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CONTENTS.

The Steam Engine, by W. H. Laurie 211
Discussion on ditto.......... 221
The Fraser River Bridge, by H. J. Cambie.......... 228
Discussion on ditto.......... 232
Energy and Labour, by G. C. Cuningham.......... 235
Discussion on ditto.......... 262
The Expansion and Contraction of Ice in Canadian Waters, by J. H. Dumble.......... 270
Discussion on ditto.......... 279
Ship Transportation and the Chignecto Ship Railway, by H. G. C. Ketchum.......... 309
Discussion on ditto.......... 343
Table on Flow and Discharge of Sewers. By Edward Mohun.......... 348
Obituary Notices—Sir John Hawshaw 351
George H. Henshaw 365
Henry Archbald.......... 366
Index.......... 369
Plates VII to XII.

ERRATA.

Vol. V.

Page 189—note at foot—*for* "page 447" *read* "page 199."

INSTRUCTIONS FOR PREPARING PAPERS, ETC.

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

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

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

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

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

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

Thursday, October 8th.

JOHN KENNEDY, Vice-President, in the Chair.

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

Members.

CHARLES RUFUS F. TWINING, A. M. WELLINGTON.

Associate Member.

ALEXANDER JOSEPH GRANT.

Students.

HERBERT JOHN BEATTY, WILLIAM NEWMAN,
JAMES HUTCHEON, GEORGE ERNEST SILVESTER,
ROBERT WALKER THOMSON.

Paper No. 54.

THE STEAM ENGINE.

BY W. H. LAURIE, M. CAN. SOC. C. E.

In tracing up the history of the steam engine, considered as a train of mechanism, we find that the modern steam engine has been fully developed within the last 200 years—or since the year 1690, and its advance during that time, may be divided into four stages, or periods of 50 years each.

FIRST STAGE OR PERIOD—1690-1740.

As a rule the great majority of inventions when first introduced to the public are more or less complicated and cumbersome, the object of subsequent improvements being to simplify and reduce the number of parts. To this rule the steam engine forms a striking exception, it having been first introduced in its simplest form, each consecutive stage in its history being marked by an increase in the number of its parts and in the complication of its construction, and a corresponding reduction in the consumption of steam per horse power.

About the year 1690, Denys Papin invented the first steam engine, or rather steam cylinder with a piston. When first introduced, the cylinder performed the functions of steam boiler, steam cylinder, and condenser. It was operated as follows :—A small quantity of water was placed at the bottom of cylinder, a fire built beneath it, the steam formed raising the piston to the top of the cylinder, where a latch engaged a notch in the piston-rod holding it up until it was desired that it should drop.

The fire being removed, the steam condensed forming a vacuum below the piston, the latch being disengaged the piston was driven down by the pressure of the atmosphere, raising a weight which had been in the mean time attached to a rope from the piston rod over pulleys. This machine made *one stroke* per minute. The inventor calculated that a 24" cylinder would raise 8,000 lbs. four feet per minute, or develope nearly one horse power.

A few years after his first invention Papin made another important invention which increased the efficiency of his engine by using a seperate steam generator, as described at the time, a kind of fire box steam boiler, in which the fire, completely surrounded by water, made steam so rapidly that his engine could be driven at the rate of four strokes per minute by the steam supplied from it.

The Papin engine was further improved and developed by Newcomen, Beighton & Smeaton, producing a combination of several of the elementary parts of the modern engine, making it capable of transmitting force directly to the resistance to be overcome, the object being to adapt it to pumping mines, &c. The piston was connected to the pump by means of an overhead beam.

During the first period of development the steam engine was used almost entirely as a pumping machine, and might more properly be considered an atmospheric engine, as steam was used only to produce a vacuum, the power being supplied by the pressure of the atmosphere, and that on one side of piston only.

Second Period—1740–1790.

The second stage or period in the development of the steam engine may be considered entirely as the work of James Watt (that stage being marked by more rapid development than any other). He, among many other important inventions and improvements, added to the engine of the first period, the separate condenser, air-pump, fly-ball governor, crosshead, guides, parallel-motion, rotary-motion, double-action, and non-condensing, high-pressure steam engine. With these additions the machine embodied nearly all of the essential features of the modern engine. He also discovered the advantages to be derived from the use of steam expansively, and specified a cut-off at $\frac{1}{4}$ stroke as the most ecomomical. This discovery has proved to be most important in the development of the economical application of steam, although shortly after its first introduction, it had to be discontinued, owing to the trouble and annoyance Watt experienced with proprietors and their engineers altering the valves. He intended to resume it at a later period when workmen of greater intelligence and reliability could be found.

Third Period—1790–1840.

The distinguishing feature of the third period was the introducing of the compound, or two-cylinder engine. Although the first compound engine was invented in 1781, by Jonathan Hornblower, it was not a success, owing to the steam pressure used at that time being so low that no advantage was gained by the device.

In 1804 the Hornblower compound engine was again introduced by Arthur Woolf, and, by using steam at a higher pressure, and expanding it from six to nine volumes, a very great advantage was gained over the Watt and other engines of that time. Other engineers followed in Woolf's footsteps, designing modifications of the compound engine, so that by the end of the third period which we have considered, the compound had become a standard engine.

Fourth Period—1840–1890.

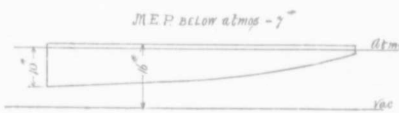
The most important features in the development of the economical use of steam during the fourth period, or that of the immediate past, has been the invention and introduction of the automatic engine, and the system of expansion (in two cylinders during the former period) being carried to three or four cylinders.

The first automatic engine was invented by George H. Corliss, about the year 1850. An adjustable drop cut-off had been invented ten years earlier by F. E. Sickels, but Corliss was the first to attach the governor directly to the cut-off mechanism, and, by so doing, regulate the speed of the engine by adjusting the point of cut off, and also using steam in the cylinder at nearly boiler pressure up to that point.

To form an idea of the advantages of modern steam practice as compared with that of the earlier stages of its use, and to note the advance made during the four different stages we have considered; we shall assume an average indicator card for each period from the information we have, and, by analyzing each, form a comparison.

For that purpose we shall assume a steam cylinder of $13\frac{5}{8}''$ diameter, or a net area of 144 square inches in each, and for the first period a guage pressure of 1 lb. or 16 lbs absolute.

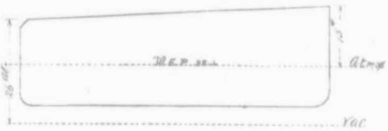
CARD No 1



Allowing 1 lb. to raise weight of piston, rod, etc., and that a vacuum be produced equal to a M. E. P. of 7 lbs. below the atmospheric line, and allowing a piston travel of 100 feet per minute, the power developed will be $144 \times 100 \times 7 = 100{,}800 \div 33{,}000 = 3{\cdot}05$ horse power, and the theoretical consumption of steam will be 100 cubic feet per minute or 6,000 cubic feet per hour, and as steam at 16 lbs. absolute weighs ·0411 per cubic foot, then $6000 \times {\cdot}0411 = 246{\cdot}6$ lbs. of steam per hour, and as we have found that the power developed will be 3·05 H. P. then $246{\cdot}6 \div 3{\cdot}05 = 80{\cdot}85$ lbs. of steam per hour per H. P. as the consumption for the first period.

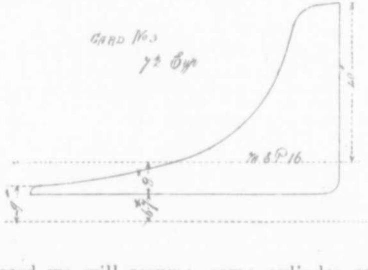
For the second period with same cylinder area we will assume

200 feet of piston travel. (Steam at this period was used above atmospheric pressure, and double acting.)



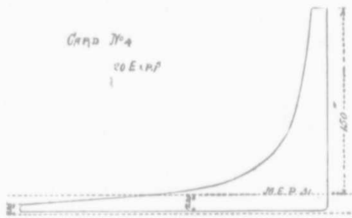
For this card we will assume a steam pressure of 15 lbs. and a terminal of 26 lbs. absolute, a M. E. P. of 22·4 lbs., the power developed will be $144 \times 22{\cdot}4 \times 200 \div 33{,}000 = 19{\cdot}5$ H. P. and the amount of steam consumed will be 200 cubic feet per minute or 12,000 cubic feet per hour; and as steam at the terminal pressure, viz.: 26 absolute, weighs ·0650 per cubic foot, then $12{,}000 \times {\cdot}0650 = 780$ lbs. per hour; this divided by $19{\cdot}5 = 40$ lbs. of water per hour per H. P. for the second period; or about one-half of that required to develop a horse power 50 years earlier.

For the third period a still higher steam pressure was used, and expansion carried to 6 and 9 volumes.



For this card we will assume, same cylinder area, 400 feet piston travel, 40 lbs, steam pressure expanded $7\frac{1}{2}$ volumes and a M. E. P. of 16 lbs. The power developed will be $144 \times 400 \times 16 \div 33{,}000 = 27{\cdot}93$ H. P. and the steam consumption measured from terminal of 9 lbs. will be 400 × 60 = 24,000 × ·0239 ÷ 27·93 = 20·5 lbs. of steam per hour per horse power, or about one-half of the cost of same power during second period and one-fourth of cost of same power during first period.

For the fourth and last period of steam engine practice we have in many instances a steam pressure of 200 lbs., also cylinder steam jacketed with superheated steam, and other refinements that tend to reduce steam consumption.



For this period we will assume a steam pressure of 150 lbs., expanded 20 volumes, a M. E. P. of 31 lbs. referred to same cylinder area as in other cards, viz. 144 inches and a piston travel of 800 ft., this will develope 108 horse power, and the steam consumption will be about 10 lbs. per hour per horse power.

In reviewing these four periods we have in the first, steam used at a little over atmosphere pressure, without expansion, a piston travel of 100 ft. per minute, a power developed of 3.05 H. P., at a cost of 80 lbs. of steam per hour per H. P.

In the second period we have steam at 15 lbs. above atmosphere, without expansion, a piston travel of 200 ft. per minute, a power developed of 19·5 H. P., with a steam consumption of 40 lbs. per hour per H. P.

In the third period, we have steam at 40 lbs. above atmosphere, expanded to 7½ volumes, a piston travel of 400 ft. a minute, a power developed of 27·93 H. P., with a steam comsumption of 20 lbs. per hour per H. P.

And in the fourth period we have steam at a pressure of 150 lbs. above atmosphere, expanded to 20 volumes, a piston travel of 800 ft. per minute and a power developed of 108 H.P., with a a steam consumption of 10 lbs. per hour per horse power.

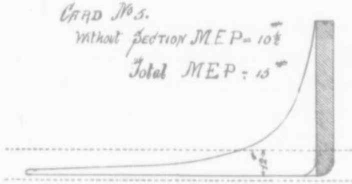
Cyl. Area.	Piston tr'vel.	Steam P.	Power.	Theoretical Consumption
1st....144	100	1	3·05	80 lbs.
2nd... "	200	15	19·5	40 "
3rd ... "	400	40	28·0	20 "
4th.... "	800	150	108.0	10 "

From these figures we find that the tendency through all the different periods has been increased steam pressure, and higher ratio of expansion or high initial and low terminal, *i.e.*, theoretically the higher the initial and the lower the terminal, the greater the economy. But practice has established it to be a fact that the higher the initial and the lower the terminal, or the greater the ratio of expansion in a *single cylinder*, the greater the loss both by *clearance* and *condensation.*

Clearance is the space between the piston and valve face when an engine is on its centre (including area of ports, passages, etc.) which has to be filled with steam each stroke before the piston moves forward, and is computed by the percentage its volume bears to the area of piston multiplied by the length of its stroke. This varies from 2 p.c. in long stroke engines to 15 and even 20 p.c. in short stroke engines.

The loss by clearance is quite a serious one where expansion is carried to extremes in a single cylinder and also in short stroke engines, where it forms a high percentage of the volume of cylinder.

If we take as an illustration a condensing engine card, with steam pressure 80 lbs., expanded 20 volumes without loss by clearance, we get a mean effective pressure of 15 lbs.



Then expand the same volume of steam in a cylinder of same area, but with 5 per cent. clearance, we find that the card shows the steam to have been cut off at the time the engine was on its centre; we get the same expansion line and same terminal, but the area does not include that at initial pressure, or a mean average pressure of 10.5 lbs. instead of 15 lbs., as in the first instance, representing a loss of 30 per cent. in power.

Then, again, if the same pressure, viz., 80 lbs., be expanded 10 volumes, the loss is reduced to 16.66 per cent.; expanded 5 volumes, the loss is reduced to 9.75 per cent., and if only expanded 3 volumes, the loss is reduced to about 7 per cent.

Therefore the greater the ratio of expansion in a single cylinder the greater the loss by clearance, and the less the expansion in a cylinder the less the percentage of loss by clearance. The loss by clearance may be reduced to a certain extent, but not entirely overcome by compression or cushion.

Condensation.

The loss by condensation is due to the variation in the temperature of steam during expansion. If steam at 80 lbs. gauge pressure, or 95 absolute, be expanded 20 volumes, the initial temperature would be 324 degrees Fahrenheit and the terminal about 160 degrees.

During expansion, as the temperature of the steam falls, the temperature of the metal of the cylinder falls in proportion, so that when the boiler pressure is again admitted to the cylinder it takes a certain proportion of the steam admitted to raise the temperature of the surrounding metal to the initial temperature;

the greater the ratio of expansion the greater the variation in temperature in the cylinder, and the greater the proportion of steam required to raise that temperature; the less the expansion in a cylinder the less the variation of temperature, and the less steam will be condensed in raising that temperature each stroke; or the smaller the volume of steam admitted to the cylinder each stroke the greater will the percentage "of loss by condensation" bear to that volume, and, on the other hand, the greater the volume of steam admitted to the cylinder each stroke the less will the percentage "of loss by condensation" bear to that volume.

From experiments carried out these losses have been computed approximately for unjacketed single cylinder engines with low percentage of clearance as follows, viz.:—

Expansions.	Power.	Loss.
20	55 p. c.	45 p. c.
10	65 "	35 "
5	75 "	25 "
3	80 "	20 "
2	85 "	15 "

With 5 per cent. added for condensing engines.

Another serious objection to high ratios of expansion in a single cylinder, is the very great variation in the working strains throughout the stroke. For example, if we expand 80 lbs. steam pressure to 20 volumes in a single cylinder Condensing Engine, we have a pressure of 92 lbs. per square inch of piston at the beginning of the stroke, 1.75 lb. at the end of the stroke, and a M. E. P. of 15 lbs., and as the strength of an engine in all its working parts must be in proportion to the greatest pressure to which it is subjected, then the weight of the working parts must be entirely out of proportion to the power actually developed, and the fly wheel especially must be very much heavier than that required in an engine where steam is expanded from 3 to 5 volumes.

The theoretical gain by expansion in a condensing engine is approximately as follows, taking 80 lbs. gauge pressure without expansion as a basis.

Expanded to	20	volumes,	70	per cent.	
"	10	"	65	"	
"	5	"	60	"	
"	3	"	50	"	
"	2	"	40	"	
"	$1\frac{1}{3}$	"	20	"	

To obtain the economical advantages resulting from high ratios of expansion, and at the same time avoid the enormous losses attending its expansion in a single cylinder, is the object of the introduction of the compound, Triple and Quadruple expansion engines. For example, in a compound engine with low pressure cylinder four times the area of high pressure, 16 expansions may be obtained with four expansions in each cylinder. In this way the high pressure cylinder works with steam between limits of temperature, such as occasion comparatively small losses by con densation, and the low pressure cylinder works between the temperature of the exhaust from high pressure and that of the condenser; these temperatures not varying very widely the loss by condensation is correspondingly small. Another great advantage of the compound over that of the single cylinder engine (expanding steam to the same number of volumes), is the better distribution of the work throughout the stroke, admitting of the working parts being made much lighter in proportion to the actual power developed.

It would almost appear as if the economical limit in expansion had been reached, as by our example for the last period, the theoretic consumption for 150 lbs. expanded 20 volumes, was 10 lbs. of water per hour per H. P., whereas, if we raise the pressure to 200 lbs. and expand 30 volumes, the gain is only about 5 per cent.; if raised to 400 lbs. and expanded 40 volumes, the gain is about 20 per cent.; and if to 800 lbs. expanded 40 volumes, about 25 per cent.

But to counteract this apparent gain, we have increased coal consumption in raising the water to the temperature due to the increase of pressure, and also increased losses by condensation in using steam at that temperature.

DISCUSSION.

Mr. P. J. L. Bolland said the assumption of an average indicator card for each successive period of 50 years may be correct for tracing up the history of the steam engine, considered as a train of mechanism, but appears to be misleading in considering the progress of the steam engine as a prime mover; the progress has not been so uniform in economy as would appear from this paper. This applies more especially to the last thirty years of the fourth period. Mr. P. J. L. Bolland.

Under cards 1 and 2 we practically are treated to a piston speed of 200 feet, in each period. One would think this a rather high speed for the first period. The third period has the credit of the introduction of the compound engine, but it is questionable if in any of the gain therein credited to steam consumption the compound engine played any important part, though the foundation was laid for its successful use during the next period. Card 3 calls for an expansion to $7\frac{1}{2}$ volumes. This must mean a theoretical expansion to these volumes, as it is hard to think such actual expansions were used at this period. A 10 per cent clearance would not be excessive to take for this period; this will give an actual expansion to nearly 4.72 volumes, using 55 lbs. steam pressure absolute, M. E. P. 27 lbs. (allowing 2.7 lbs. for back pressure) H. P. = 47.1. Terminal pressure = 11.65 lbs. at a density of about .0301 lbs. per c. f., this gives a consumption of 16.3 lbs. of water per H. P. per hour theoretically. Possibly the actual practice for the latter part of this period would be 30 lbs. of water evaporated with from 4 to 5 lbs. of coal per I. H. P. per hour. (10 per cent more in volume of steam at initial pressure is used in working out this way owing to clearance.)

The fourth period from 1840 to 1890 embraces the period of rapid strides in the economic use and generation of steam. It seems unfair, in comparing the progress in the economic use of steam, that the generator of the power should be left out of consideration. Improved boiler construction and working have during the last thirty years added materially to the possibility of using efficiently a high grade of expansion in the steam engine, without which high ratio of expansion the triple and quadruple engine would be at a discount. In making the consumption of coal a standard of comparison for the power developed, we have the advancement of the steam engine, as a prime mover, put on an economic base, embracing the whole cycle of changes from the formation of the steam to its final working point. Each part of of the system, engine and boiler, can afterwards be credited with its proportion of efficiency.

The average expenditure of coal per I. H. P. per hour may be taken for the several dates embracing the last thirty years as

1891.—1.5 lbs. of coal consumed per I. H. P. per hour developed by engine.

1887.—1.82 lbs. of coal consumed per I. H. P. per hour developed by engine.

1872.—2.11 lbs. of coal consumed per I. H. P. per hour developed by engine.

1860.—3.00 lbs. of coal consumed per I. H. P. per hour developed by engine.

Showing a saving of 50 per cent during the last thirty years. This is scarcely an overestimate but rather under, if we take the best performance of the present day.

Card 4.—Dealing with this latter period calls for an expansion to 20 volumes. If this is a theoretical expansion it is perhaps an extreme for single cylinder expansion. A 5 per cent clearance will bring the actual expansion down to 10.5 volumes; this would be very low for a multiple expansion engine.

Under card 5, 80 lbs. pressure appears to be the absolute pressure, and in expanding to twenty (20) volumes, one volume occupies the clearance space (the other 19 volumes after expansion representing an imaginary piston travel) or no admission work, this gives a clearance of $\frac{100}{19} = 5.21$ per cent, not 5 per cent.

It is stated by the author—"Practice has established the fact that the higher the initial and the lower the terminal, or the greater the ratio of expansion in a *single cylinder*, the greater the loss both by *clearance* and *condensation*."

As far as the loss by clearance is concerned it appears to be contrary to this up to a certain ratio.

Take the volumes of expansion as representing successive feet travel into an unit of area—take a clearance of 5 per cent of the volume swept through by our imaginary piston in all cases—and take a constant volume of steam at an initial pressure of 80 lbs. absolute in all cases.

Then for the four grades of expansion called for we have the following data:—

Two Lbs. Pressure per Square Inch Allowed for Back Pressure.

Expanded to volumes.	Proportion of clearance volume to unit vol.	P ÷ R	Proportion of admission volume to unit volume.	Hyp. Log. R.	Back pressure.	Mean effective pressure.	Travel of steam representing piston travel.	Work effective in ft., lbs. per unit of area.
20	.9524	$\frac{80}{20}$ ×	(.0476	+2.9957)	— 2	= 10.173	× 19.0476	= 193.771
10	.4762	$\frac{80}{10}$ ×	(.5238	+2.3026)	— 2	= 20.611	× 9.5238	= 196.295
5	.2381	$\frac{80}{5}$ ×	(.7619	+1.6094)	— 2	= 35.940	× 4.7619	= 171.142
3	.1429	$\frac{80}{3}$ ×	(.8571	+1.0986)	— 2	= 50.152	× 2.8571	= 143.289

Note.—The ratios of clearance and admission volumes to the unit volume of steam used, are put as near as can be; working only to four decimal places, showing an increase of effective work up to a point somewhere between 10 and 20 expansions.

Taking some other ranges of expansion we have

Expanded to volumes.	Proportion of clearance volume to unite volume	P ÷ R	Proportion of admission volume to unit volume.	Hyp. Log. R.	Back pressure.	Mean effective pressure.	Travel of steam representing piston travel.	Work effective in ft., lbs. per unit of area.
18	.8572	$\frac{80}{18}$ ×	(.1428	+2.8904)	— 2	=11.4808	× 17.1428	= 196.813
16	.7620	$\frac{80}{16}$ ×	(.2380	+2.7726)	— 2	=13.053	× 15.2380	= 198.901
15	.7143	$\frac{80}{15}$ ×	(.2857	+2.7081)	— 2	=13.966	× 14.2857	= 199.514
14	.6667	$\frac{80}{14}$ ×	(.3333	+2.6391)	— 2	=14.985	× 13.3333	= 199.795
13	.6191	$\frac{80}{13}$ ×	(.3809	+2.5649)	— 2	=16.128	× 12.3809	= 199.679
12	.5715	$\frac{80}{12}$ ×	(.4285	+2.4849)	— 2	=17.422	× 11.4285	= 199.107

Showing that the effective work of our volume of steam arrives at its maximum, close on the expansion to 14 volumes, where the total resistance due to back pressure is equal to the total work done by admission alone. This point will, of course vary with the percentage of clearance and amount of back pressure.

The volume of clearance increases, and that of admission decreases, as we expand to a greater number of volumes, but more effective work is got out of the same quantity of steam used, so that with any fixed percentage of clearance, in a single cylinder engine, the greater number of expansions up to a useful ratio give out effective work, which more than counterbalances the work lost by reduction of initial or admission steam.

In an automatic engine working under a varying load, where the proportion in volume of admission steam to clearance steam varies, the work done per lb. of steam used will increase up to a certain ratio of expansion; the clearance volume doing more effective work as the expansion increases. It is then a question of engine proportion to work to be done.

With a given percentage of clearance, it is true that for each increasing grade the percentage of loss increases, relatively to an ideal expansion without clearance. But we must have clearance, and having started with a given percentage of clearance; increased expansion allows the clearance volume to recover more of this initial loss.

The reduction of loss by cushioning, practically amounts to the use of a less percentage of clearance.

In a single cylinder engine, the greater the expansion of a given volume, the longer the stroke, and the less the percentage of clearance. For instance, with a 24-inch stroke, a 5 per cent. clearance is equal to a volume equivalent to 1·2 inches of the stroke, and this using a 36-inch stroke would only represent a 3·3 per cent. clearance—and the ratio of expansion would be increased by 50 per cent.

Take a case in point, using the same data as employed in the tables:—

	Foot lbs. per unit of area.
With 5 expansions—with a clearance of 5 per cent.—the effective work......	= 171·142
" 7½ " " " " " 3·3 " " " "	= 200·38

A gain of over 17 per cent. in net work.

The losses due to condensation, as given in the paper, seem to refer to initial condensation—this is the greatest, but a part is recovered by re-evaporation, in high grades of expansion. Steam jacketing also considerably reduces this loss in a single cylinder engine.

Mr. F. A. Bowman said: There was a paper read before the May meeting of the American Institute of Electrical Engineers, by Prof. Ball, of Harvard, on an electrical method of measuring the heat absorbed by the cylinder walls of a steam engine. The writer's method was briefly this: He had an iron plug made to fit one of the holes in the cylinder used for attaching an indicator. On the end of this plug and coming just flush with inner surface of the cylinder was a thin plate of iron. A rod of nickel passed through the plug and was insulated from it, but was soldered to the thin plate. The nickel and iron form a very good thermo-electric couple and the deflections of a galvanometer are proportional to the heat at the junction. His method of work is this: a series of observations are taken with varying cut off and with different thicknesses of the thin plate on the end of the plug. The idea being to discover the temperature of the cylinder walls at varying depths, and thus the amount of heat absorbed by them. The paper did little more than describe the mode of operation, as the writer stated he had not yet gathered sufficient data to be able to give diagrams or tabulated results. The method would seem to promise to throw some light on the vexed question of the rapidity with which heat can be absorbed and radiated from cylinder walls. Mr. F. A. Bowman.

While recognizing the great gain in economy due to the introduction of the compound principle in steam engines, it should be remembered that much of the large reduction in coal consumption in marine work, where compound engines were first used, is due to the use of surface condensers which return *hot, fresh* water to the boilers, and save the enormous waste of heat and steam that was occasioned by the necessity of blowing off when using salt water.

Mr. W. H. Laurie, replying to Mr. Bolland's remarks, said: Referring to card No. 1, it is necessary in computing the power or consumption of a single acting engine to reckon the piston speed at one stroke in each revolution, as power is only developed and steam consumed during one stroke. The object in assuming 100 feet piston travel during the first period was to adopt Mr. W. H. Laurie.

a basis that would make the calculation "of consumption" of the simplest; to enable those not conversant with the operation to follow the process with the greatest ease, and at the same time to show the general tendency during all the different periods. The theoretical consumption would be the same whether it were 10 feet piston travel or 100 feet.

In reference to the introduction of the compound engine, the speaker finds in Rankine's historical sketch in the introduction to his steam engine: "The double cylinder engine was invented by Hornblower in 1781, and was afterwards combined with Watt's condenser by Woolf." And in R. H. Thurston's history of the steam engine, page 138, "Arthur Woolf in 1804 re-introduced the Hornblower or Falck engine with its two steam cylinders, using steam of a higher tension. His first engine was built for a brewery in London, and a considerable number were subsequently made. Woolf expanded his steam from six to nine times." In some of his pumping engine tests, his compound engine performed a duty of 33 per cent over the Watt engine. This was in the early part of the third period. The card assumed for this period is not supposed to be perfect, the steam line is defective as is usual where a single valve is used, and the vacuum is not as good as can be produced by the more perfect mechanisms of the present. Revaporation is shown to have taken place, bringing the terminal up to 9 lbs. as is stated. In the data from which the consumption is calculated in the card, between $1\frac{1}{2}$ and 2 lbs. (which is not uncommon in engines of the present day, where the cylinders are unprotected and steam cut off at an early point in the stroke) will be found correct.

Referring to the fourth period and the advisibility of computing the consumption in coal. As it is the steam engine only that we have under consideration it would be a mistake to refer its consumption to coal. The amount of coal used in producing steam for a given engine may vary from 2 to 4 lbs. per hour per horse power, according to the quality of coal or the construction and condition of the generating plant in which it is used. Many other circumstances tend to vary the coal consumption, whereas the quantity of steam required for a given engine will be constant no matter what amount of coal is used and irrespective of the class of generating plant, providing the quality and pressure be the same. It is customary in contracting for large engines "even where the generating plant is included in the same contract" to specify that the engine will produce a horse power on a given number of lbs. of water.

Referring to card No. 4, the 20 volumes does not mean that the steam is cut off when the piston has moved $\frac{1}{20}$th of its stroke, but that a quantity of steam is admitted to the cylinder equal to $\frac{1}{20}$th of its total volume and expanded to 20 times its original volume. In actual practice in computing the number of expansions clearance is always included, as it would be impossible to arrive at the facts otherwise. An engine may show a cut off at $\frac{1}{4}$ stroke exactly, but it does not follow that the steam is expanded four volumes. In most engines it would not mean more than $3\frac{1}{2}$ expansions.

In regard to loss by clearance, Mr. Bolland seems to have mistaken the author's meaning. Mr. Bolland has furnished two efficiency tables to prove that clearance up to a certain point is an advantage. The speaker has not had time to follow up the calculation, but thinks he can prove without going very deeply into figures that the greater the ratio of expansion in a single cylinder the greater the percentage of loss by clearance.

In card No. 5, taken in the first place without clearance, we assume a M. E. P. of 15 lbs.; we will assume the engine constant to be one; then the 15 M. E. P. will represent 15 H. P. Then in the second case with 5 per cent clearance the same volume of steam only developes a M. E. P. of 10.5 lbs. or 10.5 H. P. with same consumption of steam. This loss of initial pressure is constant throughout all variations of load, representing a loss in clearance in the present instance equal to 30 per cent of the steam used or 4.5 H. P. Now, if we assume a card without clearance of 45 lbs. M. E. P., the same card with 5 per cent clearance will represent 40.5 M. E. P. or 40.5 H. P., reducing the loss by clearance to 10 per cent instead of 30 per cent as in the first instance. The loss by clearance being constant, then the greater the M. E. P. the less will be the percentage of loss, and the less the M. E. P. the greater will be the percentage of loss. As to the efficiency from expansion of the clearance steam, that is in proportion to the point of cut off, but the speaker's assertion only refers to the initial loss, which is the loss by clearance.

Thursday, 22nd October.

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

Paper No. 55.

FRASER RIVER BRIDGE.

CANADIAN PACIFIC RAILWAY, MISSION BRANCH.

By H. J. Cambie, M. Can. Soc. C. E.

To render the following description of the bridge over the Fraser River on the Mission Branch of the Canadian Pacific Railway intelligible, it is necessary to offer a few words of explanation as to the location, and the reasons therefor.

The Fraser River, after following a course nearly due south for 300 miles, breaks through the Cascade range of mountains by the Yale Cañon and continues on the same course to the Village of Hope about thirty miles from the boundary of the United States (49th parallel.) It then turns sharply to the west and flows in that direction for about 100 miles in a wide alluvial valley, till it empties into the Strait of Georgia. This is known as the lower Fraser and the lands on either bank are very fertile, forming the best agricultural district in British Columbia.

The main line of the Canadian Pacific Railway follows the right bank of the Fraser to Port Hammond, where it turns northward to Burrard Inlet and the City of Vancouver, while the Westminster Branch diverges to the city of that name situate on the Fraser River, about twenty miles from its mouth.

To connect the Canadian Pacific with the railway systems of the State of Washington, Mission Station, about forty miles from Vancouver, was selected as the most suitable point from which to branch oft to the south, and the Fraser River had therefore to be crossed in that neighborhood.

The actual site of the bridge was selected in the longest straight reach in that part of the river, and which showed no signs of having changed its course in recent years. It is there a considerable depth all the way across—1,600 feet wide at high tide level, 42 feet deep near the north, and 25 feet deep near the south bank. A short distance above the bridge it is 200 feet narrower, and a similar distance below, 200 feet wider. In winter there is six feet of tide which decreases gradually for about twenty-five miles farther up where it ends. Freshets usually occur in June or July and have risen as much as seventeen feet, continuing in flood for a couple of months.

With these characteristics it was hoped that there would not be much trouble with ice or driftwood, and that the bottom would be less likely to scour than elsewhere. Also that the water would not be dammed up to any appreciable extent by the piers, for on the south bank is a dyke six feet high, which reclaims from the overflow of the river about 10,000 acres of magnificent land. This dyke was completed in the winter of 1889-90 under the superintendence of Mr. G. A. Keefer, M. Can. Soc. C. E.

The bottom is of silt, which is probably of great depth, for the valley from Hope downwards has evidently at no very distant (geological) period been one of the great fiords or inlets which reach from the Pacific Ocean, far into the Cascade range of mountains, and are found all the way from Puget Sound to Alaska.

These inlets are exceedingly deep, and this one which has been filled up during the lapse of ages by the silt brought down by the Fraser River, was no exception to the rule.

The work was started rather hurriedly, only four days being taken to prepare a plan and specification, and contractors having only three days in which to tender, nevertheless the work has not been materially altered since its commencement. The viaduct is of wood 3,000 feet long, and consists of pile trestle approach 150 feet, one span 100 feet, seven spans 150 feet, swing truss 239 feet over all, one span 150 feet, and 1,250 feet of pile trestle approach. Howe truss spans of 150 feet each were selected as being the largest which it is desirable to build in wood.

The chief difficulty lay in designing piers of moderate cost which should be safe in winter when there is thirty-five feet of water, a current of two and one half miles an hour, and at times ice which shoves with great force, and in summer when there is fifty-nine feet of water, a current of five miles an hour and driftwood coming in tangled masses, sometimes nearly an acre in area, as well as trees of great size.

Piers were originally proposed with four rows of piles placed at two feet centres both ways, but the piles averaging fifty-five feet in length the butts were so large, that it was found impossible to drive them so close together, and consequently only three rows could be used, placed three feet centres across the current, that is in the line of the bridge, and two feet centres up and down stream.

Around these piles cribs were built of square timber, with ties nine feet apart for which spaces were left between the piles. The cribs are eleven feet wide outside measurement, and forty-one feet long, with noses at each end projecting five and a half feet farther and meeting in a right angle.

Ballast chambers were formed between the ties in two of the spaces—the centre row of piles being left out—and the cribs were sunk as built. When they reached bottom they were filled to the top with rock small enough to sink between the piles and form a solid mass. Rip-rap was then placed on the outside, eight feet deep next the cribs and extending fifty feet in all directions from them.

Some difficulty was experienced in sinking such a large mass of timber with small ballast chambers, and in some cribs ties near the bottom were allowed to extend six feet outwards, and two ballast platforms formed on each side, which arrangement was convenient for sinking the cribs during construction, but cannot be recommended where the bottom is soft, as in the present instance, as the surrounding riprap in settling into the mud, fell away from the platforms leaving a space through which the current scoured the material underneath to some extent before it was noticed and remedied.

The piles are driven about twenty feet into the bottom of the river, and are cut off at the level of high water neap tides, being thus wet to the top twice every day. The cribs are built to the same height and are expected to last for a very long time, as the water is fresh, very cold, and not known to be inhabited by any noxious insects. Resting on the piles are piers formed of framed bents twenty-five feet in height, which places the bridge seat just eight feet above the highest flood known, viz., that of 1882. These have cutwaters with a slope of 1 to 1.

Two of the framed piers were in position before the flood of this year (1890) and one of them was tested by a boom of logs descending the river, which a tug was unable to control. They were of long lengths, many of them four feet and upwards in diameter, and struck with such force as to slide up the cutwater several feet without jarring it in the least.

For reasons which it is unnecessary to discuss here the swing has been built with an opening of 100 feet on each side of the pivot pier, and far enough from the shore to give twenty-four feet of water in one channel and nineteen feet in the other. This pier is thirty feet in diameter, and being placed so far out in the current has caused a good deal of scour, so much so that the bottom of each channel has to be riprapped right across and for a considerable distance up and down the stream.

The substitution of mattrasses of brush for the riprap, or a portion of it, was fully considered, but owing to the depth of water and rapidity of the current it was feared that difficulty would be experienced in sinking them exactly where required. It was found, moreover, that the amount of rip-rap necessary to ensure their remaining permanently in position would bring the cost up to a higher figure than the rip-rap alone.

The swing truss and gear was designed by Mr. P. A. Peterson, the Chief Engineer of the Canadian Pacific Railway Company, and has an arched upper chord, fifty of the sticks in which are about 6″ x 12″ and range, from seventy-eight to ninety-seven feet in length. These are of Douglas fir, sound and almost clear, and were sawn by one of the mills at Vancouver.

As a further instance of the facilities afforded by the timber of British Columbia for special classes of bridge work, it is worth mentioning that all the piles used in the false works of this bridge, reached up to the lower chords, and ranged from seventy to eighty-five feet in length.

It is expected that the track will be laid over the bridge early next month. (January, 1891.)

The general character of the bridge will be best seen by reference to the accompanying plans, (Plates VII and VIII.)

VANCOUVER, B. C., December 27th, 1890.

DISCUSSION.

Mr. E. P. Hannaford.

Mr. E. P. Hannaford said that an uneven number of panels in a Howe truss bridge was an evident error, as it did not permit the main braces meeting in the centres of the spans as they should do, and it left the centre panels without sufficient bracing. He observed that with the exception of the swing bridge and one fixed span, the remaining spans of 150 feet each were arranged with uneven number of panels.

Mr. J. W. McCarthy.

Mr. J. W. McCarthy said Mr. Cambie's paper would have proved far more interesting had he given detail dimensions and cost of different structures. Mr. Hannaford remarks that in the Howe truss mentioned by Mr. Cambie the panels being uneven, shows a faulty design and not at all good practice. This is not the case, and it is not, in his opinion, a question to an engineer in dividing up a Howe truss whether the panels will be even or uneven. In designing a Howe truss, like any other truss, the first thing to decide is the length of panel. Now should the panels be even, the main braces will abut at the top chord prism at centre of truss; if the panels are uneven the braces in this middle panel become counters. There are cases where even number of panels are most generally used, and that is in trusses which have a single system of bracing.

Mr. W. J. Sproule.

Mr. W. J. Sproule said that information on the following points, which Mr. Cambie can no doubt add to his interesting paper, will be of value:

1. The elevation of the Fraser River at the site of the bridge, above sea level. This is of deep interest in connection with the rise of tide and the currents developed by freshets, especially of such as rise seventeen feet above normal level of the river.

2. More particulars of the river bed. It is said to be of "silt," "probably of great depth." What is the nature of this silt? Is it very soft, or medium, or heavy silt? What is its depth? Have any borings or tests by bars or other means, been made to ascertain its character or depth?

3. Additional details of the piers. Apparently the superstruc-

ture is supported entirely on the piles, and the cribwork is merely a casing to protect the piles from abrasure by ice or drift-wood. Is this the case, or are the superstructure piles and cribwork all bound together? If the latter, how was settlement of the cribwork arranged for? Settlement would probably take place in such a soft bottom and the cribwork might continue settling for some time.

4. Did the scour mentioned as occurring in the swing spans take place at the normal state of the river or during a freshet? If the latter, was it a high freshet or a moderate one.

5. From the spans and dimensions of piers and rip-rap it is seen that the normal cross section of water-way is decreased about 18 per cent, while the wetted perimeter is increased nearly 40 per cent. This interference with the discharging capacity of the river must to a certain extent increase the current in parts of the remaining water-way and is important in the case of an unstable bed and may become serious in case of extraordinary freshets.

Mr. Alan Macdougall said that to consider the scheme, prepare plans and specifications in four days, and let the contract in three days thereafter, is a *tour de force*. Mr. Alan Macdougall.

The paper is a good general description of what is undoubtedly a difficult engineering work, but the details are so meagre there is no opening for discussion in the paper. A few details of cost of work, reasons for limiting the spans to 150 feet, and size of openings for swing span to 100 feet, would have been valuable as engineering information and for discussion.

