal and Winnipeg, and Winnipeg and Vancouver.

At St. John, N.B., the two quadruplexes were connected by automatic repeaters, and at Montreal one-half of the same was connected with a duplex to New York, thus practically giving New York a double circuit to Canso, and Montreal a double circuit to the same place. In other words, both New York and Montreal could work duplex with Canso at the same on the one wire east of Montreal. On the Ottawa circuit a single Morse wire to Deseronto is connected at Ottawa on one half, and the other half used for local business between Ottawa and Montreal.

One half of the Montreal-Sudbury and Port Arthur-Winnipeg "quads" is connected by a duplex, giving a double circuit to Montreal and Winnipeg. The second half of the Sudbury set is connected to a single Morse wire to Sault Ste. Marie, Michigan, and the second half Port Arthur and Winnipeg is used for local business between those points.

The circuits between Winnipeg and Vancouver are more complicated. One half of the Winnipeg Swift Current quadruplex is connected at Swift Current with a duplex to Great Falls, Montana, the other half with a duplex to Donald, B.C., where it is connected with one side of the quadruplex to Vancouver. A duplex is worked from Winnipeg to Donald (with automatic repeaters) and there connected with the other half of the quadruplex to Vancouver. Winnipeg thus worked two double circuits to Vancouver and a double circuit to Great Falls, Montana, employing two wires as far as Donald and but one from there to Vancouver. Some of the "quads" are only used in cases of emergency, such as extra press of business, or when some of the wires are interrupted. The quadruplex is worked from Vancouver to San Francisco, about 1130 miles, with automatic repeaters at Portland, Oregon and Ashland, Cal.

The Great North-Western Co., the speaker believes, has the following quadruplex circuits:—Montreal and Quebec, Montreal and Ottawa, Montreal and Toronto, Toronto and Detroit; he thinks this is the extent to which quadruplex is used in Canada besides the cable system between Sydney, C.B., and New York.

The Canadian Pacific Telegraph Co. works duplex nightly between New York and Winnipeg, and very frequently from New York to Vancouver or San Francisco. Intermediate or way offices cannot work on these circuits, the offices which can do so, except the terminals, are where the automatic repeaters are placed,—for instance, St. John, N.B., can work on the Montreal-Canso system.

In the United States between such places as New York and Boston and New York and Chicago, the quadruplex is very largely used, there being sometimes as many as ten or more quadruplex sets between two cities.

CORRESPONDENCE.

Mr. Gisborne.

Mr. F. N. Gisborne regretted being unable to be present at the discussion of Mr. Keeley's paper on the multiplex telegraph. It is, in his opinion, novel but practical, and may finally be adopted in preference to quadruplex or any present form of multiplex apparatus.

Mr. Pope.

Mr. E. Pope said Mr. Keeley's paper sums up very fairly the good and bad points of various systems of telegraphy now in actual use; his proposed plan is most ingenious, and when fully developed will no doubt be an advance on the present multiplex systems. It certainly will be if it can be made available for a "way" wire, but in that direction the "way agent" is an unknown quantity which has to be taken into account, for the necessary skill to handle the instruments to be used is seldom found even in the larger "way" offices.

Mr. Keeley has noticed the difficulty of harmonizing the automatic reversals of current with the free motions of the operators' keys, and he applies a remedy which seems to be insufficient to prevent such a mutilation of signals as would be found destructive to proper work. It may be found necessary to give the operators a key system by which their signals will all be taken up and transmitted into the line automatically to suit the automatic reversals. In actual working it is doubtful if any reduction can be made in the size of the earth plates, as Mr. Keeley calculates on. The wire will require to be thoroughly cleared after each signal, as in the systems now used.

Mr. Bott.

Mr. H. Bott said in the Delaney system one objection is, that during the passage of the brush over the ground plates the line is idle and its theoretical capacity not fully utilized. In the "interchangeable way wire multiplex" system, although the receiving apparatus is not susceptible to the influence of the preceding circuit, still the brush will have the same function to perform, the wire remaining idle during its contact with the ground plate, as in the Delaney system. Will the capacity not utilized in that system be gained in this? May not the induction from other parallel lines make it a very difficult matter to adjust so as to neutralize the effect of the induced current?

According to the theory advanced by Mr. Keeley, his system seems to overcome one of the disadvantages of the other multiplex systems in use, in that it allows way offices to work by providing a separate circuit for them, instead of as now leaving the wire idle between the two terminal points.

Mr. A. A. Dion said Mr. Keeley had dealt so thoroughly with the subject in his paper that there is little to be said, except to endorse in a general way his statements as to the important part the "multiple" principle is destined to play in the telegraphy of the future, and to congratulate him on his discovery of the means to extend its present application and usefulness. Mr. Dion.

To those who have given attention to the subject of telegraphy, the beauties and advantages of the "Simple Morse circuit" and the many difficulties attending the operation of "Automatic" or "Complex Circuit" systems, are so evident, that any invention tending to increase the capacity of the line wire, while retaining the many excellent features of the pioneer system, should receive a hearty welcome. In none of the various systems now in the field have those features been preserved. The nearest approach to the realization of the desired conditions is found in the "Synchronous Multiplex" systems based on the following established fact, viz.:—

If a number of electro-magnets are successively put in circuit, each for a fraction of a second, with a line wire carrying a current of electricity, and if the operation is repeated with sufficient frequency, the effect on each electro-magnet will be practically the same as if it had been constantly in circuit with the wire, and a continuous, instead of a pulsating, current had passed through it. The writer is of opinion that Mr. Keeley is justified in the assumption, that the line of further improvement in telegraphy lies in the full utilization of the line wire in the manner above stated.

Among the desirable features of the "Simple Morse Circuit" partly realized in the "Multiplex" systems is the possibility of extending their advantages to "way" offices, a matter of considerable importance in many ways. It may, however, be a costly privilege, or it may be obtained at the price of so much inconvenience as to make it undesirable. The writer knows of a multiplex system where this may be done by providing at *every* office a battery capable of operating the *whole* line. When one station is sending, the batteries of all other stations are idle as far as that particular circuit is concerned. This is the principle of the English open circuit system which does not seem suitable for this continent. It never found favour in America.

Whenever the "Simple Morse Circuit" is mentioned herein, the American or closed circuit system is meant, which permits way-offices to be opened anywhere or closed without much trouble or expense. In that particular as well as in many others, the system under discussion would seem to be the *only one* possessing the facility of operation and the flexibility of the "American Morse" just mentioned. That alone would entitle it to the serious consideration of telegraph engineers and electricians. But its aims are higher still. It claims to increase by fifty per cent. the number of circuits heretofore obtainable in practice, and to treble the distance over which a wire has been so utilized.

The way in which this is accomplished by the combination of an induction coil with a polarized relay, so as to make the latter responsive to *single pulsations* of current of $\frac{1}{333}$ of a second duration, is ingenious and original. The property the armature has of remaining on its contact, after being once attracted, until forced back by a pulsation of opposite direction to that which produced the attraction, making it unnecessary to make contact between the line and any one set of apparatus oftener than once every $\frac{1}{24}$ of a second, etc.

To many persons who have not followed very closely the later developments in the applications of electricity, the matter of synchronism suggests serious difficulties; but the problem having been solved very efficiently in other "Multiplex" systems, there is no reason to anticipate any trouble in this case, as Mr. Keeley proceeded upon the same lines as his predecessors. The claims of the inventor are based on well known laws of electro-magnetism, and the writer thinks that the "Interchangeable Way-Wire Multiplex" is a healthy and promising infant, and that if all cannot feel enthusiastic about it, they can at least wish it success and watch its practical application with the attention it merits.

Mr. Keeley may not care to let us further into his confidence; but, in the hope of obtaining more light, the writer ventures to ask the following questions, which need not be answered if the information asked for is not yet ripe for the public:

1st. The keys, corresponding to any one circuit, being closed at all offices, the circuit not being used, the + and — pulsations will occur alternately every $\frac{1}{24}$ second. Will not the armatures of the polarized relays vibrate between their contact points in unison with the alterations of current in the line, sounding a series of dots; and if not, how are they prevented from doing so?

2nd. How many series of contact plates is it proposed to have in the circle? In other words, what will be the rotary speed of the brush?

3rd. It is not stated that a second wire is used to carry current to operate the motors. If the line currents are used for that purpose would the synchronism be affected if, perchance, all the keys in one station were depressed? Or is there a special circuit (without a key) including the motor? In that case the current through the motor would consist of alternate + and — pulsations of $\frac{1}{333}$ second duration, with intervals of ($\frac{1}{24}$ — $\frac{1}{333}$ =) $\frac{1}{26}$ second between them, and the motors must be constructed so as to respond to those detached pulsations. Is that the case?

Mr. George Black said that he considered the review of the various systems of telegraphy, introductory to the new system described, as very clearly presented and their value not under-estimated. The "Interchangeable Way-wire Multiplex" is, in his opinion, correct in principle, and the difficulties which may possibly be encountered in practice will no doubt be easily overcome. Mr. Black.

Mr. Keeley said he had now prepared diagrams, Plates I and II, to illustrate his subject. The absence of these at the time the paper was read and the necessarily brief description of the Way Wire Multiplex, given in the concluding part of his paper, left room, it appeared, for some misconception of his ideas. This, however, he believed he would now be able to satisfactorily clear away. Mr. Keeley.

Taking up the questionable points as they had been presented, Mr. Pope's objection as to the doubtful skill of the average way office operator to handle the instruments was well taken. The speaker was himself well acquainted with that feature of the business, and has in his plans provided for it by rendering the operations of the circuits independent of any local disarrangement of the apparatus. In the present everyday experience on a single Morse line, there are instances when the instrument at a given office on a way line is disarranged —"not adjusted." That office is practically inoperative for the time being; but it does not interfere with the exchange of signals between other offices on the same line. As the system proposed does not pretend to excel the regular Morse circuit in its characteristics, but rather to preserve them all intact, the writer has faith in the skill of the average way-office operator being found equal to the occasion, for all that is required of him. Mr. Pope noticed an apparent difficulty in obtaining a correspondence of the key movements with the regular alternations of main line current in the act of transmission. If it had been practicable to furnish in the paper the details with reference to that feature, which the writer was unable to submit, this objection might not have been advanced. It would be seen presently how he had arranged for it; but supposing he were wrong and Mr. Pope right, it would be quite practicable to dispense altogether with the semi automatic function of the transmitter, and operate the circuits directly, provided that the main current alternations were increased sufficiently to furnish both phases of current during each position of the key. This would of course, on the basis of 40 words per minute, reduce the number of signalling circuits one-half; but even allowing that the number would be 5 on a 300 mile line, and 11 on a 100 mile line, *adaptable to way stations;* whereas, with Delaney's system, the best of those heretofore introduced, 6 circuits on a 100 mile line limited to terminals, is all that can be obtained. The next and last point advanced by Mr. Pope is the supposed necessity for effecting a complete discharge of the line between the successive circuits. This was due to a misconception. The explanation of this feature given in the paper was necessarily meagre. There is this difference between the writer's method of signalling and that of previous methods. Take five successive circuits in Delaney and Calahan's first form of the Synchronous Multiplex, or in Lieut. Patten's system; let 1, 3 and 5 be *closed*, and 2 and 4 *open*. The line has to be traversed by currents successively as follows $\overset{+}{1}\ \overset{-}{2}\ \overset{+}{3}\ \overset{-}{4}\ \overset{+}{5}$. Unless a + current is obliterated, the succeeding — is ineffectual; and unless the — current, in its turn, is obliterated, the succeeding + will not be effectual. Now, taking the same circuits according to the writer's method, the line would be traversed by $\overset{+}{1}\ \overset{0}{2}\ \overset{+}{3}\ \overset{0}{4}\ \overset{+}{5}$ and, after a discharge, by $\overset{0}{1}\ \overset{-}{2}\ \overset{0}{3}\ \overset{-}{4}\ \overset{0}{5}$, since the + and — phases, in series, take turn about. The narrow earth segments introduced between the succeeding line plates prevent an accumulation of the charge in the line which would occur when several successive circuits were closed. For instance, without them, it might be (graphically) $\overset{+}{1}\ \overset{+}{2}\ \overset{+}{3}\ \overset{+}{4}\ \overset{+}{5}$ in this case the tailing of the charge from 3 would operate in 4, which should otherwise be unaffected. With the segments, the charge would be $\overset{+}{1}\ \overset{+}{2}\ \overset{+}{3}\ \overset{0}{4}\ \overset{+}{5}$; in this case the charge is kept down, so there is a very slight tailing into 4. In Delaney's (improved) system, that dealt with in this paper, the latter condition, if narrow segments are used, would obtain; and as the receivers are worked on intermittent currents, it is necessary to obviate even the slight tailing (by putting in wide segments), in order to allow the armature to fall away. According to the writer's arrangement, the receiver is positive in action, moved one way by a *full* + and the other way by a *full* — pulsation; and in it a + pulsation never occurs at the same time as a — tailing, or a — pulsation concurrently with a + tailing, in consequence of the + and — phases being in series; so the slight tailing (which is always of the same sign as the current following upon it) from one circuit into the other is wholly ineffectual.

In reply to the remarks of Mr. Bott, in Delaney's system the discharge plates are uniform in size with the signalling plates, whereby 50 per cent. of the line-time is lost. Again, in that system, 34 contacts per second are required to accommodate the sending operator's manipulation. In the Way Wire Multiplex system, on the other hand, only very narrow segments are required between the signalling plates, for the purpose explained in the reply to Mr. Pope's objection; and only 24 contacts per second are required for the operator's accommodation. It must therefore be very clear that the signalling capacity of the line will be utilized to a far greater extent in the latter than in the former, in fact, to its *greatest extent*, both theoretically and practically. As regards the interference from induction from neighbouring lines, there could be none, for the reason that the receivers proper are in local circuits and actuated through the medium of induction coils, whose currents are ineffectual excepting when occasioned by a full pulsation of the main line current. A careful perusal of what is stated in the paper with reference to quadruplex circuits will show that this matter of induction has not been disregarded in the devising of the speaker's new system. It was no doubt in consequence of Mr. Bott's experience with that class of multiple circuit systems that he suggested the possible difficulty of interference.

The remarks of Mr. A. A. Dion are fully answered in the explanatory notes accompanying the diagrams, Plates VIII and IX. The relay levers do vibrate in response to the current alternations. There could be no objection to this, however, because it need only occur, so far as the sounders are concerned, on one or more of the circuits that may be set apart for calling purposes. The moment actual transmission begins, the circuit is under control of the key, and the continuous vibration cannot then occur. The other two questions, as to the number of signalling plates and speed of rotation of the line brush, are answered in the diagram, Plate I; they are there set down as 8 series, with 3 revolutions of the brush. Obviously it might be 4 series with 6 revolutions, or any other modification resulting in 24 alternations per second; but it is more convenient to obtain perfect synchronism with comparatively low speed, and 3 revolutions per second is calculated to afford the best results. Mr. Dion was mistaken in supposing that the intention was to operate the motors directly by the main currents, by pulsations recurring every $\frac{1}{24}$ of a second. As indicated in Plate II, two circuits are set apart for the operation of the motors, by means of receiving relays actuated in the same way as those for signalling. These relays are not connected to all of the series, and are only brought into operation at every half revolution; the one overlaps the other in the matter of closing and opening by the length of one series of contacts. Each is therefore actuated for $(\frac{1}{6} + \frac{1}{24})$ a trifle over $\frac{1}{5}$ second, so there is nothing at all delicate about it.

Exception has been taken to that paragraph on page 256 in the paper which reads :—

"*Now, having an economical method of signalling and the requisite apparatus therefor, it is only necessary to associate it with means for transferring the line wire from one set of instruments to another simultaneously, at as many stations as desirable on a line, in order to produce a multiplicity of signalling circuits.*"

As he regarded it, this paragraph, read in a general way, bears a liberal interpretation such as was intended, and there is nothing extravagant in its composition; but he was told that one might just as well argue in the following strain :—

"Now that we have a horse that has run one mile in three minutes, and a car capable of holding fifty passengers, all we have to do is to attach the horse to the car and carry the passengers at the rate of twenty miles an hour."

Of course, this latter argument is preposterous; and in looking for the analogy that is assumed to exist between it and the one quoted from his paper, the writer finds that the latter has been construed as disregarding the element of counter-electromotive force that is introduced into circuit by the exclusion of way circuit apparatus. He has therefore to explain that this possible impediment to the practicable operation of an unreasonable number of way offices in any one circuit has not been overlooked. In the paragraph alluded to, the expression is "at as many stations as desirable." As is known in practice it is very rarely that more than two or three offices are simultaneously handling the same despatch, so it would be idle to have apparatus included in circuit where there in no occasion for it. His idea is to have on a line of 15 or 20 stations a system of multiple circuits, one or more of which are set apart exclusively for calling purposes. All of the offices are included in these circuits,—some in one, some in another, as will be found most convenient. When the operator at a given office has answered his call, he switches his signalling apparatus into one of the other circuits designated by, or predetermined for, the office that has called him. In this way the circuits can be utilized to the best advantage. As for the multiplicity of offices on the calling circuits, the counter E. M. F. presented by their apparatus need not be taken into account, for its deleterious effect consists in hampering the rapid transmission of signals, and on calling circuits speedy signalling is not at all requisite. He must here emphasize the fact that in designing this system, he has been guided by thoroughly practical considerations throughout. He could now perhaps to some advantage present a further and fuller explanation as to the operation of the system, having reference to the drawings Plates I and II.

It will be understood, in view of the descriptions already given in the paper, that the conditions for operation comprehended 24 reversals of current, that is 12 + and 12 — alternations per second. And as it was shown that this provision is necessary for the transmission of signals at the fastest practicable rate of Morse transmission, and since the downward movements of the key are reproduced by the currents of one polarity, and the upward movements by the currents of opposite polarity, it is obvious that the key movements must be brought into correspondence with the regularly alternating pulsations.

The means whereby this correspondence is effected is shown in Plate I.

In the act of transmission the opening of the switch S corresponds to an upward movement of the key K; this, as already explained, allows a — phase of the main current to pass, and interrupts the + phase. The relay R responds to the — phase, and the lever l rests on the back stop b. If now the key K is closed, the lever Tr of the transmitter will be drawn down, and a circuit, independent of the key K, will be closed through the magnet Tm, by the lever Tr, its lower stop, the dotted lines battery Tb and the lever l and back stop b of the relay. So, if the key is now upraised, the transmitter lever will remain depressed. In this position it affords a path for the + pulsations of current. The first + pulsation passing through it will actuate the lever l of the relay, and carry it from the back stop b to the front stop f, where it will close the circuit of the sounder So. The instant the lever l leaves its back stop b, the transmitter lever will be released and upraised.

As this effect is produced within a quarter of a second of the upraising of the key, and as it is physically impossible for the manipulator to depress the key again within that brief space of time, it is clear that the uprising cannot be prevented by any subsequent depression of the key.

But in order that the uprisal of the lever Tr may be effectual, it must remain undisturbed for a brief space (not exceeding $\frac{1}{24}$ sec.) to allow the next — phase of the current to pass.

It is therefore necessary to obviate the possibility of a downward movement of the key during that period affecting the position of the transmitter lever. A further inspection of the circuits will show how this is done.

If, at the moment the lever l of the relay R is brought against its front stop f, the key K is open, a circuit is formed by the contacts l, f, including the batteries Tb Sb and the sounder So. If, now, the key K is depressed, the lever Tr of the transmitter will be unaffected, because the battery Sb is in shunt with Tb, and its current through the magnet Tm is opposed to that of Tb, and renders the power of the latter inadequate to pull down the lever Tr. The instant, however, that a — pulsation passes to line, the lever l of the relay R is carried away from the stop f; the disconnection opens the circuit described through So, the current of Sb is withdrawn, and that of Tb alone operates by way of the key K through Tm, and the transmitter lever is pulled down. This action all occurs within $\frac{1}{24}$ of a second of the key movement.

As each movement of the key occupies no less than $\frac{1}{24}$ of a second, and the reversals of current occur with that frequency, the key cannot act faster than the currents.

When it happens that the downward and upward movements of the key are respectively concurrent with the + and — phases of current, the lever l of the relay in responding will not interfere with the position of the transmitter lever Tr, because the balance of current obtaining when Tb is opposed by Sb (though inadequate to draw it down when upraised) is sufficient to hold it in position after it has been depressed by the action of Tb alone in circuit with the key.

Each upward and downward movement of the key is therefore faithfully reproduced in the main circuit. The lever l of the relay R follows the movements of the key as shown; and the same currents that affect the relay R affect every other relay that is included in its circuit.

In further explanation of the brief description given on Plate II it should be pointed out that the synchronous motors are purely local in action, though controlled by the main line receivers Ra Rb. In consequence of this, the main circuit is quite independent of the way station conditions, because normally all of the circuits are connected "through;" and if the apparatus at a way station gets out of adjustment, the entire plant presents as it were a unit of conductivity in the circuit, permitting the uninterrupted passage of the regularly recurring currents between the terminal stations. On the other hand, when the way station apparatus is in proper working order, each of the multiple circuits presents the characteristics of a single Morse line; any one or more of which can be grounded without interfering with the other circuits. In the diagram the ground switches E at the way office indicate how this is done. Of course in such a case the circuit is operated by the currents emanating from one end alone, as in a regular Morse line.

In the actual arrangement of the way office circuits, spring jack switches are provided for the ready introduction of the signalling apparatus into circuit, or on either side of an inserted ground wire in any circuit.

With this further explanation the writer thinks he has about covered the ground, and believes he has amply justified the high opinion of his new multiplex system which has been expressed by the general superintendent of the Government telegraphs, Mr. F. N. Gisborne.

It is also satisfactory to have such a favourable expression of opinion regarding his proposed system from Mr. Camp, who, from his wide experience as electrician to the Canadian Pacific Telegraph Co., is thoroughly cognizant of the requirements of the general telegraph service. The information Mr. Camp has given affords a good idea of the extent to which the quadruplex systems of multiple circuit telegraphy are now in use, though their operation is confined to terminal stations, and this argues the existence of an increasingly wide field of application for a system of the kind dealt with in the paper, which, while affording a larger number of circuits than is obtainable by the methods of quadruplex construction, is adaptable for the accommodation of intermediate and terminal stations.

Thursday, 23rd October.

JOHN KENNEDY, Vice-President, in the Chair.

The discussion of Mr. D. H. Keeley's paper on "Developments in Telegraphy, etc.," occupied the evening.

Thursday, 6th November.

E. P. HANNAFORD, Vice-President, in the Chair.

Paper No. 45.

THE ERRORS OF LEVELS AND LEVELLING.

By Prof. C. H. McLeod, Ma. E., M. Can. Soc. C.E.

PART I.—THE DEFECTS OF LEVELS.

As is well known, levels are manufactured from glass tubes by grinding the inner surface of the tube with emery powder placed on an arbor rotating in a lathe, the arbor having been previously turned from a template to the desired curvature. The tube should be slowly turned about its axis, so as to present the whole of its inner surface to the arbor, giving when the grinding is completed a similar internal section for all planes through the axis of the cylinder. The surface intended to be uppermost should then be brought to the highest possible degree of polish. This completed, the ends are temporarily plugged and the tube filled with liquid. The level is then tested on a trier, and if the curvature proves to be uniform the ends are hermetically sealed and the centre line of the upper surface graduated in equally distant divisions.

The levels used on the ordinary engineering instruments can be made with sufficient accuracy by this method. In the practice of one of the best American makers, all levels of less delicacy than 5″ per division of 2 mm. are machine made, in this manner. For levels having a scale value of from 1″ to 5″, such as are used for astronomical and geodetic instruments, it is necessary to apply local corrections after the level is first roughed out on the machine. As the level must be tested after every correction, this is a very tedious as well as most delicate operation, and indeed not infrequently ends in failure. It is very important that the upper interior surface should have the highest possible polish,* and be entirely free from grains of emery or other foreign particles. The glass employed should be of the hardest and least

*Some makers maintain that the highest polish dces not give the best results, for what reason is not known to the author.

hygroscopic kind, in order to avoid any deterioration of the accuracy of the level through chemical action on the glass by the liquid filling. The tube should be of uniform bore and thickness. The liquid most commonly employed for engineering levels is alcohol. A certain percentage of ether is sometimes added to the alcohol, in order to obtain greater fluidity and therefore increased sensitiveness in the level. Ether of naphtha is also sometimes used for instruments of this class. For the highest class of levels the filling liquid generally employed is sulphuric ether, with sometimes a small percentage of chloroform.

