Issued, September, 1893.

TRANSACTIONS

OF

The Canadian Society of Civil Engineers.

VOL. VII., PART I.

JANUARY TO JUNE

1893.

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E. P. Hannaford

TMAN & SON, PHOTO.

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CONTENTS.

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 46 and 47.

CANADIAN SOCIETY OF CIVIL ENGINEERS.

LIST OF OFFICERS FOR THE YEARS 1888 TO 1893.

	1888.	1889.	1890.	1891.	1892.	1893.
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Secretary	H. T. Bovey.	H. T. Bovey.	H. T. Bovey.	H. T. Bovey. C. H. McLeod.	C. H. McLeod.	C. H. McLeod.
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Librarian	F. Chadwick.	F. Chadwick.	F. Chadwick.	F. Chadwick. Wm. McNab.	Wm. McNab.	Wm. McNab.

Friday, 6th January.

JOHN KENNEDY, President, in the Chair.

Paper No. 71.

DISCHARGE OF SEWERS.

By C. H. RUST, M.Can.Soc.C.E.

In connection with the proposed intercepting sewer along Front street, Toronto, for which plans have been prepared, it was considered advisable to gauge all the main sewers for the purpose of ascertaining the amount of sewage to be intercepted and carried away by the main trunk sewer along the front of the city.

Dams were constructed in the different sewers and a weir built by taking a one or two inch plank, and cutting a notch of the proper size varying from 1′ 2″ up to 4′ 0″ with a depth of water over them from 2″ up to 6″, care being taken to have the top of the weir, over which the water discharges, of a horizontal sharp corner in thin partition. The formula used is the one given by Mr. James B. Francis, compiled from the result of his observations at Lowell, Mass., and is as follows :—

$D=333\ (1-\frac{nh}{10})\ h^{3/2}$ Where D = discharge in cubic feet per second 1 = width of weir in feet, n = number of end contraction (= 2 in these gauging) h = head (measured at some distance back from weir). This formula gives results from 10 to 15 per cent. less than quoted by Mr. Baldwin Latham in his Sanitary Engineering. The gauging was carefully done by Mr. W. T. Ashbridge, an associate member of the Society. Observations were recorded every hour from 5 o'clock a.m. till midnight. It was found that the flow in the sewers between midnight and 5 o'clock a.m. varied so slightly that it was not considered of sufficient importance to take any record between these hours. The observations were carried on during the months of March, April and May, 1891; the dry weather flow only being recorded. From the results of the gaugings it has been ascertained that the total daily dry weather flow of the sewage of Toronto amounts to 2,150,901 cubic feet in the twenty-four hours. The average quantity of water pumped during this period was 2,400,000 cubic feet per day. The population from the last census returns being 181,220, this gives an average discharge of 11.87 cubic feet per head per day, the highest discharge being from the Bay

Street sewer, which gives 42.14 cubic feet per head per day. This sewer drains a district almost composed entirely of wholesale houses, nearly all of which use lifts. The lowest discharge is from the Simcoe Street sewer, which gives 7.02 cubic feet per head per day. This can be accounted for from the reason that this sewer drains the district embracing the Queen's Park and University, the old Upper Canada and Government House grounds. The total area drained by the sewers is 7,277 acres, this gives an average of 24.9 persons to the acre,—the maximum population is 45.7 per acre for the district drained by Spadina Avenue sewer. This is almost an entirely residential district, nearly every house being connected with the street sewer, the area being 311 acres with a population of 14,213 persons. And the minimum 8.8 for the area draining into Fort Rouille Streets where this sewer drains the extreme west end of the City, and at present is very sparsely populated, the area drained being 360 acres with a population of only 3,168 persons. The population for the different districts drained by the various sewers was taken from the census returns, giving the population for each Ward. This, the author thinks, will hardly be absolutely correct for the business districts, which during the day have a much larger population. This would apply more particularly to Bay street and Yonge street. The total amount of sewage discharged per minute is 1,493.4 cubic feet, which gives an average of ·205 cubic feet of sewage per acre, the highest being 1.29 for Bay street and the lowest .09 for Fort Rouille. It was found that one-half of the sewage flows off in an average of 10.37 hours, Bay street giving 7 hours and Yonge street 9 hours as the time discharging one-half. As before mentioned, a large number of wholesale places drain into these sewers in which a number of lifts are in constant use during business hours. Several sewers, amongst others the Garrison and Rosedale Creeks, give 11 hours as the time discharging one-half. These two sewers take the drainage of a large portion of the Township of York, outside the City limits, and consequently the flow is more regular. This is especially the case with the Rosedale Creek of which at least one-half of the flow is from outside the City limits. In some of the older sewers no doubt a certain amount of subsoil water finds its way, and being nearly constant in volume throughout the days tends to modify the hourly fluctuations.

In the diagrams attached to this paper, it will be seen by looking at Yonge and Bay streets, that in Yonge street the flow varied from 150 to 300 cubic feet per minute, and Bay street from 8 cubic up to 33 cubic feet per minute. It will be seen how, during business hours, that is from 8.30 a.m. until 5 p.m., the flow ascends very rapidly, owing, as stated before, to the number of lifts constantly employed. Again, taking Spadina avenue and Simcoe street, which drain a district almost entirely residential, Spadina avenue, the flow of which only varies from 100 to 140 cubic feet per minute, Simcoe street from 80 to 112 cubic feet per minute. From the result of these observations it will be seen that the hourly flow of sewage varies to a large extent throughout the twenty-four hours. In designing sewers this variation in the hourly flow has to be carefully considered. Especially is this the case where the sewage has to be treated by chemical means.

(See Plates I and II).

COMPARATIVE LENGTHS OF MAINS AND BRANCHES.

Sewer.	Length of main sewer in feet.	Total fall in feet.	Length of Br'ch. sewers in feet.	Ratio.
Garrison Creek....	11,600	90	333,000	1—2.9
Yonge Street......	9,460	121	68,500	1—7.2
Fort Rouille.... ..	6,900	33	40,700	1—6.0
Bay Street........	2,050	14	4,250	1—2.1
Sherbourne Street..	9,000	120	10,750	1—1 2
Berkeley Street....	2,280	19	4,800	1—2.1
Dufferin Street.....	6,600	57	38,000	1—6.0
Bathurst....	11,000	114	26,520	1—2.4
Church...........	9,130	128	25,500	1—2.8
Jarvis.........	9,200	124	25,500	1—2.8
Rosedale Creek....	11,200	109	63,720	1—5.7
Parliament.... ...	8,360	125	40,950	1—4 9
Cherry.....	7,265	89	36,700	1—5.0
Queen Street, E....	7,600	12	86,000	1—11.3
Spadina......	10,300	115	60,000	1—6.0
Simcoe....	10,300	111	64,000	1—6.2
Eastern Ave.... ..	2,130	5	4,500	1—2.1
			Average......	1—7

CORRESPONDENCE.

Mr. R. A. Davy. Mr. Davy said the interesting diagrams and paper would have been of still greater value if accompanied with information as to the length and inclination of the mains and the extent of their branches, and he trusted Mr. Rust will at some future day favor us with further and fuller information on this interesting subject. The method of taking the observations was simple, and would be expected to give accurate results if taken under ordinary conditions; but in the confined space and bad light obtainable in a sewer, very great care and patience must have been exercised to produce such results.

The quantity of water discharged seems abnormally small, being less than the quantity of water pumped by the city although receiving considerable volumes of water from other sources, and the season of the year when the observations were taken would not lead one to expect much loss from either evaporation or percolation. Is there anything to account for the quantity being so little?

Another strange feature is the fluctuation, or rather the want of it, in the flow during 24 hours. It has been usual to expect that half the flow will take place in 8 hours or less, whilst in Toronto it takes over 10½. Is this occasioned by the great length of the mains and their branches, or by the very large proportions of extraneous but constant flow of water into the sewers?

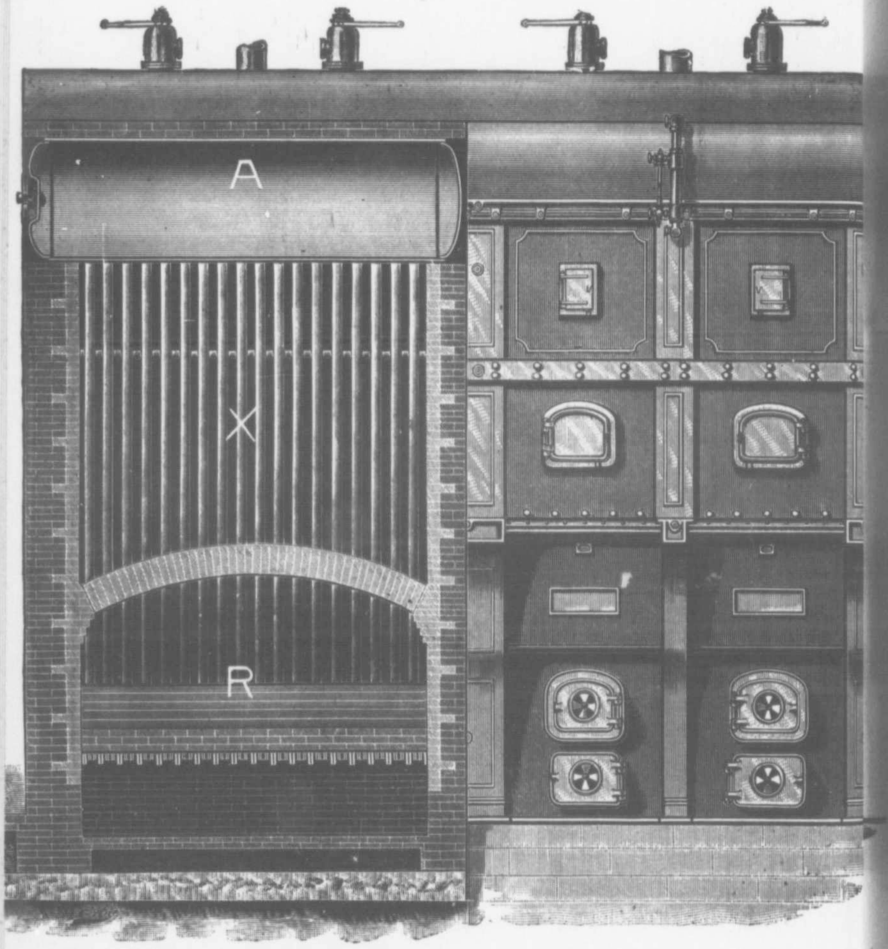
With such a large water supply, 82 gals. per head, one would naturally expect that a considerable quantity would be used for lifts and other manufacturing purposes, but the diagrams give little indication of such use; in fact, they seem to indicate a too steady flow during the 24 hours, which is usually associated with waste of water.

Mr. C. H. Rust. Mr. Rust, in reply to Mr. Davy, gave the table of lengths and inclinations of the mains and branches, as on page 23. There was no great difficulty in taking the observations. Of course the observer was very careful and the sewer was well lighted by means of lanterns.

The daily flow of sewage as compared with the water supply appears small, but the author is strongly of the opinion that the engines were not pumping the quantity as returned.

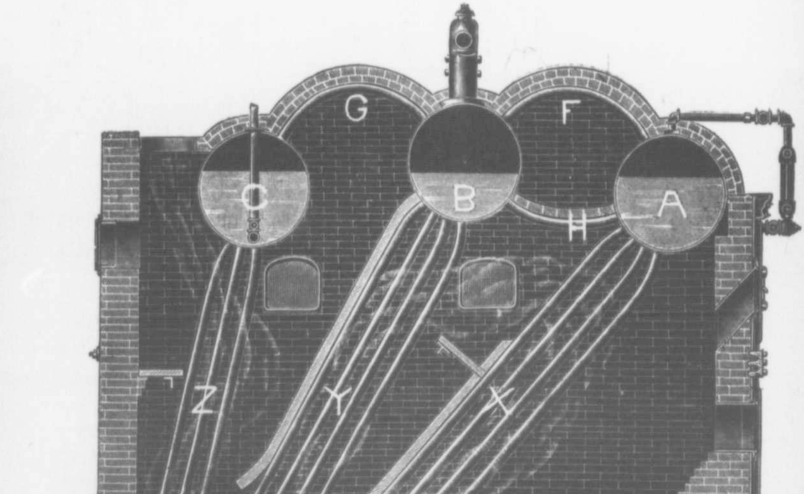
Referring to the want of fluctuation in the sewers: by looking at the flow in the Yonge and Bay St. and other sewers it will be seen that there is a considerable fluctuation, amounting in some cases to over 100 per cent. The want of it in the other sewer he thinks can be attributed to the constant flow of ground water, especially at the season of the year these gaugings were made.

STIRLING BOILER.



Transverse Section and Front View.

STIRLING BOILER.



Longitudinal Vertical Section.

Friday, 20th January.

JOHN KENNEDY, President, in the Chair.

Paper No. 72.

A NEW FORM OF STEAM BOILER.

BEING A DESCRIPTION OF THE STIRLING BOILER.

By R. F. OGILVY, Stud.Can.Soc.C.E.

Among the most generally adopted water tube boilers are found many of the essentials of an ideal boiler, but none of them can ever become universal so long as the present grounds for objection are retained by them. In the most common type exception is taken to the cast metal used in the construction, the difficulty of making inspection and repair and the extreme first cost. It is needless here to state the objections to the use of cast iron when in a state of strain and subject to a varying temperature.

In the numerous hand hole covers, the removal of which is necessary for inspection and repair, is found the point of construction which, in this type of boiler, receives probably the most adverse criticism, as they entail a great amount of labour and necessitate the skill of a practiced mechanic for their safe refitting. It is, however, only on account of very important advantages possessed by water tube boilers that they have attained the favourable position they now hold, and for a boiler which, being absolutely safe against dangerous explosion, will be equal in all points to the water tube boilers recognised as the best, and of which the design will eliminate the objectionable features enumerated above as possessed by water tube boilers, there may be expected a popularity as yet not extended to any boiler.

That the Stirling boiler possesses the essentials that may place it in that position there are good grounds to believe; and as in some respects it differs much from the generally known forms of boilers, a brief description of it will, it is thought, be of interest to the members of this Society.

The letters used refer to the parts so marked in the accompanying sketch.

The Stirling is a water tube boiler with tubes inclined but little *from the vertical.* In special cases the angle of inclination is sometimes greater.

The boiler consists of three upper or steam drums and one lower or mud-drum connected together by tubes, thus having three nests or banks of tubes, one connecting each upper drum to the mud drum. The whole is enclosed in brickwork, built square or oblong, according as the size of the boiler requires. The gases from the furnace R, which is in front of the mud-drum, pass in among the tubes of the first bank at their lower ends, and by means of firebrick partitions, are caused to traverse up among the tubes of this first bank, down among those of the second, and around the tubes of the last bank to the exit at the top of the boiler.

The water is fed into the back upper drum C and passes down through the tubes of the back bank Z to the mud-drum M, from which the tubes in the other two banks Y and X take the supply of water required to replace that which has been generated into steam.

The upper middle drum B is joined to the back drum C by a row of tubes G connecting the steam spaces, and to the front drum A by two rows of tubes, one F connecting the steam spaces, the other H the water spaces.

From the centre of the middle drum B the steam is drawn from the boiler.

The centre drum is a few inches higher than the first drum, and the water level is kept at half the vertical distance between their centres.

With this general description we shall be enabled to study intelligently the action of the water, steam, and furnace gases in the boiler.

The water fed into the back upper drum C is heated during its passage to the mud-drum M. If any steam is made in these tubes, its quantity must indeed be small; however, the water must be heated to a temperature almost if not quite equal to that which the steam pressure requires. It can therefore now hold only in suspension the impurities in solution in it when fed into the boiler, and these, if the water be allowed to remain undisturbed, will settle out. This is the condition of affairs which takes place. The water from the back bank of tubes is discharged into the large body of water in the mud-drum, the heavier materials fall to the bottom, while the hot pure water remains at the top until it is drawn into the tubes of the front and middle banks.

From the bottom of the mud-drum the impurities are blown off from time to time as frequently as the circumstances of the case require. In this way we have the tubes in which the steam is generated supplied with water free from sediment.

The greater quantity of steam will be produced in the tubes of the front bank, as they are the first to receive the products of combustion from the furnace, and on this account some contend that a current of water and steam must traverse these tubes very rapidly, and the overflow from the front to the middle upper drum through the row H of tubes connecting the two must be relatively great. But experiments on the generation of steam in inclined tubes go far to prove otherwise. As these tubes are inclined, the steam separates from the water and finds a passage for itself along the upper side of the tube to its outlet at the top; and as each steam bubble leaves the face of the tube, the surrounding water takes its place against the heating surface. It is difficult to understand in a tube in this position properly proportioned—that is, with an area not too small for the amount of heating surface—how there can be any *violent* circulation of the water.

The steam thus made passes through the water to the steam space above. Each tube is its own outlet, and there is abundance of disengaging surface, and, with this, and remembering that pure water will not foam, is explained why the steam produced is dry. The steam from the first drum passes to the middle drum through a row F of tubes for that purpose.

Reference has already been made to the furnace. At a glance it is seen that ample room is provided for a large fire-place, and convenient opportunity afforded to make it any size desired. For the proper utilization of its products of combustion, the space above the grate must be of sufficient size to permit of thorough intermixture of air with the fuel gas, a condition which in many boiler furnace designs is overlooked. Also, if any cooling surface is brought into contact with the fire the temperature of the furnace is thereby limited. In this boiler the furnace is surrounded with firebrick. The sides and arch on top of the fire-place are gradually heated until the bricks are in a state of incandescence; the fuel readily burns, and with the fire properly handled the gases are thoroughly ignited before being carried against the tubes through which the heat is conveyed to the water; the fuel is burned to economical advantage and little smoke is produced. Soot cannot collect on the tubes on account of their steep inclination, and the products of combustion act on a thin heating surface comparatively clean without and within. On their passage through the boiler the gases are made to intermix several times, and, at the last, are brought into contact with tubes containing the feed water, so that the products of combustion leave the boiler with a minimum temperature.

When it is desired to make an inspection, this form of boiler admits of thorough examination with little labour. There are no braces, and by the removal of four manhole covers, access is given to the interior of the four drums where each tube may be inspected. For the examination of the exterior surfaces of the tubes the open spaces between the banks may be entered through openings in the brickwork provided for this purpose. On account of these provisions, repairs, though rarely required, are readily effected, and where materials for repair are not at hand, any tube may be cut out from working by both ends being plugged, and the boiler continued in operation.

Save the manhole joints there are no made joints to get slack and cause leakage, and as the manhole covers are so fitted that the steam pressure holds them in their places, it is a simple matter to so adjust them that they will remain tight.

The tubes are expanded independent of each other into the tube sheets of the drums, and leakage or other damage through difference in expansion and contraction in them is guarded against by each tube being more or less bent. As the tubes are put into place on the ground where the boiler is to be operated, the plant is conveniently transported, one of the drums being the largest single piece.

For these reasons the Stirling boiler has proved an easily transported steam generator, capable of carrying a high steam pressure, and which, using impure water and poor fuel, can be operated economically with absolute safety without requiring a skilled mechanic to keep it in working order.

From actual results obtained, the writer believes that this form of steam generator or a modification thereof is destined to be more extensively used than any other form of boiler.

Before closing this paper, the writer would like to state that the Field-Stirling Boiler with which some here may be familiar is neither identical with nor similar to the Stirling, as the most cursory glance at the two designs will show, although each is the invention of the same engineer.

DISCUSSION.

Mr. Torrance asked what independent scientific tests of the efficiency of this boiler had been made? **Mr. Torrance.**

Mr. Ogilvy replied that all independent tests of which he had any knowledge were simply tests for coal consumption and water evaporation, and were not in any sense complete scientific tests. **Mr. Ogilvy.**

Mr. Torrance.—What means are employed to prevent the deposition of soot, etc., around or among the front tubes, or to remove it after it has accumulated? Experience with a boiler of this type in this city clearly establishes that this is the weakest point in the design of this boiler and its setting. The speaker said, he was convinced that this is the most satisfactory water-tube boiler yet invented. The circulation is well defined. All parts are readily inspected. Its design is unusually compact. It surpasses all others with regard to portability, and all danger of disastrous explosion is avoided. **Mr. Torrance.**

Mr. Ogilvy replied that soot cannot collect on the front tubes, that is the nearest the fire, as all soot there is burned by the gases from the fire. Soot may adhere to a limited extent to the surfaces of the back tubes and those of the middle bank, but any accumulation is prevented by the steep inclination of the tubes. The adhering soot is blown off as circumstances require by a steam jet from apparatus supplied for this purpose. Soot which has collected at the back of the mud-drum is removed through openings in the brickwork provided for the purpose at the back of the boiler. **Mr. Ogilvy.**

The boiler referred to was one of the first boilers of this type to be built, and the trouble was occasioned through the neglect to clean away the soot collected at the bottom. In that particular case the accumulation of soot was very great on account of insufficient draught and poor fuel, and the provision for removing this soot entailed considerable labour and inconvenience.

The boiler referred to has two upper drums only. All Stirling boilers are now built as described with three upper drums.

Mr. Walbank asked—How does this boiler compare with the Babcock & Wilcox in regard to efficiency, cost, etc.? **Mr. Walbank.**

Mr. Ogilvy replied that he had no knowledge of comparative tests having been made with this boiler and any other. He said they would probably first get these from the World's Fair authorities in Chicago, as he understood tests were to be made of all boilers supplied **Mr. Ogilvy.**

to the World's Fair Company. He believed the Babcock & Wilcox Company get better prices for their boiler than is paid for any other water tube boiler on the market. He did not know exactly what the difference in price of Babcock & Wilcox and Stirling boilers would be.

Mr. Walbank. Mr. Walbank asked—Are any of these boilers in use in this city?

Mr. Ogilvy. Mr. Ogilvy replied—There are no boilers as described in use in this city. The only ones in Canada are the property of the Acadia Coal Company, limited, of Stellarton, Nova Scotia.

Mr. Walbank. Mr. Walbank asked—What is the difference between the cost of this boiler and the ordinary Horizontal Return Tubular Boiler?

Mr. Ogilvy. Mr. Ogilvy replied—As both are rated, and for ordinary pressures, the ordinary horizontal boiler costs from twenty to thirty per cent. less than the Stirling boiler. However, it must be borne in mind that all Stirling boilers are built strong enough to run at 150 lbs. steam pressure if desired.

Mr. Walbank. Mr. Walbank—Is this boiler easily repaired? Suppose one of these tubes got out of order, could it be easily repaired?

Mr. Ogilvy. Mr. Ogilvy—If a tube should for any reason require to be removed and another put in its place, the exchange is easily effected. Both ends of the damaged tube are cut and the tube loosened from the inside of the drums into which the ends of the tube are fastened. The tube is then lowered free of the upper hole into which it has been expanded, and the upper end guided clear of the upper drums. The tube is then drawn from the lower hole and taken out from the top of the boiler. If the injured tube be in the middle of a bank the same operation has to be gone through with one, or at most two, other tubes, in order to be able to get at the injured tube. "At most two other tubes" as a tube is removed from the bank only towards the front or back of the boiler, never towards the side. The new tubes to replace those removed are put in position similarly, but with the operations reversed.

Mr. Ogilvy in conclusion said there is to be a good exhibit of water tube boilers at the Exposition in Chicago, there being about 17,000 H. P. of water tube boilers used by the World's Fair Company. Seven different designs are represented, each set of boilers is equipped with separate feed water and fuel supply, so that the water evaporated and fuel consumed in each case can be ascertained at all times. Undoubtedly arrangements will be made for testing the quality of the steam and accurate scientific tests provided for. Of the boiler power required, the Stirling Company is to furnish sixteen hundred horse power.

Friday, 3rd February.

JOHN KENNEDY, President, in the Chair.

Paper No. 73.

NOTES ON GOLD AND SILVER MINING IN THE PROVINCE OF QUEBEC.

By JOHN FRASER TORRANCE, B.A., M.Can.Soc.C.E., and M.Am.Inst.M.E.

It is too much the fashion with our local capitalists to seek for profitable mining investments as far as possible from home in British Columbia, Colorado, the Black Hills or even in Mexico, while totally ignoring the vast wealth of precious metals lying neglected at their very doors. Perhaps a brief résumé of some of the well-established facts about these resources might prove of service to counteract this tendency.

Quite recently a very valuable report on this subject drawn up by Dr. R. W. Ells, LL.D., etc., was published in Vol. IV of the New Series of Reports by the Geological Survey of Canada. It is a matter much to be regretted that the general public rarely consult these volumes. No doubt this arises in part from a vague impression that such reports must necessarily be too technical for any but trained geologists to comprehend, but specially from the size and absurd price of the volumes and all lack of public advertising of their contents.

In this paper it is proposed to use freely the facts so carefully collected by Dr. Ells and the other officers of the Survey, in the hope that they may thus reach some readers not familiar with the publications of the Geological Survey. Some notes of personal observations and experiences in this mining region are added by the author.

His faith in the mineral resources of our central provinces was well grounded by Principal Dawson. It was strengthened and confirmed by the lectures of the famous geologist, Von Cotta, at the Saxon School of Mines. He pointed out very clearly that the forces to whose influence we trace the formation of ore-deposits have been operating ever since the earliest geologic ages. And he drew the logical conclusion that (other things being equal) the oldest geological formations should be the richest in valuable mineral deposits, because they have been subject to the action of those forces so very much longer than more modern formations.

As these palæozoic rocks are more widely distributed in this province and Ontario than in almost any other country, we might feel reasonably certain of the existence of many rich deposits of the precious metals and other minerals of economic value—even before such deposits were actually opened.

Comparatively little prospecting for minerals was carried on in Quebec until quite recently. But the successful development of our phosphate mines and the more recent exploitation of our valuable asbestos deposits may lead us to hope that brighter days are at hand for our gold and silver mines also.

The first published report of the existence of alluvial (or placer) gold on the Gilbert River in Beauce Co. appeared as far back as 1835—sixteen years before the first samples of gold dust and nuggets from Australia created such a profound sensation in Great Britain. It has always been a puzzle why the nuggets and dust from Beauce Co. and Ditton never produced any similar effect.

Although Dr. T. Sterry Hunt published the results of an assay of the quartz from a vein in the Devil's Rapid on the Chaudière River as far back as 1851, and thus established the existence of gold in the veins of that region, and other observers noted the striking lithological resemblance between the formations on the Gilbert River and in Ditton, etc., to the auriferous belt in Nova Scotia, yet many geologists clung for a long time to the delusion that the placer gold of the district had its source in some hidden veins among the Notre Dame range of hills far to the North-East, and had been transported thence by glacial action. The first map of the Geological Survey that assigned these auriferous rocks to the same geological horizon as the similar deposits in Nova Scotia and Wales was not published until about five years ago (dated 1886). It covers only a portion of the gold field.

On referring to this South-East sheet of the geological map of the Eastern Townships, we notice that the area within its limits assigned to the Cambrian rocks is about one thousand square miles. We may safely assume that the N. E. Quarter Sheet will show about as much more. This leads me to estimate the gold area at 2,000 sq. miles. One of the richest belts lies close along the frontier, which it crosses from the sources of the Indian Stream in New Hampshire into Ditton and passes north-eastwards close to the flank of Big Megantic Mountain across Lake Megantic, and embraces the head-waters of the Samson and DuLoup. This belt re-crosses the United States boundary in the vicinity of the Penobscot Lakes and about the head of Sandy Stream.

Let me here note some of the chief facts already established about the occurrence of gold and silver in this belt. We have the authority of Professor Hitchcock for the report that placer gold has been found upon the head-waters of Indian Stream in the State of New Hampshire. He says:—"The points examined were on and near Indian Stream about 3½ miles from the boundary. The stream here is quite rapid, and on either side the hills rise 300 to 400 feet above its bed, while every few rods, either from the East or the West, it receives a tributary. The rocks here, as elsewhere on Indian Stream, consist of argillaceous schists. These are often so wrinkled and corrugated that it is difficult to determine the dip, while elsewhere, especially where the rock is of a coarser texture, the flexures and contortions are not seen. In every respect the rocks are similar to those of Ditton. Immediately on Indian Stream the gold is chiefly found in the fissures of the schist, which is here so fragile that it is easily broken up by picks. A quarter of a mile from the stream we found the characteristic drift of this section. It consists of a bluish clayey gravel. and contains boulders of schistose rocks, and it has a depth, where we excavated, of three to four feet. The gold seems to be distributed through the entire mass, although it is nowhere very abundant. The streams are rapid, and the descent of the bed rock is sufficient to carry away the loosened sand, if the hydraulic process is used."

The distance from the boundary to the Pope property in Little Ditton is not more than four miles. But we find the surface conditions here quite different to those described by Prof. Hitchcock, although the rock formations are the same. Here we find the country almost level and the surface from six to fifteen feet in depth. There is no chance of finding any suitable dumping ground for the tailings, even if a sufficient head of water could be obtained for hydraulicing. There is no question of the productive value of the alluvial deposits on this stream, although no official returns have ever been made of the gold obtained. It seems that the grant to the Hon. John Henry Pope was issued in such shape as to exempt him from the necessity of making returns. At any rate the returns were not made. But it seems probable that the total value of gold extracted there has exceeded $100,000. On the death of Mr. Pope this gold property, embracing 4750 acres, passed into the hands of his daughter, Mrs. Ives, who leased it last spring to some Toronto people. Shortly after they took possession, the author visited the place, and on his return to Cookshire searched the title and found that they had paid $5000 for one year's lease of this property, being lots 52 to 61 (inclusive) in Range 7, lots 39 to 44 (inclusive) and lot 62 in Range 8, with lots 34 to 53 (inclusive) in Range 9, and the South half of lot 14 in Range 10, with lot 8, part of lot 13 and the whole of lot 14 in Range 11—Ditton.

There is no doubt that much gold has been extracted from these lots by very primitive methods of washing. Most of the gold sold was very coarse. The natural inference is that the inexperienced workers left fully as much gold in their tailings as they secured. Dr. Ells reports that the coarsest and most abundant gold was always found immediately below where quartz veins crossed the stream. But nobody seems to have tested any of these reefs as yet.

The author is thus particular in giving the numbers of the lots included in this Pope location and their total area, because Dr. Ells has stated that " the Ditton area is inaccessible to the general miner and explorer." But his own map shows that the area of Cambrian rocks between Big Megantic Mountain and Chesham village on the north-east and the boundary on the south-west is fully 450 square miles, whereof the Pope property covers less than 7½ square miles.

The easiest way to reach this region is by Canadian Pacific Railway to Scotstown. On this flying trip a number of places were noticed that looked well worth prospecting. It seems certain that the Pope location does not include all of the best placer diggings or all the rich veins in that district. But a great obstacle in the way of prospecting any of the numerous quartz veins is the absence of any quartz mill in this province where working tests could be made. There are no available mills for this purpose nearer at hand than Nova Scotia.

Between Little Ditton and Lake Megantic no search for gold has ever been recorded, although the experience of the quartz miners in Australia would lead us to expect to find the richest veins in the immediate vicinity of large masses of intrusive granite such as the Big Megantic Mountain. A few miles after crossing Lake Megantic this same belt reaches the Samson stream, a rapid tributary of the Chaudière.

In a hurried *reconnaissance* through this belt in the summer of 1891 the author noticed a number of very promising-looking quartz veins traversing the black corrugated pyritiferous slates crossing the road near this stream. The owner of the saw-mill stated that specimens containing visible specks of gold had been repeatedly broken out of the quartz at his dam. But he had never sent any for assay. The author is not aware of any attempts to prospect this stream for placer deposits. But it would be a very promising field for a party of skilled miners to explore.

The distance through the woods from the Samson to the Armstrong property on the Du Loup is only four or five miles. The same belt of rocks extends all the way. This property covers 750 acres on the left bank of the Du Loup. The main prospecting pits have been sunk on the brow of a hill about 400 ft. above the stream and half a mile back from it. In what was called the Main Shaft a vein of quartz averaging 11″ in breadth has been tested to a depth of 36 feet. It contains a good deal of blende with high-grade leaching ores of silver. There is very little galena to be seen. Our assays averaged about 30 ozs. silver with traces of gold.

Two other parallel veins were opened close by, one to the N. W. and the other to the S.E. Some of the assays ran high in silver. One piece from the "North" vein assayed by Rev. Mr. Pagé of Laval yielded 430 ozs. per ton. But none of our other assays approached anywhere near this. The course of these veins is N. 60° E. mag. The "South" vein is vertical and the "Main" vein dips towards it at an angle of 75°. If these attitudes were maintained in depth they would soon come together and form quite a bonanza.

About a mile from these pits to the S.W. a series of silver-bearing veins was uncovered and followed for 1000 ft. along their course. The two largest and most persistent veins are the outside ones of the series. The Armstrong vein averages 14″ in width and assays high in silver with ½ oz. in gold. Its strike is S. 40° E. mag., dipping S. 50° W. 45°. At a distance of 173 ft. to the S. W. there is a vein of similar size called the "New Discovery." Between them lie the "Senator" and "Big Indian." An assay from the Senator gave 260 ozs. per ton. These veins all carry more galena than the veins previously mentioned. By concentration they would yield a very valuable smelting ore.

The author's report on this property strongly recommended its purchase at a moderate price and its equipment with a first-class modern concentrating plant. But it was impossible to get his employers to act before their bond expired.

It is a fact worth noting that both belts of veins are accompanied by heavy dykes of diorite and olivine, running parallel to them. Probably the same causes that led to their formation contributed largely to the origin and mineralisation of these veins. The presence of similar dykes elsewhere in the Cambrian formations should encourage prospectors to look for valuable veins of gold and silver in their vicinity. Such clues are often of very great service.

The ground along the Du Loup and its branches in this locality was all surveyed and laid off in so called mining blocks of about half an acre each many years ago, and eagerly bought up by speculators who never had any intention of spending their own money in its development. The author believes that some gold has been found in the beds of these streams. But absentee proprietorship has been the curse of this whole region. Prospectors will not waste time and trouble in hunting for gold that legally belongs to others. Nearly all the tributaries of the Chaudière and Du Loup have been surveyed in the same way, and the mining blocks sold for a trifle to friends of the government of the hour. The results of such queer methods of encouraging the arduous search for gold might easily have been foretold. The banks of all these streams have remained an untrodden wilderness, although our geologists all agree that immense wealth of virgin gold lies hid in the prehistoric channels of most of these streams.

If we pause to contrast this lonely region with the rich and busy cities of the mining regions of Australia and California, we see how closely suitable mining laws or the reverse are connected with the growth or stagnation of large territories.

The author has mentioned the presence of gold in the "Armstrong" vein. Two years ago he shipped some barrels of quartz to a Nova Scotian mill from a vein near the Kennebec Road quite close to the boundary of Maine. The milling test yielded $4.07 per ton, which is considerably above the average yield of the quartz at the famous Homestake Mine in the Black Hills. As this vein is fully 6 ft. wide and has been traced for 1¼ miles, it is well worth some attention.

On the Maine side of the boundary, gold and black sand have been found on Sandy stream. The usual stories are told of mysterious hunters who always had plenty of money although they never would work. An intelligent lumberman working limits on the head waters of the Penobscot told me that he had noticed much black sand in the streams and numerous quartz veins in the banks, but he never attempted any prospecting, not knowing how. The States of Maine and New Hampshire have one immense advantage over Quebec in the eyes of gold hunters. Mining laws are unknown there. The man that owns the soil owns everything under it. After coming to an understanding with the owner, there is no danger of interference with your freedom by anybody else.

The second belt of Cambrian rocks shown on this geological quarter sheet appears on the W. Shore of Lake Massawippi and to the Eas of Little Magog L. and along the valley of the Magog River.

It has been traced through Stoke and Dudswell, etc., to Lake Aylmer and across Lake St. Francis into the county of Beauce. Its course is almost due north-east to the De Lery Seigniory, with the village of St. Francis in its centre. From Dr. Ells' report we learn that several mining companies have done some work in the south-western part of this belt. The Golconda Mining Co. and the Ascot Gold Mining Co. report that they found good workings on lot 11 of Range 11, Ascot, and on lots 2 and 3 of Range 13. The surface was about six feet deep, exhibiting the same sequence of stratified gravel and clay as on the Gilbert; but apparently they did not strike any old channel of the Magog. Dr. Ells does not state the reasons for the winding-up of these companies.

Apparently the ground between Lakes Aylmer and St. Francis has never been tested. It is not until we enter the De Lery Seigniory from this side that we learn of discoveries of gold once more. Very little prospecting has been done on the south side of the Chaudière in this Seigniory compared to the great amount of work accomplished on the Gilbert, Des Plantes and other streams on the north side. But enough gold has been obtained on the Mill stream and elsewhere behind the village of St. Francis to give us a high opinion of the value of this half of the Seigniory. Numerous large quartz veins are exposed in the banks of the streams and elsewhere. Inducements should be offered to enterprising prospectors to test some of these veins properly, and to hunt for rich alluvial deposits in their immediate vicinity.

Crossing the Chaudière we come to the famous Gilbert River, where fully three-fifths of all the gold mining in this province has been carried on. Gold was first discovered here by a French-Canadian woman about 60 years ago, but nobody seemed to trouble themselves looking for more until another woman ten years later found a nugget of 1,056 grains close to the same spot.

In 1846 the seignior, Mr. De Lery, was fortunate enough to obtain from the Crown a perpetual grant of all the gold and silver mines within his seigniory, on condition of paying a royalty of ten per cent. upon all the precious metals obtained by smelting in furnaces. As no gold is ever extracted in this way from any such deposits, this proviso for royalty is not likely ever to enrich the provincial treasury.

After several temporary leases to other people, Mr. De Lery leased all his mining rights in 1864 to the De Lery Gold Mining Co. for a term of thirty years, with right of renewal for another thirty years on payment of fifty thousand dollars additional. The terms of this lease are of some interest to miners just now, as the first period expires in 1894; and it is exceedingly doubtful whether the long-suffering shareholders of the D. L. G. M. Co. will assess themselves to raise this fresh capital.

At the outset this company seemed inclined to work in a sensible way. They selected a mill site near Devil's Rapid on the Chaudière, and built a substantial quartz mill, close to the quartz vein assayed for gold and silver by Dr. T. S. Hunt in 1851. Unfortunately this mill proved a dismal failure from the very start. None of the prospectors ever got back enough gold from their sample lots of quartz to encourage them to keep on mining. After almost 30 years, stories are still rife of sceptical people throwing rich specimens and even gold coins into the batteries without obtaining any amalgam. It seems certain that a large part of the gold and quick-silver flowed off into the tailings and was lost. The total amount of quartz crushed in this mill cannot have been large, although quite a number of large veins yielding high assays are known to exist within a radius of three miles.

This is greatly to be regretted, as all the miners on the Gilbert River are fully agreed in saying that the coarsest and most abundant gold in the old channels was always found just below points where quartz veins existed in the slates. Many of these veins are of such large size, give such good assays, and are so persistent that they might easily rival the great Homestake Mine of the Black Hills in their dividend-paying powers, if they were operated with equal skill and on the same scale.

The De Lery Gold Mining Co. began sub-letting portions of its territory to other companies from the very start. The amount of gold obtained by some of these lessees would have attracted notice in Australia or California. In 1866 some miners drove a tunnel across lots 15, 16 and 17 in the concession De Lery, and reported to the inspectors gold valued at $142,581.00. Two of the heaviest nuggets found by them were valued at nearly $1,800.00. In the following summer Mr. John McRae took fully $15,000 out of a claim of 75 sq. ft. on the same stream.

It is no part of the author's purpose to write a history of all these undertakings. But he must call your attention to the operations of two companies in particular, to enable you to account for the disrepute into which the whole region has fallen.

An English corporation, named the Canada and North West Land

and Mining Company, obtained a lease of no less than three large sections of the seigniory.

At the time of Dr. Selwyn's first visit to this district in June, 1871, there was no mining going on (apart from a little prospecting by the local inhabitants) except by this company. The amount of capital permanently invested there was somewhere about £50,000 sterling (if the author is not mistaken).

The only useful result of these operations was establishing the fact that the richest alluvial deposits about here are found in ancient river channels at considerable depths below the present level of the streams.