Mr. H. J. Cambie, in reply to Mr. Sproule, stated that: Mr. H. J. Cambie.

1. There has not been any occasion in connection with the railway works to observe the tides very accurately at the bridge, but it is known that tidal high water there is about $\frac{3}{10}$ feet higher than at Burrard Inlet on salt water, and that during spring tides there is only a rise and fall of 6 feet, while at Burrard Inlet on similar occasions there is $16\frac{4}{10}$ feet.

2. The silt deposited in the tidal portion of the river is heavy, but extremely fine, and when protected from scour forms a fairly solid bottom. Many of the piles which were driven 20 feet into it, did not even when first entered, go more than four inches to each blow of a 3,000 lb. hammer falling a distance of eight feet, and offered more and more resistance as they went down.

There is no record of any boring having been made to ascertain the depth, but the configuration of the ground is such as to suggest its being great. And there are lakes which appear to have been arms of the inlet referred to, which are of great depth. The silt brought down by the Fraser filled up the main valley but could not reach into the side ones, thus Harrison Lake is known to be deep and Pitt Lake is shown on the Admiralty charts with soundings of 200 to 450 feet, although the outlets to the Fraser are shallow.

3. The superstructure is supported entirely on piles, the cribs filled with stone being used principally as a means of bracing the piles together, though they are also a protection against ice and drift logs. The cribs are not bound in anyway to the piles, nevertheless they have not settled perceptibly. The stone filling sank about 4 feet in three months, was made up again, and has since remained stationary.

In the same way the riprap round the outside of the piers settled from four to six feet, was partly filled up again and seems to be now quite solid.

4. The scour in the swing spans took place during the freshet of 1890, which rose $12\frac{8}{10}$ feet above the highest tide. It came up suddenly in the month of May, nearly a month earlier than usual, immediately after the cribs had been sunk and before any considerable quantity of riprap had been placed round them. The highest known freshet (that of 1882) was $3\frac{8}{10}$ feet higher than that of 1890.

5. During freshets, such as that of 1890, the water-way is reduced just about 10 per cent., and the current is perceptibly increased between the piers, but no effort has been made to ascertain the rate.

Four of the piers have now stood the freshets of three seasons without any injury, and the others for two seasons, so that the structure may be considered satisfactory.

Thursday, 5th November.

JOHN KENNEDY, Vice-President, in the Chair.

Paper No. 56.

ENERGY AND LABOR.

By G. C. Cuningham, M. Can. Soc. C. E.

In presenting the following paper to the Canadian Society of Civil Engineers some apology should, perhaps, be offered for having taken up a subject that is different in style from those usually brought forward. Instead of describing some particular work, a general investigation of labour in its application to work is undertaken. Engineers have constantly to deal with questions of cost of construction, and these questions immediately involve the question of the cost of that labour, from which all construction results. Therefore an investigation into the cost of labour—an enquiry as to what constitutes labour—cannot, perhaps, be without interest to engineers, and may prove of some value. It is impossible, however, to make this investigation or enquiry without crossing, at some points, the well beaten paths of the political economist. Indeed, we do not proceed far before we find our track running parallel to his, and in a comprehensive survey of the question it is necessary to include much that has been mapped out by previous explorers. When the country is particularly difficult and rugged—to pursue the metaphor—we will often find it best to follow the established trail; but at other points, again, with true engineering instinct, we may bridge some deep chasm rather than make a long and labourous detour to avoid it.

What is labour? An answer to this question that will be sufficiently wide to embrace all kinds of labour is that, "Labour is the expenditure of energy," and so far as the work of producing or constructing is concerned, "Labour is the expenditure of energy to the doing of useful work that commands remuneration."

Man, in his dealing with nature, can create nothing. All that he can do is to arrange matter in different forms from those in which it previously existed. The whole phenomenon of production consists only in the collection, separation, combination, arrangement and distribution of matter. There is nothing made, in the sense of something being brought into existence that previously was non-existent. The only means by which this treatment of matter can be effected is by the application to it of energy, the energy of force or motion. By the application of force and motion to matter it is brought into new combinations, and is made subservient to human uses. The object of labour is to bring matter into such conditions that it may be immediately useful, or that, when acted upon by natural forces, such as solar heat, it may produce commodities that are of use.* Broadly speaking, manufactured articles come under the first division, agricultural commodities under the second. But whatever the commodity may be, the expenditure of energy is required, *i.e.*, labour, to obtain or produce it. Even the fruit growing wild on the tree requires the labour of gathering it before it can be used.

Before going further it may be well to devote a little time to the consideration of energy, in the special sense in which the term is now used, and to the source from which energy, as we know it upon the earth, is derived. A full discussion of the subject would occupy more space than can be afforded here, but a most complete and beautiful elucidation of the question will be found in the eighth chapter of Herbert Spencer's "First Principles"—on the Transformation and Equivalence of Forces.

The doctrine of the conservation of energy shows that energy or force, like matter, can be neither created nor destroyed. All that can be done is merely to transform energy, that is, to change it from one form of being into another. Joule and others have investigated the energy of heat and have determined its mechanical equivalent; this they have found to be 772 foot pounds in order to raise one pound of water one degree fahrenheit. That is to say, there is as much energy expended in this operation as would raise 772 pounds weight a foot high, or conversely 772 pounds weight when raised a foot high would, if let fall under the action of gravity, give forth the same quantity of heat by the force of the fall. The weight, when raised up, possesses energy in the potential form. So long as it remains raised it is capable of doing work by letting it fall. When it has fallen it no longer retains

* Compare "Principles of Political Economy," J. S. Mill, Book I, chap. I, sect. 2.

potential energy, but its energy appears in the heat caused by the fall, or it may be in the work it has done in falling. Thus this weight in falling might be made to raise another similar weight to a similar height (friction disregarded), when the potential energy would be transferred to No. 2; or it might be used to raise half its weight to twice the height, or a quarter of its weight to four times the height, or so on, in all of which cases the potential energy would simply be transferred from one weight to the other.

In a quite analogous manner fuel possesses potential energy. The fuel, before combustion, is a store of energy. During the process of combustion heat is given out which can be applied to the doing of work. Whence comes the energy of the fuel? Modern science shows that it comes from the sun's rays. The energy of the sun has been absorbed in the production of the fuel and is held stored up there until combustion again sets it free. And each unit of heat set free by combustion has, as before explained, its mechanical equivalent. If each unit could be captured and made to do work all could be transformed into work done. Unfortunately, our appliances and engines for converting heat into work are as yet so imperfect that by far the greater part of the heat evolved in combustion escapes and spreads through the surrounding media, and only a very small portion of it is converted into useful work. From calculations which the writer made in regard to the energy of fuel in locomotives *, it was found that on the Canada Southern Railway, a line having very flat gradients, running through the southern part of the Province of Ontario, so small a quantity as 2.3 ounces of coal produced in combustion sufficient energy to move a ton weight (American) one mile. Though the fact that a little piece of coal such as this—that can easily lie in the palm of one's hand—possesses within itself the dormant force that is capable of moving a mass more than thirteen thousand times its weight a distance of a mile is sufficiently astonishing, yet what must be our wonder at the power of fuel, when we find that to do this great work only 3½ per cent. of the total energy contained in this little piece of coal is used, and 96½ per cent. is lost and wasted. If all the energy contained in the 2·3 ounces of coal could be harnessed and made to do work, it would, on the Canada Southern

* Cuningham on "The Energy of Fuel in Locomotives;" minutes of proceedings Inst. Civil Engineers, Vol. lxxxiii, p. 311.

Railway, be capable of moving a ton weight 28½ miles! While we have this fact before us, let us compare it with similar work done by human energy alone, unaided by mechanical appliances. To convey a ton (2,000 lbs.), a distance of a mile by "bearers" would require the full energy of two men for a whole day. If they took 100 lb. loads, each would require to make ten "trips," and thus walk 20 miles to do the work. The energy of two men being expended for a day, would therefore, only accomplish what the energy of 2·3 ounces of coal does on the Canada Southern Railway in three minutes,—taking the speed of a freight train at 20 miles per hour. We see from this how much better adapted fuel energy is to the doing of such work than human energy.

The energy of the human body that is expended in doing work, or carrying on the vital processes, is obtained in a similar manner to the energy of the locomotive. The food that we eat is the fuel that supplies us with energy, and the assimilation of this food is analogous to the combustion of fuel that takes place in an engine furnace. The energy of the food is also derived from the same source as the energy of the fuel, namely: the sun's rays. This will be made clearer by a quotation from an article on this subject written by Prof. Balfour Stewart, that appeared in the *Contemporary Review* for July, 1882, "On the Conservation and Dissipation of Energy."

"A healthy man possesses energy, for he has the power of "doing work: there must, therefore, be in his body a store of "energy, and this must be energy of position, or potential energy, "as it is called. This is clearly derived from the food which he "eats, taken in conjunction with the air which he breathes. Something analogous to combustion must be taking place in his "animal frame, and just as in an engine the energy of the fuel "is converted into heat and work, so in his body the energy of "food is converted into heat and work. Food, therefore, has a "kind of energy analogous to that which fuel possesses. Now, "whence does food derive its energy? It is either animal or "vegetable; if the former, no doubt the animal which furnished "it had fed on vegetables, so that we may limit our enquiry to the "latter. Whence then do vegetables derive their energy? We "reply, from the sun's rays."

A complete investigation of this subject in all its aspects, such as is undertaken by Spencer in the chapter before mentioned, shows that the prime source of all energy on the earth is the sun's rays. In order to lay the foundations on which to build the succeeding argument in regard to labour, it is necessary to make some quotations from this chapter. At page 206, Spencer says: *

"When we enquire under what forms previously existed the "force which works out the geological changes classed as "aqueous, the answer is less obvious. The effects of rain, of "rivers, of winds, of waves, of marine currents, do not manifestly "proceed from one source. Analysis, nevertheless, proves to us "that they have a common genesis. If we ask, whence comes "the power of the river current, bearing sediment down to the "sea? The reply is, the gravitation of water throughout the "tract which this river drains. If we ask, how came this water "to be dispersed over this tract? The reply is, it fell in the shape "of rain. If we ask, how came the rain to be in that position "whence it fell? The reply is, the vapour from which it was "condensed was drifted there by the winds. If we ask, how "came the vapour to be at that elevation? The reply is, it was "raised by evaporation. And if we ask, what force thus raised "it? The reply is, the sun's heat. Just that amount of gravi-"tative force which the sun's heat overcame in raising the atoms "of water, is given out again in the fall of those atoms to the "same level. Hence, the denudations effected by rain and rivers "during the descent of this condensed vapour to the level of the "sea, are indirectly due to the sun's heat. Similarly with the "winds that transport the vapours hither and thither. Conse-"quent as atmospheric currents are on differences of temperature "(either general, as between the equatorial and polar regions, or "special as between tracts of the earth's surface of unlike "physicial characters), all such currents are due to that source "from which the varying quantities of heat proceed. And if the "winds thus originate, so too, do the waves raised by them on "the sea's surface. Whence it follows that whatever changes "waves produce,—the wearing away of shores, the breaking "down of rocks into shingle, sand, and mud—are also traceable "to the solar rays as their primary cause. The same may be said "of ocean currents. Generated as the larger ones are by the "excess of heat which the ocean in tropical climates continually "acquires from the sun; and generated as the smaller ones are

* "First Principles." Second Edition.

"by minor local differences in the quantities of solar heat "absorbed; it follows that the distribution of sediment and other "geological processes which these marine currents effect, are "affiliable upon the force which the sun radiates. The only "aqueous agency otherwise originating is that of the tides, an "agency which, equally with the others, is traceable to unex-"pended astronomical motion. But making allowance for the "changes which this works, we reach the conclusion that the "slow wearing down of continents and gradual filling up of seas, "by rain, rivers, winds, waves and ocean streams, are the in-"direct effects of solar heat."

Again at page 269:

"That animal life is immediately or mediately dependent on "vegetal life, is a familiar truth; and that, in the main, the pro-"cesses of animal life are opposite to those of vegetal life, is a "truth long current among men of science. Chemically considered, "vegetal life is chiefly a process of de-oxidation, and animal life, "chiefly a process of oxidation. Chiefly, we must say, because "in so far as plants are expenders of force for the purposes of "organization, they are oxidizers (as is shown by the exhalations "of carbonic acid during the night), and animals in some of their "minor processes are probably de-oxidizers. But with this "qualification, the general truth is that the plant, decomposing "carbonic acid, and water, and liberating oxygen, builds up the "detained carbon and hydrogen (along with a little nitrogen and "small quantities of other elements elsewhere obtained), into "branches, leaves and seeds, and absorbing oxygen, recomposes "carbonic acid and water, together with certain nitrogenous "compounds in minor amounts. And while the decomposition "effected by the plant, is at the expense of certain forces emanat-"ing from the sun, which are employed in overcoming the "affinities of carbon and hydrogen for the oxygen united with "them; the re-composition effected by the animal, is at the profit "of these forces, which are liberated during the combination of "such elements. Thus the movements, internal and external, of "the animal, are re-appearances in new forms, of a power "absorbed by the plant under the shape of light and heat. Just "as in the manner above explained, the solar forces expended in "raising vapour from the sea's surface, are given out again in "the fall of rain and rivers to the same level, and in the accom-

"panying transfer of solid matters; so the solar forces that in "the plant raised certain chemical elements to a condition of "unstable equilibrium, are given out again in the actions of the "animal in the fall of these elements to a condition of stable "equilibrium."

And again at page 220:

"Not only is the force expended by the horse harnessed to the "plough, and by the laborer guiding it, derived from the same "reservoir as is the falling cataract and the roaring hurricane; "but to this same reservoir are eventually traceable those subtle "and more complex manifestations of force which humanity, as "socially embodied evolves * * * * * Currents "of air and water which before the use of steam were the only "agencies brought in aid of muscular effort for the performance "of industrial processes, are, as we have seen, generated by the "heat of the sun. And the inanimate power that now, to so "vast an extent, supplements human labour, is similarly derived. "The late George Stephenson was one of the first to recognize "the fact that the force impelling his locomotive, originally "emanated from the sun. Step by step, we go back from the "motion of the piston to the evaporation of the water; thence "to the heat evolved during the oxidation of coal; thence to the "assimilation of carbon by the plants of whose imbedded remains "coal consists: thence to the cabonic acid from which their car-"bon was obtained: and thence to the rays of light that deoxi-"dized this carbonic acid. Solar forces, millions of years ago "expended on the earth's vegetation, and since locked up beneath "its surface, now smelt the metals required for our machines, "turn the lathes by which the machines are shaped, work them "when put together, and distribute the fabric they produce."

These few extracts will indicate, with sufficient clearness, the sense in which the term "Energy" is used, and give in as condensed a form as possible, the conclusions arrived at by the application of the modern doctrine of the Conservation of Energy. From this we see that all force with which we are acquainted on the earth (except the force of gravity) is primarily due to the sun's rays. All human energy and all animal energy, the force of rivers and winds, the energy of heat and light in whatever manner manifested: all are ultimately due to the solar rays. And thus a strong healthy man, and a heap of coal are each of them sources from which can be obtained energy that may be applied to the doing of work; and both derive their energy from the same source—the Sun.

Reverting now to the definition given, that "Labour is the expenditure of Energy," we can understand how wide that definition is. Both energy and matter are alike uncreatable and indestructible. All that man can do is to move matter, and to guide and control energy. The energy that he can make use of appears under various forms; but under all these forms it can be used by man to certain extents and degrees, and can be directed by him to the doing of work. And in so far as energy is used to do work that commands renumeration, it is Labour in the sense in which that word is used by the *Political Economist.* With this fundamental notion of what Labour is, we will be in a position the better to investigate all the phenomena of Labour.

In his primitive condition man has control over no other energy than that stored up in his own body, and produced by the consumption or combustion of the food he eats. If he wishes to move from one place to another, he can do so only by his own muscular exertion: *i. e.* by the expenditure of his own energy. If he wishes to convey anything from one place to another, he can do so only by carrying it himself: *i. e.* by a further expenditure of his own energy. The first step in advance of this primitive condition is taken when he rears and trains animals,—horses and cattle—to do this work for him; thus substituting the less costly animal energy for his own: or when he makes boats, "dugouts," or canoes, by which he can convey himself and his goods on the water with a less expenditure of his own energy than he would have to make to do the same work on land. A further advance is made when he constructs vehicles for his horses to draw, and prepares ways on which the vehicles may travel, thus economising the energy of his horse, and enabling it to convey more goods in this manner than it could when loaded in the primitive fashion on its back: and when he improves the build of his boats, so that, by offering less resistance to the water, his energy in propelling may be able to convey a larger weight of goods than formerly, and thus rendered more efficient. A still more decided advance is made when he applies sails to his boat, and employs the energy of the wind—which he can obtain without any cost of production—to propel the boat and its load, while his energy is expended merely in directing and guiding the vessel. Every improvement in ship-building has been made with constantly the same object: to obtain the largest and fastest carrying capacity with the least expenditure of human energy: to build vessels, and to construct and arrange sails for them, that will enable them to be moved with the slightest breeze, and at as many angles to the direction of the wind as possible: that is, to make the largest possible use of the energy of the wind, without the direct propelling force of human energy.

The application of animal energy to the doing of work has proceeded on lines similar to those above indicated. Horses have been carefully bred and reared so as to produce animals that were capable of exerting great strength, or putting forth great speed; that is, animals in whose bodies the energy of the food consumed would be transformed into the largest possible amount of active energy, and whose bodies should be best adapted to re-transform this energy into work. Vehicles have been constructed as light as possible, and of the best form that could be devised for easy movement, and roads have been built offering as little resistance as possible to the movement of vehicles, so that a minimum of the energy of the animal might be wasted in overcoming mere resistances of the vehicles or road, while a maximum should be devoted to the performance of useful work. Every one knows that with a heavy, lumbering vehicle on a hilly broken road, a horse could take a much smaller load than with a light well constructed vehicle on a smooth, evenly-built road; the reason being that in the first instance a large part of the horse's energy is absorbed in overcoming the resistances of vehicle and road, and a small part only left to be applied to the conveyance of the load, whereas in the second case a small part of the energy is absorbed by the resistances of vehicle and road, and the larger part applicable to the conveyance of the load.

Similar, too, has been the application of the energy of flowing or falling water to the doing of work. Man built dams, and constructed mill races with sluices, wheels and other appliances, so that he might make use of the energy of water falling from a higher to a lower level, and apply part of it to the doing of work. In order to secure this supply of energy from the water, it was necessary first to expend energy in the construction of dams, mill races, etc., just as, in order to get the full benefit of animal energy it is necessary previously to expend energy in the construction of vehicles and roads, and in the rearing of animals. But this first expenditure of energy is more than recouped by the subsequent saving effected in the energy expended in the doing of work. The true reason for the use of energy other than human, is that other kinds of energy can do certain kinds of work quite as well as human energy, and that other kinds of energy in the doing of this work are much less costly than human energy. The amount of work done—using work in the scientific sense of "foot pounds"—in raising a ton one hundred feet, is the same whether it be done by men, horses, or wind or water-driven machinery. The quantum of energy expended or absorbed is the same in one case as in the others; but the cost of the energy is much greater for men than for horses, and much greater for horses than for wind or water-driven machinery.

A further and great advance in obtaining cheap energy was made when man discovered how to apply the energy of heat developed in the combustion of fuel, to the doing of work. This energy of fuel is precisely analogous to the energy of men or horses, and is derived ultimately from the same source. It is also much less costly than the energy of men or animals, and though in direct comparison, not less costly than the energy of wind or falling water, yet in its application to the doing of work has so great an advantage over these energies, in continuity and portability, that ultimately in practice it is found to be less costly than either in the vast majority of cases. Wind-driven machinery is subject to the fitful changes of the wind, and to the complete loss of the energy when the wind dies away. Water-driven machinery is liable to similar drawbacks through changes in the weather, causing the water to be frozen in cold or dried up in great heat. When these contingencies arise the machinery stops, production of commodities is suspended, while the maintenance of the men and animals engaged about the machine must be continued during the enforced idleness, just the same as while work is going on. This cost of maintenance has, therefore, to be borne with no concomitant production to support it. But no such drawbacks exist in regard to the use of energy derived from fuel. So long as we have fuel we have our store of energy, and the application of it to the doing of work can go on whether the wind blows or not; alike in cold or in hot weather. That fuel energy is less costly than the energy of men or animals, when coal can be obtained without extraordinary difficulty, the following example will show:

The amount of effective energy that can be obtained from 30 pounds of food consumed by a strong work horse in a day, is about 13,200,000 foot pounds. On a good road, with a wheeled vehicle, this energy would be capable of transporting a ton weight (including the weight of the vehicle) 30 miles.* But on a well constructed railway, with flat gradients, there is sufficient effective energy in 5 pounds of coal to transport a ton weight 30 miles. Now disregarding the energy that must be previously expended in either case for the construction of the road or railway, we can at once see that in order to procure horse food, by the ordinary methods of farming followed in a settled and cultivated country, there must be a much greater amount of energy expended in raising 30 pounds of such food, than in obtaining 5 pounds of coal where the coal mines are at all reasonably convenient or accessible; in other words that the horse food would cost a great deal more than the coal. Reducing the comparison to a common money basis, such as would hold for Ontario, we would find that the horse food cost 30 cents, while the coal cost one cent; that the source whence the horse energy is derived cost thirty times more than the source of the railway locomotive energy; and besides this, to the cost of the horse energy must be added the cost of a man's energy expended in driving and tending the animal, while to the cost of the fuel energy must be added only a very small fraction of a man's energy; for two men together could quite well direct and control the energy developed in the combustion of 20 tons of coal. Thus a day's energy of a horse is only equal to the energy derived from 5 pounds of coal, in a locomotive engine running on a good line of railway; and the work which occupies a horse the whole day in the doing can be done by 5 pounds of coal in about an hour and a half.

Similar reasoning may be applied to make the comparison with human energy. A strong, able-bodied, well-nourished man can develope in a day's work about 2,200,000 foot pounds of energy, equal to one-sixth of the energy of a horse. To produce

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* Taking the resistance at 80 lbs. per ton, would almost exactly absorb all the energy of the horse.

this energy the combustion of from 3 to 4 pounds of food is required. The cost of this, reduced to similar money basis to that above given, is 30 cents per diem. To accomplish the same amount of work, of a similar kind to that done by a horse (such as hauling a vehicle on a good road), six men would have to be used; and the cost of the food from which their energy is derived would be $1.80, as compared with 30 cents for the horse and 1 cent for the coal. In this comparison we do not speak of the *remuneration* that must be paid for the different kinds of labour used, which is something very different, but simply of the cost of the matrix from which the energy is evolved. In any case whether 6 men, 1 horse or 5 pounds of coal be used, the same amount of "work" is done, the same amount of foot pounds are effected, the same quantum of solar energy is turned into useful work. But when this energy is obtained through men the cost of the matrix (measured by a common money standard) is $1.80; through a horse it is 30 cents, and through coal it is 1 cent. Therefore if work can be done by coal instead of by men or horses, it will evidently be done much more cheaply; and if man can devise a means of substituting fuel energy for human or animal energy in the doing of work and making of commodities, the cost of the work and the commodities will be greatly reduced. Such a means has, of course, been devised by the steam engine; and we daily see work performed by one locomotive in a tenth part of the time that would formerly have been required by hundreds of horses and men, and at an amazingly small fraction of the former cost.

It is only during the present century that man has discovered, and been able to apply, the stored up energy of heat in fuel to the performance of work—that man has been able to substitute this energy for that of men or animals. From the days of Jehu to George IVth there was no other way of rapidly moving on land, from one part of the country to another, except by the aid of horses. Now man has discovered the energy of fuel and how to use it, and consequently the cost of locomotion is wonderfully decreased and the rapidity of it as wonderfully increased. A single locomotive on a line of railway with flat gradients, such as the Canada Southern Railway, can easily convey 500 tons of freight, which with the weight of the vehicles would amount to 1,000 tons, a distance of 250 miles in 12 hours. The consumption of fuel required for this would be about 20 tons of coal.[1] To do the same work with horses, at least 300 pairs would be required, with 300 drivers, and they would be engaged about the work for not less than 10 days. The weight of food that these horses and men would consume in this time would be about 97 tons. We therefore have 20 tons of coal as—roughly speaking—the "energetic equivalent" of 97 tons of animal and human food; and the coal does the work in a twentieth part of the time required by the men and horses. The locomotive engine, as a doer of work, has also this great advantage over men or horses, that it expends energy only while it is working; when it stands idle we let the fires go out. It is not so with the horse—he must be fed and his energy maintained whether he works or stands idle. There has to go on continuously an expenditure of energy in order that his energy may be available at the time that we desire to use it.

The application of fuel energy to the doing of work other than locomotive has gone forward, during the present century, in a similar manner, and has produced analogous results. Whenever it has been possible to substitute fuel energy for human or animal energy in the thousand and one mechanical operations used in turning out commodities, that substitution has been made, with the result of enormously reducing the cost of production, because the energy of fuel is much less costly than the energy of men or animals.

The bent of inventive genius, as applied to manufactures, is always towards designing and perfecting what we call "labour-saving machinery." The true significance of all these inventions—whether they be sewing machines or steam hammers, printing machines or sawmills, reaping machines or locomotives, racing skiffs or triple expansion marine engines—is that they aim at either economising the energy used and thus getting more work out of it than formerly, or substituting a less costly and more efficient energy for that formerly used. No woman would use a sewing machine if she found that with the same amount of exertion expended on the machine she could do less work than she could formerly accomplish by hand. The locomotive engine never would have displaced horse labour if the cost of doing the work by fuel energy had been greater than the

[1] This is arrived at from the figures adduced in the paper before alluded to, "On the Energy of Fuel in Locomotives," Vol. lxxxiii Proceedings Institute C. E.

cost of doing it by horses and men, or if the locomotive had taken a longer time to do the work than the other agents. The progress of mechanical invention is always, and rapidly, in the same direction, and each day sees the evolution of some new device intended to economize energy. The world is only yet on the very threshold of discovery in the use of heat energy. The steam engine, wonderful though it be, and wonderful though the results are that it has effected in cheapening energy, is still a most wasteful and extravagant machine. When man has learnt how to secure much of the heat that is now lost, a ton of coal may be able to do twenty times as much work as now performed, and yet have a large margin for evaporation and radiation. Future ages will see vastly more than at present of the coarse and rough labour of life and the purely mechanical work of manufacturing done by cheap fuel energy, with the result that the cost of producing commodities will be proportionately reduced.

The whole phenomena of production, the whole phenomena of the formation and increase of wealth, can be rightly understood and interpreted only through a proper understanding of this application of energy. Labour is the cause of value; by labour only are commodities produced. The value of the labour absorbed in the production of a commodity defines and limits the value of that commodity. Therefore, as the labour absorbed in producing a commodity decreases in value so will that commodity decrease in value. What is meant by the "value of labour?" We mean the amount and value, as measured by the cost, of labour absorbed in producing the labour. And by labour is to be understood, not merely the labour of human beings, but "energy" in its widest sense, that is, foot pounds of work done by whatever agency the work may be effected. Therefore, if the production of a commodity requires the absorption of a certain quantity of "foot pounds" of work, then the less costly the energy is that is used to effect these foot pounds the less costly will the commodity be. And what is meant by "less costly energy" is that less energy has been absorbed in producing *this* energy than would have been absorbed in producing energy of another kind. To reduce this somewhat complicated statement to a concrete example, take the following:

Suppose there is a certain work to be done of a simple kind, such as pumping water, that might be performed either by human, animal or fuel energy. The quantity of work done, the number of foot pounds raised, the amount of energy expended in any case is the same. Let the quantity of work be 13,200 million foot pounds, which would about represent the daily exertion needed to pump the water supply for a town of 200,000 inhabitants * to a height of 135 feet. To use human energy for the performance of this work 6,000 men would be required †; animal energy would require 1,000 horses, and fuel energy would require the combustion of about 26,400 pounds of coal ‡, or roughly 13 (American) tons. By any of these agencies we could do the work. Six thousand men, one thousand horses, or thirteen tons of coal: each of them is the "potential" of the effective energy needed to pump the water to the desired height. But see how different is the value of the different energies, and how much more costly the water would be if pumped by the human energy instead of by the fuel. Each of the six thousand men would have to have been maintained and well nourished from birth up to about 25 years of age in order to be capable of putting forth the exertion required; and this represents a very large amount of exertion and energy expended both by himself and others in the providing of food and shelter during that long period. Each of the one thousand horses would also have to have been reared, fed and tended for seven or eight years from birth before being capable of performing the duty above indicated, and this also implies a large expenditure of energy in order that the horse labour may be available when required. But the fuel energy is obtained merely by the expediture of the energy necessary to extract the coal from the earth. The energy is in the fuel, implanted in it by the sun's rays thousands of years ago, and waiting to be liberated by the process of combustion. It does not require to be built up, as it were, by a slow and careful process, as in the case of men and horses, but whenever we possess the fuel we have a concentrated mass of energy, ready for immediate use, or that can be stored for use at any future period. The cost of this source of energy is much less than the cost of using men or animals as our source. For when we employ men or animals we have not only to give as the remuneration of their labour the cost of the matrix whence their

* 12 million (U. S.) gallons, taking 60 gallons per head as the requisite quantity.

† Taking the effective energy of each man at 2,200,000 foot pounds per diem.

‡ This is assuming the effective energy of the fuel at 5 per cent. of the total energy, the total energy being 10 million ft. lbs. per pound of coal.

energy is derived (*i.e.*, their food), but we also have to remunerate the labour involved in producing the man or the horse in the proper strength and condition to do the work; we have to take account of the energy previously expended in a series of years to produce the energy we are about to use. But when we get our work performed by the energy of fuel the problem is different. We are not required to remunerate the sun for the work he did thousands of years ago in storing up his energy in the fuel for us; we merely have to consider the cost and remuneration (based upon the cost) of the machine through which the fuel energy is turned into work, and the cost of the coal. The *energy* in the fuel we obtained with the coal, and it costs us no greater expenditure of energy to dig coal from the earth than to dig stone.

We may make a rough comparison of these three energies by reducing the matrix whence each energy is derived to the common measure of a money value. For the men and horses the matrix is, of course, their food, for the engine it is the fuel.

The daily food of 6,000 men would cost	$1,800.00
" " 1,000 horses " "	300.00
Thirteen tons of coal " "	52.00

But, as pointed out before, the cost of the food for the men and horses represents only a fraction of what would be the cost of employing these agencies to supply the needed energy. The wages of the men would (in this country at least) be quite four times the cost of their daily food. The cost of the horse labour, including the wages of men required to control and tend the horses would be not less than 3½ times the cost of the horse food. But the cost of the human labour required to superintend and direct the energy of the fuel in the engine would add only about two-thirds to the cost of the coal.* Therefore we may expand the comparison of the cost of labour for doing this pumping work as follows:—

By men, per diem	$7,200.00
By horses " "	1050.00
By coal " "	87.00

This is for labour alone in each case. Nothing is said of the cost of the machinery that would in any event be needed. We can see at a glance now how much more valuable the water

* "A Treatise on Water Supply Engineering," by J. T. Fanning, p. 575, N.Y.; D. Vannostrand.

would be if the pumping were done by human energy instead of fuel energy. Labour is the cause of value, but human labour in such a case as this would make the water so valuable as to put it beyond the reach of most people. It is only when we use the cheap labour of fuel that the cost of this commodity can be brought low enough to be purchaseable by all, even the poorest. If water were pumped for a city by human labour it would be so expensive a luxury that none could afford to use it. Even slave labour, where the slaves were captured in war, would be too costly. It is only since man has discovered the cheap labour of fuel that it has been possible to pump water to supply the needs of large cities.

This view of labour and energy has been dealt with for the purpose of emphasizing the fact that labour, in the science of political economy, should not mean human labour only, but should be understood as the application of energy to matter. Labour is the basis upon which all transactions connected with the accumulation and distribution of wealth rest, and therefore the problems of labour are those which should first be solved. It is the more necessary to draw attention to the view of labour above set forth, because writers on political economy have almost entirely identified labour with human labour, pure and simple; have, therefore, considered the cost of labour as being almost synonymous with the rate of wages; and—recognizing labour as the cause of value—have reached the erroneous conclusion that a lowering of the cost of production of commodities (and therefore a cheapening of commodities) can be brought about only by—or is dependent chiefly upon—a lowering of the rate of wages. That this conclusion is erroneous the plain facts of every day life abundantly tell us. Commodities have wonderfully decreased in price of late years, and yet wages have risen: the explanation being that commodities are now to a great extent produced by a quite different, and much cheaper, kind of labour from that used seventy-five years ago; and have therefore fallen in value (and in price, as being a measure of value) in accordance with the proposition that "The value of the "labour involved in the production of a commodity is a factor in "defining the lower limit of its exchange value."

When Adam Smith wrote his "Wealth of Nations" (in 1776), the power of applying the energy of fuel to the doing of work was unknown. The steam engine had not been born. His attention was of course directed to human labour, but he has a very instructive example of the difference of the cost of conveying goods by land and by water, drawn somewhat on the lines above followed. The passage contains so much that is interesting, and marks so clearly the change that has taken place in the premises of the economic problem, that it is here transcribed :

"As by means of water carriage, a more extensive market is "open to every sort of industry than what land carriage alone "can afford it, so it is upon the sea coast, and along the banks "of navigable rivers that industry of every kind naturally begins "to sub-divide and improve itself, and it is frequently not till "a long time after that, those improvements extend themselves "to the inland parts of the country. A broad wheeled waggon, "attended by two men, and drawn by eight horses, in about six "weeks' time carries and brings back, between London and Edin-"burgh, near four ton weight of goods. In about the same time "a ship, navigated by six or eight men, and sailing between the "ports of London and Leith, frequently carries and brings back "two hundred ton weight of goods. Six or eight men, therefore, "by the help of water carriage, can convey and bring back the "same quantity of goods between London and Edinburgh as fifty "broad-wheeled waggons, attended by a hundred men, and drawn "by four hundred horses. Upon two hundred tons of goods, "therefore, carried by the cheapest land carriage from London "to Edinburgh, there must be charged the maintenance of a "hundred men for three weeks, and both the maintenance and, "what is nearly equal to the maintenance, the wear and tear of "four hundred horses, as well as of fifty great waggons. Whereas "upon the same quantity of goods carried by water, there is to "be charged only the maintenance of six or eight men, and the "wear and tear of a ship of two hundred tons burthen, together "with the value of the superior risk, or the difference of the "insurance between land and water carriage. Were there no "other communication between those two places, therefore, but "by land carriage, as no goods could be transported from the one "to the other, except such whose price was very considerable in "proportion to their weight, they could carry on but a small "part of that commerce which at present subsists between them, "and consequently could give but a small part of that encour-

"agement which they at present mutually afford to each other's "industry. There could be little or no commerce of any kind "between the distant parts of the world. What goods could "bear the expense of land carriage between London and Cal-"cutta? Or if there were any so precious as to be able to sup-"port this expense, with what safety could they be transported "through the territories of so many barbarous nations? Those "two cities, however, at present carry on a very considerable "commerce with each other, and by mutually affording a market, "give a good deal of encouragement to each other's industry."

"Since such, therefore, are the advantages of water carriage, "it is natural that the first improvements of art and industry "should be made where this conveniency opens the whole world "for a market to the produce of every sort of labour, and that "they should always be much later in extending themselves into "the inland parts of the country. The inland parts of the coun-"try can, for a long time, have no other market for the greater "part of their goods, but the country which lies round about "them, and separates them from the sea coast, and the great "navigable rivers. . . . . . In our North American Colo-"nies the plantations have constantly followed either the sea "coast or the banks of the navigable rivers, and have scarce any-"where extended themselves to any considerable distance from "both."[1]

Thus wrote Adam Smith, and the deductions that he drew from the facts presented to him, were undoubtedly sound. At that time man had at his command no other agency for the convey-ance of commodities on land than the energy of men or animals; no other agency for their conveyance by sea than the energy of the wind. These energies, widely unlike though they seem, we now know owe their being to the same parentage, the solar rays. Since Smith's day we have discovered how to use the solar energy through the combustion of fuel. This now conveys our goods for us on land as well as on sea; and does it so cheaply, that the difference in cost between land and water carriage is inconsider-able. The results flowing from this it is almost impossible to enumerate. Every part of the country, no matter how far inland or remote from a navigable river, is now accessible to every

[1] Wealth of Nations." Chapter III. Book 1.

market in the world. Populous towns that in former times of necessity grew only on the sea coast, or on the banks of large rivers, so that by water carriage their wants might be supplied, are now to be found far inland, distant from any waterway, and yet unconscious of any disability as the result of this position; as instance, the large inland cities of the United States. Without fuel labour and the locomotive, it would have been impossible to have peopled the North American Continent as we see it to-day. The conveyance of commodities enormous distances, and in vast quantities on land, is now scarcely more costly than formerly it was by water, and every day the cost is being decreased. If an all rail route were constructed from London to Calcutta, as doubtless will be done some day, goods of many kinds would be brought by it to England, and the cost of bringing them would be no bar to their use. Since Smith's day, all the conditions of the economic problem have been utterly changed; what appeared to him ridiculously impossible, is now a matter of every day occurrence; and all this has been brought about by the introduction of cheap labour; not such labour as he thought of and wrote about, but labour in the wide sense of the application of energy to matter.

But, though it was not to be expected that Adam Smith should be able to forsee the effect of the introduction of a power that was unknown in his day and generation, it is surprising to find that so great and so recent an author as John Stuart Mill, should have dealt with the question of labour as being confined solely and entirely to human labour. His whole theory of production is built upon this view of labour, with the result that his conclusions are erroneous. The writer is well aware, that in confuting the doctrines of a man so eminent as Mr. Mill, he is doing that which will lay him open to the charge of rashness, but the work is undertaken simply from a desire to set forth the truth on a subject that is extremely difficult and complicated.

That Mr. Mill confines himself to the restricted view of labour as stated above, a few extracts from his work will abundantly show. The quotations are from "Principles of Political "Economy," book i., chapter x., "Of the Law of the increase of "Labour." The steps of his argument are as follows:—

"Production is not a fixed, but an increasing thing. * *
" * Nothing in Political Economy can be of more import-

" ance than to ascertain the law of this increase of production; " the conditions to which it is subject; whether it has practically " any limits, and what these are. * * * * * " We have seen that the essential requisites of production are " three,—labour, capital, and natural agents; the term capital, " including all external and physical requisites which are pro- " ducts of labour, the term natural agents all those which are " not. * * * We may say then, without a greater " stretch of language than under the necessary explanations is " permissible, that the requisites of production are labour, capital, " and land. The increase of production, therefore, depends on " the properties of these elements. It is a result of the increase, " either of the elements themselves or of their productiveness. " The law of the increase of production must be a consequence of " the laws of these elements; the limits of the increase of pro- " duction must be the limits, whatever they are, set by those laws. " We proceed to consider the three elements successively, with " reference to this effect; or in other words, the law of the " increase of production, viewed in respect of its dependence, " first on labour, secondly on capital, and lastly on land."

" The increase of labour is the increase of mankind; of popula- " tion."