Too little attention is paid to the mounting of bubbles. The usual method of enclosing the glasses rigidly in a metal tube may give rise to such serious changes of form in the level as to render it wholly unreliable. Some examples of change of form due to the mounting will be given hereafter. Levels for "precise" work of all kinds should be connected with the frame at only two points, and should then rest on some yielding material such as cork or sheet lead, and be held in place by light strips of metal; the ends of the tube abutting against a piece of cork. The more delicate levels having a scale value of $3''$ or under require protection from air currents or from rapid changes of temperature, due to radiation from surrounding objects, and should be enclosed in a glass tube. The ends of such levels are chambered—that is there is a diaphragm cutting off from $\frac{1}{2}$ to 1 inch of the end of the tube, the diaphragm having a small hole in it—to admit of adjusting the bubble to a standard length under varying temperature.

Having thus briefly reviewed the construction of levels we are brought to the object the writer has in view,—a consideration of some of the defects to which levels are subject.

Irregular Curvature.—This gives rise to a shift in the zero position of the bubble with each change in the temperature of the liquid, since the bubble shortens or lengthens more towards one end than the other as the liquid expands or contracts. An engineer's level having this defect will, when placed in adjustment at any one temperature, not be in adjustment for any other temperature. Where the level is used to measure angular values, as, for example, the inclination of the axis of an astronomical transit, it is obvious that the result will depend on the position of the bubble on the scale. Irregularity of curvature is unfortunately a common defect in engineering levels, and to it are no doubt due many of the discrepancies so often met with in levelling. Where the range in the scale value is not great, such an instrument may, with proper precautions, be used on ordinary engineering work, but would be quite inadmissible for astronomical purposes, where the scale value is the important factor.

A level which was made for McGill College some years ago, to be used as a striding level for a transit-theodolite, has a scale value running somewhat as follows, from end to end :—12″, 37″, 34″, 22″, 20″, 3″, with a portion of the ends flat or of reversed curvature. This instrument is of course worthless. When the fact is added that its maker has made and can make good levels, it will be acknowledged that every level, no matter what may be the reputation of the maker, should be subject to most careful test before being put into use.

Difference of sectional area of the ends of the tube also gives rise to a shift in the zero, since for a given change of temperature the air space at one end will be altered in length to a greater or less extent, according as it is towards the smaller or larger end of the tube. Where the grinding tool has been carefully applied around the whole circumference, the axes of the grinding arbor and tube being maintained parallel to each other during the operation, and the tube is of fairly uniform diameter, the condition of equality in the two ends is most perfectly fulfilled.

Roughness of the upper interior surface, arising from imperfect polish or from small particles of emery adhering to the glass, will give results which at first sight closely resemble those arising from irregular curvature. The bubble is held back by the rough particles, while the level is turned through a considerable angle, thus giving the appearance of increased scale value, and when the bubble finally breaks away, it moves through several divisions of the scale as if the curvature at that point were very much flattened out. A level, which was recently sent to the writer for examination, gave a reasonably uniform scale value for long runs, but when it was examined more closely showed great irregularity. Two points were found on the tube, at which the tests showed there must be some obstruction. In one position the bubble held through a change of inclination of 6″. Examination with a magnifying glass revealed very minute particles of emery embedded in the glass at each of the points. After these were removed the level was found to be of very uniform scale value and sensitive at all points. Such a defect in an engineering level would render good work impossible, and would, in addition, be very annoying to the observer, inasmuch as it would be difficult to keep the bubble in the centre, unless indeed the obstruction happened to be at one end of the bubble when in its central position. The common defect of sluggishness and uncertainty in the position of rest is no doubt largely due to a rough surface, though doubtless also to some extent arising from the character of the liquid filling.* When there is such roughness of surface the position of rest of

* For effect of length of bubble on sensitiveness see Discussion.

the bubble is noticeably affected by the velocity with which it moves. When the position of the level is quickly altered the bubble over-shoots its mark and is held beyond the proper resting place. When, on the other hand, the level is very slowly moved, the bubble will not quite reach its true position of rest. In these cases a slight tap on the glass will usually suffice to bring the bubble to its true position. Up to a few years ago all the levels the writer had met, of the manufacture of a certain well-known London maker, had this defect. The level of the telescope of one of the 5 in. transit instruments in McGill College, the scale value of which is 25″, may be made to take up a position in this way, anywhere within a range of 7″, or up to a maximum of 3.″5 from its true position.

Levels are subject to change of form, either from a change in the glass itself or from the pressure due to change of form of the mounting, under the influence of temperature or otherwise. The latter may be guarded against by a proper form of mounting. The former, whether from permanent structural changes in the glass or from temporary changes under varying temperature, can only be met by an investigation of each individual level. If there be a permanent change of form there is of course liability to an irregular change of curvature, rendering the instrument worthless as an instrument of precision. The only example of this kind of change which has come under the writer's notice is an excellent level made by one of the best American makers. It is described by the maker as made from the best kind of Bohemian glass. It is needless to state that the possibility of any change of form is stoutly denied by the maker. Here, however, is the evidence in the case :—

Purchased in April, 1883, and forwarded by the maker to Prof. W. A. Rogers, then of Harvard College Observatory, for examination and determination of the scale value. The level was placed in wyes attached to the cube of the meridian circle of Harvard College Observatory, and adjusted so as to be parallel to the optical axis of the telescope. The scale values were read off on the circles in a series of seventeen separate determinations, extending from April 6th to April 25th. The resulting mean value of one division was 2.″19 ± 0.″02.

The level was then forwarded to Montreal, and has been in continuous use as a striding level for an astronomical transit up to date. It has received two severe jars, falling from the transit instrument to the floor,—first in June, 1883, and the second time about one year afterwards. On April 1st and 2nd, 1884, the scale value was determined on a level trier in the workshops of Messrs. Hearn & Harrison, and gave a mean value, from three sets of sixteen determinations each, of 2″.40 with an inappreciable probable error. The value of one revolution of the screw on this trier was measured by comparison with an Elliot Bros. $\frac{1}{1000}$th gauge, which was itself verified by comparison with a standard bar by Professor Rogers.

During the years 1889 and 1890 several determinations at different times and under various conditions have been made on a level trier in McGill College, the screw of which has been compared with the gauge above referred to; the results of these comparisons are given below:—

Date	Temperature of the air.	Length of Bubble.	Resulting Scale value.
1889			
Jan. 30th.	7°	51 mm.	2.″63
May 16th.	62°	37 mm.	2.″48
July 15th.	69.°5	35 mm.	2.″56
July 15th.	69.°5	54 mm.	2.″58
	At 52.°0	Average value in 1889 =	2.″56
1890			
Feb. 22nd.	75°	51 mm.	2.″56
March 6th.	15°	39 mm.	2.″60
Sep. 20th.	65°	43 mm.	2.″51
	At 52°	Average value in 1890 =	2.″56

In order to discover if the change in form was in any way due to straining by the frame, the glass tube was removed from its frame and binding screws immediately after the test on Sept. 20th last, and in one hour was again examined and gave the same result. It was again examined, forty hours after removal from the frame, with the same result. There has undoubtedly been a decided change of form in the glass, and that, as was to be expected from the method of mounting, without external strain. Fortunately there is no serious change in the uniformity of the curvature. The final form which the glass now seems to have attained may have been reached several years ago, but certainly not within three years after it had left the hands of the maker. These results would point to the desirability of the finished levels being kept in stock for one or more years by the makers, in order to give time for any change of form to reveal itself. Such inquiry as the writer has been able to make has failed to discover a maker who adopts this precaution. It is well known that a similar trouble has arisen in the case of the glass used for thermometers, but here the makers recognise the need of seasoning the glass before the thermometer is graduated and put on the market.

An examination of the table given above will also show a slight change of scale value, due to temperature. Although small, amounting only to about 0."0015 per degree Fah., it is of quite sufficient importance to be taken into account in a longitude determination, amounting as it does to over one-tenth of a second of arc for our average range of mean temperature in the year.

The writer is unable to offer any observations of his own in illustration of temporary changes of great extent in a level, unstrained by its mounting; but that there are such, and very serious ones, rendering the instrument quite unfit for delicate measurements, the following extract from a paper read at the Montreal meeting of the American Association for the Advancement of Science, by Prof. W. A. Rogers, will show :—" In "order to show the necessity for repeated and continuous observations "for the determination of the value of one division of the level, I record "here my experience with the companion level of the instrument known "as the Russian transit" (H. C. Observatory). "It was made in the "workshop of the Pulkowa Observatory.

"I began the observations about 8 o'clock in the morning of Nov. 13, "by comparing the readings of the circle with bubble first at the mid-"dle of the tube and then at the extreme end. Proceeding in this way "with each five divisions in succession, I was surprised to find, not only "a continued diminution of the value of one division, but a well-defined "shifting of the zero of the level. By noon I had nearly completed the "examination for the first half of the divisions. I then opened the "shutters for an observation of the sun. After an interval of ten "minutes, observations with the level were resumed, when it was found "that the value of one division, determined from the same space as "before, had increased by one-fourth of its mean value. It will be "sufficient to give in illustration the results of the observations on three "days.

1881.	Nov. 13th.	Nov. 14th.	Nov. 15th.
"Shutters closed	1 div=1.76" Th.=38°	1 div = 1.20" Th. = 40°	1 div = 2.06" Th. = 47°
"Shutters open	1 div=2.08" Th.=65°	1 div = 2.06" Th. = 70°	1 div = 1.78" Th.=86°"

Subsequent observations made under different conditions confirmed these results. Professor Rogers adds :—" It is hardly necessary to say "that this level has been discarded as worthless. On the other hand, "the mounted level furnished with the Russian transit proves to be an "excellent one."

Here, then, are two levels made in the same workshop,—the one proving to be a good instrument, the other totally unreliable. A difference in the quality of the glass is the cause to which one would naturally refer this discrepancy, and this suggests an investigation of the permanence of form of the different kinds of glass, one which, so far as the writer is aware, has not yet been undertaken. The peculiar behaviour of this level, under the conditions of the test imposed, emphasizes the necessity of shading levels from the direct heat rays of the sun, a practice which is always insisted on in geodetic levelling, and which with little trouble might be adopted for the more important lines of levels in railway or canal work. A shade over the level is also important on account of the errors in reading the bubble, arising from the sun's rays falling obliquely upon it, giving a different illumination to the opposite ends.

Examples of change in the form of levels due to the varying strain in the mounting are only too abundant. In two Dumpy levels, in which the glass tube is held in a brass case and plaster of Paris, the scale values were determined as follows :—In one 21."5 at 66° Fah. and 17."1 at 20° Fah., and in the other 26."7 at 67° Fah. and 24."0 at 20° Fah., giving respectively changes of 1" for each 10° and 17° of temperature. The mere change of scale value is not the important point in such levels, but the associated circumstance, of which there can scarcely be a doubt, that a change in the zero of the level takes place with each change of scale value, putting the instrument which may have been placed in adjustment at a given temperature out of adjustment for any other temperature.

Since the introduction of ether as a filling fluid in levels, it has been found that in some level tubes so filled a deposit has occurred on the surface of the glass, the accuracy of the instrument being in consequence either greatly impaired or destroyed. The rough particles hold the air bubble and prevent that freedom of motion so essential in a good level. Dr. F. Mylius* has shown that these deposits occur through the action of the small quantity of water remaining in the ether, on the potash or soda in the glass. It is a matter of very great difficulty to fill a level tube with perfectly dry ether. Dr. Mylius used eosin as a re-agent in his investigation since it imparts a light yellowish colour to ether† and gives a bright red colour to water.

* Zeitschrift für Instrumentenkunde.

† Perfectly pure anhydrous ether is not coloured by eosin.

By adding some eosin to a tube filled with ether at the ordinary temperature of a room, and then lowering the temperature of the tube and the liquid considerably, small globules of water were found to be separated from the ether and to deposit themselves on the walls of the tube, becoming visible by reason of the bright red colour caused by the eosin.

He demonstrated also that these small particles of water, retaining their places, very shortly became saturated with potash or soda from the glass, and that after the lapse of a few weeks small particles of potassium or sodium compounds appeared within the drops. Where an acid is present in the filling material—as is usually the case—the deposit will take place in a crystalline form. Dr. Mylius and others have found that these deposits are more likely to occur in glass rich in alkalies, while in those having a large proportion of lead or zinc they are less likely to occur. The harder the glass the less likelihood is there of the deposits occurring. Also that they are more likely to occur where the surface is rough than where it is highly polished. To demonstrate this he roughened a delicate level tube previously uninjured, and found after the lapse of some weeks deposits occurring on the roughened surfaces.

Where such substances as alcohol and water are used for the filling material, the formation of crystal is prevented since the alkalies extracted from the glass will go into solution. Alcohol is, however, not sufficiently mobile for delicate levels. Experiments on the use of other fluid substances, such as benzoline, petroleum, and chloroform, have been made, but in them also the deposit of water occurs. The solution of the difficulty seems to lie in a proper selection of the glass. Flint glass having a large proportion of lead is not suitable owing to its softness and liability to alter its form. The choice of glass would seem to lie between Bohemian glass containing lime, thermometer glass containing zinc, and crystal glass containing lead.

When we consider the many defects to which a level is subject, it becomes obvious that it is an instrument which, while it is capable of yielding results of the highest accuracy, is also one to be used with great precaution. In fact, it can only be considered an instrument of precision when subjected to careful examination and test during the period covered by the observations in which it is being employed, and under conditions similar to those in which it is being used.

THE ERRORS OF LEVELS AND LEVELLING.

By Prof. C. H. McLeod, Ma.E., M.Can.Soc.C.E.

PART II.—ERRORS OF LEVELLING.

In considering the errors of levelling, reference will only be made to such operations as are ordinarily included under the name of spirit levelling, omitting any reference to trigonometrical levelling, in which the spirit level plays an equally important part. It will first be proper to remark that spirit levelling may be broadly divided into two classes: The ordinary levelling undertaken in connection with railways, canals, drainage, etc.; and "geodesic" or "precise" levelling, where the highest attainable accuracy is sought in fixing the elevations of inland points with reference to a common mean sea-level datum. Nearly all European countries are carrying out such systems of levelling in connection with trigonometrical surveys; and in the United States many thousands of miles have been run under the direction of the Coast and Geodetic Survey, the Lake Survey and the Mississippi River Commission. Some few hundreds of miles have, the writer believes, been levelled in Canada by precision methods, but he has not the details before him.

The instruments employed in spirit levelling may for convenience be divided into three classes,—the dumpy, the wye, and the precision level. The form of the dumpy and wye as employed for ordinary levelling need not be described here. The precision level appears under a variety of forms. Those which have been used in the best European work and in America are of the wye type. The level tube is detached and used as a striding level on the collars of the telescope. One wye is moveable in a vertical direction under the control of a micrometer screw, in order to obtain the small final adjustment necessary to bring the delicate level employed to a central position on the scale. There is a wide range of scale value in the levels employed in the two classes of work, and also amongst the individual instruments used in each class. This divergence is much more marked in the ordinary levelling instruments than in the geodesic instruments. In illustration of this point, the scale values of the levels (as they came from the hands of the maker) belonging to McGill College are given in the table below. The scale values employed for geodesic instruments are usually within the limits of 3″ and 6″ per division of 2^{mm}; equal respectively to 3.75″ and 7.5″ per div. of 0.1 in., the length of the division on the levels referred to below.

SCALE VALUES at 65° Fah.

Kind of Instrument.	Maker's Name.	Scale value per div'n. of 0.1 in.	Optical powers.
12 in. Wye level.	Hammersley.	75″	18 and 26
14 in. Dumpy level "A."	Do	21″	18 " 26
14 in. do " "B."	Do	26″	20 " 25
14 in. do "	Stanley.	27″	20 " 25
14 in. do "	Troughton & Simms.	14″	18 " 30
18 in. Wye. "	Buff & Berger.	12″	37

The optical powers in this list will be referred to hereafter.

Before proceeding to a consideration of the errors of levelling, it will be necessary to review briefly the methods of adjustment in the several forms of instruments, and in this connection certain defects of construction will most conveniently be referred to.

The object of all methods of adjustment is to bring the line of sight parallel to the line tangent to the inner surface of the level tube at its zero point,—this line will in this paper be referred to as the "bubble-axis." In the dumpy this condition can only be reached by the direct method of reading the rod on two "pegs," the difference in the level of which is known, one point being near the instrument while the other is several hundred feet distant, and shifting either the position of the cross hairs or of the level tube, until the readings give the true difference in level. The only error in this method is the slight one due to the curvature of the earth, amounting to about $\frac{1}{100}$th of a foot in 600 feet, and to one-quarter that amount in 300 feet.

The method usually employed to obtain the difference in level of the pegs is by setting the instrument at a point midway between them. The errors of the readings then being the same, the difference is the true one. A second method of determining this difference of level, which is not so generally practised and is perhaps not known to all engineers, is as follows:—First set the instrument over one of the pegs, so that the eye end will just swing clear of the rod, held vertically on the peg. When the instrument is level, view the rod through the telescope, with the eye at the object end; the centre of the small circular portion of the rod thus seen can be accurately estimated and its position read by the aid of a pencil or knife edge held against the rod. Then read the rod as usual on the distant peg. Now move the instrument over the second peg, and obtain a reading of the rod as in the case of the first peg. Then read the rod on the first peg which is now the one distant from the instrument. If we call the difference of the rod readings in the first position of the instrument m, and the difference of those in the second position n, then the true difference in the elevation of the pegs is $\frac{m-n}{2}$. Results thus obtained, being from four separate readings instead of two, and being independent of the accuracy of any horizontal measurement, are susceptible of greater precision than the usual method. The instrument and rod are now in position for the necessary adjustment, and the distant rod reading will be corrected by the above amount.

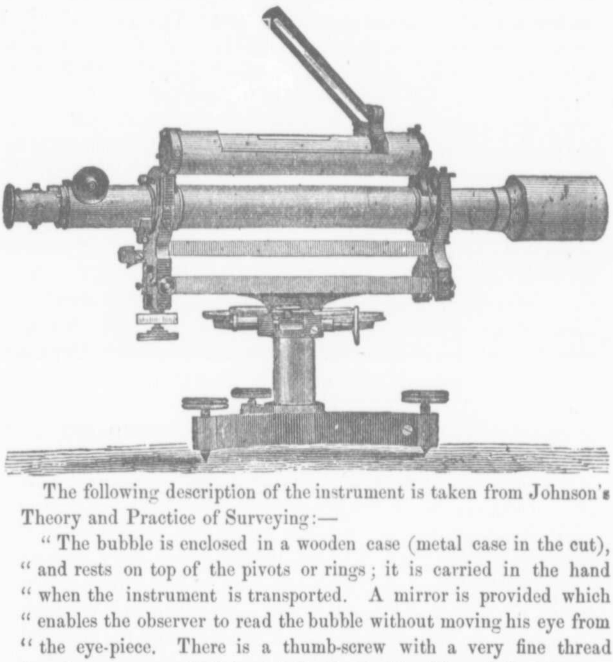
It is customary to adjust the wye level by the indirect method. The line of sight being examined for coincidence with the axis of the collars by revolving the telescope in its wyes, the bubble-axis is then tested for parallelism with the bearings of the collars by turning the telescope end for end in its wyes, and the necessary corrections applied. This method is based on the assumption that the collars of the telescope are true cylinders, and have equal diameters—an assumption which is often wide of the mark. In the case of one level used by the author, the error due to this cause amounts to somewhat over $\frac{1}{100}$th of a foot in 100 feet, a condition of adjustment which should be quite inadmissible for good railroad levelling. It is not an uncommon circumstance, in his experience, amongst users of wye levels, to find the fulfilment of the first portion of this test—the revolution of the telescope in its wyes—accepted as a guarantee of the perfection of the whole. Such an error of judgment is of course impossible with persons acquainted with the theory of the instrument; but alas, the holder of the position of "Engineer" in this free country of ours may readily be a touch above theoretical considerations.

For convenience only is it desirable that the bubble should remain central while the instrument rotates about its vertical axis. In the dumpy this adjustment must be made before, and in the wye after, the essential adjustments have been completed. It is commonly stated in defence of the indirect method, that there is a saving of time as compared with the direct or "peg" method. Such is, however, not the author's experience. The time-consuming portion of the work is the making of the necessary corrections to the level tube and reticule. In the essential adjustments by the indirect method both may require correction, whereas in the direct method only one of them—preferably the reticule—should be moved. We have then in comparing the relative convenience of the two, on the one hand the matter of setting up the instrument once and making two or three rod readings, and on the other the complete adjustment of the level tube. The writer would rather set up ten instruments and make as many rod readings (and could do it in less time), than adjust one bubble tube. This indirect method seems to him to have, for the purposes of ordinary levelling, no one point to commend it in preference to the direct method, and has the disadvantage that it does not guarantee correct adjustment, unless the pivots have, after careful examination, been ascertained to be equal; or the proper correction determined and applied. The wye is undoubtedly the most scientific instrument, and for precise work has some advantages,—such, for example, as the possibility of eliminating the error due to want of coincidence of the sliding tube with the line of sight. In a well constructed dumpy, however, this error must always be trifling. The writer has never been able to understand why the wye level should be used in ordinary levelling in preference to the dumpy. The wye form is more difficult of construction, more expensive, less rigid when constructed, and hence more liable to get out of repair. The most abominable instrument ever put in the hand of man is an old and shaky wye level. He submits that in the interest of good work, if not of economy, the construction of the wye form for ordinary levelling should be abandoned in favor of the more compact and rigid dumpy. The modification of the dumpy, such as Cushing's reversible level and other deviations from the type form, do not, for similar reasons, commend themselves to him. The adjustments for coincidence of the optical axes of the objective lens and the eye-piece with one another and with the axis of the tube, provided for in the wye but not in the dumpy, are really makers' adjustments, and except in the case in which the axis of the objective slide makes an angle with that of the tube are not essential to correct work.* A very important point to be attended to in the construction of all levels, and in the examination of them from time to time by the Engineer, is that the object lens is not loose in its cell, and that the cell is not loose in the telescope tube. Both these defects are apt to occur through time. The tightening

* The test for this error is most conveniently made in the wye by sighting on a distant and a near object in the reversed position of the telescope tube, and in the dumpy should be made by the three peg method referred to by Mr. Irwin in the discussion.

band at the back of the cell should screw into place in order to permit such a defect being rectified. An instrument having a loose objective is impossible of adjustment and fatal to good work.

The accompanying cut, taken from Fauth's catalogue, represents an instrument of the form used in geodesic work. The pattern employed by the United States Coast and Geodetic Survey differs slightly from this instrument, which is the one prescribed by the International Geodetic Commission, held in Berlin in 1864, and used in this country on the Lake and Mississippi River surveys.



The following description of the instrument is taken from Johnson's Theory and Practice of Surveying:—

"The bubble is enclosed in a wooden case (metal case in the cut), "and rests on top of the pivots or rings; it is carried in the hand "when the instrument is transported. A mirror is provided which "enables the observer to read the bubble without moving his eye from "the eye-piece. There is a thumb-screw with a very fine thread "under one wye, which is used for the final levelling of the telescope, "when pointed on the rod. There are three levelling-screws and a "circular or box level for convenience in setting. The telescope "bubble is very delicate, one division on the scale corresponding to "about three seconds of arc. The bubble-tube is chambered also, "thus allowing the length of the bubble to be adjusted to different "temperatures. The magnifying power is about 45 diameters. "There are three horizontal wires provided, set at such a distance "apart that the wire interval is about one-hundredth of the distance "to the rod. The tripod legs are covered with white cloth to dim- "inish the disturbing effects of the sun upon them. The level itself is "always kept in the shade while at work.

"The levelling-rod is made in one piece, three metres long, of dry "pine, about four inches wide on the face, and strengthened by a "piece at the back, making a T-shaped cross-section. The rods are "self-reading, that is, they are without targets, and are graduated to "centimetres. An iron spur is provided at the bottom, which fits "into a socket in an iron foot-plate. The end of the spur should be "flat and the bottom of the socket turned out to a spherical form "convex upwards. A box-level is attached to the rod to enable the "rodman to hold it vertically, and this in turn is adjusted by "means of a plumb-line. Two handles are provided for holding the "rod, and a wooden tripod to be used in adjusting the rod-bubble. "The decimetres are marked on one side of the graduations and the "centimetres on the other; all figures are inverted since the telescope "is inverting."

In the use of such a level according to the methods of precise levelling, it is necessary to determine the instrumental constants:—

1. The angular value of one division of the level tube. This may be found in the field by sighting on a rod at a known distance, taking readings of the bubble along the whole length of the graduated part of the tube, but it is more satisfactorily determined on a solidly mounted level trier.

2. The inequality in the diameter of the telescope collars. This is found by reading the striding level on the collars in the two reversed positions, thus eliminating the error due to the unequal length of the striding level legs and obtaining the true inclination of the surface of the rings. The telescope is then reversed in its wyes and the levelling repeated. The difference in the two inclinations, divided by four, gives the angular value of the error or correction sought.* The following observations are given as an example:—

	Level readings.		
	Eye end.		Object end.
Striding Level direct	7.4		9.0
" " reversed	8.0		8.4
Means	=7.7	and	8.7
			7.7
			2)1.0
Inclination of upper surface of collars.			=0.50

* See Chauventet's Astronomy, Vol. II, p. 153.