As an offset to this useful knowledge, we must charge a large part of the discredit into which this whole gold field has fallen to the reckless mismanagement and utter failure of this large corporation. The author's first meeting with its manager was very characteristic. Just as he entered the little shanty near the Gilbert that this gentleman occupied as an office, he was shouting angrily that he did not want any miner from Australia or California or anywhere else to come and try to teach him how to mine, that he knew all about gold-mining. On asking the gentlemanly victim of this tirade afterwards what was the cause of all this uproar, Mr. Attrill explained that he had ventured to suggest that, if the sluice boxes below the shaft were set in a straight line, they might save more gold than set as they were, in a slovenly serpentine fashion. Any sensible man would have been glad to receive such suggestions from this experienced Australian miner.

It did not surprise the author to learn that no record was kept at this mine of the amount of dirt hoisted daily with the yield of gold per cubic foot or yard. He is afraid that the large majority of the English shareholders never learned the real causes of their total loss, but were led to attribute it to the poverty of the whole territory.

The entire district was condemned.

Other companies were equally to blame. One American company about the year 1865 secured a large tract of land on the Du Loup just below Marlow P. O., where the wreck of their immense two-story boarding-house still stands as a monument to the folly of spending a company's entire capital in preliminary building operations before testing the mine in any way.

The notorious failure of a hydraulic mining enterprise near the mouth of the Du Loup rendered the name of Beauce offensive in the nostrils of many Englishmen of high rank. This enterprise was entrusted absolutely to the skill and judgment of a gentleman who had been previously connected with the lumber trade in one way or another. He was entrusted with the expenditure of about $200,000, involving elaborate surveys and the construction of a canal (or ditch) about 11 miles long, to furnish the necessary water under sufficient pressure to break down and disintegrate the gravel benches. This ditch cost more than would have been required to build a first class railroad along the same route. After it was finished, mining operations were carried on for a remarkably short period and then totally abandoned.

The failure of this enterprise seems to have led some others to regard its manager as a very competent mining engineer. Shortly after the collapse of the hydraulic company, the author found him in charge of the operations of the St. Onge Company, on Slate Creek, right behind the village of St. George. The old channel here was 165 feet deep, and some of the overlying strata of sand and gravel were very wet.

More than a year's time and much money was spent in sinking a shaft here. It was finally accomplished by sinking a series of very heavy wooden boxes by the aid of pumps, which removed a vast quantity of semi-liquid material. Every stroke of the pump increased the fluidity of the surrounding mass, and threatened to collapse the structure. After passing through such ground, when a denser stratum was reached, the box lodged and could not be moved. Then a smaller box had to be started inside of the first one; and it was driven as far as possible before it lodged in turn. The author believes that a third box was sent down before dry ground was reached. The natural result of these operations was the rapid diminution of the area of the shaft, until it was barely large enough for a tub to pass through. It was hard to find men willing to risk their lives in such a place. But the work proceeded for some time and a considerable amount of coarse gold was obtained. One of the partners stated that the final abandonment of the work was caused by the manager's foolishness in blasting a passage through the side-rock of the channel to try and reach an imaginary Eldorado beyond. All the remaining capital was exhausted in this attempt. Then the sheriff sold out their rights.

The author has gone somewhat fully into the record of this costly failure, because it shows clearly that this cannot be justly attributed to the poverty of the ground. There is no doubt in his mind that there are rich alluvial deposits as well as very promising quartz ledges on this creek. But the skill of genuine mining engineers will be required to exploit them with sufficient economy to reward the shareholders.

It is a serious misfortune to this region that no competent men have been employed as yet to sink through the deep wet ground which overlies nearly all these channels. If one such shaft had ever been sunk in the district and earned a rich reward for its owners, there would have been no lack of shafts sunk in search of similar channels.

As far back as 1851 we find Dr. Hunt reporting on the gold and silver contents of the vein exposed in the Devil Rapids of the Chaudière. In the same year Sir Wm. Logan organised a small mining company to work the deposits at the junction of the Du Loup with the Chaudière. Their operations showed a fair margin of profit, and were duly published in the reports of the Survey.

The joint report on our Quebec gold regions by Dr. Hunt and Mr. Michel, published by the Geological Survey in 1866 clearly established the wide distribution of placer deposits, while the accompanying assays of samples from numerous quartz veins demonstrated clearly the local origin of the gold.

When Dr. Selwyn arrived in Canada, fresh from the gold fields of Australia, his attention was at once directed to the gold fields of Nova Scotia and Quebec. His published reports show how much he was impressed with the similarity of these formations to the auriferous zone in Victoria. The few points of difference are all in favor of our Canadian gold fields. Our abundant water supply, our cheap labour, cheap food, low freights, etc., should stimulate mining operations here.

The points of resemblance between the gold measures of Nova Scotia and those of Quebec have often been noted. But I have been often struck with the dissimilarity in size of the auriferous quartz veins of the two regions. It is comparatively rare in Nova Scotia to meet with one over two feet thick. Probably the average size of all those mined for gold in that province does not much exceed one foot. But on the Gilbert River and elsewhere in Beauce very large auriferous veins are the rule and small ones are the exception.

The samples of quartz selected by Mr. Michel for assay by Dr. T. S. Hunt were taken from veins ranging from three feet in thickness up to twenty feet and over. None of them showed any coarse gold where exposed. But several samples when crushed fine in a mortar and panned out yielded good "colours." The fire assays of many of them gave a large enough yield to justify the expenditure of large sums in their proper development on a large scale.

It is well established by sad experience that it is only 2 or 3 quartz veins out of every 100 that carry enough gold to pay for working, even in the richest gold regions. And it is equally well recognised that such veins generally carry their free gold in pay streaks or "chimneys," separated by large areas of comparatively barren quartz. There is no reason for considering the quartz veins of this province to be any exception to these general rules.

Dr. Selwyn has pointed out that the richest quartz veins in Victoria are generally found not very far from a mass of intrusive granite.

Prof. Hind was the first to point out the close relationship between the main anticlinals of the Nova Scotian gold fields and the richest quartz veins.

It is a well-known axiom among competent engineers that the mineral deposits of every new district have their own peculiarities, and are likely to present some characteristic variations from modes of deposit studied elsewhere. The prudent man will be cautious, therefore, about committing himself too far to any very definite predictions about any undeveloped prospect, until he has had opportunity to examine and study closely some mines already operated in the same district.

If we bear in mind this caution, we may venture to lay down a few hints for prospectors in this region.

Enough work has been already done on the placer deposits to prove that the richest ground is always to be looked for: (1) in areas occupied by the black, greasy, highly contorted slates often impregnated with pyrites; (2) more especially in the old channels buried deep below the present beds of these streams; (3) and richest of all, just below the points where heavy quartz veins cross these channels.

In regard to quartz veins, prospectors are most likely to find paying ones: (1) among these black slates; (2) close to the axis of an anticlinal; (3) not very far from granite; (4) or associated with dykes of diorite and olivene.

Perhaps we might help to avert some very foolish undertakings by adding that it is never wise to sink deep on any quartz vein that yields no gold at the outcrop, in sanguine hopes of finding a bonanza somewhere below. From what has been stated already, the chances are at least 33 to 1 against its proving to be a gold bearer.

Even if you have a vein that carries some gold at the outcrop, but not quite enough to pay the cost of mining it, the chances are always against its becoming richer as depth increases We all know that veins are sometimes found to gain in richness with depth. But such cases are the exception. The general abandonment of the theory of vein-filling by injection from below has destroyed all excuse for maintaining this costly delusion.

On the other hand, if any company is lucky enough to secure a good vein of paying quartz, and begins to exploit it successfully, the directors should lose no time in establishing a substantial cash reserve, to provide funds for the necessary dead work in sinking shafts or driving galleries to pass through the inevitable barren zones between one pay-streak or chimney and the next adjacent one.

Eight years ago the author published in the *Gazette* of this city his opinion that, when capital and skill combined should enter this field, the results would astonish the world. He is still of the same opinion. But the investigations and reports of such men as Sir Wm. Logan, Dr. T. Sterry Hunt, Dr. Selwyn and Dr. Ells of the Geological Survey carry a far greater weight than the opinions of any private individual.

DISCUSSION.

Mr. Blackwell said he would like to ask Mr. Torrance how he accounted for the progress Nova Scotia had made, as compared with the Province of Quebec, in gold mining. Mr. Torrance, replying to Mr. Blackwell, said this difference is entirely due to the contrast shown by the mining laws of the two provinces. The Nova Scotian law is long established and rarely modified in any particular. Its interpretation is left to the Supreme Court of the Province. In Quebec, on the other hand, there is rarely a session of the legislature without some alterations to the Mining Act, and its interpretation is left absolutely to the Inspectors of Mines, who are appointed by the local government as a reward for political services. Capital is very shy of placing itself at the mercy of any such appointees.

Mr. A. B. Barry said he agreed with the author that Canadian capital is unfortunately generally invested in foreign mines; but we have not far to look for the cause.

There is no country in the world where "*mining sites*" and "*indications*" are as plentiful as in Canada; but how many "*mines*" have we?

The trouble is that mining agents and speculators are ever on the lookout for *finds* and *indications:* these they either assume or purchase from the poor prospector for a nominal amount, register at once in their own names, do no development work at all, but hold as a valuable "mine," and ask fancy prices.

This evil exists in the Province of Quebec as well as in the rest of Canada, and is answerable for the small interest now taken in native mining lands. Only lately cases have come under my notice where parties willing to open up and develop certain lands were prevented by the insane price asked by "option holders." This remark applies to other than gold and silver property as well. Asbestos mica, plumbago, etc., are plentiful, but how little is done with them, and for the same reason?

As regards the auriferous area of Quebec, gold is found all through the Cambrian formation, but only in paying quantities at certain points. The "Ditton" property has always been considered as one of the richest, if not *the* richest, in Canada; and having spent over seven months in that district last year, the writer may be pardoned for saying, that the author is very much error in describing the country as "almost level." It is, in fact, one of the roughest in the Province, and in many places almost inexplorable.

There is no difficulty at all in finding suitable dumping ground for tailings, as experience has amply proved, and hydraulicing is easy, a sufficient head being obtained almost over the entire property.

The tailings do not contain much fine gold. The steam mill and machinery erected for separating and washing the gravel, clay and slates was so perfect, that practically no gold was lost; and this is best proved by stating that a first class American amalgamator failed to detect $10.00 worth of fines during the season, the coarse and fine gold being all "caught" before reaching this point.

As to gold being generally found close to quartz veins, the writer may say that these veins disintegrate or decompose very quickly, and when crossing the rivers act as natural riffles, and so detain a considerable portion of the gold brought down by floods, etc.; but the chief depositary is to be looked for in ancient courses or gutters, and in no place was this found to be the case as in Ditton; but the property being absolutely free from government inspection or royalty (the mining rights having been bought out for ever), the present proprietors allow no outsiders on the land, and, as business men, give no account of the gold, etc., found.

This secrecy is observed all over the Province. A great deal more prospecting has been done than is acknowledged; and from personal observation the writer can say that extensive areas are yearly closely examined by professional and other miners and engineers.

A large number of "habitants" and others make an easy living by indulging in "hunting" during the summer months; but as these trips invariably terminate at the U. S. mint, it is easy to guess at the nature of the "hunt."

The quartz veins all through this section have been carefully examined, and for several years past very many assays have been made, but so far without important results, although other and very valuable information has been thereby obtained.

The mining expert, who was associated with the writer last year in the Ditton gold fields and neighbourhood, was a celebrated geologist having had a large experience as government inspector of mines to Prussia. He encouraged settlers and prospectors to bring in for examination all quartz and other specimens found, and so investigated large numbers of so-called "valuable finds," but in no case was anything of economic value found.

To make the gold fields of Quebec pay, placer mining must be carried on upon a large scale; the gravel and hard rock is rich in spots, but the general average per cubic yard is small, perhaps not over fifty cents; but when we consider that ten cents per cubic yard should cover all expenses, the profit is ample.

REPLY TO MR. BARRY'S DISCUSSION.

The author has read Mr. Barry's discussion with great care, and regrets that he cannot find any precise facts or figures or data of any kind about the gold deposits in Ditton entrusted to his charge. Mr. Barry's flat denial of the author's statement about lack of head for hydraulicing would carry greater weight if he had told us just how many feet of head they obtain and what length of flume is requisite in order to secure this.

It is difficult to understand how a vein that "disintegrates or decomposes very quickly" can act as a natural riffle. It is generally understood to be the duty of a riffle to rise above the level of the sluice box instead of sinking below it. With respect to the scant courtesy shown to visitors at Mr. Barry's works, the author is thankful to say that he never experienced such "secrecy" at any other mine (whether gold, silver, copper, phosphate, mica or lumbago) in the province during a professionnal experience of twenty years.

It is a pity that Mr. Barry does not give us the name of the celebrated geologist associated with him at Ditton, and tell us the nature of the methods employed by him in this "investigation" of all the valuable finds in that region. Until some such data are supplied, the author is not inclined to accept Mr. Barry's implied assertion that there are no quartz veins worth exploiting in that whole district, but prefers to refer for geological facts to such authority as Dr. T. Sterry Hunt and Dr. R. W. Ells.

Mr. Barry's concluding assertion, that the placers of the Province of Quebec are of the "small" general average of perhaps not over fifty cents per cubic yard, is most startling. He agrees with other authorities in placing the cost of hydraulicing at ten cents per cubic yard as a maximum. The difference between this and fifty cents, when applied to the whole area of the Quebec Cambrian rocks, gives us such a colossal quantity of gold that all the wealth of California, Australia and the Indies sinks into utter insignificance.

But if we confine this estimate to the 4750 acres included in the old Pope property, the statement still retains a strong flavour of the prospectus. It is highly desirable that the technical details of the tests and determinations whereon Mr. Barry bases such unusual figures should be published.

The author hopes that Mr. Barry will favour the Society before long with a paper on this subject, embodying the results of his own professional work and giving us some useful technical information about the methods so successfully employed at Ditton for separating and washing the gravel, clay and slates.

Friday, 10th February.

H. Irwin, Member, in the chair.

Paper No. 74.

DISPOSAL OF SEWAGE AT MARLBORO, MASS.

By Jas. A. MacPhail, Stud.Can.Soc.C.E.

An efficient plant for the purification of sewage has recently been put in operation at Marlboro; and as the circumstances which led up to its erection are of interest in the history of sanitary reform, they will be briefly outlined as an introduction to a detailed description of the system.

The city of Boston derives the greater part of its water supply from the Sudbury and Cochituate basins, these sources furnishing at least 400,000 people with the amount of water necessary for domestic and manufacturing purposes. The total drainage area of the two basins is 94 square miles, and includes the towns of Framingham, Westboro, Southboro, Natick and Marlboro, besides several villages. Part of the rain which falls over this area drains into Lake Cochituate, a natural lake, which has been divided into three separate basins and otherwise prepared as a storage reservoir; and the several dams which have been built on the Sudbury River retain the water which falls over its basin.

The total area of the storage reservoirs is 556 acres when the water is drawn down to the levels of the several intakes. From the basins the water is conducted by gravity to the distributing reservoir at Chestnut Hill near the city, by means of conduits 14 or 15 miles long.

The aggregate population of the towns and villages, mentioned above as being in the drainage area of Boston's water supply, is fully 30,000; and as the boot and shoe-making industries are largely carried on in them, the necessity of taking means to prevent the pollution of that water supply will be readily admitted. As early as 1879, this necessity was urged by Mr. Desmond Fitzgerald of the Boston water-works, and efforts at once began to be made to exclude the sewage of factories and hotels from the immediate sources of supply. As yet none of the towns in the area had constructed public water-works or sewerage systems, and the city's officials necessarily directed their attention to individual cases. In the lower courts they were beaten several times, but finally in 1885 secured a decision of the Supreme court, which gave the city of Boston authority to exclude all sewage from the drainage area of its water supply.

The particular case in which the decision was given is that of the city of Boston *vs.* Gleason, the mayor of Boston having applied for an injunction to prevent the latter from discharging the sewage from his hotel at Natick into Pegan Brook. The case is an important one in the sanitary legislation of the United States, and is treated at some length in the report of the Boston Water-Board for the year ending April 30, 1885.

When several of the towns in question adopted public water-works, the necessity of some means of sewage disposal became more urgent; and when a town had decided and received permission from the State Board of Health to construct a sewerage system, the city of Boston agreed to bear the extra expense involved in purifying the sewerage or conveying it out of Boston's supply area, or both. The result of these circumstances is to be seen in the fact that South Framingham and Marlboro are now provided with plants for the removal and purification of their sewage, and that similar plants are in course of erection for Westboro and Natick.

The theory of the self-purification of rivers applies to comparatively few instances, and consequently the question of sewage disposal, other than by discharging the crude aggregate of large cities into streams or other bodies of water, is fast becoming a vital one in this country as it has been for many years in England and on the continent of Europe, where the subject has received much attention and great success in many cases been attained. The case of Manchester may serve as an instance. But the altered conditions with which engineers are confronted in this country do not altogether justify the adoption of foreign methods, and, besides, the information regarding them is very meagre; so that the attempts made as yet have been more or less experimental in their nature.

More than thirty towns and cities in the United States have erected some sort of plant for the purification, chemical or otherwise, of their sewage, and in most cases the results have justified the expense involved.

Marlboro contains about 15,000 inhabitants, the principal business being in connection with the manufacture of boots and shoes. Previous to 1885, its water-supply was derived from wells and its sewage was disposed of by means of cess-pools, much of whose contents ultimately found its way into Boston's drinking water, though the cess-pools were cleaned at an annual cost to the town of $1,800. In 1885 the town constructed an efficient system of water-works, built by Mr. M. M. Tidd, the supply being drawn from Williams pond. (See Plate III.) This work presented no difficulties. On the introduction of the water-works, the need of a public sewerage system became more pressing, and several schemes were proposed, which were more or less feasible. Mr. Philbrick proposed the construction of filter-beds at the Y (marked A on the plan), a short distance from the town. The effluent was to be discharged into Stony Brook. But as Stony Brook is one of the feeders of Lake Cochituate, and as Boston proposed to build an additional reservoir which would leave only 100 feet between this effluent and its storage area, the purification would require to be at all times complete,—a thing almost impossible to secure.

In 1891, the town applied to Mr. M. M. Tidd, to whom, with Mr. F. C. Coffin as assistant engineer, is due the construction of the present system.

Surveys were at once made and a site selected for the beds, about 2½ miles from the town. This site is marked B. on the plan. The construction of filter-beds at this point would involve the making of a ditch to carry the effluent to a feeder of Hagar's pond. It was afterwards found that the making of this ditch would involve much more labor than was at first supposed, and the situation was finally abandoned in favor of the present one, which offered many advantages to offset the expense of the extra amount of sewer required. The land for the beds could be secured at a much lower rate, and the effluent could be discharged direct into a feeder of Hagar's pond, which in turn discharges into the Sudbury River below Boston's intake.

The large plan shows the proposed site of the beds and also their actual position (C). The proposed ditch is shown in full lines. The greater distance of the beds from the town in no wise displeased the residents, while the configuration of the ground was better adapted to the purpose for which it was intended.

The preliminary arrangements having been thus outlined, some details of construction and cost will be given and some facts as to the present working of the system submitted.

The work was let to the contractors in two sections, one to comprise the laying of a sewer from the town to the separating tank, and the other section to include the building of a separating tank and the preparation of 20 filter-beds. The laying of the sewer presented no special features. It may be said, however, that the work was of the most thorough description, every care being taken to lay the sewer so as to prevent the leakage of its contents into Boston's water area, which would serve to defile the water and render the system imperfect. Defective joints would also permit ground water to enter the sewer, and thus in rainy seasons tax it beyond its capacity. Notwithstanding the excellence of the work, it has, however, been found impossible to exclude ground water from the sewer, and Mr. Felton estimates the amount of leakage of joints at from 300,000 gals. per day in the wettest time to almost nothing in September and October, and this over a length of pipe of 20 miles. The sewer terminates in a separating tank 18 feet wide and 28 feet long. Briefly, the system of disposal consists in separating the heavier portions of the sewage and passing the resulting liquid to the filter-beds by means of a distributing pipe. At regular intervals the sludge is removed from the tank in a manner to be described afterwards. The separating tank demands special reference; when the excavation for the tank had reached the proper grade, a layer of concrete 15 inches thick was laid as a foundation, the concrete extending one foot beyond the tank on every side. This was put on in layers of 5 inches, and was well compacted by ramming. It was composed of one part by measure of first class American hydraulic cement, two parts of clean sharp sand, and such an amount of broken stone or clean gravel, that the mortar slightly over-filled all the voids in the stone. On this concrete foundation was started the brickwork, which was of good hard burnt brick, full joint in mortar, the brick being well wet just before laying. All that portion of the brickwork below grade of surface of ground was laid in cement mortar. The wall was 16 inches thick, the inside 4 inches not being bonded with the rest of the wall but carried up independently, and between the two parts of the wall there was a continuous layer of cement mortar one inch thick.

Above the grade, the brick was laid in good lime mortar. In the centre of the tank a division wall was carried up to the grade of the main sewer, dividing the tank into two distinct longitudinal compartments, and on the top of this wall was laid a 15 inch sewer pipe set in cement. By this means the sewage can be conveyed directly to the beds, if it should be thought fit to do so, and either compartment can be used while the other is undergoing cleansing or repairs. The manner of making connection can best be seen by reference to the accompanying plans. In the walls, 15 feet from the inlet, were set 4 vertical cast iron grooves intended to receive stop-planks which retain behind them all heavy portions and allow the water to pass over them. Some four feet beyond the stop-plank a wall was built across the tanks, having an aperture in each compartment through which the water passes to the screens. The screens, one for each compartment, are laid horizontally in the space between this wall and the end wall of the tank, and are formed of No. 8 galvanized wire 1 in. mesh set in wooden frames. It will be noticed that the sewage passes upward through the screens, thus avoiding the clogging of them by the sludge. After flowing through the screens the sewage passes out of the tank, a pipe for that purpose leading from each compartment to the main sewer, which may be said to run through the tank on top of the division wall. At each end of the tank a manhole was constructed for inspection of joints, Over the tank a house was built, the walls of the tank being carried up to form the four walls, and 7 I beams were set across to receive the floor grating. From this house the various gates are operated, by which the flow of sewage is regulated.

From the separating tank there was laid a distributing sewer of 15 inch vitrified pipe, having 2 manholes. The trench was specified to be at least one foot wider than the pipe, and great care was taken in laying every pipe to the proper grade. The laying proceeded up grade, every joint being thoroughly filled with cement, and the inside being wiped down to the surface of the pipe. In backfilling, the earth around the pipe was thoroughly rammed without disturbing the pipe, and no stones of over two inches in diameter were allowed within one foot of the pipe. The rest of the trench was then filled in layers of six inches, no stones of over six inches being allowed to go in the trench; where rock excavation occurred, the rock was blasted 2½ feet wider than the pipe, and six inches below grade of bottom. The pipe was then laid in a bed of well packed gravel and the backfilling completed. Wherever an embankment was necessary, the loam was removed and the earth put on in 6 inch layers until grade of pipe was reached. Then the pipe was laid and the earth well packed around it. The top of such banks was made six feet wide and the slope 1 on 1½.

At present, 20 filter-beds are in use, and others will be added as they are needed. In preparing these the land was cleared, and all the loam removed except that portion under the embankments dividing the beds from each other. That was left in place and enough of the rest placed upon it, in order to bring the embankments to the proper lines and grades. This was put on in six inch layers, and well rolled and watered.

The sand or gravel under the loam was then graded so as to give the bed a level surface. Under the area of the beds were laid 12 lines of 6 and 4 inch of open joint drain pipe at right angles to the distributing sewer and discharging into the brook. See plan of first 16 filter-beds. The drain pipes were laid in trenches dug 3 inches deeper than grade of bottom of pipe, and coarse gravel was packed around to a depth of six inches above the pipe. The remainder was backfilled in layers of six inches.

An open ditch was built along the upper side of the land occupied by the beds, to intercept the water coming from above.

From the manholes mentioned above 2 lines of 10 inch iron pipe with lead joints were laid in the embankments between the beds, and 8 outlet chambers of brick masonry were built with cast iron outlet gates; from each side of an outlet chamber, a 15 inch sewer pipe extends through the embankment, the outer end being protected by an abutment of rubble masonry and an apron of cobblestones. Iron pipe was required to withstand the head from the distributing sewer. The sludge carrier remains to be noticed. It leads from the lower end of the tank, and is built of concrete on a foundation of rubble masonry. It is provided with outlets, controlled by stop planks sliding in iron grooves, the section being in the form of a U. The outlets are paved with cobble stones, and admit the sludge to beds 1-8.

As to cost—the separating tank was built for $2,500, while the total cost of the beds, tank and distributing apparatus reached the amount of $13,000. The cost of the system, including the main sewer and connections, was $62,000, of which $41,000 has already been paid by the city of Boston. The cost of maintaining the plant will of course be very small as the disposal is almost automatic, the only attention required being in the removal of the sludge. To do this it is only necessary to remove the stop planks, open the sludge conduits and allow the sewage itself to bear the collected material of a day or a week, as the case may be, to the sludge beds, whence the deposit is removed by a farmer in the vicinity and used as a fertilizer. And this at no cost to the town. Up to the present time the cost of maintenance of the beds has been about 40 cents per day. A man is paid 30 cents a day for changing the sewerage; and the sludge tank is cleaned twice a month, taking about $\frac{3}{4}$ of a day each time. The beds have also been harrowed several times.

At present the beds are not being worked at anything like their full capacity, as may be seen from the fact that while there are nearly 2000 users of water in the town, only about 700 houses are connected with the sewer, including all the factories and business section. House connections, however, are being made rapidly, and it is only a question of a very short time until the whole of the town's sewage will be disposed of in a proper manner. The quantity of sewage filtered daily varies greatly, or rather cannot be determined accurately on account of the large amount of ground water which finds its way into the sewer. Measurements have been made, however, by using the separating tank as a meter, and the average at present may be taken at 700,000 gallons a day. It has varied from 300,000 gallons per 24 hours to 12,000,000 gallons, the latter lasting not more than 2 or 3 days after a very heavy rain, when all the cellars were flooded and water ran in at the manholes. The leakage of the joints has already been mentioned.

This winter has given the system a very severe test, which it has stood remarkably well.

The winter has been unusually severe, the thermometer being at or below zero nearly every night for five weeks preceding January 24. During this weather the beds have been covered with ice from 1 to 4 inches thick, but no trouble has been experienced other than at times to turn on the sewage once or twice a day. The beds fill up, and it takes from 1 to 3 days for them to drain off.

The sewage goes on the beds at a temperature of about 40°, and thaws out the sand to a depth of 8 inches or until the temperature is lowered to near the freezing point when the water passes through the frozen ground.

No exhaustive analyses of the filtered sewage have been made so far; to the eye as it comes from the under drains it is perfectly pure; and one would have no hesitation in drinking it if he were ignorant of its source. No unpleasant odour is experienced on approaching the beds, except at times when the sludge is being removed, and this lasts only for a short time. Appended are the results of analyses made at 3 different times by the State Board of Health, the first when there were about 50 connections and the greater part of the sewage running was ground water. The last was taken during cold weather.

No official report has yet been published concerning the efficiency of the plant, but Mr. B. R. Felton, who had charge of the construction, and is now resident engineer of Marlboro, is collecting statistics, and his report to the State Board of Health, which will appear shortly, will be awaited with great interest by many who have long lifted up their voice in the cause of sanitary reform.

* All water containing suspended matter is filtered through filter paper before determining the colour and residue on evaporation. Occasionally these determinations are also made on the unfiltered water, the results in such cases being indicated by an asterisk.

The colour of water is expressed by numbers which increase with the amount of colour. Boston water has an average colour of 0.40, other water supplies vary from 0 to 1.45.

No.	Date of		Appearance.			Odour.	
	Collection.	Examination.	Turbidity.	Sediment.	Color.	Cold.	Hot.
8687	1892 Mar 30	31	Very slight	Consid'ble sand.	0.0	V. faintly mouldy	V. faintly mouldy
8689	30	31	Dist. turbid	Consid. gray	0.05	Offensive	Offensive.
9168	July 28	28	None	very slight fibrous	0.02	Musty	V. disagr., Musty
9169	27	28	Thick	Heavy brown	about 0.70	Offensive	Offensive
9819	Dec. 20	21	Dist. milky	Slight	0.08	Decidedly disagreeable	Decidedly disagreeable
9817	20	21	Thick	Heavy Dirty	0.70	Offensive	Offensive

Residue on Evapor'n.			Ammonia.				Chlorine.	Nitrogenous.		Hardness.	Remarks.
					Albuminoid.						
Total.	Loss Ignition.	Fixed.	Free.	Tota	In solution.	In sus pens'n.		Nitrate.	Nitrites		
13.7	......	......	.0480	.0034	......	......	2.21	.5500	.0020	4.43	Effluent ab. 50 con Sewerage
20.20	5.50	14.70	.1600	.0250	.0100	.0150	3.22	.7000	.0040	6.57	
29.00 *67.90	3.50 *29.50	25.50 *38.40	.4000	.0120	......	......	6.62	1.0500	.1000	6.4	Effluent ab.350 con Sewerage
40.00	13.40	26.60	2.0000	.8100	.3360	.4740	7.73	.0100	.0000	....	
26.40 *47.20	...... *19.40	...... *27.80	.8800	.0580	......	......	5.50	.6000	.0050	7.0	Effluent ab.700 con Sewerage
34.90	10.10	24.80	2.4000	.5900	.3080	.2820	7.20	.0180	.0300	6.8	

Thursday, 23rd February.

E. P. **Hannaford**, President, in the Chair.

Paper No. 75.

TRANSMISSION AND DISTRIBUTION OF POWER BY COMPRESSED AIR.

By **John T. Nicolson**, B.Sc., M.Can.Soc.C.E., M.Am.Soc.M.E.

The intention of this communication on the subject of the transmission and distribution of power by means of compressed air is mainly twofold. In the first place, to lay before this Society the fact, which has now been plainly proved by the experiments on the Paris installation, that the utilisation of energy by means of air under pressure is a more economical, convenient, and secure method than any other yet known. Secondly, and as a consequence of this statement, to present a précis of the theory of the whole subject as founded on recent experimental results, so that the necessary data may not be wholly lacking from the records of this Society, when its members are called upon (as it is the author's belief that they shortly will be) to enter upon this department of engineering work.

Reference must be made incidentally to the importance (from the politico-economical point of view) of the encouragement of small industries in great manufacturing centres; and an attempt will be made to estimate the commercial feasibility of a scheme to supply and distribute power by air compression in Montreal; where, unlike Paris, competition with electricity as an energy-transformer may be expected to be very severe.

Until quite recently it has been supposed that energy transmission by the agency of air is of necessity an extremely wasteful process, the idea of its ever being able to compete with electricity for instance having hardly entered anyone's thoughts. This widespread notion has now, however, been traced to its true source, by the eminent engineer, Professor Riedler of Berlin, and its erroneus nature completely demonstrated by the valuable and extensive experiments made by him and Professor Gutermuth on the 5,000 H.P. plant now at work in Paris. In illustration of the kind of evidence on the strength of which such views are commonly held on this subject, we may refer to Riedler's treatise on "New Experiences with the Power Supply of Paris by Compressed Air," where on page 37 it is stated that the usual efficiency of small mining plants is 10 per cent. to 15 per cent.; and that even with such compressors as those used at the St. Gothard Tunnel and by Sturgeon in Birmingham, three-fourths of the power is lost before the air reaches the mains. And yet the feasibility of the economical transmission of power by compressed air has been criticised by the results of such inherently bad installations as these. It is as if the efficiency of the steam engine were to be judged by considering the economical value of one using forty or fifty instead of fourteen or fifteen lbs. of water per H.P. per hour. Is it not, on the other hand, altogether surprising that with the common occurrence of such extremely bad results, the system should have in any case survived? Had it not been for the inherent vitality and power of this method it must certainly have perished under such ill usage.

The recent adoption of the two great improvements of compression by stages and the use of a preheater before expansion have enabled Riedler to state definitely as the results of his experiments, that with even the ill made motors used in the small industries in Paris an efficiency of 50 per cent. is obtained, and with the old steam engines of larger power which are commonly used, 80 per cent. of the work of compression at the central station is developed in the motor; and that it is actually possible by using all the latest improvements in compressors and motors and with a very insignificant expenditure of fuel in the preheater easily to obtain just as much work at the motor as is supplied at the distant compressors, or in other words to leave a practical working efficiency of 100 per cent.

Such a result as this is quite unattainable by any other mode of power transmission; and is due simply to the fact that on this system alone is it possible to insert a charge of energy at the working point with no sacrifice to convenience and at an almost insensible cost.

Without further comment or comparison at present, let us pass on to investigate the theory of this surprising (practical) result.

The system of compressor, air main, preheater and motor, is diagramatically represented in Fig. 1; where *a* is the compressor driven either

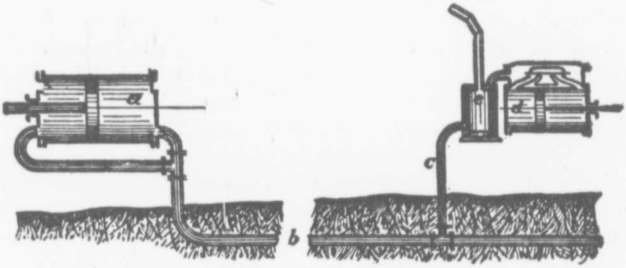


Fig. 1

by steam or water power; *b* is the air main leading from the central power generating station to the distributing mains; *c* represents a branch main taken off to run a motor *d*, and which, before supplying air to the motor, passes through a small heating stove or preheater *e*.

Compressors.

Considering the action of the compressors first: figure 2 is a diagram supposed to have been taken from air compressor *a* and given for the purpose of comparing the amounts of work done when one pound of air is compressed adiabatically and also isothermally.

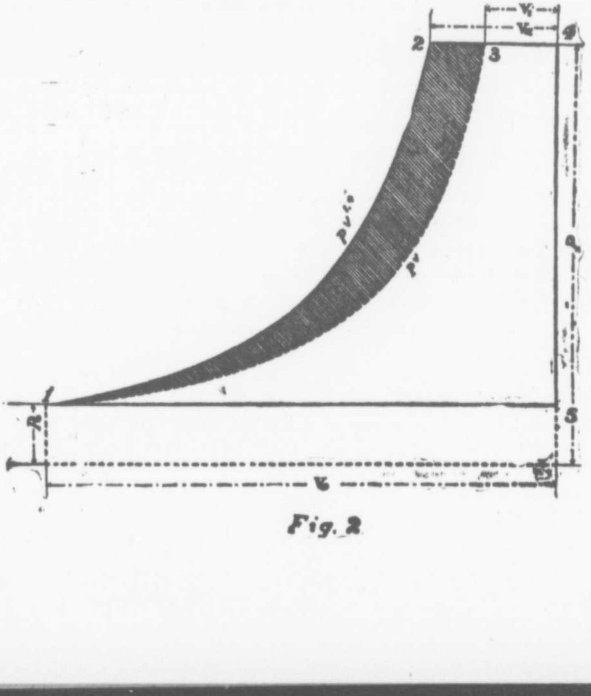


Fig. 2

If no heat be removed from the air during compression, it expands along the curve 1 2, whose equation is $p\,v^{\gamma}$ = constant and the work done is

$$\frac{p\,r_a - p_o\,v_o}{\gamma - 1}$$

this is spent in increasing the intrinsic energy of the air; the temperature rises from T_o to

$$T = T_o \left(\frac{p}{p_o}\right)^{\frac{\gamma - 1}{\gamma}} \text{..........................(1)}$$

where $p\ v_a\ T$ and $p_o\ v_o\ T_o$ are the pressures, volumes and absolute temperatures of the air at the points 1 and 2 respectively.

When the exhaust opens, the temperature of the air falls to that of the reservoir, which is T_o; the air gives up heat of the amount $K_p\ (T-T_o)$, while the piston does the work $p\ (v_a-v_i)$ to keep up the pressure; the state of the gas is then represented by point 3. During stage 3, 4, the piston delivers the pound of air at constant pressure and temperature; work of amount $p\ v_i$ being done. Part of the work done by the piston was, however, effected by the atmospheric pressure on the other side; so that the whole work supplied through the piston rod of the compressor is

$$\frac{p\ v_a - p_o v_o}{\gamma - 1} + \ p v_a - p_o v_o = \frac{\gamma}{\gamma - 1}\ (p\,v_a - p_o\,v_o) \text{..........(2)}$$

this may be put in the form

$$\frac{\gamma}{\gamma - 1}\ c(T - T_o) \text{...............................(3)}$$

and as $K_p = \frac{c\,\gamma}{\gamma - 1}$, we see that the whole work done in the adiabatic compression and delivery of one pound of air is equal to the heat generated during * stages 1 2 and 2 3, abstracted during stage 2 3,

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[*] This might also have been inferred by observing that the intrinsic energy of the air is the same at 1 and 3, and that therefore the whole of the work done by the piston during 1, 2, 3, must have been abstracted as heat. This work

$$\frac{p\,v_a - p_o\,v_o}{\gamma - 1} + (p\,v_a - p\,v_i) \text{ however, is equal to}$$

$$\frac{p\,v_a - p_o\,v_o}{\gamma - 1} + (p\,v_a - p_o\,v_o) \text{ since } p\,v_i - p_o\,v_o.$$

and lost in the reservoir when, as is usually the case, this is of large dimensions. Inserting the value of T from expression (1) in (3) we obtain for the work of adiabatic compression and delivery in the compressor

$$W_{ca} = c\,T_o \frac{\gamma}{\gamma - 1}\left[\left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

When, on the other hand, compression takes place at constant temperature the work done by the piston is $p_o\, v_o\, log_e \frac{v_o}{v_i}$. During delivery a further amount $p\ \ v_i$ is done; and subtracting the work $p_o\, v_o$ due to the back pressure, as in the last case, we obtain $p_o\, v_o\, log_e \frac{p}{p_o}$ for the work of isothermal compression and delivery of one pound; or

$$W_{ci} = c\,T_o \log_e \frac{p}{p_o} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Referring again to Fig. 2, the cycle is now 1345 instead of 12345, and the work done is seen to be much less, owing to the fact that the pressure of the air is kept down by abstracting heat as fast as it is generated, so that the state of the working substance is represented by the curve $p\ v =$ a constant. It is obvious then that, if the air is to be transferred to some distant point before doing work in the motors, the most economical way of compressing it is the isothermal mode; and this has long been acted on in practice by the use of cooling jackets round the cylinder and even in the piston. For the purposes of a central compressing station, however, this is far from an efficient plan; and is only to be recommended for mining plants where the injection of a spray of cold water is impossible owing to its impurity or to great undesirability of any additional mechanism.

Even with the very best forms of spray injectors now in use, the equation to the curve of compression is altered only from $p\ v^{\ 1.4}$ to $p\ v^{\ 1.2}$ instead of $p\ v =$ a constant. This is illustrated in Figs. 3 and 7, the latter of which shows a combined high pressure and low pressure card taken from an air compressor by Messrs. Riedinger & Co. in Augsburg, Germany, who are now in the foremost rank of constructors of this class of machinery.

The most successful way of preventing the accumulation of heat in the compressors is to do the work in two (or more) stages. This is accomplished by allowing the air after its pressure has risen a certain amount to flow through an intermediate receiver of sufficient capacity to cool it almost down to the temperature of the atmosphere, so that when drawn into and compressed to the final amount in a second or high pressure cylinder its state is again represented by a point on the

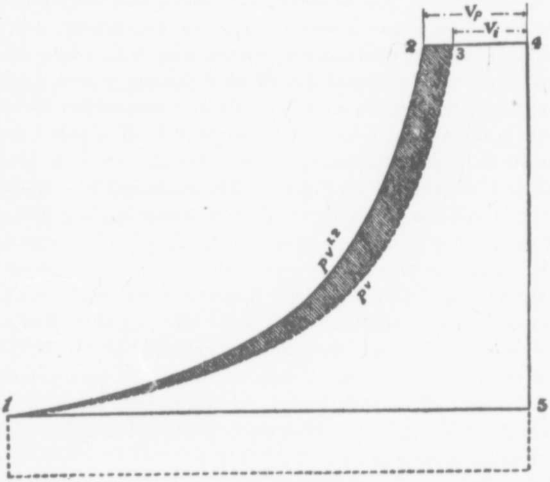


Fig. 3

isothermal of atmospheric temperature. A theoretical diagram, illustrating this case, is given, viz.: Figure 4.