Mr. Mill then proceeds to discuss all the various circumstances and conditions governing the increase of population; the questions of natural fecundity, of marriage, of the circumstances that encourage or check marriage; of the circumstances that conduce to the production, rearing and maintenance of large or small families, etc. In view of what we have been considering, this view of labour is utterly fallacious, and when extended logically —as it is by Mr. Mill—to the question of wages, cost of production, etc., inevitably leads to false conclusions. The increase of labour is *not* the increase of mankind. It is the increase of the application of the energy of motion to matter, but that energy of motion is not necessarily the energy of human beings. By the discovery of how to convert the energy of heat into work a large addition has been made to the amount of labour done in the world, without any increase in the amount of human labour performed,—nay rather, with a concomitant decrease of human labour. A simple invention that secured some of the heat that at present, with our imperfect engines, escapes and is lost, and converted this heat into work, would be an increase of labour; and this without any increase of human workers, or even of the quantity of fuel consumed. This is a matter of such every day occurrence, that people are prone to miss the true significance of the large, broad facts that lie constantly before them. The work of conveying goods from place to place on land is now carried on to an extent never before seen in the world; the labour expended in this is far greater than ever before; but this labour is mainly fuel energy, not human energy. The engine driver, conductor and brakemen on a freight train, are there merely for the purpose of controlling and managing the energy of the fuel; the actual work—the labour of moving the train—is done by this energy and not by the men who control it, just as the foreman of a gang of labourers merely controls and directs the energy of the labourers; the work is done by them, not by the foreman. Adam Smith, with the data at his command would pronounce it impossible that the common necessaries of life could be transported hundreds of miles overland to supply the wants of a large town population; the cost of the labour involved in the transaction; the expense of the hundreds of men and horses needed for the work; would be so great that the town population could not afford to purchase the necessaries of life, in other words they could not exist; and therefore large towns could only grow near the sea coast or on the banks of—or close to—navigable rivers. But by dispensing with this costly human and animal labour, by substituting for it a much cheaper and far more efficient kind of labour, the work that was in Adam Smith's time utterly impossible, is now done every day all over the world, and is so common place a matter that it scarcely attracts any attention. Cheap labour is essential to cheap production, and cheap production is a pre-requisite to the general dissemination among mankind of those comforts, conveniences and luxuries of human life that are essential to the improvement of the race. But cheap labour is not synonymous with low wages, as economists have taught; nor is it synonymous with greater productiveness on the part of the toiling millions. Low wages produce comfort and luxury for one portion of humanity at the expense of the other, and that other by far the larger portion. The workers on low wages, by reason of their small remuneration, could not enjoy the fruits of their labour. Low wages in the long distant past produced the magnificence and luxury of Egypt, Greece and Rome; but what masses of festering, degraded, enslaved, and crushed humanity underlay that gorgeous exterior! The cheap labour that will make the world better and happier—that will elevate humanity—consists in substituting a totally different kind of energy from human energy for the doing of all the coarse and slavish kind of work in the world; it means making coal work, instead of coolies. Electricity and the steam engine will effect the emancipation of labour.

To say, as Mr. Mill does, "that the increase of labour is the increase of mankind," is to ignore the progress that the world has made in scientific knowledge, and in the practical application of that knowledge, during the present century. To argue that increase of production, resulting from increase of labour, can be brought about only by an increase of human labourers, or an increase in their efficiency, is to lose sight of what men of science have been doing during the past 50 years. Labour has increased and production has increased, not by adding to the laborers, but by dispensing with the labourers; not by rendering their labour more efficient, but by using a different source whence to derive the energy their bodies formerly supplied. To attempt at the present day to furnish all the labour required to carry on the world's daily life, from the energy of men and animals would result in the complete break down of the social machine. Every large town would in a short time be reduced to starvation. The share of the world's labour that is now borne by fuel energy is almost beyond our power to measure; but if any catastrophe were suddenly to deprive us of this power, and we were to be reduced to the energy of men and animals to carry on our work, we would then realize how labour has been silently and steadily increasing during past years independently of human labourers. To continue all the land-carrying trade of the world with men and horses only, to do all our factory work, spinning, weaving, sawing, turning, iron working, etc., with only the energy of man, would be an utter impossibility. Already the world is absolutely dependent upon the energy of fuel to do its work, and to ignore this energy and this labour in any treatise upon Political Economy is certain to land us in false conclusions.

Labour, in the world of work and trade, now means to a very large extent applying the energy of fuel to matter; human labour is being gradually and steadily relegated to the higher work of guiding and controlling fuel energy. As Nasmyth, the inventor of the steam hammer pointed out, "What every mech-"anical workman has to do, and what every boy can do, is not "to work himself, but to superintend the beautiful labour of the "machine."[1] Every year sees a larger amount of the labour of the world performed by fuel energy: a larger amount of this energy substituted for human energy. In the future, to an extent now unforeseen by us, the work of the world will be done by fuel energy, or at least by energy other than human; human energy will be almost solely employed in merely directing and controlling the inanimate energy of fuel or electricity. The cheap labour resulting from this wide application of energy, will not only largely decrease the cost of production of commodities, but will also largely increase the quantity produced. Commodities will therefore be more widely disseminated among mankind; in other words a far larger portion of the human race will enjoy the comforts and luxuries of life then at present enjoy them. What are luxuries now—far beyond the reach of the poorer classes—will then be necessaries at the service of all. The work of the human toilers will be in a far greater degree than at present, merely directive, controlling and managing the inanimate energy that labours. Humanity will be lifted to a higher plane, removed from the brute-like toil that has constituted the daily life of millions in past ages.

The distinct tendency of modern times, since the introduction of fuel energy, is towards a rise of wages and a fall in the price of commodities. Production in these days is a very inexact index of the quantity of human labour employed in any trade. It is first necessary to know what sort of energy is used in turning out the commodities. Increase of production is now most frequently accompanied by a large reduction of human labour employed. More "foot pounds" of work are of course done in turning out the greater production, but these foot pounds are obtained from coal, and not from labourers. What is necessary to low cost of production is cheap labour: we have obtained cheap labour in fuel energy—not in low wages. The cheap fuel labour of these modern days is coincident with higher wages,

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[1] Nasmyth's evidence before the Trades-Union Commission, quoted by Karl Marx, "Capital" Vol. II: Chap. XV., p. 268.

and greater comfort among the labouring classes than has ever before been seen in the world.

Mr. David A. Wells, in his book entitled "Recent Economic Changes"[1] — a book that is full of most interesting reading to engineers—has collected a great many facts proving the truth of the foregoing statements. Even within the last fifteen or twenty years, to go no further back, great changes have been effected in the substitution of fuel energy for human energy. During so brief and so recent a period as this, fuel energy has (in the United States) displaced human energy to the extent of forty-five per cent in the making of agricultural implements; fifty per cent in the making of shoes; about forty-five per cent in the making of carriages, and thirty per cent in the making of machines and machinery. In the cotton mills of Rhode Island, in 1886 as compared with 1840, eighty per cent of human energy has been displaced by fuel energy, calculating from the production,[2] while wages have increased sixty per cent. Perhaps the most striking example of the change that has taken place, and is still taking place, is to be found in the manufacture of pins. Adam Smith, in the "Wealth of Nations,"[3] writing in 1776, shows that then, as the result of the division of labour, ten men could in a day turn out 48,000 pins; and Smith points to this as a wonderful result from a very simple cause; as no doubt it is. Mr. Wells prints this passage from the "Wealth of Nations" in a parallel column with an extract from a report to the United States Government, made in 1888, on Technical Education;[4] which report shows that now, in a factory where seventy pin making machines were at work, tended by only five men in all, 7,500,000 pins are turned out per diem. To do this amount of work in Smith's day the labour of one hundred and fifty-six men would have been required; now only five, and these five merely for the purpose of guiding and controlling the fuel energy. In this instance practically the whole labour has been displaced by fuel labour. We may assume that the same amount of "work" is done, of "foot pounds" absorbed, in making 7,500,000 pins to-day as in Smith's day; but there is this difference, that now we ob-

1 New York: D. Appleton & Co., 1890.

2. "Recent Economic Changes," p. 28, note. The above calculations have been made from data furnished in Mr. Wells' note.

3 Ibid: p. 50. "Wealth of Nations." Book I. Chapter I.

4 Recent Economic Changes," p. 59. The report is by U. S. Consul Schoenhoff.

tain our foot pounds from the energy of heat evolved in the combustion of fuel, whereas in Smith's time it was obtained from the food comsumed by one hundred and fifty-six men. Numerous other instances, all shewing the same tendency to substitute fuel energy for human energy in the doing of work, could be furnished; and the reason for this substitution, and the effect of it, is always the same, viz., to reduce the cost of production of commodities.

Perhaps it may be objected that such displacement of human labour by fuel labour is not beneficial to the human race; that the workers thus thrown out of employment are necessarily placed in hard straits. But this objection, though at first sight reasonable, is not valid. Though the workers are displaced in particular handicrafts and occupations, yet the great increase of production caused by the employment of fuel labour in such trades, causes a vast development of employment for human labour in related occupations and trades. The introduction of fuel labour has been of great benefit to the human race, as is shown by the unparalleled increase of population that has taken place during the present century since the introduction of fuel labour. Population will increase just as fast as, and no faster than, the means of subsistence increase. Now the effect of the introduction of fuel labour has been largely to reduce the price of commodities, and to increase wages; in other words, the means of subsistence have been brought within the reach of a much larger number of people than formerly, and have been supplied more amply and fully. Therefore, population should increase. That it has increased wonderfully, statistics amply prove. In the 300 years from 1300 to 1600, the population of England and Wales did not double (2,500,000 to 4,812,000); in the 200 years from 1600 to 1800, it did not double (4,812,000 to 9,335,000); but between 1801 and 1891, it has increased over three times (9,335,000 to 29,001,000), besides the very large numbers that have been thrown off by emigration. The nineteenth century has been much more favourable to the expansion of the human race than any preceding century, because the introduction of fuel labour has rendered the means of subsistence so much more easily attained.

To the Engineer—the Civil or Mechanical Engineer—the view of labour set forth in the preceding pages can hardly fail to be of interest. Our work consists mainly of devising means for substituting other energy for human, in the doing of all kinds of work, and in preparing ways for the more complete attainment of this. All kinds of steam-driven, hydraulic or electrical machinery, have this object in view; so too, has the construction of all railways, canals, electrical railways, cable car systems, etc. The root idea is always to economise energy, to substitute a less costly for a more costly energy, to make the energy we are at present using do more work if possible than it formerly did. The effect of this is to reduce the cost of producing those commodities that are necessary for the sustaining and developing of human life, and to supply those commodities in greater profusion. Our work has been so thoroughly done,—triple expansion marine engines have so reduced the cost of conveying commodities, and cheap energy the cost of producing them—that politicians have felt themselves called upon to interfere, and by taxation to nullify the results that our labours would otherwise produce. "Protection," as it is called, counteracts what science achieves. But the discussion of this would lead to matters foreign to a society of engineers; and, therefore, having reached this point, this already lengthy paper may fittingly be brought to a conclusion.

DISCUSSION.

Mr. W. J. Sproule.

Mr. W. J. Sproule said it is an agreeable task to discuss Mr. Cuningham's paper, dealing as it does with the relation that human exertions and the other forces of nature bear to one another in supplying the requirements of humanity and ministering to its highest advancement. There is no doubt that this is a subject intimately related to the higher phase of the profession of Civil Engineering. Besides drawing our attention to many important scientific truths, this very interesting paper gives us striking examples of the great achievment of man in transforming the latent forces of nature into active powers. The author deserves our thanks for undertaking a subject so complicated, and for devoting to it the labour that is indicated by its careful and comprehensive treatment, and deserves also our admiration for attacking the doctrines and conclusions of such a comprehensive and incisive investigator as John Stuart Mill. The weight of high authorities have, at least, sometimes in the past sustained, for a period, mistaken theories, as for instance the corpuscular theory of light, subscribed to by the great Newton, for a time bore down the Wane theory which is now accepted in preference by the scientific world. To question established authorities shows a worthy self-reliance and originality that are likely to be beneficial, either in pointing out errors or in establishing more firmly the doctrine that is attacked, should the questioner be unable to support his contention.

But in the present instance, the speaker fails to see that the author of this paper has shown Mr. Mill's conclusions to be erroneous. To do this it would be necessary to critically examine a large portion, if not all, of Book I of "Principles of Political Economy," which treats of Production. To deal with a short extract from Book I, chap. x, without carefully considering what Mr. Mill elsewhere defines as meant by labour, capital and natural agents, is misleading. Mr. Mill's definition of "labour," or rather the explanation of what is included by the term labour as he uses it, must be gathered from several chapters, but particularly from chapters i and ii of Book I of the "Principles of Political Economy." These of course are too long to quote, but a careful perusal of them will show that the application of the word is very comprehensive, although it is not given any new meaning or arbitrary definition. It is used as including every physical or mental action that a human being is capable of, in so far as they relate to production. In these chapters which critically and at great length investigate the relation that human exertions or influences, be they physical or mental, bear to production, it will be found that there is the fullest appreciation of the work done by the energy that is found stored in inanimate nature, such as the energy derived from the combustion of coal, or the work done by the proper combination and direction of other forces in nature.

A few extracts may be permitted simply as examples of how Mr. Mill estimates the several factors in production. Book I, chapter i, "Principles of Political Economy," sections 1 and 2:—"In this case, natural agents, the winds or the gravitation of the water are made to do a portion of the work previously done by labour. Cases like this, in which a certain amount of labour has been dispensed with, its work being devolved upon some natural agent, are apt to suggest an erroneous notion of the comparative functions of labour and natural powers; as if the co-operation of these powers with human industry were limited to the cases in which they are made to perform what would otherwise be done by labour. . . . This is an illusion. . . . If we examine any other case of what is called the action of man upon nature, we shall find in like manner that the powers of nature or in other words the properties of matter, do all the work, when once objects are put into the right position. This one operation of putting things into fit places for being acted upon by their own internal forces, and by those residing in other natural objects, is all that man does or can do with matter. . . . He has no other means of acting upon matter than by moving it. Motion and resistance to motion are the only things that his muscles are constructed for. . . . But this is enough to have given all the command which man has acquired over natural forces, immeasurably more powerful than themselves, a command which, great as it is already, is without doubt destined to become indefinitely greater. He exerts this power either by availing himself of natural forces in existence, or by arranging objects in those mixtures and combinations by which natural forces are generated, as when by putting a lighted match to fuel, and water into a boiler over it, he generates the expansive form of steam, a power which has been so largely available for the attainment of human purposes."

"Labour then in the physical world is always and solely employed in putting objects in motion, the properties of matter, the laws of nature do the rest. . . . But the muscular action necessary for this is not constantly renewed, but performed once for all, and there is on the whole a great economy of labour."

Mr. Mill defines the other two requisits of production, capital and labour thus:—"The term capital including all external and physical requisites which are products of labour, the term natural agents those which are not."

It will now be seen that Mr. Mill's doctrine of production may be briefly stated as follows:—The requisites of production are labour, capital and natural agents. Labour means human labour in every form, and it may increase by the increase of human means. Capital, which is the product of labour only, and hence can increase only through labour. Natural agents meaning physical requisites that are not the product of labour, and these do not increase in the sense in which we are considering increase; for example, coal does not increase; the sun's rays do not increase, and so of the other natural agents, they are constant.

A new invention may economize labour and by its action on natural agents may greatly increase production, but it is none the less labour as an invention. When once invented it in itself becomes capital—a product of labour—and remains constant until improved by human labour. Suppose the invention to be the steam engine. It aids production by being substituted for human labour and freeing that labour to be turned to other useful purposes, and by making achievements possible that before were not, but itself is nevertheless the product of human brain and hands, and must be guided by the same. And as soon as the first engine is working, its aid to production is constant or is at its limit: an increase is effected by making a second engine which must be made with human hands and so on, indefinitely; each increment or advance in the means of production is the result of human labour.

The speaker, therefore, holds that Mr. Mill is correct in saying that the increase of labour is the increase of mankind, and respectfully submits that Mr. Cuningham is mistaken when he says the increase of labour is *not* the increase of mankind.

Mr. Roswell Fisher said it would appear that Mr. Cuningham in his paper on "Energy and Labour," supposes that by extending the definition of labour to the liberation or utilization of the energy of natural objects some new understanding of economics is gained. The speaker hardly sees, however that he has made this out or has helped us to a clearer understanding of economic phenomena. The economists have defined labour to be human energy consciously directed to economize production. Human energy expended in games and other non-productive directions is hardly labour. This is a simple and easily intelligible definition, and the speaker fails to see that anything is gained by extending it to include the natural objects to which labour must always be applied to sum their energy into economic production. It is surely simpler and clearer to talk of labour burning coal for the production of steam than to assert that steam is the result of coal labour applied in a certain way. By whom applied? Always by human labour. Mr. Roswell Fisher.

Therefore it still remains true according to the simple definition of the economists that production calls for two powers labour, that is human energy applied to natural objects, that is utilizing the energy latent or active in nature. Thus a call for labour is a call for men, or at least for the exertion of human energy. But, as Mr. Cuningham has so well shown, the more human energy can utilize in the production of wealth the latent or active energies of nature, the greater is the wealth produced by a given number of men. The speaker does not say the greater the product of the expenditure of a given amount of human energy or of labour, because the labour of a Stephenson in inventing the locomotive, measured by its results is equal to the labour of millions of men merely using their muscles, and consequently it may in a sense be quite true to say that a given product always calls for an equal expenditure of labour, and consequently a call for more product always means a call for more labour, but whether the call for more labour means a call for more men or greater population, depends upon whether this added labour is purely muscular or chiefly, or altogether intellectual energy applied to natural objects in such a manner as to produce the greater result demanded.

The greater proportionate output per man to-day in comparison with bygone times is then due altogether to the advance in intellectual labour applied to economic production, and the more man can substitute this intellectual labour for mere muscular labour the greater will be the output per head, and the greater the wealth of the society so advancing. All this is practically apprehended by those employed in the production of wealth, but how this greater and increasing output per head is to be more equitably, or perhaps it may be more correct to say, more evenly distributed among those who aid in the output is the coming question, upon which, however, the paper under discussion calls for no answer.

Mr. H. Irwin. Mr. H. Irwin said Mr. Cuningham deserves the thanks of the Society for the time and trouble he has devoted to the investigation of the subject of his paper.

The speaker had hoped, however, that instead of dealing with the cost of work performed respectively by men, by horses, and with the aid of coal, Mr. Cuningham would have given us some comparison of the cost of work done through the agency of steam, compressed air and electricity; since every one now knows well enough the respective cost of labour of men and horses as compared with that performed with the aid of steam.

As the paper before us does not deal with the comparative merits of wire rope, compressed air, water or electricity, the speaker thinks that it may add to the practical side of the question to quote some figures from Mr. Gilbert Knapp's recent work on the electric transmission of energy. Mr. Knapp finds the commercial efficiency of the four agencies last mentioned to compare as shown in the following table:—

Distance of transmission.	Electric.	Hydraulic.	Pneumatic.	Wire Rope.
100 meters	78	50	55	96
500 "	77	50	55	93
1,000 "	75	50	55	90
5,000 "	68	40	50	60
10,000 "	58	35	50	36
20,000 "	38	20	40	13

Thus for over a distance of 5,000 meters, electric transmission is the cheapest, but under 5,000 meters wire rope is the most economical means of transmitting energy.

Mr. Knapp concludes that for all powers it pays to transmit *cheap* water power by wire rope for distances of less than a mile, and by electricity for distances of over a mile.

Also that it pays to transmit *cheap* steam power if the energy at the receiving station be not over ten horse power, and that under these latter conditions wire rope should be used for distances from one mile to three miles.

Beyond the power and distances stated he finds that it is cheaper to use local steam or gas engines. The saving that can be effected by using natural agencies in the proper way is well shown by the fact that it takes 312 cubic feet of gas to give 1,000 candles per hour when the gas is used with an ordinary burner, while 22 cubic feet of gas, used in a gas engine, will run a 1,000 candle arc light for an hour. The interest on the cost of the gas engine and the dynamo would of course make the comparison less favorable to electricity.

Since the figures above refer to transmission of energy from one place to another by direct communication it may be also of interest to give the results of the working of the Birmingham Central Tramways Co. for last year.

This company uses steam, electric storage batteries, horses and cables as means of propelling its cars, and the comparison of the respective cost and profits, under the various systems, is all the more to be depended on since it is made on cars owned by one company and run in one town, under somewhat similar circumstances. The costs and profits are given in the table below:

BIRMINGHAM CENTRAL TRAMWAYS CO.'S OPERATIONS FOR YEAR 1890.

Motive Power.	Average cost in cents per mile run.	Net profit per cent.
Steam..........................	22	$9\frac{3}{4}$
Storage Batteries...............	$19\frac{1}{2}$	$10\frac{1}{4}$
Horses	$19\frac{1}{4}$	$1\frac{1}{4}$
Cable (6 miles).................	12	$12\frac{7}{8}$

The remarks made as to the present high cost of building operations for want of capital invested in plant are only applicable to the case of houses, stores, factories and similar buildings.

There is, however, a considerable decrease in the cost of building such structures as piers of bridges, also in the time necessary to construct them. This decrease is largely due to the investment of capital by contractors in better plant and appliances, but a fair share of the decrease must be given to greater experience and better methods of executing work, and to the decided advance in the scientific knowledge of engineers.

Thursday, 19th November.

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

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

Members.

John T. Nicolson. William George Pinder.

Associate Members.

John Benjamin Bright. Edward Chas. Steele.
Chas. Anthony Stoess.

Associates.

William Gibson. Joseph Walter McFarland.

Students.

William Bruce Almon.
William Francis Campbell.
Henry Augustus Jônes.
Guy Stanhope Kinnear.
George Gildersleeve Rose.
John William Martin Wallace.
Louis Whitman.

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

Frederick Allison Bowman, Robert Todd Locke.
Robert Edward Palmer.

The discussion on Mr. Cuningham's paper on "Energy and Labour" occupied the evening.

Thursday, 3rd December.

JOHN KENNEDY, Vice-President, in the Chair.

Paper No. 57.

SOME OBSERVATIONS ON THE EXPANSION AND CONTRACTION OF ICE ON CANADIAN WATERS.

By JOHN H. DUMBLE.

The movement of field ice on Canadian waters, by expansion and contraction, from change of temperature, is a matter of interest to the Civil Engineer, and one that he cannot safely disregard, when called upon to erect structures within its influence.

As Resident Engineer of the Cobourg and Peterborough Railway in 1857, the author had a very painful experience of the force of ice on the Railway Bridge across Rice Lake. He subsequently experimented and practically tested the susceptibility to change of temperature, by expansion and contraction, of a floating piece of ice, on a pond near Cobourg, the result of which he will hereafter mention. The better way to illustrate the power of ice in motion will be to briefly describe the Rice Lake Railway Bridge.

The lake is a sheet of water over twenty miles in length and of an average width of two miles and one-half. The bridge crossed it at its widest part, and was nearly three miles in length. The depth of the water to the clay bottom (except in the channel) was less than twenty feet. A small island was crossed by the bridge within three-quarters of a mile of the south shore. The bridge, with the exception of half a mile of truss in the centre, was built on oak piles, bents were fourteen feet apart, with very heavy caps and stringers. The truss-bridge was very strong, with eighty feet spans resting on stout timber piers filled with stone. The whole structure was of the strongest and most substantial character of its kind, and yet this bridge was wrecked in a few minutes, in the early part of December, by an ice shove, and, when the ice was comparatively thin. The pile work south of the island was inclined like a pack of cards to nearly an angle of forty-five degrees. An engine was caught on the bridge during the shove, much to the alarm and consternation of the driver. Subsequent shoves from all directions seriously affected the bridge, and twisted it into many curves and kinks. and, it was only saved from complete destruction by isolating it from the main field by cut-channels cut in the ice and constantly kept open on each side of the bridge for its entire length. The piers under the truss-bridge, including the larger ones under the swing, were toppled over, and he had to protect them by building larger piers around them, with a covering of timber at an incline on each side, like the roof of a cottage, against which the ice fractured and spent itself.

The railway was subsequently abandoned, owing to the neglect and destruction of the bridge, and a million of dollars spent in its construction was lost, not to speak of the disappointment to the town of Cobourg and vicinity. So much for ignorance of one of the forces of nature.

And now as to the ice itself. The formation of ice, as is well known, takes place at a certain fixed temperature (32° Fah.), and which remains constant during the process of solidification. A higher temperature causes ice to melt. Ice must, therefore, at formation, be at its greatest or maximum dimensions, and cover its largest area. The first movement of ice, after formation must necessarily be shrinkage or contraction. There is, however, a peculiarity about the contraction of ice which perplexed the author very much for some time, as he could not see any tangible evidence of its contraction.

The ice field does not draw away from the shore during shrinkage, as might be expected, and leave open water to the extent of its contraction.

The expansion of a large field of ice is manifested by its encroachment on the shores of the lake. It fractures at the ripple mark and shoves on to the shore, and when the line of fracture occurs at a distance from the shore, it is evidenced by the appearance of a vertical ridge formed by the fractured ice. Such being the case it would naturally be expected that the ice field, during contraction, would recede from the fracture, whether on shore, or at a distance from it, or that fissures and cracks would be easily observed somewhere in the ice field of widths somewhat commensurate to previous shoves. Such evidence of the contraction of ice does rarely if ever exist. That contraction causes fissures however, is true, but so exceedingly small that they easily escape detection. It was sometime before he discovered this. As he crossed the lake one morning, after a cold snap, a very slight covering of snow lay on the ice, and showing innumerable cracks running in every direction, filled with water, and of widths from one-eighth of an inch to an inch in width. He counted over one hundred in the distance of a mile. The aggregate width of these fissures would fully equal the width of the greatest shove. This manner of contraction is, he thinks, readily accounted for. If the ice field were equally thick, dense and bare, which it is not, it would contract uniformly towards its centre or centres, and draw away from the shore by the extent of its contraction.

But ice forms in waters with currents, islands, headlands, and perhaps during snow storms. It is not, therefore, equally thick and pure and dense, and has many centres, and in shrinking to them pulls and opens fissures in all directions. These fissures fill with water and freeze, the ice field occupying its original area, but in a state of contraction. When a change to higher temperature occurs or the sun shines, expansion takes place and from a centre towards its circumference, the ice is shoved towards the shore to an extent equal to the width of the fissures.

These shoves sometimes exceed four or five feet in width, and occur on the shores, in the channels, or from headland to headland, it being easier to fracture on the chord than the arc of the bay, and will always fracture on the line of least resistance.

It will be thus seen that the capacity of ice to expand and shove, and shove again, is only limited by its capacity to contract and recuperate. The repeated shoves have lodged ice on top of a high embankment over 30 feet in width and has lifted large boulders and pressed them against the abutments of the bridge. A very slight covering of snow acting as a non-conductor, prevents all movement of the ice from change of temperature, hence all damage from shoves occurs early in the season before the snow falls. The effects which the author has endeavoured to describe occur on all Canadian waters in cold climates, but to some extent are governed by the size of the field ice.

Being much interested in the movements of ice from his experience at Rice Lake, he endeavoured one winter after his connection with the Cobourg Railway had ceased, to practically test by experiment the nature of ice movement. He regrets that he had not the time or the skill to follow up and solve the question more satisfactorily. The result of the experiment, however, is interesting and somewhat instructive. He built a rough shed on the ice of a mill pond in Cobourg, and cut out the ice 110 feet long by 10 feet in width and allowed new ice to form. When it became an inch and a half thick he isolated a strip of ice 103 x 7 and kept it floating with an open channel eighteen inches in width all around it. He then inserted a small block of pine within 18 inches of each end which became frozen in and firmly embedded. To one of these blocks I attached and nailed the end of a seasoned pine rod three inches in width and 100 feet in length, and one and a quarter inch thick and firmly connected at the joints. To the other block was firmly attached a circular target with a scale, through which the graduated end of a rod moved freely. It was an American engineers' levelling rod and read accurately to the 1,000 part of a foot. Small rollers underneath caused it to move freely.

The floating piece of ice was kept isolated from the main field day and night with great care and precaution taken to ensure accuracy of result. He may add that he visited the rod and registered it every few hours, day and night, during part of January and the whole of February, (he was young and enthusiastic then,) and the annexed tables show the hour, day, temperature, and the reading of the rod as taken and entered at the time. The accompanying diagram shows the movement of ice corresponding to the readings in the tables. The datum is the time, the upper profile or section shows the lineal contraction and expansion of a piece of ice 100 feet in length as read on the rod (to which should be added the expansion and contraction of the rod itself to give the actual movement). The section beneath represents the atmospheric changes as indicated by the thermometer (Fah.)

The lower line exhibits the thickness of ice on the different days and times during the experiment. It will be observed on referring to the ice section that it exhibited no movement until it attained a thickness of three inches, notwithstanding various changes in temperature.

From that time, however, until it became five inches thick, it appeared most sensitive and responded quickly to every change of temperature, but its extent of expansion and contraction was much less than when it attained a greater thickness. Over five inches in thickness the ice was ever uniform and regular in its movement, and shows a contraction and expansion of .026 for 100-foot rod, over 32 degrees or from zero to 32°. He presumes his reading of the thermometer at 34° should have been 32°, as it hung a little above the ice instead of being in it. This movement would indicate some sixteen inches to the mile for that range of temperature, irrespective of the expansion of the rod. It will be observed from the tables that the contraction of the ice at zero on the 1st February was only .011 from formation at 32°. The same influence (the underlying water) which prevents movement up to three inches in thickness doubtless, continued to a certain extent as the ice had barely attained a thickness of five inches on the 1st February. The ice expanded to its original dimensions at 32° on the 8th and 9th February, and from that time forward was very uniform in movement, notwithstanding that it was subject to a high and wasting temperature at times, and even to the rays of a mid-day sun at 45° which he allowed to act upon it for several hours.

It has been observed on Rice Lake that thick ice did not move with the same alacrity as thin ice. It is well understood that the most violent shoves occur when the ice is between five and twelve inches in thickness. The author's experiment confirmed this, and it appeared that the rapidity of ice movement is inversely as its thickness. This lagging behind of ice and not responding readily to rapid changes of temperature is well shown on the diagram of observations — 55, 62, 65, 73, 84, 92, 96, 100, 120 and 158. The temperature during his experiment did not fall below minus 4°, but uniformity of movement throughout was ever observed.

From these brief observations and somewhat crude experiment may we not summarize as follows:—

That ice, like all other bodies, is subject to expand and contract by change of temperature.

That ice forming at a temperature of 32° is at its greatest or maximum dimensions.

Its first movement must, therefore, be contraction. That the underlying water prevents movement in ice under three inches in thickness from change of temperature.

That up to five inches in thickness the ice is affected from the same cause, and, although its movement is uniform, its capacity to contract is reduced from what it afterwards attains.

The rapidity of ice movement is inversely as its thickness.

The capacity of ice to expand and shove towards the shores and to repeat the operation is due to the peculiar manner in which it contracts.

A slight covering of snow (as non-conductor) prevents all ice movement.

That the ice field expands from a centre or centres and fractures on the line of least resistance.

That the piers of Railway Bridges or other structures crossing extensive waters, if not constructed in a *massive manner*, will need protection from the ice field, which is most effectually done by isolation and cut side channels, otherwise an inclined surface must be presented to the ice, on which it may run up, fracture, and spend its force and shield the piers.

CONTRACTION AND EXPANSION OF ICE.

Table of Observations (on 100 feet of Ice), Jan. and Feb., 1860.

No.	Date.		Hour.		Tempra-ture.	Thickness Ice.	Graduated Rod.	Remarks.
1	Jan.	29	1	p.m.	32°	3 "	·011	Wind, N. W.
2		29	6	"	34	3	·012	W.
3		29	10	"	34	3	·012	W.
4		30	9	a.m.	27	3½	·009	N. W.
5		30	12	"	26	3½	·008	W., clear.
6		30	2	p.m.	28	3½	·009	W.
7		30	3	"	31	3½	·010	W.
8		30	5	"	33	3½	·010	W.
9		30	6	"	34	3½	·011	W., strong wind.
10		31	12	"	22	3½	·007	N.
11		31	12.30	"	19	3½	·006	N.
12		31	2	"	17	3½	·006	N., blowing a gale.
13		31	4	"	14	3½	·005	N. E., snowing.
14		31	9	a.m.	9	4	·003	" "
15		31	12	"	9	4	·003	N. E., light wind.
16		31	2	p.m.	9	4	·003	N. E.
17		31	4	"	8	4	·003	N. E.
18		31	5	"	6	4	·002	N.
19		31	7.30	"	6	4	·001	E., clear.
20	Feb.	1	1	a.m.	Zero.	5	·000	N.
21		1	6	"	4°	5	000	N. E.
22		1	9	"	10	5	·001	N. E.
23		1	11	"	14	5	·005	E.

5

No.	Date.		Hour.		Temperature.	Thickness Ice.	Graduated Rod.	Remarks.
24	Feb.	1	3	p.m.	16	5	·006	E.
25		1	5	"	13	5	·005	E.
26		1	11	"	12	5	·006	E.
27		2	4	a.m.	10	5	·003	N.
28		2	9	"	14	5	·004	N. E.
29		2	10	"	16	5	·004	N. E.
30		2	10.30	"	18	5½	·005	E.
31		2	1.30	"	23	5½	·007	E.
32		2	3	p.m.	22	5½	·007	W.
33		2	5	"	19	5½	·006	N.
34		2	9.30	"	16	5½	·004	Calm.
35		2	11	"	12	5½	·002	"
36		3	3.30	a.m.	18	6	·004	"
37		3	8	"	18	6	·004	....
38		3	1	p.m.	22	6	·006	S.
39		3	4	"	20	6	·005	S.
40		4	12	"	24	6	·007	W.
41		4	1	a.m.	22	6	·007	S. E., snowing.
42		4	7	"	22	6	·007	....
43		4	11	"	26	6	·008	Calm.
44		4	12	"	28	6	·009	....
45		4	1	p.m.	30	6	·010	Ther. 60° in sun.
46		4	5	"	30	6	·010	....
47		4	6	"	28	6	·010	....
48		4	7	"	24	6	·008	S.
49		4	9	"	26	6	·008	S.
50		5	2	a.m.	26½	6	·008	E.
51		5	7	"	24	7	·007	S., snowing.
52		5	10	"	32	7	·011	S. E.
53		5	1	p.m.	34	7	·012	S E.
54		5	5	"	34	7	·012	S. E.
55		5	7	"	33	7	·011	....
56		5	8	"	36	7	·011	Water on ice.
57		6	2	a.m.	37	7	·011	W.
58		6	7	"	33	7	·011	W.
59		6	11	"	32	7	·011	W.
60		6	3	p.m.	30	7	·011	N. W.
61		6	5	"	28	7	·010	N. W.
62		6	9	"	24	7	·007	S. W.
63		7	12	"	28	7	·007	S. W.
64		7	2	a.m.	24	7	·007	S. W.
65		7	4	"	22	7	·005	....
66		7	8	"	28	7	·005	S. W.
67		7	9	"	32	7	·009	S. W.
68		7	12	"	32	7	·011	S. W.
69		7	1	p.m.	34	7	·012	S. W.
70		7	3	"	35	7	·012	S. W.
71		7	5	"	36	7	·013	Ice dry.
72		7	9	"	28	7	·010	Calm.
73		8	12	"	28	7	·009	S. W.
74		8	9	a.m.	32	7	·011	Ice dry.

No.	Date.	Hour.	Temperature.	Thickness Ice.	Graduated Rod.	Remarks.
75	Feb. 8	11 a.m.	38	7	·012	Ice wet.
76	8	11.30 "	39	7	·012	S. W., ice melting.
77	8	12 "	37	7	·012	S. W.
78	8	3 p.m.	34	7	·012	W.
79	8	4 "	34	7	·012	W.
80	8	7 "	32	7	·012	....
81	8	8 "	32	7	·012	N. W.
82	8	9 "	17	7	·006	N. W., surface water freezing.
83	8	11 "	13	7	·015	N. W.
84	9	12 "	8	7	·004	....
85	9	3 a.m.	6	7	—·009	Blowing a gale.
86	9	6 "	Zero.	8	—·014	N.
87	9	8 a.m.	4°	8	—·011	N.
88	9	9.30 "	6	8	—·010	N.
89	9	11 "	9	8	—·009	N.
90	9	12 "	10	8	—·006	....
91	9	2 p.m.	12	8	—·006	N.
92	9	9 "	7	8	—·005	N.
93	10	1 a.m.	10	8	—·005	Calm.
94	10	5 "	10	8	—·004	E.
95	10	8 p.m.	11	8	—·004	E.
96	11	10 a.m	12	8	—·004	E.
97	11	1 p.m.	20	8	+·001	....
98	11	3 "	24	8	+·005	N.
99	11	8 "	17	8	+·002	N.
100	11	10 "	16	8	+·001	N.
101	12	12 "	13	8	—·002	N.
102	12	2 a.m.	10	8	—·004	N.
103	12	6 "	9	9	—·008	N.
104	12	9 "	13	9	—·006	N.
105	12	11 "	19	9	—·001	N.
106	12	1 p.m.	23	9	+·003	N.
107	12	3 "	24	9	+·005	W.
108	12	6 "	24	9	+·006	S. W.
109	13	8 a.m.	26	9	+·005	E.
110	13	12 "	34	9	+·012	W.
111	13	2 p.m.	34	9	+·012	E.
112	13	8 "	30	9	+·012	....
113	14	4 a.m.	26	9	+·008	....
114	14	8 "	26	9	+·006	N. E.
115	14	12 "	26	9	+·006	N. E.
116	14	1 p.m.	27	9	+·006	N. E.
117	14	3.30 "	28	9	+·008	N. E.
118	14	10 "	15	9	—·002	Clear night.
119	15	4 a.m.	12	9	—·005	N. W.
120	15	12 "	20	9	—·000	N. W.
121	15	2 p.m.	20	9	+·001	N. W.
122	15	5 "	22	9	+·003	S. E.
123	15	10 "	29	9	+·009	S. E.
124	16	9 a.m.	18	9	+·002	S. E.

No.	Date.	Hour.		Tempera-ture.	Thickness Ice.	Graduated Rod.	Remarks.
125	16	11	a.m.	18	10	+ ·001	N. E.
126	16	2	p.m.	18	10	+ ·001	N. E.
127	16	3	"	16	10	— ·000	N. W.
128	16	6	"	14	10	— ·002	W.
129	16	9	"	8	10	— ·008	W.
130	17	6	a.m.	8	10	— ·014	....
131	17	8	"	— 4	10	— ·017	N.
132	17	5	p.m.	+14	10	— ·004	N. E.
133	17	8	"	6	10	— ·009	N. E.
134	17	10	"	4	11	— ·011	N E.
135	18	8	a.m.	12	11	— ·009	....
136	18	10	"	12	11	— ·009	Snow drifting through roof.
137	18	12	"	18	11	— ·006	N. E.
138	18	2	p.m.	18	11	— ·004	N. E.
139	18	6	"	16	11	— ·001	N. E.
140	19	9	a.m.	10	11	— ·008	N. E.
141	19	5	p.m.	16	11	— ·003	N E.
142	19	9.30	"	10	11	— ·006	E.
143	20	8	a.m.	26	11	+ ·003	E.
144	20	9.30	"	27	11	+ ·005	W., moves slowly.
145	20	12.30	"	30	11	+ ·007	E.
146	20	2 30	p.m.	32	11	+ ·010	W.
147	20	6	"	34	11	+ ·012	W.
148	21	8	a.m.	20	12	+ ·001	E.
149	21	12	"	34	12	+ ·012	E.
150	21	2	p.m.	38	12	+ ·012	E.
151	21	4	"	37	12	+ ·014	E.
152	22	12	"	37	12	+ ·012	E.
153	22	12	"	32	12	+ ·011	E.
154	24	12	"	30	12	+ ·010	E.
155	25	12	"	24	12	— ·000	E.
156	25	5	"	24	12	— ·000	E.
157	25	10	"	17	12	— ·000	E.
158	26	8	a.m.	12	12	— ·007	N. E.
159	26	9.30	"	22	12	— ·006	N. E.
160	26	5	p.m.	30	12	+ ·007	....
161	27	8	a.m.	34	12	+ ·012	N. E.
162	27	12	"	45	12	+ ·012	S. W., exposed ice to sun.
163	28	12	"	34	12	+ ·012	S. W.