Telescope reversed in Wyes.

	Level readings.		
	Object end.		Eye end.
Striding level reversed	5.6		11.0
" " direct	5.0		11.6
Means	=5.3	and	11.3
			5.3
			2)6.0

Inclination of upper surface of collars=3.00

$$\frac{\text{Difference of readings}}{4}=\frac{3.00-0.50}{4}=0.625$$

The value of one division of the level was=5″. Hence, correction in seconds of arc = 5 × 0.625 = 3. 12, and the eye end is the largest, requiring a negative correction to all rod readings.

3. The ratios of the portions of the rod intercepted between the three wires and the distances of the rod. This for the double purpose of obtaining a measure of the length of sights and furnishing a check on the readings.

The adjustments—making due allowance for the fact that the level tube is moveable—are the same as those for the ordinary wye. Since, however, it is impossible to do anything exactly, and in the best work the smallest errors should be provided for, the after-treatment of the adjustments is essentially different. They are reduced to as near zero as possible, and the outstanding errors determined as follows :—1. The difference in the average of the three rod readings in the two reversed positions of the telescope tube gives twice the collimation error of the mean line of sight, at the known distance of the rod. 2. The inclination of the bubble-axis to the top surface of the rings is found by taking a series of readings of the bubble in the reversed positions, the average of the mean differences at the eye end and at the object end, for level direct and level reversed, gives twice the correction required for the inclination of the level tube. Thus, in the example already given, the difference is 0.6 div. and the correction 0.3 × 5.0 = 1.″50.

These determinations are made at the beginning and the end of each day's work, and their resulting values combined with the correction for inequality of collars, applied, in the reduction of the notes, to all rod readings.

Methods of work. The method of using these instruments differs from ordinary work only in that there are three rod readings for each setting of the rod, and the reading employed is the mean of these. In some cases the bubble is kept central by means of the micrometer screw and the reflecting mirror; and in other cases only approximately so, the ends being read and recorded by an assistant. A correction is, in the latter case, afterwards applied to each rod reading for the inclination of the line of sight. The three readings of the rod in each position should always be compared before the level is moved, in order, if necessary, that any doubtful reading may be checked. Self-reading rods, usually graduated to centimeters and estimated to millimeters, are employed on the Lakes and Mississippi River surveys, and in most of the European work. On the Coast and Geodetic Survey, target rods are used, and the method of work there pursued is much more elaborate than the foregoing.

The methods of levelling are sometimes described as *single* or *double* levelling, according as single or double back and fore sight are taken. The latter has been the practice of the Coast Survey, and is a self-checking system—in so far at least as the readings are concerned—really amounting to two lines of levels in the same direction. The single system is, however, the more generally adopted. There is a decided economy in time and in accuracy of result in the use of two rods alternating with one another on turning points.

In reviewing the construction of levelling instruments, the principal points to be held in mind as conducive to the best results in the various departments of work would seem to be. First,—stability of construction; second, properly constructed levels of sufficient delicacy; third, adequate optical power for the purpose in view. The first condition should be secured by a proper distribution of the metal, for the attainment of the necessary strength from a minimum of material. The second and third are to a certain extent interdependent. For railroad and canal work from 10″ to 20″ per division of 0.1″ would seem to be limiting values for the scale values of levels. Levels having a scale value of 12″ are entirely satisfactory on ordinary work, while those beyond 20″ the writer has considered as lacking in sensitiveness. It has always seemed to him better to have an over-sensitive than an under-sensitive level, admitting the difficulty of keeping the former central.

Increased optical power is of course secured at the sacrifice of light and definition. The powers demanded for our instruments are, however, much below the maximun limit for good lenses, under the ordinary conditions of illumination. Referring to the list of instruments already given, the practice of the makers of dumpy levels seems to be to keep in the neighbourhood of 25 for the higher powers for 14 in. instruments. The object lenses of all these instruments would stand higher powers. With a good object glass of 1.5 in. aperture there should be no difficulty in using a power of 40 under the ordinary conditions of seeing. In the smaller apertures of the wye levels the matter of loss of light becomes serious. But the makers of wye levels seem altogether born to perversity,—having decided to use an object glass of small aperture, they must of necessity add to this a four lens eye-piece, as if it were any advantage to get an erect image. The four lens inverting eye-piece has no advantage over the ordinary erecting eye-piece, and its use results in serious loss of light, giving a comparatively indistinct image —one of the most fruitful sources of error in levelling.

The use of the mirror on level tubes to view the bubble is not in such favour with engineers as it should be. The usual process of reading the rod while standing in a different position from that in which the instrument was levelled must necessarily introduce errors of a serious nature. When the mirror is used it should always be placed at the same inclination, and the observer should by trial, assisted by another person, obtain that position of the eye in which the bubble may be viewed without parallax, and from which he will always afterwards observe it.

It is usual to classify sources of error somewhat as follows:— 1, instrumental errors; 2, errors from unstable supports; 3, errors of observation; 4, personal errors; 5, atmospheric errors. The chief source of error from *instrumental* causes is no doubt due to either a permanent or temporary lack of parallelism between the line of sight and the bubble-axis. No adjustment can be perfect, and even if perfect under stated conditions is liable to change under other conditions. The causes which might produce a change in adjustment due to the influence of varying temperature on the glass of the level has been discussed in the first part of this paper. A temporary change may result from the unequal heating of the metal of the instrument, which would probably take place in bright weather when levelling, in a direction towards or away from the sun. The direct action of the sun should be avoided by the use of a shade—a heavy canvas umbrella is used on geodetic work. In order to obviate the effect of any possible change in the scale value of the level, readings should never be taken when the bubble is at any considerable distance from central. If the bubble is sluggish there is a possible source of error in its being read before final settlement. This latter difficulty can be overcome, with a chambered level, by avoiding the use of short bubbles. Errors arising from defects of adjustment are of course completely eliminated by equality of sights, except in such a case as that mentioned above, where, on account of the direct heating action of the sun, a change may take place between sights. Such changes are much more likely to affect the results of ordinary levelling where there is an interval of time between centering the bubble and reading the rod. Errors of this nature are, though small for any given sight, of serious consequence through always being in the same direction, or cumulative in character. If there be, of necessity, a difference in the lengths of sights, the possible error so introduced should be neutralized by making, on the first opportunity, a similar difference in the opposite direction. In the Indian Survey sights are made equal by chaining. Where, as for example in crossing a wide river, a long foresight is unavoidable, the method of reciprocal levelling, explained in connection with the peg adjustment, should be employed. This also eliminates the error due to curvature of the earth. Where there are two vertical wires and the rod is read anywhere between them, there may be a slight error introduced through the lack of horizontality of the wire. This should be provided for in making the adjustment by swinging the telescope, when correctly levelled, around its vertical axis, and rocking the reticule ring until the wire is observed to continuously bisect a fixed point. Where no rod level is used, as is usually the case in ordinary levelling, it is, however, more important that the vertical wire should be truly vertical; and where both cannot, in this case, be secured, the rod should always be read in the same position on the horizontal wire. Wye levels should always have a means of preventing the telescope from rotating in the wyes.

Errors due to the rod will also fall under this class, and we should first look to the accuracy of its length and uniformity of its graduation. Mr. I. W. Wright in his work on the adjustment of observations remarks that:—

"An important source of error in spirit levelling, and one very "commonly overlooked, is the change in length of the levelling rod "from variations of temperature. From experiments made by the "Prussian Land Survey, in which the rods were compared daily with "a steel standard, the following fluctuations in length were found for "four rods made of seasoned fir:—

Rod 13,	from	May	19	to Aug.	18	0.51	mm. per metre.
14	"	"	20	"	15	0.46	" " "
9	"	"	24	Sept.	6	0.37	" " "
10	"	"	24	"	6	0.43	" " "

"It is quite possible that errors from this source may largely exceed "the errors arising from the levelling itself. Each field party should "therefore be provided with the means of making a daily comparison "of the rods used, with a standard of length. A steel metre and a "micrometer microscope mounted on a stand would be all that would "be necessary."

The maximum expansion above quoted would amount to .007 of a foot in the length of a 14 foot rod. It will be noted that the variation of temperature is not given. Experiments conducted by Prof. Van de Sande-Bakhuyzen on the staves used in the Netherlands, give results of much less magnitude then the above. He found the rate of expansion for seasoned fir rods to be 4.4 micra per metre, per degree centigrade, and that other changes amounted in all to not more than .05 mm. per metre.

For ordinary work the self-reading telescope rod is almost universally adopted, on account of its portability and convenience in use. The rods of this form, though sold as "standard" by the makers, are liable to be most inaccurate. Of the seven 14 ft. self-reading rods in use at McGill College, four are within .002 of a foot of being correct, one is .006 too short, and two are .014 too long, at 62° Fah. There are then two of these rods, and surprising as it may seem, both from the same makers—a London firm of high repute—which differ between themselves to the extent of .020 of a foot. Two 12 ft. target rods by different American makers are within .002 of the correct length. Amongst a lot of five telescope rods, recently measured in the warehouse of a dealer, one was found to be .020 too long at 14 feet and .015 too long at 17 feet. In most of the above cases the total error was roughly distributed throughout the length of the rod. In that last mentioned, and in one of the College rods, the graduation was somewhat irregular.

Where rods are properly constructed they should not be influenced to any great extent by moisture. The utmost precaution should, however, be exercised to keep them dry. In the Swiss levelling the errors due to temperature and moisture are stated as being "small, slow in action, and somewhat irregular." The reports published from time to time of extreme changes from moisture are no doubt due to improper protection. Where rods are used under proper direction they are of course subject to careful comparison with the national standard, and any errors in their lengths allowed for.

Errors arising from *unstable supports* may occur through the instrument or the rod, and are usually of a cumulative character. The instrument may settle slightly between the reading of the back and fore sights, or the converse may occur, depending upon the character of the ground.

Similarly, the turning points may settle or spring up between sights. In soft ground, settlement is likely to occur; while in stiff clay both instrument and rod—if the latter is supported on a peg driven in the ground—may spring back slightly. Pegs are preferred as turning points for soft ground, and plates having a projecting knob or spherical hole for the rod, as already explained, for hard soil or roads. The rod should never be removed from the point until all the readings have been made, and the weight of the rodman should never be allowed to rest upon it. When both instrument and rod move in the same direction the effects are additive, and the character of the soil continuing the same over a considerable stretch of country, a large error may be accumulated. To obviate such a result, Colonel Walker adopted, in India, the plan of alternating the order of observations at successive stations of the instrument, by reading the back staff first on one station and the forward staff first on the next. The error may in part at least be eliminated by levelling between bench-marks in opposite directions. Duplicate levels in opposite directions between benches or along the whole length of line should completely eliminate it. This is indeed the sovereign cure for all errors of a cumulative character.

Mr. Hirsch, one of the Directors of the Swiss precision levelling, has shown that the error due to settlement, other things being equal, is proportional to the length of line run. In ordinary levelling operation, the character of the ground affects the work in a different way, the feet of the observer compress the ground near the tripod legs, and displace the line of sight in the interval of time between levelling and reading the rod. To obviate this, Colonel Goulier has recommended that two of the legs be always placed parallel to the line of sight. The use of the mirror, already noticed, would also remove this source of error.

The largest source of *observational errors* is believed to be due to the want of careful centering or reading the bubble. Every leveller should know what rod reading is covered by a range of one division of his bubble at a given distance of, say 100 feet, in order that he may fully appreciate the effect of errors of this kind.

When the illumination of the two ends of the bubble is different, an error in centering is almost sure to follow, there being a tendency to bring the bubble too much towards the light. Error is also introduced through parallax, the bubble being viewed obliquely to its length. It has recently been urged by a German observer—Dr. Reinhertz*—that the bubbles should be viewed in profile. Clearness of the glass and distinctness of the graduations have much to do with the accuracy of

* Zeitschrift für Instrumentenkunde, Oct., 1890.

bubble readings. Errors of rod reading are more common with a target than with a speaking rod. The best check on the former is for both rodman and leveller to make independent readings. Where three wires are used, errors with self-reading rods are of very rare occurrence. The mean of the three readings is also without doubt more accurate than a single reading on a target rod. It does not by any means follow that because a target rod reads to .001 of a foot, that the reading is accurate within that limit. A difference in the illumination of the rod will also affect the relative accuracy of the readings, and a line running east and west will probably show different results, according as it is levelled in the forenoon or afternoon.

Under *personal errors* we have merely to note that each observer has his own peculiarities, which will largely affect the resulting difference of level over a great length of line. This is in fact the personal equation of the observer. To quote from the report of the Chief Engineer, U. S. A., for 1884: "These discrepancies vary with different observers, and are not even constant for the same observer, are "nearly proportional to the distance, and seem to be independent of "the nature of the ground, the direction in which the work is done, "the season or the manner of supporting the rod." The results of some recent levels on the Mississippi survey go to show that this personal equation may be somewhat evanescent, particularly with young observers, and that every line of levels should be duplicated in opposite directions by the same observer within the shortest possible limits of time, in order to reduce the probability of change in the personal equation. With skilled observers of long practice, this habit is probably a constant from year to year.

For the effects of *atmosphere errors* we cannot do better than quote from Professor J. B. Johnson, who was for some time engaged on work in connection with the Lake survey. (Van Nostrand's Magazine for October, 1883.)

"Errors from this source may be classified as coming from: "1, Wind; 2, Tremulousness; 3, Variable Refraction.

"1. Wind generally shakes the instrument, and makes the holding "of the rod difficult or impossible. For two seasons I have used a "tent on windy days to protect the instrument, and with great success. "Good work can be done in this way so long as the rod can be held. "We also have large square canvas umbrellas that can be set on the "ground to the windward of the instrument, and these effectually "shield them in ordinary windy weather.

"The tents used were wall-tents, 5 × 6 feet, and one 8-foot centre "pole. A square iron frame, $3 \times 3\frac{1}{2}$ feet, sewed into the canvas near "the top, formed the lateral support there. It was held down by six or "eight steel pins, 18 inches long and $\frac{1}{2}$ inch diameter, with flat heads. "These passed through iron rings sewed into the bottom. There were "openings for the line of sight and a flap for the observer to enter and "pass out with the instrument. These tents were made to be used on "Gulf coast at a very windy season, when one half the time would have "been lost from high winds without them. The rodmen supported "their rods by sticks held in the hand and braced against the rod "at an angle, resting on the ground. Care had to be exercised that "the rods were not thereby lifted from their sockets in the foot plates.

"2. Tremulousness is caused by a difference of temperature between "air and ground, and always occurs in clear weather after the sun is "a few hours high. This causes the target, or figures on a speaking "rod, to appear to move up and down, giving rise to what is known "as 'dancing' or 'boiling.' This simply causes an uncertainty in "the reading, depending directly on the degree of unsteadiness. It "is a compensating error, and the observer must be his own judge as "to when he must stop work in order to obtain the required degree of "precision. The only remedy is to shorten the length of sight; but as "there are some errors that multiply directly with the number of sights "taken in a given distance, there is also a limit to which this remedy "may be profitably carried. I do not think it advisable to use sights "less than 100 feet if the highest accuracy is sought, and perhaps "never more than 400 feet, even when the atmosphere is perfectly "clear and steady. In clear weather not more than 3 or 4 hours a "day can be utilized for the best work.

"3. Variable refraction occurs when the sunshine suddenly comes "up or leaves the line; this happens along the edge of timber or under "the brow of a hill, as when the line rapidly emerges from or comes "into the shade from the sun's movement, or on partially cloudy days, "when the sun is alternately covered and clear. When from the first "source, it occurs about 8 a.m. and 4 p.m. It is a peculiar phenome-"non, and is more common in winter than in summer. The atmosphere "is apparently steady and the sight well taken; but upon checking it, "the reading has changed, and may be observed to change gradually or "suddenly, and sometimes to recover a part or all of its original move-"ment, when the instruments were known to be stable. I have seen "these changes of reading amount to 5 millimeters, or $\frac{1}{5}$th of an inch "in a distance of 100 meters, or 328 feet. If the atmosphere is found "to be in this condition, the work should be stopped for a while, as "this state of affairs is not likely to continue long."

Errors due to carelessness—and their name is legion—need not be discussed. We can make no provision for the acts of the rodman, who, being sent to hunt up a turning point, triumphantly brings it to you in his hand; nor yet for the leveller, who fails persistently to distinguish between a 6 and a 9.

Looking at the unavoidable errors of levelling in a more comprehensive manner, we may regard them as composed of three classes,—compensating errors, cumulative errors, and accidental errors. The first classes should be so manipulated as to eliminate themselves during the progress of the work. The second should be removed by the same observer repeating the work under as nearly as possible the same conditions, and in an opposite direction. Levels checked only in the same direction give fallacious results. The third are the legitimate errors inseparable from all observations, and are proportional to the square root of the distance. The errors of a properly conducted system of levels are usually considered to be of this character, and their precision tested accordingly.

The limit of probable error allowed in the Ft.

U. S. Coast and Geodetic Survey is...... 0.029 $\sqrt{\text{Dist. in miles.}}$

Lake Survey.. .041 $\sqrt{\text{Dist. in miles.}}$

Mississippi River Commission.................. .021 $\sqrt{\text{Dist. in miles.}}$

between duplicate lines.*

The following interesting table of the results of levelling in Great Britain, India and Switzerland has been compiled by Mr. Wilfrid Airy, M. Inst. C.E.

Average differences in a single mile of the results obtained by two observers, on ground of different degrees of inclination.

CHARACTER OF GROUND.	SWITZERLAND.	INDIA.	GREAT BRITAIN.
	Foot.	Foot.	Foot.
Nearly level, very favourable circumstances of weather.	**.0230**	**.0142**	.0125
Slightly undulating, gradients not exceeding 1 in 100.	.0238	.0168	.0148
Gradients between 1 in 100 and 1 in 20.	.7039	**.0208**	.0183
Gradients between 1 in 20 and 1 in 10.	**.0566**	**.0350**	.0308
Gradients steeper than 1 in 20.			.0416

NOTE.—The quantities in bold face type are estimated from analogy afforded by Swiss levelling, as no direct data could be furnished.

*For two measurements the formula for probable error $\left(\pm .674 \sqrt{\frac{e\ (vv)}{m\ (m-)}} \right)$ reduces to $\pm \frac{v'}{3}$ where v' is the difference in the measurements.

In illustration of the high degree of accuracy attained over long lines, the following is taken from the report of the levelling operations in India for 1866, by Colonel Walker :—

Section.	Length in Miles.	Maximum Divergence of two Observers.	Terminal Divergence.
		Foot.	Foot.
Calcutta to Tilliagarhi.	242	0.20	0.15
Tilliagarhi to Patka Gerouli.	346	0.40	0.38
Agra to Patka Gerouli.	342	0.15	0.06

Some excellent results over duplicated lines have in recent years been obtained with the wye levels used in the engineering branch, U. S. Army. The methods adopted were practically those of precision levelling. As an example of these the following extract is given :—

Section.	Length in Miles.	Max. Divergence of two observers in Feet.	Terminal Divergence in Feet.
Sioux City to Fort Randal	179	.082	.060
Fort Randall to Pierre, Dak.	190	.156	.154

The best levelling has, however, undoubtedly been done in Switzerland. The field rules there adopted are as follows :—

1. The levelling to be executed by equal rights whenever possible ; the difference between the length of back and fore sights never to exceed ten metres.
2. The length of sight is as a rule to be limited as under :—
   (*a*) Upon railroads with gradients 1 in 100, to 100 metres.
   (*b*) " " " steep gradients, 50 to 100 metres.
   (*c*) " highroads in the plains, 30 to 60 metres.
   (*d*) " mountain roads, 10 to 25 metres.
3. The spirit level to be always shaded from the sun.
4. The three instrumental errors, viz : Collimation of optical axis, inequality of pivots, and bubble error, to be determined at least once each day.

5. The field work to be carried on continuously except on wet or windy days. Three kilometres at least should be the length of line levelled per day along railways and two along highways.
6. Bench marks to be made at every kilometre, and to be clearly described in the field book.

In preparing this paper the author has endeavoured to touch upon all classes of engineering levelling ; naturally, however, the subject being one which bears more particularly on geodesic work, he has given greater attention to that department. In deprecation of a possible criticism to the effect that the major portion of the methods herein detailed are of no consequence to "practical" engineers, he would beg to remind any so disposed that possibly their particular line of work has not embraced the whole sphere of labours of the profession. He would also wish to express the hope that the members of the Canadian Society of Civil Engineers may, at some day not far distant, be called to do geodesic levelling within the boundaries of their own country.

DISCUSSION.

Mr. Hannaford asked if Professor McLeod, in writing the paper, intended to refer more particularly to astronomical observations or to everyday levelling in the field? Mr. Hannaford

Professor McLeod, in reply, stated that the paper referred to both astronomical and engineering levels—that where his remarks applied more particularly to one or the other class of levels, it is so stated in the body of the paper. Prof. McLeod.

Mr. Dodwell said that the discussion of a paper should of course consist of criticism and additional information on the same subject. In general, intelligent and profitable criticism should be either confirmation or refutation of the author's views from personal observation and experience. In the present case he was not in a position to add any information or particulars of a scientific character to the interesting paper they had just heard. The importance of accuracy in levels used in connection with astronomical telescopes is too obvious to need re-stating, but it had never occurred to him that the requisite degree of accuracy in their manufacture was so difficult—almost impossible—of attainment. For all purposes for which engineers use levels, such extreme accuracy was, happily for them, quite unnecessary. A scale value of 5.15 seconds represents, at a distance of 400 feet, a vertical height, or difference of reading on a levelling rod, of only .01 foot, from which it will readily be seen that, within ordinary limits the scale value of an engineer's level is an unimportant factor, and that the requisite degrees of accuracy in levels for engineering and for astronomical purposes respectively are not to be compared. He observes that among the liquids mentioned in the paper for filling level tubes, bisulphide of carbon does not occur. He would like to ask the author whether this very mobile substance is not sometimes used for this purpose? Perhaps also, when he closes the discussion, the author will give in brief detail an account of his method for determining the scale value of levels of precision. In the second part of his paper on the "Errors of Levelling," the author will no doubt give some material that will appeal more directly to engineers. Mr. Dodwell.

Mr. St. George.

Mr. St. George said with regard to the errors of levelling in different temperatures, engineers and railroad men notice continually that when they adjust an instrument at a certain time in the day, especially in the winter time, if they happen to adjust that instrument near noon when the sun is high, and go out later in the afternoon, it would appear as if there was something wrong with the level around the centre. In levelling, an equalized sight should always be taken on the bubble.

Mr. Irwin.

Mr. Irwin said he had never noticed a spirit level failing to reverse at any time during the same day on which it had been adjusted. He had a very good dumpy level which only required to be adjusted once in three or four years, and after it had been adjusted at an average temperature in summer, he found that in using it in very cold weather (once for instance when it was about zero, at which temperature the bubble occupied almost the entire length of the visible part of the tube) the bubble would not reverse to within two divisions on the glass, that is to say, its position of reversing would be two divisions further from the zero at one end of the tube than at the other, which amounts to an error really of only one division. On these occasions he used two spring clips sliding on the tube of the level, and moved them up to the points at which the bubble would reverse. He would like to ask Professor McLeod if in his opinion the level should not then work correctly. He had occasion to level once for three days, when the thermometer was about zero, and on checking back found his levels to close exactly; and during checking back he checked on a bench mark left on the end of the second day, and was only $\frac{1}{100}$th wrong in his check on that. This, he thought, showed that the method which he adopted for marking the position of the bubble was correct, and that any error due to the change in the position of the zero point of the graduations would be avoided.

CORRESPONDENCE.

Mr. G. N. Saegmuller (of Messrs. Fauth & Co., Washington) said as Messrs. Fauth & Co. grind levels at long intervals and generally a number at a time, they have always "well seasoned" ones on hand. He does not think that they ever sent out a level which had not been finished at least one or two years. They have probably a hundred fine levels on hand which were ground over two years ago. Each level has its record; they are tested after they are ground (the writer does not know how often during the operation), and the value is recorded on the level. When they use them they re-determine this value. They have never found a single instance where a decisive change in the curvature could be noticed. Nor is there any reason why they should change, and no rational explanation can be given. If the level were only ground on one side, then they could anticipate a change, and the level would have to become of lesser curvature or larger value. He does not think that Professor McLeod's figures bear out his deductions. In the first place the temperatures differ so widely among the different determinations, and in the second place the difference in the length of the bubble will explain *more* than the differences in the different resulting scale values. A short bubble will creep, and it requires a long time before it is really settled, while a long bubble will always move briskly and settle down quickly. Mr. Saegmuller.