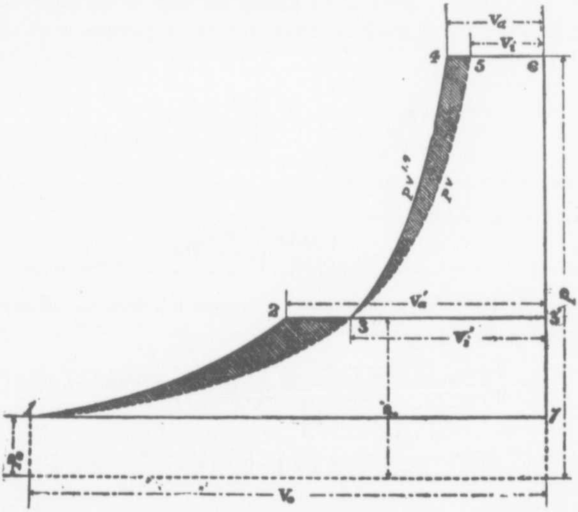


Fig. 4

Here the curve 1 2 is adiabatic, the cooling being supposed very slight, from 2 to 3 heat is abstracted in an intermediate receiver called an intercooler, until the temperature falls to T_o; Line 33′ or 3′3 represents the delivery of the air at a pressure p_1 into the high pressure cylinder, in which a further adiabatic compression up to the pressure p takes place, as shown by curve 3 4. The part 4 5 and 5 6 needs no further explanation, being of the same nature as already explained in connection with Fig. 2. Riedler has applied this plan to the new installation of ten thousand horse power in Paris with very great success, but as to the originator of the idea nothing seems to be known. Professor Elliott in his admirable paper on compound air compressors (read before the British Association at Cardiff), mentions his having seen an installation working in this way at the Newbattle Collieries near Edinburgh, built as an experiment by Mr. Morrison, the manager; and Professor Unwin, in one of his communications to the Institute of Civil Engineers, on this subject, states that the Newark Iron Works, Conn., constructed compound compressors with an intercooler as early as 1881.

If the efficiency of a compressor working isothermally, and which therefore wastes no energy in useless heating of the air, to be afterwards lost in the mains, be denoted by 100, then the efficiency of what we shall call Case I, a simple adiabatic compressor, will be found to be 74½. This is obtained by finding the ratio of the areas 1345 and 12345 in Fig. 2, which represents the case in question, or we may find it analytically by evaluating

$$\frac{Wci}{Wca} = \log_e r \Big/ \frac{\gamma}{\gamma - 1}\left[r^{\frac{\gamma}{\gamma}} - 1\right]$$

where $r = p/p_o$ .... (6)

In this case r being 7

$$\eta_1 = \frac{1{\cdot}9459}{3\ 5[7^{\cdot 286} - 1]} = 0{\cdot}744$$

Case II. For a simple compressor with spray injection, the efficiency is (see Fig. 3) 84½ °/ₒ or

$$_2 = \frac{Wci}{Wcp} = \frac{\log r}{\frac{n}{n-1}\left[r^{\frac{n-1}{n}} - 1\right]} = \frac{1{\cdot}9459}{6[7^{\cdot 166} - 1]} = 0{\cdot}85 \text{ .... (7)}$$

if $n = 1 \cdot 2$.

Case III. Similarly in the case of two stage adiabatic compressions the efficiency obtained from Fig. 4 is 86.2 %. The pressure (p_1) in the intercooler is to be chosen so as to make the work done in the two cylinders a minimum. This work is expressed by

$$W_{2ca} = cT_o \frac{\gamma}{\gamma - 1}\left[\left(\frac{p_1}{p_o}\right)^{\frac{\gamma-1}{\gamma}} + \left(\frac{p}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 2\right] \ldots\ldots\ldots\ldots ($$

which being differentiated and equated to nothing gives for the value of the receiver pressure $p_1 = \sqrt{p_o\, p}$.

In that case (8) becomes

$$W_{2ac} = cT_o \frac{2\gamma}{\gamma - 1}\left[\left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{2\gamma}} - 1\right] \ldots\ldots\ldots\ \ldots\ldots (9)$$

Hence $\eta_3 = 0 \cdot 862$ as above.

Case IV.—Lastly, taking the case of three stage compression with spray injection, which would only be resorted to for the largest plants: we can obtain an efficiency as per Fig. 5, of 95.5 %.

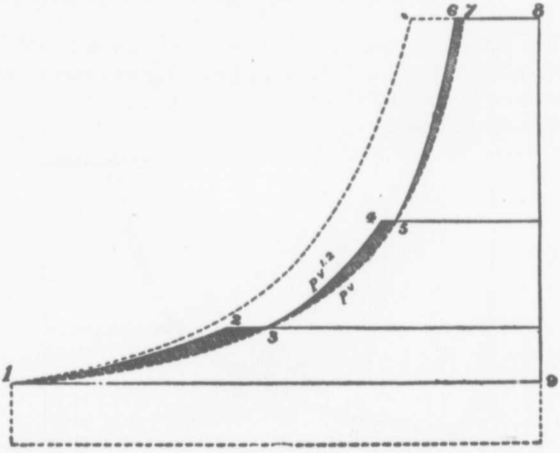


Fig. 5

Analytically determined, it is

$$\eta_4 = \log_e r \Big/ \left(\frac{3n}{n-1}\left[r^{\frac{n-1}{3n}} - 1\right] = \frac{1.946}{18[7^{\cdot 056} - 1]} = 0 \cdot 95 \ldots\ldots\ldots (10)$$

That these efficiencies are not mere figures deduced by analytical special pleading, and which are utterly distant from practical results, is evinced by examination of the annexed cards taken from actual compressors. The first, Figure 6

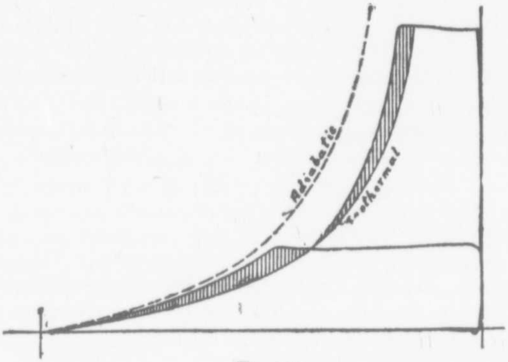


Fig. 6

is from Riedler's first two stage compressor, made on trial for the Paris installation by altering a Cockerill machine. It gives a ratio of actual work to isothermal work of 0·9.

The other, Figure 7

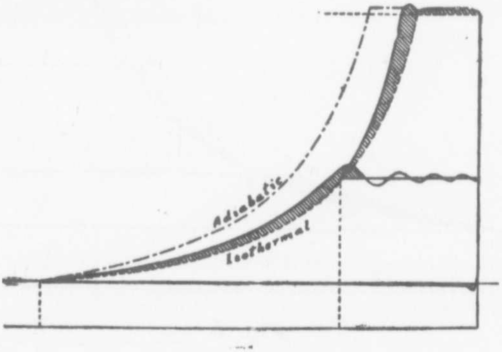


Fig. 7

is taken from an experimental two-stage compressor built by Messrs. Riedinger to the designs of Mr. Lorenz. Its figure is 0·91.

These results show how nearly the cycle of a well designed compressor, with correctly proportioned valves, first-class valve gear, and good jet injection, will approach to the theoretically predicted card.

Figs. 8 and 9, taken from Riedler's "Kraftversogung," show diagrams from the older machines of Paxman & Cockerill. The inefficient cooling and ill-proportioned valve gear are the causes of the large amounts of lost work shown. Their efficiencies are 0.68 and 0.728 respectively.

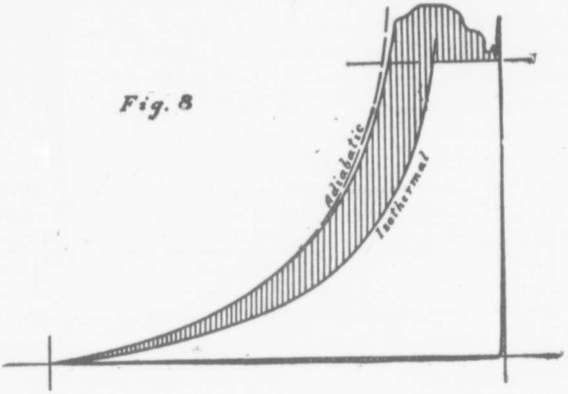


Fig. 8

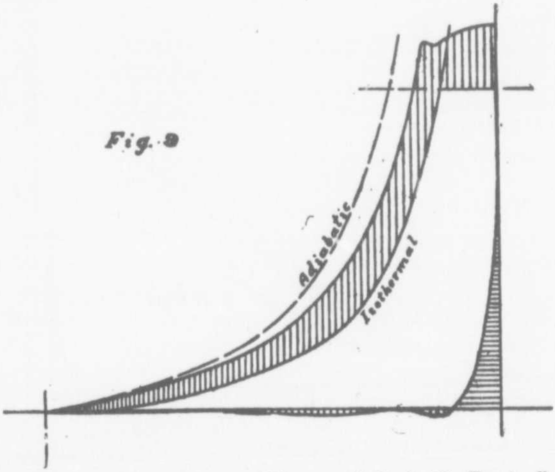


Fig. 9

Fig. 10

45 Revs. per min.

38 cub.ft. per. H.P. per hr.

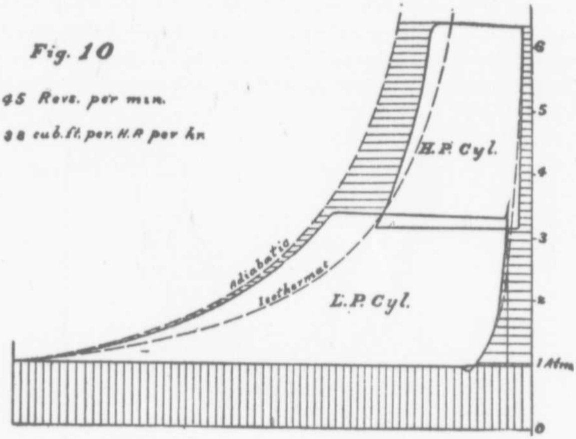
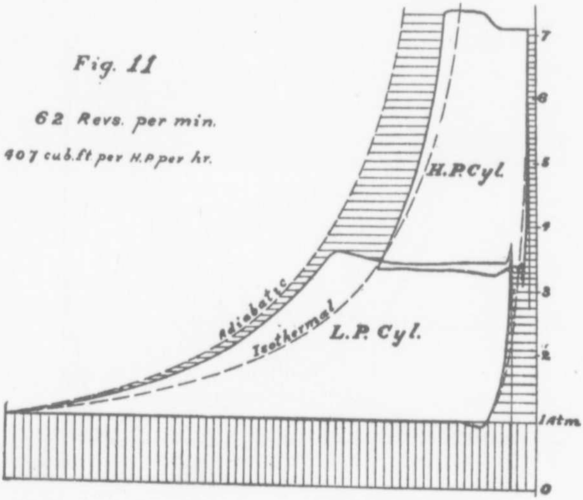


Fig. 11

62 Revs. per min.

407 cub.ft per H.P per hr.



Figs. 10 and 11 are diagrams from one of the 2000-horse-power compressors, which have been working at the new Central Station at Quai de la Gare, Paris, since the spring of 1891.

LOSSES IN THE MAIN FROM LEAKAGE AND FRICTION.

The general opinion has hitherto been that long distance power transmission by compressed air involves of necessity great losses from leakage and fluid friction in the mains. This view can, however, no longer be held in the face of the experimental results obtained with the Paris supply pipes. The tests carried out there by Gutermuth and Riedler are the most exhaustive and on the largest scale ever attempted. By permission of the authorities in the French Capital, trials for leakage and friction were conducted and repeated with lengths of pipes varying from two to ten miles, the diameter being about one foot.

The amount of leakage from the mains was determined by allowing them to stand under pressure, and observing the amount of fall on the gauges as time went on. As the mean result of several experiments it appeared that 2,330 cubic feet of air at atmospheric pressure were lost by leakage per mile per hour. This amounts to 8 per cent., as the main was one foot in diameter and the pressure 7 atmospheres absolute; so that the pressure fell to 6.44 atmospheres at the end of the hour. If the velocity of the air be increased from 1.46 at which rate it would have moved to pass a mile of pipe in one hour, to 30 feet per second, its usual velocity; then the air, instead of being one hour, would only remain 3 minutes in the mile of main, and the loss is reduced to 0.4 per cent. This loss will cause a fall of pressure of about 0.41 pounds per square inch per mile.

This surprisingly good result is an evidence of the extremely efficient joints fitted on the Paris pipes. These pipes are of cast iron with plain ends, and are jointed by means of three cast iron rings and four bolts acting on two elastic packing rings.

Better results even than these can certainly be obtained with new mains equally well laid, for the results given by Riedler include several unknown losses such as the pneumatic clock system supply, and that to some small motors which could not be stopped.

Previously to the large scale and careful work of Gutermuth and Riedler, the only experiments on the subject of loss of pressure by friction of air flowing in long pipes were those of Arson (v. P.I.C.E. Vol. 63), of Devillez on pipes up to 5 inches diameter, and of Stockalper on the 6 and $7\frac{1}{2}$ inch pipes supplying the drills in the St. Gothard Tunnel.

Taking these older results and those obtained at Paris together it appears that they agree fairly well, provided the co-efficient of friction be supposed to diminish as the size of the pipe increases. Unwin has discussed in four papers (Vols. 43, 63, 93, and 105) in the Proceedings of the Institution of Civil Engineers the question of the loss due to friction of air flowing in long pipes. For the coefficient of friction he gave, using D'Arcy's formula, in 1880,

$$\zeta = 0.0027\left(1 + \frac{3}{10d}\right)$$

[vide also "Encyc. Britt." (IX) "Hydromechanics"]; and for the pressure p_s at the supply end of a length of main L, of diameter d, when the initial velocity is u_1 feet per second; he obtained

$$p_s = p\sqrt{\left[1 - \frac{\zeta u_1^2 L}{222900d}\right]} \text{......................} (11)$$

If we choose to insert the value of ζ as depending on the diameter, then we put for ζ in expression (11) the value

$$.0023\left(1 + \frac{3}{10d}\right);$$

where Unwin's formula has been slightly altered to suit the experimenta results obtained by Riedler and Gutermuth; which gave for pipes 1 foot in diameter $\zeta = 0.003$. Putting then in equation (11) this value for ζ and 5280 for L we obtain

$$p_s = p\sqrt{\left[1 - \left(\frac{u^2}{18350d} + \frac{u_1^2}{61160d^2}\right)\right]} \text{.............} (12)$$

If it be allowed that one steam horse power will compress 360 cubic feet of air at atmospheric pressure up to 7 atmospheres absolute (the new Paris compressors do from 407 to 440), then the volume passing any point in the mains will be $\frac{1}{70}$ cubic feet per second for each horse power. We must therefore have

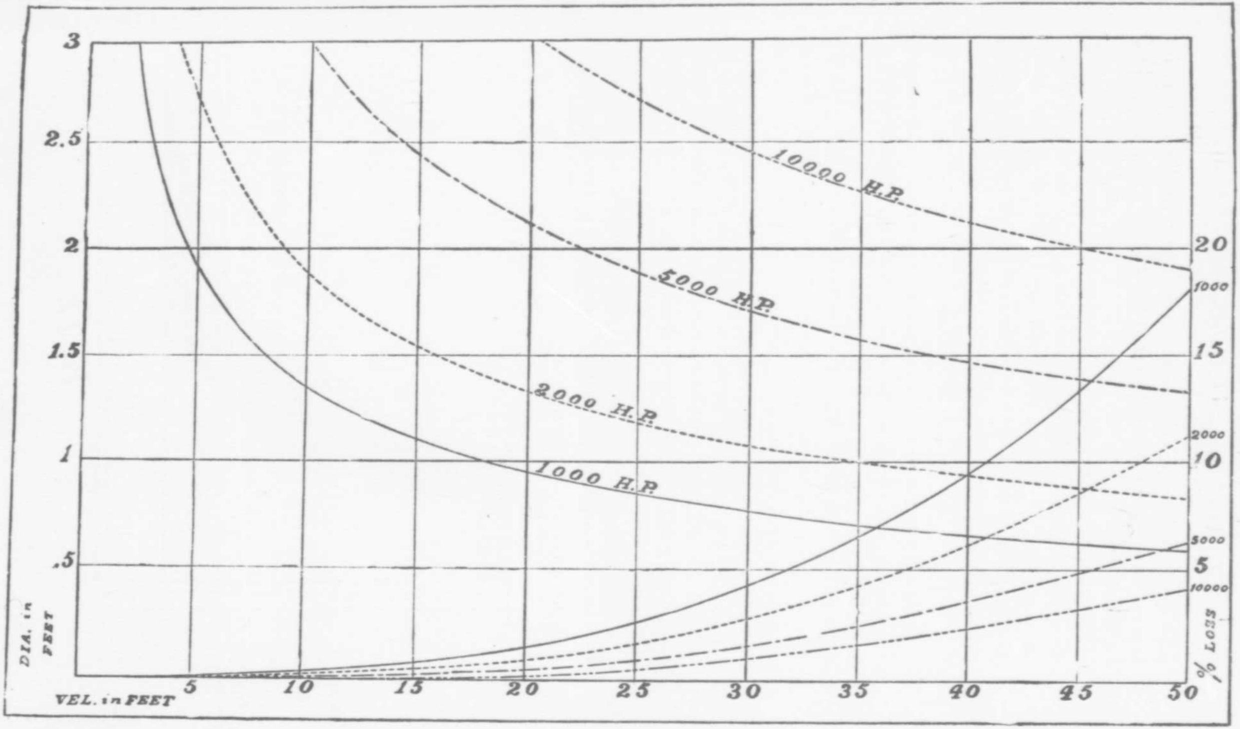
$$\frac{\pi}{4} d^2 u_1 = \frac{H}{10}$$

$$\text{or } u_1 = \frac{H}{55d^2} \text{.......................} (13)$$

Inserting this in (12) we have

$$p' = p\sqrt{\left[1 - \left(\frac{H^2}{3025 \times 18350d^5} + \frac{H^2}{3025 \times 61160d^6}\right)\right]} \text{..} (14)$$

which is in a convenient form for calculating the sizes of mains; where the diameter must be fixed by the relative rate at which first cost increases and running expenses diminish as the pipe gets larger.



Curves of percentage-loss of pressure in mains

In the figure, curves have been drawn co-ordinating the sizes of main required with various initial velocities for 1,000, 2,000, 5,000, and 10,000 horse power.

The lower curves show the loss of pressure per mile in percentage of the original pressure for all the cases. Taking, *e. g.*, the 10,000 H. P. curves we find that with an initial velocity of 45 feet per sec. and a consequent diameter of 2 feet for the main, the percentage loss of initial pressure is 3.3 per cent. per mile.

MOTORS.

The air having now arrived at the motors may be allowed to expand adiabatically, *i.e.*, without addition of heat, or it may be warmed during expansion by a spray injection; or again it may be worked in two stages and warmed in an intermediate receiver of sufficient capacity. The best mode of using the air, however, is to pass it through a heating stove or preheater, and begin expansion in the motors with air at as high a temperature as is convenient, the expansion afterward taking place along the adiabatic curve. If the motor be large enough to warrant the necessary primary outlay, it should indeed be heated twice; being delivered by the high pressure cylinder at a pressure of two or three atmospheres, again passed through a heater and expanded in a large cylinder until its pressure falls to that of the atmosphere.

Consider then, Case I, Figure 12, a simple motor with no preheater, no injected spray *i.e.*, adiabatic expansion.

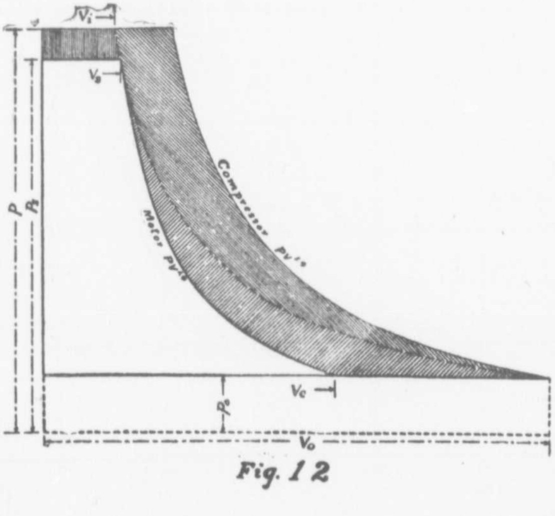


Fig. 12

The air enters the motor from the mains at pressure, volume, and temperature, denoted by p_s v_s T_o. It does work of amount

$$p_s v_s + \frac{p_s v_s - p_o v_e}{\gamma - 1} - p_o v_e$$

$$= \frac{\gamma}{\gamma - 1}\left(p_s v_s - p_o v_e \right) \ldots (15)$$

$$= \frac{\gamma}{\gamma - 1} c(T_o - T_e) \ldots . (16)$$

As before $T_e = T_o\left(\frac{p_o}{p_s}\right)^{\frac{\gamma - 1}{\gamma}}$ ....(17)

so that, expressed in terms of p_s, p_o, and T_o the work done during adiabatic expansion in the motor is

$$W_{ma} = c\, T_o \frac{\gamma}{\gamma - 1}\left[1 - \left(\frac{p_o}{p_s}\right)^{\frac{\gamma - 1}{\gamma}}\right] \ldots\ldots (18)$$

If the motor were as good as possible, so that the air expanded isothermally, heat being added from the store in the atmosphere, it would do the work.

$$W_{mi} = c\, T_o \log_e \frac{p_s}{p_o} \ldots\ldots (19)$$

The efficiency of the simple adiabatic motor is therefore :

$$\eta = \frac{W_{ma}}{W_{mi}} = \frac{\frac{\gamma}{\gamma - 1}\left[1 - \left(\frac{p_o}{p_s}\right)^{\frac{\gamma - 1}{\gamma}}\right]}{\log_e \frac{p_s}{p_o}} \ldots\ldots (20)$$

In this case p_s and p_o are 6.5 and 1 respectively, so that

$$\eta = \frac{3.5(1 - .154^{.286})}{1.8718} = 77\%$$

This is illustrated by diagram No. 12, where the white card is that expected from the motor; the shaded areas show the losses in compressor, mains, and motor respectively.

If there were no fall of pressure in the mains, expression (18) would be changed to

$$W_{ma} = c\, T_o\left[1 - \left(\frac{p_o}{p}\right)^{\frac{\gamma - 1}{\gamma}}\right] \ldots\ldots (21)$$

so that the air gains in volume by its fall in pressure, the effect due to pipe friction being to make the rate of expansion in the motor less. The ratio of the works done in two perfect motors working one with and the other without loss by pipe friction is

$$\frac{\log_e \frac{p_s}{p_o}}{\log_e \frac{p}{p_o}} \text{.................... ....} (22)$$

If $p = 7$ and $p_s = 6.5$ this ratio is $\frac{1.8718}{1.9459} = 0.964$.

The total thermodynamic efficiency of the system or the ratio of the indicated work of the motor to that done on the simple adiabatic compressor (Case I) is then

$$0.77 \times 0.964 \times 0.744 = .554.$$

Allowing 0.85 for the mechanical efficiency of the prime mover driving the compressor, and 0.9 for that of the motor, we have $0.85 \times .554 \times .9 = .423$ for the total efficiency of the system. Or 42 per cent. of the work indicated in the steam engine is delivered on the brake at the motor.

Case II. With spray injection; but otherwise as in last case the work would be

$$W_{ms} = c\, T_o \frac{n}{n-1}\left[1 - \left(\frac{p_o}{p_s}\right)^{\frac{n-}{n}}\right] \text{......................} (23)$$

were n may be from 1.25 to 1.4.

Case III. In a compound motor the air is exhausted out of the first cylinder into a large receiver at atmospheric temperature, and is thus, or by mixing with a jet of spray, raised in temperature (nearly) to that at which it entered from the mains; which, if no preheater be used, will also be that of the atmosphere.

In this case the work done in the high pressure cylinder is

$$\frac{\gamma}{\gamma-1}\,(p_s v_s' - p' v_e') = c\, T_o \frac{\gamma}{\gamma-1}\left[1 - \left(\frac{p'}{p_s}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

That done in the low pressure cylinder is

$$\frac{\gamma}{\gamma-1}\,(p' v_s' - p_o v_e) = c_i T_o \frac{\gamma}{\gamma-1}\left[1 - \left(\frac{p_o}{p'}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

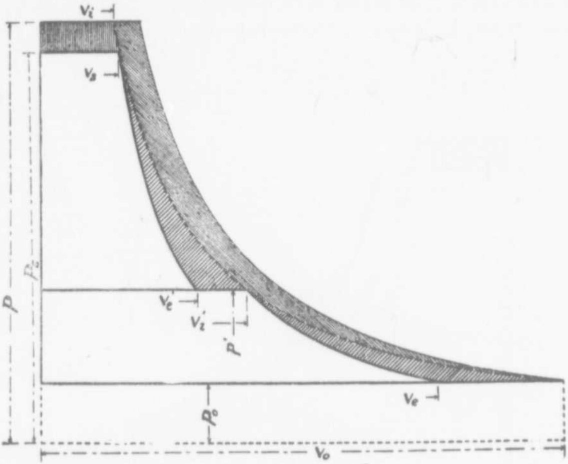


Fig. 13

The work done by both is

$$W_{m2a} = e\,T_o \frac{\gamma}{\gamma - 1}\left[2 - \left(\frac{p'}{p_e}\right)^{\frac{\gamma-1}{\gamma}} - \left(\frac{p'}{p_s}\right)^{\frac{\gamma-1}{\gamma}}\right] \text{.........(24)}$$

If p' be taken equal to $\sqrt{p_s\,p_o}$ which gives maximum work in the motor and equal power developed in each cylinder; then

$$W_{m2a} = c\,T_o \frac{2\gamma}{\gamma - 1}\left[1 - \left(\frac{p_o}{p_s}\right)^{\frac{\gamma-1}{2\gamma}}\right] \text{...............(25)}$$

If this two stage motor be supposed supplied from a three stage compressor working with spray injection (Case IV of compressors) the the total thermodynamic efficiency

$$\iota = \frac{\dfrac{2\gamma}{\gamma - 1}\left[1 - \left(\dfrac{p_o}{p_s}\right)^{\frac{\gamma-1}{2\gamma}}\right]}{\dfrac{3n}{n-1}\left[r^{\frac{n-1}{3n}} - 1\right]} = \frac{7[1 - .154^{\cdot 142}]}{18[7^{\cdot 056} - 1]} = .796$$

and the total working efficiency : – .765 × 796 = 0.61.

Case IV. Let one pound mass of air arriving from the mains in the state $p_s\, v_s\, T_o$ be heated at constant pressure in a small stove to a temperature T_r, so that its volume increases to

$$v_r = v_s \frac{T_r}{T_o}$$

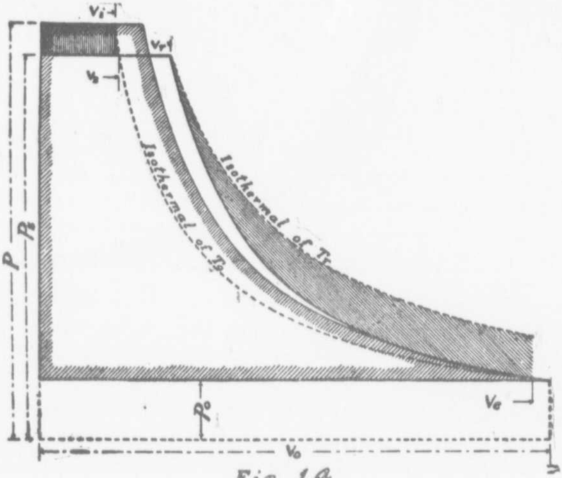


Fig. 12

If the expansion be adiabatic the work done in the high pressure cylinder is

$$p_{sr} + \frac{p_s v_r - p^1 v_e^1}{\gamma - 1} - p^1 v_e^1 = \frac{\gamma}{\gamma - 1}\left(p_s v_r - p\ v_e^1\right)$$

$$= c\ T_r \frac{\gamma}{\gamma - 1}\left[1 - \left(\frac{p^1}{p_s}\right)^{\frac{\gamma - 1}{\gamma}}\right]$$

Let the air then exhaust into the low pressure cylinder passing through a second small heating stove on its way, and thereby being raised in temperature again to T_r.

The work done in the low pressure cylinder with adiabatic expansion down to the atmosphere will be

$$\frac{\gamma}{\gamma -}\left(p^1 v^1 - p_o v_e\right)$$

$$= c\ T_r \frac{\gamma}{\gamma - 1}\left(1 - \left(\frac{p_o}{p^1}\right)^{\gamma - 1}\right)$$

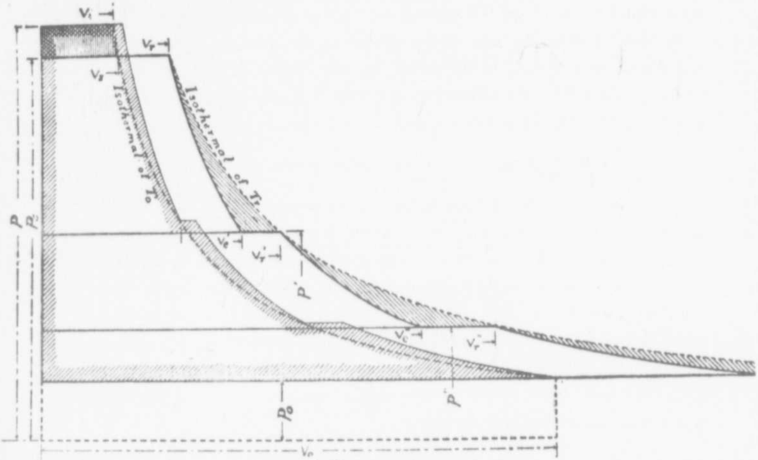


Fig. 15

and the total work when $p^1 = \sqrt{p_s p_o}$ is

$$W_{m2r} = cT_r \frac{2\gamma}{\gamma-1} \Bigg[1 - \left(\frac{p_o}{p_s}\right)^{\frac{\gamma-1}{2\gamma}} \quad \text{.........................} \quad (26)$$

So that the work done increases proportionately to the rise of absolute temperature. Diagram 15 illustrates a three stage motor.

The ratio of the work indicated here by the motor to that indicated in the compressing cylinder is

$$\eta_t = \frac{c\,T_r \frac{2\gamma}{\gamma-1}\left[1-\left(\frac{p_o}{p_s}\right)^{\frac{\gamma-1}{2\gamma}}\right]}{c\,T_o\,\frac{3n}{n-1}\left[r\ \ 2n\ \ -1\right]} \quad \text{.............. ......} \quad 27$$

if $T_r = 400 + 461$ and $T_o = 60 + 461$, then

$$\eta = \frac{861 \times 7[1 - .154^{.142}]}{521 \times 18\,[7^{.056} - 1]} = 1.306$$

and the total efficiency of the system is

$$\eta_t = .765 \times 1.306 = .999$$

against this must be set a quantity of coal which by experiment has been found to be about 0.3 pounds per horse power per hour.

Without preheating, one horse power in the distant steam engine was found to give 0.61 horse power on the motor brake. With preheating to 400° F. we get 1.0 horse power. Hence we get 0.39 horsepower by an additional expenditure of 0.3 pounds of coal or

$$\frac{.3}{.39} = 0.78 \text{ pounds of coal per horse power per hour.}$$

It will be remembered that it was found advantageous in the compressor to keep down the temperature by abstracting heat during compression, which is delivered to natural reservoirs such as water or air at atmospheric temperature. (v. Prof. Elliott's paper.) Similarly we see that in the motor the most economical mode of doing work is to keep up to the isothermal curve as much as possible by adding heat during expansion from these same natural sources, water and the atmosphere, either by injecting a spray or by using an interwarmer at atmospheric temperature.

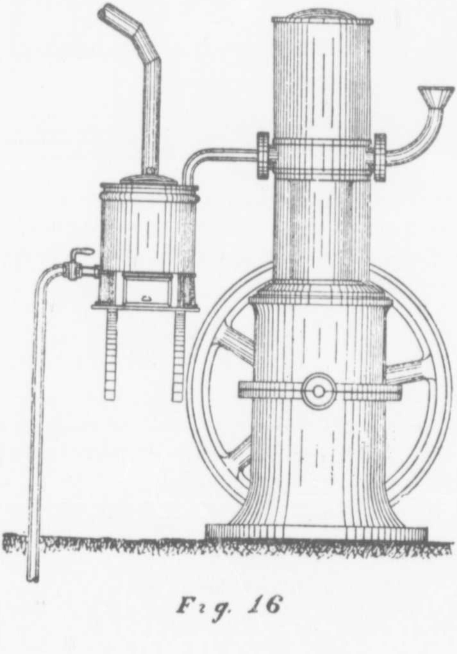


Fig. 16

1 H.P MOTOR

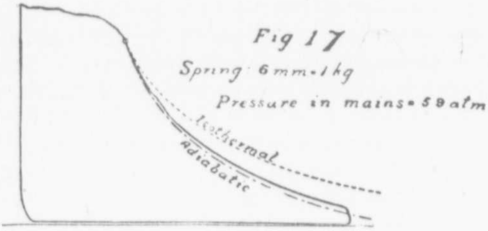


Fig 17

Fig 18.

40 H.P MOTOR

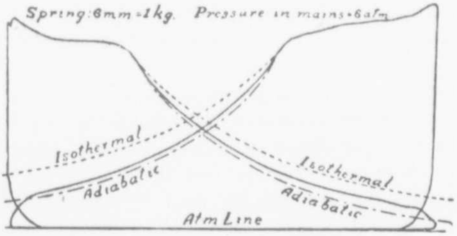
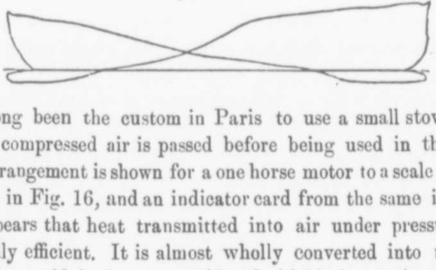


Fig 19



It has long been the custom in Paris to use a small stove through which the compressed air is passed before being used in the motors; such an arrangement is shown for a one horse motor to a scale of one inch to the foot, in Fig. 16, and an indicator card from the same in Fig. 17. It now appears that heat transmitted into air under pressure is extraordinarily efficient. It is almost wholly converted into mechanica effect. This would lead us to consider the highly interesting question of the theory of the preheater. The author prefers, however, to withhold this for the present, pending the completion of some experiments now being made on the subject at McGill College, by which he hopes to be enabled to fill in the necessary constants in the expressions obtained for the heat transferred into the fluid under given conditions of heating surface, temperature difference, velocity, and dryness of the air. Suffice it for the present to give the following practically realized data for a moter of one brake horse power:—the air can be heated from 60° up to 400° F., with a stove whose external dimensions are 8″ diameter and 12″ high at an expenditure of 0.44 pounds of coke screenings per hour; while for a motor of 40 horse power the preheater need only be 16″ diameter and 28″ high, and will require only 0.22 pounds of fuel per horse power per hour.

The possibility of the subsequent addition of energy at such an insignificant cost is a special characteristic of this system of energy transmission. Such a supplementing charge can indeed only be administered when compressed air is the working fluid; and by this means not only can the heat uselessly produced at the generating station and lost in the mains be made good; but, as has just been shown, more heat may be added than was originally lost, and the motor may at a very small expense, and without any additional trouble or inconvenience, give out more power than was spent on the compressor.

In reference to this point it may be stated that the air motors and preheaters in Paris are attended to,—perhaps more correctly stated are left unattended,—by waiters and domestic servants who have all manner of other employments. All they have to do is to turn on the air-cock, refill the lubricators, and put on a shovelful of fuel once or twice a day. As Prof. Riedler has remarked, the air motor appears to be even a more long suffering machine than the steam engine, which is so deservedly celebrated in this respect. With regard to the amount of preheating to be resorted to, this depends on the size of motor and the desired temperature of exhaust. If the motor is a large and powerful one it may be advisable to use two heaters, both a preheater and an interheater. For motors of 10 horse power and under, however, one will usually be sufficient. If the air enters without preheating, it will be exhausted at temperatures from 10° to 25° F., in which state it may be used for cold storage or other similar purposes. This is largely the case in Paris, where in many restaurants and cafés, air motors drive the dynamos for lighting, and the escaping cold air is afterwards led into refrigerators for obvious purposes. Confectioners again use the motor during the day to drive the mixing and other machines, light their shops in the evening, and use the exhaust for making ice. The exhausting of clean cold air into a workshop is a great advantage in a hot climate. If, on the other hand, recourse is had to a considerable amount of preheating, the air will be exhausted at or even above atmospheric temperature ; and with a large motor, enough warm fresh air may be obtained to serve in winter for heating and ventilation.

In concluding this part of the paper it will be well to recapitulate in brief the several efficiencies of the different parts and the combined efficiency of the whole system for one or two of the cases most likely to occur.

The mechanical efficiency of the compressing machine may be safely taken to be 0.86, the Paris installation compressors gave this result; and with the new 2000 horse compressors Riedler has obtained 0.9. A turbine will give from 0.75 to 0.8 for the same ratio.

The thermodynamic efficiency of the compressors is for a single stage compressor with spray injection 0.85, and for a two stage compressor 0.92.

The loss in the mains due to leakage and fall of pressure for a 5 mile transmission may be put at 3.8 per cent., so that the efficiency of the mains is 0.962.

The thermodynamic efficiency of a simple adiabatic motor without preheater is 0.77 ; of a two stage adiabatic motor 0.9 ; of a simpler preheated motor 0.8 to 0.9 ; and of a two stage preheated motor 1.1 to 1.3.

The total efficiency or ratios of the *brake horse power* of the motor to the horse power used in the compressors for the two cases which we have to consider in estimating the financial possibilities of a pneumatic power supply are therefore as follows :—

Case I. Turbines driving best compressors, power transmitted through 5 miles of main, largest air motor for factory, with two stage heater,

Easily possible : $0.92 \times 0.96 \times 1.25 = 1.1$.

Actually done : $0.90 \times 0.96 \times 1.16 = 1.0$.

Case II. Turbines driving best compressors, power transmitted and distributed by 7½ miles of main, medium sized simple air motor with preheater,

$0.92 \times 0.94 \times 0.87 = 0.75$.

Case III. Triple expansion steam engines driving best compressors at central station in or near city, power distributed in 5 miles of main and consumed in an average simple preheated motor,

$0.92 \times 0.96 \times 0.87 = 0.76$.

The mechanical efficiency of the turbine or steam engine is here left out, as it will be allowed for in the estimated cost of a horse power delivered to the compressor.

In entering upon the consideration of the commercial feasibility of a transmission and distribution scheme by compressed air, let us direct our attention to a concrete case, and postulate the conditions which obtain in the locality in question as regards cost of coal, nature and amount of available water and other power.

Referring, for example, to Montreal, let us take for granted that an abundant supply of water with a fall of, say, 20 feet can be obtained 5 miles from the city; and that all difficulties in connection with the utilisation of this power, such as frazil, can be, as the author believes they can be, successfully overcome. This being the case, let us in the first place consider whether power can be supplied on a large scale to a mill owner at anything like the same price as he can make it for himself by burning coal in steam boilers and using the steam in a first class steam engine.

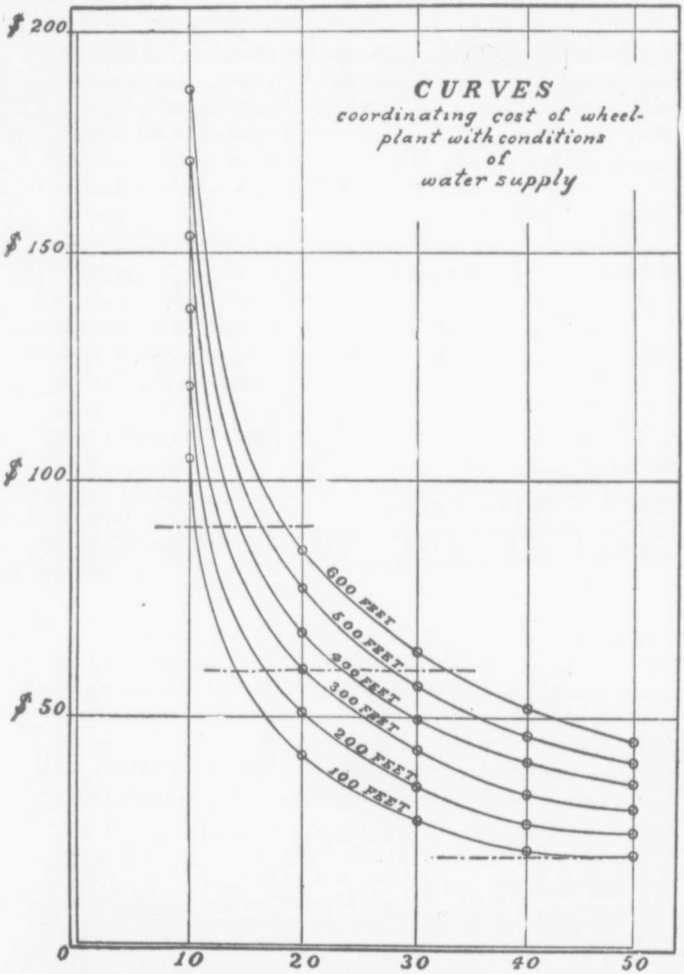
First then let us ascertain at what price per horse power per annum a pneumatic power supply company owning its water supply can afford to deliver to a consumer 5 miles away compressed air at a pressure of, say, 95 lbs. on the gauges.