DISCUSSION.

Mr. E. P. Hannaford said—Mr. Dumble has given the Society much interesting and valuable information. Although Canadians experience the effects of ice, yet there is much to be learned in overcoming its power on engineering works. As an instance of this it occurs to the speaker in connection with this paper to examine the effects of ice upon a structure recently built in Canada, viz: the Bay of Quinte Bridge at Belleville, Ontario, Mr. C. H. Keefer, M. Can. Soc. C. E., Engineer. Mr. E. P. Hannaford.

This bridge was built for ordinary highway traffic to connect the city of Belleville with Prince Edward county, and spans the bay where it narrows to about one-half mile in width. It was opened for traffic in the spring of 1891. Cost about $120,000.00.

The Bay of Quinte at the site of the bridge has a straight reach westward to Trenton of twelve miles and eastward to Deseronto of about eighteen miles, the average breadth of the Bay being from one and one-half to two miles.

The waterway of the bridge between abutments is about 1,900 feet. There are 17 piers making 18 spans with a swing bridge near the south end. The superstructure is a through truss of steel, the floor being about 12 feet above the water. The depth of water is given as 20 feet from the north abutment to pier 14, from thence to the south abutment it increases to 32 feet.

Piers 1 to 14 inclusive are on pile foundations, the remaining 3 piers being on crib foundations with stone filling.

Piers 1 to 14 consist of a cluster of piles (30 to each pier). These are cut off at 2 to 3 feet below water and capped with timber, upon which is constructed rockfaced ashlar masonry, without ice breakers. The ends of the piers being round and almost vertical. The piles are encased with a margin of timber, forming a box, which is filled with stone and rests upon the bottom of the Bay. The three piers on the south side have similar masonry to the other piers but are built upon the crib work which forms the foundation of each pier.

This describes the Bridge which the ice after forming in the early winter of 1890 affected by moving its piers.

The Board of Bridge Directors asked Mr. Walter Shanly, C.E., M.Can.Soc.C.E. to confer with the Engineer of the Bridge "as to "the best means of remedying the defects and of preventing such "occurrences in the future."

Mr. Shanly's report, as published, is full of interest to Engineers, and in conjunction with Mr. Dumble's paper on ice is most instructive to the profession.

Mr. Shanly, in his report of January 2nd, 1891, says he found, at the time of his examination, the piers fully finished, the steel superstructure in course of erection and more or less in place over the fourteen openings, and that each pier was loaded to nearly its full proportion of ultimate dead weight, but adds "all "the piers were discovered immediately the ice had parted to be "out of line to an extent varying so far as instrumentally ascer-"tained between 11 and 15 inches each pier."

It appears that those piers, three in number (also the abutment) that had stone crib foundations carried to the rock or to solid bottom were not so materially affected by ice, but that the piled piers were those thrust mostly out of line.

The report says "there has been no 'shifting' of the piers of "the Bridge, but only a 'drag' due to the contracting or expand-"ing of the vast ice plane," causing the pile structure to bend, but not to move at its base.

Mr. Shanly adds: "Its elasticity saved it from permanent "displacement and injury. This is proved by the readiness "with which such of the piers as have so far been released by "cutting the ice from around them at once began to return to "their normal line, and by the comparative ease with which, when "subjected to the pull of the screw jack, they were brought fully "back to it."

The speaker, however, desires to say that when he visited the Bridge in April, 1891, the piers and superstructure were out of line sufficiently to attract attention, and that at this date it presents a most uneven appearance. Mr. Shanly says, "Piers of solid masonry under similar strain "to that which caused the "elastic pile structure to *spring* would have been dislocated some-"where below the water line rendering repairs and restoration "to line almost impossible."

And then as to the remedy, Mr. Shanly says, "Assuming the "work to have been thoroughly well done throughout, and there "seems to be no reason as already said to doubt that it has been "so done, there are no defects to prescribe for."

"The recent disturbance of the piers has naturally alarmed the "Company, and we are asked to say "how such occurrences are "to be prevented in the future,"—I think I have stated my "opinion in sufficiently decided terms that the structure is not "of a kind fitted to cope with the ice. I will add that I do not "think it should be of such a sort—a Bridge capable of setting "the ice at defiance would be a commercial impossibility on the "Bay of Quinte or in any waters similarly conditioned."

"What must be done, the only sure and certain thing that can "be done, is to forestall the cracking of the ice by cutting it and "keeping it cut right through the winter, lengthwise of the bridge "from shore to shore, two cuts one above, the other below the "line of piers, each to take the form of a trench or ditch, some "three feet in width."

Now, Mr. Dumble shows that ice is at its greatest dimensions when it forms. Hence the damage to the piers was during or immediately after formation. The cracking of the ice was caused by its contraction. Hence at such a time the piers would be in course of being released from ice pressure.

Leaving the Bay of Quinte Bridge for the present, it will be interesting to consider the behaviour of some other bridges under ice pressure. The Victoria Bridge at Montreal having been completed 32 years without experiencing failure, may be accepted as being fully capable of withstanding ice shoves. But it may be said we cannot afford such enormous masses of masonry in ordinary cases. We must bear in mind that the St. Lawrence is no ordinary river, but is during the ice run, by far the most formidable of the rivers emptying into the Atlantic ocean, and hence the Victoria Bridge was designed in early days to be on the safe side—better so.

The speaker some twenty years ago was engineer in constructing the International Bridge across the Niagara River at Fort Erie and Buffalo. The main river is 1,900 feet wide, has a maximum depth of 45 feet. The centre current is generally about seven miles an hour. This structure was in course of erection when Mr. Geo. Lowe Reid, Captain Eads and Mr. Cheeseworth (the two latter are now dead), made a report for the Great Western Railway of Canada, which contemplated taking an interest in the ownership of that structure, and all three concurred and so reported that in their opinion the piers would be sheared off by the action of the fields of ice moving against their cutwaters. Time has proved that these engineers were wrong in their opinion; the piers have stood over twenty years and have suffered no damage from ice.

It was found by experiments made by the President of this Society, Sir Casimir Gzowaki, in 1871, that hard ice, its temperature being below freezing point, crushes at 208 lbs. per square inch. Hence if resistance is opposed to moving ice sufficient to crush it, the object is attained. A sloping cut-water upon which the ice will run up and break is however the natural remedy for ice pressure on piers.

Mr. Dumble speaks of the Rice Lake Bridge in 1860, but it was in 1857 the speaker first saw Rice Lake. The bridge had then failed and it was in course of being filled in. Hence he thinks there is an error in the date, although not in the fact. The wrecking of this Bridge was in effect similar to that of the ice pressure upon the Bay of Quinte Bridge. Mr. Dumble says the Rice Lake ice acted on the pile Bridge in the early part of December. At the Bay of Quinte Bridge, the injury took place on the 20th December, 1890.

In placid waters like the Bay of Quinte, the resistance required to overcome the effects of ice can be calculated with as much precision as on rivers where "ice runs" in spring are the features to be encountered. Piers with sloping cut-waters at each end, and built of solid masonry or of crib-work are effectual, and the cost of such works should offer no obstacle so serious as to cause a project of public benefit to be abandoned. It cannot be admitted in the history of our country that ice offers difficulties that cannot be successfully overcome. What has to be done is to oppose ice pressure by sufficient resistance to crush it, viz: 208 lbs. per square inch, or to provide sloping ice breakers upon which it will creep or run and break. It is shown that ice in its formation attacks structures in its way. Hence ice should not be allowed to form around works too weak to repel it by crushing or by breaking. The damage is often done when the ice has formed and then cutting channels comes too late for first results.

The site of the bridge at Belleville being at the narrows, the ice on either side expends itself here, and the two ice fields east and west of the "narrows" often meet, expanding in opposite directions and pile into great heaps. The site is hence one of least resistance, subject to ice pressure from each side.

Mr. Shanly, in his report upon the Bay of Quinte Bridge says after speaking of the effects of the ice:

"And yet the structure is a good structure. In design well "adapted to its situation. In detail well and carefully thought "out, and discovering no signs of the work not having been well "and faithfully done. Nevertheless the piers have "given" to "the ice, as they would have given only in a more damaging "degree had they been built at enormously increased cost of "solid masonry all the way up from the rock to the waterway."

This reasoning is to the intellect of the average Engineer—not apparent, and certainly is against facts; because had the work been "well and carefully thought out" the structure would not present the failure it does to-day; and when Mr. Shanly says, "the structure is not of a kind fitted to cope with "the ice. I will add that I do not think it should be of such a "sort," the speaker fails to understand the meaning of the argument, because if the Bridge was not competent to cope with ice, and that it should not be competent to do so.—What practical use was there in constructing it at all? Are we to assume that a cluster of spring piles with masonry on top is to be taken as all that can be done, or that should be done? Or are we to repose with the assurance that solid masonry piers cannot be economically and successfully constructed to resist ice, or that a combination of cribwork and masonry cannot be built to meet requirements both physical and financial? As certain as the failure of the first, can the success of either of the other systems be depended upon.

Mr. Dumble's experience at Rice Lake thirty years ago, and that of Mr. C. H. Keefer at the Bay of Quinte, are very similar, and even now it would seem as if the failure of the latter is to be attributed to a cause we cannot commercially overcome instead of (as Mr. Dumble in his paper on Rice Lake experience says), to "ignorance of one of the forces of nature." History simply repeats itself. We do not admit that the ice difficulty in the construction of bridges in Canadian waters cannot be met with success and with economy. On the contrary, we say that ice effects can be dealt with as readily as those of wind or storm, and that it only requires a knowledge of the laws of nature to do so. Ice, Mr. Dumble says, forming at a temperature of 32° Fah. is then at its greatest or maximum dimensions. The observations of Mr. Dumble show that at zero Fah. when the vane of the staff read zero, and at 32° Fah. the vane read .01—with only $1\frac{1}{2}$ inches difference in the thickness of the ice between the readings—would only give about six inches per mile. The speaker refers to readings 20 and 46. Hence the movement of ice in still waters, *whem it first forms*, is not great, but local causes, as Mr. Dumble says, may arise to increase the ratio of movement in formation or subsequently.

Engineers must be prepared to build works to meet all the contingencies of our climate, and Mr. Dumble's paper gives to the profession a mass of collated evidence that will guide the engineer in his design, and show him the behavior of ice, and how its movements sympathize with the temperature of the air, forming almost parallel lines on the diagram. Evidently the profession has much to learn with regard *to the economical management of ice*, and we are indebted to Mr. Dumble for the valuable paper he has given our society, furnishing as it does much for reflection and interest to engineers in all countries where ice forms a factor in its opposition to the construction and maintenance of works.

Correspondence by Mr. C. H. Keefer.

Mr. C. H. Keefer said, he trusted that Mr. Dumble's interesting paper would draw out a full discussion and lead to other experiments, throwing light on the nature and effects of ice movements, as it is a matter on which there is great deficiency of professional literature. The writer had, while acting as Chief Engineer for the Bay of Quinte Bridge, last winter, some experience of the enormous power exerted by the contraction and expansion of a large ice field which may be of interest in discussing this subject. This was a highway bridge, built across the Bay of Quinte, at Belleville, to connect the city of Belleville with Prince Edward county on the opposite or south shore. From Dundas street, in Belleville, to Bushy Island, the approach, about 2,800 feet in length, consisted of a light embankment across a marsh, and from Bushy Island the approach, about 800 feet in length, was formed by an embankment ending at the north abutment in about 20 feet of water. Between the north abutment and south abutment, the bridge consisted of 13 spans of 98 feet, centre to centre of end pins, two spans of 148 feet, one draw span 238 feet, and one span 63 feet. The sub-structure consisted of masonry piers on pile and crib foundations below low water level. The south abutment is on rock foundation; the north abutment and piers, number 15 and 16 (the pivot pier) and 17, are on crib work foundations. All other piers are on pile foundation, the piles being cut off so that the platform on which the masonry rests, may be below lowest water, and enclosed in crib filled with stone, to protect and strengthen the piles. These cribs being sunk in the soft silt in the bottom of the Bay, and extending up to the foundation level of the masonry. The piling varying in length from 30 to 60 feet, is driven to the rock in each pier. The depth of water is generally 20 feet; the bottom is composed of silt and soft clay, of which there is a depth of from 22 to 40 feet overlying the rock. The erection of the steel superstructure was commenced early in November, the spans being erected on a scow and floated out into position. On the 1st of December the ice formed on the Bay, but the contractors still continued the use of this scow for erection, cutting a channel for it through the ice. The season was very favorable for a continuous and strong formation of ice, as there was little or no snow, and continuous cold weather. On the 20th December, when the ice was perfectly glare, and of a thickness of from 10 to 12 inches, we had the first ice movement and consequent ice fissure or crack of the season. The crack starting of the south shore of the Bay, about 400 feet east of the bridge, and striking the bridge about the centre, where the scow used for erection of superstructure, was frozen in, followed the line of the bridge to the north abutment. On the line of the channel that had been cut through the ice, from pier to pier for the erecting scow, in which, though frozen over again, the ice was probably weaker than at other points, and formed its line of least resistance. At this time all the piers were built and with the ice frozen around the masonry, it was practically in the grasp of an enormous ice field, whose force exerted in contraction or expansion, must either move, break, or bend them. The effect of this enormous thrust, was to spring the piling, so as to throw the piers from 2 to 12 inches out of line, not having the rip-rap or gravel filling which has since been placed around the crib to replace and consolidate the softer material, the holding ground for the piling was sufficiently soft to allow of their springing under such a thrust, though the depth of holding ground, in some cases 40 feet, prevented a lateral movement in the piles themselves. After the ice was cut away, and pressure on the piers relieved, they came back of themselves nearly to their original position. The writer was on one pier when it was relieved from the strain, and could very distinctly feel the movement of the piling straightening out as it came back to its original position. As this ice trouble naturally created some anxiety as to the bridge, the writer had a consultation with Mr. Walter Shanly, M.Can.Soc.C.E., who, after examining the bridge, and seeing the extent and nature of the ice field, was of the opinion that the bridge was a good structure, well adapted to its situation, and that the piers would have "given" to the ice only in more damaging degree, had they been built at enormously increased cost of solid masonry all the way up from the rock to the roadway. There is no doubt that the elasticity of the pile foundations saved us from serious trouble. Now, to guard against future trouble, a channel will be kept cut during the winter, east and west of the bridge, so as to isolate it from the main ice field of the Bay. It would be very interesting if we could have a record of continuous observations, extending over the entire winter of a large ice field, to determine, as far as possible, the nature and extent of ice movement. Mr. H. B. Aylmer, A.M.Can.Soc.C.E., the Resident Engineer of the bridge, managed to get a few observations from lines fixed from points on shore, 150 feet west and 250 east of the bridge, and parallel to its axis, and found that the movement was constantly towards the crack from the east and west, closing in on it and breaking, and piling up the ice at it. From the line he established west of the bridge, he found the movement between the 28th January and 5th February, to be from three inches near the north abutment to 12 inches near the south abutment, the ice moving east towards the crack, and from the line established east of the bridge between the 28th Jan. and 5th Feb., he found a movement of from 9 inches near the north abutment, to 16 inches near the south abutment, the ice moving west towards the crack. The writer noticed in the cracks formed in other parts of the Bay, at a later date, that at first they were little more than narrow fissures, about an inch in width at the top, and closed at the bottom, showing that in contracting the surface of the ice was strained in tension.

Mr. J. D. Barnett said—The Rice Lake bridge was believed to be at the time of its construction the longest railway bridge on this continent. A description of it accompanied by drawings was communicated to the Canadian Institute, 21st April, 1855, by T. C. Clark, C.E., of Port Hope, and may be found printed and and illustrated in its journal for that year, page 249. Mr. Clark said:—"It was predicted by many persons, previous to commencing this undertaking, that no structure could possibly be built which could resist the power of the ice in Rice Lake, which forms to the thickness of two and half feet; expands with such power as to buckle up into high ridges, from the heat of the noonday sun; and contracting again in the cold nights, cracks and splits with a noise like that of artillery, and with a tremendous power which, as they declared, no artificial structure could resist. Moreover, they said, after the ice has 'taken' the lake rises up some two or three feet, and the ice being frozen to the piles, must inevitably drag them all out. To these evil forebodings it was replied that it was not supposed that a pile bridge could sustain the thrust of the ice for any length of time; it might be disturbed and thrown out of line and level, but notwithstanding it could serve to carry the trains across the lake until such time as it could be filled up with a solid embankment. When there is no snow on the ice the heat of the sun in the middle of the day expands it, and it moves slowly, carrying the bridge with it. When night comes on and the temperature falls, it contracts again, and cracks and splits in a surprising manner. One of these cracks took place at a very acute angle across the bridge, throwing one portion up stream about eighteen inches, and the other down as much. The most injury that the bridge received was about the first of January of this year. The weather was particularly trying, the days being warm and the nights very frosty; and this, it must be observed, is the only kind of weather in which the bridge takes injury—uniformly cold or warm weather not affecting it. On this occasion there appeared to be an expansion of the ice from the channel towards each shore, and the effect was irresistible. The pile bridge north was thrown towards the Indian shore, but owing to the number of cribs in it, it moved but little. The truss bridge was pushed towards Tic island, so that the last span slid four feet upon the solid abutment. South of Tic island, the pile bridge was crowded over towards the Cobourg shore, so much that at the place where

Correspondence by Mr. J. D. Barnett.

it parted near the island the stringers were drawn apart nearly seven feet, so that they fell from the corbels. The piles were leaned over, and where the thrust met the resistance of the shore, it crushed up the solid 12x18 (oak) stringers, turning them into splinters, and bent the iron rails double. This has all been repaired, and the trains are now crossing regularly."

Mr. T. Andrews, in 1886, carried out an elaborate series of experiments to measure the dilatation of ice, between the temperature of 35° below zero (F) up to freezing point—see Proceedings of the Royal Society of London, Vol. 40, p. 544. He used pure distilled water, artificially freezing it into a cylindrical mass, 25½ inches diameter, and of the same depth, having inserted into both sides and face, two sets of iron bars an inch square and 13 inches deep. The measurements between these bars, 16¼ inches apart, were at the different temperatures of the mass accurately taken by a delicate micro-vernier guage, the limit of error in reading, which, by the aid of a telescope, did not exceed two-thousandth of an inch. The average of 100 measurements in each case regarded as the correct reading, and the results are recorded in the following table. A difference was observed between the longitudinal and transverse dilatation. This was not owing to error in observation, as the deviation was constantly noticeable during the course of the measurements. Certain crystaline bodies dilate unequally, and the ice also appeared to behave in a similar manner. The difference noticed may therefore, possibly, have been due to the mode of crystallization of the cylindrical mass of ice.

It will be be noticed that the co-efficients become less as the temperature is reduced.

TABLE—DILATATION OF PURE ICE BETWEEN —35° AND +32° F.

	Column 1.	Column 2.	Column 3.	
	Traversly Measured at 32° F Became	Longitudinally Measured at 32° F Became	Linear Expansion.	
			Transverse.	Longitudinal
1000 parts at +16° F..	1000.654	—	1 in 1,529	—
" " zero F...	1001.103	1000.657	1 " 906	1 in 1,522
" " —21 F...	1001.533	—	1 " 652	—
" " —30 F...	1001.712	—	1 " 584	—
" " —35 F...	1001.871	—	1 " 534	—

Linear co-efficient for 1° between + 16 F and + 32 F = 0.000,040,876.
" " " " " 0 and + 16 F = 0.000,028,042.
" " " " " —21 " 0 F = 0.000,020,484.
" " " " —30 " —21 F = 0.000,019,744.

These figures (even for ice of extreme thickness) between zero and 32° F. show a longitudinal contraction per mile of fully 41½ inches, against Mr. Dumble's 16 inches. The difference will be in part due to the variation of his measuring rod, but more largely the writer thinks, due to the influence of the higher temperature of the water in which the test piece floated. There is no doubt that below freezing point the test piece was at different temperatures on its upper and lower surface, in fact was radiating heat to the colder atmosphere. We are not in the habit of thinking of ice as a heat conductor, but its relative conductivity as given by Dr. Pfaff is as follows:—Gold, 1,000; iron, 374; ice, 314; tin, 303.

That a wide range of ice contraction after formation is possible will be the more readily granted when we remember that the water increases in bulk practically one-eleventh. The various experiments for density at 32° F. being: Thomson, 0.940; Berzelius, 0.916; Plicker & Gleissler, 0.920; Kopp, 0.909, and Dufour, 0.9175.

Mr. W. J. Sproule said—on Lake St. Peter, in winter, there is an expanse of ice about twenty miles in length, by eight to ten miles in width. The speaker spent the greater part of three winters on this lake, making surveys in connection with the ship channel. Each winter a crack occurred near the north shore of the lake, in apparently the same locality. No systematic observations were made. The crack was about a mile from the north shore, and opened and closed with changes of temperature during the winter. It was at times four feet wide, so that it was necessary to bridge it for the passage of horses, and at other times the two edges were over-lapped or buckled up into a ridge. The expansion or contraction, seemed to be accumulated at this crack, for if any others occurred between this one and the middle of the lake, they were not of sufficient dimensions to attract attention. As this crack was near one shore, it seems probable that the ice, wnen it contracts, would pull away from the shore if it were not fastened to it securely enough to overcome the tensile strengh of the ice. This condition may arise from the fact that the ice "takes" or freezes first at the shore. The water rises in rivers, or lakes, on which there is a current, and the ice "takes", and being held down by its attachment to the shore, the ice is overflowed. This overflow then freezes, and thus the ice near shore is thickened, and the area of attachment to the shore is increased. Mr. W. J. Sproule.

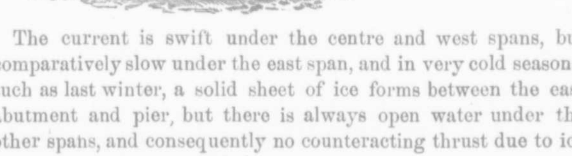
Mr. Duncan MacPherson.

Mr. Duncan MacPherson said:—In reading over Mr. Dumble's interesting paper on "Expansion and Contraction of Ice," one cannot but give great credit to the author, for the careful and exceedingly onerous experiments which he carried out, and which probably, establish pretty correctly the behaviour of ice under the given conditions. It does not, however, appear equally clear that the forces which acted with such disastrous results on the Rice Lake Bridge, were due entirely to the contraction and expansion of the surrounding ice. The speaker has had under his immediate supervision, for a number of years, several pile trestles crossing lakes and wide bays; some in deep and others in shallow waters. These structures have been completely frozen in with ice, more or less thick, according to the season, but have never been shifted in the slightest noticeable degree by ice expansion. It would appear possible, that there must have been very thin ice or open water near the Rice Lake trestle, and lying to one side of it; or else that winds and currents, acting separately or together, caused regular ice shoves.

Last winter, the speaker had a case come under his immediate observation, which illustrates the tremendous power of ice expansion, and the result when acting on one side only of a structure.

The Canadian Pacific Railway crosses the Riviere des Praries, or Back River, by means of three through truss spans of steel; two of 155'.5 and one of 203' feet, centre to centre of end pins.

The east span, shown in the diagram below, was 148'.3 between masonry at ice level, January, 1891.



The current is swift under the centre and west spans, but comparatively slow under the east span, and in very cold seasons, such as last winter, a solid sheet of ice forms between the east abutment and pier, but there is always open water under the other spans, and consequently no counteracting thrust due to ice expansion on the west side of pier.

The anchor bolts $1\frac{1}{4}$ in. diam. at the roller end of the superstructure on east pier, were found badly bent, and some of them broken ; check measurements revealed the fact that the pier was slightly out of level, and the top had moved two inches towards the west. The ice under the span at this time was 12 inches thick, and the depth of water from top of ice to bed of stream at east side of caisson, 18 feet. Top of ice to top of masonry pier, 17 feet 6 inches. A narrow channel was cut through the ice to open water, and the pier immediately came back to its normal position. This was quite apparent to the eye, by observing a fixed gauge which had been run out from the abutment, on the superstructure, to the pier. This pier is built of heavy rock-faced limestone ashlar. It was built inside a timber caisson, and the bed formed by excavating a few inches of hard pan from the solid rock. The space between caisson and pier is filled in with broken stone. Height of masonry of piers, 35 feet, and length of straight side at low water line, 42 feet. It has been suggested in discussion, that the pier probably cracked at the offset, near the top of the caisson, but this seems impossible, as the point of application of the ice thrust was only $3\frac{1}{2}$ feet above this offset, which would be too short a lever arm when counteracted by weight of pier and superstructure above; moreover, subsequent critical examinations with divers, proved that the masonry had not been disturbed above the top of the caisson, and that the sides of the caisson and foundations were in good order. It appears more probable, either that the whole pier moved slightly by tilting about its bottom edge, inside the caisson, or that the whole pier and caisson tilted together. Assuming the former, and allowing for the buoyancy of the part submerged, the total weight of pier and superstructure lifted by the ice with an arm of about 17 feet, was approximately 1,000 tons, which was not only lifted, but held up under passing trains. The top of ice is shown in the diagram by a full line, and the bottom by a dotted line, but the movement of the pier was too little to show on such a small scale.

Mr. H. Irwin said—the subject of Mr. Dumble's paper is one of great importance to Engineers, many of whom, judging by Mr. Hannaford's remarks with regard to the bridge at Belleville, must still know very little, with regard to the destructive effect of ice when expanding. **Mr. H. Irwin.**

The figures given by Mr. Dumble, in the table, showing the movement of a 100 foot strip of ice, require, as he says, to be corrected for the expansion of a deal rod also 100 feet long.

It is true that Joule found, that while pine, when wet, scarcely expanded at all, so that for any measurements, when the temperature was over, say 30 degrees, it is most likely that no correction would be required; however, for temperatues below 30 degrees, the correction should be made.

The average co-efficient of expansion of dry deal as given by Trautwine, Hurst and Deschanel, (the latter quoting from experiments, by Joule) is 0.0000024 per degree Farenheit, which would give 0.00768 feet for the expansion of the 100 foot deal rod, from zero to 32 degrees; adding this 0.00768 feet to the 0.026 feet given by Mr. Dumble, as the average expansion of the 100 foot strip of ice, less, that of the deal rod, it would appear that the actual expansion of the 100 foot strip of ice from zero to 32 degrees, would be 0.033 feet, or say 0.001 foot per degree for the 100 foot strip; which would make the average co-efficient of expansion of ice between Zero and 32 degrees to be 0.00001.

An abstract of the results of the experiments made in 1886, by Mr. T. Andrews, and quoted by Mr. Barnett, may be found in the Scientific American Supplement for January 1st, 1887, page 9173. The block experimented on was two feet square by one foot thick, and was cooled down by placing it in a freezing mixture.

In round numbers his experiments show the co-efficients of expansion to be as follows, viz:

From—30° to 0° Far.—0.00002 per degree,

From—0° to 16° Far.—0.00003 per degree, and

From 16° to 32° Far.—0.00004 per degree.

Taking the average from Zero to 32° as 0.000035, it would appear that Andrews found the rate of expansion three and a-half times greater than that observed by Mr. Dumble.

The conditions, however, under which the experiments were made were very different, as Mr. Barnett remarks. Ice floating on water at a pretty uniform temperature would not contract under the influence of the cold air above, as much as if entirely surrounded by a freezing mixture. The speaker thinks, however, that a long narrow strip of ice, like that experimented on by Mr. Dumble, might expand much more per foot in the direction of its width, than in the direction of its length; and that, in estimating the probable expansion of a field of ice, it would be safer to count on a co-efficient of expansion of 0.00002, which is about a mean between the values found by Mr. Andrews and Mr. Dumble.

Mr. Andrews also found that ice at low temperatures became extremely hard. May not this fact be connected with the marked decrease in the co-efficient of expansion at low temperatures, when the crystals may have become so firmly laced together that the aggregation could not contract so readily?

Mr. Peterson states that no damage has been done to any of the trestles on the line of the Canadian Pacific Railway through the expansion of ice, though there are several in large lakes, on the shores of Lake Superior and of Lake Memphremagog, and in other localities. This is probably due to a difference in the condition of the ice which surrounds them. Along the shores of Lake Superior, the expansion of the ice may take place towards the open water of the lake, and there may be very little movement at all near the shore. In the case of the inland lakes and ponds, the ice may be uniformly thick, so that when a change of temperature takes place, there being no reason why the ice should crack any more in one place than another, it does not crack at all. There are, therefore, no cracks to fill up, and cause the ice to expand over double the space through which it had previously contracted. The consequence is that scarcely any movement takes place and no damage is done.

The speaker had a practical demonstration that ice may have a great tendency to crack, and yet not do so till a line of least resistance was given. During the first winter he was in Canada, not being accustomed to Montreal winter sidewalks he took to wearing spikes in his rubbers. When there had been a thaw and a sudden drop in temperature, so that the sidewalks were well coated with glare ice, he found that when he punched a small hole in the ice with his spikes the ice cracked across the sidewalk with a loud report, while it did not crack at all under heavier people who were walking gently and carefully for fear of falling, showing clearly that the crack was due to a tendency to contract and not to weakness, as in the case of thin ice on a pond. At the same time the speaker also noted the extreme hardness of ice at low temperatures, for he found that when it was below zero it was very difficult to make spikes catch in the ice, except when they were very sharp.

The decrease in shoves when the ice gets very thick, as observed by Mr. Dumble, may be due to the fact that the interior of the ice was not much affected by a change in the temperature, and besides when the ice is thick it is generally well coated with snow.

As to the suggestion that it is difficult to account for the amount of the movement observed at Rice Lake, if it be caused only by expansion due to changes in temperature, and that the movement may be similar to that of glaciers. The speaker does not think that the ice in question is nearly thick enough for any glacial flow, nor could such a flow take place in the surface of a lake. He does not see any difficulty at all in accounting for the amount of the expansion. Mr. Hollinshead informs him that there is a flow of water constantly going on down the centre of Rice Lake. The ice would be weaker over the current. When the ice contracted it would break at this weakest place, over the centre of the lake, and being frozen to the stones and boulders along the edge of the lake would not draw away from the shore, where the ice would be thicker and stronger. The cracks would, therefore, open out. When it got cold again these cracks would fill with ice, then when mild weather came the ice must expand somewhere and would have to push towards the shore or crumple up as described by Mr. Dumble. This process would be repeated over and over again during the winter and the resulting movement might be very large.

The conditions at Belleville are evidently somewhat different from those at Rice Lake, since the ice seems to move at the former place in the direction of the length of the channel. It would seem, therefore, that the exact nature of the effect ice may have on a structure exposed to its expansion can only be learnt by a winter's observation on the spot.

In connection with Mr. MacPherson's remarks as to the Canadian Pacific Railway Bridge at the Back River, the speaker has calculated the pressure that would have to be exerted by the ice as follows:—

Weight of submerged part of pier........................	1,100,500 lbs.
Weight of part above the ice............................	625,460 "
Weight of two halves of the 150 foot spans with flow	310,000 "
Total weight pushed over by the ice.............	2,035,960 "
Say total...	2,036,000 "

Suppose this weight to rest on a width of one foot of the floor of the crib when the pier was tilted up, then the lever arm of the weight would be 5 ft. 6 in., the pier being twelve feet wide at the bottom.

The moment of stability is 5.5 x 2,036,000, equal to 11,198,-000 foot pounds, which divided by 20 for the lever arm of the ice, gives the pressure exerted by the ice as 559,900 pounds. This pressure was exerted against a length of 37 feet 6 inches of the side of the pier, and say an equivalent of 6″ more for the nose of the cutwater, which is dressed, or 38 feet in all. The ice being one foot thick, this would give an area of 38 square feet, against which the said pressure of 559,900 pounds was exerted; this would give 102 pounds per square inch as the necessary pressure to tilt up the pier, as described by Mr. MacPherson.

Experiments made in Toronto, some years ago, on blocks of ice one foot square, showed that ice would stand a pressure of 210 pounds per square inch, so that the pressure of 102 pounds per square inch is well within what the ice would stand.

If the pier were tilted, as assumed, so as to be carried by one foot in width of the floor of the caisson, the pressure on the wood would be about 2,036,000 pounds, divided by 38 square feet, or about 53,600 pounds per square foot, equal to about 372 pounds per square inch, or about half the weight necessary to indent dry pine one-hundredth of an inch, so that it is not unreasonable to suppose that the timber of the crib would stand the assumed load, as it has always been in deep running water since it was sunk, and has had the weight of the pier and bridge on it all the time. With regard to Mr. Sproule's suggestion that the Pier at the Back River Bridge was not tilted up bodily by the ice, but that it probably opened at the joint where it narrows in, from 12 feet wide to 10 feet wide, the speaker does not think that the pier gave way in that manner, as a diver examined it carefully and reported no cracks in the masonry. As Mr. Sproule does not seem quite satisfied, however, the speaker has calculated the approximate tension that there would be at the outside of the pier, supposing the pressure of the ice to have been 14,734 pounds per square foot, as previously calculated. The joint referred by Mr. Sproule, is 6 feet 6 inches below the centre of the ice when the movement occurred. The bending movement therefore, on a vertical strip of the pier one inch wide, would be 95,771 inch pounds at the joint mentioned.

Assuming the pier to be sufficiently elastic to act as a beam, which would seem reasonable, as tall spires and chimneys will move a few inches in a storm without cracking, and calling the outer strain per square inch f, the width at the joint in question being 10 feet, the outer strain $f = \frac{97{,}771 \times 6}{1'' \times 120'' \times 120''} = 40$ lbs. per square inch. From this must be deducted the uniformly distributed pressure from the load above the joint. This pressure is about 18 pounds per square inch. The actual outer unit strain, at the joint in question would be therefore about 18 pounds per square inch. The pier was probably built with 2 to 1 Portland cement mortar. The tensile strength of this might be taken at 300 pounds per square inch. Trautwine gives the adhesion at about three-fourths of the tensile strength at the same age.

The adhesive strength of the joint would therefore be about 225 pounds per square inch, which appears to be far too high from data given in Mr. Ira O. Baker's book on masonry. Mr. Baker states that Mr. Mann found the adhesive power of neat Portland cement to be only from 60 to 80 pounds per square inch, as an average of 12,000 experiments. He does not give the age of the cement tested, but it is not likely to have been over 6 months on the average. As the adhesive power is supposed to increase very much with the age, it is probable that the adhesive strength of the 2 to 1 mortar after several years, would be at least 60 or 70 pounds per square inch, which would give an ample margin of safety for a strain of about 18 pounds per square inch. It does not seem at all probable, therefore, that the joint in question opened at all.

Prof. J. T. Nicolson said—Mr. Dumble does not attempt to estimate the actual contraction of the ice due to fall of temperature. What he measured, as he himself states, was the difference between the contraction of the pine rod and the ice. Correspondence by Prof. J. T. Nicolson.

The only figure for the specific contraction of the wood the writer has been able to obtain, is for oak, and this makes the length increase by .000746 of its length for a rise from 0° C. to 100° C. If the co-efficient holds for such temperatures as 0° F. to 32° F., then the oak should contract about .013 feet in 100 feet for a fall from 32° F. to 0° F.

Mr. Dumble gives .026 feet in 100 feet as the mean shortening for 32 degrees fall of temperature, of the ice relatively to the pine. If then, pine contract anything like oak, we shall obtain $(.013+.026)=0.039$ ft. (per 100 ft., per 32 degrees fall) as the actual contraction of the ice. This amounts to about 24 inches per mile instead of the 16 Mr. Dumble mentions.

The writer would be glad to know what Mr. Dumble has observed as the contraction or expansion per mile?

Mr. Thomas Curtis Clarke said—as the Rice Lake Bridge had been referred to as "some of his early work," he wished to state that he had nothing to do with it. Correspondence by Mr. Thomas Curtis Clarke.

The writer was associate Engineer with Mr. R. G. Benedict, upon the Port Hope, Lindsay and Beaverton Railway, when the Rice Lake Bridge was being built in 1854, (not 1840, as stated by Mr. Dumble) and living near Rice Lake was naturally interested in watching the effect of the ice upon it. His observations, as published in the proceedings of the Canadian Institute, he has now read over as quoted by Mr. Barnett, and finds nothing to change.

As a matter of fact, the damage to the bridge was repaired, and trains were run over it. All the trouble could have been prevented if cribs filled with stone, and shaped as ice breakers, had been used in sufficient numbers, as Mr. C. H. Keefer has done in his bridge at Belleville.

After the injury had taken place, the use of such ice breaker cribs would have prevented its repetition. But, a rival road had been built from Peterboro to Port Hope with much easier grades than the Cobourg and Peterboro, and all the business went that way, and the Cobourg and Peterboro lost its traffic and was finally abandoned.

Mr. Dumble deserves great credit for his energy and patience in making the experiments described in his paper, but the conclusions drawn by him are not reliable, as pointed out by Mr. Barnett in his discussion, and for the reason given by him. Few men are born experimenters. This usually comes from training.

If progress in engineering is to be continuous, it will be greatly due to the fact, that most modern engineers have received a scientific training in technical schools.

Engineering is *construction according to scientific methods*, and these are—observation, experiment and theory combined.

Correspondence by Mr. Walter Shanly.

Mr. Walter Shanly said—in December, 1890, he was asked by the Directors of the "Bay of Quinte Bridge Company" to examine the bridge, then under construction, and advise as to the best means of preventing the recurrence of certain threatening action of the ice on some of the piers.

Early in the following month, the writer made a report giving his views and suggestions. The report was published in the columns of the local (Belleville) papers, and his opinions, as therein stated, have been criticized by Mr. E. P. Hannaford in the course of this discussion.

In prefacing his remarks, Mr. Hannaford has sketched a fair general outline of the bridge, its site, mode of construction, etc. The writer need not, therefore, enlarge on these points. Also, he finds himself so nearly in accord with Mr. Hannaford, as to how floating ice acts in its effects on bridge structures, and as to the surest methods of counteracting its forces as to leave not much room for argument, on those points either.

"Piers," Mr. Hannaford says, "with sloping cutwaters at each end, and built of solid masonry or crib work, are effectual, and the *cost of such work should offer no obstacle so serious as to cause a project of public benefit to be abandoned.*" Again, he says, "It cannot be admitted in the history of our country that ice offers difficulties that cannot be successfully overcome." He further lays down the doctrine that it "*only* requires a knowledge of the laws of nature" to enable us to deal effectually with ice. (The italics in the quotations are the writer's.)

Knowledge of the laws of nature will not alone suffice for the building of bridges capable of resisting ice movement. Money, too is an essential, and while we have learned from the "unanswerable logic of accomplished facts" that the power of ice, even as illustrated in such grandly phenomenal form as here at Montreal, can be successfully combatted, we also know that only Governments or wealthy and powerful railway corporations can provide engineers with the means of building bridges after the fashion of the Victoria Bridge. Lesser corporations, country municipalities, and such like humble bodies must be content in dealing with lesser waters to be governed by the homely old rule "Cut your coat according to your cloth."

The construction of the Victoria Bridge marked the opening of a new era in the engineering "history of our country," depriving the ice problem in our great northern rivers of half its terrors. The masonry of that great structure was completed in 1858, it therefore sounds somewhat strangely that some thirteen years later, as related by Mr. Hannaford, three distinguished engineers should have given a unanimous opinion that in the case of the International (Niagara River) Bridge, then about to be undertaken, the "piers would be sheared off by the ice fields." It would be interesting to learn how it came that those three distinguished engineers so entirely ignored the teachings of the great bridge at Montreal.