Some astronomers have claimed to have found evidence of changes in levels. Several were returned to the writer as having changed their values, but in every case this was the result of bad mounting. The writer believes that a violent blow or a fall may change the curve, but he has never met with such a case. He tried several levels having a value of about 5″ for 1 div. of 2 mm. These he laid on blocks resting on the ends, and pressed them down at the middle, trying to bend them. He left them in this strained position for two weeks. At the end of this time he examined them again, and found that they had their old values. He pressed them as hard as he dared to go; one of them broke. Now, when a level rests, as it ought to, at the two ends, with scarcely any pressure on it, and when it is considered that a tube of brittle glass has great strength, the writer cannot see why it should change. He should like to have from Professor McLeod an explanation of what would cause such a change.

Prof. Rogers. Professor W. A. Rogers said that the only point, in addition to those which the author considers, which occurs to him is, that Messrs. Fauth & Co., who have a machine for grinding levels to any desired curvature, state that the machine will not give the finishing touches, which must be put on by a delicate hand movement. It is his experience that the general excellence of levels made in this way is greatly improved. The general curvature is more likely to be accurate if made by a machine movement, and the general form is not much disturbed by the hand finishing. Two of these levels have been investigated by the Naval Observatory with superb results.

Prof. Eastman. Professor Eastman (of the U. S. Naval Observatory, Washington) said that there is one difficulty with levels when the scale is *engraved on the tube* which is not mentioned in the paper. This etching or engraving of the lines is not of uniform depth, and after several years of use this cutting of the surface of the tube weakens it, and gives rise to irregular curves and utterly ruins the level. He used an excellent level for more than fifteen years, but in less than one year it changed from a first-class to a worthless instrument. An examination showed that the upper engraved side was a series of irregular curves.

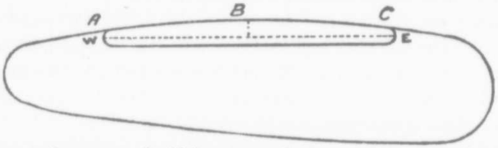
He has lately examined two level tubes for the use of the Naval Observatory, and the results are as follows:—

Values in seconds of arc of one division on level tubes.

Nos. 5 and 6 were selected from a lot of six tubes. These values were obtained by running the bubble by stages, of 5 divisions, from one end of the tube to the other, and then reversing the motion.

No. 5	No. 6
one div. = 0″.95	one div. = 0″.90
.91	.90
.92	.91
.93	.88
.94	.89
.95	.88
.93	.87
.93	.86
.94	.89
.94	.88
.94	.91
1.00	.92
1.01	.92

Mr. Chas. Carpmael (Director of the Meteorological Office) said that with nearly all of the paper he heartily agreed, but would call attention to one point, in which it seems to him that the author had not made matters clear. It is stated that "difference of sectional *area* of the ends of the tube also gives rise to a shift in the zero, *since for a given change of temperature the air space at one end will be altered in length to a greater or less extent, according as it is towards the smaller or larger end of the tube.*" The writer has underlined the part to which he refers as needing explanation. The matter would be perfectly clear if a diaphragm were inserted in the tube, preventing the flow of liquid from one end of the tube to the other, when the temperature changed; but it is not so clear at first sight why there should be any shift when the liquid is free to take up a position of equilibrium. Mr. Carpmael.



Suppose the upper (inside) curve of a central longitudinal section of the bulb be one of uniform curvature, *i.e.*, let A B C in the diagram be the arc of a circle, and further let the portions of all transverse sections (normal to A B C) which come into contact with the common surface of liquid and vapour be of one curvature, then the shape of the common surface at one end will be the same as at the other. If we take in the two ends corresponding points W and E, the total curvature of the common surface at these two points will be the same, consequently the difference of pressure between vapour and liquid will be the same and the line W E will be horizontal. Also, since the form of the surfaces is the same at both ends, W E will be equidistant from the glass surface. Also, if the perpendicular from B bisects W E, the tangent at B will be parallel to W E, and therefore horizontal. To state this result otherwise, if B be the point at which the tangent is horizontal and W E be corresponding points in the two ends, the perpendicular from B will bisect W E. No change of temperature will in this case shift the zero. If, however, the curvature of the transverse section, where it cuts the common surface, be not the same at both ends of the bubble, the shape of this common surface will not be the same at both ends. The tangent at B need not, therefore, be horizontal, nor will it in general be inclined at the same angle to the horizontal at all temperatures, as one end of the bubble will expand towards parts of greater and the other end towards parts of less sectional curvature. In this case not only will the zero shift with differences of temperature but also (to a greater or less degree) the scale co-efficient.

Capt. Deville. Capt. E. Deville, Surveyor General, said that the results of his own experience are somewhat scattered, and he could not collect them without devoting to the subject more time than he has at his disposal. He has not been actively engaged in observing for the last eight or nine years, and his recollections are somewhat indistinct. He has been rather unfortunate in the matter of levels; of all those he has used (they are many) only one was good: it was made by Repsold. He has tried since to obtain others from the same firm, but they decline to make them except for their own instruments.

During the last two or three years the writer has ordered and received from the best makers, American and European, about one dozen of levels, and although the prices were very high, not a single one proved satisfactory. Some were plugged at the ends instead of being sealed; these it was found would invariably leak.

The mode of setting which was found most satisfactory is to let the ends of the tube rest in two brass Y's, a spring at each end pressing a piece of cork on top of the tube just above the Y. The adjustments, when made, are very steady, and there is no strain on the tube.

The conclusion the writer has come to is that a level should never be assumed to be good because it comes from a good maker; and when an observer is fortunate enough to obtain a good one, he should spare no care or pains to preserve it from accidents.

Mr. Woodward. Mr. R. S. Woodward, of U. S. Coast and Geodetic Survey, said that he could think now of only one point which it might be interesting to add to the discussion of this valuable paper, and that is that many reputable makers of instruments of precision still mount their levels very badly. Sometimes it will happen that a reasonably good level will be set in plaster of Paris. He had occasion a few years ago to exhume several good level tubes, which were set in this way by the distinguished firm of Troughton & Simms, London.

In ordering a delicate level an engineer should specify that the tube be delicately mounted. The use of V's as supports for the level tube with delicate springs to hold it in position seems the most approved way.

Professor E. A. Fuertes, of Cornell University, said that his experience with astronomical levels shows, that in addition to uniformity of curvature in a vertical plane, the internal surface of the level should be a true torus. Also, levels which at a given temperature, with a given length of bubble, seem to be uniformly graduated, will give poor division values for the same length of bubble at a different temperature. Also the manner of mounting the level in its tube has a great influence on the performance of the level. The writer would suggest the support of the level at its middle part upon a cork-lined ring, the extremities being held by cork wedges, for the purpose of steadying the level vial laterally, and placing the zeros of the graduation an inch beyond the edges of the supporting central ring. He purchased a new level (reading about 2″ per millimeter), and when he again investigated it, a year or so afterwards, its scale had changed very materially. Both trials were made on the vial, free from its mounting, and adjusted on the wyes of the level trier for the verticality of the plane containing the axis of the tube. Prof. Fuertes

Experiments are under way at Cornell University upon a plastic substance, into which the level vial may be sunk without adhering to the vial, giving the level a chance to adjust itself to temperatures, without the changes of form due to strains produced by the corresponding changes of metallic and rigid supports. A mixture of caramel syrup, glycerine and glue may produce a compound sufficiently stiff to afford a secure seat to the level, and yet allow it to expand or contract without such strains as may force an undue change of form in the glass; but the difficulty lies in the proportions of the ingredients, so as to give useful results in extremes of heat and cold. This difficulty is not considered insurmountable, however.

The most refined astronomical and geodetic observations are frequently made to depend upon the testimony given by the divisions of a level; and this testimony, the best attainable, cannot be depended upon without special investigation of the errors to which it is liable. Any effort to bring under less complex laws the inequalities of the indication of the level is worthy of encouragement, in view of the indispensable use of this instrument in many important fields of research.

Professors Chas. L. Crandall and C. B. Wing, of Cornell University, said Professor McLeod's paper shows how the zero point is affected by the length of the bubble when the tube is poor. It may not be uninteresting to determine the effect of length of bubble not due to a poor tube. With this end in view, the level tube of a geodetic level Profs. Crandall and Wing.

belonging to the University, was placed upon a level tester, and readings taken for each five seconds of arc through which the tester moved. The motion was continued through one minute of arc and back again, and the time which the bubble required to move each five seconds noted. The tube has 12½ divisions to the inch, and each division is about 3.7 seconds.

Between the limits of 10 and 36 divisions for the length of the bubble, the time required to move over five seconds of arc is about inversely as the length, varying from about twenty seconds for the shortest to six seconds for the longest. When the bubble was less than twenty divisions long it would usually move beyond the point of rest, in which case the time required to return was as great as for the first motion; or for the short bubbles, the time required for *rest* should be doubled.

The value of a division is slightly less for the short bubble, but the more important fact is that the divisions are much more nearly equal for the long bubble. The probable error for a single reading in the length of a division with the bubble ten divisions long being 1.2 seconds, with the bubble twenty divisions long 0.6 seconds, and with the bubble thirty divisions long 0.5 seconds, showing the quality of the level to improve with the length of the bubble up to the limit taken, although the difference is slight beyond twenty divisions.

Comparing the two level readings for the same position of the tester, the bubble having come from opposite directions, the indications are that the bubble is carried beyond the true point about one-half second, the amount being slightly greater as the bubble is shorter. We say indications, because the readings were not so arranged as to eliminate instability of the tester.

Another level with about two second divisions was tested in this same manner. The bubble, when ¾ inch long, would only move for every third turn of the screw representing fifteen seconds of arc, while when lengthened to two inches the motion was uniform and the curvature apparently constant.

In conclusion, these experiments indicate that increasing the length of the bubble decreases sluggishness and increases the apparent uniformity of curvature and the accuracy of the final position of rest. This apparent uniformity of curvature may decrease if the length is carried beyond a certain limit; or it is probable that each tube will have a length of bubble for which the divisions are more nearly constant in value than for any other. This length is probably the one used by the maker in grinding and testing.

Mr. Arthur Hill said that Professor McLeod's interesting paper has afforded him at last an explanation of the probable cause of the exasperating behaviour of the bubble of a London made Dumpy level, which he has been using for the last twelve years, and which has never yet properly maintained its adjustment for twelve hours at a time. Placed in perfect adjustment in the morning it would perhaps be off at noon, and back again in the evening. Adjusted at midday, it would in all probability strike work before six o'clock. It was plain that those freaks were due to a change of temperature, but the writer never could make out *how* the change produced its annoying results. Mr. Hill.

The great advantage of having a chambered bubble tube, as described by Professor McLeod, will be appreciated by any who have experienced the difficulty referred to.

Professor McLeod, replying to the criticisms of Mr. Saegmuller, who is of opinion that no change of form can take place after the level is ground, said that there must necessarily, from the character of the manufacturing process, be internal strain in the glass of the tubes. When the skin is removed to unequal depths in the process of grinding, and relief thus given to the tensions, the whole tube will slowly take on a new figure. Even in blown glass, where there is no interference with the outer skin, it is, as has been pointed out, customary and necessary to season thermometer tubes before calibrating and graduating them. It would, even could no reason be assigned or no analogous case given, obviously be useless to maintain, in the face of the evidence given, that no change can take place. The cases cited by Professors Eastman, Fuertes and others, furnish additional and conclusive evidence in refutation of the stand taken by Mr. Saegmuller. The deduction which Mr. Saegmuller takes the speaker to task for making is, he supposes, the same change of form with age. The effect due to temperature has little or no weight in the general result, and is trifling as compared with the change through age. The constant though slight changes of form in the glass through change of temperature is probably the most efficient agency through which the greater change takes place. Prof. McLeod.

As to the effect of the length of the bubble, it will be seen that in the tests made on July 15th, 1890, the extreme limits of length of bubble employed are used, and give results which are practically identical.

It is of course well known that a long bubble will come to rest more quickly than a short one. When the length of the bubble on the level in question is half an inch long, it will come to rest in about sixty seconds; when it is one inch long, in about 35 seconds; when it is two inches long, in about 20 seconds; and when three inches long, somewhat less than 15 seconds. Or, speaking very roughly, the length of time which the bubble takes to settle is inversely proportional to its length. A very short bubble is more searching in detecting local irregularities of curvature, and unless the level is a good one there will be a resulting lack of uniformity of scale value in the use of a short bubble. The long bubble extending to opposite ends of the tube evens up any small local errors, giving the average value of the scale value at the two ends. A level which is fairly good for a long bubble may be very poor when the bubble is short. Such was not, however, to any great extent the case with the level in question. Professor Fuertes has given an instance of this kind, and Professors Crandall and Wing have made a special investigation as to the effects of different lengths of bubbles. The average of one division along the whole length of the scale, which is the point in question with Mr. Saegmuller, is not, however, different. The speaker has this afternoon tested the level in question for a length of bubble of half an inch and for a length of 2.7 in., obtaining exactly the same average scale value for both lengths.

The length of the bubble can have and has no effect whatever on the average scale value of a perfect level. Mr. Saegmuller does not quite grasp the idea of the change of form which, the author has maintained, may take place in a properly mounted level. He seems to look to all change as being due to external strain, whereas what we are dealing with is obviously a question of internal strain.

Referring to Mr. Carpmael's remarks where the sectional area of the tube is different at the two ends, the curvature in cross section at the upper surface will, from the nature of the usual process of grinding, be different, giving the resulting change of zero referred to in the paper.

Mr. Dodwell's remarks refer more to the errors of levelling. The speaker has not been able, through lack of time, to look into carefully his suggestion to use bi-sulphide of carbon. There would be three points to consider: 1st, Its mobility. In this it probably ranks below ether; 2nd, its hygroscopic properties; and 3rd, the practical question of its use by the maker. Its highly volatile character would increase the difficulty of closing the tube. Some experiments are being made on these points, and the speaker would like to be allowed to add the results, if any are obtained, to this discussion.*

If the change in the position of the bubble referred to by Mr. Irwin

* The experiments above referred to show that bi-sulphide of carbon is somewhat more mobile than ether, and there does not seem to be any objection to its use in levels except the difficulty of manufacture.

was due to a shift of the zero, as it would seem to be, then undoubtedly the method pursued by him is the correct one, and would eliminate any error arising from that cause. It should, however, be borne in mind, that a similar result might follow from unequal contraction of the metal of the instrument, and in this case there would be an error introduced in so using the level. The golden rule is to test for each and every condition in which an instrument is used.

Professor W. Wright said he had read Professor McLeod's paper with great interest. It seems a very clear and practicable exposition, and contains many things not generally known. Prof. Wright.

One or two points might have been elaborated. For example, people should be warned against Troughton & Simms' method of placing the level tube in a metallic case and filling up with plaster of Paris. He has seen levels of this kind made by them to accompany a 14 inch theodolite for primary triangulation work. Again the very troublesome question of personal equation is touched on rather lightly.

Professor J. B. Johnson (of Washington University) said that probably Professor McLeod could have added with some profit a method of adjusting up the levels of a city plot. For instance, every city has a great many determinations of the difference of elevation between its various bench marks, and when a sufficient number of observations are obtained, it would be well (if the expense cannot be incurred of going over the whole set by *precise* methods) to try and find the most probable values of those differences. This means some system of reduction similar to that used in the writer's work on surveying, for adjusting up a network of polygons. Most city engineers do nothing of the sort, but arbitrarily fix these values. Prof. Johnson.

Neither has the author said anything on the significance of weight (or mass) in a levelling instrument. The heavier the instrument the less it is affected by wind, and a heavy instrument is always better than a light one. Most engineers seek light instruments for *comfort*, and thereby sacrifice largely in the matter of accuracy.

Mr. W. McNab said that the Society is indebted to Professor McLeod for his excellent paper on this particular branch of engineering science. The information and suggestions contained in it are of a practical nature, and cannot fail, if carefully considered, to largely assist those engaged in the work in obtaining a degree of accuracy such as perhaps may not have been aspired to before, or considered possible or necessary. Mr. McNab.

In regard to errors arising from the improper adjustments of the instruments themselves, it is noteworthy that there are, unfortunately, many levellers who obtain very incorrect results by reason of a lack of proper knowledge of the construction and principles of the level in all its details. Perhaps the most common error met with in every day work is that arising from the too frequent acceptance of the instrument as being in perfect order, provided the bubble remains stationary during a revolution of the telescope.

If those who use the instruments, but who are not well acquainted with the principles of their construction, realized for a moment the serious discrepancies that frequently result from such ignorance, it would appeal to them forcibly that the art of correct levelling consists in more than the mere mechanical reading of the staff (however accurate that may be) and bringing the bubble to the desired central point by the aid of the levelling screws.

Professor McLeod has furnished some tables showing the accuracy with which levelling has been accomplished over long distances in India and the United States; and in connection therewith it might be interesting to cite an example of what has been done in Canada in that respect. In a series of levels which were taken over the main lines of the Grand Trunk Railway in 1878, a difference of only $\frac{22}{100}$ of a foot in 220 miles was found to exist between them and levels taken in 1858, reckoning from an established bench mark in Belleville, Ont., and one in Montreal. In the former the levelling was run in a westerly and in the latter in an easterly direction between the points mentioned. Similar cases might also be quoted in respect to the result of the check levels from the railway line to the water level of Lake Ontario, at various points between Kingston and Toronto. At none of the points on the lake noted between these two cities was a difference of more than $\frac{12}{100}$ of a foot observed. The height of the normal surface of the lake had been previously determined by an arranged plan of simultaneous observations at the various points by parties detailed for the purpose; and at noon on a certain day, when the elements were perfectly calm at all the places, and had been so for at least 24 hours previously, the water level was accurately marked, and the check levels were taken from the line of the railway to these various marks.

For general use, the speaker prefers the Dumpy (but of course due allowance must be made for the makers); the adjustments may require the use of measures not necessary in the Wye, but when once thoroughly adjusted, his experience is that the former can be depended upon to preserve that condition much longer than the latter.

There is a source of error that might be mentioned in connection with levelling, and that is incorrect reading of the staff, owing to an inferior or bad style of delineation of the graduations. There are some staffs in frequent use to-day having such a confused method of graduation that they somewhat resemble a set of hieroglyphics—probably the design of some one, who, to be different from others, has sacrificed utility to originality. One style of staff which the speaker has found very simple, and the most serviceable, is graduated with a series of triangles whose angular points represent the tenths. These triangles are then subdivided into the hundredths by lines parallel with the base, the spaces being painted alternately black and white.

Professor McLeod has embraced very concisely the various sources of error connected with the instruments, and his paper, with the suggestion thrown out, cannot fail to result in benefit to those engaged in the work of levelling.

Mr. H. Irwin said Professor McLeod's paper is the more welcome since there is very little satisfactory information on the subject to be found in books. Mr. Irwin.

With regard to bubble tubes—"Gillespie," the standard American author on surveying, on page 224 of the 1883 edition, says that the bubble tube "consists of a glass tube slightly curved upwards at its middle," and on page 240 of same edition describes it as being "a curved glass tube."

In Gillespie's later book called "Higher Surveying" (a most satisfactory work), edited by Captain Cady Staley, and dated 1881, the spirit level is described on page 12 as being "a curved glass tube."

Rankine, in his edition of 1885, states that a spirit level is "a glass tube having a slight curvature, convex upwards."

Loomis, on page 44 of the edition of 1882, describes the spirit level as "a glass tube apparently cylindrical, but really a portion of a ring of very large radius."

The above is about all the information to be found on the subject of the bubble tube in the books mentioned.

Heather in his very useful book on Mathematical Instruments, edition of 1880, page 10, describes the spirit level "as a glass tube differing "from the cylindrical form by having its diameter largest in the middle "and decreasing slightly and with great regularity from the middle to "the ends;" he also gives very good criteria of a good level tube taken from Pearson's Astronomy, as well as the method of adjusting a Dumpy with three pegs, but does not explain the reason for each part of the adjustment. Indeed the speaker has never seen any explanation of the adjustment of the cross hairs by this method in any book, and had his attention first called to that subject by his old friend and college class fellow, Mr. H. B. Hollinshead, a member of the Society.

In mentioning the correction of the cross hairs Rankine quotes Professor Blood of Queen's College, Galway, as proving that "the exact "coincidence of the cross wires with the axis of the telescope tube is not "absolutely essential to accurate levelling." See page 84 of edition of 1885. It should be noted here that he calls the line of collimation the "axis of the telescope."

Professor Blood's proof is as follows:—

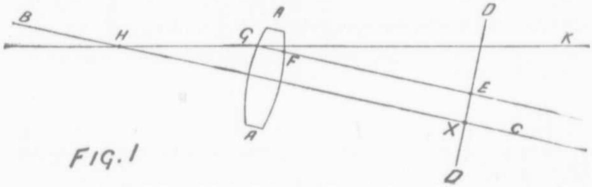


FIG. 1

"Let A A (Fig. 1) be a section of the object glass, B C the axis of "the telescope tube, and D D the diaphragm. Let E be a section of the "horizontal cross hair, not in the axis of the telescope; then when the "inner tube is drawn in and out the cross hair E will move along the "line E F, provided always that the maker has put the inner tube cor-"rectly in its proper position in regard to the outer tube so that it will "slide parallel to the outer tube.

"Let H be the *outer principal focus* of the object glass, situate on "C. B. Then, since all rays of light, whose paths within the telescope "are parallel to B C, pass through the focus H, and since, for that "reason, all possible positions of E coincide with the images of points "situate in one straight line G K; consequently G K may be regarded "as the true line of collimation, and if the spirit level be adjusted so as "to be parallel to that line correct results will be obtained in levelling, "though the cross hair be not in the axis of the telescope."

Now this proof may have seemed very satisfactory to Professor Blood, but the speaker does not believe that he ever did any very accurate levelling with a level adjusted on the above principle, and it must be noted that Professor Blood does not give his method of making the bubble tube parallel to G K.

In point of fact when an object is placed at H (the principal outer focus) no image of it can be formed at any point on the line D D; the image would only be formed at a point infinitely distant from the object glass A A, since all the rays from H, after passing through A A, become parallel to H C, as for instance the ray F E.

Indeed an object must be placed considerably further from A A than H in order that it should be seen distinctly. The object is then at the conjugate focal distance which corresponds to the position of the cross hairs at which the object is clearly seen, and in that case, the rays of light coming from the object are no longer parallel to the line H C but converge to some point on the line D D, which point should be at X on the line B C; and the horizontal cross hair should correspond with this point.

The speaker would like to know Professor McLeod's views on the subject, Professor Blood's proof failing for the reason, that an object cannot be seen through the telescope when it is at the principal focal distance.

The correction of the cross hairs in a Dumpy level by the three peg, method, already referred to, is intimately connected with this point where Professor Blood's proof seems to the speaker to break down.

In giving the manner of correcting and adjusting a Dumpy level by the two peg method (referred to by Professor McLeod, who does not mention the three peg method), the Professor does not show how the proportion of the error due to the cross hairs being out of position and that due to the axis of the telescope not being perpendicular to the spindle, or vertical axis, can be separated.

By the three peg method, as explained in Heather's book above referred to, and which is most easily performed when the three pegs are set exactly level, by placing the instrument midway between each pair, after having adjusted the bubble so as to reverse and thereby made it at right angles to the axis of the spindle, the error due to each of the last mentioned causes can be readily ascertained. For if, after getting the three pegs exactly level (and a stout nail in the head of each will be found very convenient for accurate adjustment), the level be placed as close as possible to one of the pegs and a reading be taken on each peg, then if the error at the furthest peg be exactly double of the error at the middle peg, this error is due altogether to the axis of the telescope not being parallel to the bubble and, therefore, not at right angles to the spindle; and the error must be corrected by the screws which connect the telescope to the bar across the top of the spindle. These screws are commonly called the "body screws." But if the discrepancy at the furthest peg be either more or less than double the discrepancy at the middle peg, then this excess or deficiency in the discrepancy is due to the cross hairs being out of position, i. e., not in the axis of collimation.

The reason why the error in reading the rod caused by the cross hairs not being in the axis of collimation is not directly proportional to the distance of the rod, seems to the speaker to be that in adjusting the focus for very distant objects, again for objects at a medium distance say of 200 feet, and finally for objects as close as can be distinctly seen through the telescope, the eyepiece and with it the cross hair is not moved out by an amount directly proportional to the distance of the object.

The result of this is that the length of rod, which can be seen in the field of view of the telescope, is not directly proportional to the distance of the rod.

For example in the case of a 16 inch Wye level, lately used by the speaker, at a distance of 400 feet can be seen 5½ feet of the rod in the field of view; at a distance of 200 feet, 3 feet of the rod, and at a distance of 12 feet, only 0.26 feet of the rod can be seen in the field of view.

Were these various lengths of rod proportional to the distances at which each length can be seen, the length of the rod which can be seen at 200 feet would be 2.72 feet instead of 3 feet.