From statistics and data given by Swain, Manning and Main, it appears that the cost of one H. P. on the wheel shaft, that is for dam, head and tail races, turbines and shaft, penstocks, gates and wheel-pit, for a 2,000 H.P. plant, varies from $17.00 with a fifty foot head, 100 foot distance from supply to discharge, to $153.00 with a ten foot head and a distance of 600 feet. (See Fig.)

In the case of the works now approaching completion at Austin, Texas, the figure, as kindly supplied me by Mr. Lea, of McGill College, is $14.00 for an average head of 57 feet and a distance from canal to river of 600 feet.

In the present case it has been assumed that the cost of one wheel H.P. is $90.00; which will allow, with a head of 20 feet, a distance from supply to discharge of about 700 feet, or, with a head of only 10 feet, a distance from river to canal of 100 feet.

It will probably be admitted that this is a somewhat high estimate for this location, where the average head may be expected to be from 20 to 30 feet, and the possibility of dispensing with a dam will allow for almost any reasonable length of supply and discharge canals. The fixed expenses on this capital sum are here taken at interest 5 per cent., repairs 1 per cent., depreciation, etc., 2 per cent., or a total of 8 per cent., which on $90.00 amounts to $7 20. The running expenses, including attendance, oil and waste, are taken at $0.75 per H.P., making a total annual expense per H.P. supplied at the turbine shaft of $7.95.



The compressors will cost considerably less than a steam engine of equal power; for although they cannot be said to be now in the market in this country (the highest type of modern first class compressor being here in question), yet this will be more than compensated for by the lack of air and circulating pumps, and the fact of there being no crank shaft to charge against the compressor, this having been already reckoned along with the cost of the turbines. The cost price of compressors may therefore be taken at $10.00 per gross H.P., and if we take the fixed expenses at :—interest 5 per cent., depreciation 4 per cent., repairs 2 per cent., together 11 per cent., and the running expenses at 75 cts. per H.P., the total cost per H. P. per annum of compressors is $1.85.

The twelve inch cast iron mains with special flexible joints, as used in Paris, may be expected to cost $30.00 per ton ; which is at the rate of $1.00 per running foot. Adding 25 cts. per foot for trenching and laying, we obtain a total of $33,100, or $16.55 per H. P., for 5 miles of 12 inch main. Taking interest 5 per cent., depreciation 3 per cent., repairs ½ per cent., together 8½ per cent., the cost per H. P. per annum amounts to $1.40.

The total cost per annum to the Power Supply Company of one compressor horse power is

Water Power....................................	$7.95
Compressors....................................	1.85
Mains....................................	1.40
or a total of	$11.20

This includes 5 per cent. interest on the capital expended.

The capital expended up to this point by the company, including that upon dam, canals, penstocks, wheel-plant, compressors and mains, amounts to $116.55 per H.P. Five per cent. on this sum amounts to $5.82, which added to $11.20 makes a total of $17.03. If then the Supply Company charge the consumers at the rate of $17.00 per H.P., they will secure themselves a revenue of 10 per cent. on their outlay.

For this sum of money the Supply Company do not supply to the consumer a quantity of air sufficient of itself to produce one H.P. But in order to effect this it is only necessary for the mill owner to fit, as part of his motor plant, one or two heaters to supply the energy lost in transmission. The cost of the motor, including these heaters, may be expected to be less than that of a steam engine of the same power. But, taking the cost at $12.50 per H.P., and reckoning on this, fixed expenses at the rate of 11 per cent., viz., 5 per cent. interest, 4 per cent. depreciation, 2 per cent. repairs ; taking also $5.00 as the cost of the motor house, with 10 per cent. as fixed charges, the total cost to the consumer of his own power plant is $1.90 per H.P. per annum. To this must be added the running expenses as follows : —

One man at $2.50	$1.56
Oil waste and supplies	0.80
Coal for the two heaters at together 0.3 lbs. per H.P. hr. at $4.00 per long ton	1.65
Total	$4.01

The air discharged by the motors will be of sufficient amount and at such a temperature as to heat some portion of the mill; but for security we shall add a plant for heating alone of one-fifth the size of the original steam plant replaced by the air motor. This plant will cost about $15.00 per H.P., so that the capital outlay will be $3.00 per H.P. of power. Taking the fixed expenses at 12½ per cent. on $3.00, that is $0.38; the running expenses (viz. : coal at $2.00 ; attendance (one man at $1.40 for 150 days say $0.42) at $2.42; the total cost of this heating plant per horse power of power plant will be $2.80.

Adding together all the items of the mill owner's annual expenditure viz. :

Cost of air supply	$17.03
Air motors	4.01
Extra heating	2.80
	$23.84

We obtain a total of $23.84 as the annual cost to the mill owner of his air supply, air motors, and steam heating plant.

With this we have now to compare the cost to him of steam engine and boilers of the same power.

Assuming with Mr. Main (Trans. Am. Soc. Mec. Eng., Vol. XI.) that the consumption of coal per 1 H.P. per hour of a compound engine is 1.75 lbs. and of a high pressure engine 3.00 lbs., and allowing that 25 per cent. of the steam exhausted from the high pressure cylinder is taken from the receiver for heating purposes, we obtain a consumption for this combined steam power and heating arrangement of $(1.75 \times .75 = 1.31 + 3.00 \times .25)$ 2.06 lbs. per horse power hour. The coal bill @ $4.00 per ton will therefore amount to $\left(2.06 \times 10 \times 308 + \frac{4.00}{2240} =\right)$ $11.35. For boiler attendance we must allow two men at $1.50 and for the engine one man at $2.50 for every 500 Horse Power or $\left(\frac{4.00 \times 308}{500} = \right)$ $2.46 per H.P. per annum. With $0.80 for oil and vaste and no allowance for cost of feed or tax on condensing water, which are supposed to be supplied free by engine circulating pump, the running expenses amount to $14.61 per H.P. per annum.

The fixed expenses must be reckoned on the cost of boilers, engines and houses.

Boilers of the Babcock Wilcox type cost about $20.00 per H.P. and $5.00 for setting, together $25.00. With interest at 5 per cent., depreciation 5 per cent., taxes and insurance 2 per cent., repairs 2 per cent., together 14 per cent., this works out to $3.50 fixed expenses on boilers. The boiler, coal houses and chimney cost about $6.00 a horse power, which comes to $0.60 per H.P. per annum, if interest, depreciation and repairs be taken at together 10 per cent.

The first cost of a steam engine in the neighbourhood of 500 horse power is $10.00, with 25 per cent. for setting, $12.50. Taking the charges at 11 per cent., viz. : interest 5 per cent., depreciation 4 per cent., repairs 2 per cent., the fixed cost of the engine will amount to $1.40, while the engine house costing $5.00, at 10 per cent., increases this by $0.50.

The total expense incurred by the mill owner for the production of power by steam is therefore :—

Fixed expenses	Boilers	$3 50
	Boiler house and chimney..	0 60
	Engines	1 40
	Engine house	0 50
Running expenses	Coal	11 35
	Oil and waste	0 80
	Attendance	2 46
		$20 61

per horse power per annum.

The cost of a horse power supplied by means of water and air was found to be $23.84, hence we see that so long as coal remains so abundant and cheap, and can be so cheaply transported by land and sea, other natural sources of energy will continue to be of an inferior value.

The great transmitters of energy are indeed our railways and steamships, which transport at a rate infinitely cheaper than by any other means the enormous stores of mechanical energy accumulated in our coal fields; and that in any required amounts and to any distances unhampered by the losses of power which inevitably accomplish every transformation.

The only chance for a commercially successful utilisation of water power in a neighbourhood well situated for coal supply is a case where the capital outlay for water plant can be reduced considerably below $90.00. As, for instance, by the accident of great head; such natural fitness that the supply and discharge canals may be short, or that a dam is not necessary. Then and then only can power be supplied to a distant mill by means of compressed air at a price which competes with the cost of production by steam at the mill or factory itself. If, for example, we take the capital outlay at $20.00 (a point shown on the diagram near the lower limit) instead of $90.00 for power delivered by the turbine shaft, then the annual cost to the mill owner of his air supply, air motors, and steam heating plant on the same scale as before is reduced to $15.34, or about two-thirds of its former estimated cost, one-fourth less than the calculated cost of steam. It remains for experts on water utilisation in this district to examine whether a source of water power supply cannot be found, such that the initial outlay per horse power delivered to the compressors need not be more than $60.00; in which case, power can certainly be supplied on the pneumatic system at a cost less than that of steam even to a large factory working full time.

It will of course be observed that in these two estimates of transmitted power, it has been tacitly assumed that the horse power indicated by the motors was the same as that given to the compressors. Not merely can this be certainly secured *even on the motor brake* with such an insignificant expenditure of coal as that mentioned above; but, as has been actually effected with plant, far from being near the limit of that which is technically possible, an actual gain of work is possible, a working efficiency of 116 per cent. having been obtained.

Any other system of transmission, wasting as it must at least 25 per cent. of the energy supplied at the wheel shaft, at once raises the cost per horse power from our supposed $15.34 (when the capital outlay for water power is $20.00) to $20.45, or the same as that of steam.

Let us now turn to the case of an employer using a small amount of power, and we shall find, as is well known, that he must fall an easy prey to our central power supply company, even if he does not use his power intermittently, as is almost always the case.

We have seen that the air compressed at a water power station can be delivered to a city five miles away for $23.84, when the cost of water plant is $90.00 per horse power. If we increase the price to $25.00 we shall have allowed for about 5 miles of 9 inch mains in the city; and the supply of consumers at this rate allows the Power Company 10 per cent. on their capital outlay. We shall assume that a ten horse air motor gives out on its brake for a given quantity of air only 75 per cent. of the power used in compressing that air. Experiments made on the smallest motors of less than one horse power commonly used in Paris gave this total efficiency at close on 50 per cent., while larger machines, as a general rule, simply old steam engines with very small mechanical efficiency, gave 80 per cent. with but 90° F. preheating of the air and a coal consumption of $\frac{1}{5}$ pound per horse power per hour. Then our small consumer must pay $\$25.00 \times \frac{4}{3} ==$ $33.33 for the air required to deliver him *one brake horse power;* not *one indicated* which he usually pays for.

If his motor and preheater cost him $33.00 per horse power, the fixed charge at 10 per cent. will be $3.30; and if he uses 0.2 pounds of coal, his running expenses will be $1.10 per horse power per annum when he works 3,080 hours a year. The total cost to this consumer of one brake horse power thus amounts to:—

Air..............................	$33 33
Fixed charges....................	3 30
Running expenses..........................	1 10
	$37 73

$37.75. This assumes that he works at full power for 10 hours a day during 308 days. If he works only at $\frac{1}{2}$ power, this price will be reduced almost in proportion to the smaller power employed, as the air motors cut off automatically; and if he work intermittently, it will be reduced in the same manner, as he is only charged for the air which actually passes through his meter. For example, if his 10 brake horse power motor works 10 hours a day, his power bill will be $377 per annum. If he runs only five hours a day, the amount sinks to $210; and smaller quantities in the same proportion meted out with the precision of an ordinary gas meter. This estimate is based on an assumed necessary expenditure of $90.00 for wates and wheel plant. The author believes this to be a very high price for Montreal.

The cost of a horse power varies in Montreal from $60 to $120, rented to or supplied by consumers using from 3 to 25 horse power; so that on the lowest estimate these would save from $22 to $39, according to amount used, per horse power per annum, by a system of compressed air distribution.

Let us now inquire what can be done by generating power in a Central Station near the city, by means of first class triple expansion steam engines and first class compressors; and distributing the same to customers in a main of a length of two miles for each 2,000 horse power.

Without troubling the Society with details, the schedule of annual charges will run somewhat this :—

Fixed expenses,	Boilers	$3 50
	Boiler and engine houses and chimney.	1 20
	Triple expansion steam engines	2 23
	Compressors	1 10
	Mains (12″ dia.)	0 56
Running expenses,	Coal	8 28
	Oil waste, etc	1 00
	Attendance	2 46
		$20.33

The total cost to the Central Station Company of one compressor horse power is thus $20.33, which includes 5 per cent. interest on their expended capital of $71.37 per horse power.

This outlay is made up as follows:

High-pressure boilers and setting	$25.00
Houses and chimney	11.00
Triple engines and setting	18.75
Compressors	10.00
Mains	6.62
Total	$71.37

Allowing 5 per cent. more on this, or $3.57, we have a total of $23.90; which is the price at which the Central Station Company can upply air for one-horse power and secure at the same time 10 per cent. interest on their capital outlay.

The easy inference from this is that 500 consumers in this city, of an average of four-horse power each, would, by forming themselves into a Central Power Supply Company, reduce their power bill by from 45 per cent. to 75 per cent. ! It ought to be mentioned that the lower limit of saving just mentioned, assumes that the consumers' steam engines, which, without alteration, will serve equally as air motors, have a present value of $33.00 per horse-power.

Regarding the question of heating in winter, there seems every possibility, in view of the successful system of steam distribution in New York, of being able to supply heat by laying mains to the city from the Central Power Station, and leading the exhaust from the steam engines in the same to be delivered to the workshops and houses in turn; and this at an enormous saving of fuel and expense to all concerned.

This would also be a most desirable scheme from the point of view of the elimination of smoke from our large cities.

The great benefit to small producers by such a great reduction in cost of power is obvious, and need not at present employ our further attention.

Reference ought here to be made to many advantages apart from the question of cost which attend the adoption of the pneumatic system of power supply.

In the first rank we may place the elimination of 95 per cent. of the smoke which now renders manufacturing centres so obnoxious from an æsthetic point of view, and of the dangers and responsibility attending the use of steam boilers by unskilled persons, these being done away with or removed from the more crowded parts of the city. The possibility of running air motors in the centre of the city, where a supply of water for condensing or even feed is extremely expensive, is an obvious advantage.

The extreme handiness of the working medium and its suitability for use by technically unskilled attendants has already been adverted to. In this respect the air motor bears away the palm from the electric motor, the gas engine, and even the much enduring steam engine; all of which require a certain modicum of knowledge or experience. The repairs also of such a machine require only a knowledge of perfectly well understood mechanical details.

The use of the exhaust for either refrigeration, ventilation, or even heating renders the rejected air a beneficial by-product, instead of a nuisance, as the exhaust from a steam engine certainly is in summer.

The suitability of compressed air for the working of lifts ought not to escape mention; a cheapening of the first cost of at least 10 per cent. and of running expenses at the rate of 75 per cent. over other systems can be easily attained.

Tram cars worked by compressed air are now in use in Nantes Brussels, Chester, and other places; they have there proved both serviceable and economical in spite of the fact that the power they use is generated in small compressing stations. A reservoir capacity with air at a perfectly safe pressure can be obtained with an ordinary sized car to do a return journey of 5 miles without any intermediate charging station; and the consequent removal of a dangerous overhead wire, such as is used on the electric trolley system, is not to be despised in a populous city such as this. The difficulty of snow could be overcome by having a car devoted to clearing the tracks alone; but this will be preferably effected by having a light overhead railroad, as the ruts in the streets caused by keeping a clean tramroad in winter are extremely unpleasant, not to say dangerous, to occupants of vehicles.

The convenience with which compressed air as a working agent could replace steam in a city already supplied with power by a number of small steam engines is sufficiently indicated when it is stated that all that is necessary to be done, without altering the engine in the slightest degree, is to uncouple it from the boiler and connect to the air main in the street with the interposition of a reducing valve and an air meter. The steam boiler may then be sold and the engine tender may devote nearly his whole time to other duties.

The low price of small motors may be referred to. They cost less in Paris than even steam engines, which are of course easily the cheapest of all small motors; and the introduction of good rotary patterns has rendered their availability for small industries still more marked.

We have concluded from the calculations above elaborated, and which are based upon results already obtained with the Popp system in Paris, easily improvable, that a great economy in the cost of power to small employers can be effected by the adoption of a scheme for the centralised production of mechanical energy and its distribution by the use of compressed air. The question now naturally arises: Is this encouragement of small employers a wise thing to aim at from the point of view of the whole community, or ought we not rather to repress and altogether annihilate them in order that all industrial work may be confined to large factories?

A complete answer to this far-reaching question will not here be attempted; but the following considerations may not be out of place.

Statistics show that three-fourths of the mechanical power now used in the world has originated within the last thirty years; and it has also been computed that one hundred times more work is done by the aid of machinery at the present day than by the combined efforts of the whole human race. The work of this vast and terrible mechanical agency must of necessity ever increase and grow in amount; it cannot in the slightest degree be limited or discontinued without the instant decline and final cessation of our material civilisation.

We are therefore face to face with this enquiry:—Are we to confide to the capitalists the sole mastery and control of this enormous power, upon the wielding of which the very destinies of the race depend? Or ought not rather the vast stores of Nature's energy to be at the common disposal of all, as a beneficent working agent?

It truly appears to the author that the results of the long continued operation of the former alternative are at the very root of the great Labour questions with their accompanying Socialisms and Communisms which are now so momentous in all the countries of Europe, and are beginning to agitate even the New World.

Consider the conditions of life of the factory hand. When a young workman, he sees no prospect of ever being able to compete as an independent employer with the large establishments producing the commodities he helps to make; he accordingly never dreams as a rule of saving his earnings for the purpose of establishing himself in business; but on the contrary uses the same to minister merely to his pleasures, and frequents the society of men like himself who, naturally ill content with their conditions of life, indulge in noxious political talking, if nothing worse. This state of things is certainly not improved, when, as he advances in life, from which the freshness and gloss have now been removed, he sees nothing before him but his day of toil unrewarded save by his weekly wage.

It is far otherwise with a man who can be his own employer. He takes pleasure in, and works with diligence and foresight at, an occupation from which he anticipates a personal reward for his own industrious skill. His intelligence is quickened by the invention of better methods for the carrying on of his work and in the buying of his own materials and the sale of his own finished products. He will have an apprentice or two who ought, if they are not already members of his family, to live in his house, and who consequently, from personal esteem, will take as keen an interest in the business as he does himself. They know that they themselves will some day be small employers, so that no detail of the whole organization will escape their vigilance.

There is no reason why these people should not have high moral and political aims, if only a strong government attends to the just protection of their rights and property; and they can then have no possible grounds of complaint.

It would seem therefore not illogical to draw the conclusion that in a state where small industries flourish there will reign peace, contentment, order, and prosperity; that discord imported from without can find no root, while discontentment from within can never arise.

We all know that the factory hand is a much more common object than the contented small employer; and this is the direct result of the extremely unfavourable condition in which such small employers are placed as regards the obtaining of mechanical power. As a consequence they have to work with antiquated tools; for almost all the great technical improvements pass over without touching them, the first requirement for their application being the possession of motive energy, so that they shortly fall hopelessly behind in a race in which they are so heavily handicapped. How can it be otherwise when it is remembered that they must pay from 4 to 10 times more for power than the more fortunate capitalist does; and are at the same time encumbered with taxes and regulations by the authorities levied upon the possession of prime movers in the midst of populous cities?

Sooner or later it must come that the small employer will obtain for himself the advantages accruing from the economical use of power which are at present the monopoly of the capitalist alone.

The great technical advances recently made in electricity and in the use of compressed air evidently point to the speedy accomplishment of this desirable result. And in a very few decades we may confidently predict the removal from our manufacturing cities of all the wasteful and noxious gas-producing prime movers now used; in their stead the employment of more convenient and more economical secondary motors supplied from mains in the streets which lead the working fluid from well conducted and favourably situated power supply stations. When the time comes, compressed air as an energy medium will be found to be an irrepressible young giant demanding and exacting his due recognition.

My best thanks are due to Mr. R. S. Lea, Ma.E., of McGill College, for valuable help in connection with the estimates of cost; and to Mr. G. S. Smith, B.A.Sc. of McGill College, for much careful assistance, without which the preparation of this communication in the midst of a busy session would have been almost impossible.

DISCUSSION.

Mr. Cuningham. Mr. Cuningham said in the using of compressed air, as he understood it, the question which it would resolve itself into would be the saving of energy in the doing of the work. You would expend a certain amount of energy in compressing the air, and that portion would be transmitted into the pipes, and then you would expend more energy in heating the air and turning it into work again. The crucial question is whether there is a saving of energy in doing it in this way or in doing it in the ordinary way.

Mr. Gower. Mr. Gower said as to the question of the depth of the main, he would like to know whether the temperature would have any effect on the air in the pipes? He was of the opinion that it would. He understood that you get 400 degrees with the ordinary preheater, of course you can get as much more as you like by burning a larger amount of coal, this being the case, and it could be brought up to, say, 700 degrees. Would there be corresponding advantage, and to what extent?

Mr. Armstrong. Mr. J. S. Armstrong said he was specially interested in compressed air, and had for some time contemplated making sundry experiments with it. He would like to ask: What pressure will a cubic foot of compressed air, of 6 atmospheres pressure at 60 Fahr., develop when raised to 400? Has any arrangement of valves been used in the connection leading to the pre-heater? Otherwise, does not the expanded air work back into the main as well as forward into the engine or motor?

Prof. Nicolson. Prof. Nicolson in reply said Mr. Cunningham's comments are discussed in the paper.

The depth of the mains need not be more than three feet, as cold does not affect the air when from suspended moisture. The limit of temperature to be restored to it by pre-heating depends on lubrication and packing and not on thermo-dynamical effect.

In answer to Mr. J. S. Armstrong: (1) From $P\ V = c\ T$ (where P V and T are pressure per square foot, volume of a lb., and absolute temperature respectively, and c is the numeric 53.2). We have P varies as T if V remains constant, so that

$$P_{400} = 7 \times \frac{461 + 400}{461 + 60} = 11.56 \text{ atmos absolute.}$$

2nd. The air being heated at constant pressure, not at constant volume, there is a saving in the amount used, and not by means of increased pressure. No arrangement of valves is therefore necessary as suggested.

Thursday, 9th March.

E. P. HANNAFORD, President, in the chair.

The discussion on Mr. Rust's paper on the "Discharge of Sewers," on Mr. Torrance's paper on "Gold and Silver Mining in the Province of Quebec," and on Prof. Nicolson's paper on the "Transmission and distribution of Power by Means of Compressed Air," occupied the evening.

Thursday, 23rd March.

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

Paper No. 76.

TRANSITION CURVES FOR RAILWAYS AND ELECTRIC TRAMWAYS.

By J. S. ARMSTRONG, B.A., M.Can.Soc.C.E.

Mr. A. M. Wellington, M. Am. Soc. C.E., was apparently the first to call attention to the curve used in the following paper, and the writer acknowledges indebtedness to Mr. H. K. Wicksteed's paper, No. 53, Vol. V., Can. Soc. C. E.

The curve herein used is exactly the same as his, but the writer has generalized its use, adding additional and simpler formulæ.

Mr. Wicksteed and others have not proposed to use this curve beyond certain low limits of curvature, because the connection with the higher curves became faulty; but the writer, by certain corrections easily made in the process of finding the starting point, has made these transition curves universally applicable.

Other papers seen by the writer are more or less accurate and generally complicated with higher mathematics not easily followed by those long past college life.

Note.—Since writing the above the writer has seen several other papers, of which Prof. Searle's is on the compound curve principle, while Mr. Howard's is similar to the writer's in some respects, and is most admirably worked out.

Mr. Howard starts from the proposition which gives:

$$Ds_n = \tfrac{1}{3} \text{ Ver Sin } i^\circ R_n$$

$$X_n = Ds_n + \text{ Ver Sin } i^\circ R_n$$

$$Ds_n = \frac{X^n}{4} \text{ (exact within limits)}$$

$$Xc = \text{Ver Sin } i^\circ R_n$$

$$Yc = \text{Sin } i^\circ R_n \qquad \text{See Fig. II.}$$

Scientific Railway location is governed by two opposing considerations: the one making for the best practicable line for future operation; the other obtaining a workable line at the least expenditure of capital.

In balancing these, the engineer on an important line, with ample capital, gives the first the preponderating weight. On lines of less immediate importance, with small capital, he must look most to the last, though, if possible, allowing for future improvement.

The layman has little idea what sums can be saved by good engineering. Hundreds judiciously expended in scientific skill and experience may save thousands otherwise uselessly expended in shovelling mud and in added working expenses.

To get round obstacles and adjust the line as nearly as may be to the surface of the ground necessitates curvature, and connecting the straight parts of the line with the curved by tapered or transition curves adds nothing to the first cost of the line, while it adds materially to the comfort and ease of working.

As greater speeds are used when sharp curves have been, or are, for any reason employed, the more necessary do transition curves become.

It only seems necessary to insist that trackmen keep to well defined lines, and that the professional work be done in a convenient, definite and rapid way to have the use of transition curves more generally adopted.

One such way (applicable to any case, and that can be worked roughly, or to any degree of precision, as the engineer's judgment may dictate) the writer endeavours to show in the following paper.

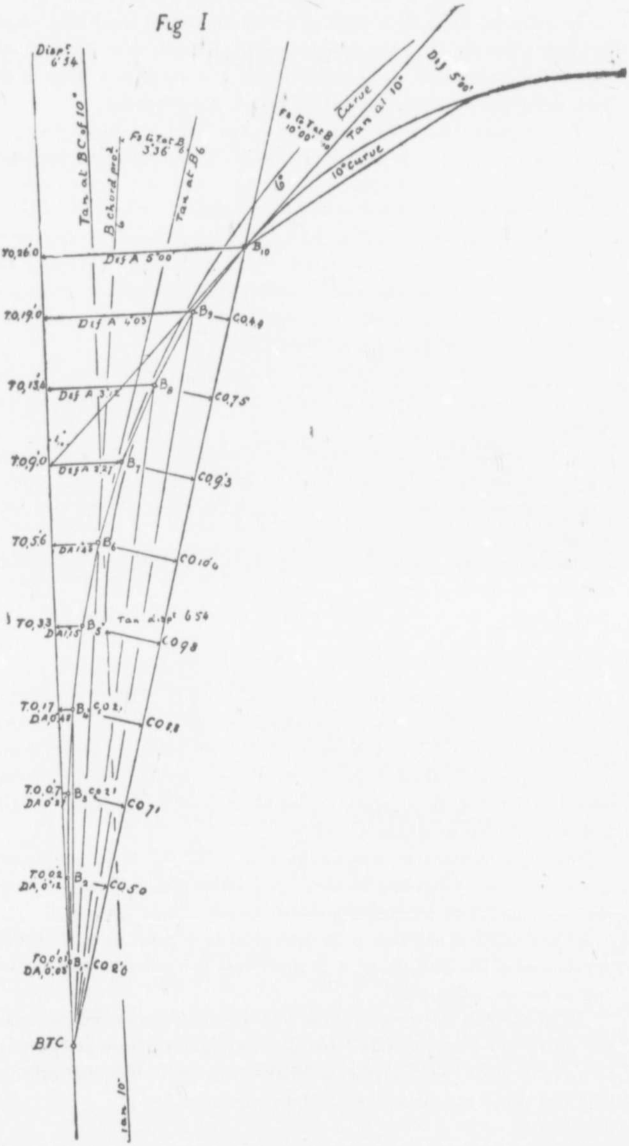
A curve, gradually increasing in curvature, may be run with equal chords, say, of 10′, 20′, 30′ or any other length, with deflection angles from the tangent at the starting point, the first of which, in minutes equals 1-10 of the length of the chord in feet, and the succeeding deflections to the different points on transition curve are proportioned as the squares of their distances from the starting point, or (what comes to the same thing, equal chords being used) to the square of the index numbers of said points.

The curve obtained in this way is such, that its curvature (as expressed in our Canadian or American idiom) is increased by one degree of curvature at each chord end.

At the end of chord one it is equivalent to a point on a 1° curve. At the end of the fifth chord it is equivalent to a point on a 5° curve, nd so for any other point.

An illustration of this is given in Fig. I., which shows such a curve, the angles being exaggerated (drawn three times as large as figured), to make it clear, and represents what for shortness has been called a "30 foot chord transition" or "30 ft. transition."

Fig I



Dispᵗ 6'54
Tan at BC of 10°
B₆ chord proᵈ
Fs G Tat B₆ 3°36'
Tan at B6
Fs G Tat B₁₀ 10°00'
6°
Curve
Tan al 10°
Def 5°00'
10° Curve
B₁₀
T.O. 26'0
Def A 5°00'
T.O. 19'0
Def A 4°03
B₉
CO 4.9
T.O. 13.6
Def A 3°12
B₈
CO 7.5
T.O. 9'0
Def A 2°21
B₇
CO 9'3
T.O. 5'6
DA 1°43
B₆
CO 10'6
T.O. 3.3
DA 1°15
B₅
Tan dispᵗ 6.54
CO 9.8
T.O. 17
DA 0°48
B₄
C O 2.1
CO 8.8
T.O. 0.7
DA 0°27
B₃
CO 2.1
CO 7.1
T.O. 0.2
DA 0°12
B₂
CO 5.0
T.O. 0'01
DA 0°03'
B₁
CO 2'0
BTC
Tan 10°

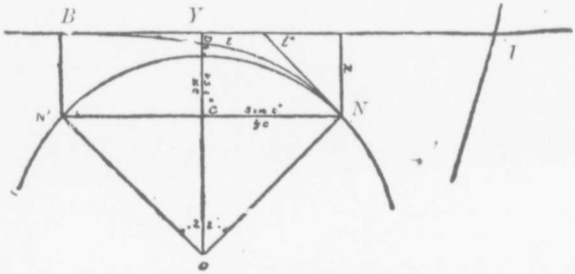
The figure would equally apply to a "10 foot chord transition," in which case the deflection angles would be one-third of those marked.

In this fig. the transition runs to the end of the 10th chord or to a 10° curve point, and the line is continued by a 10° curve beyond. It also shows a 6° curve branching out from the 6th chord end.

The functions written on are the same as given in Table II., to be described in Part II.

To give room for the tapering of the curvature between the tangent and the regular curve, the circle of which the regular curve is a part must be moved away from the tangent as in Fig. II., giving the displacement marked *Ds.*

Fig. II.



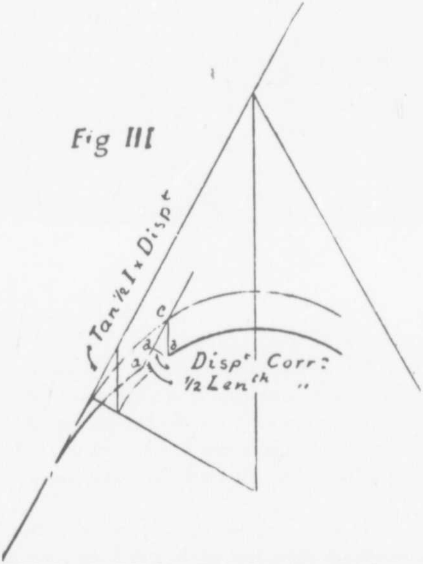
Let the curve *N'N*, Fig. II, represent a curve of any degree of curvature, and *BN* a transition curve of corresponding number of chords. We can draw a tangent to the transition curve at the last chord end, which will intersect the original or survey tangent at a certain angle, and evidently we can find a point on the circular curve the tangent from which will intersect the survey tangent at the same angle.

When transition chord lengths are short and the degree of curvature moderate, very simple rules give us the transition curve and the starting point on survey tangent (in relation to the intersection I) that will make these points coincide; but it requires more complicated rules or modification by way of corrections, to make the said simple rules applicable to long transition curves connecting with the sharper circular ones. With a "10′ chord transition" no corrections are required to connect with a regular curve up to 10° and they are very small up to 16° ; with a 30′ chord transition there are no corrections up to a 7°, and they are very small to a 10°.

Fig. III. shows a case of connecting with a sharp curve where the ordinary rules do not make the corresponding points "*a*" and "*b*" (the tangents to which respectively make the same angle *i*° with the survey tangent) coincide, and is a case where the corrections are required (the fig. is, of course, much exaggerated). These are made by carrying the point "*a*" with its transition curve to "*c*," and the point "*b*" with its curve also to "*c*," (both along lines parallel to the governing lines), thus giving a double correction.

The half length one moves "*a*" to *d* opposite *b*, and the other, the *Ds* correction, moves "*a*" the rest of the way to "*c*," and also moves "*b*" to "*c*."

Fig III

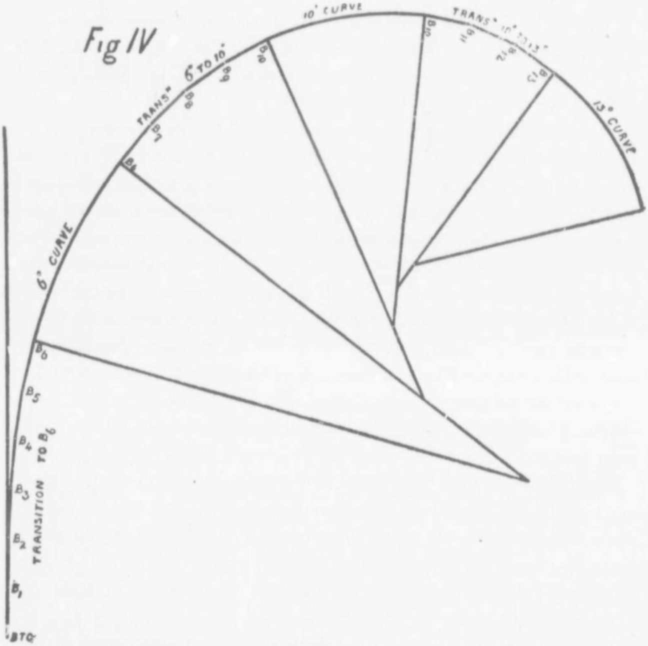


To make matters clear, Table II., described below, is given, and the manner in which the functions were worked out is described in detail; but from inspection of the table, and comparing trial calculations, simpler arithmetical formulæ have in some cases been deduced; these, or the processes described, put in the form of formulæ, are given in Part V. of this paper. A glossary of letters and terms is given in Part IV.

It should be remembered that the greater part of the complicated work shown in this paper is necessitated by carrying the work and tables to higher curvatures than generally used on first class railways, and when understood, the ordinary work is very easy.

Beside connecting tangents with regular curves, one regular curve may be connected with any other regular curve in similar way. As shown in Fig. IV.

Fig IV



In locating or re-locating, the object is generally to put the line in the best position as governed by all the circumstances. It may or may not be practicable to do this by offsets only from an old line or lines.

The curves must be adjusted to the topography, and on first location it will often be unnecessary to mark much more than the *BTC*, the *PCCs* and the *ETC*, with the regular stations on the line. So the important points are to decide on the main curve or curves to use, and the length of displacement; then select the corresponding chord transition and find the distances of the *BTC* and *ETC* from the intersection or other known point.

PART II.

The accompanying table, No. II., of transition curves, is based on the following assumptions, calculations, corrections, etc.

The sub-chord lengths are all 30 feet (one rail length). The linear measurements used are along the curve.

The *BTC* and *ETC* are respectively the beginning and end of curvature (using transitions) at main tangents; B_1, B_2, B_3, etc., and E_1, E_2, E_3, etc., are the end points of 30-foot chords, progressing from *BTC* or *B*, and *ETC* or *E*, respectively.

The curvature is gradually increased (or diminished if towards *E*) 1° in passing over each 30-foot chord, so that the transition curve at every successive chord end has a curvature corresponding to its index number, and is equivalent to a point on circular curve of the same denomination. The tangent to the transition curve at any such poin is the tangent from which the circular curve of like denomination would continue; *e.g.*, at 180 feet from *B*, the curvature would be 6°, and the tangent at this point would be in proper direction to carry on the regular 6° curve, which, with like transition curve at the other end, would complete the curve connecting the tangents worked from.

Above the headings in the table are given two sets of figures, "The transition half-lengths," and "The tangent displacements"; these are subject to the corrections shown, for the reasons given in Part I.

The differences have been found by treating the chords of the transition curve as a traverse, and calculating the position of the desired point of junction on the circular curve; thus starting from the point given by the simple rule to connect with successive curves, we find the points on transition curve after a time begin to fall short of those on circular by the amount of the corrections given.

The transition half length is the distance to be measured back to the *BTC* along the main tangent, from the line perpendicular thereto that passes through the center of the circular curve to be connected with, and in simple cases is half the length of, the transition curve, and is also equal in length to the part of the circular curve replaced by the transition. When we work to the higher curves, the half-length correction becomes necessary.

The distance the circular curve is moved in, to make room for the more gradual curve, we call the displacement, or "Dis." of the table, and is subject to the correction shown.

The total deflection is the same for the transition and the piece of circular curve replaced.

The tangent deflection angles are turned off by instrument from the tangent at B or other tangent point as in running an ordinary curve.

In the first horizontal compartment under the headings, the first line of figures gives a series of angles or tangent deflections at B to 16 points on transition curve, beginning with 0°.03′ to B_1; these angles may be called *the foundation series*, and they *are proportioned* to each other *as the squares* of the distances from BTC to the points to which they refer; or, each space being equal, *as the squares of the index numbers* of the several points,

$0^\circ.03'$ being the deflection to B_1,
$2^2 \times 0^\circ.03' = 0^\circ.12'$ " " B_2,
$3^2 \times 0^\circ.03' = 0^\circ{\cdot}27'$ " " B_3, etc.

In each compartment, the upper figures give the deflections from the tangent indicated, to the point under which they are found—transitioning towards higher curvature on the right and towards lower on the left. The deflection from tangent at any point (or from tangent on corresponding curve) [transitioning towards points of sharper curvature (+) or towards flatter (−)] equals the ordinary tangent deflection for the curvature from which we start, multiplied by the distance to the point required in 100-foot stations, or decimals thereof, + or − the series angle corresponding to the number of chord lengths the point to be sighted to is distant from the point worked from, or more quickly by Formula XII. or XIII.

Suppose we have set up at B_4 backsighting on B, we turn 1°.36 into tangent (or if on 4° curve, turn into tangent in the ordinary way); then if we want to turn to B_7, the tan. deflection of 4° curvature = 2°, which, multiplied by .90 (the distance), + 0°.27′ (the serial angle for that distance) = 2°.15′ as given in the table. If we were running from E_4 to E_1 the deflection from tangent would be $2^\circ \times .90 - 0^\circ.27' = 1^\circ.21$ as per table, and so for any other in increasing or decreasing curvature.

"*The foresights to tangents*" are the deflections to tangents from the production of the chord through the point set upon, and the former point worked from; in the first series (backsighting on B) they are twice the deflections to said points, and the total deflection is the sum of the deflection and backsight, or three times the deflection.

The foresight deflection to tangent at any point on the transition curve (from backsight on any given point) equals the deflection angle D° proper to the curvature at said tangent point, multiplied by the distance to the backsight point in chains and decimals thereof + or − the series angle corresponding to the distance between them, the sign being *plus* if the backsight point is on higher rate of curvature, *minus* if on lower; *e. g.:*

The *fs.* at E_8 from *bs.* on E_{10} is 2°.30′x(5x.30) + 1°.15′ = 5°.00
" " B_8 " " " B_3 is 4°.00 x(5x.30) − 1°.15′ = 4°.45
as per Table II.

Having turned into tangent at any point, we can continue the transition curve, looking down the column in Table II to the tangent point under its heading, then using the deflections, etc., in that compartment, or we can start a circular curve of curvature corresponding to the index number of that point.