What is known as the "shearing" process is effected by detached masses or "fields" of moving ice. The water is the active power in the operation; the ice its agent or weapon. The Victoria and International bridges are both alike subjected to the shearing action and both alike have withstood it. But the sloping "cut-water" was not a new idea in reference to either one of these structures. It might have been seen long years before the first of them was thought of, in the rude constructions of cribwork for the protection of ordinary highway bridges and booms on many of our minor Canadian waters.

The winter condition of the Bay of Quinte offers a widely different problem from that presented in the cases quoted above. There is no ice in floating or "running" motion. The Bay closes completely over, exposing to the atmosphere a wide level, frozen surface, the unfrozen water underlying it being meantime in a state of rest and taking no part in the phenomenal cracking of the ice that covers it. Instantly on the parting taking place the divided field recedes, on both sides of the opening, and then just as instantly quiescence is again the ruling order. Here the atmosphere is the active agent, and to the law of contraction and expansion under its influences was due the movements that in December 1890 drew the bridge piers out of line. Clutched in the relentless embrace of the receding field they yielded by bending (not moving at the base) to the force they could not wholly resist, and just to the extent that the ice had *snapped* they "gave." Sloping cut-waters would neither have averted or neutralized the effect upon the structure. Only piers of such massive construction as by their *vis inertia* would offer sufficient resistance to the moving plane as to cause it to break at, against and around them would have prevented the disturbance that occurred. The parting of the ice field took place not on but some distance away from the line of the bridge.

In writing of the Bay of Quinte Bridge, the writer said that a substructure so solidly constructed as to be able to defy ice forces, would, under all conditions of the case, render the undertaking a "commercial impossibility." The cost of such a structure, even using cribwork in place of masonry, would have been out of proportion to its *paying* ability, or even from the local benefits to be derived from it. Differing from Mr. Hannaford, that "cost should be no obstacle where a project of public benefit" has to be considered, the writer believes that the projectors of the Bay of Quinte Bridge, did wisely in seeking for a design that could be carried to completion within the limit of the means they expected to be able to command, and still provide them a crossing of the Bay, safely adapted to the needs to be served, and fairly certain to be good security for the capital (chiefly borrowed capital) to be invested.

Traffic estimates warranted the Company in bonding the bridge for an amount on which it could be represented as reasonably sure to make fair returns. They could not honestly have sought to borrow on its credit the very much larger amount that the mode of construction advocated by Mr. Hannaford would have cost.

Mr. Hannaford thinks one illogical, because after characterizing the bridge as a good structure of its kind, and fittingly adapted to the uses it is intended to satisfy, the writer added that "it is not of a kind fitted to cope with the ice," and he asks, "What practical use was there in constructing it at all?" The writer answers, that for all practical uses the bridge meets its requirements, just as well as if supported on stone piers, as massive as those of the Victoria Bridge. Cost, which Mr. Hannaford counts as of only secondary moment, was the turning point in the case. It was simply a question of bridge or no bridge. The writer, in his report, prescribes the means of guarding the piers from disturbance in future winters. Free them from the death grip of the ice by cutting it. The remedy —"antidote"—will be found, *is* found, the writer supposes he may say, effectual and of light expense, and is not a novel application in cases of like necessity. The bridge not being of a kind fitted to cope with the ice, the ice must not be allowed to cope with the bridge.

If, where ice difficulties have to be encountered, our bridges must always, and only, be constructed on the most expensive system, regardless of cost, then the Engineer has an easy stereotyped path in which to tread, providing his employers and a "confiding public" will supply him all the money he may want; but where the *minimum* of cost has to be the ruling factor in the "commercial possibility" of the needed bridge, then he will have to draw on his own wits and "reserved powers" to meet the emergency. These latter, were the conditions under which the work in debate was projected and carried out, and therefore, it was that, after due investigation, the writer pronounced the structure to be a fitting one in its place, "in design, well adapted to the situation, and in details, well thought out." The Bay of Quinte Bridge reflects credit on Mr. C. H. Keefer, the Engineer who designed it and saw it to completion. Proper care and watchfulness pre-supposed, the bridge will stand and prove its "practical use" as an immense trade convenience to the district it serves, while as far as yet financially tested, it seems tolerably safe to earn interest on its cost also.

Correspondence by Mr. C. H. Keefer.

Mr. C. H. Keefer said—Mr. Hannaford, M. Can. Soc. C. E., in his remarks on the effect of ice on the Bay of Quinte bridge during its construction, has evidently been unfortunate in the quantity and quality of the information he has received or he could hardly make the assertions of failure that he does. Had the writer known he was so deeply interested in this particular work, it would have afforded him much pleasure to have furnished him with the information that he evidently very much needed to properly understand the case, and avoid the wrong conclusions he has reached. Taking his statements in the order he makes them, the cost of the bridge was not $120,000, and a discount of nearly fifteen per cent from these figures would have been nearer the mark. The general depth of water of twenty feet, extends from piers numbers one to thirteen. At number fourteen the last foundation in which bearing piles are used the depth of water is twenty-four feet. The three remaining piers, numbers fifteen, sixteen (the pivot pier) and seventeen on the south side of the bay are in the deeper water of the navigable channel and are founded on crib-work extending to the rock without bearing piles. At pier fifteen the depth of water from ordinary water surface to the rock is forty-three feet. The rock at this pier being overlaid with a deposit of silt and clay about ten feet in depth. At number sixteen, the pivot pier, the rock is practically bare and depth of water thirty-two feet. At number seventeen, which is close to the south shore, an irregular deposit of loose rock was removed to reach rock foundation, at a depth of twenty-eight feet. In saying piers one to fourteen are on pile foundations, Mr. Hannaford has forgotten to add that the piling is in each case properly protected by cribs of the same design as those used in carrying the load direct, but instead of carrying any part of the load due to masonry and superstructure, are free to move or settle vertically into the soft upper stratum of the bed of the bay, and being filled with stone they protect and stiffen the piling below the grillage of timber with which they are capped and on which the masonry rests. The writer does not understand Mr. Hannaford's reference to a "margin of timber" and "a box filled with stone" as describing the crib-work enclosing the piling. Mr. Hannaford is right in saying that there were thirty piles to each pier. The writer thinks, however, they can hardly be described as "clusters" as they were driven at regular intervals, namely, two feet nine inches apart centres on the line of the axis of the bridge, and three feet apart at right angles to it. The masonry of piers is first-class heavy rock faced ashlar, and was not affected in the slightest degree by the springing of the piling, although the thrust of the ice field was exerted, and only could be exerted, directly on the masonry, and the strain transmitted through it to the piling. As Mr. Hannaford says, there are no ice breakers on the piers, the ends being rounded. However, as they are battered at the ends with a batter of two inches to one foot, the writer thinks he can hardly agree with him that they are "almost vertical." No ice breakers were used or intended to be used, the conditions being entirely different from river practice, where the upstream end of piers alone require protection and where running ice driven in masses by varying currents at a greater or less velocity will if obstructed, and not destroyed by properly constructed ice breakers, not only threaten the stability of piers, but possibly reach the superstructure itself. On the other hand, a lake or bay such as the Bay of Quinte being almost stagnant water with only a very slight current in the channel on the south side, the rest of the bay depends on changes of the wind and the force derived from them to produce an agitation of its surface. There is no running ice to deal with. The only reason for the use of ice-breakers would be with the object, granting that a sufficient amount of money was placed under the control of the Engineer for that purpose, of constructing an ice-proof bridge, in which case, in the writer's opinion, a conical shaped pier would probably be required, as the ice strains are from all and every direction, depending on which way the combined forces exerted by the ice field in expansion and contraction may be applied, and ice-breakers in every direction would be the order of the day. The Bridge Company's resolution about remedying defects was a good sample of "hasty legislation," moved when the excitement caused by the bridge's wrestle with one of the "great forces in nature" was at its highest, and before they knew whether the defects existed or not. The writer can thoroughly agree with Mr. Hannaford's remark that Mr. Walter Shanly, M. Can. Soc. C. E., when called in as consulting engineer made a report full of interest to engineers, and he is sure other members will agree with him, that Mr. Shanly's name and reputation is sufficient guarantee that we may profit by what he says. Mr. Hannaford's quotation from Mr. Shanly's report that the piers were out of line after the ice parted, between fifteen and eleven inches each pier, is evidently a mistake, as the facts were, as given in Mr.

Shanly's report, that they were from two inches to a maximum of twelve inches out of the line. The writer inspected the bridge in April last. There has never been any settlement of the piers on pile foundations and the bridge floor is as close to grade line as possible. He failed to see the "most uneven appearance" and bad alignment that struck Mr. Hannaford on his visit Probably, however, he may have been the victim of an optical delusion or have been wearing glasses of an extra high magnifying power. Mr. Hannaford says "the cracking of the ice was caused by its contraction, hence at such a time the piers would be in course of being relieved from ice pressure." But, as they were frozen around at the time and immovably fixed in the ice field it is evident that as Mr. Shanly says, as the "ice moves, it moves, must move." Fortunately in this case the only movement possible was a springing of the piling, which, as the piles were in some cases nearly sixty feet in length and passed through a silt deposit below the cribs protecting them, and which as the work was in an unfinished state, had not been consolidated as has since been done by gravel filling around the piers. It was not at all surprising, as it can readily be seen, that a very slight bend or spring in a pile (securely anchored in its holding ground) at a point probably thirty feet below the point of application of ice strains would produce a considerable change in direction at the level of roadway which might be forty feet above the point at which bending took place, and produce the variation in alignment which was the result, namely, two to twelve inches.

The comparison which Mr. Hannaford kindly makes of the Bay of Quinte bridge, an ordinary highway bridge, which could only be built for the most reasonable amount consistent with safety, and as a dividend earning investment, with the Victoria and International bridges, is as wide of the mark as were the financial and engineering conditions under which they were built.

Mr. Hannaford's assumption that the Bay of Quinte bridge was a similar structure to Rice Lake bridge is entirely wrong, In the case of the Rice Lake bridge, as the writer understands it. the main part of the structure was simply pile trestle without protection for the piling on which the ice acted directly both by its expansive and contractive as well as by its lifting power tending to draw as well as spring it. The writer trusts Mr. Hannaford will favor the Society with the precise formula he gives us to understand he possesses for calculating the effects of ice in expansion and contraction in similar cases. He would confer a lasting obligation on the profession at large by doing so. Mr. Hannaford thinks that the writer's experience is very similar to that of Mr. Dumble at Rice Lake; that is, he compares a pile trestle which failed to a bridge which did not. The forces at work are similar, but only ignorance of facts can excuse his statement that the Bay of Quinte bridge is a failure. He evidently from the tone of his remarks considers that it did not cost enough, and the writer must acknowledge that he tried to the best of his ability, as a matter of professional duty, to solve the problem he had before him, of building a good bridge for the least amount of money so that the shareholders, as well as the public, might derive some benefit from it, as well as to render possible its construction. He may fairly claim he has built the bridge on those lines and that it is to-day in good and safe condition, and able to stand up for itself for, he trusts, many years to come. The writer has had difficulties to encounter in construction, and that of ice was the greatest, but he does not know of any work where troubles may not come which it is part of our duty to cope with and overcome to the best of our ability.

The writer may say that the Bay of Quinte bridge has proved successful in every way and has, as Mr. Shanly predicted, made a good return already to the shareholders on its cost; as in the first eight months of its operation it has earned enough to pay working expenses, interest on its borrowed capital, a dividend of four and a half per cent to the shareholders and placed about five hundred dollars to rest account to meet contingencies. The Secretary of the bridge Company writes him on the 2nd instant, as follows: "The result of the eight months during which bridge has been in operation was quite satisfactory to the shareholders, and we hope another season to show still better returns. So far this winter there has not been a day that it did not more than pay expenses of attendance, keeping ice cut, etc." As in the winter the ice affords a free natural bridge it was not expected the earnings of the bridge when in competition with it would cover expenses, and the writer is glad to learn that the Company have been agreeably disappointed. He has had for some time plans prepared of the Bay of Quinte bridge to submit with a descriptive account of its construction to the Society, and regrets that he has been unable before this to carry out his original intention.

Mr. J. H. Dumble.

Mr. J. H. Dumble said—He was gratified that his paper has been so ably discussed by eminent engineers, and in replying briefly in order would say that the Belleville bridge, built by Mr. Keefer, crosses in winter an ice field very similar to that of Rice Lake. although, perhaps, not so extensive. The old Truss bridge on Rice Lake was of about equal length to that of Belleville, and that similar disturbance from the expansion and contraction of the ice must always be anticipated.

Mr. Barnett refers to an old paper by Mr. Thomas Curtis Clarke to the Canadian Institute which gives a very correct and graphic account of the action of ice on the railway bridge at Rice Lake, and to which the author will subsequently refer. Mr. Barnett also gives the results of Mr. Andrews' experiments on a block of artificial ice, in which it appeared that the expansion was $41\frac{1}{2}$ inches to the mile against Mr. Dumble's 16 inches, "and thinks the difference will be in part due to the variation of his measuring rod, but more largely due to the influence of the higher temperature of the water in which the test piece floated."

There is no doubt that an allowance must be made for the rod, but the difference in temperature of the underlying water (if any) must be inconsiderable. Mr. Barnett, however, overlooks the fact referred to by Mr. Irwin that the conditions under which the experiments were made were very different. In the one case the block of ice was subjected to cold and freezing mixtures, and in the other to water of a uniform temperature, or rather that the block of ice showed the contraction out of water and the surface ice the contraction while floating in water.

Mr. Sproule refers to the rising of the water after the ice takes as a probable cause of expansion. The water, however, does not rise in Rice Lake at that time of the year and cannot possibly be considered in the matter.

Mr. MacPherson mentions the fact that the Trestle bridges across water under his charge are not affected by the winter ice. If these waters are extensive, the immunity from ice shoves can only be explained by the circumstance that snow possibly falls earlier in the season in that region, and prevents movement. The suggestion of the possibility of thin ice, or open water near the Rice Lake bridge and on one side of it, or of winds, or currents, acting separately or together, causing ice shoves, is untenable, as such phenomena do not exist there in winter.

Professor Nicolson says truly that the writer only measured the difference between the contraction of the pine rod and the ice, and he regrets he cannot state the exact contraction and expansion of ice per mile. While shoves of three and four feet in width are frequently observed in the lake, it is difficult to accurately locate the centre of movement, and the radius of expansion.

Mr. Thomas Curtis Clarke wisely disclaims any responsibility in connection with the Rice Lake Bridge, and says he has carefully watched the effect of the ice on it. He states in his paper referred to by Mr. Barnett, "That it was predicted by many persons, previous to commencing the undertaking, that no structure could possibly be built which would resist the power of the ice on Rice Lake, and that to these evil forebodings it was replied that it was not supposed that a pile bridge could sustain the thrust of the ice, etc., but it would serve to carry the trains until it would be filled in as a solid embankment."

The author's reply to this is, that the bridge was too costly and substantial for a temporary structure, and too weak and ill planned for a permanent one. More gross blundering or ignorance was never exhibited by professional men. Mr. Clarke further says, that the use of ice breaker cribs used in sufficient numbers, as has been done in the bridge at Belleville, would have prevented the trouble. This may be applicable to the trussed portion of the bridge, but from the author's experience in the matter, *sufficient numbers* of cribs to protect the pile bridge would have almost necessarily touched each other, making the cost exceed that of an embankment.

Mr. Clarke is pleased to say that the conclusions drawn by the author in his paper are not reliable, and for the reason given by Mr. Barnett.

If the reason mentioned, is the apparent discrepancy in the measurement of the contraction of ice under different circumstances, as stated by him and Mr. Irwin, it will, the author thinks, on consideration, appear that it is the *reason* that is not reliable, and not his conclusions.

The paper which has created this discussion and the conclusions in which Mr. Clarke thinks are not reliable, contains the observations, and somewhat crude experiments of the writer when an enthusiastic young man in pursuit of knowledge of a subject of which he had a painful professional experience, and which could not have been found in the books.

He trusts that the "Modern Engineer" may more successfully pursue the investigation of this very interesting, and to him, especially important subject, The Expansion and Contraction of Ice on Canadian Waters.

Thursday, 17th December.

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

The discussion on Mr. Dumble's paper on "The Contraction and Expansion of Ice on Canadian Waters," and on Mr. H. J Cambie's paper on "The Fraser River Bridge" occupied the evening.

Thursday, 29th December.

JOHN KENNEDY, Vice-President, in the Chair.

Paper No. 58.

SHIP TRANSPORTATION.

By H. G. C. KETCHUM, M. Can. Soc. C. E.

Ship transport, in some form or other, has been practised for ages, even before the Christian era. The first example we have on record is that of the Diolcus of Corinth. Some excavations recently made on the Isthmus of Corinth exposed to view remains of this ancient Diolcus. It was a means for land carriage of ships of that period from the harbour of Schænus to the eastern extremity of Port Lechœum. Ships were run ashore and dragged from one sea to the other. The derivation of the word Diolcus is from the Greek verb 'to drag.' The work existed in the time of Aristophanes 427 B.C. and is said to have been in operation 300 years. The site of Schœnus is now called Cocosi. This ship road is thus described in the Lexicon of Cornelius Schrievelius *Διολχος* (Diolcos): "*Tractatus in Isthmo* "*Corinthiaco ubi naves ex Ionio in Œgæum et vicissum trahebantur*" —"A track on the Corinthian Isthmus where ships were hauled "out of the Ionian into the Œgœan Sea and neighbourhood." It was such a great advantage to commerce (owing to the difficulty of weathering Cape Malœa) that Corinth became, by its means, the emporium of trade between Italy and Asia. The size of the ships carried is said to be about 149 feet long, 18 feet wide, with a draught of 8½ feet. It is said that this] method of ship transport was practised by the Greek Admiral Nicetas Ooryfas in the year 831 in order to enable him to attack the Arabian Corsairs who were then devastating the coasts of the Peloponesus.

In 1438 the Venetians carried a fleet of thirty galleys overland from the River Adige to Lake Garda, a distance of 200 miles, the motive power being oxen, assisted on the mountains by windlasses. One thousand oxen are said to have been employed.

This herculean enterprise was proposed by Blasio de Arboribus and Nicolo Sorbolo and was successfully carried out with the loss of but one vessel.

In 1453, at the siege of Constantinople, Soleiman Pacha transferred his fleet by land into the Gulf of the Golden Horn by timber ways, greased and laid on trestles and staging. The feat was carried out in order to avoid a huge chain laid across the Hellespont, which presented an impassable barrier to the entrance of his fleet by water. This *coup de guerre* was accomplished in a single night. The vessels were dragged over two miles, so, on the morning of 22nd April, 1453, the astonished inhabitants saw a large fleet lying close under their walls, and capitulated.

In 1718 Count Emanuel Swedenborg conveyed a shallop, two galleys and four large boats five leagues over mountains and valleys from Stromstadt to Idefjal, in Sweden. Swedenborg, the founder of the Swedenborgian religion was ennobled on account of his invention, which is described as 'a sort of rolling machine." It was also used by Charles XII. to transport cannon to the siege of Frederickshall.

All these examples of ship transportation overland were undertaken and carried out principally for warlike enterprises.

Coming nearer our own time, we have the example of a Portage railway, fifty years ago, from Holidaysburg to Johnstown, Pennsylvania, where canal boats were carried in sections thirty miles from one canal to another, before the Pennsylvania Central Railroad was opened. The Portage Railway was constructed to connect the canal system of Eastern and Western Pennsylvania. It was a system of "gravity railways," with ten inclined planes, and up and down these steep inclines the large boats of the "Pioneer Packet Line" made regular trips until the Pennsylvania Railroad was built, when it ceased to be operated.

There was another of similar construction on the Morris and Essex Canal, in the State of New Jersey.

In Cornwall, England, between Bude and Launceston, the Bude Canal has existed since 1826. At Hobbacote Downs the canal boats, which are furnished with small iron wheels, ascend the uplands by an inclined plane 900 feet long, provided with two lines of rails terminating at each end in the canals. The iron wheels fit the rails and the boats are raised by an endless chain moved by two vast tanks alternately filled with water and descending into wells 220 feet deep. There are seven of these inclined planes in operation on the Bude Canal.

In Germany vessels of sixty tons capacity are carried overland from the upper to the lower part of the Elbing-Oberland Canal, in West Prussia. This transport system has been in successful operation for over twenty years, but when the idea was first broached it was ridiculed by everybody.

In 1860 Sir James Brunlees and the late Mr. E. B. Webb proposed to the Emperor Napoleon III. a ship railway across the Isthmus of Suez in lieu of the present ship canal. Marshal Vaillant, Minister of War for the Emperor, referred the matter to M. de Lesseps, who rejected the idea. Amongst the advantages mentioned in favour of the proposed Suez Ship Railway was the convenience with which the ship's hulls could be examined whilst on their cradles during the passage from sea to sea. The railway was to have been level throughout. The ships were to be supported on a framing of iron resting on numerous wheels and springs, these, again, on ten rails. The speed was to have been twenty miles an hour, and the estimate of cost was one-seventh that of a ship canal. The passage from the Mediterranean into the Red Sea was to have been made in 16 hours. The speed of steam vessels in the present canal is reduced to about 2½ miles an hour.

The Hydraulic Lift invented by Mr. Edwin Clark, M. Inst. C. E, was proposed to be used for the first time by Sir James Brunlees as the means to be employed for raising and lowering vessels at each terminus of the proposed Suez Ship Railway.

This invention, first carried out at the Victoria Docks, London, renders it possible to construct Ship Railways anywhere on the globe where canals have been projected. The author will have the pleasure of exhibiting a model of the ship lift this evening by which it will be plainly demonstrated that by its means, not only ships can be lifted out of their natural element, but that anywhere on dry land, physical difficulties, hills and valleys may be overcome by the use of the Hydraulic Lift, thus avoiding heavy gradients and obtaining shorter lines than would be possible under any other contrivance.

An hydraulic lift can be used to lift vessels on land as well as from the sea. It only requires a water supply sufficient to feed the engines. The water used in the presses can be supplied from a separate tank, which once filled is a sufficient supply for a very long time by re-using the water which is all the better for a little mixture of grease and oil.

By the use of the hydraulic lift to surmount differences of level, and a simple Turntable to change direction, it is easy to build Ship Railways anywhere.

It was owing to a suggestion of Mr. Edwin Clark, in his paper read before the Institution of Civil Engineers in 1866, that the author turned his attention to the possibility of largely cheapening the construction of the Baie Verte Canal by using the Hydraulic Ship Lift, with boat shaped pontoons to convey large draught vessels on a shallow canal. The first plan for a canal was to have a depth of only four feet, the next plan was for eight feet. When Captain Crawley, R.E., proposed nine feet of water on the sills of the canal locks, he declared it to be impracticable owing to the deficiency of a fresh water supply, and he objected to the use of the Bay of Fundy water, owing to its turbid nature. The clear water of Baie Verte could not be used owing to its lower level, which, without being pumped to the height required to supply the deficiency, could not be made available. The author thought, that with such a working depth as the fresh water obtainable would supply, it would be a great advantage to adopt Mr. Clark's suggestion (vide Minutes Inst. C. E. Vol. XXV. page 309): "This system," he said, "affords ready "means, by the construction of a shallow canal of transporting "the largest vessels in cargo, either across an isthmus or over "river shallows; and of removing vessels of war inland, either "for their protection, or for their employment as a means of "internal defense."

The author found a difficulty in working out the problem at the Bay of Fundy *without using some sort of a railway* to transfer these pontoons from the Ship Lift to the proposed shallow canal. This idea led to the present Ship Railway in construction at Chignecto. It became apparent that vessels might as well be lifted to the surface of the ground and hauled across the neck of land on steel rails, thus avoiding all the question of water supply and its various perplexities in this particular locality. It occurs to the author that such a scheme might be used in all the canals of Canada, to convey vessels having any draught, say up to twenty feet. There is no necessity of deepening the existing canals at immense expense when by using pontoons you may so easily and safely convey ocean vessels of 20 feet draught and more through the present canals. All it requires is a lift at or near each terminus at a convenient place where the water is deep enough for the purpose. The pontoon should be open at the top and provided with blocking gear to receive the vessel on the Hydraulic Lift. When lifted the pontoon can be towed away with the vessel upon it to the other end of the canal, in the vicinity of which another lift would be erected, and ready to receive the vessel and release her from the pontoon, when she could continue her voyage to her destination. The simplicity and economy of this method is beyond question.

The hydraulic Lifts could also be utilized as Graving Docks for all sorts of Lake craft. With proper precautions to preserve the pipes from frost, as proposed to be used at Amherst, N.S., on the Chignecto Ship Railway, there is no danger of damage from this cause, or from ice if properly situated and protected. The system of pontoon floating may also be applied to the River Shallows of the St. Lawrence in many places. The pontoons, which may be called "steel rafts," would draw from six to eight feet water according to their size and the load of vessel carried upon them. They are largely used at Malta in the Mediterranean for vessels of 3,000 tons in cargo.

In 1872 a remarkable Ship Railway was proposed by the Republic of Honduras across its territory from Puerto Caballos on the Atlantic Ocean to the Bay of Fonseca on the Pacific Ocean, about half way between the Panama canal of M. de Lesseps and Captain Eads' Ship Railway on the Isthmus of Tehuantepec. It was intended to adapt the Interoceanic Railway, then under construction by the Republic, for the purpose of a Ship Railway. It was to carry 1,200 tons and would doubtless have been carried out if the Republic could have found the money, which they failed to do.

Later on Sir John Fowler prepared plans for a Ship Railway for the Khedive of Egypt to overcome the cataracts of the Nile.

Then the Tehuantepec Ship Railway, the huge enterprise of Mr. Eads, the engineer of St. Louis Bridge and Mississippi Jetties, was projected and a concession obtained by him from the Mexican Government.

This Ship Railway project is still alive. It will be about 130 miles long and will connect the Gulf of Mexico with the Pacific Ocean. The gradients are to be 50 feet to the mile. The elaborate investigation into the merits of this great work, which took place before a committee of the United States Senate brought forward an amount of evidence of experts in ship building which ought to silence forever any objections that might be raised against Ship Railways in general as to the liability to unduly strain vessels during their transport from sea to sea. Mr. Eads and his able coadjutor, Mr. Corthell, have done valuable work in the cause of Ship Railways, by spreading abroad their views and disseminating the evidence given before the committee of Congress. The projectors of all Ship Railways will be greatly indebted to Mr. Corthell for so clearly setting forth the economy to be gained by the introduction of Ship Railways in his paper on "Canals and Railroads, Ship Canals and Ship Railways," read at the Convention of the American Society of Civil Engineers, June 25th, 1885.

The conclusions derivable from Mr. Corthell's valuable paper are "that a canal cannot compete in speed or economy or facilities with a railroad; and that a Ship Canal must also be much more expensive than a Ship Railway in first cost, maintenance and operatiou, and much inferior to it in dispatch facilities and conveniences."

He says: "The cost on the best railroads is three mills per ton per mile for *through* freight."

Deducting irrelevant items, such as do not pertain to a Ship Railway, the cost can be properly reduced to one and a half mills. But he also maintains that the cost can be reduced on Ship Railways to *one mill per ton per mile*, because much larger loads are carried.

'The ratio of paying to non-paying loads is greater,' 'The frictional resistance to the motive power is reduced,' 'The Line of Railway is straight,' 'The Track perfect,' 'The Gradients, if any, very easy,' 'Greater results are obtained with less fuel and service.'

Detailed plans of a Steamboat Railway on the Dalles of the Columbia River, Oregon, have been submitted to the Secretary of State for war, U.S.A., and General Casey, Chief of Engineers, U. S. Army, in forwarding his report to the Secretary of War pronounced it feasible and the best solution of the problem presented! A Ship Railway has also been proposed across the Peninsula of Florida.

Torpedo boats 35 metres in length have been transported from Brest to Toulon, France, on an ordinary railway, on five specially adapted luggage trucks. In fact, Ship Railways may be largely used in war to transfer even ironclads from one sea to another and even into the interior of a country.

The author will now turn your attention in general terms to his own project of the Chignecto Ship Railway—17 miles long, to carry vessels of 1000 tons register with cargoes, total 2,000 tons weight. At the time it was conceived he had not the most remote idea of its ever being brought to its present stage of completion, and it was not until Sir Charles Tupper took hold of it that there seemed any probability of its being carried out. It was Sir Charles Tupper who gave it life and prevented the project from being crushed beneath the weight of ridicule and incredulity which assails any great work of a novel description. The declaration of your Ex-president, Mr. Thomas C. Keefer, C.M.G., that a Ship Railway was the only feasible method of overcoming the obstacle to commerce presented by the Isthmus of Chignecto was also of powerful influence in support of the scheme in its early stages.

The first essential of a Ship Railway is to have good ports at each terminus, not only to enable vessels of the maximum depth to enter with ease, but also to provide a receptacle or basin for them to lay in quiet water, so they may take their turn to be floated over the Grid of the Lifting Dock, otherwise in any great breeze of wind, it would be difficult to insert the blocks properly under the bilges of the vessels whilst they are about to be lifted from the water to the level of the Railway.

A few remarks now about Hydraulic Lifts and the strains on vessels will conclude this paper, which is an introduction to another paper on the "Chignecto Ship Railway, the substitute of the Baie Verte Canal," which will be read this evening.

The present paper is a proper prelude as illustrating the many steps leading up to the Chignecto undertaking, whereby Canada will be the first country to actually inaugurate this new and economical system of ship transportation for steamers and large sized vessels.

The Hydraulic Lift Graving Dock at the Victoria Docks, London, has been in operation nearly thirty years and has lifted about four thousand vessels with perfect safety. It is 300 feet long and sixty feet wide; it can lift a vessel of 3,000 tons weight. The successful operation of this first experiment of the kind led to the construction of others in different parts of the world.

In 1876, the Clarence Lifting Dock at Malta was another great success. It was the first to lift vessels in cargo. Ships coming through the Suez Canal stop here when they require repairs and these repairs are made without disturbing the cargo. In August, 1886, the ship "Glenasteg" of 2,143 tons gross register was lifted with 2,000 tons of cargo, and many other examples can be given.

Another Hydraulic Ship lift was erected at Bombay, now owned by the Peninsula and Oriental S. S. Company, which lifts vessels of 5,000 tons register.

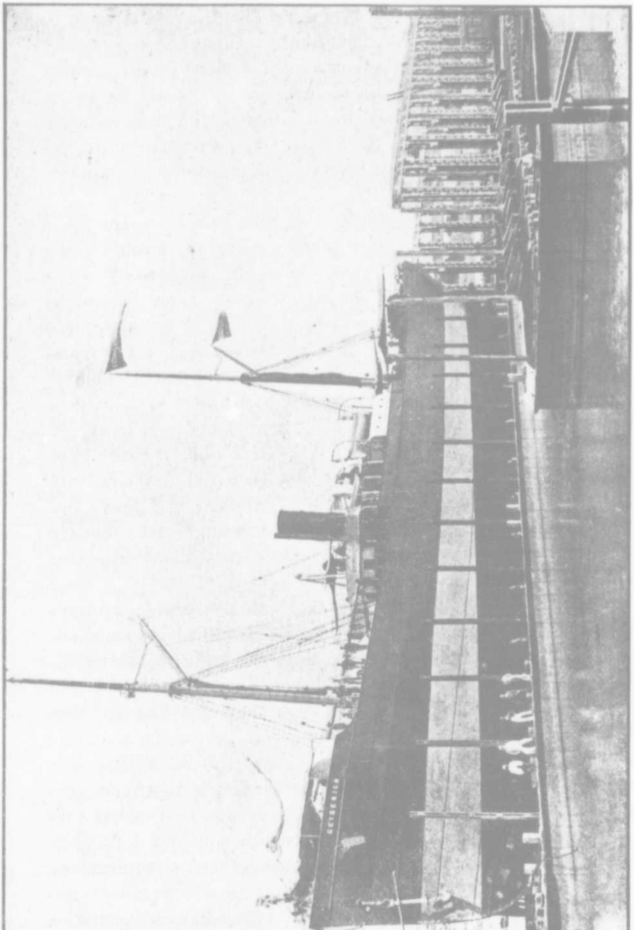
There is no Hydraulic Lift that the author has heard of in America excepting one at San Francisco. Here vessels are placed and blocked directly on the grid without the intervention of pontoons. All the others named have used open pontoons, for the purpose of floating vessels away to another place to undergo repairs. Any number of pontoons may be employed to multiply the uses of the dock. Without their aid (as in the case of the San Francisco dock) one vessel only at a time can undergo repairs

An Hydraulic Lift is in use at Anderton, Cheshire, where one press lifts a trough of water fifty-five feet high, from the River Weaver to the level of the Trent and Mersey Canal.

Many persons thought a water cradle or a trough of water would be necessary to carry vessels on a railway. A little study will prove the contrary. One vessel would then be inside of another one, really weaker in construction, as the outer vessel could not very well have cross beams like the one to be carried, and it is also carrying double the load.

Mr. W. M. Smith, M. Inst. C. E. of Aberdeen, has patented a Ship Cradle with hydraulic cushions—"a series of plain "tubes of india rubber and canvas filled with water, and placed "side by side athwart the ship from stem to stern, the open ends of "each tube on a level with the deck and the middle of the tubes "bent underneath the ship's bottom, and resting on the car."

The idea is ingenious, and time will show whether it ought to be adopted. It is desirable not to set up any oscillating motion to



PONTOON FLOATING IN THE MEDITERRANEAN.

A STEAMER OF 4000 TONS ON A PONTOON DRAWING ONLY 8 FEET OF WATER.

prevent the undue distribution of the weight of vessels and cargo while on the cradle. The inventor claims that the vessels would be as good as water borne, but if oscillation should be in any way caused by this mode, the advantage of a merely soft cushion would be neutralized by this defect, and it would be better to stick to proved methods of blocking in the first instance.

Sir Edward J. Reed, K. C. B., late Chief Constructor in the British Navy, in his evidence before the Committee on Commerce before mentioned, said :—

"I should like to say at first that, as a naval constructor, I have no fear whatever of a ship undergoing any strain in the process of lifting out of the water (as would be necessary in the case of a ship railway) that she is not liable to at present in ordinary docking. I would say, further, that I am quite sure that the processes of ordinary docking carried on in a vast number of private establishments are very negligent and insufficient in comparison with those which would be adopted in the case of the hydraulic lifts connected with the proposed ship railway.

"They seem to think there are no vibrations or jerking, or forces of some kind the ship would be subjected to on the railway that she is not subjected to at sea. That feeling, I know, is a pretty general one. I can only attribute it to the fact that the gentlemen who so think are not acquainted with the strains that ships undergo at sea.

"The next thing I would say is that we have ships on railways and we have them in the worst form. Nothing is commoner than heaving up slips upon which ships are pulled up out of the water. They have to take their bearing first at the bow, and gradually come up until they get upon the solid, and are then hauled up by chains.

"That has been done everywhere, all over the world, thousands of times in this country, and it is now carried on to a very large extent indeed. With docks for ships of 3,000 or 4,000 tons nothing is thought of pulling these ships up, and nothing is thought of any strains they undergo under the circumstances.

"If it is sufficient on a Ship Railway to provide against something like the worst hurricanes at sea, then I have no hesitation in saying that it is perfectly impossible for these ships on the railway to come to any grief from wind, because the resistance to hold the ship upright on her cradle on the railway track is, I think, very many times greater than the forces which keep her upright at sea.

"With a track like that, and with locomotives adapted to it, there would be no difficulty in transporting ships. It would be best to avoid a very high rate of speed. It would not be necessary, I should think, to move these ships at a greater speed than eight or ten miles an hour, although I am quite prepared to believe that, with a proper track and locomotives, vessels could be transported much faster."

In September, 1882, the author referred the question of ship strains to Professor T. Claxton Fidler, M. Inst. C. E., now of the Dundee University, who reported as follows:—

"In connection with the ship herself, it will be important to arrive at some estimate of the strains to which she may be exposed during the process of land-carriage, as compared with the strains which she frequently undergoes in a heavy sea, and to which her strength *should* be, and generally *would* be proportioned.

"The gross weight of ship and cargo being taken at 2,000 tons, her displacement will be 2,000 x 35 = 70,000 cubic feet; and with an ordinary coefficient of fineness the leading dimensions of a sailing vessel of this displacement may be taken to average roughly.

Length........	200 feet
Breadth...........	35 "
Depth............................	16 to 17 feet

"As an average example, I may, perhaps, take the case of an actual sailing ship whose length is 205 feet and breadth about 36 ft. 6 in.; the greatest load displacement of this vessel is somewhat greater than 2,000 tons, but she has that exact displacement when loaded to a smaller depth of 16 ft. 3 in. The ends of this vessel are of moderate fineness, while her middle body is very full and for one-third of her length nearly parallel, the average area of the immersed cross section for the middle third of her length is about 520 sq. ft., or nearly 15 tons displacement per foot of length. One half of the total displacement is therefore contained in the middle third of her length, the other half is divided between the two ends and will average $7\frac{1}{2}$ tons per foot. This represents the actual distribution of the supporting forces when the ship is floating in quiet water; the distribution of the *load*, however, will, of course, vary according to the lading of the ship. Assuming, with Prof. Rankine, that one half of the total load may be taken to be distributed in proportion to the displacement and the other half uniformly distributed over the length of the ship, this would give (as a rough calculation) a load of about $12\frac{1}{2}$ tons per foot for the middle body diminishing to 5 tons per foot at the extreme ends, or averaging about $8\frac{3}{4}$ tons per foot for the fore and after bodies, and this rough calculation would show that in still water the vessel suffers a hogging strain of about 7,000 foot tons as the moment due to the excess of weight of the fine ends over their buoyancy. This amount would, of course, vary according to the build of the vessel, being greatest in vessels with very fine ends, but when the ship is supported upon the crest of a wave she undergoes a further hogging strain, which is much more serious and which is greatest in vessels having bluff ends.

"The total hogging moment due to these two causes is given by Rankine equal to the total displacement multiplied by $\frac{1}{20}$ of the length for all vessels of ordinary build. In the case of the 2,000 ton ships, therefore, this will amount to $2{,}000 \times \frac{200}{20} =$ 20,000 foot tons. In order to compare this theoretical requirement with the strength of vessels as actually built in good practice, the case of an iron sailing ship 205 feet long is taken as a practical example. This vessel is $23\frac{1}{2}$ feet deep from the floor to the stringers of the upper deck, and her neutral axis lies at $\frac{5}{8}$ of the depth. The hogging moment given by Rankine's rule above quoted produces a maximum tensile strain of 3.92 tons per square inch, and a compressive strain of $3.92 \times \frac{3}{8} = 1.47$ tons per square inch only. In the case also of a well built wooden vessel it appears that the strain is within the working strength of the material in nearly the same proportions as in this iron ship.

"We may take it therefore that the safe working strength of any well built vessel is fully sufficient to carry this bending moment, viz: Displ. $\times \frac{1}{20}$ length, when acting as a hogging-strain, and $\frac{3}{8}$ of this amount as a sagging strain, and that this bending strain will not exceed the strain that she actually suffers at sea whether she is well built or not."

This report goes to show that on a Ship Railway Cradle there would be less strain upon a vessel than she suffers by simply laying in quiet water.