Now these various lengths of rod which can be seen at the different distances are really the images which are formed at the diaphram; and the distance between the cross hairs, which are supposed to be out of the axis of collimation and this axis, is projected with its constant distance on these various images, and since these images are of different but not proportional lengths of rod, it follows that this constant distance, between the position of the cross hair and the axis of collimation, will cover a different length of rod at each distance which will be practically proportional to the length of rod which can be seen in the field of view; and since this latter length is not directly proportional to the distance of the rod, it follows that the error in reading, due to the cross hairs not being in the axis of collimation, will also not be directly proportional to the distance of the rod. These remarks regarding the method of discovering and cerrecting the error due to the cross hairs not being in the line of collimation are intended to apply to the three peg method of adjustment, which the speaker believes to be the most *direct* and satisfactory manner of adjusting a Dumpy level.

Different levels will of course not give the same difference in error at the same distance of the rod, even though the error in position of the cross hairs be the same in all.

In the case of the Wye level already referred to, the difference between the focal length for extreme distance and that for objects at 12 feet distant is only $1\frac{1}{8}$ inches.

On the other hand, the speaker found in using the Dumpy level, which has a $1\frac{7}{8}$ inch object glass of 18 inch focal length for extreme distance and a magnifying power of 40, that after reading the rod at about 500 feet it was only necessary to push out the tube about $\frac{3}{16}$ of an inch to read the rod at 250 feet, while to read it at about 10 feet away the tube had to be pushed out about $3\frac{1}{2}$ inches.

In an ordinary American Wye level the extreme length of the adjustment for focus is generally about $1\frac{1}{2}$ inches.

While adjusting the 18 inch Dumpy level already referred to, the speaker found that in correcting the cross hairs, moving them enough to make a difference of two hundredths at 500 feet made very little difference at 250 feet due to the small change in the focal length for the two distances, while there was no perceptible change in the reading of the rod at 10 feet away, which *practically*, at least, confirms the theory of the correction of the cross wires before alluded to, and seems completely to refute the argument of Professor Blood.

It might be mentioned that the level above referred to has a sensitive bubble, the scale value being about $\frac{1}{100}$ of an inch in 400 feet or 5 seconds per division.

Professor McLeod gives a "*second method*" of getting the true difference in level between two points which is new to the speaker; it reminds him of a method followed by some instrument makers in adjusting Dumpy levels. They set up a Wye level, adjust it, measure the height of the object glass above the floor, mark a point on a wall or other distant object coincident with the cross hairs, and then set a Dumpy level where the Wye level was set up, get it levelled with the centre of its object glass at the same height above the floor as the Wye level was, and then make the cross hair of the Dumpy cut the same mark as made from the Wye level.

The speaker does not altogether agree with Professor McLeod as to the time taken to correct a level by the indirect method as compared with the time required to adjust it by the direct method.

Probably in the case of a very sensitive bubble the indirect would be about as long as the direct method. The speaker's experience is that it takes a very short time to adjust the bubble of an ordinary level, and it certainly takes a much shorter time to adjust the cross hairs and the telescope axis of a Wye level than those of a Dumpy.

The speaker does not agree with Professor McLeod where he says that in the direct method only one of the two adjustments need be made, and that adjustment should be preferably that of the reticule. He is of opinion that in the direct method three pegs should be used, and both of the above adjustments made by the means already described; at any rate the part of the error due to the cross hairs being out of the axis of collimation should be corrected by moving the cross hairs; and the part of the error due to the telescope tube being not parallel to the bubble should be corrected by adjusting the tube.

The speaker has had practical experience of the fact mentioned by Professor McLeod, that even after correcting a Wye level by the direct method, it may still be out of adjustment in the Y's.

He quite agrees with Professor McLeod as to his preference for the Dumpy over the Wye level, more especially the American make of the latter, in which the parallel plates are detached from the spindle each time the level is put into its box. This is the worst feature in a Wye level, as the screw used to clamp the spindle into place seems to throw the instrument more or less out of adjustment every time it is taken out of the box. And as for quickness of adjustment, though the speaker believes that an ordinary Wye level can be adjusted more readily by the indirect method than an ordinary Dumpy can by the three peg direct method, yet the former requires to be adjusted about ten times as often as the latter. With regard to the error sometimes due to the inner tube not sliding in the line of sight, the speaker considers the stout tubes used by American makers to be much better than the thin tubes of English made levels, since it is almost impossible to turn the thin tubes sufficiently true to ensure their fitting properly one within the other. He has been informed by an instrument maker that the best plan of turning the tubes is to leave a slightly thicker collar on the outside at the end of the inner tube furthest from the eyepiece, and a similar collar on the inside of the outer tube at the end furthest from the object glass. It would seem that in this case the inside tube would have to be put into position by taking out the object glass and putting the inner tube in at that end.

With regard to the object glass cell becoming loose in the tube, the speaker remembers some years since an occasion on which a transit man ran a flat curve in place of a straight line, through the object glass not being screwed tightly into place.

In regard to construction of levels, one point to be attended to is the length of the spindle. This is usually about two and one half inches, but with a sensitive level tube of say a scale value of about 6″ per division the spindle would work better if it were an inch longer. It is also important to see that the socket of the ball and socket joint does not work tight and bind on the end of the spindle so as to make the telescope turn round stiffly when the instrument is set up in a crooked position. The speaker has experienced trouble with a level from this cause.

The speaker fully agrees with Professor McLeod's opinion that it is better to have an over-sensitive level than one that is under-sensitive. With a very sensitive one, accurate work can be done when necessary; and when no great accuracy is required the bubble need not be levelled too carefully.

It is doubtful whether a higher power than 30 could be used with a fourteen inch telescope and a one and a half inch object glass, that is by persons of average power of sight.

The speaker's experience in using an 18 inch Dumpy with a one and seven eighths inch object glass is that a power of 40 is as high as can be used except in very clear weather. It must be remembered that any haziness or refraction due to moisture, or unequal heating of the air, renders it very difficult to see with a high power. Why erecting eyepieces are put into Wye levels the speaker cannot understand.

With regard to reciprocal levelling for transferring levels across a wide river or a ravine; if the instrument be in fair adjustment, it would seem to be as handy to get a reading on a point (A) close to the level and then one on the opposite side on a point (B), then to go over close to B and read A and B again, as to make use of the method described by Professor McLeod.

It may be of interest to explain how the error due to curvature is eliminated by reciprocal levelling.

This may be done as follows, viz:

Suppose that the height of instrument when set near A be 93.65, that the reading of the rod on A be 6.37 and on B be 5.25, this would give for the elevation of A 87.28 and for that of B 88.40; but since the level really gives the line of a tangent to the earth's surface at A, the reading at B will be too great, and therefore B will appear too low. Let this error due to curvature be 0.02 feet, then the reading at B should have been 5.23 and the elevation of B should be 88.42 instead of 88.40.

Now on going over near to B let the reading on A be 7.89, then assuming an error due to curvature of 0.02 feet and no error due to refraction, the reading on B will be 6.73 and the respective elevations of A and B will be 87.28 and 88.44; the height of instrument taken from the reading on B being 95.17. But on account of the error of 0.02 due to curvature, the second reading at A should have been 7.87 instead of 7.89, this would change the height of instrument to 95.15, and would give 87.28 and 88.42 as the elevations of A and B respectively.

In such a case the level book would read somewhat as follows, viz :

	STATION	ROD	HEIGHT OF IN.	ELEV.	
Instrument near A	A	6.37	93.65	87.28	
	B	5.25		88.40	88.40
Reading on B should be		5.23	Elevation	88.42	
Instrument near B	A	7 89	95.17	87.28	
	B	6.73		88.44	88.44
Reading on A should be		7.87	95.15	88.42	
					176.84
Mean of the two elevations of B being the correct elevation					88.42

Since the error due to refraction, though different in kind, may be eliminated by the same method if the readings be taken as quickly as possible so as to get the same refraction in both cases ; or, better still, if two levels be used and the readings across the river or ravine be taken at the same time, it would seem as if it were a better method than that practised by some engineers of reading across the river and then reading the rod at the same distance along the bank of the river, and then checking this latter reading by levelling over the same distance with short sights, for in this latter case it is sometimes impossible to obtain a reading along the bank at the same distance as across the river, and besides in reading along the bank the refraction is not at all the same as in reading across a river.

Since refraction has been alluded to, and since it may cause considerable errors in levelling across wide rivers, it may be of interest to give the method of ascertaining the error due to that cause which was used by General Roy on the Trigonometrical Survey. It is as follows, viz :

In the diagram (Fig. 2), let C represent the centre of the earth, A and B the true places of two stations above the surface S S ; A D and B O horizontal lines at right angles to the radii A C and B C ; *a* and *b* the *apparent places* of A and B.

In the quadrilateral AEBC, the angles at A and B are right angles therefore the sum of the angles at E and C are equal to two right angles and also equal to the three angles A, E and B of the triangle A E B ; taking away the angle E common to both, the angle C or the arc SS, remains equal to E A B + E B A, or in other words, *the sum of the reciprocal depressions below the horizontal lines A D and B O, repre-*

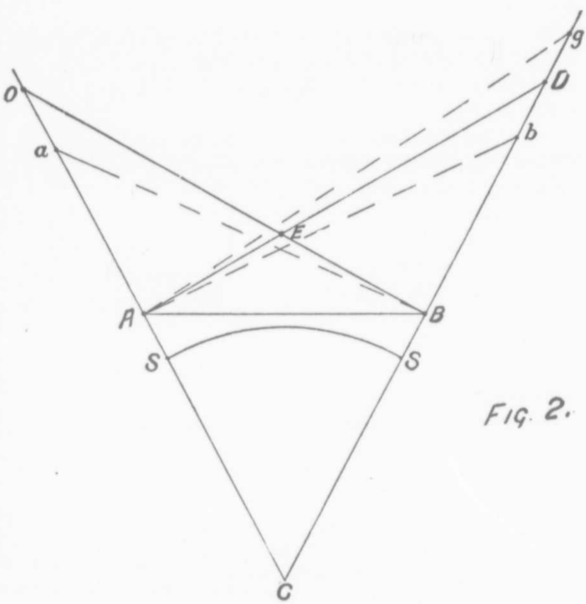


FIG. 2.

sented by the angles E A B + E B A, would be equal to the contained arc if there were no refraction. But *a* and *b* being the apparent places of the objects A and B, the observed angles of depression will be D A *b* and O B *a;* therefore their sum taken from the angle C (the contained arc of distance) will leave the angles *b* A B and *a* B A the sum of the two refractions; hence supposing half that sum to be the true refraction, we have the following rule when the objects are reciprocally depressed: *Subtract the sum of the two depressions from the contained arc, and half the remainder is the mean refraction.*

If one of the points B, instead of being depressed, be elevated suppose to the point *g*, the angle of elevation being *g* A D, then the sum of the two angles, *e* A B and *e* B A will be greater than E A B + E B A (the angle C, or the contained arc) by the angle of elevation *e* A D; but if from *e* A B + *e* B A, we take the depression O B *a*, there will remain *e* A B + *a* B A, the sum of the two refractions; the rule for the mean refraction then in this case is: *Subtract the depression from the sum of* *the contained arc and the elevation and half the remainder is the mean refraction.*

The distance between the points A and B being known, the angle C can easily be found, since the mean value of the length of the arc on the earth's surface subtended by an angle of one second at the centre is 101.42 feet.

In levelling operations the angles of elevation and depression above referred to can be calculated from the observed differences of level and the distance between the points.

The error of 0.02 feet between the lengths of two 14′ levelling rods, referred to by Professor McLeod, would make no practical difference in ordinary railway work, provided the error was evenly distributed over the rod, and that the same rod were used throughout the work; except where a steep and high hill had to be levelled over, and even then in going up 240 feet, say with 20 shifts of the level, the error would only be about 5 inches, which would be spread over about three miles of pretty stiff grades.

As regards errors from not holding the rod vertically, the speaker prefers to have his rodman stand at right angles to the line of sight instead of facing the level. In this way the rodman can see if the rod be vertical in the plane of the line of sight, and the leveller can see if it be vertical in the plane square to the line of sight. Probably for accurate levelling some form of rod level which can be readily adjusted would be useful. The speaker would like to see a series of levels carried across the country under the control of the Government.

Mr. Robertson The author's preference for the "Dumpy" level is the usual conclusion arrived at by engineers familiar with the use of both forms. Still the English tripod which is usually attached to this instrument is a decided drawback.

In Rankine's Civil Engineering it is demonstrated that the exact coincidence of the cross hairs with the axis of the telescope is not essential to accurate levelling. Still it seems that if the *direct* method of adjusting a Wye level be followed as described in this paper, there is a possibility of the cross hairs being moved far from the axis of the telescope, according to the position in which the bubble tube may be found.

The sentence referred to is: "In the essential adjustments by the indirect method, both may require correction, whereas in the direct method only one of them—preferably the reticule—need be moved."

Now, supposing some mischievous person had screwed up one end of the bubble tube, it would not be readily noticed on a Wye level, for there are no bearing blocks. You would proceed to adjust the cross hairs as directed to bring the line of sight parallel to the bubble axis, and thereby shift the cross hairs far from the axis of the telescope.

It appears to the writer that in order to insure the cross hairs remaining approximate to the axis of the telescope, in the case of the Wye level, whether adjusting by direct or by indirect method, the cross hairs should be centred first, by revolving the telescope in its bearings, and then the bubble axis brought parallel to the line of sight; whereas with the Dumpy the bubble tube should be screwed down to the blocks at both ends, which is its most secure position, and then the line of sight brought parallel to the bubble axis by moving the cross hairs.

In comparing the direct with the indirect method of adjusting a Wye level, the author will probably have everyone with him as to the greater accuracy of the former; but as to the saving of time the writer has tried to prove that there should not be the saving of the adjustment of one set of screws, and there is also the consideration that the indirect method may be practiced under shelter from wind, sunshine, rain, and above all with warm fingers.

Professor McLeod, in reply, said that Professor Johnson's suggestion of a method of establishing the most probable values of bench marks in the system of levels of a city is an exceedingly valuable one, and will no doubt be taken advantage of by our city engineers. Prof. McLeod.

Referring to Mr. Irwin's remarks, the author does not understand how Professor Blood's demonstration has survived through the many editions of Rankine's Civil Engineering. Referring to the diagram on page 312, Professor Blood's statement, that all points on the line G H will form an image somewhere on the line F E, is perfectly correct, but this does not constitute G H the line of sight. For any given position, the line of sight will be from a point on G H through the centre of the lens to a point on F E. For any other position on G H the line of sight will also pass through the centre of the lens to a point on the line F E. There will consequently be an angle between these two lines of sight, and if the axis of the level be parallel to one of them, it cannot be parallel to the other; and hence, theoretically, no perfect condition of adjustment can exist when the cross hairs are not in the axis of the instrument. It is, however, perfectly true that the extent of the deviation from horizontality of the line of sight, on change of focus due to the non-coincidence of the line of sight with the optical axis of the instrument, is very trifling in a fairly well made instrument, and may, when the adjustments are properly made, be safely neglected in ordinary levelling operations. In order that justice may be done the maker in this respect, the instrument should of course first be made to "traverse," or the bubble to retain approximately a central position, while the instrument is turned through 180°. But this is the very condition which we are told is unnecessary. Any one having a level and a spare hour may easily satisfy himself on this point, experimentally. Let him first, while the instrument is in its normal condition of adjustment, make readings on points at different distances; then throw the cross hairs out of position, to their extreme limit, and bring the level axis parallel to the line of sight. On repeating the readings on the same points as formerly, the different condition of adjustment will be obvious.

Intending only to touch lightly on the matter of adjustment, the author has unfortunately neglected to state specifically how this condition of adjustment may be examined in the Dumpy. One of the special advantages of the method of adjustment which he has recommended--the "reciprocal" method—is that it admits of this test being applied by afterwards setting the instrument back at a considerable distance from one of the pegs in a line with the other, and again reading the rod on the pegs. Any discrepancy discovered in the readings will be due to the lack of coincidence of the optical axis of the telescope with the line of sight, in the two positions of the draw tube. The three peg method mentioned by Mr. Irwin accomplishes the same object, but at a sacrifice of time. The author wishes to insist, however, that this is not in the ordinary sense an adjustment, and need only be applied as a test of workmanship after purchase or repairs.

The matter of length of time occupied in adjusting the different classes of instruments is entirely a question of experience. What the author has stated is his experience. The statement that the reticule only need be moved in the adjustment of the Dumpy was made for the reason that—as already stated—it is not essential for ordinary work that the bubble should remain absolutely central while the instrument is revolved about its vertical axis, and that in a good instrument the level tube usually retains its adjustment with sufficient accuracy to prevent the necessity of change. The statement in the text should, however, have been qualified in this sense. It has been already shown that the use of three pegs is unnecessary, and the author quite admits that the Wye level can be adjusted in less time than can the Dumpy by the three peg method, but he never contemplated using three pegs.

As to the uses of higher powers on levels, it need only be stated in reply that powers of 45 or over are constantly used on 1½ in. object glasses in precise levelling operations.

In this discussion we may have to some extent strained at gnats, but the author really has no intention of swallowing the large-sized camel which Mr. Irwin has laid down as an article of ordinary railroad diet—a fourteen foot rod, measuring 14.02 feet. Should a new engineer with a correct rod appear on the scene, what would an unfortunate contractor, who might be called upon to take an extra five inch cut from the bottom of a "whin" rock cutting, have to say about this matter?

Mr. Robertson, in his remarks, has also pushed the wording of the paper to an extreme of sense. No person worthy of the position of leveller could be "taken in" by the "small boy" in the way he suggests. As a matter of course any leveller would examine the level to see that the bubble remained approximately in position before adjusting, and under the ordinary conditions of use it will be found to keep this condition sufficiently well to admit of the most accurate adjustment * for all positions of focus by simply moving the cross-hairs.

* It sometimes happens that from imperfect workmanship the draw tube is not straight or of perfectly circular form throughout. In such a case perfect adjustment for all positions of focus is of course impossible.

Thursday, 20th November.

H. WALLIS, Member of Council, in the Chair.

The following, having been ballotted for, were declared duly elected as:—

MEMBER.

Elmer Lawrence Corthell.

ASSOCIATES.

Alfred Adolphe Dion.

Richard William Farley.

Edgar Wilkes Rathbun.

STUDENTS.

William Norton Cunningham.
Charles Burrard Kingston.
Horace Bruce Kippen.
J. Murray McGregor.
J. Geo. Ravenhurst Wainwright.
John Alder Smart.
James Albert Stevenson.
James Tighe.

The following has been transferred from the class of Associate Members to that of Members:—

F. X. Thomas Berlinguet.

The following has been transferred from the class of Students to that of Associate Members:—

Noel Edgell Brooke.

In consequence of the small attendance of members, it was unanimously resolved to postpone the reading and discussion of papers until the next meeting.

Friday, 28th November.

P. W. ST. GEORGE, Member of Council, in the Chair.

Paper No. 46.

CABLE RAILWAYS.

By P. H. MIDDLETON, Stud.Can.Soc.C.E.

Haulage by wire cables has of late years come into somewhat extended use in many different forms, and for many different purposes; but in this paper it is intended to treat only of the application of the endless cable system to the traction of street railway cars. San Francisco was the nursery from which this method of transit emanated, for, in 1873, that city boasted its first cable road in active operation, and succeeding years have seen the number steadily increasing, until, in 1888, the system had been adopted, not only in several of the large cities of the United States, but in Melbourne and Sydney, Australia, and in London, Edinburgh and Birmingham, Great Britain, while the number in San Francisco itself had increased to seven.

The advantages claimed for the cable system of street railways may be classed as follows :—

1st. The steepest grades are as easily worked as levels;

2nd. The easy manipulation of the cars, the stopping and starting being effected quickly and without shock;

3rd. Uniformity of running speed. The rate most suitable for any district and any service can be established and maintained with regularity;

4th. The capacity may be very largely increased at a very small additional cost;

5th. The cleanliness of the track and greater comfort to passengers;

6th. Low cost of management and running expenses.

With regard to gradients, the cable system of haulage reaches far beyond the capacities of any other method. Streets, where the grades are so steep that the use of horse cars is either too expensive or altogether impossible, can be served with cable cars as cheaply as on the level, thus meeting the public requirements in this direction, in localities which would otherwise never receive any such accommodation.

There are cable roads in operation in San Francisco, having grades of 1 in 6, and one in Los Angeles with a grade of 1 in 5. In the matter of curves there is no difficulty whatever, as street corners can be turned as readily with the cable as with horse cars. Lines can be crossed for serving streets at right angles to each other, by placing one conduit below the other; and switching from one line to another may also be accomplished with facility. The Market street cable road, San Francisco, is a good example of what can be done in this direction. By referring to Figure 1, Plate X, it will be seen that there are four separate cables driven from one station, and operating different streets; two of them being cross or side streets in connection with the main or Market street line from and to which the cars are switched as required. An auxiliary cable is necessary to take the cars from Valencia street round the large curve across the main cables to and from Market street. The connection between cars and cable is effected by means of a gripping device, one of the most important and, as it at first proved, one of the most difficult features of the system to work out in detail. It was considered by the early designers that a rolling grip was a necessity, hence the first grip used was constructed with that idea in view, as illustrated in Fig. 2, Plate X. This type proved very inefficient, and was abandoned for the sliding grip, Fig. 3, Plate X, which has been found not to injure the cable to any serious extent, as was formerly feared. There are many different forms of grip in use, more or less simple in detail, and having more or less gripping power, but all fairly efficient and easily worked. The absence of shock in starting, promptness in stopping, and the general ease with which the cars may be handled, are strong recommendations for the system for passenger service.

Figs. 4 and 5, Plate X, show a method in which the jaws of the grip are closed by raising the rollers RR against the inclined backs of the jaws, thus forcing them upon the cable.

Figs. 6 and 7, Plate X, show the "Vogel" grip, which is operated by short levers or toggles, thus causing the jaw BB to revolve around a centre pin and close on the cable.

Fig. 3, Plate X, gives yet another style, the cable is supported by rollers at C C, and the jaws DD are closed by rods connected with working lever.

Cable roads can be run at a very much higher rate of speed than horse cars—a common speed being 8 miles per hour, while in the suburbs, where traffic is not so great, 13 miles is sometimes adopted. The system also offers great facilities for accommodating the fluctuation of traffic at different hours of the day, more cars being added as required without any additional cost beyond a slightly increased demand upon the coal pile.

The absence of smoke, ashes and noise attendant upon the use of locomotives, worked either by steam or compressed air, and the noise and dirt and general disagreeableness of horse cars, renders the application of the cable system to passenger traffic an extremely desirable feature in the economy of modern cities.

The cable system consists mainly of an endless wire rope, driven by a stationary engine at any convenient point on the line, placed in an underground tube, and supported at intervals upon light sheaves. Along the top side of the tube runs a narrow slot, varying, on different roads, from $\frac{5}{8}''$ to $\frac{3}{4}''$ in width.

The road-bed is the principal feature of the cable system, one upon which the engineer is called to expend his utmost care and ingenuity, not only in the selection of the place but also in every detail of the work. It is by far the most expensive item, costing from $80,000 to $100,000 per mile, although when in operation the running expenses amount only to 8c. or 9c. per car mile, while those of electric roads vary from 12c. to 16c. per car mile. The tubes or conduits are made of greater or less depth and size, to suit the nature of the ground and climate, as they must also act as drains to carry off such water as may find its way into them. Frames, to carry guide pulleys, are built in the tube, at about 30 to 50 feet apart, and man-holes are provided at each such place to admit of the sheaves being oiled and renewed.

The track is rigidly connected to these frames and to the slot irons, to ensure their maintaining always the same relative position. Figs. 8, 9, 10, 11, 12 and 13, Plate X, show some examples of roadways and conduits, to which reference will be made later on.

The cables used are the ordinary wire rope, generally of crucible steel, as being the most durable, and vary slightly in size from 3″ to 4″ circumference, according to their length and the amount of traffic expected. Some lines run as much as 5 miles of cable in one length, at speeds varying from 6 to 13 miles per hour. The life of a cable is from 9 months to 2 years. The operating machinery may be placed anywhere on the line, a matter of great importance in working the business parts of large cities, as the necessity for purchasing expensive sites is thus avoided. The driving machinery is of a very simple character, consisting in the main of a pair of horizontal engines, geared simply on to a large sheave or drum. Sometimes a pair of such sheaves are used, round which the cable passes two or more times, according to the degree of tension required for hauling the traffic of that particular road. The grooves of these driving sheaves are liable to unequal wear, and hence a differential action is established, tending to strain the cable to breaking. To remedy this difficulty a patent sheave was invented, the "Walker" differential ring, illustrated in Fig. 14, Plate X. It will be seen that each groove is in a separate ring, which, being driven by friction, is free to move independently of its fellow, but is able to slip should the strain on the cable become excessive.