The third line, compartment 0°, gives long chords from *B* to the several points; in other compartments it gives *chord ordinates*, or ordinates from long chords to points on the transition curve. The chord ordinates are found by multiplying the sine of the angle subtended by them at the end of their chord, by the distance of the point on curve from the said end of chord, measuring along the curve is accurate enough (except perhaps when the long chord is over 200 feet, in that case, the angle and distance from the nearest end of the chord should be used.) To find this angle subtract the deflection to the given point from the deflection of the long chord. The chords to which the chord ordinates given in the Table II are measured are those connecting the tangent point of the compartment and the points *B* or *E*. If others are required, as to the chord from B_2 to B_8, they may be calculated as above.

The fourth line gives the *tangent ordinates* to points on the transition curve from the several indicated tangents. In the first compartment they are proportioned (approximately) to the cube of their distance from *B*, or to the cube of their index number, the ordinate at B_1 being 0.026181. This is accurate up to 7°; beyond that, this calculation begins to give them too large, but from the first they can be found as easily by treating the chords of the curve as a traverse, the angles of which are given by the formula below, and the ordinate to any point equals the sum of the sines of the traverse angles multiplied by 30, the chord length.

In the other compartments they are the same as the ordinates from tangent to the regular circular curve from which the same starts, plus or minus the above cubic series; but beyond the sixth or seventh point, this way of calculating them is incorrect, for the same reason as given above, and they have been calculated from traverse angles.

The *subtangent* or distance from *BTC* to the intersection of the survey line tangents, for the angle given, and the curve with transitions chosen, is found by adding together : (1st) the subtangent for the circular curve chosen (calculated in the usual way) ; (2nd) tan $\frac{1}{2}$ *I*, multiplied by the displacement (given in the table); and (3rd) the transition half length (also given over corresponding heading). If we wish to measure from the point that would have been the point of tangent, or *BC*, if no transition had been introduced, the last two items give the distance required.

If we wish to make the tangent displacement greater or less than the amount given, the transition chord lengths and the deflection angles will be altered in the ratio of the square roots of the displacements (before correction).

NOTE 1.—The new displacement chosen must be reduced by the proper correction before using it in the calculation of the subtangent.

NOTE 2.—Comparing the displacements for 30 and 60 foot chords (See table V) at B_{10} this rule holds good, but at B_{14} there is a slight variation; so on the higher curvatures comparison should be made with the "chord transition" (having its function calculated) corresponding most nearly to the one chosen : *e.g :* If we wish to make the displacement of a 14° curve 65′, we should compare it with the curve of 60′ chords, not with 30′. (Table V. gives functions for 15, 30 and 60 foot chords.

Let A, X_1, C and Ds be respectively "the initial angle of series," "the initial tangent ordinate," "the sub-chord length," and "the displacement" per table, and

A', $X_1{}'$, C' and Ds' = the new ones

$$A' = A\sqrt{\frac{Ds'}{Ds}}; \quad C' = C\sqrt{\frac{Ds'}{Ds}}; \text{ and } X_1{}' = \frac{X_1 \times Ds'}{Ds}$$

In like manner if C' is given of different value.

$$A' = A\frac{C'}{C}; \quad Ds' = Ds\frac{(C')^2}{C^2}; \text{ and } X_1{}' = X_1 \times \frac{(C')^2}{C^2}$$

E.G. : We want to make the displacement of a 6° transition curve 3 feet instead of 1.41 : *C* being 30′.

$$A = 0^\circ.03' \sqrt{\frac{3}{1.41}} = 3 \times 1.459 = 0^\circ.04'23'' \text{ or } 4.377 \text{ min.}$$

$$C' = 30\sqrt{\frac{3}{1.41}} = 30 \times 1.459 = 43.77$$

$$\text{and } X'_1{}' = .0262 \times \frac{3}{1.41} = .0262 \times 2.12 = .0555.$$

Note.—When tables do not go into decimals, to find the square root of a number having two places of decimals, enter the table with it as a whole number, and move the decimal point of the square root found one place to the left. In like manner moving the decimal point one place back in the cube root gives that for a number having three places of decimals.

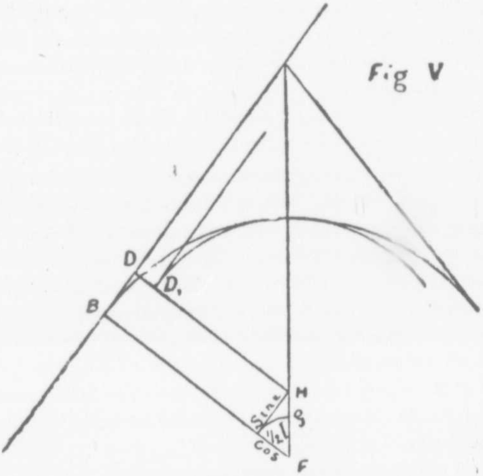


Fig V

PART III.

On new work, tables can largely be used, but in some cases, and especially on a line already constructed, we may require to have different displacements, or to vary the direction of the tangents. In old work we must often keep as near the old centre line as possible, especially at points of deepest cut or fill; in this case when old tangents are to remain unchanged, it is necessary that a sharper curve than the original one be used with transition ends (often only a few minutes sharper), and it will often be expedient to make the middle point (in length) of the new curve coincide or lie slightly outside the middle point of the original curve. This can readily be done in the manner indicated in Fig. 5, and by the assistance of Tables III and IV. In Fig. 5, a 6°

curve connects the two tangents, and a 6°.10′ curve has also been drawn with mid point coinciding. The displacement $D\ D'$ of the 6°. 10′ curve at tangent parallel to the old tangent is equal to $G\ H$. The radius of the 6° curve is 955.37, and of the 6.°10′ is 927.57. The difference being 25.70 = say R_d; then $G\ H = \text{ver. sin } \frac{1}{2} I \times R_d = 1.55$, and the distance $B\ D = Sin\ \frac{1}{2} I \times R_d$; and the sum of $\overline{\tan \frac{1}{2} I \times D\ D'}$ and the half length (both corrected if necessary) can be measured back from D to find the $B\ T\ C$. Now by Table III the displacement of a 6.°10′ curve (30 ft. chords) is 1.53, so the chord to be used, $C' = 30 \sqrt{\frac{1.55}{1.53}} = 30.2$, and the first angle of series

$A' = 3\ 02$ minutes. We could have used a 6.°16′ curve, but that would have made the chord lengths longer. Supposing it to be desired to have the chord lengths as near 30 feet as possible, R_d can be found approximately by multiplying the displacement of the original curves (from table), in this case 1.41, by a number, V, corresponding as nearly as may be to $\frac{1}{2} I = 20$, found by interpolating a number in table IV. In this case V would be less than 20, say 18; then $18 \times 1.41 = 25.38$, and referring to Table III, we find Rad. 6° 10′ is 25.70 less than Radius 6°, so a 6.°10′ curve will give us chords nearer to 30 feet in length than any other even minute curve.

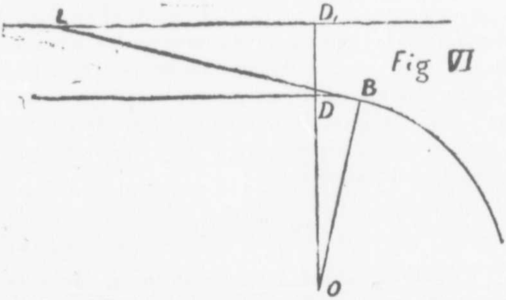


Fig VI

If it is found allowable or advisable to change the direction of the tangents, we may make a new tangent running through any suitable point outside the old tangent. Then, as in Fig. VI., whatever angle D_1LD, the new tangent make with the original one, will equal the central angle DOB between the radius to the BC and another, OD, which produced is perpendicular to the new tangent. The distance along the curve is easily calculated and run, and the displacement DD^1 measured.

The measurement to *BTC* is then measured backward from the point D_1 along the new tangent.

In locating, it would not be necessary to set every 30 foot mark for the flatter curves, every second or third point would answer. For adjusted track laying, permanent centers should be set so that the outer rail could be adjusted in alignment and elevation by a fixed gauge.

Let Se_n = the *Superelevation* for any curvature at the determined rate of speed, then it will begin rising at *BTC*, gaining *Se* at each chord end till it attains Se_n at the junction with the circular curve. Or the same result might be obtained by raising the outer rail half the rate and lowering the inner one in the same proportion.

Table I. gives a number of constants found of use in compiling table II. or other calculations, and, with the formulæ, give alternate and abbreviated ways of finding the deflections, etc.

The "*a*" series multiplied by the chord length chosen give the tangent deflections from *B T C*

The "*H*" series by chord gives "i°_{n}" the total deflection of transition curve up to each point therein.

The "*J*" series by chord gives $\frac{i^{\circ}}{2}$.

The "*w*" series multiplied by X_1 gives X_n, the tangent ordinate to any other chord end on the curve.

The *Df* series gives the tangent deflection per foot on circular curve for the various degrees of curvature. "*G*" = $6A$, which, multiplied by the curvatures or index number, gives a series used as increments, or *A* multiplied by series "*g*" gives the same increments. "*F*" = $3A$, which, multiplied by *N* or the curvatures, gives another series of increments. The "tr" series x *A* gives the traverse angles of the subchords, and of the semi or sub subchords when *N* is a fractional number, terminating at the point indicated.

PROCEDURE.

Locate tangents, if not already given, as desired; decide or calculate what chord curve to use in transitioning; take from the tables (or calculate by Formula I., etc.) the corrected distance from original *BC* to *BTC*, if the *BC* is known, otherwise from the intersection I; run from *BTC*,

If *by deflection angles*:—

Take them from compartment C° in table (or calculate them by Formula V.) as far as can be seen, then move instrument up and reset

on pt. N, back sight to last pt., and turn to tangent per foresight from table (or calculated by Formula VIII.), look down column to tan pt. N°, and turn deflections given in its compartment (or calculated by Form. IX.), repeat these two processes (using Form. XIII. instead of VIII.) if necessary to reach junction of transition and circular curves; turn to tangent and run circular curve.

Long chords may be run and chord offsets measured as per table (or per Form. XLVIII.). Intermediate points by Form. XI.

If *by tangent ordinates* : —

Offset (measuring chords along curve) per table compartment *O°* (or Form. XX.) as far as convenient; offset new tangent from points just set, starting back one or two points from last point marked, using offsets per table compartment corresponding to new tangent point, or Form. XIII., and continue repeating this process if necessary; thus strike circular curve if already in position, or if concentric with original curve, offset in at as many points as desired, using the corrected displacement, otherwise run by tangent and chord offsets in the ordinary way.

Points intermediate to regular subchord ends can be offset from tangent per Form. LIX.

The greatest ordinate for curving the rail on transition will occur about $\frac{1}{26}$ from its centre towards mid curve. The ordinate is given near enough by the usual tables for the curvature *N°* nearest its centre.

On 30 feet chord transition the mid ordinate for the rail

from point 7 on = .145
" 8 " = .165
" 9 " = .184
" 10 " = .209
" 11 " = .228

or a little more than a mean between that given in tables for the curvatures between which they lie; suppose $N-1$, N, and $N+1$ to be three points on transition. Stretching a line from $N-1$ to $N+1$ and measuring the offset to N and dividing it by 4, gives the mid-ordinate for rail with center at N, and for rail beginning or ending at N, it is about 1–100 more or less respectively.

PART IV.

The following abbreviations are used :—

A or A_1 = first tangent deflection in series;
A_n = Any " " ";
N and n = Any index number of chord-end point on transition.

I = The intersection angle or total deflection between main tangents.

i°_n = the total deflection in degrees covered by the transition curve to point N.

i'_n = the same in minutes.

$tr.a_n$ = the traverse angle of sub chord terminating at N.

N° = the curvature of circular curve per 100 foot chord corresponding to point N on transition in degrees or corresponding minutes.

B_n^{n+1} or N^{N-1} refers to another point in its relation to tangent at B_n^1; thus X_n^{n+2} is the ordinate from tangent at N to the second chord end beyond N.

C = the subchord or chosen transition chord length.

D° = the tangent deflection of circular curve (100 ft. chords).

X_n = the ordinate to tangent from point N.

$T.O.$ = do do

Y_n = the absissa on tan. to foot of ordinate from N.

Xc_n = the ordinate to tan. of point on circular curve at which a line, making an angle i°_n with the tan. worked from, is tan. to said curve, including the displacement distance (uncorrected) to make it comparable with X_n.

Yc_n = the absissa on tan. to ordinate to said circular curve point, plus $\frac{l}{2}$ before correction to compare with Y_n.

Ds Displacement distance or distance that the circular curve and survey tangents move from each other to allow for easing of curvature.

l = the length of transition curve.

$\frac{l}{2}$ = half the length of transition curve, or length of circular curve displaced by transition curve.

R_n = Radius of N° curve.

R_d = The difference between two radii used.

$a, H, J, w, Df\ G, g,$ *and* F.

= Constants or series of constants; see table I.

Lc = long chord.

$C.\ O.$ = chord ordinate from long chord to points on curve.

Chord transition = a transition curve with indicated chord lengths and curvature varying as the index number.

Transitioning = running transition curve.

Chord ordinate = the ordinate to point on curve from a long chord.

PART V.

Formula *I.* Transition subtangent or distance from *BTC* or *ETC to I.*

$$= \overbrace{R_n + Ds \text{ (corrected)}} \times \tan \tfrac{1}{2} I + \frac{l}{2} \text{ (corrected)}$$

" *II.* $A_n = A \times N^2$;

" *III.* $3A_n = i^\circ_n = \dfrac{N^2C}{200}$ in degrees;

" *IV.* $i'_n = 3A_n = \dfrac{N^\circ NC}{200}$ in minutes,

$$\left(\text{tan from } B_1 \text{ makes } i' = \frac{60 \times 30}{200} = 0^\circ.09';\ C = 30\right)$$

" *V.* $A_n = a_n C$; $A = .1\,C$;

" *VI.* $i^\circ_n = H_n C$;

" *VII.* $\dfrac{i^\circ}{2} = J_n C$;

" *VIII.* Backsight on B, the *foresight* to tan at $N = 2A_n$;

" *IX.* To continue curve from tan at B_n, Deflection to

${}_{N}{}^{N+1} = N.F + A$;

${}_{N}{}^{N+2} = N2\,F + A_2$; $F = 3A$;

${}_{N}{}^{N+3} = N3\,F + A_3$; and so on.

" *X.* From tan at E_n, deflection to

${}_{N}{}^{N-1} = NF - A$;

${}_{N}{}^{N-2} = N2\,F - A_2$;

${}_{N}{}^{N-3} = N3\,F - A_3$;

" *XI.* To find the deflection at N to a point other than regular chord end, $def = D^f_n \times$ number feet to the point $+\ A \times$ square of fraction of chord covered; see table VI;

" *XII.* In running from E
$def = D^f_n \times$ distance in feet $- A \times fr^2$;

" *XIII.* *Foresight to* tan, backsighting on N

at ${}_{N}{}^{N+1} = N.F + 2A$;

" ${}_{N}{}^{N+2} = N2\,F + 2A_2$;

" ${}_{N}{}^{N+3} = N3\,F + 2A_3$; and so on

Formula *XIV.* Foresight to tan, backsighting on E_n
at ${}_{N}N-1=N\,F-2\,A$;
" ${}_{N}N-2=N\,2\,F-2\,A_2$; and so on.

" *XV.* Foresight to tan at fractional point.
back sighting on N
$= D^f_n$ x dist. $ft+2\,A \times fr^2$;

" *XVI.* Traverse angles
from origin at B
to 1st $pt=A$,
to 2 $pt=A+6\,A$ or G; $G=6\,A$;
to N $pt=A+G+2\,G+3\,G+\ldots\,\overline{N-1}\,G$;

" *XVII.* Traverse *angles* from origin at B_3 (increasing curvature).
to 4° $pt=3\,F+A$;
to 5° $pt=3\,F+A+4\,G$;
to 6° $pt=3\,F+A+4\,G+5\,G$;
to N $pt=3\,F+A+4\,G+\ldots\ldots\ldots+\overline{N-1}\,G$;
Traverse angle from origin $B\,4$ (" ")
to $N\,pt=4\,F+A+5\,G+6\,G+\quad+\overline{N-1}\,G$;

" *XVIII.* Traverse angle from origin at E_6 (decreasing *curv.*) ;
to N " $=6\,F-A+5\,G+4\,G+\ldots+\overline{N+1}\,G$

" *XIX.* *Tr. a.* for fractional chord beyond N
" $=Df_n$ x dist.^{e} ft. $+A \times fr^2+$ back sight from tan $_n$ to $N-1+$ traverse angle to N;

" *XX.* $X_n=w_n \times X_1$, or C Sin A (within limits) ;

" *XXI.* " $=\overline{C\,\mathrm{Sin}\,A}.\ N^3$; (" ")

" *XXII.* " = the sum of sines of traverse angles to point N x C (unlimited) ;

" *XXIII.* $X_n/^{n+n'}=$ Sum of sines of traverse angles from tan as co-ordinate Y at N, multiplied by C ;

" *XXIV.* $X_n/^{n-n'}=$ Sum of sines of traverse angles as above by C, Find " *Trav* " angles by *Form. XVIII* or by Table *I*;

" *XXV.* $X_n/^{n+n'}=R_n-(Cos\ i^o_n R_n)+X_n$ of primary series corresponding to the distance from tan *pt.* ;

Formula XXVI. $X_{n}/^{n+m} = R_n$ ver sin $i^\circ_n + X_n$ of primary series corresponding to the distance from tan *pt.*;

“ *XXVII.* $X_{n}/^{n-n'} = R_n - (\cos i^\circ_n \times R_n) - X_n$ of primary series corresponding to the distance from tan *pt.*;

“ *XXVIII.* $X_{n}/^{n-n'} = R_n$ ver. sin $i^\circ_n - X_n$ of primary series corresponding to the distance from tan *pt.*;

“ *XXIX.* $X_{n}/^{n+n'} = R_n - \sqrt{R_n^2 - dist.^2} + X_n$ of primary series corresponding to the distance from tan *pt.*;

“ *XXX.* $X_{n}/^{n-n'} = R_n - \sqrt{R^2_n - dist.^2} - X_n$ of primary series corresponding to the distance from tan *pt.*;

“ *XXXI.* $X_n{}^{n+n'} = \frac{Dist^2}{2\,R_n} + X_n$ of primary series, etc.

(approximately)

“ *XXXII.* $X_n{}^{n-n}$ “ – “ “

“ “ “ ;

“ *XXXIII* $X\,c_n = (2 \text{ Sin } \tfrac{1}{2}\, i^0)^2 \times \tfrac{1}{2}\, R_n + D\,s$;

“ *XXXIV.* “ $= ver.\ sin.\ i^0\, R_n + D\,s$;

“ *XXXV.* $Y_n = X_n \text{Cotan } A_n$;

“ *XXXVI.* $Y\,c_n = \text{Sin } i^0\, R_n + l_{\frac{n}{2}}$;

“ *XXXVII.* $= X_n - X\,c_n =$ Correction for displacement;

“ *XXXVIII.* $Y_n - Y\,c_n$ “ “ $\frac{l}{2}$

“ *XXXIX.* $Ds_n = C \text{ Sin } A \times \left(\frac{N\,C}{2}\right)^3 \times 2$ correct to 8° when $C = 30'$

“ *XL.* $D\,s_n = X_n$ at *pt.* half way to *N*, x 2 (correct to 8° when $C = 30$, beyond corrected by deduction;)

“ *XLI.* $\frac{l}{2} = \frac{1}{2}\,N\,C$ (correct to 7° when $C = 30'$; above that corrected by deduction);

“ *XLII.* $C' = C\sqrt{\frac{Ds'}{Ds}}$;

“ *XLIII.* $Ds' = Ds\,\frac{(C')^2}{C}$;

“ *XLIV.* $A' = A\,\frac{C'}{C}$;

“ *XLV.* $X' = X_1\,\frac{(C')^2}{C^2}$;

Formula XLVI. $X_1' = X_1 \dfrac{Ds'}{Ds}$;

“ *XLVII.* $A' = A\sqrt{\dfrac{Ds'}{Ds}}$;

“ *XLVIII.* Co = sine of angle subtended at end of chord x the distance therefrom ; angle = the deflection to to chord – *def* to *pt*,

“ *XLIX.* $Lc = \dfrac{X_n}{\sin A_n}$;

“ *L.* $R_n = \dfrac{50}{\sin D^\circ}$;

“ *LI.* Ex = crown distance for circular curve for angle I + Ds x secant $\frac{1}{2} I$;

or crown dist. + $Ds \dfrac{\tan}{\sin} \frac{1}{2} I$;

“ *LII.* $Ex = Ex\ Sc\ \frac{1}{2} I \times R_n + Ds \sec \frac{1}{2} I$;

“ *LIII.* $Ex = T \tan \frac{1}{4} I + Ds \times \dfrac{\tan}{\sin} \frac{1}{2} I$;

T being the sub tan, circular curve.

“ *LIV.* Add ciphers as wished to minutes ÷ 6 and the result = decimals of degree

“ *LV.* $Y_n = 2 \sin i^\circ R_n$, approximate, (too large above 6° with C = 30) ;

“ *LVI.* $X_n = 1\frac{1}{3}$ *ve. sin.* $i^\circ R_n$, (Howard) ;

“ *LVII.* The traverse angle of chord from N *to* $N + N'$ =

$i_n^\circ + def^n{}_n n + n' =$;

Note : This gives the traverse angle for any chord either with main or subsidiary tangent ; i_n° being the total deflection or central angle from tangent point considered, to point N.

“ *LVIII.* $C = \dfrac{i'_n}{H_n}$; *ver. sin.* $i^\circ{}_n = \dfrac{3\,Ds}{R_n}$.

Note : With the corrected displacement, this gives exact result to 12° or 13° on 30′ chord transition and at 16° it gives C, 0.15 too large.

“ *LIX,* $X_n^{n+fr} = X_n^{n+1} \times fr^3$ (table I).

TABLE I.

Constants used in the Formulæ.

$a_n = \frac{1}{10} N^2$ $A_n = a_n C$ $A = \frac{1}{10} C$	$H_n = \frac{3}{10} N^2$ $i^\circ_n = H_n C$ $C = \frac{i^\circ_n}{H_n}$	$J_n = .15 N^2$ $\frac{1}{2} i^\circ_n = J_n C$	Df_n = defl't$_n$ per foot on circular cv. of N°.	$w = N^3$ $X_n = X_1 \times w$ $X_1 = C.\sin A.$	N.G. = $g_n A$ $G = 6 A$ $F = 3 A$	$tr.a_n = tr_n \times A$ $tr_n = tra_n$ when $C = 10$
$a_1 = 0.1$	$H_1 = 0.3$	$J_1 = 0.15$	$Df_1 = 0^\circ.00\frac{3}{10}$	$w_1 = 1.$	$g_1 = 6$	$tr_1 = 0^\circ.01$
				$w_{1\cdot5} = 3.38$		$tr_{1\cdot5} = 0_{\circ}.04\frac{3}{4}$
$a_2 = 0.4$	$H_2 = 1.2$	$J_2 = 0.6$	$Df_2 = 0^\circ.00.6$	$w_2 = 8.$	$g_2 = 12$	$tr_2 = 0^\circ.07$
				$w_{2\cdot5} = 15.62$		$tr_{2\cdot5} = 0^\circ.15\frac{1}{4}$
$a_3 = 0.9$	$H_3 = 2.7$	$J_3 = 1.35$	$Df_3 = 0^\circ.00.9$	$w_3 = 27.$	$g_3 = 18$	$tr_3 = 0^\circ.19$
				$w_{3\cdot5} = 42.88$		$tr_{3\cdot5} = 0^\circ.31\frac{3}{4}$
$a_4 = 1.6$	$H_4 = 4.8$	$J_4 = 2.4$	$Df_4 = 0^\circ.01.2$	$w_4 = 64.$	$g_4 = 24$	$tr_4 = 0^\circ.37$
				$w_{4\cdot5} = 91.13$		$tr_{4\cdot5} = 0^\circ.54\frac{1}{4}$
$a_5 = 2.5$	$H_5 = 7.5$	$J_5 = 3.75$	$Df_5 = 0^\circ.01.5$	$w_5 = 125.$	$g_5 = 30$	$tr_5 = 1^\circ.01$
				$w_{5\cdot5} = 166.38$		$tr_{5\cdot5} = 1^\circ.22\frac{3}{4}$
$a_n = 3.6$	$H_6 = 10.8$	$J_6 = 5.4$	$Df_6 = 0^\circ.01.8$	$w_6 = 216.$	$g_6 = 36$	$tr_6 = 1^\circ.31$
				$w_{6\cdot5} = 274.63$		$tr_{6\cdot5} = 1^\circ.57\frac{1}{4}$
$a_7 = 4.9$	$H_7 = 14.7$	$J_7 = 7.35$	$Df_7 = 0^\circ.02.1$	$w_7 = 343.$	$g_7 = 42$	$tr_7 = 2^\circ.07$
				$w_{7\cdot5} = 421.88$		$tr_{7\cdot5} = 2^\circ.37\frac{3}{4}$
$a_8 = 6.4$	$H_8 = 19.2$	$J_8 \quad 9.6$	$Df_8 = 0^\circ.02.4$	$w_8 = 512.$	$g_8 = 48$	$tr_8 = 2^\circ.49$
				$w_{8\cdot5} = 614.13$		$tr_{8\cdot5} = 3^\circ.24\frac{1}{4}$
$a_9 = 8.1$	$H_9 = 24.3$	$J_9 = 12.15$	$Df_9 = 0^\circ.02.7$	$w_9 = 729.$	$g_9 = 54$	$tr_9 = 3^\circ.37$
				$w_{9\ 5} = 857.38$		$tr_{9\cdot5} = 4^\circ.16\frac{3}{4}$
$a_{10} = 10.$	$H_{10} = 30.0$	$J_{10} = 15.0$	$Df_{10} = 0^\circ.03$	$w_{10} = 1000.$	$g_{10} = 60$	$tr_{10} = 4^\circ.31$
$a_{11} = 12.1$	$H_{11} = 36.3$	$J_{11} = 18.15$	$Df_{11} = 0^\circ.03.3$	$w_{11} = 1331.$	$g_{11} = 66$	$tr_{11} = 5^\circ.31$
$a_{12} = 14.4$	$H_{12} = 43.2$	$J_{12} = 21.6$	$Df_{12} = 0^\circ.03.6$	$w_{12} = 1728.$	$g_{12} = 72$	$tr_{12} = 6^\circ.37$
$a_{13} = 16.9$	$H_{13} = 50.7$	$J_{13} = 25.35$	$Df_{13} = 0^\circ.03.9$	$w_{13} = 2197.$	$g_{13} = 78$	$tr_{13} = 7^\circ.49$
$a_{14} = 19.6$	$H_{14} = 58.8$	$J_{14} = 29.4$	$Df_{14} = 0^\circ.04{:}2$	$w_{14} = 2744.$	$g_{14} = 84$	$tr_{14} = 9^\circ.07$
$a_{15} = 22.5$	$H_{15} = 67.5$	$J_{15} = 33.75$	$Df_{15} = 0^\circ.04.5$	$w_{15} = 3375.$	$g_{15} = 90$	$tr_{15} = 10^\circ.31$
$a_{16} = 25.6$	$H_{16} = 76.8$	$J_1 = 38.4$	$Df_{16} = 0^\circ.04.8$	$w_{16} = 4096.$	$g_{16} = 96$	$tr_{16} = 12^\circ.01$

In any primary series

The angle $A_n .25 = A_n + (\frac{1}{2}{}_n$ minutes $\times A_1)$.
" $A_n .5 = A_n + (n.25$ minutes $\times A_1)$.
" $A_n .75 = A_n + (1.7_n$ minutes $\times A_1)$; to 4° nearly.
" " 1.6_n " " ; to 12° "
" " 1.5_n " " ; to 25° "
" $tr.a_n .5 = tr.a_n + (4.4_n$ minutes) nearly.

Note.—Searles' Field Book is the only one giving logarithmic tables convenient for working these formulæ.

TABLE II.

TRANSITION CURVE 30 FOOT CHORDS.

½ length transition Curve.		15	30	45	60	75.	90.	105.	120.	135.	150.	165.	180.	195.	210.	225.	240.
		Corre	ction	0	0	0	0	.	0.21	0.32	0.51	0.78	1.14	1.65	2.31	3.14	4.29
		15 ft	30	45	60	75	90	105.	119.79	134.68	149.49	164.22	173.86	193.35	207.69	221.86	235.71
Tan't Displace't		0.013	0.052	0.178	0.418	0.816	1.414	2.244	3.350	4.772	6.544	8.710	11.302	14.386	17.938	22.054	26.756
		Conne	ction	0	0	0	.003	.006	.009	.021	.037	.063	.107	.174	.269	.407	0.595
		0.013	0.052	0.178	0.418	0.816	1.411	2 238	3.341	4.751	6.507	8.647	11.195	14.212	17.669	21.647	26.161
	B & E B T C E T C main tan	B_1&E_1 **1°**	B_2&E_2 **2°**	B_3&E_3 **3°**	B_4-E_4 **4°**	B_5&E_5 **5°**	B_6&E_6 **6°**	B_7&E_7 **7°**	B_8&E_8 **8°**	B_9 & E_9 **9°**	B_{10}&E_{10} **10°**	B_{11}&E_{11} **11°**	B_{12}&E_{12} **12°**	B_{13}&E_{13} **13°**	B_{14}&E_{14} **14°**	B_{15}&E_{15} **15°**	B_{16}&E_{16} **16°**
Def	Tan	0°.03	0°.12	0°.27	0°.48	1°.15	1°.48	2°.27	3°.12	4°.03	5°.00	6°.03	7°.12	8°.27	9°.48	11°.15	12°.48
Fs to T	at	0 .06	.24	.54	1 .36	2 .30	3 .36	4 54	6 .24	8 .06	10 .00	12 .06	14 .24	16 .54	19 .36	22 .30	25 .36
Lc.	**0**	30.00	60.00	90.00	120.	150.00	179.9	209.8	239.7	269.4	299.1	328.5	357.7	386.4	415.0	442.6	470.0
T.O.	B T C	.03	.21	.71	1 67	3.27	5.65	8.97	13.38	19.03	26.05	34.60	44.79	56.72	70.51	86.20	103.86
Def	0°.06	Tan	0°.12	0°.30	0°.54	1°.24	2°.00	2°.42	3°.30	4°.24	5°.24	6°.30	7°.42	9°.00	10°.24	11°.54	13°.30
Fs to T	.03	at	.15	.42	1 .21	2 .12	3 .15	4 .30	5 .57	7 .36	9 .27	11 .30	13 .45	16 .12	18 .51	21 .42	24 .45
C.O.	.00	**1°**															
T O.	.05		.10	.52	1.41	2.93	5.23	8.47	12.80	18.37	25.32	33.79	43.91	55.77	69.48	85.11	102.71
Def	0°.24	0°.15	Tan	0°.21	0°.48	1°.21	2°.00	2°.45	3°.36	4°.33	5°.36	6°.45	8°.00	9°.21	10°.48	12°.21	14°.00
Fs to T	.12	.12	at	.24	1 .00	1 .48	2 .48	4 .00	5 .24	7 .00	8 .48	10 .48	13 .00	15 .24	18 .00	20 .48	23 .48
C.O.	.00	.08	**2°**														
T.O.	.42	.13		.18	0.84	2.12	4 19	7.20	11.29	16.62	23.35	31.59	41.48	53.13	66.63	82.06	99.46
Def	0°.54	0°.42	0°.24	Tan	0°.30	1°.06	1°.48	2°.36	3°.30	4°.30	5°.36	6°.48	8°.06	9°.30	11°.00	12°.36	14°.18
Fs to T	.27	.30	.21	at	.33	1 .18	2 .15	3 .24	4 .45	6 .18	8 .03	10 .00	12 .09	14 .30	17 .03	19 .48	22 .45
C.O.	.00	.02	.26	**3°**													
T.O.	1.41	.73	.21		.26	1.15	2.83	5.44	9.15	14.70	20.44	28.30	37.82	49.11	62.26	77.35	94.43
Def	1°.36	1°.21	1°.00	0°.43	Tan	0°.39	1°.24	2°.15	3°.12	4°.15	5°.24	6°.39	8°.00	9°.27	11°.00	12°.39	14°.24
Fs to T	0 .48	0 .54	0.48	.30	at	.42	1. 36	2 .42	4 .00	5 .30	7 .12	9 .06	11 .12	13 .30	16 .00	18 .42	21 .36
C.O.	.00	.04	0.60	.32	**4°**												
T.O.	3.35	2.12	2.05	.29		.34	1.47	3.54	6.69	11.10	16.89	24.23	33.23	44.01	56.66	71.27	87.90
Def	2°.30	2°.12	1°.48	1°.18	0°.42	Tan	0°.48	1°.42	2°.42	3°.48	5°.00	6°.18	7°.42	9°.12	10°.48	12°.30	14°.18
Fs to T	1 .15	1 .24	1 .21	1 .06	.29	at	.51	1 .54	3 .09	4 .36	6 .15	8 .06	10 .09	12 .24	14 .51	17 .30	20 .21
C.O	0.50	0.62	0.91	1.25	.94	**5°**											
T.O	6.54	4.61	2.82	1.26	.37		.42	1.78	4.24	7.94	13.05	19.69	28.02	38.13	50.14	64.13	80.16
Def	3°.36	3°.15	2°.48	2°.15	1°.36	0°.51	Tan	0°.57	2°.00	3°.09	4°.24	5°.45	7°.12	8°.45	10°.24	12°.09	14°.00
Fs to T	1 .48	2 .00	2 .00	1 .48	1 .24	0 .48	at	1 .00	2 .12	3 .36	5 .12	7 .00	9 .00	11 .12	13 .36	16 .12	19 .00
C.O.	0.00	0.91	1.66	2.12	2.09	1.44	**6°**										
T.O.	11.30	8.50	5.86	3.53	1.67	0.44		0.50	2.09	4.94	9.20	14.99	22.48	31.78	42.99	55.90	70.89

Def	4°.54	4°.30	4°.00	3°.24	2°.42	1°.54	1°.00	Tan at **7°**	1°.06	2°.18	3°.36	5°.00	6°.30	8°.06	9°.48	11°.36	13°.30
Fs to T	2 .27	2 .42	2 .45	2 .36	2 .15	1 .42	0 .57		1 .09	2 .30	4 .03	5 .48	7 .45	9 .54	12 .15	14 .48	17 .30
C-O.	0.00	1.25	1.78	3.13	3.45	3.14	2.04										
T.O.	17.92	14.11	10.46	7.12	4.24	1.99	0.52		0.58	2.41	5.64	10.44	16.93	25.26	35.52	47.81	62.12
Def	6°.24	5°.57	5°.24	4°.45	4°.00	3°.09	2°.12	1°.09	Tan at **8°**	1°.15	2°.36	4°.03	5°.36	7°.15	9°.00	10°.51	12°.48
Fs to T	3 .12	3 .30	3 .36	3 .30	3 .12	2 .42	2 .00	1 .06		1 .18	2 .48	4 .30	6 .24	8 .30	10 .48	13 .18	16 .00
C.O.	0.00	1.64	3.13	4.31	5.02	5.10	4.39	2.74									
T.O.	26.72	21.74	16.92	12.41	8.37	4.95	2.30	0.60		0.65	2.72	6.35	11.69	18.87	28.01	39.23	52.59
Def	8°.06	7°.36	7°.00	6°.18	5°.30	4°.36	3°.36	2°.30	1°.18	Tan at **9°**	1°.24	2°.54	4°.30	6°.12	8°.00	9°.54	11°.54
Fs to T	4 .03	4 .24	4 .32	4 .30	4 .15	3 .48	3 .09	2 .18	1 .15		1 .27	3 .06	4 .57	7 .00	0 .15	11 .42	14 .21
C.O.	0.00	2.09	4.03	5.65	6.79	7.32	7.06	5.73	3.55								
TO	37.97	31.68	25.55	19.72	14.36	9.60	5.64	2.62	0.68		0.73	3.03	7.05	12.93	20.79	30 76	42.91
Def	10°.00	9°.27	8°.48	8°.03	7°.12	6°.15	5°.12	4°.03	2°.48	1°.27	Tan at **10°**	1°.33	3°.12	4°.57	6°.48	8°.45	10°.48
Fs to T	5 .00	5 .24	5 .36	5 .36	5 .24	5 .00	4 .24	3 .36	2 .36	1 .24		1 .36	3 .24	5 .25	7 .36	10 .00	12 .36
C.O.	0.00	2.59	5.02	7.13	8.79	9.81	10.04	9.83	7.52	4.46							
T.O.	51.95	44.21	36.62	29.34	22.51	16.30	10.86	6.35	2.93	0.76		0.81	3.34	7.75	14.17	22.71	33.49
Def	12°.06	11°.30	10°.48	10°.00	9°.06	8°.06	7°.00	5°.48	4°.30	3°.06	1°.36	Tan at **11°**	1°.42	3°.30	5°.24	7° 24	9°.30
Fs to T	6 .03	6 .30	6 .45	6 .48	6 .39	6 .18	5 .45	5 .00	4 .03	2 .54	1 .33		1 .45	3 .42	5 .51	8 .12	10 .45
T.O.	68.89	59.58	50.40	41.53	33.11	25.30	18.24	12.11	7.06	3.24	0.84		0.89	3.66	8.46	15.41	24.63
Def	14°.24	13°.45	13°.00	12° 09	11°.12	10°.09	9°.00	7°.45	6°.24	4° 57	3°.24	1°.45	Tan at **12°**	1°.51	3°.48	5°.51	8°.00
Fs to T	7 .12	7 .42	8 .00	8 .06	8 .00	7 .42	7 .12	6 .30	5 .36	4 .30	3 .12	1 .42		1 °54	4 .00	6 .18	8 .48
T.O.	89.02	78.00	67.12	57.55	46.41	36.86	28.07	20.18	13.35	7.76	3.56	0.92		96˙0	3.97	9.15	16.64
Def	16°.54	16°.12	15°.24	14°.30	13°.30	12°.24	11°.12	9°.54	8°.30	7°.00	5°.24	3°.42	1°.54	Tan at **13°**	2°.00	4°.06	6°.18
Ff to T	8 .27	9 .00	9 .21	9. 30	9 .27	9 .12	8 .45	8 .06	7 .15	6 .12	4 .57	3 .30	1 .51		2 .03	4 .18	6 .45
T.O.	112.00	99.18	86.49	74.10	62.14	51.24	40.59	30.82	22.10	14.59	8.45	3.84	0.99		1.04	4.28	9.85
Def	19°.36	18°.51	18°.00	18°.03	16°.00	14°.51	13°.36	12°.15	10°.47	9°.15	7°.36	5°.51	4°.00	2°.03	Tan at **14°**	2°.09	4°.24
Fs to T	9 .48	10 .24	10 .48	11 .00	11 .00	10 .48	10 .24	9.48	9 00	8 .00	6 .48	5 .24	3 .48	2 .00		2 .12	4 .36
T.O.	139.41	124.71	110.15	95.85	81.98	68.66	56.06	44.31	33.57	24.02	15.83	9.16	4.19	1.07		1.12	4.60
Def	22°.30	21°.42	20°.48	19°.48	18°.42	17°.30	16°.18	14°.48	13°.18	11°.42	10°.00	8°.12	6°.18	4°.18	2°.12	Tan at **15°**	2°.18
Fs to T	11 .15	11 .54	12 .21	12 .36	12 .39	12 .30	12 .09	11 .36	10 .51	9 .54	8 .45	7 .24	5 .51	4 .06	1 .09		2 .21
T.O.	169.80	153.16	126.65	120.39	104.55	89.23	74.59	60.79	47.97	36.29	25.94	17.06	9.86	4 49	1.15		1.20
Def	25°.26	24°.45	23°.48	22°.45	21°.36	20°.21	19°.00	17°.33	16°.00	14°.21	12°.36	10°.45	8°.48	6°.45	4°.36	2°.21	Tan at **16°**
Fsto	12 .48	13 .30	14 .00	14 .18	14 .24	14 .18	14 .00	13 .30	12.48	11 .54	10 .48	9 .30	8 .00	6 .18	4 .24	2 .18	
T.O.	203.55	184.94	166.46	148.22	130.36	113.01	96.30	80.46	65.43	51.56	38.96	27.81	18.27	10.54	4.80	1.23	

Transition Sub tan - tan ½ I. [R_n + Ds] + $\frac{l}{2}$.

Dec. 7th, 1892.