It is impossible within the limits of one paper to enter more largely into the various problems that have to be worked out in connection with Ship Railway Cradles, Axles, Wheels, Rails, etc., and the Society will excuse the author from going into more details, until the problem (which has been carefully worked out at Chignecto) is fully tried there.

THE CHIGNECTO SHIP RAILWAY—THE SUBSTITUTE FOR THE BAIE VERTE CANAL.

By H. G. C. Ketchum, M. Can. Soc. C. E.

The first proposal for a canal to connect the waters of the Gulf of St. Lawrence with the Bay of Fundy was made during the French regime by the Abbè de la Loutre, the enterprising leader of the French colonists of Acadie.

In 1783 Colonel Robert Morse, Chief of the Royal Engineers, was ordered by Sir Guy Carleton, Commander-in-chief of His Britannic Majesty's forces in North America, to make a report on the "state of the defences, with observations leading to the further growth and "security of the colony of Nova Scotia," which then included New Brunswick and a part of the State of Maine. In this report Colonel Morse suggested "the idea of "opening a water communication between the Gulf of St. "Lawrence and the Bay of Fundy," which he said, "would be "attended with good effects," and he spoke of "the many and "great advantages which would result to the country from such "a communication."

In this respect all the engineers who have studied the project from that date have been in perfect accord with Colonel Morse, who, however, looked upon such a communication mostly from a military and naval point of view. He regarded the Canal as a means of naval defence, whereby war vessels could pass from sea to sea for the purpose of attack or defence without running the gauntlet of a hostile fleet on the Atlantic coast of Nova Scotia.

This isthmus of Chignecto is historic ground. Two-and-a-half centuries ago Fort Lawrence was the headquarters of Chevalier de la Vallière, the Seigneur of Chignecto and Governor of Acadie. From his day until the fall of Quebec the country within sight was almost continually the theatre of stirring action. The French regarded the possession of the Isthmus of Chignecto of strategic importance as a half-way station between Port Royal and Louisburg, Cape Breton, on the one hand, and Quebec on the other.

The English fought and struggled for its possession, as it afforded the French a base of operations from which the English settlements could be harassed. The tide of combat rolled around it intermittently for 150 years. It has been captured and recaptured in the French and Indian wars, and during the American revolution a small army of volunteers from the neighbouring republic beseiged Fort Cumberland.

The heights of Fort Cumberland have frequently beheld fleets of warships flying the Lilies of France, and the White Cross of St. George. It ranks with Louisburg and old Port Royal in historic interest and importance, and was rightly considered one of the keys of Canada.

Should there be war between Great Britain and any European power there is no doubt that a highway for vessels of war, such as gunboats and torpedo boats, would be of the greatest possible advantage to Great Britain and Canada in the defence of the Maritime Provinces.

In 1822 the Government of New Brunswick instructed Mr. Robert C. Minnette, Provincial Land Surveyor, to make the first actual survey of a canal, which he accomplished in that year.

In 1825 Sir Howard Douglas, Governor of New Brunswick, employed Mr. Francis Hall, Civil Engineer, to report on the construction of a canal on the line of Mr. Minnette's survey.

In 1826 Sir Thomas Telford, the most eminent English engineer of the day, founder of the Institution of Civil Engineers in London, was consulted as to the feasibility of Mr. Hall's plans. He reported that "if this canal were completed, ready " access would thereby be opened, not only with Quebec and " Montreal, but also with the upper lakes to a boundless " extent."

In 1843, Capt. H. O. Crawley, of the Royal Engineers, was employed at the joint expense of Canada, New Brunswick, and Prince Edward Island to report on previous schemes. He said: " It is unnecessary for me to dwell upon the importance of an " undertaking which seems to be generally admitted."

After this date public attention was directed to Railways and it was proposed to utilize the Steamship Lines now established on either side of the Isthmus by transhipping freight over a

Line of Railway to be built between the Bend of Petitcodiac on the Bay of Fundy, and Shediac on the Gulf of St. Lawrence.

In 1853, a Company was formed and a contract made with Messrs. Peto, Brassey, Betts and Jackson, and work commenced on this Line of Railway from Moncton to Point du Chene, a distance of 18 miles. It was, however, taken out of the hands of that firm in 1856 and completed by the Government of New Brunswick in 1858. This was the first line constructed by the Government of that Province under Mr. A. L. Light, M.I.C.E., Chief Engineer. Cargoes from the Gulf ports were transhipped at Point du Chene, carried over the Isthmus and again put into steamers on the Bay of Fundy. In 1860, this line was extended to St. John, New Brunswick, a total distance of 108 miles, and freight from the Gulf Ports and Prince Edward Island was then transhipped from steamers to the railway and from the railway to the steamship lines plying between St. John, N. B., and Portland and Boston.

A line from Pictou to Truro, a distance of 55 miles, was afterwards completed across another part of the Isthmus by the Government of Nova Scotia under Mr. Sandford Fleming, C.M.G., Chief Engineer.

Subsequently a line of railway from Sackville to Cape Tormentine, and branches from the Intercolonial Railway to Buctouche, Richibucto, Chatham, Caraquet, Dalhousie, N. B., have all been completed, showing the great importance attached to the trade flowing from the Gulf of St. Lawrence towards St. John and the United States.

" The business done on these lines affords evidence of the large " volume of traffic seeking transit between the Gulf and Bay, or " between the Gulf and the Eastern States of the Republic."

" Where there is so large a railway traffic it needs no argument " to show that there must be an enormous water bourne traffic " when once the Short Cut across the Isthmus of Chignecto is " possible."

Notwithstanding these railway facilities there are many bulky articles of commerce which cannot, with economy and convenience, be carried any great distance by rail, and when there is a necessity and expense of transhipment and rehandling, the railway carriage becomes sometimes too expensive to leave any profit. Such is the case with lumber, coal, gypsum, plaster, building stone, potatoes, deals, fish, &c., &c.

In 1869 a Company was incorporated by the Legislature of Nova Scotia to build the canal, as a private work, and the interest in it was accordingly revived.

In 1869 the late John Page, C. E., Chief Engineer of Public Works, was called upon to report upon all previous surveys of the Baie Verte Canal, which at this date had again become a live question, and further surveys were ordered by the Dominion Government. In 1871 a most thorough survey was made of the whole Isthmus by Mr. F. Baillargé, Assistant Chief Engineer of Public Works.

In 1872 Sir Casimir Gzowski and the late Mr. Samuel Keefer, C. E., surveyed and recommended a line of Canal approximately on the route of the present Ship Railway.

Samuel Keefer, C. E., observed that in the comparatively isolated condition of the Provinces before Confederation the necessity for this short line of communication was not felt; but now that they form one united Dominion, bound together by ties, political and commercial, the trade growing up between them must tend year by year to give greater importance to the proposed shorter and safer line of navigation.

The estimated cost of this line of canal by these engineers was $5,317,000, but Mr. Page, on examination of the estimate, alleged that there had been undervaluations and omissions, and he added to it 25 per cent. for undervalue placed on works, $1,329,250, and for omissions $450,000, making the probable actual cost of work, according to Mr. Page, $7,100,000.

Mr. Page declared "that the construction of a navigable chan-
" nel between the Bay of Fundy and the Gulf of St. Lawrence, on
" any line that can be selected, will be an undertaking attended
" with unusual difficulty, not only from the nature of the work
" to be done, but from the great difference in the elevation of the
" respective tides."

The range of the tides in the Bay of Fundy has always been exaggerated in the school books and gazetteers. The most careful observationa taken by Mr. Baillargé, C. E., in 1870, resulted in establishing the range of tides to be 38 feet at neap and 48 feet at spring tides. The greatest tide ever known occurred on the 5th October, 1869, at new moon. The range was then fifty-seven feet, six inches. It is well known as the Saxby tide, so called from a prediction made nearly a year before it happened, by Lieut. S. M. Saxby, R. N., which appeared in the London *Times* in December, 1868. The following reasons for the prediction were given in his own words: "At 7 a. m., October 5th, the " moon will be at that part of her orbit nearest the earth. Her " attraction will therefore be at the maximum force. At noon of " same day the moon will be on the earth's equator, which never " occurs without marked atmospheric disturbance, and at 2 p. m. " same day lines drawn from the earth's centre would cut the " moon and sun in the same arc of right ascension. The moon's " attraction and the sun's attraction will therefore be in the same " direction. In other words the new moon will be on the earth's " equator and nothing more threatening can occur without " miracle." This prediction was verified by very high tides and a terrible storm on the Bay of Fundy.

The extreme range of tides in Baie Verte was observed to be 10 feet 8 inches; the ordinary range being only 5 feet 7 inches. Thus while the fluctuations above and below the mean sea level were only 2 feet 9 inches at Baie Verte, they were at the same time 19 feet above and below mean sea level on the Bay of Fundy at neap tides, and 24 feet at spring tides.

A Royal Commission composed of the most representative commercial men of Canada, selected from the different provinces, was appointed by the Government in 1871 to investigate the whole canal system of Canada, with the late Sir Hugh Allan as Chairman. The Baie Verte Canal after full enquiry and examination, was placed by them in the first rank of all the canals of the Dominion. The following is extracted from the report of the Canal Commission: " The growth of Intercolonial trade depends " on cheap transit, since the merchandise passing between the " Maritime Provinces and Ontario *must be of a bulky character*, " requiring large vessels and rapid dispatch to be really profit- " able. When a propeller can go direct with a cargo of coal, or " other produce of the Eastern Provinces, to Kingston and To- " ronto, and there get a return freight of flour, barley, and other " Western produce, Intercolonial trade will have entered on a " new era.

" When Nova Scotia coal of the best description can be supplied

" abundantly and cheaply to western ports, a great impulse will " necessarily be given to the transfer of the trade of the St. Law- " rence and Lakes to screw steamers, a transfer already taking " place, as we have previously shown.

" With the canals enlarged, coal freights would be reduced to " the minimum point—a lake propeller would always bring back " from the lower ports a cargo of coal, rather than come empty " —just as the English timber ships have been accustomed to " bring the same article instead of ballast.

" Inseparably connected with the growth of Intercolonial trade " is the construction of the Baie Verte Canal across the Isthmus, " connecting the Provinces of Nova Scotia and New Brunswick. " The advantages that must accrue, not merely to the Dominion " as a whole, but to the commerce of the Maritime Provinces, are " so clearly pointed out by the Boards of Trade of all the lead- " ing cities of Canada, and by men interested in the development " of our commercial interests, not simply the merchants of St. " John and other places in the locality of the proposed Canal, but " merchants of Hamilton, Toronto, Ottawa, Montreal and Que- " bec, that it is superfluous for the Commissioners to do more " than briefly refer to a few salient features of the scheme.

" A steamer laden with flour for St. John. N. B., now goes " down the Gulf as far as Shediac, where the cargo is transported " by rail to its destination. The total distance by water from " Shediac through the Gut of Canso and around the coast of " Nova Scotia to the Bay of Fundy as far as the commercial " capital of New Brunswick is about 600 miles, and the conse- " quence is that there is little or no direct communication be- " tween the Bay of Fundy ports and those of the River St. Law- " rence. By a Canal through the Isthmus the distance from " Shediac to St. John will not be much more than one hundred " miles."

Accordingly the Government of the day decided to proceed with the construction of the canal. His Excellency Lord Dufferin, at the opening of the session of 1873, in his speech from the throne, used the following language:

" I am glad to inform you that plans and specifications for the " enlargement of the Welland, and the construction of the Baie " Verte Canal, have been completed, and that the works can now " be put under contract. The surveys for the St. Lawrence

"Canals will, I am assured, be finished in time to commence the "works at the beginning of next year. This will insure the com- "pletion of all these great works at the same period."

In accordance with the promise thus given, one million dollars was placed in the estimates for the construction of the Baie Verte Canal, which, according to the late Mr. Page's estimate of the line surveyed by Messrs. Gzowski and Keefer, was to cost $7,100,000.

In 1875, under a change of Government, another commission was appointed, with the late Hon. John Young as chairman. The report made by this Commission was unfavorable. Indeed, it is said the Commission was purposely appointed to defeat the project and save the new Government the necessity of making the outlay pledged by Parliament.

The Hon. Joseph Lawrence, one of the Commissioners, protested against the verdict of the majority, and ably defended the commercial prospects of the canal in a separate report.

It was afterwards discovered that an error had been made in their computation of the distance to be saved by the Short Cut. The Commissioners had represented the distance saved from Montreal to St. John as only 225 miles, whereas it is actually 500 miles, making an error in their calculations of 275. Their opinion was, that the small distance to be saved would not warrant the expenditure. The prejudice produced in some quarters by the misrepresentation of distance (and hence the erroneous conslusions of the report) endures to this day. The following admissions were however made:

"The evidence taken, and the observations which the Commis- "sioners have had the opportunity of making, have impressed "them deeply with the vast resources of New Brunswick, Nova "Scotia and Prince Edward Island, and the large increase which "may be reasonably looked for in their trade and commerce."

It was, however, most fortunate for the Dominion that the verdict of this Commission, incorrect as it was, delayed for a while the public expectation. It gave time for a *new idea* to be developed which was happily destined to prevent the country from falling into a most irretrievable error of judgment and from an expenditure counted by millions of dollars,—*a better mode of communication between the two seas was possible.*

In 1875 the author of this paper submitted his opinion to the public through the Press that a Ship Railway would not only fulfil all the requirements, but in many respects would be preferable to a canal; that there was no engineering difficulty either in the construction or operation of such a line; and that vessels in full cargo could be transported over the Isthmus in perfect safety and at small expense. That the transport would take less time, and the maintenance, repairs and operating would be no greater than by canal. This bold suggestion arrested all further discussions of a canal, and for six years there was no further move made tending to solve the problem of the Isthmian Transit. The Dominion Government had entered upon a policy of fostering its own manufactures and relying upon its own productions for its prosperity. The result soon showed itself in a marked increase in the raising of coal and lumber, which was followed by a corresponding increase in the coasting trade and commercial marine of the Maritime Provinces.

At length, in 1881, the author carried out, at his own expense, a survey and location for a Ship Railway, and having found a good line, submitted a proposal to the Hon. Sir Charles Tupper, Minister of Railways and Canals, offering to form a company to carry out the work, provided the Government would subsidize the work, for about one-third the cost of a canal.

The proposed subsidy took the form of a contribution by the Government to the Company of $150,000 per annum for twenty-five years, which, if capitalized at four per cent., would be equal to the sum of $2,343,312.

The proposal, therefore, if adopted, would save to the country the cost of the Canal, to which it was pledged, as before stated, estimated at $7,100,000, less the sum of $2,343,312, the capitalized value of the subsidy, or a saving of no less than $4,756,688.

Hon. Sir Charles Tupper, Minister of Railways and Canals, referred the whole question to the Chief Engineer of his Department, and Mr. Collingwood Schrieber reported as follows:—

1. "That the project is quite practicable of execution."

2. "That the Ship Railway as proposed would be a good sub-"stitute for the Canal originally contemplated."

3. "That the advantage in respect of cost as compared with "that of a Canal would be greatly in favour of the Ship Railway, "the cost of a half-tide canal being calculated by the Govern-"ment Engineers at from $5,650,000 to $8,217,849: whereas the

"subsidy asked for by the Company, namely, $150,000 for 25 "years, if capitalized at 4 per cent. would be equal to the sum of "$2,343,312 only."

The Commissioners in their Report on page 51 state: "The "distance from Shediac to St. John by the present route, via the "Gut of Canso, to be 600 miles. This distance would be reduced "by the construction of the Baie Verte Canal to about 100 miles. "and freights would, in their opinion, be diminished by 25 per "cent., greatly benefiting the coal trade and fisheries, and in-"creasing the volume of general business."

They state further (page 53): "This canal cannot be consider-"ed apart from the canals of the St. Lawrence as a Cana-"dian canal, as Sault Ste. Marie is the natural commencement of "the improvements of the inland navigation of the Dominion, so "the work through the Isthmus of Chignecto is the inevitable "conclusion necessary to give unity and completeness to the "whole system. It is Canadian in design and must prove "national in its results."

On page 79 the Commissioners say: "The evidence submitted "points out with remarkable force and unanimity the necessity "of opening a Highway for commerce between the Gulf of St. "Lawrence and the head waters of the Bay of Fundy through "the Isthmus of Chignecto dividing them."

The above statements are now twenty years old, and the tonnage of the ports adjacent to the Isthmian Transit has more than doubled itself since those words were written.

The Chief Engineer further said, that "Assuming that the "importance of a Ship Highway over the Isthmus was, at the "time of the Commissioners' Report so great as therein stated, "it must be much greater now considering the large increase "since that date in the trade of the country affected by the pro-"posed work."

The proposal of the author was accepted by the Government, approved by Parliament, and a company incorporated to carry out the undertaking. The provisional Directors were: Mr. Thomas C. Keefer, C.M.G., the first president of the Canadian Society of Civil Engineers; Mr. Edwin Clark, the eminent engineer and inventor of the Hydraulic Ship Lift; Mr. C. R. Coker, Lloyds Surveyor of Shipping; Mr. R. G. Lunt, the well-known Steamboat Manager; and the author.

The Board of Trade of St. John, New Brunswick, passed the following resolutions on the 20th October, 1883:

" *Whereas,* Means of communication between the waters of the "Bay of Fundy and the Gulf of St. Lawrence, whereby products "of the several Provinces bordering thereon may be inter- "changed without encountering the dangerous navigation of the "Atlantic Coast of Nova Scotia, whereby steamers and sailing "vessels, adapted as well for inland as for ocean navigation, may "be safely conveyed across the Isthmus of Chignecto without the "cost and delay of transhipment or breaking bulk, and whereby "the sailing distance between this port and all ports north and "west of said Isthmus may be reduced about 600 miles, would "increase the volume of trade and benefit the shipping interests "of this port and other ports in the Bay of Fundy and Gulf of St. "Lawrence; and

" *Whereas,* By means of a Ship Railway across the Isthmus, "the objects aforesaid may be accomplished, and thus stimulate "the development of the agricultural, mining, lumbering and "fishing resources of the district contiguous to the aforesaid "ports; and

" *Whereas,* A company has been formed for the construction "and operation of a Ship Railway, with commodious Docks and "Hydraulic Lifts for raising and transporting over its line laden "vessels of 1,000 tons register; therefore

" *Resolved,* That this Board is of opinion that the undertaking of said company would "greatly facilitate trade and commerce between the Eastern and Western Provinces; and further

" *Resolved,* That this Board cordially approves the project for "building the said ship railway, believing that this is a movement "which will commend itself to all classes, and prove to be of "great convenience and benefit to our trade and commerce gen- "erally."

In March, 1886, a formal contract was entered into by the Company with the Government which made a change in the annual payments of the subsidy, but reduced the time over which it extended from 25 years to 20 years. The company was not to call upon the Government for any portion of the subsidy except what might be required to make up the net earnings of 7 per cent. on the authorized capital of $5,500,000, and the company agreed to pay over to the Government one-half the surplus profits beyond the 7 per cent. until the whole of the subsidy which may then have been paid to the company shall have been repaid to the Government.

After various unsuccessful attempts by the author to get parties to undertake this novel and difficult work, and find the money, at last, in the early part of the year 1888, Mr. John G. Meiggs, the eminent contractor of South American fame, offered through the author to form a company in London to carry out the undertaking, provided an extension of time could be made to the contract already entered into with the Government.

Application was accordingly made and the extension of time granted by the Dominion Government and Parliament in the spring of 1888.

The plans were prepared and submitted to the Chief Engineer of the Department of Railways and Canals, and formal approval given by the Governor General in Council in, May, 1888.

The line of railway and docks were then finally located under the instructions of the author by Mr. J. S. Armstrong, M. Can. Soc. C. E., and tenders invited for the grading, masonry, and the various works.

The Company was re-organized in London, the preliminary stock subscribed, and the directors appointed.

The Board consists of Mr. Thomas Wood, President; Col. Paget Mosley, Vice-President; Mr. A. D. Provand, M.P.., Mr. W. H. Campbell, Mr. A. R. Robertson, and Mr. Arthur Serena, Directors.

Sir John Fowler, Sir B. Baker, and H. G. C. Ketchum were appointed Engineers.

A contract was then entered into between the Company and Messrs. John G. Meiggs & Son for the execution of the work, and subsequently £650,000 of the capital was raised in London by subscription; £300,000 being in preferred shares and £350,000 in first mortgage Bonds.

Under this contract, work was commenced by the Company in October, 1888. Messrs. Meiggs & Son contracted with Messrs. Dawson, Symmes and Ussher, of Niagara Falls, for the earthwork and masonry, for the line of railway and docks, the dredging of the entrance channels, and the platelaying and ballasting; also for the erection of the moles at Tidnish. With Messrs. Easton & Anderson for the supply of the hydraulic lift machinery, its erection and working. With Messrs. Rhodes, Curry & Co., of Amherst, for buildings containing the pumping machinery. They also supplied the heavy pine sleepers for account of Messrs. Dawson & Co. Messrs. Cammell & Co., of Sheffield, supplied the steel rails, which are 110 lbs. to the yard of toughened steel. Messrs. Handyside & Co., of Derby, supplied the ship cradles, which are made entirely of steel. Messrs. Harris & Co., of St. John, contracted for the cradle wheels, and the Canadian Locomotive and Engine Co., of Kingston, are building the heavy tank locomotives.

The engineering staff, under Messrs. Fowler, Baker & Ketchum, consisted of Mr. F. F. S. Kelsey, resident engineer; Mr. J. S. Armstrong, principal assistant; Mr. M. Fitzmaurice, assistant engineer; Mr. S. J. Symonds, inspector, and others, on behalf of the Company: Mr. George Buchanan, engineer, and Mr. Arthur W. Bateson, agent, for the Chief Contractors: Mr. J. B. Denison, and Mr. G. F. May, engineers for the Hydraulic Works: and Mr. J. F. O'Rourke, engineer for the Sub-Contractors.

The land required for the line of railway and docks was presented as a gift by the Muncipality of the County of Cumberland, Nova Scotia.

The works were prosecuted vigorously from the date of commencement to the end of July, 1891, when they were unfortunately stopped because of the impossibility of floating the remaining bonds which the company had in hand (viz., £350,000) in the present critical state of the money market.

Up to the time of suspension, the engineer's certificates for work done and materials furnished by the contractors, amounted to £670,894 5s., paid in cash, bonds and shares, and the engineering and administration expenses of the Company amounted to about £30,000 in addition.

From a careful estimate made of the cost to finish the works, to equip with rolling stock, to provide interest on capital, to finance the remaining debentures, and to provide for further-engineering and administrative expenses, it is calculated that $1,500,000 will fully cover all expenses.

The whole work may be said to be three-fourths done, and it would take but one summer season's work to entirely finish the Ship Railway and Docks fit for opening to the public.

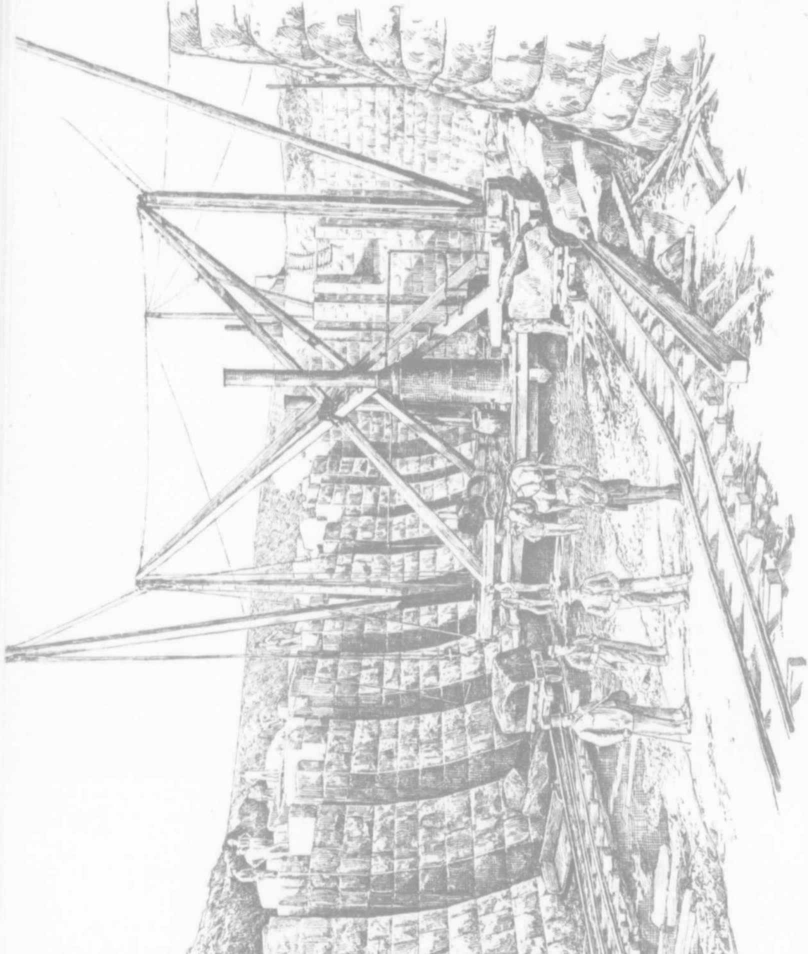
The principal excavation yet to be done is that for the entrance channels at each end of the line, which have been commenced and are considerably advanced, but can not be entirely finished until the hydraulic machinery for lifting the vessels is erected.

All the hydraulic machinery has been manufactured and delivered. All the rails, sleepers, and permanent way materials have been delivered. The whole of the line of railway has been graded with the exception of about a mile of broken work. Twelve miles of track have been laid, and the greater part of the bottom has been ballasted with broken stone. The costly work remaining to be done is the masonry and gate of the basin at the Bay of Fundy end of the line, and the masonry of the two lifting docks. The buildings containing the hydraulic pumping machinery have been nearly finished and the machinery in them erected.

The ships' cradles, manufactured of steel, and the locomotives, are nearly ready for delivery. The moles protecting the Basin on Northumberland Straits, have been entirely finished and accepted. The firm of Easton & Anderson, who undertook the supply and erection of hydraulic machinery, as well as the traversers for shunting vessels, has agreed for a specified sum to work and maintain this machinery in good order for one year from the date of the opening of the line, the Company being required to provide the coal.

The size of vessel provided for is 1,000 tons register; the maximum length would be 235 feet,breadth 56 feet,draught 15 feet, with a displacement of 2,000 tons. Accommodation space for six vessels of this size has been provided in the Basins at each terminus of the Ship Railway. This is the only instance in the history of Canada where a wet dock and harbor basins and dredged entrance channels have been provided at the expense of a private company. The cost to the Company of these entrance channels, dock gates, sea walls, basins and moles will be, when finished, about one million dollars, exclusive of the hydraulic lifts.

The following extract from Sir Benjamin Baker's description



of the Chignecto Ship Railway, as published in the *Nineteenth Century Magazine* for March, 1891, cannot be improved upon, and it is, therefore, embodied in this paper:

"The hydraulic lifts, when raised, form a part of the main railway as regards line and level; and when lowered with the cradle the depth of water over the keel-blocks on the latter is that requisite for floating the vessel on the blocks. Walls of massive masonry, 56 feet in height from foundation to quay-level, surround the hydraulic lifts. The latter each consist of twenty hydraulic rams of 25 inches diameter and 40 feet stroke, enclosed in 26-inch diameter cylinders provided with stuffing-boxes at the upper ends, and with inlet pipes for the admission of water at a test pressure of 1,300 lbs. per square inch. On the top of each ram is a cross-head, from which hang two lifting links, connected at the lower ends with the gridiron upon which the ship and cradle rest when being lifted. The gridiron, 235 feet in length and 60 feet in width, consists of a very stiff combination of longitudinal and cross girders made of steel and firmly riveted together. When lifted to the level of the railway the ends of the cross girders are supported on the quay walls by iron chock-blocks worked by hydraulic power, so that the gridiron then in effect constitutes a solid part, as before said, of the main line. Hydraulic pumping machinery is provided of sufficient power to raise a vessel weighing 2,000 tons, or, including the gridiron and cradle, a total weight of 3,500 tons, the required height of forty feet in twenty minutes. Hydraulic power is also provided for capstans and winches for manœuvring the vessels, and air-compressers are furnished for clearing the pipes and cylinders quickly of water—a precaution specially necessary in a northern climate. Special arrangements are made in the engine-house to enable the engineman to ensure the equable and simultaneous motion of the ten lifting rams on each side of the deck, so that no straining of the gridiron may occur.

"A double line of railway of the ordinary 4 feet 8½ inches gauge is laid along the top of the gridiron, upon which the ship-cradles are run. These cradles are provided in sectional lengths of 75 feet and 57 to accommodate vessels of ranging dimensions. For a ship of 2,000 tons dead weight three sections would be used. The cradles, like the gridirons, are formed of a rigid combination of steel girders carrying keel-blocks and sliding bilge-blocks of the usual lifting-dock type. Each 75 feet section of cradle is supported on sixty-four solid wheels of three feet diameter, having double bearings and four spiral springs of exceptional strength. Unlike ordinary ship cradles, therefore, a considerable amount of elasticity is provided in the present case. It need hardly be remarked that many interesting problems have had to be worked out in connection with these cradles which it is impossible to refer to here.

"The order of procedure in raising a vessel and transporting it seventeen miles across this isthmus to the sea on the other side would be as follows: A vessel coming up the Bay of Fundy on the flood tide would pass through the gate entrance into the dock and wait its turn to be lifted. If the vessel were a 'trader' on this route, its dimensions would have been recorded, and the keel and bilge blocks would have been got ready on the cradle, telegraphic notice having been received of the probable arrival of the ship. If she were a 'tramp,' a ship's carpenter would have to go on board and take some leading measurements for the arrangement of the blocking on the cradle. The blocking being arranged, the cradle and gridiron would be lowered by the hydraulic rams into the water and the vessel would be hauled over it by capstans and winches in the usual way. The gridiron would then be slowly raised until the vessel rested on the keel-blocks throughout her whole length, after which the sliding bilge-blocks would be pulled tight against the ship's bilge by chains attached to the blocks and carried up to the quay on either side. Lifting would then proceed until the rails on the gridiron attained the same level as those on the main line of railway, when, as before explained, the ends of the girders would be securely blocked. The ship and cradle would then be hauled off the gridiron on to the railway by powerful hydraulic winches, and after a final adjustment of the blocking, the vessel would be taken in hand by two of the giant locomotives already referred to, and be transported across the isthmus on to the hydraulic lift on the other side, where the converse operations would be effected to enable the vessel to resume her ocean voyage.

"Various plans have been proposed from time to time for the quick and efficient blocking of the curved surface of a ship's hull to the flat top of the cradle. Hinge bilge-blocks, hydraulic rams, elastic bags filled with air or water, and many other contrivances have been suggested, but the present universal practice in docking or in launching a ship is to use simple wooden keel and bilge blocks. In docking a vessel, nearly the whole of the weight comes on the keel blocks, and the bilge-blocks are few in number and extend only for about the middle third of the ship's length. In launching a vessel, the weight is transferred from the keel-blocks on to the launching-ways on each side of the same by means of a couple of narrow cradles or bilge-logs, of hard wood packed up to the hull of the vessel by soft wood filling. These cradles carry the ships down the too often imperfectly bedded inclined launching-ways at a speed of some twelve miles an hour. As the vessel is leaving the launching-ways her stern is water-borne whilst the bow is pressing hard on the shore, but yet it is the rarest thing for any mishap to occur to a vessel even under this singularly rough treatment. The best way of blocking a ship on a railway cradle will be quickly determined after a few weeks' experience, but at Chignecto the method adopted in the first instance will certainly be the well-tried one of timber keel and bilge-blocks.

"Nothing calls for special notice as regards the line of railway. It is, as before stated, a double line of ordinary gauge, but the space between the two lines is five feet wider than usual. Very strong steel rails, weighing 110 lbs. per yard, and exceptionally large sleepers, spaced very closely together, give the required support on the ballast to the heavily laden ship cradle. Near the Amherst end a long and deep moss or bog had to be crossed, and, as the floating system adopted by Stephenson for the original Manchester and Liverpool Railway across Chat Moss would obviously be inappropriate for the heavy loads of a ship railway, there was no alternative but to form a solid rock embankment across the bog, and this has now been successfully completed. On other parts of the line there is a heavy rock cutting and a river bridge, but beyond these matters there are no works of importance on the line."

During the construction of the railway Mr. E. L. Corthell, C. E., a distinguished American engineer of Chicago, paid a visit to the Ship Railway for the purpose of ascertaining its merits and to examine into the facilities which Canada could provide for the carrying trade of the West, and, in a letter published in the Toronto *Globe*, he reports as follows respecting the Ship Railway:

"The entire work, in all its general features, as well as in its "details, has been very carefully studied out, and the material "has been properly arranged and well put together for all of the "mechanical work. I also made careful inquiries and obtained "reliable data in regard to the commercial features of this pro-"ject. There is no question, in my opinion, about the entire "success of this work from a commercial and financial point of "view. There is a large commerce now existing which will "certainly seek this shorter and more economical route. The "opening of a line of communication for ships across the isthmus "will develope new commerce, and I do not hesitate to predict, "in view of all that I heard and saw in regard to the commercial "features, that within three years from the opening of the line for "business it will have all it can handle. A Company allied to "the Ship Railway Company has been formed in England for the "purpose of building for this new route several side-wheel steam-"boats adapted to the trade between Prince Edward Island and "the New Brunswick and Maine coast, which, I have no doubt, "will have all the business it can attend to."

Mr. Corthell also in a paper read before this Society in February, 1890, referring to the Chignecto Ship Railway, repeated that, "There is no doubt in his mind of the entire success in the "construction, operation and economy of this railway. There is "nothing novel in the method only in the combination of "methods. Vessels are at present raised out of the water con-"tinually, whether loaded or unloaded, on hydraulic lifts either "by Marine Railways or by Floating Docks.

"The increasing size of rolling stock, both motive power and "freight cars, on ordinary railroads, has proven the great ad-"vantage in carrying greater and greater loads at one time. A "few years ago 10-ton cars were the rule in this country. Now "30 tons are becoming more and more numerous. Cars for still "larger loads for special purposes are becoming more and more "common, and the locomotives have increased in weight and "power from 30 and 40 tons to 90 and 100 tons, and the cost of "transportation has been reduced from $2\frac{1}{2}$ cents to $\frac{1}{2}$ cent per ton "mile.

"A Ship Railway is the logical result of the continual im-"provements in railroad methods from the time of the first rail-"road to the present. If it is possible to raise vessels and "transport them overland with safety and economy, why should "they be compelled to make great detours costing time and "money?

"If the immense business between the St. Lawrence and the "coast of New Brunswick and New England can save 500 to 700 "miles by operating a railway 17 miles long across the Chig-"necto Isthmus, why should it continue to take this long and "dangerous voyage around Nova Scotia?"

According to the official returns from the Report on Trade and Navigation for the year ending 30th June, 1890, the tonnage arriving and departing at the various ports contiguous to the Ship Railway was as follows:—

	Vessels.	*Tons.*
Gulf of St. Lawrence.........	28,787	6,422,976
Prince Edward Island.......	8,703	1,362,861
Bay of Fundy	33,345	3,855,932
Grand Total...............	70,925	11,641,769

The rate of increase for several years has been half a million tons per annum according to official Blue Books.

This tonnage does not include any port west of Quebec or on the Atlantic coast of the Peninsula of Nova Scotia. Although the Ports of Portland and Boston might come within the sphere of trade, they, like Montreal, Toronto, and ports west of Quebec, are omitted in the above table.

The Company's estimate of traffic is based on only seven per cent. of the tonnage of the Gulf and Bay, or 800,000 tons. Should the Ship Railway draw this moderate proportion of the tonnage it is estimated that there would be a revenue nearly sufficient to pay a dividend of seven per cent. on the capital of the Company without calling on the Government for any portion of the guarantee, as appears from the following figures:—

800,000 tons freight at an average of 50 cents per ton....	$400,000
800,000 tons vessels' hulls at an average of 12½ cts. per ton.	100,000
Estimated Receipts...........................	$500,000
Working expenses and administration as per estimate of Sir B. Baker, being 30 per cent. of the receipts.......	150,000
Net Revenue..	$350,000

Setting apart the subsidy to provide interest on the bonds for 20 years, a traffic of only 320,000 tons at the above rates, would provide 7 per cent. on the preferred share capital, and 7 per cent. on the ordinary share capital, thus:

320,000 tons at the average rate of 50 cents per ton......	$160,000
320,000 tons vessels' hulls at the average rate of 12½ cents per ton	40,000
Receipts	$200,000
Working expenses, 30 per cent..........	60,000
Net Revenue	$140,000
7 per cent. on $1,500,000 preferred shares..........	$105,000
7 per cent. on $500,000 preferred shares	35,000
Total dividend..........	$140,000

The working expenses of the Ship Railway, as compared with a railway of the ordinary type, should be very small indeed. The line is perfectly straight. One half of it is absolutely level. The other half has gradients not exceeding 10 feet to the mile. The works are solidly built, the rails heavy; the sleepers of unusual size; the ballast, broken rock, it is believed the cost of maintenance of way will be reduced to a minimum. It may be considered a freight line, without the usual terminal expenses. The freight, that is the vessel with its cargo, loads and unloads itself automatically on and off the railway. The speed will be slow, not exceeding ten miles an hour. Fuel is cheap in the coal producing county of Cumberland, Nova Scotia. Besides the cost of lifting vessels to the level of the railway and depositing them afterwards into the sea, which is very small, the principal cost will be the locomotive power, which on ordinary railways bears the proportion of about 17½ per cent. to the gross earnings. It is believed, therefore, that the estimate of 30 per cent. for working expenses is full. The estimate of working expenses was based on the usual cost of maintenance and repairs on a double track railway for the whole year. Without any especial effort to economize, the Ship Railway might be worked for $50,000 per annum, which would, of course, permit of the same profits with very much less tonnage. A regular daily line of steamers between St. John and Charlottetown over the line of Ship Railway would contribute largely to the business expected. The Chignecto Steamship Company has been formed in London, with a capital of £60,000, for this purpose; the untoward financial crisis so far has prevented this object from being consummated, but it is steadily kept in view.

The tolls to be charged on the Ship Railway must be sanctioned by the Governor-General in Council before being levied and collected by the Company.

The estimated average rate of fifty cents per ton is therefore only suggested as the probable rate that the Government would be inclined to sanction for the freight carried, for it is, in fact, very similar to the charges prevalent on the Welland Canal, which have been levied by the Government itself. The proposed rates, which, although they amount in the average to half a dollar a ton, will scarcely be felt when levied on the bushel or barrel by the shipper, who is accustomed to the high freights levied by the foreign steam lines running through the Straits of Canso to Boston. At this rate one dollar will be saved on all freight going round to St. John by water. The freight from St. John to Baie Verte being $2.50 per ton, while that to the head of the Bay of Fundy is one dollar per ton, there is a difference of $1.50 per ton, and deducting 50 cents per ton for the transport across the Isthmus, there is one dollar saved in the freight, not to count the saving of time and insurance.

The charges on freight cargoes would be at the same rate, no matter by what description of vessel carried, but the rates on the hull would probably be required to be on a sliding scale according to the size of the vessel, the highest rate being on the smallest vessels, because a small-sized vessel would occupy the railway as long as a large sized one, and the revenue otherwise obtainable from small vessels would not bring a profit to the Company. The estimated proposed average rate of 12½ cents per ton would be a fair rate to charge on hulls as compared with that on Canals where the cost of towage is considered; the latter being done on the Ship Railway by locomotives and on the Canals by steam tug-boats.