Some method of providing for the variation in length of cable, due to changes of temperature, is also necessary. Some plans for this purpose are shown in Figs 15, 16 and 17, Plate X, that one which consists of two carriages being preferable to either of the others; the smaller one to take up slack due to the temperature, while the larger one is shifted when new cables are put in.

CLAY STREET HILL CABLE RAILWAY.

The first cable railway to be built in America was the Clay street hill line, in San Francisco, California. Clay street, for a long way, runs through a densely populated part of the city, and is only 49 ft. wide from house to house. Between the sidewalks there are two lines of gas pipe, one of water pipe and a street sewer, together with a few water cisterns placed at the street corners. The power station is situated about two-thirds from the lower end of the line, which has a double track of 5197 ft. in length and a $3\frac{1}{2}$ ft. gauge. The ordinary T rail, weighing 30 lbs., is used, being placed flush with the street. The grades are very heavy on this line, the steepest being 1 in 6.15. The cable is made of crucible steel wire, six strands, and of $3\frac{1}{16}''$ circumference, with a total length of 11,000 feet. Pulleys of 11″ diam. are placed every 39 ft. apart along the tube, and at the termini tension sheaves 8 ft. in diam. are used. By referring to Fig. 10, Plate X, it will be seen that the frame is made of cast iron, that the slot is $\frac{3}{4}''$ wide, being placed off the centre to prevent dirt and sand from falling directly upon the cable and pulley, and also to allow the grip to pass under the depression pulleys which are placed at the level crossings of intersecting streets. The cars are hauled by a dummy, to which the gripping apparatus and brakes are attached. The dummy seats 16 passengers and the cars 14, while they weigh 2100 and 2800 lbs. respectively.

The power is supplied by two engines and two boilers, one pair being held in reserve in case of break downs. The boilers are 54″

in diam. by 16 ft. long, and use on an average 3700 lbs. of coal per working day of $17\frac{1}{2}$ hours.

MARKET STPEET CABLE RAILWAY.

Market street cable railway is one of the most important as well as the most extensive in San Francisco. The line extends from the water front along Market street, which is one of the largest thoroughfares in the city, being $3\frac{1}{2}$ miles long by 120 ft. wide.

There are two branch lines diverging from the main line, which are worked from the same engine house. Fig. 1, Plate X, shows the arrangement of station and cables.

In all there are six cables used, making a total of about 12 miles of double track of standard gauge, viz., $4' 8\frac{1}{2}''$.

Fig. 8, Plate X, shows section of the road-bed which rests upon concrete piers, measuring 10 ft. deep by 5 ft. wide by 16 in. thick, placed 9 ft. apart. The track, tube, and steel slot rails are strengthened and held rigidly in place by yokes made of old T rails and angle irons, of the shape shown in the figure, placed 3 ft. apart; and concrete is then filled in to form the tube. The cable is supported upon grooved pulleys, 15″ diam., situated at intervals of 30 ft., a manhole 12″ × 16″ being placed directly over each one. The cable measures 4″ in circumference and weighs $2\frac{1}{2}$ lbs. per linear foot, while the average rate of speed is 8 miles per hour.

At the termini, turn-tables 30 ft. in diam., with two sets of tracks, which are worked by the moving cable, are provided. In all there are three engine houses on the line, the principal one having a power of 400 horses. The machinery is duplicated, there being four engines in use and four to spare. Fig. 9, Plate X, shows section of the Sulter street road-bed which is somewhat similar to that on Market street. The conduit is 2′ 6″ deep by 20″ wide.

POWELL STREET CABLE RAILWAY.

Powell street line, which is also in San Francisco, is one of the more recent roads, and boasts of two cable roads which cross each other at right angles. The total mileage is $1\frac{1}{2}$ of double track and $5\frac{1}{2}$ of single of 3 ft. 6 in. gauge. The line is operated from one station containing two horizontal high pressure engines of the Reynold's Corliss type of valve gear, having cylinders 22″ in diam. by 48″ stroke. Six tension reels are used of 13′ 9″ in diam., placed on an 11″ shaft, each of which is divided into two grooves. The three winding drums are a little larger than the tension reels, which are driven by a 14 ft. spur wheel, the ratio of pinion to spur wheel being as 2 to 7. The boilers, of which there are six, are 54″ diam. by 16′ long.

CHICAGO CITY CABLE RAILWAY.

Chicago City Cable Railway Co. comprises a line 17 miles long of double track, with a 4′ 8½″ gauge. In all there are seven different cables, the longest being 27,800 ft. of 4″ circumference.

Owing to the snow and frost in that city, the tube is made much deeper, being over 4 ft., while the cable is placed about 30 in. above the bottom. The driving and angle pulleys are 12 ft. in diam. The company owns 6 engines, 4 being used to work the road, the others held in reserve.

BUTTE CITY CABLE RAILWAY.

A cable road has been built on the "Vogel" system in Butte City, Montana. The principal features of this system are the limited use of concrete and its cheapness. Figs. 11, 12 and 13, Plate X, represent sections of the road-bed.

The conduit is formed by a pair of irons 10″ deep, and in lengths of 30 ft., rivetted to a sole plate. See Fig. 6, Plate X.

Inside of this subway the cable runs, and is supported at intervals of 50 ft. upon light 8″ diam. pulleys. At these intervals a man-way is built, to enable the sheaves to be renewed and oiled. This man-way may be either made of concrete, as shown in drawings, or else of cast iron, in which case it would become part and parcel of the conduit.

The irons are braced by stays rivetted to the ties, which are placed about 3 ft. apart; and thus the track, slot irons and ties become one rigid structure. Fig. 7, Plate X, represents the "Vogel" grip, which has been described before.

The Butte City line consists of 1¼ miles of double track, and passes through a short tunnel and over 2000 ft. of trestle work. The grades vary from a minimum of 3 per cent. to a maximum of 18 per cent.

BIRMINGHAM CABLE RAILWAY.

In this road the tube is made of concrete laid 19″ deep and 9½″ wide. The cast iron tube frames are placed 3′ 6″ apart, and then filled in with concrete. Pulleys of 14″ diameter, placed every 50 ft., support a steel wire cable 3½″ circumference, the tensile strength being 80 tons per sq. in., and the torsional strength 35 twists in 8″. It is composed of 6 strands of 13 wires each, laid around a hempen core, cost

£626, and lasts about 18 months. The line is worked by a pair of horizontal engines, having cylinders 20″ diam. by 40″ stroke. The driving pulley is 10′ 6″ in diam. with V grooving.

Table showing cost of construction and equipment of line :—

Track with pulley, etc., complete	$33,377
Machinery buildings, offices, chimney shafts	4,786
Engine, boilers, machinery in place	5,103
Cars and gripping machinery	4,704
Cables	1,260
Auxiliary cable gear	850
Extras and payments made to various corporations, and to city for paving	7,150
Total	$57,230

The following table has also been issued by the same company :

Horse cars per mile absorb 85.5 per cent of the gross receipts.

Steam locomotion	64.5 p.c.
Cable traction	46.5 p.c.

From the drawings accompanying this paper Plate X has been prepared.

Thursday, 4th December.

JOHN KENNEDY, Vice-President, in the Chair.

The discussion of Prof. McLeod's paper, "The Errors of Levels and Levelling, Part I," occupied the evening.

Thursday, 18th December.

K. W. BLACKWELL, Member of Council, in the Chair.

The reading of Prof. McLeod's paper, "The Errors of Levels and Levelling, Part II," occupied the evening.

OBITUARY.

SAMUEL KEEFER.—About the middle of the last century, George Kieffer, a native of Alsace, born not far from Strasbourg, on the Upper Rhine, emigrated to America, and settled at Paulinskill, near Newton, the capital of Sussex county, in the then British Province of New Jersey, now one of the United States of America. His brother Jacob went on to Pennsylvania, establishing himself near Harrisburg. Though born a Frenchman, German was his mother tongue and Lutheranism his religion. On the breaking out of the Revolution in 1776, George Kieffer espoused the cause of the House of Hanover, was mustered in the Royalist ranks, and died of army fever upon Staten Island. His son George, born in 1773, was a child at his father's death, and remained at his New Jersey home until his 18th year.

The family property, consisting of two farms and a distillery, was confiscated by the United States, and George, as the son of a "United Empire Loyalist," was offered a home in Canada by the British Government. He followed an Indian trail from New Jersey to the Niagara River, at Buffalo, and crossing over selected his home in Canada, about seven miles from the Falls of Niagara. Returning to New Jersey, he brought his mother and brother, in 1792, over the same route, by packhorses, the men marching on foot. In 1797, he married Catherine Lampman, German and Lutheran as himself, and of the five sons and four daughters of this marriage, Samuel Keefer, the subject of this notice, was the fourth son.

George Kieffer spoke German until his arrival in Canada, and here changed the spelling of his name to Keefer, to secure its proper pronunciation by his English neighbors.

Samuel Keefer was born in Thorold, county of Welland, Province of Ontario, upon the 22nd January, 1811. He was the fourth son of the late George Keefer of Thorold, who was a captain in the Canadian Militia in the war of 1812, a magistrate, merchant and mill owner, and the first president of the Welland Canal Company. That great work, commenced in 1824 and completed in 1829, was accomplished by a joint stock company, and managed as such until 1841, when, upon the union of the Provinces of Upper and Lower Canada, it was taken over by the Government. The Canal passed through his father's property, and for want of any hotel accommodation his father's house was thrown open to the engineers, and it is due to this connection that Samuel Keefer, while a lad, chose the profession of Civil Engineer. His early education was limited to that afforded by the country schools within his reach; but during the construction of the canal, Upper Canada College was founded in Toronto (then known as York), through the exertions of the Lieutenant-Governor of Upper Canada, Sir John Col-borne, afterwards Lord Seaton. Thither, on leaving the Welland Canal, Samuel Keefer went March 21st, 1831, and remained until 1833, when, owing probably to his canal experience, he was appointed secretary to the Board of Canal Commissioners for the improvement of the River St. Lawrence. The following year, on the commencement of the construction of the Cornwall Canal, he became assistant to the chief engineer, John B. Mills, and continued in this capacity under Mr. Mills' successor, Lt.-Col. Philpot, R.E., until 1839. In that year he was appointed secretary to the Board of Works, then established for Lower Canada by Ordinance of the Special Council, and upon the subsequent union of Upper and Lower Canada (which followed the Rebellion of 1837), and the establishment of a Board of Works for the United Provinces, he was appointed engineer to that Board on 17th August, 1841. Thus, at the age of 30, he attained the highest position in his profession in his native country. That this was no sinecure may be inferred from the consideration that at that time, besides the Welland Canal just taken over, and needing reconstruction and enlargement, there existed Provincial canals upon the St. Lawrence and the Richelieu rivers—while from Gaspé to Lake Huron, a main post road, crossing numerous large rivers, to be turnpiked, planked or macadamized (as stone or wood was most available), was loudly called for.

He filled this position for 13 years, 1841-1854, having also in the 3 years, from 1846 to 1848, acted as chief engineer to the Welland Canal, where he was called by the resignation of the engineer in charge. In this period he made the first surveys in 1852 for a canal on the Canadian side of the Sault Ste. Marie, the outlet of Lake Superior, which work is only now under construction.

The works constructed under the Department during the first decade of the union of the Provinces were of the most varied character, consisting of canals, roads, bridges, "slides" (for passage of timber past rapids), harbours and lighthouses. He personally surveyed and established the line of the Beauharnois Canal, the first enlargement of the Lachine Canal, and the locks and dams at St. Anne's on the Ottawa, and St. Ours on the Richelieu and directed their construction.

In 1850, he substituted for the more costly oak framed gates previously in use, solid timber ones of pine for the St. Lawrence canals, where the locks have a width of 45 and 50 feet. The timbers of pine, like very thick plank laid broadside on top of each other, were reduced at the ends to the width of the heel and toe post, but wider elsewhere, being arched against the pressure side, giving greater strength, floatation and economy of cost, as well as greater durability.

He also constructed in this period, 1843-1844, the first suspension bridge in Canada, over the Ottawa River at the Chaudière Falls, connecting the now cities of Ottawa and Hull. A wooden bridge of 300 feet span had been erected upon this by the Royal Engineers in charge of the Rideau Canal some years previously, but had fallen soon after its erection. Samuel Keefer here had an opportunity to bring his mathematical knowledge, for which he was distinguished at college, into play. He chose the Freiburg wire in preference to the Menai chain system, and made his plans with the very limited assistance of engineering literature then accessible to him, chiefly the *Engineer and Architect's Journal.* That it is not every engineer who can build a suspension bridge is evident from subsequent experience in Canada and in the adjoining State of New York. Two Canadian suspension bridges, one over the Desjardins Canal near Hamilton, Ontario, the other over the Montmorency River, near Quebec, were blown away or fell, in the one case with loss of life; while two American bridges, one on the Genesee River at Rochester, the other over the Niagara River at Queenston, shared the same fate. Mr. Keefer had not the advantage of his less fortunate successors in having a successful example to refer to. This bridge served its purpose for 45 years, and was replaced last year, although as serviceable as ever, by a wider steel truss one, which was called for by the increased traffic.

In 1845, he was again called upon to plan an original work, of which there was no type in existence. Timber slides for the passage of cribs with men to guide them had been in use for some years, but to regulate the necessary depth of water, which must not exceed 12 to 15 inches, stop logs of varying dimensions were put in or taken out as the river at the head of the slide rose or fell. Mr. Keefer had read in the *Civil Engineer and Architect's Journal* the account of the Bear Trap sluice in use at an early date, but long before abandoned on the Pennsylvania rivers, and adopted the principle to afford an automatic regulator, by which the gates of the Bear Trap, being set for a given feed of water, would rise or fall with the fluctuation of the stream, always feeding the same quantity. This was applied to the Government slides at Ottawa, and worked successfully for years, though not now considered necessary.

In 1853, he resigned his position under the Government for a more lucrative one upon the Grand Trunk Railway, and located the line between Montreal and Kingston, which he had previously surveyed for the Government while in their service. He also conducted the hydrographic survey of the site of the Victoria Bridge, fixed the line upon which it was constructed and projected the high level bridges for this railway over the Ottawa at St. Anne's, and over the Rideau Canal near Kingston. During this period, 1853-1857, he was also supervising engineer of the Brockville & Ottawa Railway, a line which connects the St. Lawrence at Brockville with the Ottawa River, about 40 miles above the city of Ottawa.

In 1857, he re-entered the Government service, as inspector of railways and deputy commissioner of Public Works, and for seven years made a personal inspection of all the provincial railways. As deputy commissioner of Public Works, he was charged, owing to the absence of the chief commissioner, with the selection of the competition plans for the public buildings at Ottawa. His report on these plans was approved by His Excellency in Council in 1859, and the works forthwith commenced under his direction, and were so far advanced that the corner stone was laid by the Prince of Wales in 1860. The arrangement of the detached blocks, forming the Parliament buildings and departmental offices, upon three sides of a square, is due to him, and no little of the effect of this splendid pile upon a magnificent site is due to this disposition.

He retired from the public service in 1864 to his home in Brockville, but not from the practice of his profession. In addition to the management of his private affairs, he undertook, in 1869, the construction of a wire suspension bridge at Niagara Falls, of a span of 1,268 feet, then the longest in existence, a detailed account of which appeared in *Engineering* in that year. For the plan and details of this work, he was awarded the gold medal at the Paris Exhibition of 1878. This bridge stood for nearly twenty years without failure of any kind. In 1889, the owners, without consulting Mr. Keefer, replaced the single track roadway by a double track one, and three months after this new roadway was torn from its cables and guys by a terrific wind, which registered at Buffalo, 18 miles distant, 88 m. per hour.

In 1870, he was appointed by the Government secretary to the Canal Commission, of which Sir Hugh Allan was chairman. The object of this commission of mercantile men was to determine the scale of navigation for the enlargement of the Canadian canals. In 1872, he made a survey, plans and estimates of the Baie Verte Canal, a route to connect the Gulf of St. Lawrence and the Bay of Fundy, a project which had been proposed early in the century, but which has now been abandoned in favour of a ship railway over the same route. Col. Sir Casimir Gzowski, K.G.C.M., was associated with him in this work, which was completed in 1873.

In 1875, he built the Dufferin bridge—cast iron arch—over the Rideau Canal in the city of Ottawa, and widened another, a stone arch built by the Royal Engineers over the same canal, about 50 years before.

In 1880, he was appointed one of the members of a Royal Commission, to enquire into the conduct and prosecution of the Canadian Pacific Railway from its inception to date. Up to this date this railway had been carried on as a public work. A reform Government had been in power from 1873 to 1878, and had given way to a Conservative one, which was now investigating the work of their predecessors. Samuel Keefer was a pronounced Conservative, hence the absence of his name in Government connection between 1873 and 1880.

No mention is made of what, especially since his retirement from the public service, was an important and lucrative branch of his private practice. As a competent and experienced hydraulic, bridge and railway engineer, his services as an expert and arbitrator were ever in request. His active participation in these duties continued until 1888, when his final illness began. From his experience on the Welland Canal, as a lad, to his cessation from labour, deducting his college years, he must be credited with about 60 years of practice, a long, useful and honourable career, which has in no small degree contributed to the position which Canada holds as the possessor of public works unsurpassed by any country of similar wealth and population.

He became a member of the American Society of Civil Engineers in January, 1869, and of the Institution of Civil Engineers in March, 1870. The year before his death, he was President of the Canadian Society of Civil Engineers.

In person he was about the middle height, stoutly built without corpulence. In disposition he was remarkably cheerful, with an entire freedom from any thing approaching irritability. A consistent member of the Church of England, which he represented as a lay delegate, both in the Diocesan and Provincial Synods and upon the Mission Board, his creed was, "Fear God, honour the King,—meddle not with them who are given to change."

Mr. Keefer died at his home in Brockville (from effects of malarial fever contracted nearly two years before in Toronto), on the 9th of January, 1890, within a fortnight of entering upon his eightieth year.

JOHN PAGE.—Chief Engineer of the Dominion Canals. This very able and distinguished engineer was born in Scotland, in the year 1815. He served under the late Robert Stephenson, as junior engineer of the Northern Light House Board, for a few years, until 1838, when he left for the United States, where he was employed on the Erie Canal as a stone-cutter, and afterwards as one of the sub-engineers, for about four years. In 1842 be obtained employment as draughtsman and as one of the assistant engineers on the Welland Canal, the first enlargement of which had been commenced the previous year. In September, 1842, he rose to the position of assistant to the chief engineer, and in 1846 to that of consulting engineer, on this work.

From 1850 to 1851, he located and began the construction of the Junction Canal, uniting the Galops and Point Iroquois links of the Williamsburgh Canals, of which he was then the resident engineer, and until he was appointed superintending engineer of the canals east of Kingston in 1852, in which capacity he acted until the 31st of October, 1853, when he became chief engineer of the public works department of Upper and Lower Canada, upon the retirement of the late Samuel Keefer who had filled that position since 17th August, 1841.

Mr. Page was appointed deputy commissioner of the department, 8th March, 1864, but resigned this position, and was re-appointed chief engineer on the 15th of the same month. When confederation took place, 1st July, 1867, he was nominated chief engineer of the Federal Government, on all works excepting railways, and acted in this capacity until October, 1879, when the Department of Public Works was divided into two departments, that of Railways and Canals, and the other of Public Works, comprising buildings, harbours and river improvements, etc. He was then appointed chief engineer of the canal branch.

In 1889, Mr. Page accepted nomination as President of the Canadian Society of Civil Engineers, for the following year, but he afterwards found himself compelled to withdraw his consent on account of his official duties. During the spring of 1890, he was appointed member of a Royal Commission, to examine and report on the Montreal Harbour improvements proposed by the Montreal Flood Commission of 1886-87, and by other parties.

He died suddenly in his office, at Ottawa, on the 2nd of July, 1890.

The principal works designed by or executed under Mr. Page were:—the

Junction Canal, 1851-52; the dioptric and catadioptric Light Houses at Belle-Ile, Amour Point, Cape Rosier, Bird Rock and Anticosti, along the Gulf of St. Lawrence, and the first-class Light Houses on Lakes Erie and Huron, 1858-67; the Culbute locks and dam for vessels drawing 6 feet at the lowest water on the Upper Ottawa, 1873-76; the last enlargement of the Welland canal, from a depth of 10½ to 14 feet of water on the lock sills, 1873-87; the enlargement of the River Ottawa canals at Ste. Anne, Carillon and Grenville, from 6 to 9 feet depth of water on the lock sills, 1871-83; the Lachine Canal enlargement, from 9 to 14 feet depth on the lock sills, 1873-84; the Galops, Rapide-Plat, Farran's Point and Cornwall canals, the enlargement of which, to a navigable depth of 14 feet, was commenced in 1875, and is still in progress; the Murray canal, at Presqu'ile, Lake Ontario, commenced in 1882 and completed in 1889; the Tay Canal branch of the Rideau Canal, enlarged and reconstructed, 1883-89; the Sault-Ste-Marie Canal, the navigable draft of which is to be 18 feet, commenced in 1888, and now in progress; the River Trent new canals at Buckhorn and Burleigh Rapids, and at Fenelon Falls, with 5 feet water on the lock sills, 1882-88.

Apart from the construction of the works enumerated above, Mr. Page submitted many valuable reports in connection with other important and projected works, and acted as arbitrator in several complicated cases, always giving satisfaction to the Government and the contractors, who relied on the soundness of his judgment, on his great experience, and on his integrity.

By his death and that of the late Samuel Keefer, his predecessor, Canada has deen deprived of the services of two of its most experienced and skilful engineers. The canal works executed under their directions are second to none on the continents of America and Europe, as regards magnitude, stability and cost.

Mr. Page was elected a member of the Society on the 12th of May, 1887.

THOMAS TIMMIS VERNON SMITH was born on the 6th August, 1824, at Duckmanton Lodge, near Chesterfield, Derbyshire, at that time the residence of his father, whose family has been settled in Sheffield for many generations, being almost certainly the oldest in England connected with the Iron and Steel trades. Vernon Smith's father was, like his forefathers, an iron and coal master; his grandfather, who was master cutler in 1797, was himself the grandson of John Smith, who was master cutler in 1722. This last was great-grandson of Henry Smith, whose name was included in the Royal Charter granted by James I., in 1612, founding the cutlers company. The glory of this still existing company has faded during the past decades, and its position with regard to the Iron and Steel trade of England is now more or less taken by the Iron and Steel Institute, of which Vernon Smith's eldest brother was one of the founders, and has been president, thus making seven generations, from father to son, associated with the manufacture of iron and steel. On the American continent it may be of interest to mention that Vernon Smith's mother was great-grand-niece of Admiral Edward Vernon, after whom George Washington's elder half-brother who served in the fleet commanded by that Admiral, named his Virginian home Mount Vernon, which has become a place of interest and of pilgrimage without a rival in the States.

Vernon Smith, as a very small boy, was present with his father at the opening of the Liverpool & Manchester Railway,—the pioneer railway of England. He was educated at Mill Hill Grammar School; and afterwards served a five years' apprenticeship at Newcastle-on-Tyne, with his father's friends, George and Robert Stephenson. At the end of this period he returned home to assist his father at the Stanton Iron Works, near Derby, where he remained until he became locomotive superintendent of the Southampton division of the London & South Western Railway. It was during this time that an accident happened in a tunnel to the Queen's train, on which occasion Mr. Smith rendered valuable service in relieving Her Majesty from a most dangerous situation.

In 1852, Vernon Smith was appointed manager of the Woodstock Iron Works in New Brunswick, owned by Sanderson & Co., of Sheffield. At the stoppage of those works he went to England, remaining, however, but a short time, and returned to Canada, in 1855, to superintend the construction of the Cobourg & Peterborough Railway.

In 1857, he was appointed provincial engineer under the New Brunswick Board of Trade, which position he held for several years. During this period he invented and patented a fog whistle, which has since been adopted not only in Canada, but on the English coasts and elsewhere. The original whistle bearing his name is still in use at Partridge Island, in St. John harbour.

In 1861, he returned to England, and during the next four years he visited and made special reports on various railway and mining enterprises, both in England and on the continent; and until the project was abandoned, superintended, on behalf of Overend, Gurney & Co., the construction of the Barcelona & Cette Railway.

In 1866, Vernon Smith returned to Canada and remained identified with the Dominion until his death. He went to Nova Scotia as engineer for Punchard & Clarke, the contractors for the Windsor & Annapolis Railway; and when the line was completed, he was appointed general manager. He resigned this appointment to become chief engineer to the Western Counties Railway, and spent four years over the surveys and construction of that road.