J. S. Armstrong, B.A., M. Can. Soc. C.E.

TABLE III

Giving Radii and Dif. for different degrees of curvature, also transition ½ Length and Displacements, showing correction.

$$\text{Rad.} = \frac{50}{\sin D} \qquad \text{30 ft chords.}$$

Curv're.	Radii.	Dif.=R_d	½ Length Correct'd	Disp't.	Correction	Disp't Corrected
2°.00	2864.93		30.	.052	Nill.	Same as displacement column.
.02	2817.97	46.89	30.5	.056	“	
.04	2772.53	92 36	31.	.058	“	
.06	2728.53	136.36	31 5	.060	“	
2°.30	2292.00	.....	37.5	.102	“	
.32	2261.86	30.14	38.	.108	“	
.34	2232.49	59.51	38.5	.112	“	
.36	2203.88	88.12	39.	.116	“	
3°.00	1910.08	.....	45	.176	“	
.02	1889.09	20.99	45.5	.184	“	
.04	1868.56	41 52	46.	.188	“	
.06	1848.48	61.60	46.5	.194	“	
3°.30	1637.27	.....	52.5	.380	“	
.32	1621.84	15.34	53.	.290	“	
.34	1606.68	30.59	53.5	.296	“	
.36	1591.82	45.45	54.	.306	“	
4°.00	1432.69	.....	60.	.418	“	
.02	1420.85	11.84	60.5	.430	“	
.04	1409.21	22.88	61.	.438	“	
.06	1397.76	34.93	61.5	.452	“	
4°.30	1273.57	.....	67.5	.596	“	
.32	1264.21	9.36	68.	.612	“	
.34	1254.98	18.59	68.5	620	“	
.36	1245.89	27.58	69.	.638	“	
5°.00	1146.28	.....	75.	.818	“	
.02	1138.69	7.59	75.5	.833	“	
.04	1131.21	15.07	76.	.848	“	
.06	1123.82	22.46	76.5	.868	“	
.08	1116.52	29.76	77.	.888	“	
.10	1109.33	36.95	77.5		“	
5°.30	1042.14	.....	82.5	1.09	“	
.32	1035.87	6.27	83.	1.112	“	
.34	1029.67	12.37	83.5	1.130	“	
.36	2023.54	18.60	84.	1.150	“	
.38	1017.49	24.65	84.5	1.174	“	
.40	1011.51	30.63	85.		“	
6°.00	955.37	.....	90.	1.414	“	
.02	950.11	5.26	90.4	1.440	“	
.04	944.88	10.49	90.9	1.460	“	
.06	939.72	15.65	91.4	1.486	“	
.08	934.62	20.75	91.9	1.510	“	
.10	929.57	25.70	92.4	1.530	“	
.12	924.58	30 79	92.9		“	

Curv're.	Radii.	Dif. R^d.	$\frac{1}{2}$ Length Correct'd.	Dispt.	Correction.	Dispt. Corrected.
6°.30	881.94	.....	97.4	1.798	Nil.	“
.32	877.44	4.51	97.9	1.825	“	“
.34	873.	8.95	98.4	1.850	“	“
.36	868.60	13.35	98.9	1.882	“	“
.38	864.23	17.72	99.4	1.910	“	“
.40	859.92	22.03	99.9	1.936	“	“
.42	855.65	26.30	100.4		“	“
7°.00	819.02	.....	104.9	2.250	“	“
.04	811.30	7.72	105.9	2.30	“	“
.08	803.73	15.29	106.9	2.38	“	“
.12	896.30	22.72	107.8	2.44	“	“
.16	789.	30.02	108.8	2.50	“	“
.20	781.84	37.18	109.7		“	“
.30	764.49		112.3	2.76	“	“
7°.34	757.77	6.72	113.3	2.83	“	“
.38	751.16	13.33	114.3	2.90	“	“
.42	744.66	19.83	115.3	2·99	“	“
.46	738.28	26.21	116.3	3.06	“	“
.48	735.13	29.36	117.2		“	“
.00	716.78	.....	119.8	3.34	“	“
8°.04	710.87	5.91	120.8	3.42	“	“
.08	705.05	11.73	121.8	3.52	“	“
.12	799.33	17 45	122.8	3.60	“	“
.16	693.70	23.08	123.8	3.68	“	“
.20	688.16	28.62	124.8	3.79	“	“
.24	682.70	34.08			“	“
8°.30	674.69	.....	127.2	4.01	Nil.	4.01
.34	669.44	5.25	128.2	4.10	do	4.10
.38	664.29	10.40	129.2	4.21	do	4.21
.42	659.21	15.48	130.2	4.30	do	4.30
.46	654.20	20.49	131.2	4.39	do	4.39
.50	649.27	25.42	132.2	4.51	do	4.51
.54	644.42	30.27	.....	.....	.....	....
9°.00	637.28	.....	134.7	4.77	.02	4.75
.06	630.29	6.99	136.2	4.93	.02	4.91
.12	623.45	13.83	137.6	5.10	.02	5.08
.18	616.76	20.52	139.1	5.26	.02	5.24
.24	610.21	27.07	140.6	5.44	.02	5.42
.30	603.81	33.47	142.1	5.61	.03	5.58
.36	597.53	39.75	143.6	5.79	.03	5.76
.42	591.38	45.90	145.1	5.97	.03	5.94
.48	585.36	51.92	146.5	6.16	.03	6.13
.54	579.47	57.81	148.0	6.35	.03	6.32
10°.00	573.69	(63.59)	149.5	6.54	.04	6.50
.06	568.02	5.67	151.0	6.74	.04	6.70
.12	562.47	11.22	152.4	6.95	.04	6.91
.18	557.02	16.67	153.9	7.15	.04	7.11
.24	551.68	22.01	155.4	7.36	.04	7.32
.30	546.44	27.25	156.9	7.58	.04	7.54
.36	541.30	32.39	158.4	7.80	.05	7.75
.42	536.25	37.44	159.8	8.02	.05	7.97
.48	531.30	42.39	161.3	8.24	.05	8.19
.54	526.44	47.25	162.8	8.48	.05	8.43

Curv're.	Radii.	Dif. R_d	$\frac{1}{2}$ Length Correct'd.	Dispt.	Correction.	Dispt. Corrected.
11°.00	521.67	(52.02)	164.2	8.71	.06	8.65
.06	516.98	4.69	165.7	8.95	.06	8.89
.12	512.38	9.29	167.2	9.20	.07	9.13
.18	507.86	16.81	168.6	9.44	.07	9.37
.24	503.42	18.25	170.1	9.69	.08	9.61
30	499.06	22.61	171.6	9.95	.08	19.87
.36	494.77	26.90	173.	10.22	.09	10.13
.42	490.56	31.11	174.5	10.48	.09	10.39
.48	486.42	35.25	176.	10.75	.10	10·65
.54	482.34	39.33	177.4	11.03	.10	10·93
12°.00	478.34	(43.33)	178.9	11.30	.11	11·19
.10	471.81	6.53	181.3	11.76	.13	11·63
.20	465.46	12.88	183.7	12.29	.14	12·15
.30	459.28	19.06	186.1	12.77	.16	12·61
.40	453.26	25.08	188.5	13.27	.17	13·10
.50	447.40	30.94	190.9	13.85	.18	13·67
13°.00	441.68	(36.66)	193.3	14.39	.19	14·20
.10	436.12	5.56	195.7	14.92	.20	14·72
.20	430.69	10.99	198.1	15.54	.22	15·32
.30	425.40	16.28	200.5	16.10	.24	15·86
.40	420.23	21.45	202.9	16.68	.26	16·42
.50	415.20	26.48	205.3	16.96	.28	16·68
14°.00	410.28	(31.40)	207.7	17.94	.29	17·65
.10	405.47	4.81	210.	18.56	.31	18·25
.20	400.79	9.49	212.3	19.28	.33	18·95
.30	396.20	14.08	214.7	19.93	.35	29·58
.40	391.72	18.56	217.1	20.59	.38	20·21
.50	387.35	22.93	219.5	21.36	.41	20·95
15°.00	383.06	(27.22)	221.9	22.05	.44	21·61
.10	378.88	4.18	224.2	22.76	.46	22·30
.20	374.79	8.27	226.5	23.58	.48	23·10
.30	370.78	12.28	228.8	24.33	.51	23·82
.40	366.86	16.20	231.1	25.08	.54	24·55
.50	363.02	20.04	33.4	26.01	.57	25·40
16°.00	359.26	23.80	35.7	26.76	.60	6·16

TABLE IV.

When $\frac{1}{2}$ I = $5\frac{1}{2}°$ The Dispt. × $\frac{\text{“V”}}{200}$ = R^d
“ “ = 9° “ “ × 80 = “
“ “ = 13° “ “ × 40 = “
“ “ = 18° “ “ × 20 = “
“ “ = 26° “ “ x 10 = “
“ “ = 37° “ “ x 5 = “
“ “ = 45° “ “ x $3\frac{1}{2}$ = “
“ “ = 53 “ “ x $2\frac{1}{2}$ = “
“ “ = 60 “ “ x 2 = “

Approximately.

TABLE V.

	15 foot chord transition.					30 foot chord transition.					60 foot chord transition.				
	Tan Or'd. or X_n.	Y_n.	Dispt.	Dispt. Correction.	½ length Correction.	Tan Or'd. or X^n.	Y_n.	Dispt.	Dispt. Correction.	½ length Correction	Tan Or'd. or X_n.	Y_n.	Dispt.	Dispt. Correction.	½ length Correction.
B_1	.007	15.	......	......	......	.03	30.	.013	.00	.00	.105	......	.052	......	......
B_2	.052	30.	.013	......	......	.21	60.	.052	.00	.00	.83	......	.210	......	......
B_3	.176	45.	.044	......	......	.71	90.	.178	.00	.00	2.83	......	.700	......	......
B_4	.419	60.	.104	......	......	1.67	119.98	.418	.00	.00	6.70	239.83	1.66	..	......
B_5	.817	74.98	.204	......	— .02	3.27	149.94	.816	......	.00	13.07	299.49	3.25	....	— .13
B_6	1.413	89.98	.353	......	— .02	5.65	179.84	1.414	—.003	.00	22.56	358.74	5.63	— .02	— .26
B_7	2.244	104.95	.560	......	— .05	8.97	209.66	2.244	—.006	......	35.75	417.27	8.96	— .04	— .56
B_8	3.349	119.91	.838	......	— .07	13.38	239.33	3.350	—.009	— .21	53.19	474.68	13.39	.05	1.04
B_9	4.767	134.85	1.194	......	— .09	19.03	268.80	4.772	—.021	— .32	75.38	530.43	19.07	— .15	—1.82
B_{10}	6.536	149.74	1.634	......	— .14	26.05	279.96	6.544	—.037	— .51	102.71	83.84	26.15	— .30	—2.99
B_{11}	8.695	164.59	2.176	— .01	— .19	34.60	326.72	8.710	—.063	— .78	135.48	634.10	34.78	— .54	—4.75
B_{12}	11.280	179.37	2.826	— .02	— .26	44.79	354.94	11.302	—.107	—1.14	173.81	680.27	45.11	— .95	—7.18
B_{13}	14.329	194.05	3.590	— .02	— .37	56.72	382.46	14.386	—.174	—1.65	217.61	721.26	57.29	—1.61	-10.53
B_{14}	17.875	208.62	4.488	— .04	— .49	70.51	409.10	17.938	—.269	—2.31	266.58	755.93	71.47	—2.63	-15.01
B_{15}	21.953	223.06	5.520	— .06	— .60	86.20	434.67	22.054	—.407	—3.14	320.09	783.08	87.80	—4.18	-20.82
B_{16}	26.594	237.33	6.698	— .09	— .82	103.86	458.93	26.756	—.595	—4.29	377.18	801.52	106.43	—6.44	-28.25

DISCUSSION.

Mr. Cuningham. Mr. Cuningham said he presumed these tables would be used only in construction work. You would not propose to do any of this work on the survey, because it makes very little difference in the actual survey of the line ?

Mr. Armstrong. Mr. Armstrong answered more or less depending on circumstances. The centre line with a 10° curve and 30 ft transition would be nearly 7 feet from where it would be without the transition. With sharper curves the displacement increases. So as we have sufficient data to know the ground the exact location can be made when most convenient.

Mr. Hannaford. Mr. Hannaford said those who have been connected with sharp sharp curves always leave them alone. His experience was that curves are sometimes put in by engineers without good reason, and that sharper curves than 2° on a main line should be avoided. The sharpest curve used on the Grand Trunk Ry. Montreal and Toronto is 2°, except at Kingston. This shows what a thorough survey did forty years ago. He questioned, if a line were built to-day between Montreal and Toronto, whether engineers would not propose sharper curves than 2°. The speaker had always avoided sharp curves. He said you may depend upon it that although in your younger days you may think sharp curves unobjectionable, you will find if you ride on an engine and get off a transition curve on to a 5° curve running at forty miles an hour, that it is not as easy as you think. The effect is very sudden and the wear very great. But when you *have* to make these sharp curves, the transition curve is no doubt a good way of avoiding some of the evils attendant on sharp curves.

Prof. McLeod. Prof. McLeod said :—There is one point which the author seems to have given special attention to, namely, the matter of calculating the sub-tangent. Mr. Irwin has already drawn attention to it, and he thought it might be very interesting if Mr. Armstrong would illustrate by example the manner of calculating the sub-tangent so as to bring in the little correction spoken of.

Mr. Armstrong. Mr. Armstrong said in reply that as there would be no correction with a 5° curve (using 30 chords) let us take a more extreme case, though the table gives by inspection the same correct data for either.

Say our tangents intersect with I = 60°, and we propose to use a 14° curve with transition ends, then by formula I.

R_{14} being 410.28 †
Corrected disp. 17.67 from Table II
427.95 × 0.57735 (tan $\frac{1}{2}$ I)
53775.0
21398
2993 (abbreviated
299 multiplication
13 of decimals)
2
247.05 †
Corrected $\frac{l}{2}$ 207.69 from Table II
454.74 = Dist. to B. T. C.

This brings out another point.

With equal transitions at either end, I must be at least equal to six times the tangent deflection to the P.C.C. or connection with the main curve.

In the case just figured the length of 14° curve between transtions would be only a fraction over 17 feet long.

If it was desired to use a 14° curve, I being smaller, it would be necessary to use a transition with shorter chords.

Mr. Hannaford

Mr. Hannaford said he would like to know at about what degree the curves on the C. P. R. were?

Mr. Irwin.

Mr. Irwin said on the C. P. R. they ran around a 21° curve regularly on the main line, but this degree of curve is not to be taken as a strong point. There is only one like that on the main line. It is a place where there was a bad mud slide in the mountains.

Mr. Hannaford.

Mr. Hannaford said he had the pleasure of passing over that some years ago with Mr. Van Horne, and the engineers were rather doubtful as to whether the cars would go around. Mr. Van Horne told him he had received a message that the cars had touched each other. He ordered them to lower the elevation, but still the cars touched; then he ordered them to take out the elevation, and if that did not do to raise the inside rails.

Mr. Irwin.

Mr. Irwin :—Oh, yes, the difficulty has been overcome; but that question of putting the elevation in the inner rail has been practically tested in a station yard where it is necessary to do it to get the locomotives to stay on the track. He thought they had quite a number of curves of 6° on the C. P. R. They had as a rule nothing on the main line much sharper than that and not very many so sharp.

Mr. Hannaford.

Mr. Hannaford :—And what elevation do you give?

Mr. Irwin.

Mr. Irwin :—½ in. per degree generally, but curves of 6° to 10° are eased by the trackmen, using what are practically transition curves.

Mr. Irwin.

Mr. Irwin said there was just another statement he would like to make. It is 24 years ago since French engineers used the same curve as Mr. Wicksteed. He thought it was in 1869 that French engineers began to use this transition curve. Things which seem to us quite new here have often long since been in use in the Old Country.

Mr. Armstrong.

Mr. Armstrong said, in regard to running on very sharp curves, the chief idea he had was that they would be required on electric roads.

Mr. Cuningham.

Mr. Cuningham asked whether they would be applicable to a 40ft. radius.

Mr. Armstrong.

Mr. Armstrong responded that you would probably have to slow down for that, but many cases would occur when they would be required, especially on country roads, and adds that he proposes to work out more tables like Table II, using shorter chord lengths, which are more applicable to the sharper curves.

The alternate way, given in the formulæ, for finding the functions in these tables is very simple. Diagrams might be made giving the corrections by inspection for a large number of chord lengths and curvatures.

Mr. Sproule said he would like to know from Mr. Hannaford if there is any other railway in America with as easy a curve as the Grand Trunk Railway?

Mr. Hannaford

Mr. Hannaford said he thought not; the Grand Trunk had paid special attention to their curves. The sharpest curves they have are between Montreal and Portland. In a distance of 297 miles there are two curves of 5°, but these are the only two excessive curves. There are easy curves between Montreal and Toronto.

In reply to a question by Mr. Sproule as to why the G. T. R. did not make better time between here and Toronto, Mr. Hannaford said the Grand Trunk Company should not, as he had told them, take over nine hours between Montreal and Toronto, but he thought it was old custom more than anything else which prevented their doing it in the time mentioned. Frost is a very dangerous element in this country. If some of us would write a paper on the effect of frost on railways it would be of great benefit.

We profess on the Grand Trunk Railway to keep the road very smooth. We run from here to Coteau Landing, 37½ miles, in 54 minutes, and we certainly could not do so at this time of the year if the road was not very smooth. But certainly the distance between here and Toronto should be covered in 9 hours, and there should be no trouble about doing it when it is all double tracked, unless during winter storms and spring frost coming out.

Thursday, 6th April.

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

Paper No. 77.

COMMON ROADS.

By C. R. F. COUTLÉE, Stud.Can.Soc.C.E.

The first road organisation in the Province of Quebec was under French rule by the edicts and ordinances of Louis XIV. The "Grand Voyer" conducted the work, and the proprietors executed the labour throughout their lands. In 1832, road commissioners were appointed, and at the union of the provinces in 1841 the municipal authorities received control of nearly all the roads.

In 1793 the first parliament of Upper Canada at Newark placed the roads under a pathmaster. The work was performed by statute labour. Since 1850 the municipalities have controlled nearly all the roads as in Quebec.

The law of Manitoba is modelled after that of Ontario. All roads are under the municipal councils except "old trails" and great highways, to which no alterations may be made without sanction of the Governor General in council. Since 1876, however, these have been maintained by the municipalities.

In Nova Scotia the settlers located the roads "by sighting from hill to hill." Statute labour has always been in force, the assessment being made by the Provincial Government, which also voted sums to be disbursed by members for various counties. Pathmasters were appointed by the Quarter Sessions composed of the county magistrates. The County Incorporation Act of 1878 vested the control of roads in the county council. Government grants are expended by the council, who appoint an overseer for each section. This officer has also charge of the statute labour.

The great road from Halifax westward passes by Truro, Amherst, Moncton, Chatham and Campbellton. It is called the Metapediac to Ste.

Flavie; thence along the South Shore by Rimouski, Cap Rouge, Montreal, Kingston and Toronto, it is called the Montreal road. It extended as far west as Sandwich, and a branch led from Hamilton to Owen Sound. The Dawson Route from Port Arthur to Fort Garry, 452 miles, was completed in 1868.

Highways suffered by the introduction and rapid growth of railways; capital and skill found a more pretentious field in the latter, and roads left to the management of the municipal authorities lacked the means, superintendence and unity of endeavour necessary to their improvement.

New roads are opened along the concession lines to prevent the cutting of farms. The work is done by statute labour, which cannot be properly superintended, and the consequence is that the ditches are uneven and their bottoms sometimes higher than the road, while the excavated material, vegetable mould, stones, roots, anything, is thrown broadcast over a width of thirty feet or so. Stumps and stones are not removed, and vehicles meandering about to avoid such obstacles render the trail tortuous and unsightly.

Old roads for similar reasons are frequently very much out of repair, their unfitness for travel depending on the nature of the soil. Clay districts are in this respect at a great disadvantage.

In winter the roads are generally good, a great part of the hauling being done at this season on this account and owing to the facility of ice crossings. Winter roads probably prevent the loss from bad summer roads being more keenly felt.

The degree of a State's civilization may, it is said, be judged from the condition of its roads. The English legislated on the matter of control and maintenance of their historic turnpikes as late as 1888, when they were placed under the councils of counties.

The practical and systematic Prussians are constantly improving their communications, and this movement has also affected Italy. The French, who in the last fifty years have obtained a most complete system of roads, are zealously extending and maintaining the same. The Atlantic States during the last few years have awakened to the necessity of good roads to supplement their railway systems, and county after county has bonded itself to raise funds for the building of metalled roads under the direction of engineers.

In Canada, our great natural products, the greater portion of which must be hauled a long distance by animal power before shipment, demand good roads during the autumn or wet season. Nova Scotia and

New Brunswick are devoting considerable attention to highways. Loans have been made by the Provincial Governments to be expended by the councils of counties on roads and bridges of importance. The statute labour tax is paid in money like other country dues. County engineers are recommended.

In Quebec, colonisation routes have received considerable attention. The Legislature has assisted the municipalities in the construction of bridges, and the macadamising of some roads has been mooted but will not likely materialise for some time. There is no skilled superintendence; each parish labours independently and without professional advice.

The abolition of tolls in Ontario was considered a great relief by the people; the obligation to pay tribute day by day is especially galling to the New World people. Toll monopoly requires to be most cautiously guarded, and the collection of dues should be made in bulk sums. Each county forms a unit in road matters, and professional aid is not general.

From the United States census of 1880 it appeared that the average cost of hauling one hundred bushels of grain by animal power was sixty cents per mile, amounting in some cases to $2.

Professor Ely, in his "Problems of To-day," places the loss from bad roads at $15.00 per year for each horse.

Horses pulling 1,400 pounds on an earth road could pull 4,000 pounds on a metalled road, and with earth roads at some seasons 1,400 pounds could not be hauled. Loads over a ton weight are the exception in Canada, while in France the peasant is accustomed to see three-ton loads, and this load on broad tired wheels is really a roadmaker itself. Such a sight in our rural districts would be a seven days' wonder.

Through bad roads town markets are scarcely supplied during wet weather and overstocked during a period of good travelling. Middlemen are busy with a view to such occurrences, while both producer and consumer lose thereby.

Prosperous farmers move into towns owing to the difficulty of sending their children to any but the nearest local school, and the children are averse to return unless speedy and comfortable travel is assured in all weathers and at all seasons. Social culture and refinement is lost through inability to attend social gatherings. Neglect of elections and small attendance at municipal meetings, attributed to a lack of public interest, is often due to the dreariness of driving over muddy dirt roads, while the nervous strain engendered by dangerous localities, jolting vehicles and fagged horses is but too well known to engineers who have the misfortune to lumber through the cahots and sloughs of despicable country trails.

This unfortunate state of affairs, however, remains unremedied by the agricultural population—city people don't bother about it—because there is no opportunity of comparison with a better condition, because the improvement of roads is considered a most expensive matter, necessitating extensive and radical legislation and a large cash outlay as in a railway construction, and because there is no organised system of labour, skilled superintendence nor distribution of information.

The ordinary pathmaster lives a life of misery, lest he be assailed on the one hand for non-enforcement of the law or attacked for over zeal and mismanagement on the other, while he realises that the system is inefficient and unpopular.

Location of common roads essentially differs from that of railways, in that the conditions of travel admit of much greater latitude in grades and curves. The classification of roads or the selection of roads to be improved in a district is dependent on their relation to towns, to railways, or to local industries.

Curves can be very sharp in France ordinarily a radius of from fifty to one hundred metres is used with a width of five metres.

Grades may generally be eased at an increase of distance. The limit of grade in the Ontario colonisation roads is as far as possible 10 per 100. This grade obtained on the Temiscouata road before its conversion into a military route in 1862, when the grade was generally reduced to 7 per 100. Telford advised a limit of 3.3 per 100, increased to 5 and even 6.7 per 100 for short distances. The better the road surface the more gentle should be the gradients, but this does not imply that steep hills are advisable on earth roads.

Drainage is the most important matter in road construction, a water logged foundation cannot support the toughest metallings. A theoretically perfect road would run along a ridge from which sub-water and storm water would naturally be shed. This is artificially obtained by side ditches and under drains, the storm water being disposed of by crowning the surface, slight longitudinal grades and the maximum exposure to wind and sun. Were road improvement to become general, men would probably be found to adopt ditching as a means of livelihood, and this important matter be in the hands of skilled labor. Metalled road surfaces resist the penetration of water, and their hard surface retaining its crowning storm water is easily passed to the ditches. For transverse form, a circular arc of 150 feet radius or an ellipse 30 feet major axis and 9 inches minor axis is sometimes used; but two planes, falling 3 per 100 to 5 per 100 toward the sides, and connected by an arc of 80 to 100 feet radius, about five feet long, is generally to be preferred.

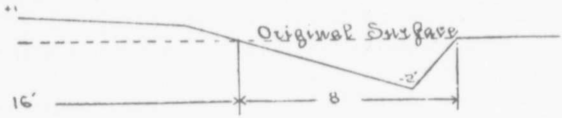
Earth roads, owing to ruts, irregularities of surface and their porosity, do not admit of speedy transverse drainage by crowning, so every facility must be given for evaporation by elevating the surface above the surrounding level if possible, or by making the ditch-slope toward the road as flat as possible. Surface stones delay drying, and narrow ruts will retain water for days after the general surface is quite hard. Trees, on account of their shadows, should not be placed too close together, though they should adorn every line of road. The frequency of culverts demands that they should be at once cheap and durable. With pipes, it is to be remembered that the covering of earth is generally slight.

Wooden bridges are very general, but with the help of local legislatures many have been replaced by iron. Masonry or concrete arches are very rare in this country. Old rails have been employed, but their use is, for some reason, not extended.

As to coverings, it should be the aim of all municipalities to eventually have their roads metalled with broken stone or its equivalent. In regard to the width of covering, if it allow of draught vehicles passing easily, then it fulfills all requirements, as fast travel can be accommodated by gravel or earth wings, the softer material causing less injury to horses.

Owing to expense, earth roads must long continue the only admissible ones for many parishes. Loose sands require tempering with clay, and heavy clays require sand or gravel; but the conveyance of materials is the greatest trouble under the statute labor system, contribution in kind being considered an unfair tax, so the best must be done with the materials at hand.

Clay roads during dry weather resemble asphalt. The wheel track about twelve inches wide becomes smoothly rolled, but longitudinal waves more or less abrupt exist to retain water. Just outside this wheel track is comparatively soft ground, and frequently a rut two to six inches deep. The horse track is pounded to a concave form, about fifteen inches wide and three inches deep; on either side between this trough and the wheel tracks are two ridges of uncompacted but hard baked clay. If the traffic be principally double, the wheel track and hoof track become one, with benefit to double vehicles but greatly increased misery to single ones. When wet, the wheel track becomes slippery, and wheels sliding to the sides make deep ruts in the wet uncompacted clay, while with continued rain the horse track and all holes and ruts become filled with water which cannot escape through the impervious clay puddle. Till the water evaporates from these basins then the adjacent clay remains surcharged with moisture, and consequently viscous though the side ditches are quite dry. The necessity of exposure to unimpeded action of wind and sun is very apparent.



Cross-Section

For the general cross section of an earth road here shown, the following advantages are claimed :—

(1) A fence beem capable of being used for a foot path.

(2) A large ditch easily cleaned and open to inspection.

(3) A long side slope securing rapid passage of storm water, safety to vehicles and free exposure to wind and sun.

(4) Its adaptability to the reconstruction of old roads either by scraper work or road machine.

Assuming 5,000 cubic yards of material, say clay, per mile, the cost of an earth road may be approximated as follows :—

With round haul from ditch to road about 40 feet, vertical lift 2 feet, drag scrapers should average 200 cub. yds. per day. This would amount to 25 days' work for a team, or 2½ days' work for ten teams.

10 teams scrapers	@ $3.00	for 2½ dys.	$75 00
2 " plowing and harrowing	@ $3.00	" "	15 00
2 men filling	@ $1.25	" "	6 25
2 dumpmen	@ $1.25	" "	6 25
			$102 50

A man taking road work say 2½ miles to either side of his own place could use his horses during spare time, and feed them in his own stables, so $3.00 per day would be a full wage.

To compact 18 feet wide by rolling would necessitate passing on each side with the outside edge of a five foot wide roller following a line 9 feet from the centre line. The next passage of the roller would be 2½ feet nearer the centre on each side, then along the centre. Over the 3 central widths of 5 feet the roller would be repassed, say five times, making in all twenty trips or about 20 miles of rolling for each mile of road, consuming with delays a day's work of a team. In addition to this, five men would be required to trim behind the roller. The expenses for rolling a mile would thus be as follows :—

1 team,	at $3.00 for 1 day	$3.00
5 men,	at 1.25 " "	6.25
		$9.25

Then excavation spreading and rolling would amount to $111.75 per mile, and with 12 per cent. added for contingencies to a little less than $125.00 per mile, nearly 2.4 cents per lineal foot. Superintendence, structures, fencing etc., are not considered in the foregoing.

As to the cost of proper maintenance, it may be considered that after each snow or rain storm some work must be done. Taking the past year the following bill of repairs has been arrived at for ten miles of road :

Dec. '91, Feb. and March, snow giving work for 15 days.		
1 team (plow and roller), at $3.00 for 15 days		$45.00
5 men	1.25 " "	93.75
April, breaking up necessitating 15 days' work.		
1 team (harrow, roller, etc.), at $3.00 for 15 days		45.00
5 men	1.25 " "	93.75
May and June, rains and traffic necessitating 25 days' work.		
1 team (roller, etc.), at $3.00 for 25 days		75.00
2 men	1.25 " "	62.50
July, Aug. and Sept., rains and traffic necessitating 15 days work.		
1 team (roller, etc.), at $3.00 for 15 days		45.00
2 men	1.25 " "	37.50
Oct. and Nov. (rains, etc., till frost sets in), necessitating 20 days' work.		
2 teams (roller, etc.), at $3.00 for 20 days		120.00
5 men	1.25 " "	125.00
	Total	$742.50

Or $74.25 per mile, say $75.00.

To apply statute labour to this estimate for maintenance would mean the expenditure of 110 days' work for a team and 330 days' work for a man on ten miles of road, or at the rate of 11 teams and 33 men per mile. With 3½ arpent farms (8 to one mile), each farm would be required to furnish 1.4 teams and 4.1 men, say a team and driver for 1½ days and 2 men for 2 days.

From descriptions of the French system of "prestations" used for the repair of the fifth class or parish roads, it appears that three days' labour is required of each rate payer besides 3 days' labour of all his draught animals.

(4) Its adaptability to reconstruction of old roads either by scraper work or road machine.

With well kept wings, either gravelled or sodded, and occasional trees, a most pleasing effect would be produced and be a mighty force toward national sentiment.

As to the two methods of minute daily repair and periodic repair, only the latter can be generally adopted.

The construction of Macadam and Telford and the various modifications have not been entered into here, as the literature on the subject is very complete. Various methods of metalling called macadamising, turnpiking, etc., are in vogue, however, wherein stones, from chips to boulders, are heaped on the ground covered with earth and thrown open to traffic. When after several years' neglect such a road becomes dangerous or particularly aggravating, a lot more stone is broken on the surface, "blinded" with six inches of earth, and considered a "first class job."

For the maintenance of earth roads a roller of some kind is primarily necessary. Ground develops a series of inequalities under continued rolling that is quite surprising. On clay roads a harrow may be used to great advantage before rolling. For light soils, road machines are becoming very general. Repairs cannot be begun till the ground is quite dry, after the spring freshets; from then till autumn they should be actively prosecuted, so the surface may be in the best possible condition to resist the fall rains and frosts.

All maintenance is materially assisted by drivers using discretion to prevent the formation of ruts by following too closely the same track and by the use of amply broad tires, according to the weight of load. The exercise of care in these matters is a habit soon acquired by our public.

Now, as to the means of obtaining gradual improvement in the manner of country road making and repairing.

It is necessary to establish an interest in good roads among the county councils of each province, the municipalities becoming interested through their delegates. To effect this it is proposed that a committee of this Society be formed to collect data, by circulars and other means, regarding the importance of roads in various counties with a view to their classification and division into districts, the committee to enlist the co-operation of the county councils and compile rules for the details of organisation and construction, these to be widely distributed to all municipal bodies throughout the Dominion. The press would be a most important factor in awakening interest in road matters. The expense of this distribution of information should be borne by the general public.

To interested corporations the committee could recommend qualified engineers to confer with the authorities and report on proposed works, the corporations to pay at a fixed rate for such professional services. On decision to execute works, professional aid would again be required to organise the construction and instruct the pathmasters. Thus a trained executive would be gradually formed, and road-making become a trade adopted by some in every county. Skilled operatives would then be available for the maintenance of highways, and when mass labour was necessary everything would be prepared for its employment to advantage.

A system of inspection, as followed on some railways, with contributed prizes to pathmasters, foremen and labourers, would give an increased interest in the work, especially were the prizes awarded at the county fairs.

When "Road Renaissance" had become a matter of practical existence, then would be the time to consider road legislation regarding the taxing of towns, railways and other institutions specially benefited. Till then, however, roads are better without too much refinement.

Thursday, 20th April.

P. Alex. Peterson, Vice-President, in the Chair.

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

Members.

Phelps Johnson, James Cron Kennedy,
George Wellesley McCready, Donald Alex. Stewart.
Francis Stuart Williamson.

Associate Members.

Newton James Ker, Forbes M. Kerby,
Alexander Potter.

Associates.

Jacob Andrea Kammerer, Harry McLaren.

Students.

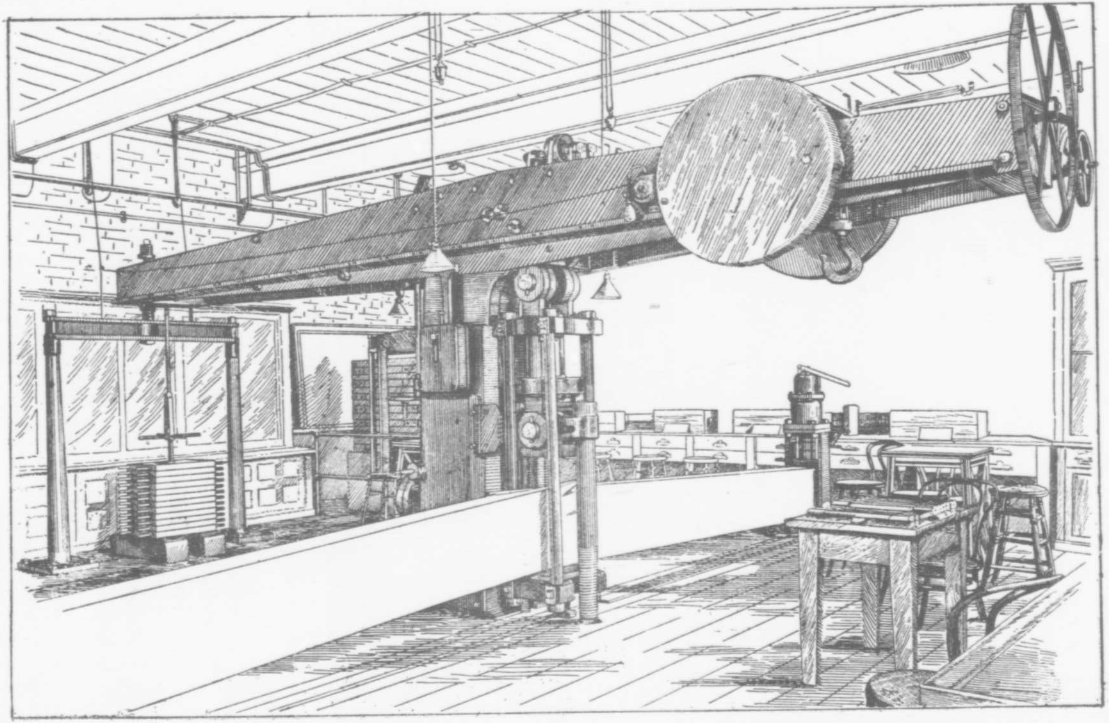
Thomas Henry Alison, Edouard Charles Amos,
Louis Auguste Amos, Henri Alexandre Panet,
Joseph Leon Spenard, Octavius B. N. Wilkie.

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

Walter C. Brough.

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

Edgar S. M. Lovelace.



Paper No. 78.

RESULTS OF TESTS OF WHITE PINE OF LARGE SCANTLING.

By Prof. H. T. Bovey, M.Can.Soc.C.E.

The following are the results of a series of experiments carried out in the McGill University Testing Laboratories with a view to determine the transverse strength of Canadian white pine.

Four sticks in all were tested, each stick being 25 ft. long x 9″ wide x 18″ deep. The sticks were in pairs, each pair being cut out of one tree. One of the trees was felled in the Gatineau Valley and the other in the Pettawawa District.

It was also specified that the timber was to be as sound and clear as possible. Hence it was natural to suppose that timber thus ordered might be assumed to be first class, and that it would correspond to the best white pine obtainable in the ordinary market.

The whole of the sticks were tested in the Wicksteed Machine, and the accompanying photograph shews one of the fractured timbers in the machine. This machine is supplied with specially designed apparatus for transverse testing. The centre of the beam is supported in a stirrup upon a hardwood bearing of large radius. The stirrup is connected by four steel rods to the lever of the testing machine, and the ends of the timber are forced down by two hydraulic pumps each having a capacity of 25 tons. The neutral axis was carefully marked, and arrangements were made to take the deflections at seven intermediate points.

The tree from the Gatineau Valley was felled in the winter, was brought to Montreal via the Gatineau and Ottawa Rivers, and remained in the water until late in the autumn of 1892, when it was piled on the land for winter sawing at the mill.

The first stick from this tree was tested February 16, 1893, with the results as per accompanying table.

Thus it will be seen that the maximum ultimate skin stress was only 2903 lbs. per square inch.

The weight of the timber at the time of testing was 37.25 lbs. per cubic foot, which decreased to 34.78 lbs. per cubic foot on March 15.

The second stick from the same tree was tested on February 24, the distance between the centres of the bearings being 24 ft. Fracture took place under a pressure of 12,000 lbs. at each end, and the maximum ultimate skin stress was 3555 lbs. per sq. in.

Distance from centre to centre of supports = 24 ft.

Loads at centre in lbs.	Deflections at centre in inches.
5,000	.32
75,000	1.02
10,000	1.45
11,000	1.95
12,500	2.16
15,000	2.45
17,500	2.97

19,600 breaking weight.

The fractured portions were now cut out of the centre part of the two sticks, and the two ends of each stick were again subjected to test. The results of the test were as per accompanying tables.

Tested 14*th March.*

Distance from centre to centre of supports = 114 ins.

Loads at centre in lbs.	Deflections at centre in inches.
10,000	.10
12,500	.125
15,000	.15
17,500	.19
20,000	.21
22,500	.245
25,000	.27
27,500	.30
30,000	.33
32,500	.37

40,000 breaking weight.

Tested 15*th March.*

Distance from centre to centre of bearings = 102 ins.

Loads at centre in lbs.	Deflections at centre in inches.
10,000	.11
12,500	.14
15,000	.165
17,500	.19
20,000	.225
22,500	.255
25,000	.285
27,500	.31
30,000	.35

51,400 breaking weight.

Tested 17*th March*.—Pieces from stick tested on 24th February. Distance from centre to centre of bearings = 120 ins.

Loads at centre in lbs.	Deflections at centre in inches.
10,000	.11
15,000	.17
20,000	.23
22,000	.25
24,000	.27
26,000	.30
28,000	.33
30,000	.36
32,000	.39
34,000	.42
36,000	.45

53,650 breaking weight.

Distance from centre to centre of bearings = 120 ins.

Loads at centre in lbs.	Deflections at centre in inches.
10,000	.13
15,000	.20
20,000	.29
22,000	.32
24,000	.35
26,000	.40
28,000	.44
30,000	.49
32,000	.53

40,500 breaking weight.

The tree from the Pettawawa District was felled five years ago, lay in the water four years, and was taken out in the autumn of last year and piled for winter sawing.

One of the sticks from this tree was tested March 8, the results being as per accompanying table.

Distance from centre to centre of bearings = 24 ft.

Loads at centre in lbs.	Deflections at centre in inches.
5,000	.37
10,000	.93
15,000	1.55
16,000	1.68
17,000	1.81
18,000	1.96
19,000	2.11
20,000	2.27
21,000	2.42
22,000	2.65
26,350 breaking weight.	

The second piece was tested the 11th March, the results being as per accompanying table.