Respecting the time to be saved and the safety of vessels on the Ship Railway, no less than twenty-four prominent firms of shipowners in London and Liverpool, having experience of the coast of Nova Scotia, have certified that a saving of ten days would generally be made by sailing vessels clearing from ports on the Gulf, and making for St. John, Portland and Boston, by using the Ship Railway, and so avoiding the weathering of Cape

North and Cape Canso, as by present route. They have certified also that loaded vessels would not be injured on the Railway, if supported on a cradle such as is used on all marine slips.

The most prominent naval architects of the day, Sir E. J. Reed, the late Sir William Pearce, Sir Nathaniel Barnaby, and Mr. William John, all certify to there being no danger to the ship nor cargo during transportation from sea to sea.

Mr. Bindon B. Stoney, the authority on "strains," says, " A ship resembles a tubular structure, more or less rectangular in section, underneath which the points of support are continually moving, so that when the waves are high and far apart the deck and bottom of the vessel are alternately extended and compressed, in the same way that the flanges of a continuous girder are, near the points of inflection, when traversed by a passing train." No such strain as this is possible on the Ship Railway.

There is reason to believe, therefore, that the Ship Railway, when completed, will be an undoubted success in every way, and become the pioneer of many works of like character.

In conclusion, the author would allude to the assiduous care and attention bestowed on this work by his colleagues, Sir John Fowler and Sir Benjamin Baker, the engineers who designed and carried to a successful completion the equally novel enterprise of the Forth Bridge. Without their powerful aid and cooperation the work could hardly have reached its present advanced state of progress. Should it be the success we anticipate Mr. Meiggs also, who undertook to raise the capital in England, as well as to contract for the execution of all the works, will be entitled to a principal share of the credit which should attach to the inauguration of a new and economic system of transportation for the benefit alike of Canada and the whole world.

CORRESPONDENCE.

Mr. William Smith, M. Inst., C. E., of Aberdeen, said he was glad to take the opportunity provided by the discussion upon the subjects of Mr. Ketchum's admirable papers, to give a short description of the system of curved and graded Ship Railway, advocated during the last five years by the writer and illustrated very fully by a 4-line Ship Railway of 7 feet aggregate gauge and 1,200 feet in length laid in the grounds of Edinburgh Exhibition, 1890, and worked successfully during the four months of the Exhibition after it was ready. The plan and section * show the railway laid on gradients of 1 in 20 to 1 in 75 with ten distinct changes of gradient, and the curves were laid to a radius of 95 feet. The wood-cut,* copied from a photograph, shows a boat 38 feet long afloat upon the hydraulic cushions in the car which is supported by trains of bogies. The flexibility of the car, the segments of which are hinged together to allow free vertical movement, allows it to run easily over the change of gradient shown by the railway on trestlework in the picture. The flexibility of the bogie trains laterally (only one bogie in each of the four trains being centre-pinned to the car frame), allows the car to run easily round the railway curves. Mr. William Smith.

It is impossible for any vibration to be transmitted through the water to the vessel. This was demonstrated thoroughly by the large working exhibit at Edinburgh where a 38-foot boat containing 40 passengers, was sailed regularly along the Union Canal shipped on the car in one and a half minutes, hauled along the railway in 7 minutes, and launched on the Canal again without stopping its way. Since Mr. Ketchum's objection was first suggested by Mr. Hurtzig at the London Chamber of Commerce on the occasion of the writer's lecture there in 1889, the Edinburgh Exhibition Ship Railway has completely demonstrated the practical nature of the system invented by the writer. It is somewhat curious that the only objection suggested by Mr. Ketchum to the writer's system, namely, the fear of transmission of vibration to the ship, is the great and inevitable danger of the

* See page 317.

block system adopted at Chignecto. The attempt to transmit vibration through a bag of water is about as feasible as an attempt to carry that fluid in a sieve.

There is no doubt as to the immense place to be filled in the transport of ships by curved and graded Ship Railways. The mechanical advantages of these are:—

1. The ships are always waterborne.

2. The car is flexible vertically to take changes of gradient.

3. The wheel base is flexible laterally to take curves, etc.

4. The hydraulic cushions are not exposed to bursting pressure or damage.

5. The car may be readily adapted to various sized ships.

6. The lines of vessels are automatically fitted in the car by the hydraulic cushions.

7. The ship floats on and off the car without adjustment.

8. The ship is fixed against horizontal movement in the car by the frictional adhesion of the cushions.

9. There is no vibration or jolting communicated to the ship from the motion of the wheels.

10. Locks, lifts, and turntables or traversers, are dispensed with.

11. A high speed is attainable with safety.

12. The Ship Railway may be economically widened by laying additional lines for larger ships.

13. Ordinary railway traffic may be conducted simultaneously with the passage of ships over the Ship Railway.

The enormous economic advantages resulting from these mechanical improvements make the financial success of Ship Railways on a great scale appear certain.

Economical Advantages.

1. Saving on cost of construction.

2. Saving on transfer of goods in large bulk.

3. Saving in sailing distances and time.

4. Saving in cost of haulage and service.

5. Gain by increased capacity for traffic.

6. Saving of dock and terminus space.

7. Capability of economical branching by enlargement or contraction of aggregate gauge for larger or smaller ships, or ordinary railway traffic.

8. Saving of insurance by keeping vessels waterborne on land in perfect safety.

1. *Saving on cost of construction.*—The cost of construction of a ship canal from 10 to 26 feet deep, or 500 to 4,000 tons burthen, has varied from £100,000 to £200,000 per mile. The Manchester Ship Canal, constructed on the most approved scientific principles, with the help of every modern labour saving appliance, estimated at £7,000,000, has actually cost over £12,000,000. The estimated rate was £200,000 per mile, the actual rate, £343,000 per mile. A Ship Railway of equal tonnage size, and owing to greater speed of transit, five times its tonnage capacity, is estimated at £86,000 per mile, and the actual rate of cost of construction would not vary more than 10 per cent of the estimate, the work being nearly all above ground. The ratio of the cost of a Ship Railway to that of a Canal to take equally large ships is generally estimated at one-fourth, and is much more exactly ascertainable beforehand.

2. *Saving on transfer of goods in large bulk.*—The finest field for the introduction of Ship Railways lies in conferring the immense advantages of direct oceanic trade upon large inland trading and manufacturing cities like Birmingham or Leeds. Every one of these inland cities may be converted into a first class seaport by the Ship Railway. The cost of transfer of goods from one vehicle to another is not merely the 6d. or 1s. per ton actually charged for stevedoring. There are demurrage of both vehicles, damage to goods from handling, terminals for storage and covering, harbour and dock dues, and petty local charges. The saving on transfer of goods to be effected by Ship Railways is really measured by the difference between the cost of canal barge carriage and ordinary railway trucking, which averages in England 1d. per ton per mile.

3. *Saving in sailing distances and time.*—The demurrage and expenses of a steamer carrying 4,000 tons of cargo is £75 per day. Where a saving is possible under this head by the construction of a Ship Canal, at least three times the amount can be saved by a Ship Railway carrying on the traffic more than three times as fast. The saving of £525 for a week's steaming and demurrage of a 4,000 tons vessel amounts to 2s. 7d. per ton, which may be effected by the construction of a Ship Railway across the middle of Britain, or the south of France.

4. *Saving in cost of haulage and service.*—The increase of the unit of mass from the truck up to the ship load, that is, from 6

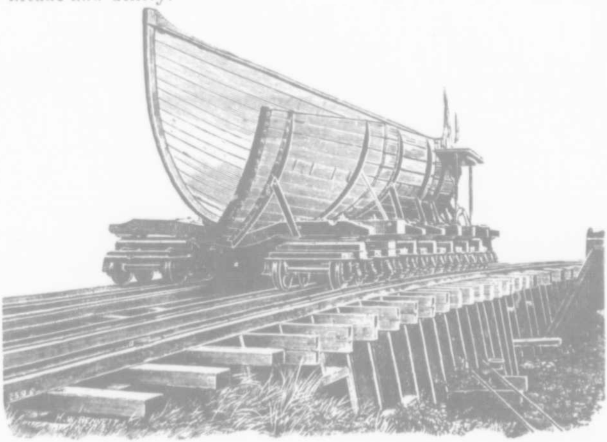
to 4,000 tons, cheapens the cost of haulage and service. The cost for fuel of hauling a vessel containing 4,000 tons of cargo would not exceed 2s. per mile with coal at 10s. per ton; service would thus cost only three times that of an ordinary train, or 7s. 6d per train mile; so that the haulage of 4,000 tons Ship Railway freight would cost $\frac{1}{33}$rd of a penny per ton per mile for working expenses—about the same as the cheapest ocean freight. Cost of general management with interest or dividends on capital have to be added. From $\frac{1}{6}$th to 1-12th of a penny per ton per mile is the average cost of transit estimated on Ship Railways. The cost per ordinary rail in England is $1\frac{3}{8}$d. per ton per mile, in the United States of America and on the continent of Europe a little over $\frac{1}{2}$d. per ton per mile. The Suez Canal rates are 1d. per ton per mile.

Mr. W. R. Kinipple, M. Inst., C.E., London, reports:—"Sir "E. I. Reed and myself examined the system (Mr. Smith's Ship "Railway at Edinburgh Exhibition) carefully; had the boat "shipped on to the car, transported over the railway, and unship- "ped at the other end. We paid especial attention to the action "which took place at changes of curvature and gradient, and we "are both of opinion that the system is a thoroughly practical "one, and that by means of it vessels of large tonnage can be "safely transported over land. The advantages of this system "of transport are so obvious that it seems almost unnecessary for "me to refer to them. Wherever an ordinary railway is feasible "a (curved and graded) Ship Railway can also be constructed, "and vessels conveyed overland from sea to sea, or inland to any "destined point. It has all the merits of a Ship Canal, with the "great advantages of the cost per mile being a mere fraction of "a canal, whilst its traffic capacity would be greater as the speed "of transit would be higher. As is well known there are many "places where Ship Canals would be most serviceable, yet the "elevation and other features of the country to be traversed are "such, that although presenting no difficulty in regard to "(curved and graded ship) railway construction, they are prohi- "bitive for canals (or rigid car Ship Railways) on account of the "great cost of locks or lifts, viaducts, embankments, etc., which "would be required. For such places the (curved and graded) "Ship Railway is eminently suited, as there would practically be "no extra expense in construction on account of difference of "level along the route to be traversed."

The Council of the Edinburgh Exhibition awarded the writer the highest prize for his exhibit of a working Ship Railway, the Diploma of Honour.

The plans and description of a Ship Railway on the writer's system to be laid across the Isthmus of Tarbet 1¼ miles long, to convey vessels up to 2,000 tons register have just been prepared to submit to the promoters. It is expected that the total cost of the "Argyll Ship Railway," with hauling engines, gear, and cars will be £120,000, while it may be constructed in twelve months.

The completion of the Chignecto and the Argyll Ship Railways will lead to the undertaking of the Forth and Clyde Ship Railway, and many other enterprises of similar or greater magnitude and utility.



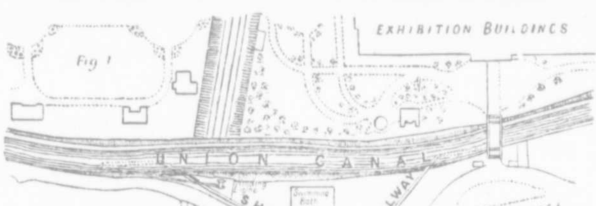


TABLE ON FLOW AND DISCHARGE OF SEWERS.

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

In a paper by Mr. Rudolph Hering, "A Formula for the Mean Velocity of Flow in Sewers," Mr. Hering shows how the somewhat elaborate formula of Kutter may be much simplified without appreciably affecting the results; and where as has been found in most instances to be the case, $N = 0.013$ the formula becomes

$$V = \frac{188\ R\sqrt{S}}{0.64 + \sqrt{R}}$$

In which V = velocity in feet a second, S = fall in unity; and R = hydraulic mean radius.

In the following table, deduced from the above formula for the velocity and discharge of circular sewers running half full, in order to obtain the velocity in feet per second, multiply the upper, —and to obtain the discharge in gallons per hour, multiply the lower figures both by $\sqrt{S}$ taken from the Table.

In Egg shaped sewers in which the depth of the sewer equals three times the radius of the larger and six times the radius of the smaller circle, it is invariably the case that,—

Running $\frac{1}{3}$ full $R = 0.4132\ r$; $P = 2.7494\ r$; $A = 1.1360521\ r^2$
$\frac{2}{3}$ " $R = 0.6314\ r$; $P = 4.78829\ r$; $A = 3.02332\ r^2$
" $R = 0.579341\ r$; $P = 7.929883\ r$; $A = 4.591195\ r^2$

where R = hydraulic mean radius; P = perimeter; A = area; and r = the radius in feet of the larger circle.

Now let v = velocity in feet per second; c = discharge in cubic feet per hour; s = fall in unity; and r = radius of larger circle in feet. We have

Running $\frac{1}{3}$ full $v = \dfrac{77.68\, r \sqrt{s}}{0.633 + 0.6428 \sqrt{r}}$ and $c = \dfrac{317711 r^3 \sqrt{s}}{0.633 + 0.6428 \sqrt{r}}$

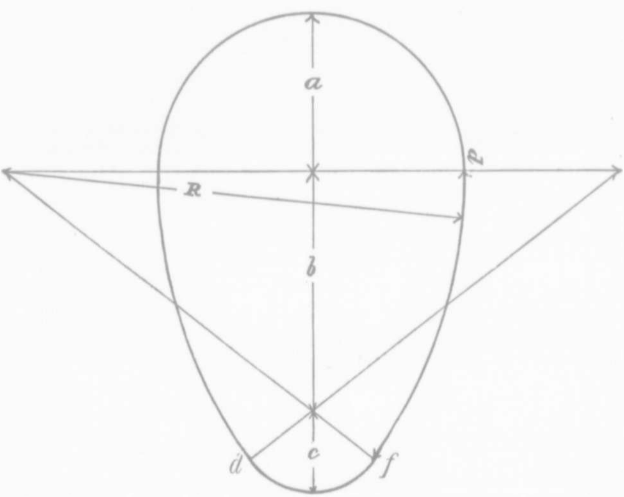
$\frac{2}{3}$ " $v = \dfrac{118.7\, r \sqrt{s}}{0.633 + 0.7946 \sqrt{r}}$ and $c = \dfrac{1291931\, r^3 \sqrt{s}}{0.633 + 0.7946 \sqrt{r}}$

" $v = \dfrac{108.92\, r \sqrt{s}}{0.633 + 0.7611 \sqrt{r}}$ and $c = \dfrac{1801428\, r^3 \sqrt{s}}{0.633 + 0.7611 \sqrt{r}}$

And the values of $\sqrt{s}$; r; $\sqrt{r}$; and r^3 may be obtained by inspection from the Table.

The radius, R of the connecting arc d, f, (see Figure) may, whatever are the relative proportions of the two circles, always be found by the formula

$$R = \frac{a^2 + b^2 - c^2}{2\,(a - c)}$$



Circular Sewers.		Fall.	$\sqrt{s}$	Egg shaped Sewers.			
Diam.				Size.	r	$\sqrt{r}$	r^3
		1 in 20	0.2236				
		30	0.1826				
		40	0.1581	1′ 0″ x 1′ 6″	0.5000	0.7071	0.1250
2″	9.28	50	0.1414	1 2 x 1 9	0.5833	0.7637	0.1985
	2271	60	0.1291	1 4 x 2 0	0.6667	0.8165	0.2963
3″	13.2	70	0 1195	1 6 x 2 3	0.7500	0.8660	0.4219
	7270	80	0.1118	1 8 x 2 6	0.8333	0.9129	0.5787
4″	16.87	90	0.1054	1 10 x 2 9	0.9167	0.9574	0.7706
	16510	100	0.1000	2 0 x 3 0	1.0000	1.0000	1.0000
6″	23.65	125	0.08944	2 2 x 3 3	1.0833	1.0410	1.2702
	52100	150	0.08165	2 4 x 3 6	1.1667	1.0800	1.5877
8″	29.89	175	0.07560	2 6 x 3 9	1.2500	1.1190	1.9531
	117050	200	0.07071	2 8 x 4 0	1.3333	1.5550	2.3702
9″	32.85	225	0.06667	2 10 x 4 3	1.4167	1.1900	2.8434
	162809	250	0.06325	3 0 x 4 6	1.5000	1.2250	3.3750
10″	35.72	275	0.06030	3 2 x 4 9	1.5833	1.2580	3.9599
	218457	300	0.05773	3 4 x 5 0	1.6667	1.2910	4.6299
12″	41.23	350	0.05345	3 6 x 5 3	1.7500	1.3230	5.3594
	363228	400	0.05000	3 8 x 5 6	1.8333	1.3540	6.1617
14″	46.47	450	0.04714	3 10 x 5 9	1.9167	1.3844	7.0414
	558542	500	0 04472	4 0 x 6 0	2.0000	1.4140	8.0000
15″	49.00	550	0.04264	4 2 x 6 3	2.0833	1.4434	9.0418
	674690	600	0 04082	4 4 x 6 6	2 1667	1.4720	10 1715
16″	51.49	650	0 03922	4 6 x 6 9	2.2500	1.5000	11.3906
	806526	700	0.03780	4 8 x 7 0	2.3330	1.5275	12.7032
18″	56.34	750	0.03656	4 10 x 7 3	2.4167	1.5546	14.1146
	1116864	800	0.03535	5 0 x 7 6	2.5000	1.5810	15.6250
20″	60.94	850	0.03430	5 2 x 7 9	2.5833	1.6072	17.2395
	1491282	900	0.03333	5 4 x 8 0	2.6667	1.6333	18.9637
22″	65.43	950	0.03244	5 6 x 8 3	2.7500	1.6580	20.7969
	1937469	1000	0.03162	5 8 x 8 6	2.8333	1.6832	22.7446
24″	69.78	1100	0.03015	5 10 x 8 9	2.9167	1.7078	24.8128
	2381060	1200	0.02887	6 0 x 9 0	3.0000	1.7320	27.0000
		1300	0.02774				
		1400	0.02673				
		1500	0.02582				
		1750	0.02391				
		2000	0.02236				
		2250	0.02108				
		2500	0.02000				
		2750	0.01917				
		3000	0.01826				

TRANSACTIONS CANADIAN SOC. C. E.

Vol. V, Part 2.

Page 348.

4th	line	from	bottom	for	$P=4.78829r$	read	$P=4.78850r$
"	"	"	"	"	$A=3.02332r^2$	"	$A=3.02335r^2$
3rd	"	"	"	"	$R=0.579341r$	"	$R=0.579345r$
"	"	"	"	"	$P=7.929883r$	"	$P=7.929898r$
"	"	"	"	"	$A=4.591195r^2$	"	$A=4.594144r^2$

Page 350.

Column	$\sqrt{s}$	Fall 1 in 2750	for	0.01917	read	0.01907
"	r	4′ 8″ × 7′ 0″	"	2.3330	"	2.3333
"	$\sqrt{r}$	1′ 2″ × 1′ 9″	"	0.7637	"	0.7636
"	r^3	2′ 4″ × 3′ 6″	"	1.5877	"	1.5881

OBITUARY.

JOHN HAWKSHAW was born in 1811, in the West Riding of Yorkshire, where his father's family for some generations were farmers in the neighbourhood of Otley, Learly and Bramhope. He was educated at the Leeds Grammar School, but left it at an early age, and was engaged for about five years under Mr. Chas. Fowler, chiefly in the construction of turnpike roads in that neighbourhood in place of the old and circuitous ones which were difficult and dangerous to travel upon. The Leeds and Whitehall, the Holme Lane End and Heckmondwike, the Dewsbury and Batley Turnpike Roads were among those constructed during that period.

Before he was twenty years old Mr. Hawkshaw became an assistant to Mr. Alex. Nimmo, the well known Civil Engineer, who was then chiefly engaged on piers, harbours and other public works in Ireland. In 1830 and the two following years Mr. Nimmo surveyed the projected railway from Liverpool *via* Leeds to the Humber. The proprietors of this railway purchased the Manchester, Bolton and Bury Canal navigation, and succeeded in obtaining an Act for a railway along the course of that canal, but failed to obtain powers for the remainder of the scheme.

After the death of Mr. Nimmo, Mr. Hawkshaw, in July, 1832, made an engagement to take charge of the works of the Bolivar Mining Association, which were situated in Venezuela, about 200 miles from Caracas. He remained there for nearly three years, being chiefly occupied in improving the navigation of the River Aroa, which he adapted for navigation by flat bottomed boats, and in making communication between the mines and the Aroa, and generally in superintending the operations of the Association. The mines, situated near St. Felipe, produced copper. They were wrought by adits driven from the mountain side into the lode, which was of great thickness and very rich. The climate was so unhealthy that many of the English miners, chiefly picked men from Cornwall, died, as did also the doctors;

and Mr. Hawkshaw had not only to perform the duties of the latter as best he could, but he also officiated at their burial. The house at which he lived at the mines not only still exists, but bears his name. Shortly after he left all the occupants of it were murdered, and the house has remained uninhabited since.

Repeated attacks of fever and ague compelled Mr. Hawkshaw to return to England in 1834, when he was engaged for some time in the Liverpool Dockyard under Mr. Jesse Hartley. Afterwards he was for a short time in the office of Mr. James Walker, who was then newly elected President of the Institution. Whilst with Mr. Walker he laid out the Leipsic and Dresden Railway.

In 1836, the year in which Mr. Hawkshaw became an Associate of the Institution of Civil Engineers, he was requested by the Directors of the Manchester, Bury and Bolton Canal Navigation and Railway to take charge of their works and of the completion of the railway, which was at that time, from various causes, only about one-half finished. Completed under his superintendence, the railway was opened for public traffic towards the end of 1838, and Mr. Hawkshaw, on the 7th August, was transferred to full member in the Institution of Civil Engineers.

In the same year Mr. Hawkshaw was called upon by the Directors of the Great Western Railway to report, in conjunction with Mr. Nicholas Wood, on the desirability or otherwise of maintaining the broad gauge on the Great Western Railway system. His report was adverse to the maintenance of the broad gauge, chiefly on the ground of the inconvenience it would occasion in the future extension of railways. Although his advice was not followed at the time, subsequent events have fully proved the soundness of his views. These remained unaltered throughout his life, and he gave expression to them on many subsequent occasions when break of gauge arose, notably in 1872 and 1873, when the Indian Government adopted a resolution to alter the gauge of the Indian railways. A reference to the discussion on Mr. Thornton's paper will show how the whole weight of engineering opinion was in agreement with Mr. Hawkshaw, and against a break of gauge, scarcely any engineers of note supporting the official view.

Soon after the completion of the Manchester, Bolton and Bury Railway in 1838, the canal, which was only adapted for the passage of narrow boats, 7 feet wide, of shallow draught of water, was deepened and widened so as to admit of boats of 14 feet beam, drawing $4\frac{1}{2}$ feet of water. In 1844 Mr. Hawkshaw became the consulting engineer to the Manchester, Bury and Rossendale Company, formed for the construction of a railway into Rossendale, which was afterwards expanded into the East Lancashire Railway Company.

The following year, 1845, he became chief engineer of the Manchester and Leeds Railway Company, which was the nucleus of the Lancashire and Yorkshire Railway Company, incorporated under an Act of Parliament passed in 1847. Mr. Hawkshaw held the post of consulting engineer to the Lancashire and Yorkshire Railway Company until he retired from practice in December, 1888. During his earlier connections with that company he constructed the Manchester and Bolton, the Liverpool, Ashton and Stalybridge, the West Riding Union, the Sheffield, Barnsley and Wakefield, the Liverpool and Bury Extension, and other railways connected with the Manchester and Leeds line, which now constitute part of the Lancashire and Yorkshire system. The difficult nature of the district through which some of these railways pass made it desirable to adopt steeper gradients than had hitherto been attempted or worked. When the West Riding Union Railway was under discussion a contest took place on the question of gradients, in which Mr. Hawkshaw was opposed to Mr. Robert Stephenson, a contest which equalled in severity and importance that on the question of the gauges. Mr. Hawkshaw clearly proved, in face of much opposition, the practicability of introducing steeper gradients, and the advantage of doing so even when, by taking a more circuitous route, easier inclines could be secured. On the Oldham Branch (1839) there was an incline of 1 in 27, which was worked by rope traction until 1853. The Hunts Bank incline (1839) was 1 in 47, and on the West Riding Union Railway (1847) there was an incline of 1 in 50. The soundness of the views advocated by Mr. Hawkshaw on the question of steeper gradients is now generally admitted, and their recognition has led to the rapid extension of railways in all parts of the world.

Amongst some of the important works designed by Mr. Hawkshaw in the Lancashire and Yorkshire district may be mentioned the Lockwood Viaduct, a stone structure of fine proportions. On one occasion, at a time when two important viaducts, the Denby Dale and Holmfirth, were about to be begun, the masons struck. Mr. Hawkshaw at once prepared designs for timber structures, which were completed without delay. These viaducts were rebuilt of stone in 1877; when this was done it was calculated that the new structures were wholly paid for by the saving in interest due to the smaller capital expended in the first instance when the change was made from stone to timber. The Liverpool and Bury and Wigan viaducts were also of timber.

In 1850, Mr. Hawkshaw removed from Manchester to 33 Great George Street, Westminster, where he remained until the close of his professional career; at first alone, and from 1870 in partnership with his son, Mr. J. C. Hawkshaw, and his former chief assistant, Mr. Harrison Hayter. In 1873 he received the honour of knighthood.

During thirty-eight years professional practice in London he was constantly employed in designing and superintending engineering works, and in reporting and advising as to their practicability, not only in this country, but in many other parts of the world. His practice was not confined to any special branch of professional work. During that time he was in constant request as a witness before Parliamentary Committees, and as an arbitrator in important cases. He was twice appointed sole Royal Commissioner, and served on more than one Committee appointed by the Government.

In dealing with his professional career between 1850 and 1888, it will be more convenient to set forth his more important work, not in order of time, but to classify it under the following heads: Railways, tunnels, viaducts and bridges, canals, harbours, forts, docks, waterworks, town drainage, land drainage, river improvements, floods prevention, Royal Commissions, Committees appointed by Government departments, arbitration.

His connection with the railways of Lancashire and Yorkshire began in 1830, and from 1836 to 1888, a period of fifty-two years, he was continuously chief or consulting engineer for the Lancashire and Yorkshire Railway system. During that time he was consulted by the Company as to every important work; he supported and defended their bills before Parliamentary Committees, and opposed those of other companies which were antagonistic to the Lancashire and Yorkshire Company's interests.

Sir John Hawkshaw constructed the Charing Cross and Cannon Street railways, now an integral part of the South-Eastern Railway, of which system he was consulting engineer from 1861 to 1881. Probably the three miles of the Charing Cross Railway are the most costly in existence, including as they do two large bridges over the Thames, and two first-class terminal stations.

He constructed the Riga and Duneburg and Witepsk Railways in Russia between the years 1858 and 1867. During that time he frequently visited the works. On his first visit to Riga, before the works were begun, he posted from Riga to Witepsk and back, arranging his stages so that the ground passed over by night in going was traversed by day on the return journey. In 1871, at the request of Messrs. Baring's, he reported on the Moscow and Koursk Railway after the line had been inspected by Mr. Hayter and Mr. J. C. Hawkshaw.

The East London Railway, which connects the railways south of the Thames with those on the north side by means of the elder Brunel's Thames Tunnel, was also his work. It presented unusual difficulties, passing as it does beneath Shadwell basin, the London docks, and at a considerable depth beneath the brick viaduct of the Blackwell Railway. The brick tunnel under this basin was built in a cofferdam. By an agreement with the Dock Company this dam could only be made to extend half way across the basin at one time, and be just of sufficient width to admit of the brickwork being built within it. When one half of the tunnel was completed the dam had to be removed before the other half could be begun. The difficulty of effecting a junction between the old work and the new beneath the dock bottom, which consisted of Thames gravel, can be well imagined.

In conjunction with Mr. J. Wolfe Barry, he was engineer to the Joint Committee of the Inner Circle Completion Railway, by which the District Railway at the Mansion House was connected with the Metropolitan Railway at Aldgate, a most complicated and troublesome work.

He constructed the Staines and Wokingham Railway in the years 1853-57, including the bridge across the Thames at Staines.

He was consulting engineer for the Mauritius railways, begun in 1862, and for railways in Jamaica.

In India he was consulting engineer for the Madras Railway from 1857 to 1888, and to the Eastern Bengal Railway until it was taken over by the Indian Government. He also constructed the West of India Portuguese Railway from Mormugao up the Ghats to the British frontier.

Owing to the hilly nature of the country traversed by the Lancashire and Yorkshire Railway, the works carried out by Sir John Hawkshaw for that line included many tunnels, but the one with which his name will always be associated is that made by the Great Western Railway Company under the Severn. It is $4\frac{1}{3}$ miles long, of which distance $2\frac{1}{4}$ miles are under the tidal estuary of the Severn, where there is a rise of tide of 40 feet, so that the tunnel may be truly called submarine. The difficulties encountered in constructing it have been ably described in a book written by the late Mr. T. A. Walker, the contractor.

Sir John Hawkshaw was engineer in conjunction with Sir James Brunlees to the original Channel Tunnel Company from the year 1872, in which it was incorporated, until the year 1886, when it ceased to exist as an independent company. For many years previously he had been carrying on independent investigations to satisfy himself that it was reasonably probable that a tunnel could be made beneath the sea to connect the railways of England with those of France. In 1865 he employed Mr. Hartzinck Day, a skilful geologist, with a knowledge also of surveying, to examine the cretaceous strata on both coasts, and to trace, as far as possible, their course beneath the channel. In the years 1865 and 1866 he employed Mr. H. M. Brunel to make a marine survey of the channel, and to ascertain, as far as possible, the nature of the strata forming the bed of the channel. Mr. Brunel's survey showed that the cretaceous strata were exposed in the bed of the channel, and that the outcrop of the beds could be traced beneath the sea from shore to shore. To ascertain the depth of the chalk near Dover and Calais, Mr. Hawkshaw had deep borings made. Mr. Brassey and Mr. Wythes, who both took great interest in these investigations, shared the expense of this costly operation with him. By 1867 he had obtained such practical information as was necessary, and had solved the Channel Tunnel question, in so far as that could be done without actually carrying on the work. The investigations carried out afterwards by French engineers, and still later by the Company promoted by the South Eastern Railway Company, have done no more than to confirm Mr. Hawkshaw's investigations. At first he looked upon the Channel Tunnel question from a purely engineering point of view, but in later years, when he had considered it as a national question, he came to the conclusion that it was more advantageous that this country should maintain its insular condition than that it should have direct railway connection with the continent, and having formed that opinion he declined to take any further part in advocating such a tunnel.

Some of the viaducts on the Lancashire and Yorkshire Railway have already been mentioned, as also the Charing Cross and the Cannon Street bridges, and the bridge over the Thames at Staines. Mr. Hawkshaw likewise designed the South Bridge at Kingston-Hull, which was a large opening bridge at the time it was constructed. He also constructed the Londonderry Bridge in Ireland (1862 to 1864), the Nerbudda Bridge in India which is nearly one mile long, and many less important ones elsewhere. In conjunction with Mr. W. H. Barlow he completed the Clifton Suspension Bridge, adapting the chains removed from Brunel's Hungerford Bridge over the Thames, when it was pulled down to make way for the Charing Cross Railway Bridge, to the piers built by Brunel at Clifton, which had remained unfinished from 1843 until 1861.

In early life Mr. Hawkshaw was connected with some canal navigations, as the Bolton and Bury Canal already mentioned, but the importance of canals was then waning before the prominence assumed by railways in this country. Some few maintained their position—among others the Weaver navigation, to which he was consulting engineer for many years prior to his retirement.

In July, 1863, when Said Pasha, Viceroy of Egypt, was in England, he requested Mr. Hawkshaw to visit Egypt, and examine the site of the proposed Suez Ship Canal, and to report his opinion to the Government of Egypt. At the close of the year Mr. Hawkshaw went to Egypt, and while there spent twenty-seven days in examining the district to be traversed by the canal. Having thoroughly investigated the question he reported that there were no works on the canal presenting any unusual difficulties, and that no obstacles would be met with that would prevent the work when completed being maintained. This report decided the future of the Suez Canal, for Said Pasha had determined to stop the work if the report were unfavorable. M. de

Lesseps fully recognized at the time how much the enterprise which was to be associated with his name owed to Mr. Hawkshaw, as the following extract from Lord Houghton's life tends to show. Lord Houghton represented the Royal Geographical Society at the opening ceremony, and thus describes what took place:—

"When Mr. Hawkshaw landed at Port Said, M. de Lesseps took him by the hand, and presented him to the engineers who were about him, and said, 'This is the gentleman to whom I owe the canal,' and it was literally true. At the time when the reputation of the canal was at its worst, when public opinion in Europe was growing against it, when money was the hardest to get, the Khedive asked for an English engineer who would give him a final opinion as to the practicability of the canal. He selected Mr. Hawkshaw, a man not only high in his profession, but of the most singular independence and simplicity of character. The Khedive told Mr. Hawkshaw that if he would report to him confidentially that the canal was impracticable he would take care that the works were brought to an end without injury to anybody. He reported that the canal was not only feasible, not only practicable, but that, to his mind, the main engineering difficulties which had been raised were not such, in any degree, as would authorize its abandonment; that he believed the canal could be made, and could be maintained at a moderate and reasonable expense. And therefore when M. de Lesseps presented Mr. Hawkshaw, as I saw him do, to the persons present at Port Said, he was thoroughly justified in saying, 'It is to him that I mainly owe the accomplishment of this great enterprise.'" Subsequent events have proved the soundness of the opinions set forth in Mr. Hawkshaw's report to Said Pasha, both as regards the completion of the canal and of its maintenance.

At the invitation of M. de Lesseps, Sir John Hawkshaw went to Paris in 1879, sixteen years later, to be present at the International Congress on the question of an inter-oceanic ship canal across Central America. He made a short statement of his views on certain points at the meeting, as he at once saw what was and will always remain the great obstacle to making a canal on the Panama site, and which had apparently up to that time been overlooked by the promoters of the Panama Canal, the difficulty of dealing with the Chagres River. He showed that as no provision had been made for the waters of that river, it would, when in flood, flow through the proposed tunnel for the canal (afterwards abandoned), and almost completely fill it, which was equivalent to saying that the canal as then designed was impracticable. He then proceeded to say that he saw no difficulty in working a ship canal with locks, provided a sufficient water supply could be obtained at the summit level; but he publicly expressed no opinion as to the practicability of a canal on the Panama site; as a matter of fact he did not believe it to be practicable at a reasonable cost. He took no further part in the Congress, and as he felt he could not support the project, he left before the conclusion of the meeting without giving any vote. It is the more necessary to state what really took place at the Congress, because M. de Lesseps, in his autobiography, has placed Sir John Hawkshaw's name first among those who notified the decision of the Congress with respect to the proposed Panama Canal. For this he has no authority, and has stated what is contrary to the fact. Among the various proposals brought before the Congress, Sir John Hawkshaw was most favourably impressed by that for the Nicaragua route, recommended by Admiral Ammen and Mr. Menocal, representing the United States of North America.

In 1862 he was appointed Engineer to the Amsterdam Ship Canal, Mr. Dircks, of Amsterdam, being the Resident Engineer. Until the Manchester Ship Canal is complete, that from Amsterdam to the North Sea will rank second only to the Suez Canal. Its length is close on 16 miles, its depth 23 feet as compared with 26 feet, the depth of the Suez Canal, which, however, it exceeds in width, being 88 feet 7 inches at the bottom, against 72 feet, the bottom width of the Suez Canal. It comprised some important contingent works: the Zuyder Zee Locks, built out in the Zuyder Zee in a temporary circular timber cofferdam, 525 feet diameter, on 10,000 bearing piles, the bottom consisting of mud for a great depth. These locks were afterwards connected with the land by two banks or dams, together nearly a mile long, made on the same soft bottom, shutting out the water of the Zuyder Zee from the canal. Large locks were also made at Ymuiden in a deep cutting in the sand hills, and the entrance from the North Sea was protected by two breakwaters each nearly a mile long, enclosing a large harbour. The pumping machinery erected to maintain the water surface of the canal at a prescribed level is on an extensive scale. He visited Holland frequently during the progress of the works, which were formally opened for traffic by the King of Holland on November 1st, 1876.

In the year 1864 Mr. Hawkshaw was asked by Ishmail Pasha, Viceroy of Egypt, to examine the first cataract of the Nile, and report as to the practicability of making it navigable. Early in the following year he sent Mr. Hayter, his son, Mr. J. C. Hawkshaw, and the late Mr. Graham, the surveyor, to make a survey of the first cataract. On their return he reported that the canalization of the first cataract was practicable, aud gave a plan for accomplishing it.

The Government Harbour of Refuge of Holyhead was begun in 1847, from the designs and under the superintendence of Mr. James Meadows Rendel. When he died in 1856 Mr. Hawkshaw was appointed Engineer-in-chief, and held that post for seventeen years, until the works were finished in the year 1873. The Prince of Wales then visited Holyhead and formally declared the harbour to be completed.

He was frequently consulted as to other harbours in the United Kingdom, such as Alderney, Dover, Folkestone, Belfast, Aberdeen, Greenock, Wick, and many others.

In 1874, at the request of the Emperor of Brazil, Sir John Hawkshaw visited some of the most important sites for harbours on the coast of Brazil, from Maranhão on the north to Rio Grande do Sul on the south. In the following year he reported to the Brazilian Government, giving designs and estimates for the harbours of Maranhão, Pernambuco, Parahyba do Sul, Torres, Rio Grande do Sul, Rio Grande do Norte and Maceio; some of these are now being carried out.

In 1861 he was called upon by the War Office to design the foundations for the Spithead Forts, which were carried out under his superintendence in the years 1861 to 1868.

He was consulting Engineer to the Hull Dock Company for twenty-six years (1862 to 1888), and designed and carried out important works at Kingston-upon-Hull. Among others an enlargement of the old Victoria Dock and the construction of a new one, the Albert Dock, opened by the Prince of Wales in 1869.

He constructed the South Dock for the East and West India Dock Company, also the Penarth Dock near Cardiff, the Fleetwood Dock, and the Maryport Dock, the Granville Dock at Dover, and he was frequently consulted by the Greenock Harbour Trust, and was often called in to advise on dock questions both at home and abroad. In 1885 he prepared designs for a system of docks for Buenos Ayres, and in 1887 he visited that city shortly after the works now in progress, had been begun.

In 1860 he was appointed sole Royal Commissioner to decide the important question of the water-supply of Dublin. His decision was given after hearing all the evidence that could be obtained on the subject, and the scheme he recommended, that originated by Mr. Hassard, for obtaining water from the Vartry, was afterwards carried out, and has proved of great benefit to the city. On a subsequent occasion he reported on a scheme, also by Mr. Hassard, for increasing the supply of water for the Dublin district from the Dodder. This work has been successfully carried out. He reported and advised on many other projects for supplying water to towns and districts both at home and abroad.

The Brighton intercepting sewer, 7 miles long, was constructed from his designs and under his supervision. He also drained the town of Cardiff, and reported on and gave designs for the improvement of the drainage of Dover, Torquay, Lowestoft, Norwich and Ayr.

In 1874 Sir John Hawkshaw was appointed sole Royal Commissioner to inquire into the causes of pollution of the Clyde and its tributaries, and the best means of remedying the evils arising therefrom. In his report to Her Majesty, he recommended engineering works for dealing, not only with the sewage of Glasgow, but also of the adjoining towns of Paisley, Coatbridge, Airdrie, &c.