In 1877, Vernon Smith conducted a survey connecting the Intercolonial Railway with Whitehaven, N.S., which had been proposed as the winter terminus of the English mail steamers. In 1878, he went to Toronto to superintend work in connection with the Credit Valley Railway, and remained in that city for five years. During this period he wrote many articles in the press on professional subjects; amongst these a long series in *Engineering* (of London, England), on "Canadian Railways," attracted much attention, as well as a popular article in the ***Nineteenth Century***, on the "Wheatfields of North America."

In 1883, a move was made to Ottawa, as a more convenient centre, and

Vernon Smith was engaged on special engineering work for the Mattawamkeag Short Line, the Gatineau Valley Railway, and other minor enterprises. In 1886, he crossed the continent on the Canadian Pacific, and prepared for the present president of that line a very exhaustive report of the railway, and the immense facilities which it afforded in opening up the interior of the country.

In 1889, Mr. Schreiber, chief engineer of Government railways, entrusted Mr. Smith with the superintendence of the survey of the proposed Harvey-Salisbury Short Line in New Brunswick. After the close of the field work of this survey, and while preparing the necessary plans and estimates for his report, Vernon Smith was attacked by "La Grippe," and after a few days illness, leaving his latest work almost completed, he died on the 15th January, 1890, in the 66th year of his age.

Mr. Smith was elected a member of the Society on the 17th of September, 1887.

EDWARD WASELL was born on the 7th of January, 1841, at Southampton, England, and died 21st April, 1890, in London, Ontario. The earliest record of him is in Canada in the year 1868, from which time until 1873 he was employed on the Great Western Railway as assistant engineer, and afterwards as chief engineer of the London, Huron & Bruce Railway, resigning in December, 1874. From 1874 to 1879 he was chief engineer of construction on the Western Counties Railway of Nova Scotia, and he also constructed the Yarmouth Water Works, Nova Scotia. From 1883 to 1885 he designed and built the sewerage system of Winnipeg, Manitoba, and was subsequently engaged in private engineering practice in Ontario.

Mr. Wasell was elected a member of the Society on the 11th October, 1888.

(Abstracts of Papers in Foreign Transactions and Periodicals.)

THE HAWKESBURY BRIDGE, NEW SOUTH WALES.

By Charles Ormsby Burge, M. Inst. C.E.

(Minutes of Proceedings of the Institution of Civil Engineers, Vol. CI., 1890.)

The author was in charge of the work for the Colonial Government, under Mr. John Whitton, engineer in chief for railways. The Colonial Government invited designs and tenders for construction, making the competition world-wide. That of the Union Bridge Company of New York was accepted.

The accepted design consisted of seven spans of 416 feet each, centre to centre of piers. The bridge is for a double track, the trusses are 28 feet apart, centre to centre. The material is of steel with eye bar tension rods and steel pins. The main girders of each span are 410 feet in length centre to centre of end pins, and 58 feet deep at centre.

The foundations are of concrete encased in steel caissons, upon which is built stone masonry. The boring showed a bed of mud and other material for a depth at maximum of 93 feet below the bed of the river. The greatest depth of water was 77 feet, range of tide 7 feet. Pier number six is the deepest, being 162 feet below water, or 50 feet of water and 112 feet of mud, etc., and being, "as far as the author is aware, the deepest bridge foundation yet sunk." The caissons for the piers are 48 feet long by 20 feet wide, with rounded or semi-circular ends, the lowest, 20 feet, is tapered outwards to 2 feet wider, making the bottom of the caissons 24 feet wide. The caissons have three dredging wells each 8 feet diameter, placed 14 feet apart centre to centre lengthwise, the spaces between the wells being 6 feet and similarly between them and the edges of the caissons. This method formed four cutting edges in longitudinal sections and two in cross section of the wells. The spaces between the wells are filled with concrete. The caissons were floated into position, and built up as their sinking progressed by dredging out the wells. The margin for lateral divergence allowed (in sinking) by the specification was 2 feet.

No. 5 caisson was the first started and proved to be the last completed. Its career was erratic. It was commenced on the 9th December, 1886, and was only ready for masonry on the 9th October, 1888. Shortly after entering the mud its tendency was to work eastward, or at right angles to the line of the bridge. Remedies by dredging, pile-driving and anchoring were resorted to, but all failed to secure the getting it into proper position. Finally, when the caisson "was well in the sand," at 144 feet below high water (being then in 67 feet of mud, etc.), it was proposed to sink an additional caisson at its west end. This failed, and the addition was in the way and could not be removed, so there was "no alternative left but to commence the masonry at the west end "at as low a level as possible, viz., 12½ feet under the original masonry "level, and to corbel out. With the aid of a coffer dam this "corbelling was carefully carried out with solid stones 7 to 8 feet in "length, with a 9 inch overhang in each course, and though adopted "as a last resource, the centre of the column of masonry above, coin-"ciding with the centre of the west girder, is well within the base of "the original caisson; and the resultant line of the pressures of "the pier and load passes very closely to the centre of the bottom "foundation area." The author attributes nearly all the difficulties of sinking to the outward splay of the caisson at the bottom, and recommends straight sides.

No. 6 pier also behaved stubbornly. Its tendency was northward (in the line of the bridge), following a declivity in the bottom of the river, and all the remedies applied did not effect the desired object, so that the span of the girders had to be changed to suit the waywardness of this pier. The maximum pressure on the bottom of No. 6 caisson (which is the heaviest) is about 9 tons per square foot.

The erection of the superstructure was by floating an entire span into position. The bridge is in an exposed situation, and beset with tidal currents. A pontoon, 335 feet in length by 61 feet wide, and having 44 water-tight compartments, was scuttled on a gridiron at Dangar Island. This pontoon had erected upon it staging high enough to float the bridge into position (its clearance being 40 feet above high water). In this position (on the gridiron) a full span was built, and when wind and tide favoured, the pontoon was floated (by closing the chamber valves at low water). The whole was then hauled to the bridge site, ¾ of a mile away, by means of 6 inch hawsers extending from the island to the bridge, all worked by steam. This method was assisted by tugs and the flowing tide, Dangar Island being below the bridge. The span being moved in position, but higher than the piers, the lowering into position was done by the ebb tide, or when necessary by partial scuttling of the pontoon. This method was not all plain sailing, there were many difficulties of wind and tide to battle with, and more than one span narrowly escaped wrecking. No. 6 parted its hawser during a squall. "The pontoon swung around into a dangerous position, from which it appeared impossible to avoid a collision with the structure already fixed." Dexterously, however, a successful movement was made, saving the span but reversing it end for end, making no difference, as the girders were symmetrical.

Mr. Thomas Curtis Clarke and Mr. Theodore Cooper of New York designed the structure. The Union Bridge Company sublet the work, the bridge superstructure being built by Messrs. Arrol of Glasgow, the caissons by Messrs. Head & Wrightson, the masonry by Mr. Samuelson of New South Wales. Messrs. Anderson & Barr of Jersey City, N.J., sank the piers, and Messrs. Ryland & Morse of Chicago erected the superstructure. The tender was for the bulk sum of £327,000 stg.; time allowed 2½ years.

Mr. Thos. C. Clarke gives the quantities as follows:—

	Estimated	As in work.
Tons of steel in girders	6,200	6,320
" " caisson	1,600	1,668
Cubic yards of concrete	27,600	26,593
Masonry	4,900	5,630
(Excess masonry due to change of plan.)		
Time	30 months	34 months.

The bridge was opened for traffic on the 1st May, 1889, by His Excellency Lord Carrington, Governor of the Colony.

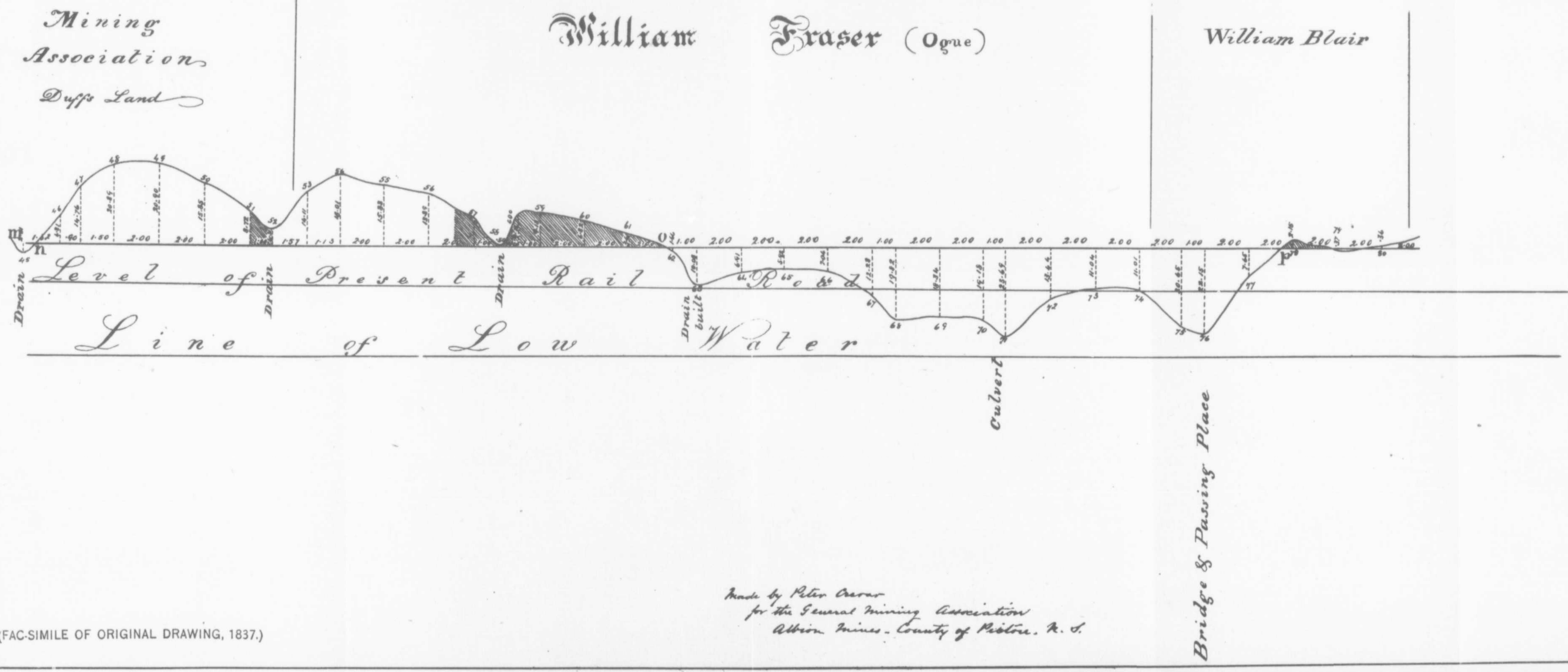
ERRATA.

VOL. IV, PART II.

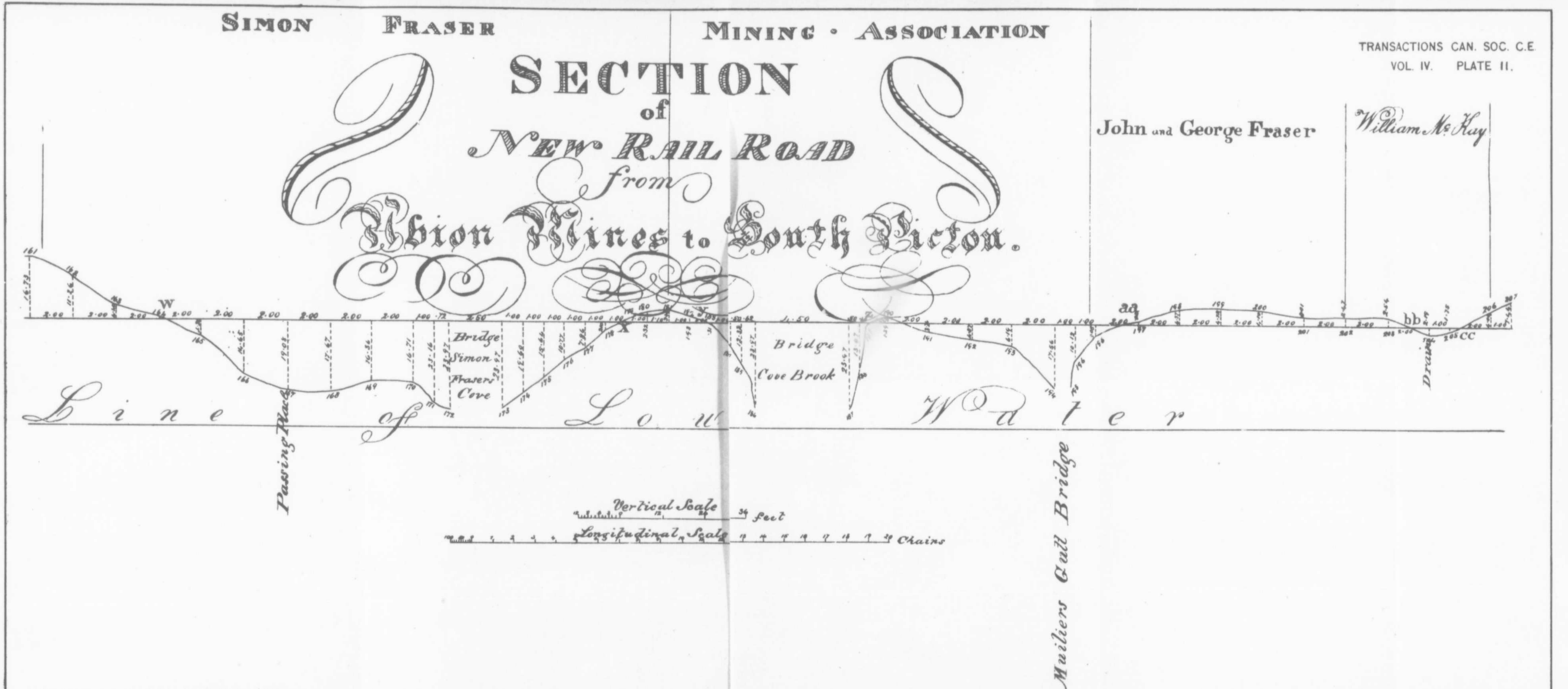
Page 342, line 8, *for* "Theodore Cooper," *read* "Charles Macdonald."

INDEX.

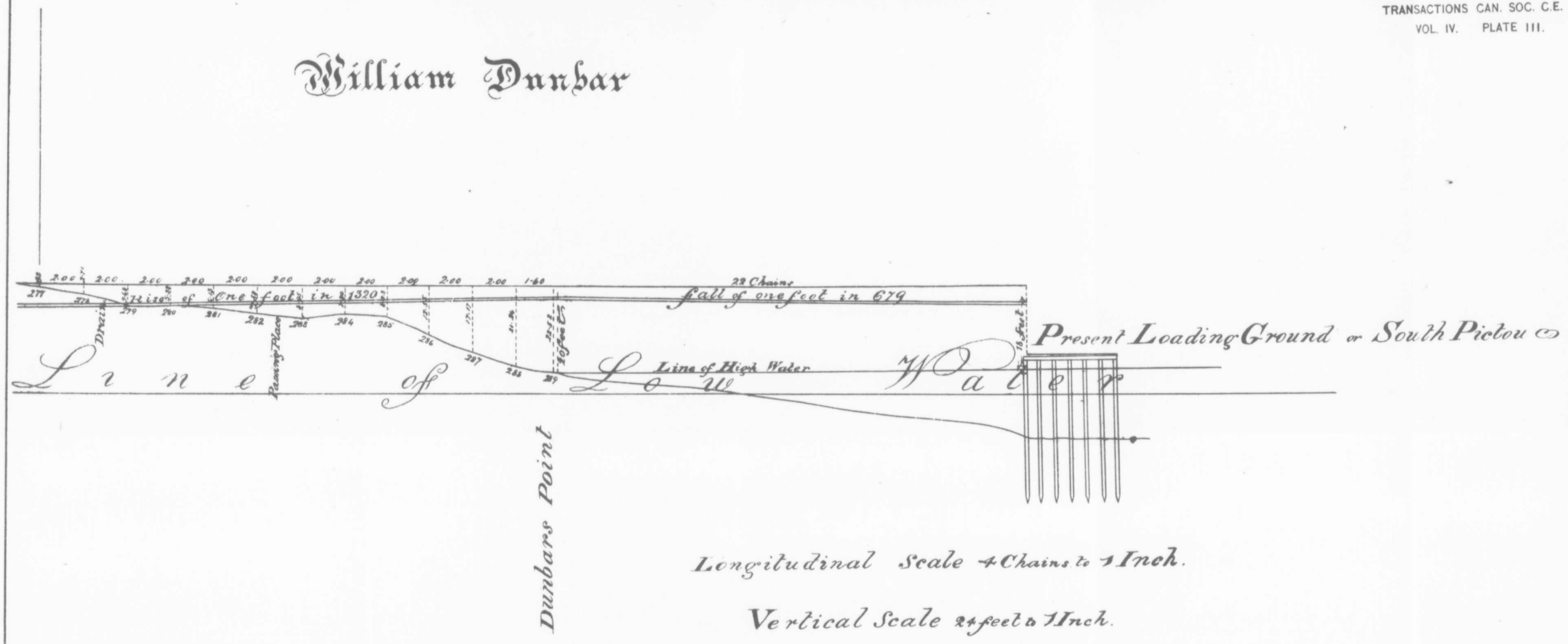
1890.—JANUARY TO DECEMBER.



(FAC-SIMILE OF ORIGINAL DRAWING, 1837.)



(FAC-SIMILE OF ORIGINAL DRAWING, 1837.)



(FAC-SIMILE OF ORIGINAL DRAWING, 1837.)

STAND-PIPES.

TRANSACTIONS CAN. SOC. C.E.
VOL. IV. PLATE IV.

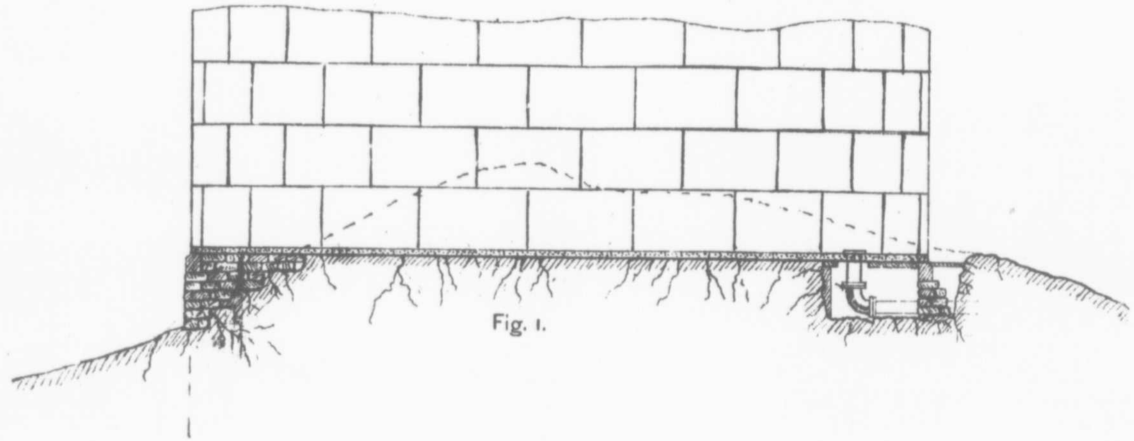


Fig. 1.

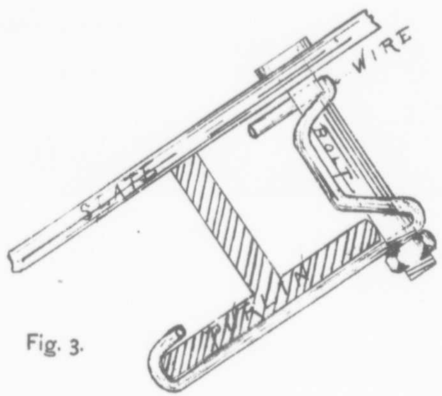


Fig. 3.

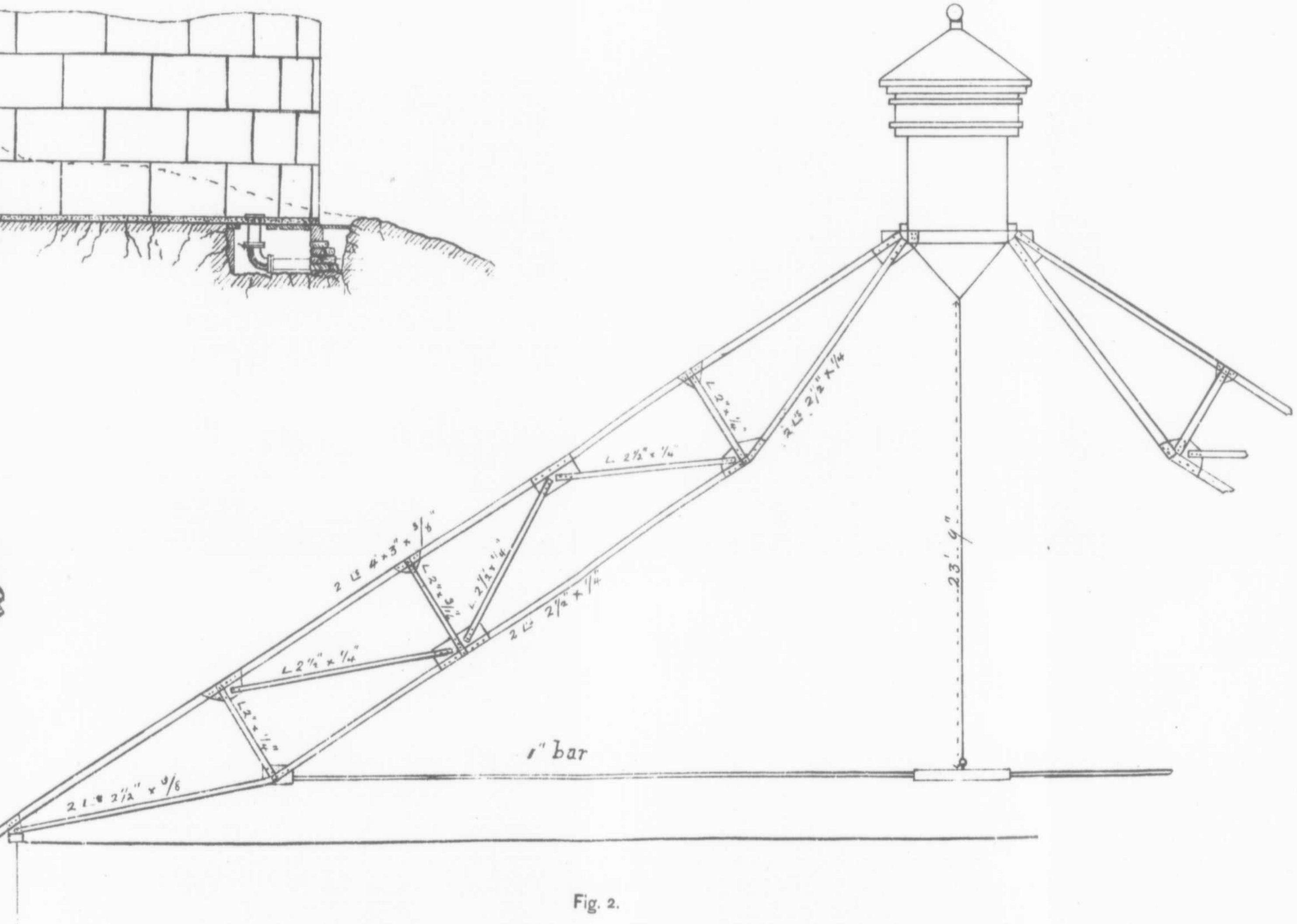


Fig. 2.

SCREENING OF SOFT COAL.

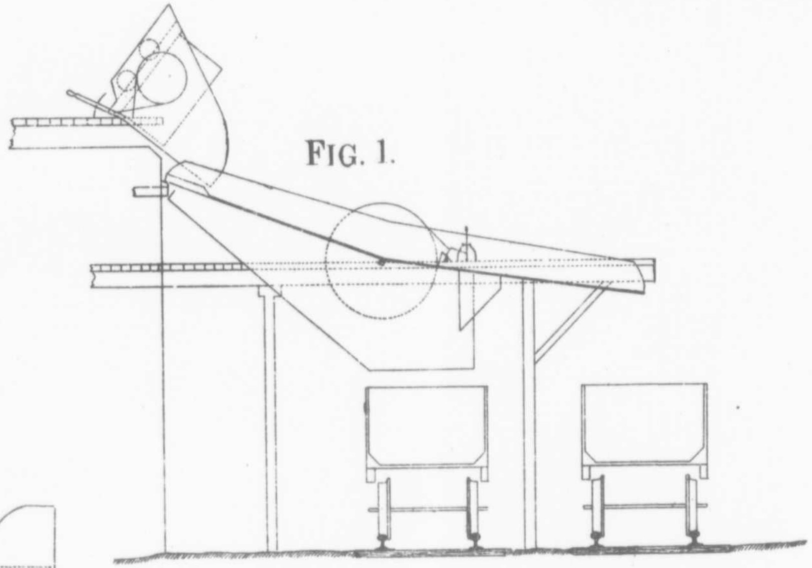


FIG. 1.