Loads at centre in lbs.	Deflections at centre in inches.
5,000	.61
10,000	1.20
15,000	1.86
16,000	2.00
17,000	2.14
18,000	2.33
19,000	2.48
20,000	2.63
24,850 breaking weight.	

The fractured parts from the centre portions of these two sticks were cut out and the ends again tested, the results being shown in the accompanying tables.

Tested 30th March.—Pieces from stick tested on 11th March.

Distance from centre to centre of bearings = 10 ft.

Loads at centre in lbs.	Deflections at centre in inches.
10,000	.12
15,000	.20
20,000	.26
25,000	.35

44,400 breaking weight.

Distance from centre to centre of bearings = 10 ft.

Loads at centre in lbs.	Deflections at centre in inches.
10,000	.10
15,000	.16
20,000	.23
25,000	.30

48,650 breaking weight.

Tested 31*st March.*—Pieces from stick tested 8th March. Distance from centre to centre of bearings = 10 ft.

Loads at centre in lbs.	Deflections at centre in inches.
10,000	.10
15,000	.16
20,000	.23
25,000	.29

48,600 breaking weight.

Distance from centre to centre of bearings.

Loads at centre in lbs.	Deflections at centre in inches.
10,000	.11
15,000	.16
20,000	.24
25,000	.30

51,870 breaking weight.

Thursday, 4th May.

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

Paper No. 79.

THE QUEBEC LAND SLIDE OF SEPTEMBER 19, 1889.

By CHAS. BAILLAIRGÉ, M.Can.Soc.C.E.

In 1879 and for years past there had existed dangerous fissures in the cliff opposite the King's Bastion of the Citadel, Quebec. The attention of the Federal Government having been called to the alarming aspect of these "crevasses," the author was instructed by Sir H. Langevin, then Minister of Public Works, to make a survey of the locality and report thereon, with such suggestions as might be deemed advisable in the premises.

Plates IV and V, together with a vertical section of the cliff at each of the proposed buttresses, were prepared at that time and sent in with the author's report in January, 1880, with the exception, of course, that as the accident had not then occurred, it did not appear in Plate IV, as since indicated as comprised within the area *A B C D E F G*, and the line to which the debris were projected, as shown, on the opposite side of the roadway.

Plate IV is a plan or bird's-eye view of a portion of the Citadel and Glacis, the south-western extremity of Dufferin Terrace, and that part of Champlain street overtaken by the avalanche, or which was likely to be in case of an eventuality.

Plate V is an elevation or front view of the cliff, etc., showing the outcrops of the almost vertical strata of the face of the cliff, as shown in Plate VI.

The conclusions of the author's report were that, should the rock give way, it would take the houses on both sides of Champlain street, and that they must either be vacated or a series of buttresses erected to stay the danger.

The rock being at the time in a state of stable equilibrium, and the portion of it which has since fallen not exceeding 36,000 tons, the aggregate counteracting weight of the buttresses being some 12,000 tons, would, no doubt, have proved effective for many years to come; but as the author laid greater stress on the recommendation to have the premises vacated, as the surer mode of conjuring the evil to be apprehended, the Government engineers advised the purchase of the property at the foot of the cliff and its demolition, as being also the cheaper alternative.

This suggestion was carried out, and a wall *a b c d e* on plan and *w* on section was erected, increasing the width of street, by eight feet, and to answer as a screen or fender to prevent falling stones from rolling over to the opposite side of the street, and thus possibly avoiding accident to life, limb or property.

It is, of course, to be regretted that the property on the river side of Champlain street, at the site of the accident, was not also bought up and demolished (or, as Major Mayne suggests, the houses vacated, but left standing and filled in as a screen against falling debris), since, in the author's report, he repeated the warning that "when the cliff falls, it will be sure to destroy the property on both sides of the street."

There is another point in which both the plan and elevation now submitted differ from the originals of 1880; to wit: the indication thereon of the drain which from the King's Bastion runs along the foot of the rip-rap facing of the lower glacis, and thence under the Terrace flooring and through the wall as shown, towards Champlain street and the river; the existence of this drain being unsuspected at the time the plans were made.

Referring now to the following conclusions as to how the slide occurred, it will be understood that *C D E* is the line of outer crevasse along which the cliff parted, *A B C D E F G* that portion of the cliff which was forced out and fell over, the debris reaching, as shown on plan and section, to about 40 feet on the river side of Champlain street.

The crevasse indicated on plan and elevation as "present crevasse" is the one now existing, into which the water poured from the broken drain at *D*, filled the crevasse as hereinafter described, forced out the rock between the two fissures, and caused the portion beyond *C D E* to fall forward.

Intermediary fissures, not at first shown on plan, or not then known to exist, are now sketched in and shown on section, giving the strata their present fan-like, diverging or radiating appearance, and accounting for the fact, that while the present inner and main crevasse is almost vertical and, in fact, inclining towards the left or westward, the outer crevasse leans over or inclines towards the right or eastward by not less than 1 in 10.

The Quebec rock is, geologically, of the Utica slate formation, and, like other sedimentary strata, originally more or less horizontal. The subsequent tilting up of the strata to almost verticality is, one need hardly be reminded, due to the puckering, folding of the earth's crust under the seismic effects of contraction of the interior nucleus in cooling, and the outcrop of the strata to still subsequent erosion and wearing away of the upper portions of the folds by the hand of time.

There appeared in the *Canadian Architect and Builder* for October, 1889, a section of the cliff and description of the Quebec land slide of 19th September, 1889. The author had not at that time reduced the accident to calculation, nor had he then the necessary data so to do. Since then he has had to work up the case for the Exchequer Court and give evidence as to how the fall of the cliff was brought about. Having visited the Citadel ditches, he found that the whole ground fell some 40 ft. in level from the western to the eastern end; that the area, including roofs of casemates, draining towards the King's Bastion just opposite the centre of the avalanche of rock, was such that, into the depth of rainfall for the 12 hours immediately preceding the accident, it gave some 30,000 cubic feet of water, the average of rain and melted snow per annum for the last twenty years being 24".06 of rain and 15".45 of melted snow—a foot of snow being assumed equal to an inch of rain—or over one-quarter of a million cubic ft. per annum which had been pouring down the cliff for years past, instead of finding its natural outlet towards the river through the drain already alluded to, which had probably been built for 60 years or more, but which the author found to be completely choked with earth and rubbish, and so solidly packed that not a drop of water could find its way through it.

This drain, some 20" in diameter, though uselessly large for the duty it had to perform, was found to be burst or broken just below the King's Bastion already alluded to and immediately to the eastward of the stairs reaching from the Terrace to the Citadel. The aperture in the drain was just above the point at which it was so completely choked as not to allow of the water getting any further, so that all the water found its way directly into the fissure which now exists and has existed for years in rear of the Terrace, and, as already stated, opposite the very centre of the land slide.

Referring to Plate VII at *A* on plan and at *A D C* on section, is the present crevasse or fissure into which the water poured and has been pouring for maybe 30 years past, or ever since the drain, which ran north-eastward down the cliff towards the river, ceased to be operative, as evidenced by the author from the fact that from its outcrop half way down the cliff no water had been running for fully that number of years.

This fissure has existed for longer than anyone now can remember, and there is no doubt that the drain was built to prevent the Citadel ditch water from finding its way into it and thus hastening a land slide; but the drain seems to have been, in after years, entirely forgotten or paid no attention to, and nearly all that portion of it north-eastward of the break in the side of the brick barrelled portion of its continuation up the cliff being a mere deeply imbedded surface drain, it soon became filled in by the fall of the crumbling face of the shaly rip-rap work of the glacis front above it, dust and vegetable growth.

This fissure *A* up to the time of the accident had been mostly hidden from view by debris from above fallen into it at its outcrop, and public attention was concentrated on, and that of the Government called to, the alarming appearance of the fissure at *B*, where the rock gave way at the south-western end of Dufferin Terrace.

As already stated, the author was called by the Federal Government, in the year 1880, to report, when he said that if the rock fell it would take the houses on both sides of Champlain street, and recommended the erection of a series of buttresses of heavy masonry some 6 ft. thick, 50 or more ft. in depth between the roadway and the cliff, and some 80 ft. in height, and rising, say, to *F*. The cliff, or the portion of it *E B F G* which fell, being, like the leaning tower of Pisa, though inclined, in a state of perfectly stable equilibrium, and such that the buttresses proposed, and which were to have been erected at distances of about 40 ft. apart—seven of them in the 300 ft. from *H* to *K* on plan—must and would have proved effective in staying the catastrophe. Major Mayne's advice, who, as stated, had recommended that the range of houses at the foot of the cliff after being vacated be allowed to remain, was disregarded, or at least their gable end walls, which, abutting or nearly so, as they did, against the rock, might have so broken or checked the fall as to prevent the debris from rolling to the opposite side of Champlain street, and there destroying the houses which, heedless of the author's written warning that the rock in falling would sweep away the residences as well on the river as on the cliff side of the street, had been allowed to stand, and in the destruction of which more than 50 persons lost their lives.

Much more apprehension was felt about the crack at *B* than that at *A*, and the Government caused the upper portion of it for some feet below the outcrop to be filled in with concrete, with the idea of preventing water from above from reaching and falling into it, which it was supposed, acting both by its disintegrating power and by swelling under the effect of frost, might gradually overthrow that portion of the cliff which has since fallen. This was a very foolish thing to do, as will soon be made apparent; for first of all, no water from the Citadel drainage above could reach the fissure, since it must on its way be intercepted by and enter the crevasse *A;* and secondly, by bringing about a contact between the opposite faces of the crack at *B*, which were some two or more feet apart, any shock or push from the rear must inevitably thrust forward that portion of the cliff to the right of *B* (as you look at the section), and hasten its destruction.

A is the crack, if any, which should have been filled in; but, being hardly noticeable to the untutored eye, and so remote from *B* or *F*, was not suspected of any foul intent.

The author had the crevasse *A* gone into and sounded to a depth of more than 70 ft. below the surface, or to *N* on section; and as at that depth there was still the breadth of a man's body, it was made evident by "similar triangles" that the total depth of the crack was 125 ft. below *A* and 100 ft. at *D*—the general level of the rock and earth beneath the terrace flooring—and to which level *D* any water filling the crevasse from *C* could rise without any possible issue below said level *D*.

Professor Laflamme of the Laval University, Geologist, in his evidence before the court, stated that he did not know enough of the cliff to lead him to infer that the fissure *C A* could fill with water, as, from the very broken and disintegrated appearance of the rock as seen along Champlain street, one would certainly be led to infer that if such disintegration and looseness of structure extended to the interior, any water pouring into *A* must leak out from below as fast as it entered from above; but it so happened that having seen and examined this cliff ever since the land slide of 1841, in view of the likelihood of a recurrence of such an avalanche, and more especially during the last 20 years, the author knows it to be a fact that the water from the fissure could only find its way out of it by a very slow process of filtration through the intervening space of over a hundred feet between the crevasse and the face of cliff at *F G*.

The author repeatedly watched the water running from out the foot of cliff after heavy rains, and particularly while surveying the cliff in rear of the houses for his report of 1880, and never saw anything more all along and beyond the 300 ft. of rock frontage towards the St. Lawrence than a mere trickling of the water from the cleavage fissures and others to be seen, and it always took several days after each fall of rain before the slowly running water from the fissures ceased, showing that the crevasse *A* would eventually become clear of water, but by an extremely slow process.

And even at this time, when the front rock has fallen away from *B*, and leaves the face *BP* exposed, the closeness of the component elements is anything but conducive to the view that water flowing into *A* would flow out from below as fast as it passed in at top; and if the face of the cliff as now exposed at *BP* is a little shaky or of apparently loose structure, that is no reason to infer that at 60 to 70 ft. in the interior of the mountain, and where so far removed from atmospheric and disintegrating influences, the texture of the separate strata is anything like as loose, if loose at all, as the view at *BP* would lead one to infer.

The component strata of the cliff just alluded to, which the section shows to be vertical or nearly so, having, of course, been tilted up from their originally more or less horizontal position by an uplifting force from beneath the earth's crust, similar to that which on a smaller scale throws the crust of a sea pie into hills and ridges by the expanding forces of the imprisoned vapours underneath, or, as geologists also incline to think, by the puckering effect on the earth's crust of lateral pressure due to the contraction of the surface incident on the cooling down of the interior, subsequent erosion and denudation of the apices of the folds leading to the outcrops now visible at the surface on a bird's-eye view thereof.

In the section of the cliff published, as already stated, in the *Canadian Architect and Builder* in 1889, or shortly after the accident, all the strata are shown parallel and leaning outwards from the vertical; but a closer survey and actual measurements, levellings and plumbings have disclosed the fact testified to by the author before Judge Burbridge, that the inclination outward or overhanging at *B* is 6 ft. in the 60 ft. from *B* to *P*, or 1 in 10, while at M and O on plan Plate VII, the strata incline inwards just as they do at *A* on plan and section. The author was for some time at a loss to account for this, until, after digging away the overlying earth, he discovered a series of crevices between *A* and *B* on plan and section, varying in width at the outcrop from 1½" to 2" and 4" and 8", to as much as 11" and 20" as seen on section, and which fully accounts for the present non-parallelism of the strata.

Coming now to the actual solution of the problem as to the hydrostatic power of the water to bring about the accident, the following are the data: The crevasse at *A* extends and can be followed for 150 ft. or more from *A* to *O* on plan, where it thins out to nothing. In the opposite direction, or from *A* to *M*, it is also assumed to close or come to nought at a like distance of 150 ft., together 300 ft., and this assumption is based on the fact that the crack was gone into in that direction to say 70 ft. from *A* towards *M*, and its breadth at that point such—that of a man's body—as to warrant the assumption.

It has already been said that the depth of crevasse is from *D* to *C* on section 100 ft. At *A*, the outcrop, the amplitude of crack is now 3½ ft. and at *D*, 3 ft.; but before the accident occurred it was but 2½ ft. at *D* or 3 ft. at *A*, the crevasse having opened by some 6 inches at its centre of position or at *A* on plan and section at the time of the catastrophe. Now, 2½ ft. at *D* and nought at *C* gives 15 inches at *N*. Again, these 15 inches at *N* or half way down beneath *A* on plan, and as the crack dies out at *M* and *O*, give a general average of 7½ inches for the breadth or width or amplitude of the crevasse.

The face of the crevasse is, as already inferred, 300 and 100 ft., or 30,000 square ft., and the average breadth being 7½ inches, gives 17,500 cubic feet capacity, or say from 15,000 to 20,000 cubic ft. The 30,000 cubic ft. of rainfall, which during the 12 hours, or from 8 a.m. to 8 p.m. of the 19th Sept., 1889, precipitated itself through the side aperture in the drain, and which is in about the same vertical plane as *A B* on plan and section, found its way into this crevasse and filled it up to *D* (the spare 10,000 to 12,000 being more than abundantly sufficient to allow for any leakage out at the bottom or sides as it entered at the top), exercising therefore on its opposite faces a separating effort of not less than 6,250 lbs. per square ft. at *C*, 4,166⅔ lbs. at the centre of pressure, or ⅓ up from *C*, 3,125 lbs. at the centre of gravity of the figure, or half way up, the figure being a parallelogram, and a total thrust on the whole surface of 46,875 tons.

Now, the cliff between *A* and *B* on plan and section is, as already said, 300 ft. in length, and it is an average of 65 ft. in breadth or thickness from *N* to *R* and an average height of 85 ft., the height decreasing towards *K* on plan. These figures give 1,657,500 cubic ft. for the portion of the cliff which was thrust forward against the rock *P B F*, and caused it to topple over; but it still remains for the author to show that the hydrostatic pressure of the water in the crack *D C* could produce this effect. The weight per cubic foot of one specimen of solid stone from the debris of the cliff being, as weighed in water, 160 lbs., while another specimen gave 152 lbs., an average of 156, or within a lb. of that given by the author in 1866. This, as just stated, is for solid stone; but the debris at the site of slide show that there is a large proportion of rotten shale and earth variously estimated at from 20 to 33 per cent. of the whole. Taking this at only 20 per cent. to be on the safe side, and this earthy or shaly matter at 100 lbs., réduces the average weight of the cliff to, say, 145 lbs. to the cubic ft. Another way of arriving at this same average weight of the still persistent cliff is the allowance to be made for the earth-infiltrated and mostly empty fissures between *A* and *B* on plan and section.

The cubic feet of cliff which was thrust forward, and which pushed over the rock beyond *B*, is 1,657,500; this into 145 lbs. average per cubic ft. gives 240,337,500 lbs. or 120,169 tons.

Now, had the rock *A B C E* on section, or *H M O K* on plan been a solid monolithic block of stone, and supposing it even to be detached or non-adherent at its base *C E*, but subject to the friction there due to its weight, and incapable of moving forward along *C E*, or of starting to move forward, under a less force than .71 of its own weight (the coefficient of friction of dry stone at rest on dry stone on a horizontal plane) if unobstructed, but which it could not do in this case, because obstructed by a weight of cliff beyond it much more than equivalent to the remaining ·3 of its said weight: the stress against the rock at *A C* could, had it been a single homogeneous mass, have acted only in a way to turn or topple it over, by causing it to rotate on its outer edge at *E*. The force to be exerted by the water to do this must have been equivalent to half the weight of cliff or to 60,084½ tons, while, as already shown, the total hydrostatic pressure exerted did not exceed 46,875 tons or less by over 28 per cent. than the force required to lift the cliff at *C* and cant it forward at *B*.

But as already seen, the cliff is not a homogeneous mass, and on the contrary the section shows it to be thoroughly divided into nearly vertical and parallel strata ranging from a few inches to several feet in thickness; and these strata are again divided by planes of cleavage, as indicated by the lines drawn obliquely across the strata* into

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* These lines indicated in the original sketches or manuscript have been inadvertently ignored by the engraver.

layers lying in a more or less horizontal direction from east to west along the River front. The angles of the planes of cleavage, of which the author measured several among the fallen debris, varied between 17 and 23 degrees,—an average of 20.

The planes of cleavage, therefore, had the strata been vertical at *B E*, would have inclined some 20° from the horizontal, or say 1 in 3; but it has already been shown that the inclination outward at *B E* is 1 in 10 or another 7 degrees, together 27°, an inclination of 1 in 2, and such that just one-half the force need be exerted to thrust the rock forward as would have to be exerted on a horizontal plane.

As stated incidentally, the co efficient of friction of stone on stone at rest is .71 on a horizontal plane, wherefore, to start the cliff at *B* and down to *P*, where unlike at *E* it had liberty to move forward or through a portion of the vacant or partly earth-filled and therefore compressible and reducible space in the chasm *B E*, would have required .7 of its weight or of the 120,169 tons weight of cliff *B C*, say 84,118.3 tons, which the hydrostatic pressure could not have done had the planes of cleavage or of motion been parallel to the horizon; but on an inclination of 27°, or of 1 in 2, it would only require one-half that force to thrust the rock forward, it being absolutely as if made up of so many more or less vertical piles of dry stone on dry stone, set at such an inclination as to cause them to move forward under a stress or pressure of much less than half their own weight.

The conclusion therefore is that the 46,875 tons water pressure could and did cause the still existing portion of the cliff *B C* to move forward at *B* or along *B E*, where it came in contact with the portion *E F* and caused it to fall forward.

But the resistance of the cliff to a motion forward of some 6 inches may have been, and probably was, much less even than assumed, as it had been raining continually for 3 or 4 days before the accident (showing that no allowance need be made for evaporation from soil so thoroughly saturated as it must have been under the circumstances), and the planes of cleavage and other fissures in all directions must have been so well lubricated, there being thin beds or strata of unctuous clay between them, as to have allowed the rock to move forward by the mere effect of gravity almost as does a vessel on its ways set at a much less inclination to the horizontal.

That the movement forward was at *A* only some 6 to 7 inches is still evidenced by the fact that the dislocation in the stairway from the Terrace level, 182 ft. above the St. Lawrence, up to the rampart heights, gives just that separation, and the Terrace flooring, which had been scribed to fit the rocky crags along the rear line thereof show to this day, as they did the very moment after the avalanche, a separation of a like number of inches north-eastward of *A* and decreasing or dying out at about 150 ft. still eastward therefrom.

If there still remains any doubt as to the cause which brought about the result, what other force can it be ascribed to? The only other cause that could be assigned would be an earthquake, a momentary quake or shock of the earth's crust at the point in question, and this could not have occurred without being noticed by someone at an hour when everyone was up and doing, as was the case when the accident occurred between 7 and 8 on the evening of the date recorded; and the very fact of the still persistent portion of the cliff having moved forward by only a few inches is proof incontrovertible that it must be due to the cause assigned, as any other force like that of an earthquake could never have been so instantaneous as to stop short at a mere 6 inch move, while this is fully explained in the case of the cause assigned, where, the moment the cliff moved forward, thereby increasing the capacity of the fissure, the water level at *D* immediately sank and decreased the pressure against the rock in a way not to continue it, and even though the co-efficient of friction of stone on stone in motion is but .7 of what it is at rest, or the resistance only .5 (.71 x .7 = .497) of the total weight of cliff.

The greatest stress the author supposes to have been exerted at the "centre of pressure" and upwards, or between it and the centre of gravity, where the loose material filling the fissure *E B* would allow of being crushed into a less bulk, and thus brought about a contact between the pushing rock and that pushed over.

General Cameron and Major Mayne of the Royal Military College, Kingston, who reported to the Federal Government on the subject in 1889, or just after the accident, were of opinion that the fallen portion of the cliff had given by sliding out at the base; but this view, the author submits, can hardly be maintained, as in such case the vegetable mould, grasses and other growths at *B* would have been found at *P*, while, on the contrary, they were found at the extreme outer edge of the fallen debris, showing that, as testified to by several witnesses, the cliff actually fell forward from the top.

DISCUSSION.

Mr. Cuningham.

Mr. Cuningham said it was an extremely interesting paper and on a very unusual subject. It seemed to him that the principal point is that the remaining rock is in very great danger of falling, and that some means might be devised to prevent this filling in of water which appears to have been the initial cause of the upsetting. Possibly the best thing to do would be to drive a tunnel from the face to drain off all these crevasses, so that as the water falls in it will be carried off by the tunnels and drain away. If it is as Mr. Baillairgé states, and such would appear to be an incontrovertible fact, then the remaining portion of the cliff under the present conditions will also go.

Mr. Baillairgé.

Mr. Baillairgé said yes, this would no doubt be effective in removing infiltrated water, which even if insufficient in quantity to fill one or more of the crevasses between *A* and *B* on section, Plate VII, and act by hydrostatic pressure, or pressure due to head, might, as in the past, act by pressure due to swelling under frost, thus separating the component vertical layers or strata more and more during each successive year, until the outer stratum were pushed over, to be succeeded in course of time or followed up by other strata in the rear.

Mr. Peterson.

Mr. Peterson asked what was the part of the cliff that fell out?

Mr. Baillairgé.

Mr. Baillairgé :—This is shown on plan, Plate IV, between letters *A B C* to the left, *E F G* to the right, *C D E* to the rear, and the front line by the words, "foot of cliff before accident," as also by the words, "fallen cliff say 300 ft." between *B* and *F*, the average length.

The same is shown in section, Plate VII, between letters *B P* and *F G*, and again in section, Plate VI, leftward of *D*, where the words occur, "fallen portion of cliff say 36,000 tons."

Mr. Cuningham.

Mr. Cuningham said, was not the idea of tunnelling in from the front and draining all these crevasses the most practical one?

Mr. Baillairgé.

Mr. Baillairgé :—The most practical, the surest and safest plan would be to demolish or cut down the cliff, allowing the fallen debris to find their own level at about $1\frac{1}{2}$ horizontal to 1 vertical (as such material does when dumped into embankment for a railway, etc.), thus hastening what the hand of time is sure to do in the long run.

This, however, would destroy some 300 ft. of the south western end of the Terrace, which our people are loath to part with, and necessitate the shifting of that portion of Champlain street further towards the St. Lawrence, the estimated cost of doing which is not less than $60,000.00.

Now to save the Terrace and avoid the necessity of shifting the roadway, the author proposes that a retaining wall be built some 300 ft. in length, 40 ft. high, 20 ft. thick at bottom and 15 ft. at top, battering back 5 ft. in the 40 or 1 in 8, and with layers perpendicular to the batter or dipping towards the cliff, so that any effort to thrust the wall forward must be increased by the necessity to lift the wall along an inclined plane of 1 in 8, the rock foundation having to be cut or stepped to this slope for the purpose.

The outlying debris which now cover the roadway to a depth of say 20 ft., and render access to our drainage and water mains an almost hopeless and very expensive task, would be lifted and swung into the space between the cliff and wall, thus clearing and relieving the roadway and leaving some 10,000 yards of stone to be brought from Cap Rouge or elsewhere and dumped down from the edge of the terrace to complete a slope reaching high enough to prevent future slides and accidents.

One or more drainage tunnels as proposed by Mr. Cuningham would further eliminate any danger of additional pressure by water or frost.

Mr. Cuningham. Mr. Cuningham asked has there been anything done to check the probable giving away of the rest of the rock?

Mr. Baillairgé. Mr. Baillairgé:—Nothing as yet.

Mr. Walbank. Mr. Walbank asked had the drain been noticed before the accident? The author replied it had not.

Mr. Walbank. Mr. Walbank asked what portion of the rainfall went into this drain?

Mr. Baillairgé. Mr. Baillairgé:—The whole of the rainfall of the 11½ hours preceding the accident, and which was 3·4 inches during that interval of time. The area draining towards the land slide is 90,000 square ft., and this into 3·4 inches gives 25,500 cubic ft. of water, while the rain falling direct on the area intervening between the crevasse and the Citadel and glacis gives another 5,000 cubic ft., together some 30,000 or more cubic ft. as stated; nothing, as already explained, having to be allowed for absorption, since, as evidenced by the data from the Observatory, it had been raining continuously for the three or four days preceding the land slide, and that the soil must have been and certainly was most thoroughly drenched and saturated in a way not to require any allowance for absorption. Nor did such weather require any allowance for evaporation, the air being, like the soil, so thoroughly saturated as to be incapable of further absorption, since it was so laden as to have to be relieved by precipitation.

The retaining wall at *a b c d e* on plan, Plate IV, was merely some 8 ft. high and 3 to 4 ft. thick, intended to act as a screen or fender to prevent falling debris from reaching the opposite side of Champlain street, and thus causing accidents to life, limb or property.

Mr. Hannaford. Mr. Hannaford asked if they had noticed any sign of its moving since the accident, or had there been any change?

Mr. Baillairgé. No increase has been noticed in the breadth or amplitude of the crevasse at *A*, Plate VII, though possibly the leaning over at *B R* may have been slightly increased since 1889 by the continued opening of the intervening fissures by frost expansion pressure.

Mr. McNab. Mr. McNab would like to know if, when Mr. Baillairgé made his first survey, he had noticed this drain?

Mr. Baillairgé. Mr. Baillairgé replied:—No, this drain had not been noticed at the time of survey in 1880, it being, though only a deep-set surface drain along the foot of the rip-rap face of the glacis, completely filled in and grown over with long rank grasses and shrubs.

Mr. Cuningham. Mr. Cuningham asked, after a rain such as we have had just now (4 days), could you sound the crevasses?

Mr. Baillairgé. Mr. Baillairgé:—Yes, the rain of the last few days at Quebec would hardly have done more than saturate the soil, and not have filled the fissure *A* to a depth capable of preventing its being gone into and explored.

The author would say in conclusion regarding the planes of cleavage that the inclination of the surface of the cliff at *B* and *F* on section, Plate VII, shows the direction of these planes, which his original or manuscript sketches indicate as existing all through the cliff between *A* or *N* and *F*; but they have been mistaken by the engraver for mere etchings, and a false impression conveyed by etching the engraving at nearly right angles to the planes of stratification.

He would also add that for any one wanting to take in the whole case at a glance, the note at the head of Plate I is sufficiently satisfactory.

Mr. Baillairgé. Mr. Baillairgé said he would leave a piece of the stone from the debris of the slide, illustrative as it is of the highly rhomboidal figure of the component elements of the cliff.

Thursday, 18th May.

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

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

MEMBERS.

ERNEST GEORGE BARROW, GEORGE LUDLOW WETMORE.

ASSOCIATE MEMBER.

ROBERT GILMOUR EDWARDS LECKIE.

STUDENTS.

WILLIAM NELSON DRAPER,
ROBERT KENNEDY RUSSELL.
JAMES TURNBULL LAIDLAW,
RICHARD HENRY SQUIRE.
CUTHBERT COLEMAN WONFOLD.

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

JAMES HENRY KENNEDY.

Paper No. 80.

TEMISCOUATA RAILWAY.

Running from Edmundston, New Brunswick, to Rivière du Loup, Quebec, a distance of 81 miles.

By R. Adams Davy, M.Can.Soc.C.E.

Prior to the construction of the Intercolonial, this project has formed part of many schemes to build an Interprovincial Railway, and was first surveyed by Captain Pipon and Lieutenant Henderson in 1846, acting under instruction from Mr. Gladstone, then Secretary of State for the Colonies. Again, between the years 1864 and 1868, when the whole country between Rivière du Loup and Halifax was exhaustively surveyed under the direction of Mr. Sandford Fleming, it received some attention as forming part of the frontier routes which were ruled out in favour of the Shore Line. From that date up to 1886 the ground was generally covered by one or more charters, and a survey was made by one of the companies, but nothing was done beyond this by them. In 1884, when the Dominion Government had the country between Montreal and St. John, N.B., surveyed, in order to decide upon a short line between Montreal and the Atlantic seaboard, Mr. W. J. Crawford was sent to survey this route, and one from Rivière Ouelle, but the route was not adopted. By 1886 the company in possession of the charter had secured bonuses from the Dominion, Quebec and New Brunswick Governments, amounting in all to about $9000 a mile, which put them in a position to make arrangements with the firm of Messrs. McDonald and Boswell to construct and equip the road. Immediately after this agreement was signed three engineering parties were organised, and surveys made of alternative routes on each side of Mr. Crawford's line. On the completion of this work it was decided that the Crawford route was the best, taking all things into consideration.

A line via the St. Francis River, which is crossed by the present track 16 miles from Rivière du Loup, would have given a summit about 350 ft. lower, but would have increased the distance to Edmundston 14 miles. The Rivière Ouelle route was also considered; it would have given a line from Quebec to Edmundston about 24 miles shorter, but would cross a summit about 230 feet higher. As soon as the route was decided, the three parties commenced the location of the 60 miles between Rivière du Loup and St. Rose, at the foot of Lake Temiscouata, and by the 1st of December this was completed, and the parties came in to make up the plans, profiles, etc.

The adopted line crosses the divide between the St. Lawrence and St. John waters several times. The first being only 16 miles from the St. Lawrence River, but the summit is only reached at the 24 miles at an elevation of 1330 ft. above the sea level and 1004 ft. above the junction with the I. C. Ry. With the exception of the Intercolonial Railway this is the lowest summit by about 500 ft. of any crossed by the roads from Ontario and Quebec to the Atlantic seaboard. This summit elevation is kept for three miles, then the line descends 830 ft. to Lake Temiscouata at the 44th mile. From this point to Edmundston at the 81st mile the line follows closely the shores of the Lake and the Madawaska River, and no great differences in elevation are met with. The Governments limited the grades to a maximum of 1.50 per cent. and the curves to 7 degrees. The line laid down by Mr. Crawford was followed very closely, the greatest deviation being about ½ mile. The ascent to and descent from the summit are very little broken by minor undulations, and the maximum grades are frequently eased off by lighter ones or level stretches. The longest maximum grade is 2½ miles ascending east, whilst ascending west the longest is 1 mile.

Four sub-contracts were let, covering the 60 miles located, and construction was commenced in October, and during the winter a few of the heavier cuts were commenced, and considerable quantities of timber and ties were taken out, and the order given to Messrs. Cammel & Co. for the requisite quantity of their toughened steel rails weighing 56 lbs. to the yard. In the section chosen the head of the rail is rounded off more than the present ideal calls for, but this is probably an advantage on a road with light traffic and considerable curvature. Owing to the severe winter in this part of the country it was June before the grading could be pushed forward with rapidity, and up to that time less than 5 per cent. had been done. From this time on, every exertion was made to complete the grading and lay the track before the close of the season. The rails having arrived, track laying was commenced June 15th, and pushed on from the Rivière du Loup end as fast as the trestling and grading would allow, and whenever delayed from any cause the track laying gang were set to work ballasting.

The balance of the location from St. Rose to Edmundston, 21 miles, was finished in September, and the grading commenced, and by the 23rd October it was sufficiently advanced for tracklaying to be started at the Edmundston end also. By the close of the year only a few miles remained between the ends of the track, and on January 7th the rails were connected, and on January 10th the contractors took the directors of the company and their friends from Rivière du Loup to Edmundston, returning the same evening.

The following summer the ballasting was completed; 6 tanks of 21,000 gallons capacity each erected; 5 were fitted with Worthington steam pumps and 1 filled by gravity, and all are located at stations. Station buildings; offices; machine shops; engine sheds; turntables, etc., put up and the equipment completed, which consists of 5 locomotives, 3 first and 2 second class cars; 2 combination, 1st and 2nd; 2 baggage, 7 frost proof, 41 box and 54 flat cars, 5 snow ploughs, 2 flangers, etc., all new and equal in construction and fittings to those used on the Trunk lines. Snow sheds and fences were commenced at necessary points and the line was open for traffic in the fall.

Several swamps and muskegs were crossed; some had to be crosslaid with timber, across others the track was laid on the original surface and afterwards raised with ballast, brought by trains. The use of ditches near the track was avoided as much as possible in such cases. Ballast of good quality was found at several places along the line. One pit was worked with a steam shovel, the others by hand. The material was ploughed off the cars when used as ballast, but when filling had to be done side dump cars were used.

Spruce timber was used in temporary trestles which was flatted for the stringers, caps and sills and round for the posts and braces, and all put together with spikes and drift bolts.

Across the Madawaska River a temporary trestle was built 350 feet long and about 32 feet high across the bed of the stream, which is here about 280 feet wide and 7 feet deep at the ordinary summer level. The bents were 12 feet centres except 4, which were 15 feet, and each consisted of 4 piles from 40 to 45 feet long driven from 7 to 10 feet into the bed of the river. No bracing was used on the lower 16 feet of the structure, but the upper portion was well braced both longitudinally and transversely with 8″ x 6″ flatted timber spiked to the piles with 12″ ship spikes. The caps were of flatted timber 14 feet long, 12″ thick and 10″ face. The stringers 26 feet long and of the same dimensions; one was used under each rail except for the 15 openings, where they were used double. The same class of ties was used as those in the road beds. The caps, stringers and piles were bolted together with drift bolts 20″ long by ⅞″ square. The river rises about 8 feet during the spring freshets, and has a current of about 6 miles an hour, and this continues for several weeks. During this high period about 13 million feet of timber had to be passed through the structure, and to prevent a jam, piles were driven in W-shaped rows on the up stream side, and boom logs laid against them leading to the 15 feet openings, through which was passed the whole drive without trouble or damage to the structure. After the completion of the permanent structure all the piles were cut off close to the bottom with dynamite. The permanent bridge consists of 2 ordinary type through steel spans of 140 feet each, built by the Dominion Bridge Co. The substructure of 2 abutments and 1 pier was built of 18 and 24 inch courses of granite brought from near McAdam Junction, and laid with Portland cement mortar. The abutment masonry rested on a grillage of timber supported on piles. As piles could not be successfully driven in the centre of the stream owing to the hard bottom of cemented gravel, a cofferdam was built and the bottom excavated to a depth of 7 feet; on this 4 courses of timber were laid and the masonry built on this.

Across the Rivière du Loup are two 100 feet steel through pans of the same type as the last mentioned, and built by the same company. The substructure consists of 3 piers of masonry built of field stone found in the vicinity; the courses were 15″ and 18″ thick, and laid in Portland cement mortar. The foundations were of piles driven 25 feet into tough blue clay and cut off level with the bottom of the river, and capped with a grillage of timber on which the masonry rests.

All the box and beam culverts, except 2 of dry masonry, are built of cedar, of which there is an abundance in the neighbourhood, of very good quality. Pile trestles usually had 4 piles to a bent, with bents 12 feet centres; caps 16 ft. long 12″x12″; stringers double 12″x10″, one on top of the other, and long enough to span 2 bents so as to break joints; ties 12 ft. long 8″x8″ placed 8 inches apart; guard-rails 8″x6″ notched down on the ties, and the whole structure braced longitudinally and transversely to suit its height. In trestles the bents were placed 15 ft. centres. Sills and posts were of 12″ x 12″ timber; stringers double 12″ x 10″ one on top of the other, with blocks between, and bolted; caps 14 ft. x 12″ x″ 12; ties, 12 ft. x 8″ x 8″; double guard-rails 10″ x 6″ and 8″ x 6″, the outer one being bolted through to a jack-stringer 8″ x 8″ resting on corbels 5 ft. x 14″ x 8″; vertical braces 9″ x 4″; girts, wailings and horizontal braces 9″ x 6″. The foundations were generally of cedar sills so as to keep the main sills out of the ground. All the timber was of pine procured in Quebec, and was of exceptionally good quality. The longest trestle was 550 ft. and 50 ft. high in the highest part; it had two decks, the upper part of each bent had 4 posts of 16 ft. x 12″ x 12″ and the lower 6 posts 12″ x 12″ of the required length.

Several timber trusses were built from 25 to 40 ft. long.

All piles were driven with an 1800 lb. hammer, and an inspector was put on to record the penetration at each blow. No fixed rule or formula was laid down for stopping the driving, but the nature of the ground was carefully considered after driving a few piles, and the inspector instructed accordingly. With a drop of 25 feet the penetration at the last blow was allowed to run as high as 6 inches, and no structure has yet failed. Most of the rock met with was a soft slate which worked badly. The Temiscouata Highway, which was built as a military road, fortunately followed the same general route as the Railway, and afforded an easy means of access to it at many points. Since the completion of the main line a branch of 32 miles has been built up the St. John River to near its confluence with the St. Francis, where the International Boundary unfortunately deviates to the north, checking further progress. During construction the Engineering staff consisted of 1 Chief, 1 Division and 5 Assistant Engineers and a Draughtsman. Each engineer was allowed a man and horse, and the assistants a rodman in addition, and were furnished with a house and office near the centre of their sections.

Via the Temiscouata and existing Railways the distance from Montreal to St. John, N.B., is 592 miles, and to Halifax 867 miles, all through Canadian territory.

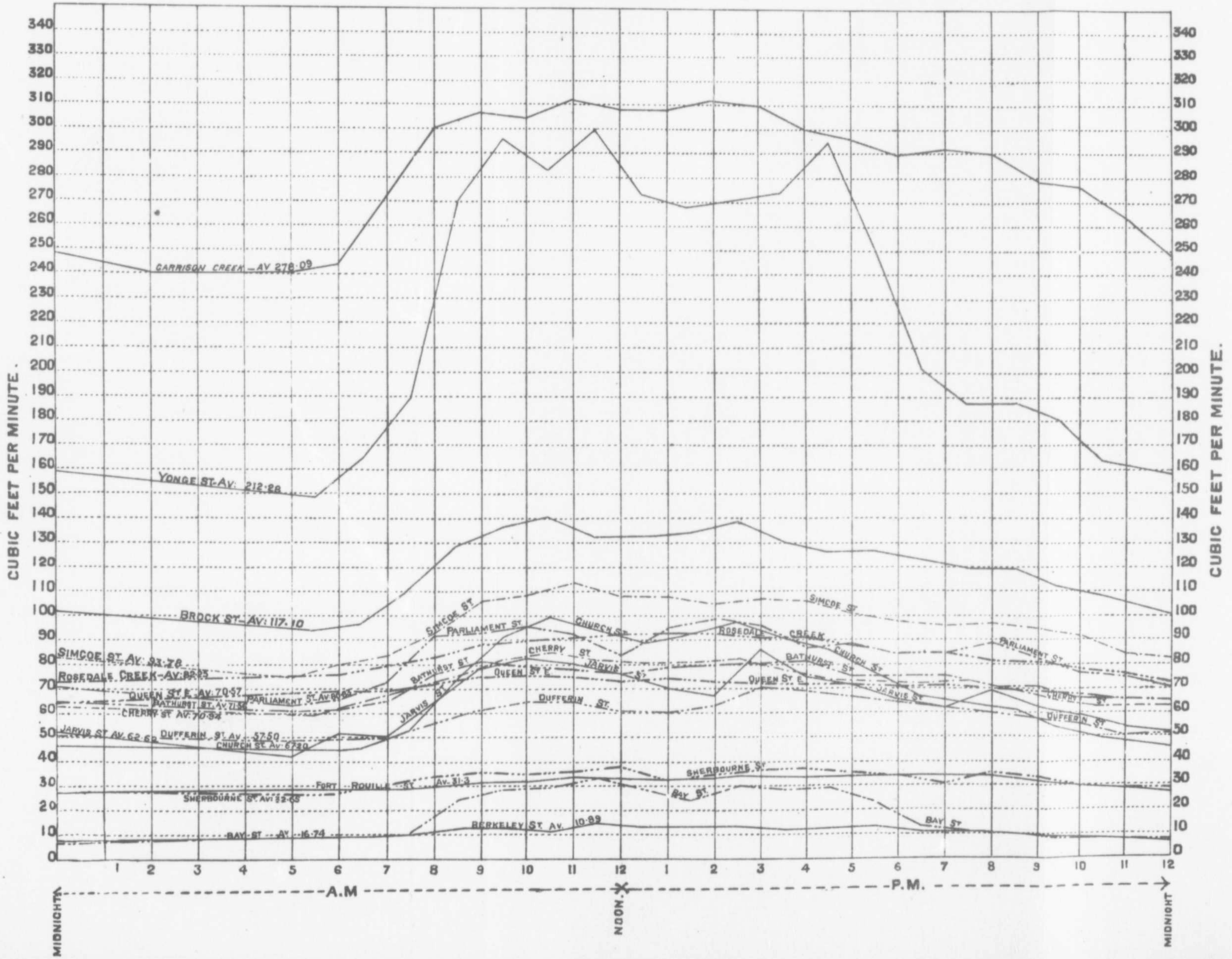
(See map of railway, Plate VIII).