He was consulting Engineer for the General Commissioners for drainage by the River Witham, and was also consulted by the Boston Harbour Trust, who were interested in the outfall of that river. The River Witham was widened, deepened, and improved under his advice, and important works were carried out in the adjoining fens. Among other works he erected the Lade Bank pumping-engines for the Fourth District, which proved a great success.

He was also Consulting Engineer to the Middle Level District in Norfolk. One of the most troublesome tasks which he was ever called upon to undertake was to remedy the disaster caused by the failure of the Middle Level outfall sluice at St. Germains. The sluice, originally designed by Mr. J. Walker and built in 1847, gave way on May 4th, 1862, and admitted the tidal waters of the Ouse into the drain, up and down which they flowed each tide with great velocity for a distance of 20 miles. In a few days the drain bank gave way and 6,000 acres of land were inundated. Mr. Hawkshaw at the time when this occurred was much engaged in Parliamentary Committee work, so that it was with difficulty he could find time for the necessary journeys to and from Lynn to inspect the remedial works which he recommended. The tide was finally shut out by a dam of novel design, across which sixteen large siphons, 3½ feet diameter, were laid, which fulfilled all the requirements of the drainage of the district for many years. The siphons still remain, but are no longer used, as the Commissioners built a new sluice by the side of them from his designs in the years 1876 to 1880.

He was called upon from time to time to advise as to the amelioration of British river-channels. He laid down river-lines for the Humber, and was consulted as to the channels in the entrance of the clyde. Sir John Hawkshaw was engineer to the Thames Valley Drainage Commissioners, and prepared designs and estimates for works to diminish the floods in their district, which includes Oxford. Some of these works have been carried out with good results. After the disastrous floods, which occurred at and near Lincoln in 1877, when part of the town was flooded and some of the fen lands laid under water for weeks, he was consulted and after a careful survey of the district gave plans and estimates for remedial works. He was consulted by the Norwich Municipal authorities after the floods which did much damage in that city in 1877, and also by the authorities of Burton on-Trent when that town was flooded in 1879.

He served on more than one occasion on Committees appointed by Government Departments to investigate important questions. He was one of a Committee of five members appointed by the War Office in 1868, to enquire into the construction, condition and cost of the fortifications erected and in course of erection. During this enquiry the Committee personally examined the whole of the works. He was also one of the Committee appointed by the Board of Trade in 1880, to consider the question of Wind-Pressure on Railway Structures.

By an Act of Parliament passed in the year 1868, to enable the Postmaster-General to purchase the Electric Telegraphs, the Marquis of Salisbury, and failing him Mr. Hawkshaw, was appointed arbitrator to distribute the purchase money among the shareholders of the different Companies in such proportion as he should award and determine after due consideration. As Lord Salisbury did not accept the post, this important duty devolved on Mr. Hawkshaw, who divided the large sum in question among the various shareholders.

His professional engagements left no time for literary work other than the many reports he was called upon to write. In 1838, after his return from Venezuela, he published in one volume a short account of his experiences in that country. This work shows that he was a good observer taking interest in questions of natural science, especially in those relating to geology. He became a Fellow of the Geological Society of London in the same year (1838). The sixth volume of the Transactions of that Society contains some papers by him. In 1843 he wrote a paper entitled, "Some Observations on the present state of Geological Enquiry as to the Origin of Coal," published in Sturgeon's Annals of Philosophy, 1843. He was also a Fellow of the Manchester Geological Society. In 1855 he was elected a Fellow of the Royal Society and was also a Fellow of the Royal Society of Edingburgh.

He was President of the Institution of Civil Engineers in 1862-63, and of the British Association in 1875. He was for twenty-six years an officer of the Engineer and Railway Transsport Volunteers, and was the Lieut.-Colonel Commandant from the year 1878 until his death.

Political life had no strong attraction for him, no one who knew him could imagine him a party man. Nevertheless he was persuaded in 1863 to offer himself as a candidate for Andover in the Liberal interest, but he was not successful. In 1864, he bought the estate of Colonel Pinney at Lyme Regis in Dorsetshire, and made arrangements to offer himself as the Liberal candidate for the borough at the general election in 1865. Being advised only a few days before the election that he was disqualified by his holding a Government, his son took his place and lost the election by nine votes. He was always a Liberal in the true sense of the word, and so in due course became a Liberal Unionist. Like all Yorkshiremen he was not without some love of sport. For many years he had a moor in Scotland. In earlier days, before the luxurious lodges of the present day had come into existence, he shared a room in black bothy in Aberdeenshire with his old friend William Dunlop, a director of the Edinburgh, Perth and Dundee Railway. Later on he rented Inverkroskie Lodge in Pertshire for some years. In 1865 he bought the estate of Hollycombe in Sussex, and there continued to enjoy covert shooting until within two years of his death.

He was never happier than when out for a day visiting some of his professional works during their progress, for he had a true love of his work and was little influenced by questions of pecuniary gain. His common sense was remarkable. This was apparent not only in his reports and in the work which he carried out, but by the kind of work with which he allowed his name to be connected. His firmness of character often stood him in good stead. He did not give his support to any project until he had carefully and honestly considered it, and when he had once made up his mind, and felt sure that his decision was correct, no cross-examination could make him waver in the least degree. As a witness before Parliamentary Committees and other tribunals he has not had many equals. Though reserved in private life he was of a kindly disposition, as many who have known him can bear witness.

Sir John Hawkshaw was undoubtedly one of the greatest engineers of the century, and his membership of this Institution forms an important episode in the history of the society. Throughout his long connection of fifty-five years he steadily supported it, freely contributing information of the most valuable and practical kind from the stores treasured up in the conduct of his large and successful practice. In the Name-Index to Vols. I. to LVIII. of the Proceedings, which correspond to the most active period of his career, there are no less than six closely printed pages referring to his contributions, whilst many of his works, such as the railway bridges over the Thames, the docks at the Isle of Dogs and Hull, Holyhead and Alderney Breakwaters, the Amsterdam Ship Canal, Brighton Main Drainage, etc., formed the subject of communications by his assistants, most of whom subsequently achieved positions in the front rank of the profession.

In 1850 Sir John Hawkshaw was made a Member of Council, being afterwards continuously re-elected until he reached the President's chair in 1861. In 1864 he was one of the first to respond to the appeal made for a Benevolent Fund, subscribing £500 to that undertaking. Two years later, when the subject of rebuilding the premises in Great George Street became urgent, he subscribed £2,000 to the fund proposed to be raised among the members for that purpose, and although the subscription list was afterwards cancelled, there is no doubt the money would have been cheerfully paid had it been needed. Lastly, by his will he left the society £500 free of legacy duty.

This distinguished engineer died on the 2nd June, 1891, leaving a reputation such as few have achieved for variety of good and honest work. Certainly no man has done more to enchance the honour and reputation of the profession.

(*The foregoing is from the Minutes of Proceedings of the Institution of Civil Engineers, Vol. CVI*, 1890.)

Sir John Hawkshaw was elected an Honorary Member of the Canadian Society of Civil Engineers on the 14th November, 1889.

GEORGE HOLT HENSHAW was born in Montreal, September 1st, 1831. At a very early age he evinced a strong desire to acquire a knowledge of mathematics and drawing; and as a pupil of the Rector of the Montreal High School, the Revd. Mr. Simpson, he attracted much attention, and while pursuing his studies at the school, was advised by the Rector to engage the services of Mr. Andrews, professor of Mathematics at Cambridge, who had recently come to this country to settle. Under the tuition of Mr. Andrews he made such rapid progress that he was invited by Mr. Alfred Barrett, chief engineer of the Board of Works of Canada, to enter the Government service. His first work was on the improvements and enlargement of the locks of the Lachine Canal in 1847.

In 1849, Mr. Henshaw was offered the post of assistant engineer on the construction of the James River and Kenawa Canal, Virginia, and in charge of the divisional drawing offices.

From 1852 to 1854 inclusive, he was engaged on the Chicago Water Works and various Railway Surveys in Illinois and Michigan. From 1854 to 1856 on the New York and Erie Railway, and from 1857 to 1859 was resident Engineer on the Trois Pistoles section of the Grand Trunk Railway. In 1860, he was appointed by Mr. Tho. Brassey, as "Engineer in charge of the Western Division of the Danish Railways." After seven years service in Denmark he returned to Montreal, and from 1869 to 1872 was resident engineer on sections 4 and 11 of the Intercolonial railway. During 1872–73 he was engineer in charge of survey between Three Rivers and Montreal on "North Shore" railway. Mr. Henshaw's last service in Canada was as resident engineer of the Canadian Government at St. Anns, P. Q., from 1873 to 1888 when on the final completion of Canal and Locks at that place he removed to the United States and for the last two years has resided in Brooklyn and New York, being engaged in the development of a project for the protection of beach fronts from the action of the sea.

Mr. Henshaw died at Brooklyn, N. Y., January 10th, 1891, age 59 years 8 months. He was elected a member of this Society on the 20th January, 1887.

HENRY ARCHBALD was born in Montreal, 21st May, 1861, and his early education was received at the Montreal High School. In September, 1878, he entered the Faculty of Applied Science, McGill University, and after a successful career as a student in the course of civil engineering, graduated in April, 1881, with the degree of "Bachelor of Applied Science." His first practical work was as an assistant on the topographical survey of a portion of the maritime provinces. In the autumn of 1882 he joined the Canadian Pacific Railway as assistant in charge of construction of branch lines and maintenance of bridges and permanent way, under Mr. D. McPherson, divisional engineer, with whom he remained, giving valuable assistance until April, 1889, when he joined the United States engineer corps, at Montgomery, Alabama, under Captain Price, as assistant to Mr. Charles Firth, engineer in charge of improvements in the Coosa River. These improvements comprise an extensive system of locks, with water stretches between, where dredging and jetties are made use of to improve the natural channel. From summer of 1889 to autumn of 1891 he was engaged with Mr. Firth in an elaborate survey of the Coosa River and the adjacent country, for the purpose of locating the exact sites for the locks and the different portions of river bed in need of improvement. This survey had been completed and construction started on the locks at Wetumpka, when a sudden attack of dysentery, brought on by unavoidable exposure to dampness and heat, carried him off November 21st, 1891. Mr. Archbald was elected an associate member of this society on the 20th January, 1887.

NOTE.

The Council regrets the insertion, as an appendix to the last Annual Report, of an obituary notice, accepted as such without examination, and disclaims any intention to embark in the controversy therein referred to.

INDEX.

1891.—JANUARY TO DECEMBER.

Address to President, 3.
Almon, W. B., elected student, 269.
Amendments to By-Laws, 10.
Analyses of Pictou Iron Ores, 110.
Anderson, W. P., elected member of Council, 10.
Annual General Meeting, 1.
Annual Report, 1.
Automatic Engine, 214.

Back River Bridge over C. P. Ry., 290.
Balance Sheet, 8.
Ball, J. P., transferred associate member, 121.
Barnett, J. D., elected member of Council, 10. Correspondence on Contraction and Expansion of Ice, 287.
Bay of Quinte Bridge at Belleville, 279, 282, 284, 298.
Beatty, H. J., elected student, 211.
Bell, J., elected associate, 121.
Blackwell, K. W. elected member of Council, 10. Discussion on Mining in British Columbia, 176.
Blain, Hon. D., Discussion on Enlarged Waterway, 74.
Bolland, P. J., Discussion on the Steam Engine, 221.
Bovey, H. T., elected Secretary, 10. Vote of thanks to, 11.
Bowman, F. A., Correspondence on the Steam Engine, 225. Transferred associate member, 269.
Bridge across Back River, C. P. Ry., 290.
" Bay of Quinte at Belleville, 279, 282, 284, 298.
" Coteau, 78.
" Fraser River, 228.
" International at Buffalo, 281.
" Rice Lake Railway, 270, 287, 297.
" St. Lawrence, 17, 89, 90, 91.
" Victoria, 13, 281.
Bright, J. B., elected associate member, 269.
Brown, F. R. F., elected member of Council, 10.
Budden, H. A., Correspondence on Enlarged Waterway, 76. Building Fund, 7.
Butler, M. J., Correspondence on Sewerage and Waterworks of St. John's, Newfoundland, 140.
By-Laws, Amendments to, 10.

Cambie, H. J., Fraser River Bridge, by, 228, 233.
Campbell, W. F., elected student, 269.
Canal, Erie and Oswego Ship, 14. Enlargements, 58.
" Georgian Bay and Toronto Ship, 54.
" Ottawa Ship, 52.
" Niagara Falls Ship, 57.
" St. Mary's Falls, 41.
" Welland, 42, 47.
Chadwick, F., elected Librarian, 10. Vote of thanks to, 11.
Chambers, R. E., Correspondence on Iron Ores of Nova Scotia, 120.
Chignecto Ship Railway, by H. G. C. Ketchum, 310, 323.
Clarke, T. C., Correspondence on Enlarged Waterway, 76; on Contraction and Expansion of Ice, 297.
Colliery, International, Bridgeport, C. B., 19.
CONSTRUCTION OF THE COTEAU BRIDGE, THE, by G. A. Mountain, 78. Site of bridge, 78. Channels, 79. Velocity of current, 79. Measurement of base line, 80. Caissons, 80. Piers, 82. Accident to dredge, 82. Resistance of pivot caisson, 84. Composition of concrete, 85. Stone, 85. Superstructure, 85, 87. Erection of spans, 86. Discussion, 88. Cost of bridge, 88. Cost of St. Lawrence Bridge, 91. Table of dates fixed for completion of caissons, 90.
CONTRACTION AND EXPANSION OF ICE ON CANADIAN WATERS, by J. H. Dumble, 270. Rice Lake Railway Bridge, 270, 287, 297. Formation of ice, 271. Expansion of ice, 271. Table of observations on contraction and expansion of ice, 275. Discussion, 279. Bay of Quinte Bridge, 279, 282, 284, 298. Victoria Bridge, 281. International Bridge at Buffalo, 281. Table of dilatation of ice, 288. Back River Bridge, C. P. Ry., 290.
Corthell, E. L., An Enlarged Waterway between the Great Lakes and the Atlantic Seaboard, by, 32.
Council, members of, 1891, 10.
Crangle, Capt., Discussion on Enlarged Waterway, 74.
Cuningham, G. C., Energy and Labour, by, 235.

Davidson, J. I., elected associate, 209.
Davis, W. M., transferred member, 121.
Diplomas, Statement of, 11.
Dodwell, C. E. W., elected member of Council, 10. Discussion on Coteau Bridge, 91.
Dominion Bridge Co.'s Works, 15.
Dominion Wire Works, 16.
Domville, J. W. elected student, 121.
Donkin, H. E. elected member of Council, 10.
Dorval, H. E. W., elected associate, 31.
Drummond, T., Mining in British Columbia, by, 142, 176, 180.

Duff, W. A., elected student, 209.

Duggan, G. H., Notes on Superstructure of Coteau Bridge, by, 94.

Dumble, J. H., Contraction and Expansion of Ice on Canadian Waters, by, 270, 306.

Election of members, etc., 31, 121, 209, 211, 269.

Election of officers and members of Council for 1891, 10.

Ellis, H. D., elected associate member, 209.

ENERGY AND LABOUR, by G. C. Cuningham, 235. Introduction, 235. Definition of Labour, 235. Discussion, 262.

ENLARGED WATERWAY BETWEEN THE GREAT LAKES AND THE ATLANTIC SEABOARD, AN, by E. L. Cortbell, 32. St. Mary's Falls Canal, 41. St. Clair River improvements, 41. Welland Canal, 42. Trent River navigation, 43. St. Lawrence improvements, 43. Erie and Oswego Canals, 44. Lake Champlain and Hudson River, 45. Railroads, 45. Harbours, 46. Commerce, 47. Physical features, 52. Ottawa Ship Canal, 52. Georgian Bay and Toronto Ship Canal, 54. Enlargement of Welland Canal, 57. Niagara Falls Ship Canal, 57. Niagara Falls Ship Railway, 58. Michigan Peninsula Ship Canal and Railway, 58. Lake Champlain route, 58. Erie and Oswego Canal enlargements, 58. St. Lawrence River enlargements, 59. Comparison of commercial condition, 59. Table of sailing distances, speed, time and cost, 60. Ship railway discussion, 68. Discussion, 74. Correspondence, 76.

Excursion, account of, 13.

Finances, 11.

Fisher, R., elected associate, 121. Discussion on Energy and Labour, 265.

FLOW AND DISCHARGE OF SEWERS, by E. Mohun, 349.

FRASER RIVER BRIDGE, MISSION BRANCH, C. P. RY., by H. J. Cambie, 228. Description of bridge, 228. Piers, 229. Swing truss and gear, 231. Discussion, 232. Tides, 233. Nature of "silt," 233. Superstructure, 234.

Galbraith, Prof., Discussion on Enlarged Waterway, 74, 75,

Georgian Bay and Toronto Ship Canal, 54.

Gibson, W., elected associate, 269.

Gilpin, E., The Iron Ores of Nova Scotia, by, 97.

Gisborne, F. N., elected member of Council, 10. Discussion on Enlarged Waterway, 76.

Glaenzer, E., elected student, 209.

Gould, O. M., elected associate, 121.

Grand Trunk Railway Workshops, 14.

Grant, A. J., elected associate member, 211.

Grantham, A. M., elected student, 121.

Gzowski, Col. Sir C. S., address to, 3. Reply by, 3. Elected President, 10. Vote of thanks to, 11.

Gzowski Medal, rules for the award of, 9.

Gzowski Medal, Committee, report of for 1891, 11.

Hannaford, E. P., elected Vice-President, 10. Discussion on construction of the Coteau Bridge, 88; on the Fraser River Bridge, 232; on contraction and Expansion of Ice, 279.

Haskins, W., elected member, 31.

Hoare, E. A., elected member of Council, 10.

Hobson, Jos., elected member of Council, 10.

Hopkins, M. W., transferred associate member, 121.

Hornblower, Compound Engipe, The, 213.

Hoskin, J., elected associate, 209.

Howland, O. A., elected associate, 209.

Hutcheon, J., elected student, 211.

Ice, Contraction and Expansion of, 270.

International Bridge at Buffalo, 281.

INTERNATIONAL COLLIERY, BRIDGEPORT, CAPE BRETON, by C. B. Kingston, 19. Geological formation of, 19 Coal cutting, 20. Underground haulage, 21. Roads, 21. Haulage, 21. Rope, 22. Engine, 22. Signals, 22. Horses, 23. Tubs, 23. Tail rope system of haulage, 24. The Shaft, 25. Timbering of the Shaft Bottom, 26. Ventilation, 26. Pumping, 27. Coal Cleaning, 28. Shipment of Coal, 29.

IRON ORES OF NOVA SCOTIA, THE, by E. Gilpin, 97. Early Mining, 97. Table of Ores, 102. Pictou County, 104. Analyses of Pictou Iron Ores, 110, Londonderry, 113. Conditions upon which Iron Ore Lands are Granted, 119. Correspondence, 120.

Irwin, H., discussion on Railway Curves, 200; on Energy and Labour, 266; on Contraction and Expansion of Ice, 291.

Jennings, W. T., elected member of Council, 10.

Jones, H. A., elected student, 269.

Keefer, C. H., correspondence on Contraction and Expansion of Ice, 284, 301.

Kennedy, J., elected Vice-President, 10.

Ketchum, H. G. C., Ship Transportation and the Chignecto Ship Railway, by, 310.

Kingston, C. B., International Colliery, Bridgeport, Cape Breton, by 19.

Kinnear, G. S., elected student, 269.

Lake Champlain and Hudson River, 45.
Lake Champlain route, 58.
Laurie, W. H., The Steam Engine, by, 211, 225.
Library, additions to, 5.
Locke, R. T., transferred associate member, 269.
Londonderry Ore, 113.
Lynch, F. J., elected Vice-President, 10.

Macdougall, A., Discussion on Enlarged Waterway, 75. Sewerage and Waterworks of St. John's, Newfoundland, by, 122, 141. Discussion on Fraser River Bridge, 232.
MacPherson, D., Correspondence on Railway Curves, 205. Discussion on Contraction and Expansion of Ice, 290.
Masson, G., elected member, 209.
Matthews, W. D., elected associate, 209.
McCarthy, J. W., Discussion on Fraser River Bridge, 232.
McCulloch, A. L., elected associate member, 121.
McFarland, J. W., elected associate, 269.
Michigan Peninsula Ship Canal and Railway, 58.
Millican, C. A., elected associate member, 31.
MINING IN BRITISH COLUMBIA, by T. Drummond, 142. Introduction, 142. Discoveries of gold, 143. Table of gold production, 154. Methods of working placer mines, 156. Vein mining, 165. Discussion, 176. Returns from coal mines in British Columbia, 178. Correspondence, 179.
Modern Steam Practice, 214.
Mohun, E., Table on Flow and Discharge of Sewers, by, 349.
Monro, T., elected member of Council, 10.
Moore, J. E. A., elected student, 31.
Mountain, G. A., The Construction of the Coteau Bridge, by, 78, 88, 92.
Murphy, Hon. E., Discussion on Enlarged Waterway, 76.

Newman, W., elected student, 211.
Niagara Falls Ship Canal, 57.
Niagara Falls Ship Railway, 58.
Nicolson, Prof. J. T., elected member, 269. Correspondence on Contraction and Expansion of Ice, 297.
Nominating Committee, 10.

Obituary Notices, Sir John Hawkshaw, 352. G. H. Henshaw, 366. H. Archibald, 367.
Ordinary meetings, 4.

Ores, Table of, 102.
O'Rourke, J. F., elected member, 31.
Ottawa Ship Canal, 52.

Palmer. R. E., transferred associate member, 269.
Pani, C. E., elected associate member, 121.
Papers, 4.
Papin, Denys, Invented Steam Engine, 212.
Peterson, P. A., elected member of Council, 10. Discussion on Construction of Coteau Bridge, 88.
Pictou County Ore, 104.
Pinder, W. G., elected member, 269.
Poole, H. S., correspondence on Mining in British Columbia, 179.

RAILWAY CURVES, by H. K. Wicksteed, 182. Location of Railways, 182. Curvature, 183. Sharp Curves, 187. Perfect Curve, 189. "Cubic Parabola," 190. Discussion, 200. Correspondence, 205.
Redway, Discussion on Enlarged Waterway, 75.
Reid, W. G., elected associate, 31.
Rice Lake Railway Bridge, 270, 287, 297.
Roll of the Society, 1.
Rose, G. G., elected student, 269.
Russell, T. S., transferred associate member, 31.
Ruttan, H. N., elected member of Council, 10. Discussion on Enlarged Waterway, 76.

Saunders, B. J., elected associate member, 121.
SEWERAGE AND WATERWORKS OF ST. JOHNS, NEWFOUNDLAND, by A. MacDougall, 122 Early History of St. Johns, 122. Water Supply, 124. Sewerage, 126. Tunnel, 128. Trenching, 129. Materials, 129. Manholes, 130. Sewer Inspection, 130. Sewer Ventilation, 131. Cost of Work, 131. Roadways, 131. Scavenging and Street Cleaning, 132. Sanitary Work, 133. Tables, 134. Discussion, 137. Correspondence, 140.

Sewers, Table on Flow and Discharge of, by E. Mohun, 349.
Shanly, W., correspondence on Contraction and Expansion of Ice, 298.
Sheraton, R. L., elected student, 31.
Ship Railway discussion, 68.

SHIP TRANSPORTATION AND THE CHIGNECTO SHIP RAILWAY, by H. G. C. Ketchum, 310. Early Ship Transport, 310. Hydraulic Lift, 312. Baie Verte Canal, 313. Erection of various Hydraulic Lifts, 317. Ship Cradle, 318. Chignecto Ship Railway, 323. Correspondence, 344.
Silvester, G. E., elected student, 211.
Smith, W., correspondence on Ship Transportation and the Chignecto Ship Railway, 344.
Society's Rooms, 5.
Special General Meeting, 2.
Sproule, W. J., discussion on Fraser River Bridge, 232; on Energy and Labour, 262; on Contraction and Expansion of Ice, 289.
St. Clair River Improvements, 41.
STEAM ENGINE, THE, by W. H. Laurie, 211. History of the Steam Engine, 211. Denys Papin, 212. James Watt, 212. Hornblower Compound Engine, 213. Automatic Engine, 214. Modern Steam Practice, 214. Clearance, 217. Condensation, 218. Discussion, 221. Method of Measuring Heat, 225.
Steele, E. C., elected associate member, 269.
St. George, P. W., elected member of Council, 10.
St. Lawrence Bridge, 17, 89, 90, 91.
St. Lawrence Improvements, 43. Enlargements, 59.
St. Mary's Falls Canal, 41.
Stoess, C. A., elected associate member, 269.
Students Meetings, 4.
SUPERSTRUCTURE OF COTEAU BRIDGE, NOTES ON, by G. H. Duggan, 94.

TABLES:—
Analyses of Picton Iron Ores, 110.
Cement tests, by the late Mr. C. J. Harvey, 136.
Flow and Discharge of Sewers, 351.
Observations on Contraction and Expansion of Ice, 275.
Ores in Nova Scotia, 102.
Returns from Coal Mines in British Columbia, 178.
Tate, R. F., discussion on Enlarged Waterway, 76.
Tessier, J. H., elected associate member, 31.
Thomson, R. W., elected student, 211.
Thompson, W. G., elected member, 31.
Tout, W. H., elected associate member, 121.
Trent River Navigation, 43.
Trutch, Sir J. W., elected member of Council, 10.
Tully, K., discussion on Enlarged Waterway, 75.
Turner, F. E. P., elected member, 31.
Twining, C. R. F., elected member, 211.

Van Buskirk, W. F., elected associate member, 121.
Vantelet, H. E., presented with Gzowski Medal, 11.
Victoria Bridge, 13, 281.

Walbank, W. M., discussion on Sewerage and Waterways, St. Johns, Newfoundland, 137.
Wallace, J. W. M., elected student, 269.
Wallis, H., elected Treasurer, 10, vote of thanks to, 11.
Waterway, An Enlarged, between the Great Lakes and the Atlantic Seaboard, 32.
Watt, J., Development of Steam Engine by, 212.
Webb, P., elected associate member, 121.
Welland Canal, 42. Cost of Enlargement, 57.
Wellington, A. M., elected member, 211.
Whitman, L., elected student, 269.
Wicksteed, H. K., Railway Curves by, 182, 206.

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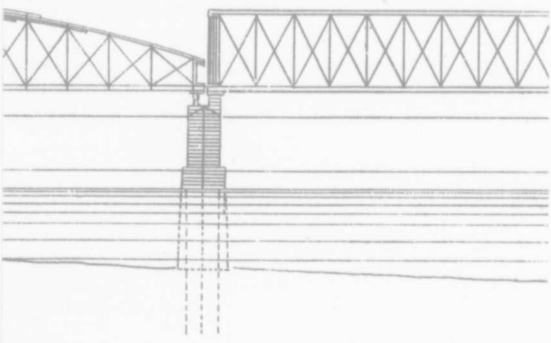
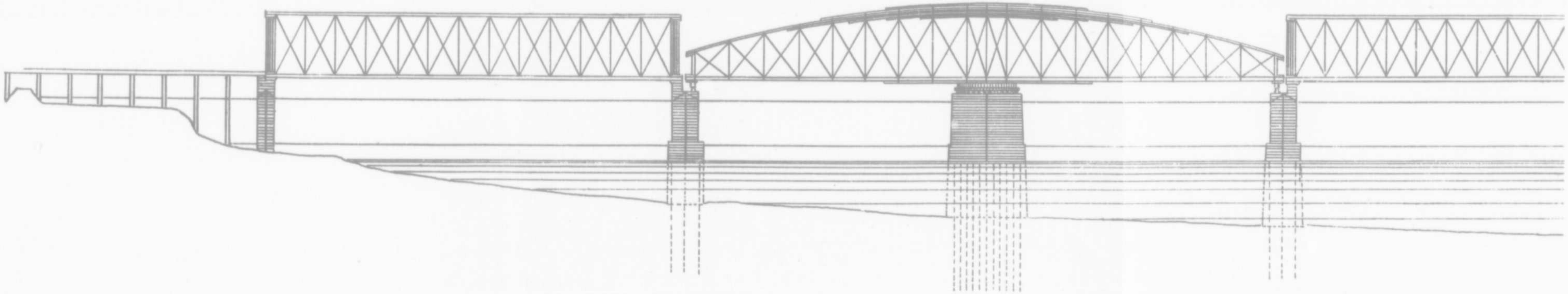


TRANSACTIONS CAN. SOC. C.E.,
VOL. V. PLATE VII.

FRASER RIVER BRIDGE—MISSION BRANCH,

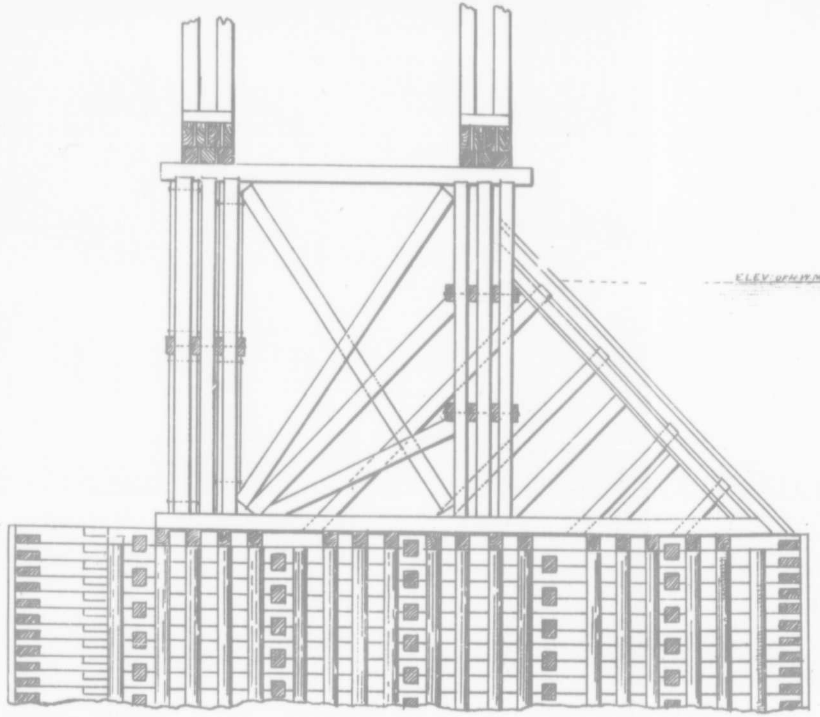
CANADIAN PACIFIC RAILWAY.

SCALE: 50 FEET = 1 INCH.

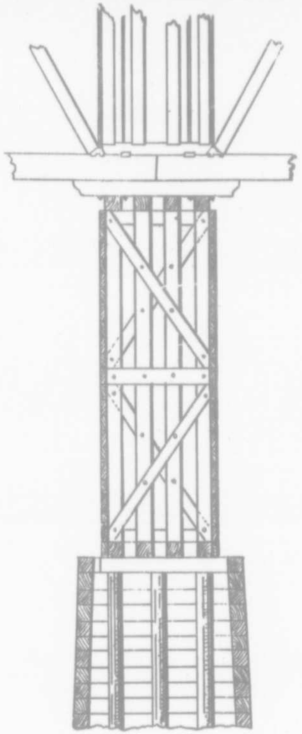


FRASER RIVER BRIDGE—MISSION BRANCH,

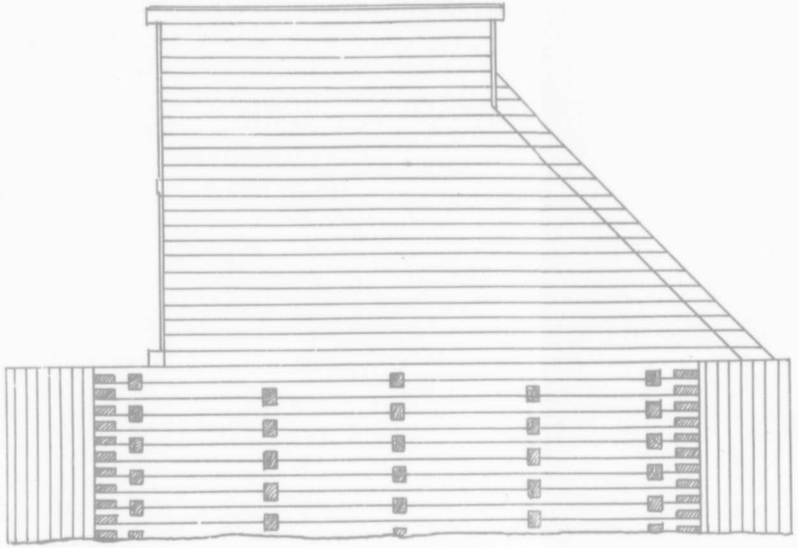
CANADIAN PACIFIC RAILWAY.



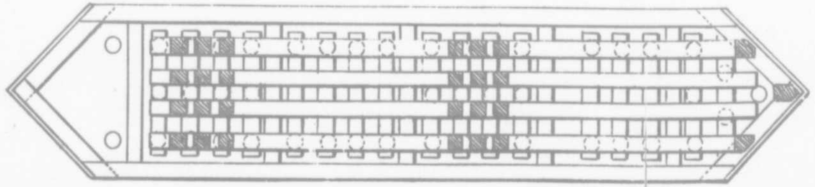
—LONGITUDINAL SECTION OF CRIB & FRAME—
—OF PIER.—



—X SECTION OF CRIB SHOWING REAR—
—ELEVATION OF PIER.—



—SIDE ELEVATION.—



—PLAN OF CRIB WITH BOTTOM PLAN OF PIER.—

—SCALE 10 FT = 1 INCH—

Can: Pac: Ry: Eng. Office
Vancouver, Dec. 18th 1890
A.L.R.

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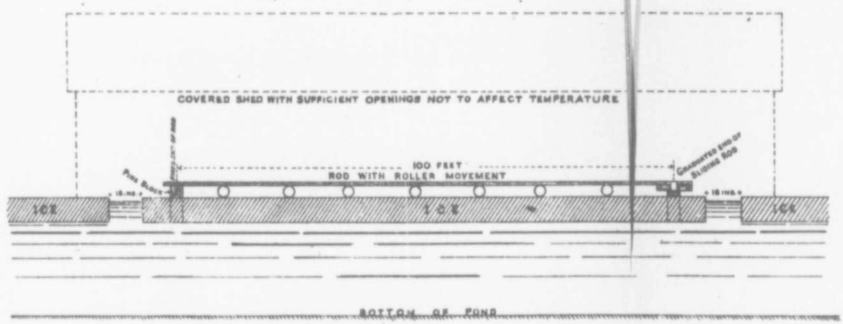
VOL. V. PLATE IX.

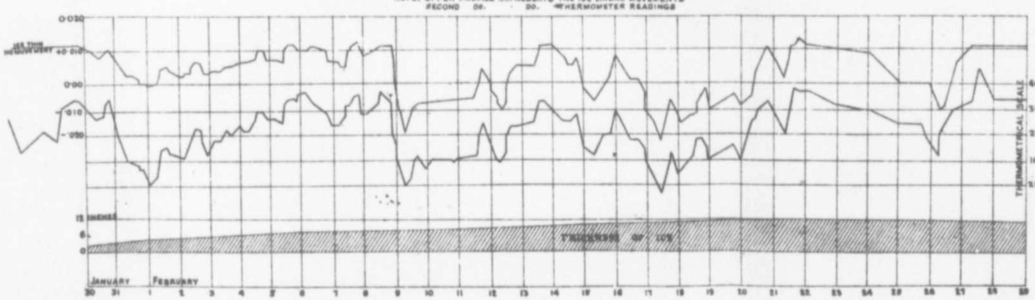
SKETCH SHEWING METHOD OF OBSERVING CONTRACTION AND EXPANSION OF ICE
COBOURG C.W. 1860



TRANSACTIONS CAN. SOC. C. E.
VOL. V. PLATE X.

DIAGRAM
SHEWING EXPANSION AND CONTRACTION OF ICE 100 FEET IN LENGTH, ALSO THERMOMETRICAL SECTION CORRESPONDING TO THE ICE MOVEMENTS

NOTE. UPPER PROFILE REPRESENTS THE ICE LINEAL MOVEMENTS
SECOND DO. DO. THERMOMETER READINGS




RIVER ST LAWRENCE
C. MAGDALEN
C. GASPE
Gaspe Bay
GASPE
Mal Bay
PERCE
Bonaventure
COUNTY OF GASPE
GULF OF ST LAWRENCE
Shipping 1890. Total 6,422,976, Tons of Entries and Clearances in Gulf and River St Lawrence from Quebec eastwards
MAGDALEN ISLANDS
Byron I.
Gross I.
Allright I.
Amherst I.
C. ST LAWRENCE
C. NORTH
Aspee Bay
CAPE BRETON ISLAND
Mira Bay
C. BRETON
SYDNEY
COAL MINES
BADDECK
BRASDOR LAKE
PORTHOOD
COUNTY OF BONAVENTURE
Miscou I.
Shippigan I.
CARLISLE
CHALEUR BAY
NIPISIGHT BAY
DALHOUSIE
BATHURST
CAMPBELTON
MIRAMICHI BAY
PRINCE EDWARD ISLAND
NORTH PT
Shipping 1890, 1,362,861 Tons
EAST PT
GEORGE TOWN
CHARLOTTE TOWN
SUMMERSIDE
C. EGMONT
C. TRAVERS
C. TORMENTIN
HILLSBOROUGH
PRIM PT
C. GEORGE
STRAITS OF CANSO
GEORGE BAY
PT HAWKESBURY
TRACADIE
CANSO
CHEDABUCTO B
C. CANSO
ANTICONISH
Tor Bay
NORTHUMBERLAND STRAIT
PICTOU COAL MINES
NEW BRUNSWICK
NEWCASTLE
CHATHAM
RICHIBUCTO
BUCTOUCHE
SHEDIAC
BAY VERTE
SHIP RAILWAY
TIONISH
DORCHESTER
AMHERST
MONCTON
SACKVILLE
HILLSBORO
SHEPODY
NOVA SCOTIA
TRURO
LONDONDERRY
NOEL
PARSBORO
MINAS BAY
JOGGINS COAL MINES
CHIGNECTO BAY
WINDSOR
CORNWALLIS
HALIFAX
Clam Bay
ATLANTIC OCEAN
ST MARTINS
FREDERICTON
MAGARETSVILLE
LAURENCETOWN
BRIDGETOWN
ANNAPOLIS
Mahoney Bay
C. Le Havre
Port Medway
LIVERPOOL
ST JOHN
CARLETON
St John Har
BAY OF FUNDY
Shipping 1890. Total 3,855,932, Tons With Cargo
ST GEORGE
ST. ANDREWS
Passamaquoddy B.
CAMPORELLO
GRAND MANAN
S.W. HEAD
DIGBY CUT
DIGBY
WEYMOUTH
NEW EDINBURGH
CHETICAMP
SHELBOURNE
YARMOUTH
LURCHER SHOAL
C. SABLE
LUREC
MACHIAS
Machias Bay
Englishman's B.
Pleasant River Bay
Goldsboro Bay
Frenchman's Bay
BANGOR
Penobscot Bay and River
UNITED STATES
Map
SHEWING
CHIGNECTO SHIP RAILWAY
Total Tonnage 1890, 11,641,769, Tons
NAUTICAL MILES
0 10 20 30 40 50 60

CHIGNECTO SHIP RAILWAY,

By H. G. C. KETCHUM.