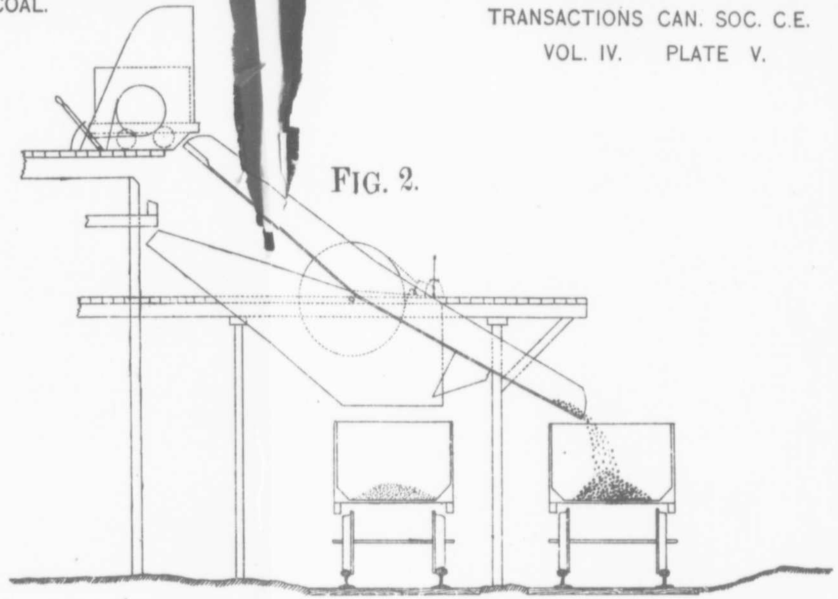


FIG. 2.

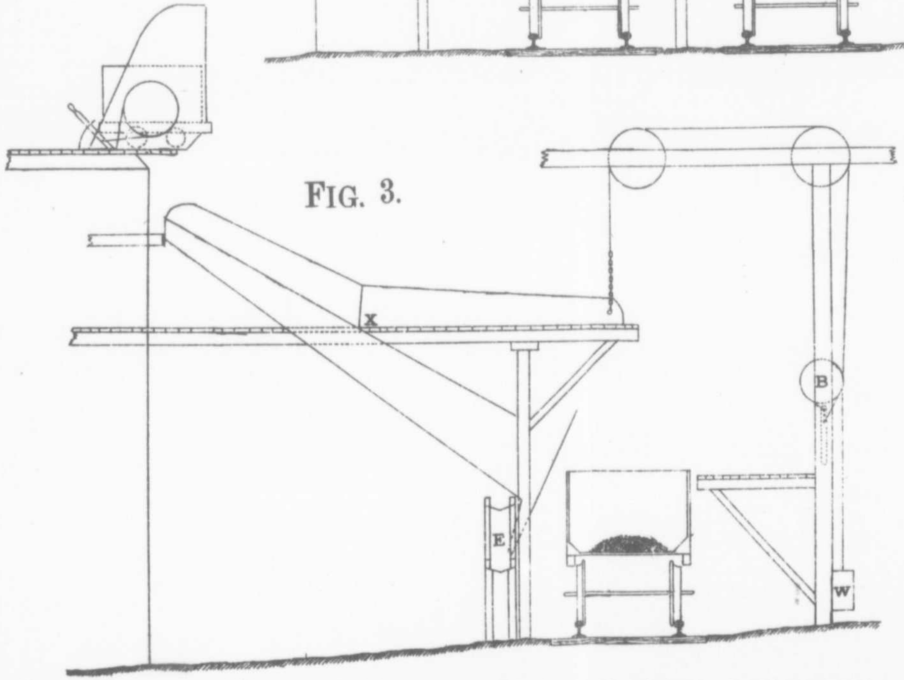


FIG. 3.

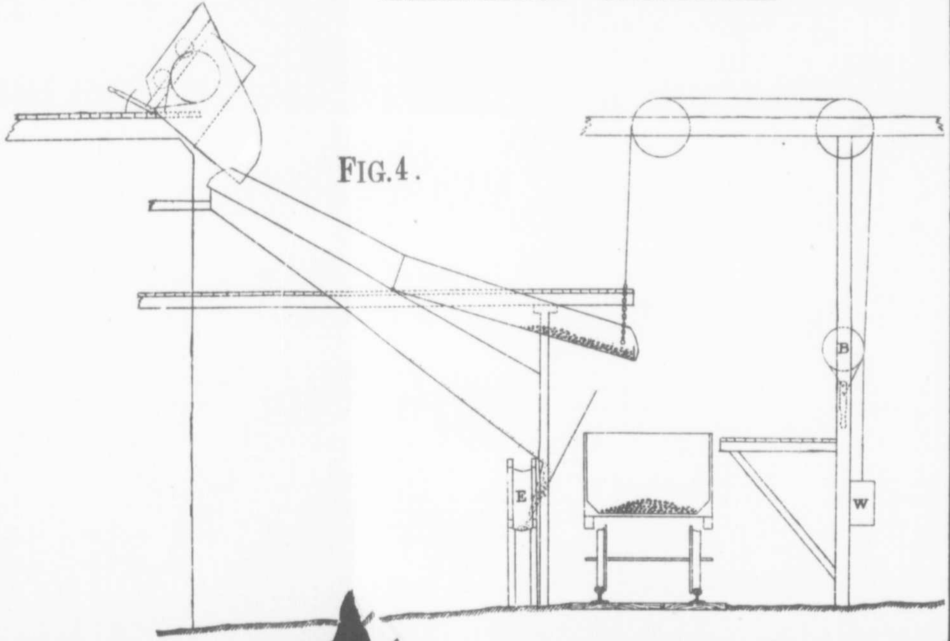
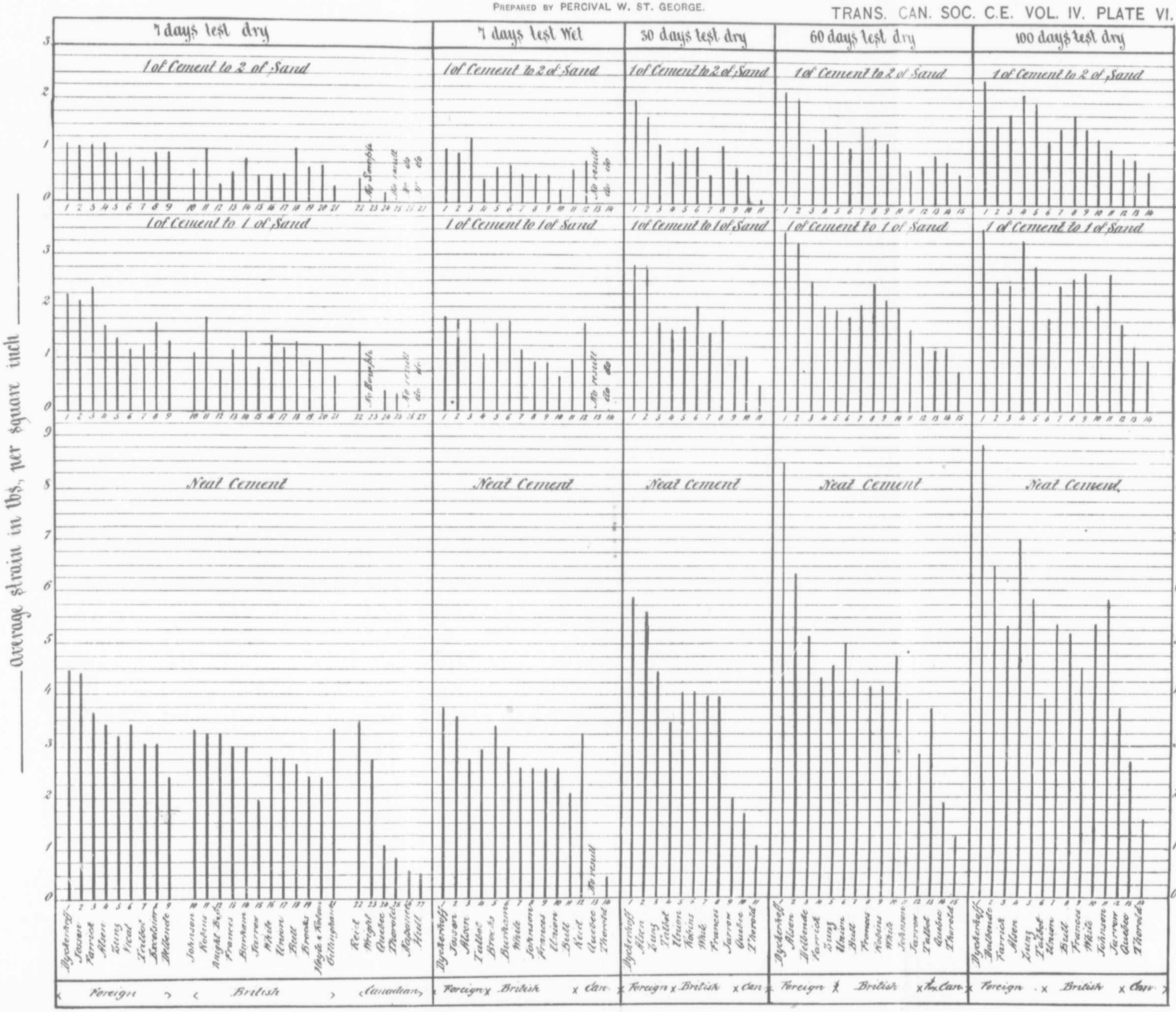


FIG. 4.

DIAGRAM SHOWING RESULTS OF TESTS MADE WITH VARIOUS CEMENTS, TO ACCOMPANY DISCUSSION ON MR. BUTLER'S PAPER ON NAPANEE CEMENT.

PREPARED BY PERCIVAL W. ST. GEORGE.

TRANS. CAN. SOC. C.E. VOL. IV. PLATE VI.



TRANSACTIONS CAN. SOC. C.E.
VOL IV. PLATE VII.

FIGURE 1.

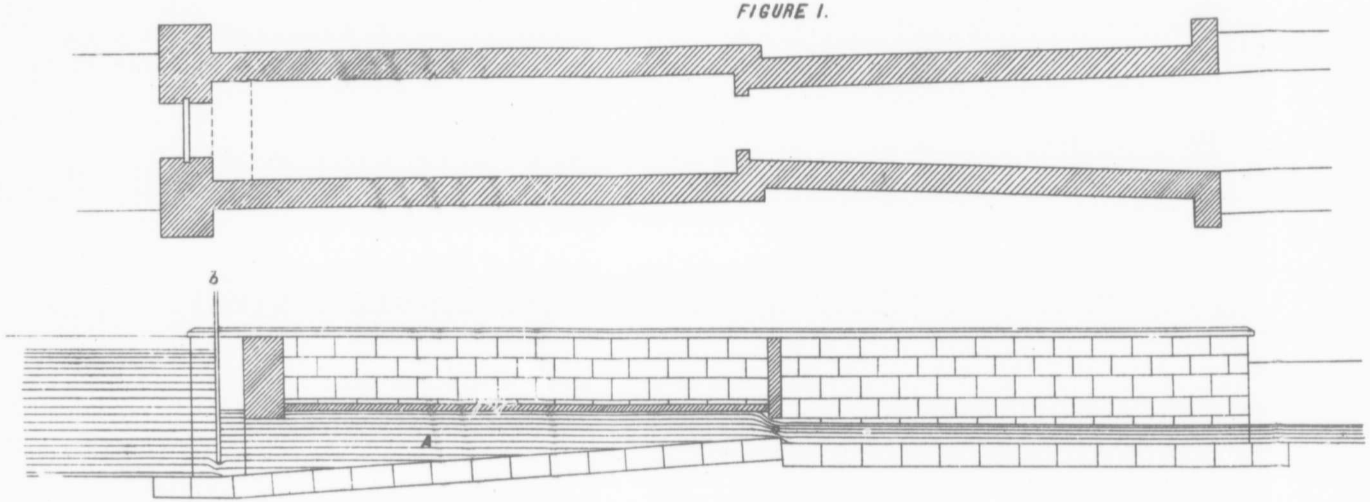


FIGURE 2.

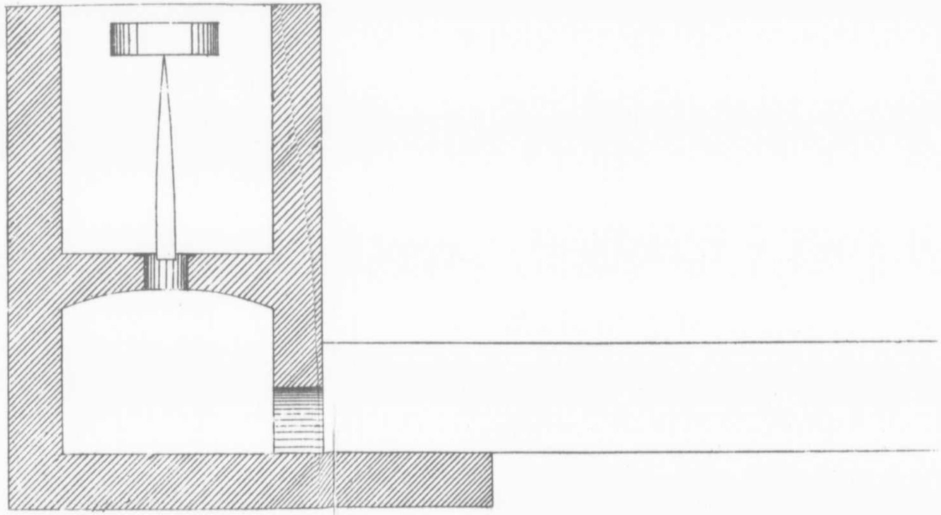
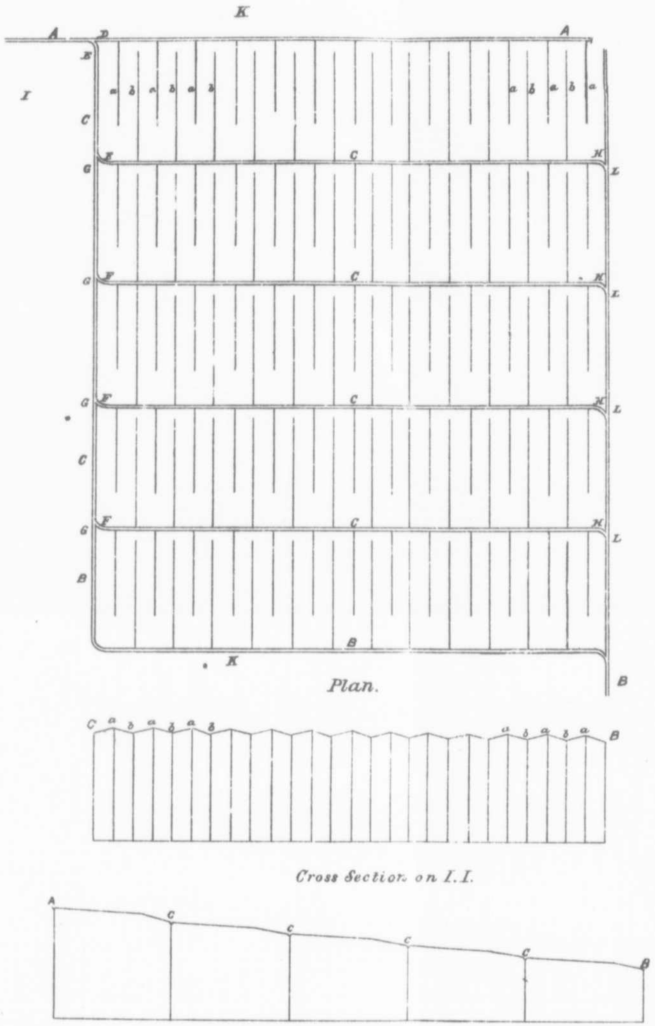


FIGURE 3.



Plan.

Cross Section on I.I.

Section on K.K.

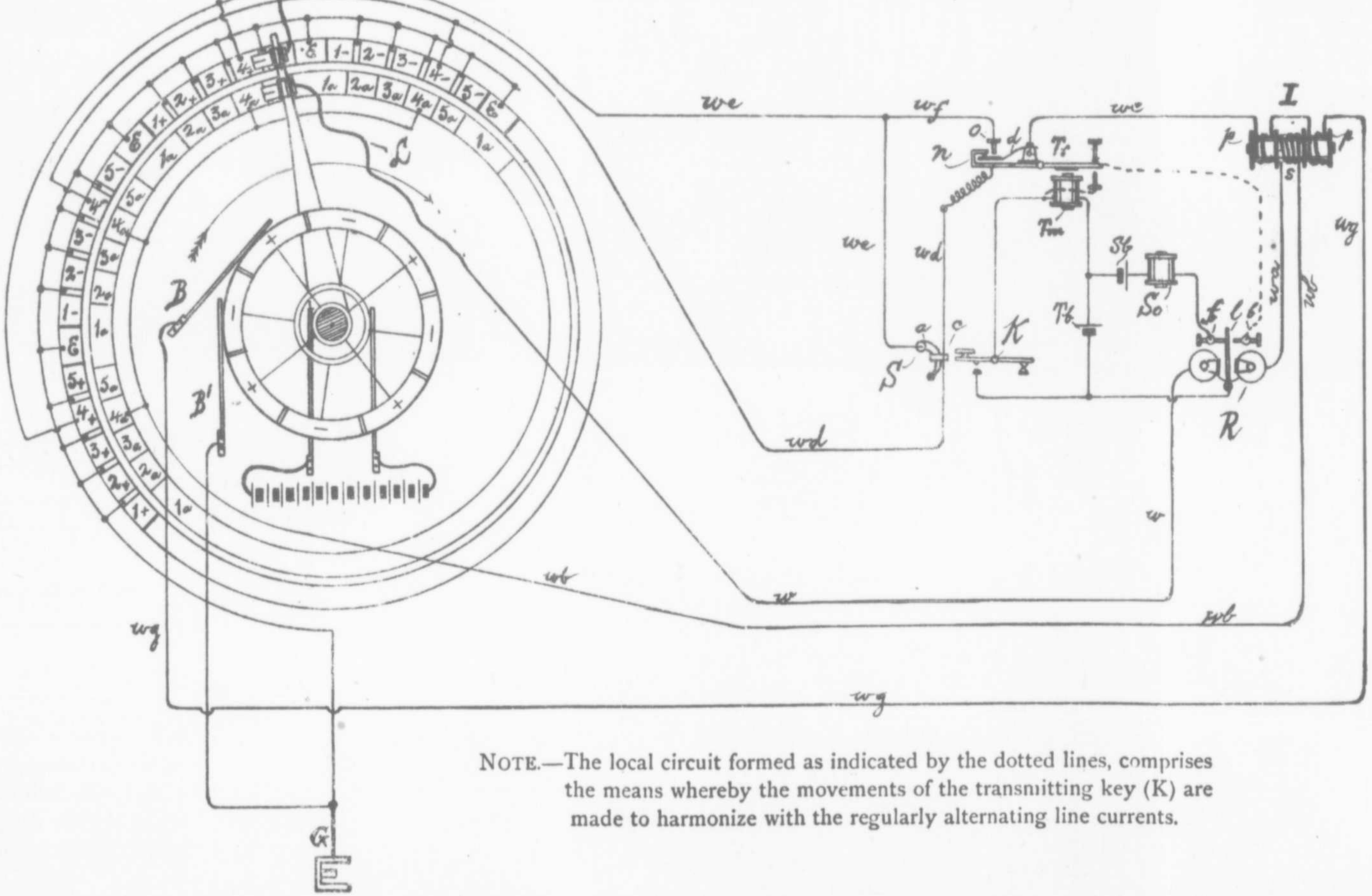
DEVELOPMENTS IN TELEGRAPHY,

TRANSACTIONS CAN. SOC. C.E.
VOL. IV. PLATE VIII.

BY D. H. KEELEY.

THE INTERCHANGEABLE WAY-WIRE MULTIPLEX.

PLAN OF TERMINAL, SHOWING CONNECTIONS FOR THE SIGNALLING CIRCUITS.



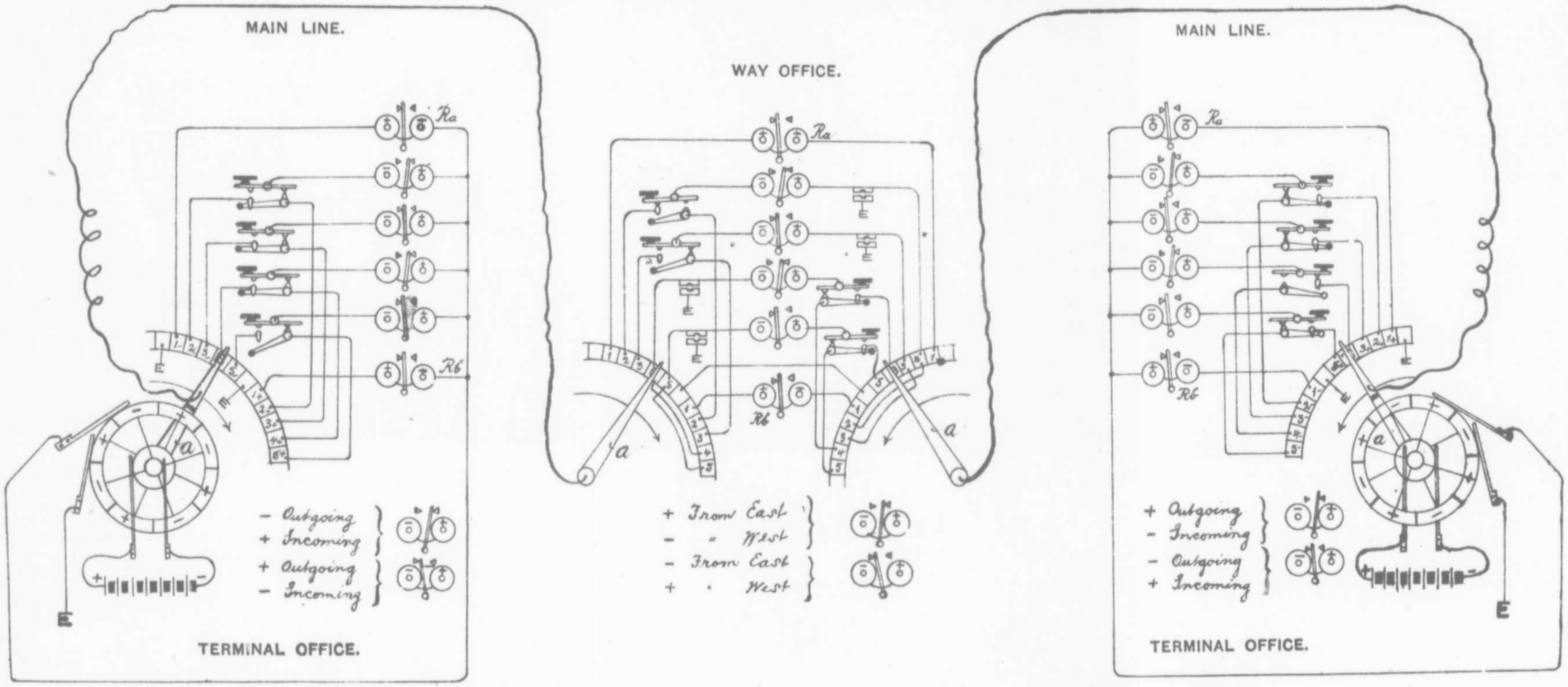
NOTE.—The local circuit formed as indicated by the dotted lines, comprises the means whereby the movements of the transmitting key (K) are made to harmonize with the regularly alternating line currents.

TRANSACTIONS CAN. SOC. C E.
VOL. IV. PLATE IX.

DEVELOPMENTS IN TELEGRAPHY,

BY D. H. KEELEY.

THE INTERCHANGEABLE WAY-WIRE MULTIPLEX SYSTEM.



PLAN OF CIRCUITS SHOWING METHOD OF OPERATION.

The local circuits, discharge plates, and the adjuncts of the polarized receivers, shown in the other print, are here omitted. The arms A, A, A, A, are revolved synchronously by motors governed by the receivers Ra, Rb, which are alternately actuated at every half revolution. The main line currents are presented at both ends concurrently; + at one end and — at the other, alternately. Normally, the receivers respond to the alternations. The keys, upraised and depressed, operate to interrupt the path of one phase or the other of the current in their respective circuits. The movements of a given key are therefore reproduced in all of the receivers included in its circuit.

CABLE RAILWAYS.