TRANSACTIONS CAN. SOC. C.E.
VOL. VII. PLATE I.

DIAGRAM SHEWING

— DISCHARGE OF TORONTO SEWERS — SPRING 1891 —

By C. H. RUST, M. CAN. SOC. C.E.



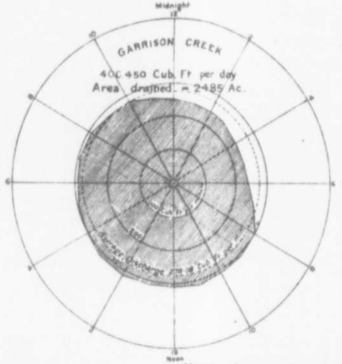
TORONTO, OCT 31st 1892

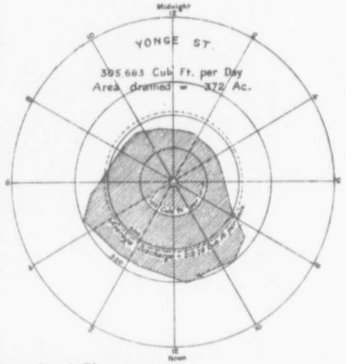
C. H. RUST,
M. CAN. SOC. C.E.

DIAGRAMS SHEWING
DISCHARGE OF TORONTO SEWERS
THROUGHOUT THE 24 HOURS
Gauging made in Spring 1891.

TABLE OF SEWAGE DISCHARGE

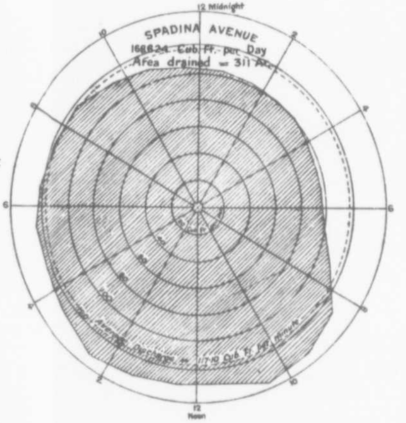
LOCATION OF SEWER.	SIZE OF SEWER	AREA DRAIN'D ABOVE WEIR ACRES	NUMBER OF PERSONS PER ACRE	POPULATION	DISCHARGE IN CUB FT PER MIN	CUB FT PER AC PER MIN	CUB FT PER HEAD PER DAY	CUB FT PER DAY	REMARKS.
GARRISON CREEK.	7'.6 diam	2485	15·7	39,014	278·03	·11	10·27	400,450.	
YONGE ST.	3'.6x5'.0"	372	46·2	17186	212·28	·57	17·78	305,883.	*Population estimated from Assessment of 1890 and Census Returns of 1891*
FORT ROUILLE ST.	3'.9x2'.6"	360	8·8	3,168	31·30	·09	11·07	45,072.	
BAY ST.	2'.0x3'.0"	13	44·0	572	16·74	1·29	42·14	24,105	
SHERBOURNE ST.	2'.6x5'.0"	101	45·5	4595	32·83	·32	10·23	47,016.	
BERKELEY ST.	2'.0x3'.0"	25	41·8	1,045	10·89	·43	15·00	15,682.	
DUFFERIN ST.	3'.9x2'.6"	350	17·6	6,160	57·50	·16	13·44	82,800	
BATHURST ST.	3'.9x2'.6"	263	42·3	11,125	71·56	·27	9·26	103,046.	
CHURCH ST.	2'.8x4'.0"	163	39·8	6,368	67·20	·42	15·19	96,768	
JARVIS ST.	3'.6x5'.0"	195	42·4	8,268	62·62	·32	10·90	90,168	
ROSEDALE CREEK.	6'.6x diam	740	11·8	8,732	82·25	·11	13·56	118,440	
PARLIAMENT ST.	3'.6x5'.0"	225	43·7	9832	80·83	·36	11·84	116,395	
CHERRY ST.	2'.8x4'.0"	271	41·7	11,300	70·94	·26	9·04	102,153	*Those marked in Red are estimated from those above*
QUEEN ST.	2'.4x3'.6"	770	9·4	7,238	70·57	·09	14·04	101,616	
SPADINA AVE.	4'.0x5'.6"	311	45·7	14,213	117·10	·38	11·86	168,624	
SIMCOE ST.	4'.3" diam	503	38·3	19265	93·78	·19	7·02	135,043	
EASTERN AVE.	2'.0x3'.0"	53	22·0	1,166	8·83	·17	10·91	12,720	
CARLAW AVE. Etc	18"	80	13·0	1,040	8·00	·10	11·08	11,520	*This includes Blong, Logan Morse & Howard Ave. Sewers*
SMALLER DRAINS & Portions below Weirs.	Various Size	350	31·2	10,933	120·50	·35	15·88	173,600	
AVERAGES.			24·9			·205	11·87		
TOTALS.		7277		181,220	1493·40			2150,901	

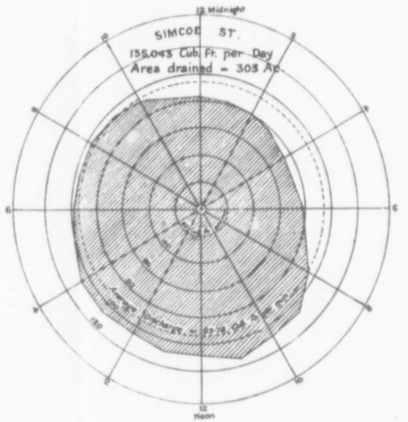


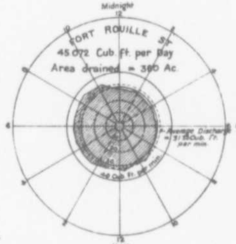


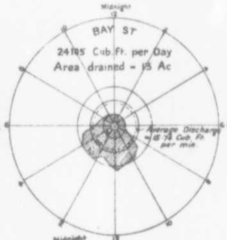
NOTE.- Garrison Creek & Yonge Street Diagrams are on a differant scale from those below.

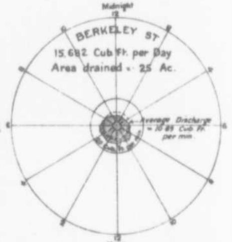
NOTE

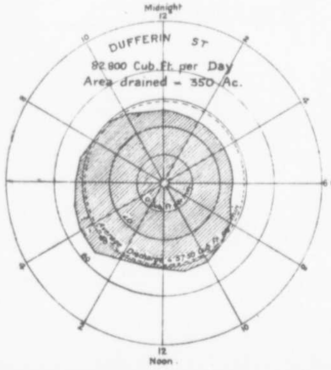


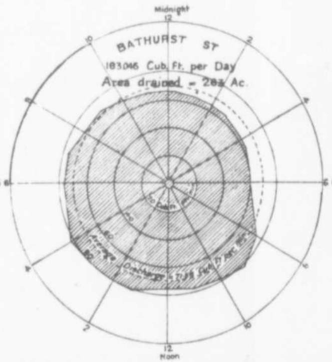


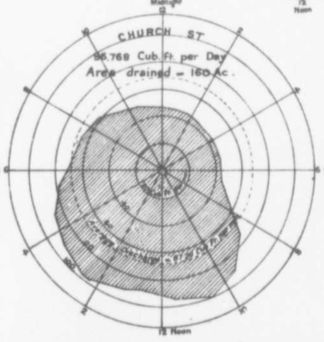


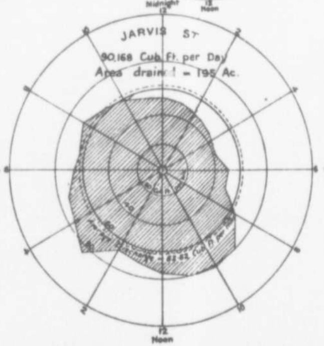


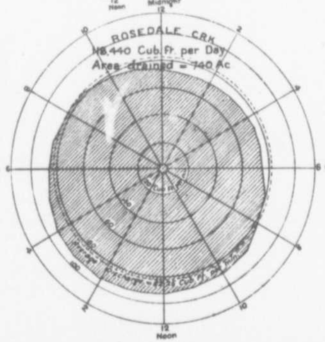


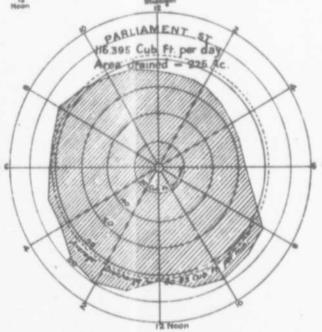


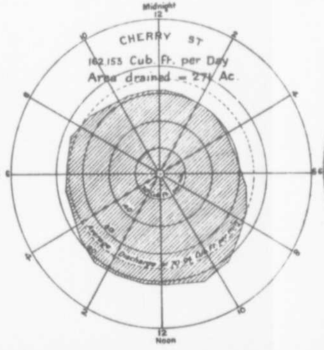


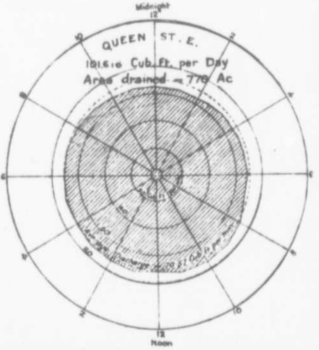












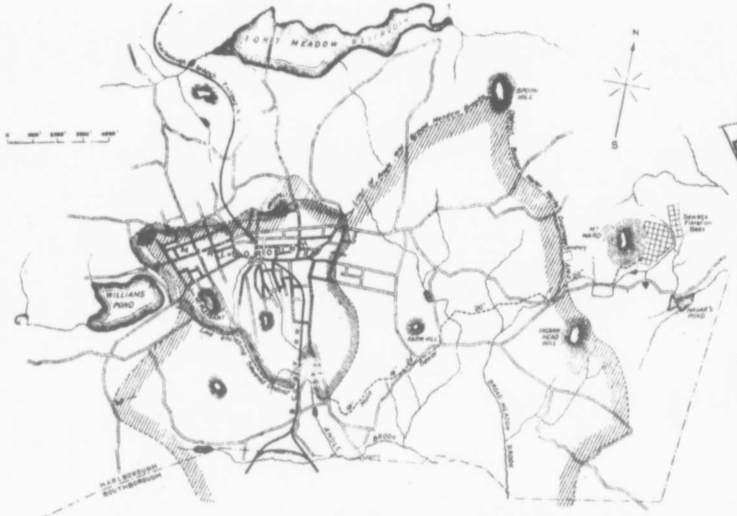


FIG. 4. MAP OF MARLBOROUGH SHOWING SEWERAGE SYSTEM.

FIG. 5. PLAN OF FILTER BEDS.

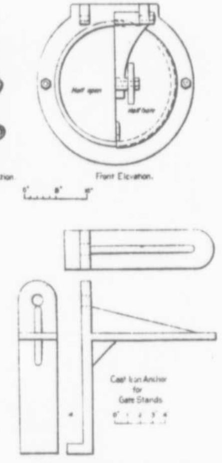


FIG. 8. 18-IN. SWINGING GATE.

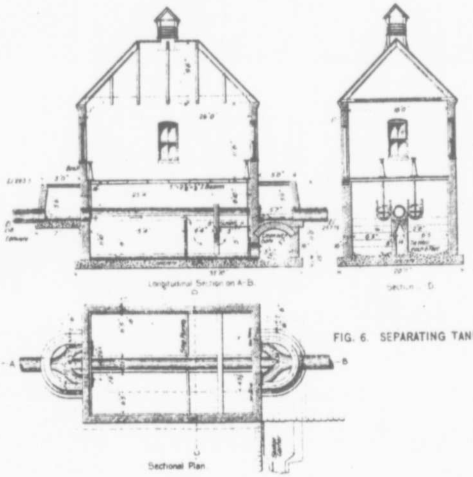


FIG. 6. SEPARATING TANK.

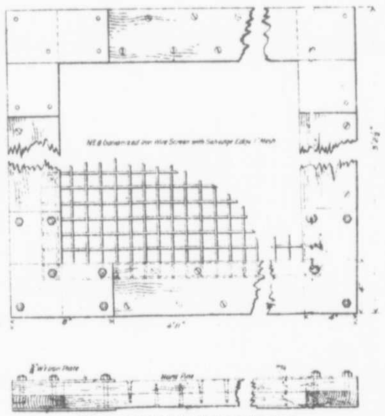


FIG. 9. SCREENS IN SEPARATING TANK.

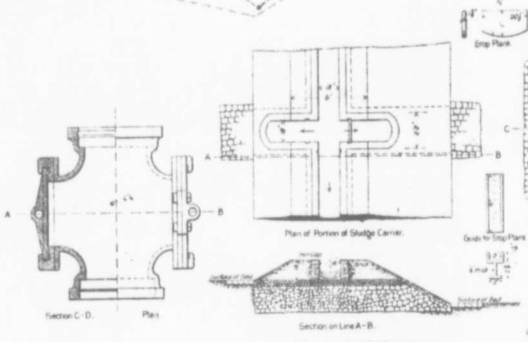


FIG. 12. SLUDGE CARRIER.

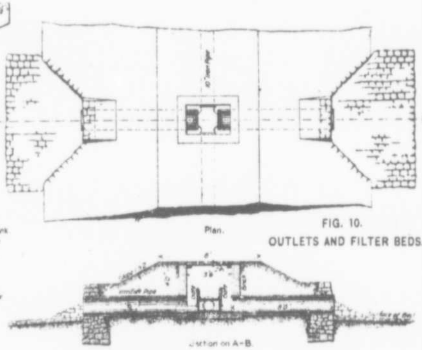


FIG. 10.
OUTLETS AND FILTER BEDS.

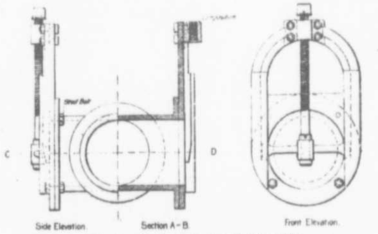


FIG. 11. 10-IN. GATE TO FILTER BEDS.

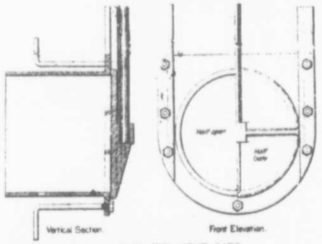


FIG. 7. 18-IN. INFLUENT GATE.

SEWAGE PURIFICATION PLANT AT MARLBOROUGH, MASS.

Mr. M. M. Tidd, M. Am. Soc. C. E., Boston, Engineer.

TRANSACTIONS CAN. SOC. C. E.
VOL. VII. PLATE IV.

THE QUEBEC LAND SLIDE OF 1889

BY CHAS. BAILLAIRGÉ

HOW THE ACCIDENT OCCURRED

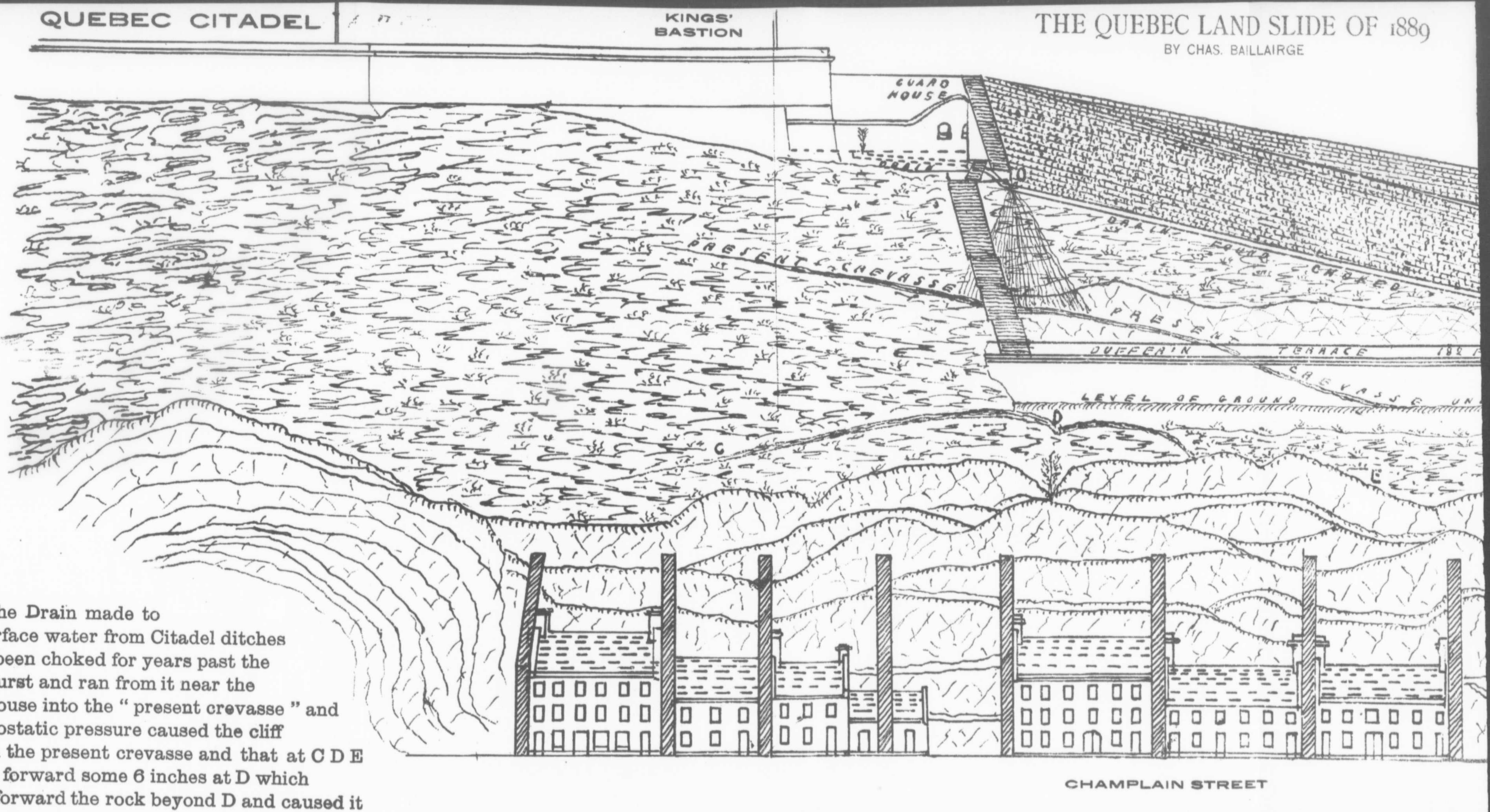
The drain marked " choked " on plan having burst where indicated near guard house opposite the Kings' bastion, the citadel surface drainage water from ditches poured into and filled the " present inner crevasse"; its hydrostatic pressure thrusting forward by some 6 inches the intervening mass of rock between the " present inner crevasse " and the outer crevasse at C D E against the rock A B C D E F G and causing it to fall over.

N. B. The " houses " so indicated along west side of Champlain St. were after 1880 purchased by the Fed. Govt. demolished and a screen wall built along a b c d e to widen street and guard against stones from cliff rolling over roadway and thus causing accidents.

Ground plan of dangerous cliff and property between old land slide of 1881 and Smith's lane and between Champlain Street and Citadel and Champlain Street., to a scale of 40 feet to one inch English measure

THE QUEBEC LAND SLIDE OF 1889

BY CHAS. BAILLAIRGE



N. B. The Drain made to take surface water from Citadel ditches having been choked for years past the water burst and ran from it near the guard house into the " present crevasse " and by hydrostatic pressure caused the cliff between the present crevasse and that at C D E to move forward some 6 inches at D which pushed forward the rock beyond D and caused it to fall over.

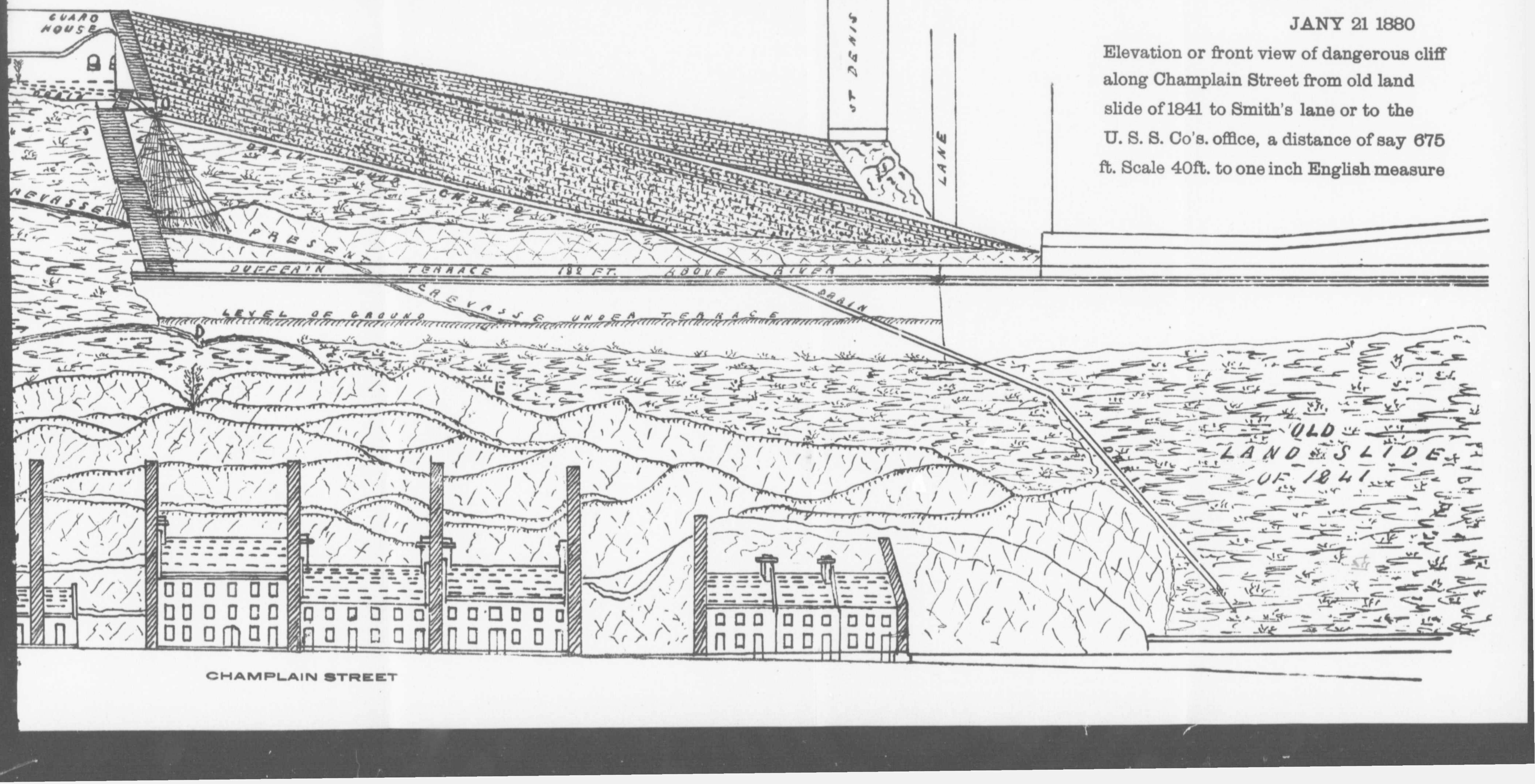
THE QUEBEC LAND SLIDE OF 1889

BY CHAS. BAILLAIRGE

TRANSACTIONS CAN. SOC. C. E.
VOL. VII. PLATE V.

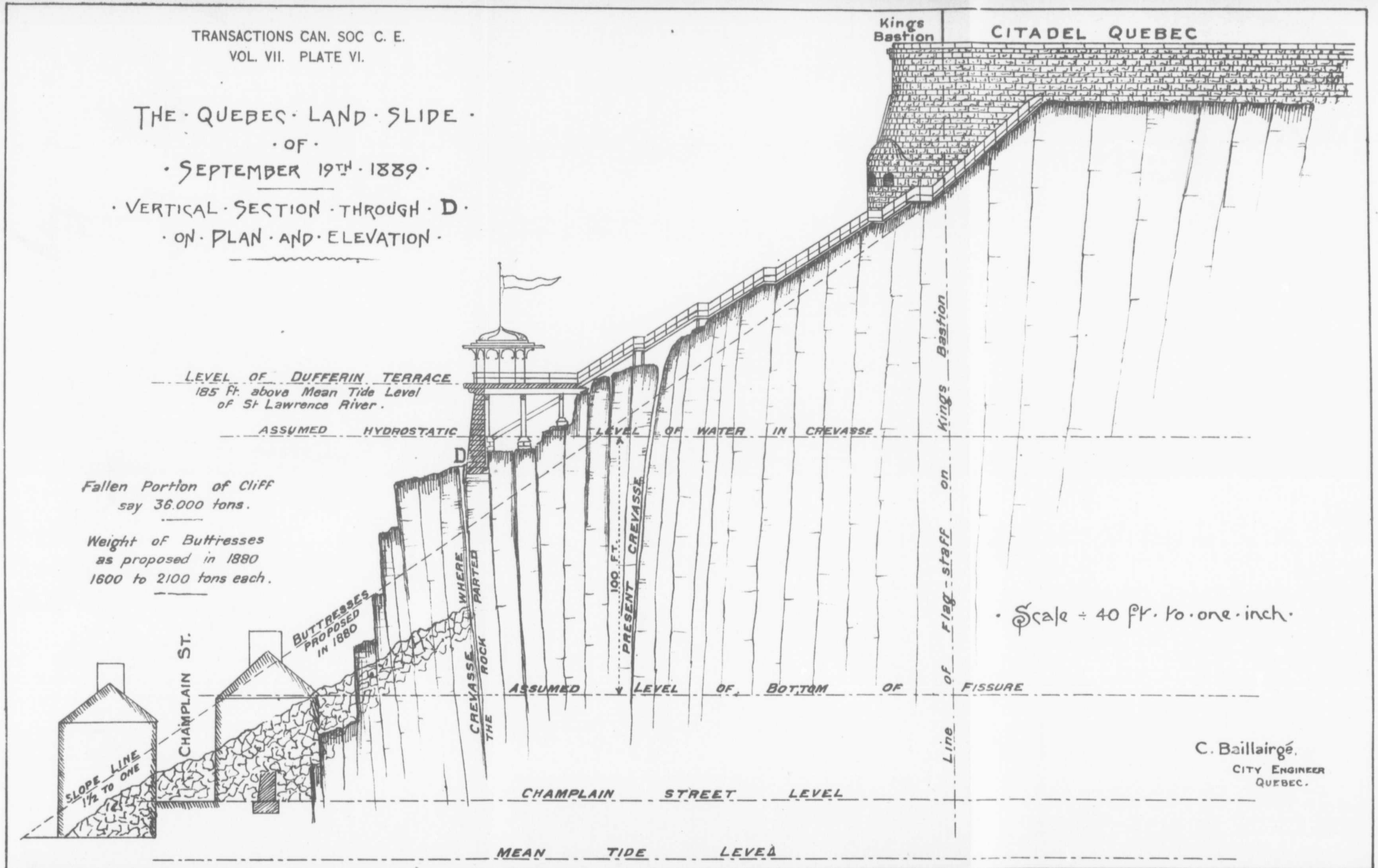
JANY 21 1880

Elevation or front view of dangerous cliff along Champlain Street from old land slide of 1841 to Smith's lane or to the U. S. S. Co's. office, a distance of say 675 ft. Scale 40ft. to one inch English measure



THE · QUEBEC · LAND · SLIDE ·
· OF ·
· SEPTEMBER 19TH · 1889 ·

· VERTICAL · SECTION · THROUGH · D ·
· ON · PLAN · AND · ELEVATION ·



C. Baillairgé,
CITY ENGINEER
QUEBEC.

TRANSACTIONS CAN. SOC. C. E
VOL. VII. PLATE VII.

THE QUEBEC LAND SLIDE OF 1889

BY CHAS. BAILLAIRGÉ

SKETCH · BIRDS-EYE · VIEW · OF · CLIFF ·
· BETWEEN · A · AND · B · ON · SECTION ·
· Scale ÷ 50 feet · to · one · inch ·

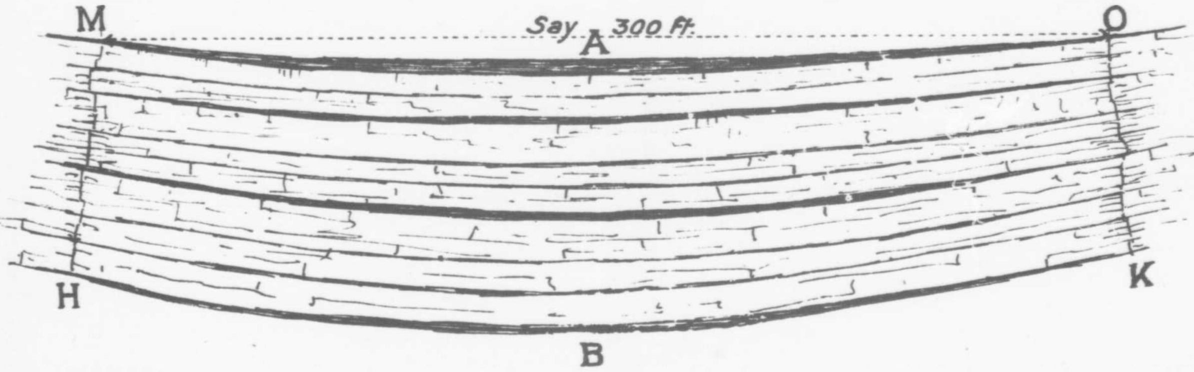
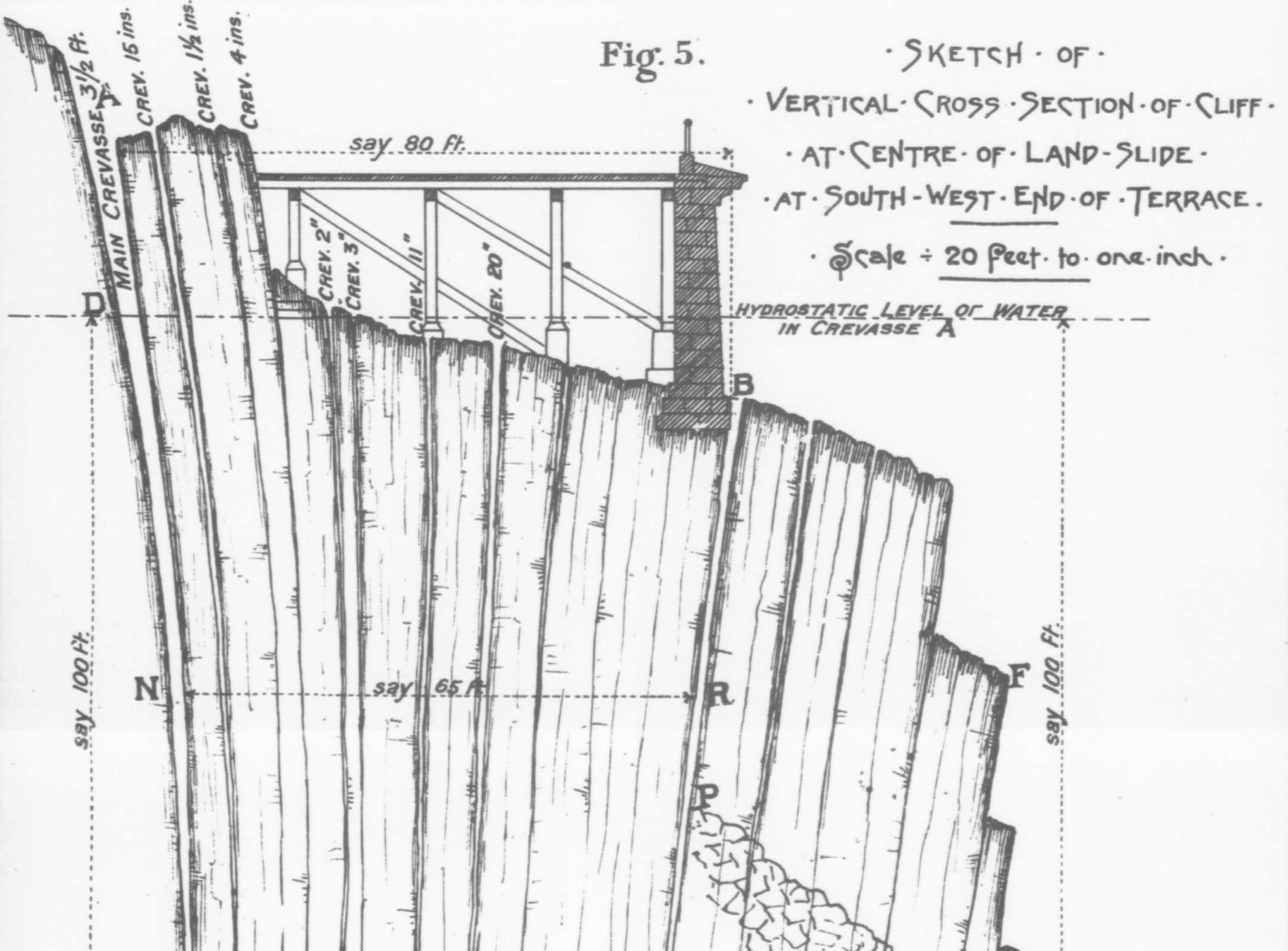
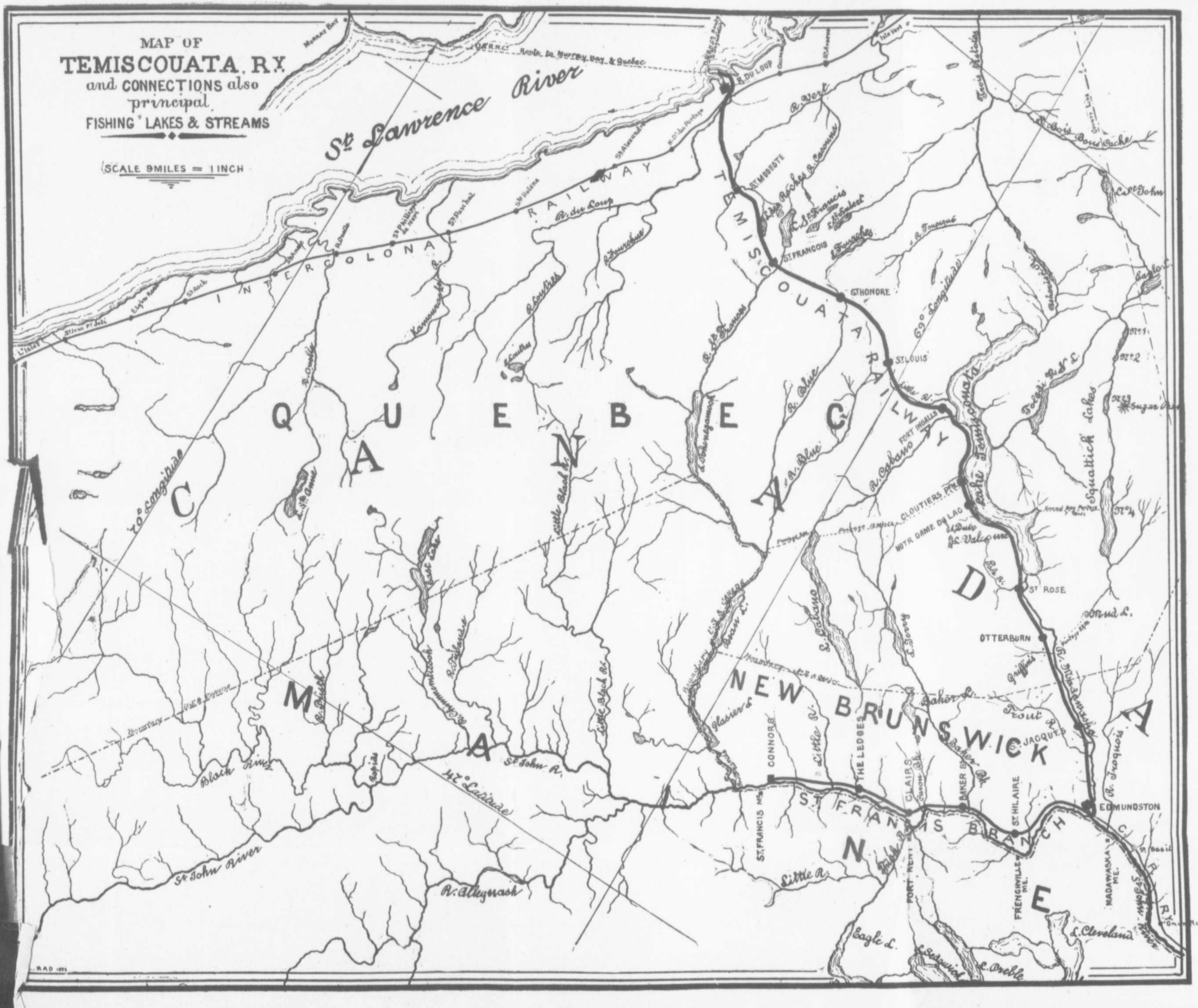


Fig. 5.

· SKETCH · OF ·
· VERTICAL · CROSS · SECTION · OF · CLIFF ·
· AT · CENTRE · OF · LAND-SLIDE ·
· AT · SOUTH-WEST · END · OF · TERRACE ·
· Scale ÷ 20 feet · to · one · inch ·




MAP OF
TEMISCOUATA R.Y.
and CONNECTIONS also
principal
FISHING LAKES & STREAMS
SCALE 9 MILES = 1 INCH
St Lawrence River
INTERCOLONIAL RAILWAY
TEMISCOUATA RAILWAY
R. DU LOUP
R. du Loup
R. Verte
Route to Murray Bay & Quebec
ST MODESTE
ST FRANCIS
ST HONORE
ST LOUIS
FORT INGALLS
CLOUTIERS
NOTRE DAME DU LAC
ST ROSE
OTTERBURN
EDMUNDSTON
Lake Temiscouata
Squattick Lakes
R. Touladi
R. Cabano
R. Blue
R. Iroquois
Baker L.
Trout R.
JACQUES
QUEBEC
CANADA
NEW BRUNSWICK
MAINE
70° Longitude
69° Longitude
47° Latitude
St John R.
St John River
Black River
R. Allegnash
Little R.
ST FRANCIS BRANCH
CONNORS
THE LEDGES
CLAIRS
BAKER BR.
ST HILAIRE
ST FRANCIS ME.
FORT KENT
FRENCHVILLE ME.
MADAWASKA ME.
Eagle L.
L. Sedgwick
L. Preble
L. Cleveland
Boundary