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Issued June, 1887.

TRANSACTIONS

OF

The Canadian Society of Civil Engineers.

VOL I. PART I.

MARCH TO JUNE.

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FIRST GENERAL MEETING.

The first general meeting for the organization of the Canadian Society of Civil Engineers was held in the Harbour Commissioners' Building, Montreal, on Thursday, February the 24th, 1887.

The following gentlemen were present:

Messrs. T. C. Keefer, G. A. Mountain, W. P. Anderson, J. L. P. O'Hanly, T. Guerin, R. Surtees, D. McPherson, J. P. Pim, E. V. Johnson, R. Steckel, H. A. F. McLeod, ...of Ottawa.

Messrs. P. W. St. George, J. Kennedy, H. T. Bovey, W. W. Gilbert, M. S. Blaiklock, P. A. Peterson, G. H. Henshaw, W. J. Sproule, W. McLea Walbank, L. Lesage, T. M. Lesage, W. McNab, J. A. U. Beaudry, G. R. Nash, H. Wallis, R. Forsyth, J. H. Bartlett, J. M. Shanly, J. R. Roy, B. D. McConnell, W. H. Laurie, S. Howard, L. J. Papineau, A. E. Childs, A. G. Eneas, C. H. McLeod, J. R. Barlow, A. Brittain, E. Berryman, J. Simpson, E. P. Quirk, H. G. Stanton, G. Holland, E. E. Gilbert, T. Middleton, R. F. Tate, F. Chadwick, F. B. LaVallee, K. Blackwell, F. R. Redpath ....of Montreal.

Messrs. A. Macdougall, H. Smith, C. H. Chapman, of Toronto.

Messrs. L. N. Rhéaume of Morrisburg, T. Berlinguet of Three Rivers, E. Deniel of Grenville, J. E. Belcher, J. G. Macklin and A. J. McLean of Peterborough.

L. S. Pariseau of St. Johns, P.Q., R. Rinfret of St Stanislas de Batiscan, J. D. Barnett of Port Hope, G. F. Languedoc of Outremont, St. George Boswell of Quebec, C. E. Dodwell of Ste. Anne de Bellevue, H. Carre of Brockville, T. Monroe of St. Catharines, J. W. Harkom of Richmond.

It was moved, seconded and resolved that Mr. T. C. Keefer, C.M.G., be requested to act as chairman of the meeting.

It was moved, seconded and resolved that Mr. A. Macdougall be requested to act as secretary of the meeting.

It was moved, seconded and resolved that Messrs. M. S. Blaiklock, G. A. Mountain, W. W. Gilbert, J. D. Barnett, J. G. Macklin and J. H. Bartlett be requested to act as scrutineers for the election of the President, three Vice-Presidents, Secretary, Treasurer, and of fifteen other members of Council for the ensuing year.

Resolved,—That the Report of the Provisional Committee be received and approved.

Resolved,—That the Constitution and By-Laws, as submitted by the Provisional Committee, be adopted.

Resolved,—That the Council be authorized to make application to the Dominion Government for an Act of Incorporation.

The thanks of the meeting were presented to the following :—

To the members of the Provisional Committee for the efficient manner in which they had prepared the provisional Constitution and By-Laws.

To the Grand Trunk and Canadian Pacific Railway Companies, for certain travelling facilities.

To the Harbour Commissioners for the use of their building.

To the Members of the Society, resident in Montreal, for the Conversazione, given by them in the Peter Redpath Museum, McGill University, in honour of the inauguration of the Society.

To Mr. T. C. Keefer, C.M.G., for the efficient manner in which he had conducted the business of the meeting as chairman.

To Mr. A. Macdougall, for acting as secretary, and for the efforts he had made to further the establishment of the Society.

The scrutineers then announced that the following gentlemen had been duly elected:—

First General Meeting.

President.

Thomas C. Keefer, Ottawa.

Vice-Presidents.

C. S. Gzowski, Toronto.
John Kennedy, Montreal.
Walter Shanly, Montreal.

Secretary and Treasurer.

Henry T. Bovey, Montreal.

Council.

H. T. Bovey, Montreal.
F. N. Gisborne, Ottawa.
E. P. Hannaford, Montreal.
W. T. Jennings, London.
Samuel Keefer, Brockville.
Louis Lesage, Montreal.
H. D. Lumsden, Toronto.
Alan Macdougall, Toronto.
Henry F. Perley Ottawa.
Hurd Peters, St. John, N.B.
P. A. Peterson, Montreal.
H. S. Poole, Stellarton, N. S.
H. N. Ruttan, Winnipeg.
P. W. St. George, Montreal.
H. Wallis, Montreal.

The thanks of the meeting were presented to the Scrutineers, for the satisfactory manner in which they had discharged their duties, and the ballot papers were ordered to be destroyed.

Prof. Bovey having resigned from the Council, Mr. C. Schreiber, of Ottawa, was appointed to fill the vacancy at a meeting of the council held on April 14.

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Canadian Society of Civil Engineers.

SESSION 1887—PART I.

TRANSACTIONS.

Thursday, 17th March.

J. KENNEDY, *Vice-President*, in the Chair.

Paper No. 1.

FRAZIL ICE:

ON ITS NATURE, AND THE PREVENTION OF ITS ACTION IN CAUSING FLOODS.

BY GEO. H. HENSHAW, M. CAN. SOC. C. E.

The subject of this paper is one destined to become of increasing interest to Engineers in Northern countries, especially to those engaged in works liable to be affected by ice, whether through direct attack or through floods caused by the arrest of its movements. The author's object is to define the true nature of frazil, and to suggest a method of dealing with it, so as to prevent its more than suspected agency in producing floods.

Whether the vast masses of comminuted ice, which in places are found to underlie the surface ice, are composed of true subaqueously formed ice, or are made up largely of drifted snow and the broken scales of surface ice carried down by the current, is yet to be positively determined; still, from the evidence which exists of enormous quantities of spongy looking ice seen rising from the bottom, it is reasonable to conclude that whatever may be the proportion of these substances, true frazil is, really, their principal constituent.

Now, for an engineer to meet a difficulty with intelligence and success, it is almost essential to understand the actual character of the enemy against which he is to contend. To speculate on this, in the present case, brings us somewhat out of the sphere of the practical engineer and into that of physical science; but we are often compelled to this course when scientific men neglect the subject, or leave us in the dark.

That so little of the nature of frazil is known among engineers is not surprising, when we find that the haziest notions, if any, regarding it, prevail among our highest scientific authorities.

At a meeting of the B.A.A.S., held in Montreal on the 1st September, 1884, in presenting a paper on the subject, the writer was confronted with a casting in type metal, made in a plaster mould, by Mr. W. B. Dawson, of frazil ice, as stated on the label, but which was really a representation of anchor ice.

As explained by the President (Sir William Thompson), frazil was supposed to be the product of currents of water passing over and disintegrating solid anchor ice, exposing, as he expressed it, its "bones," just as rock is worn into irregular forms by the removal of its softer parts. Now, it is difficult to conceive how anyone, practically familiar with the appearance of frazil, could attribute its minute, needle-like fragments to a water-worn origin, or believe that a substance so developed could be produced in large quantities. We do, indeed, in the spring, see ice disintegrated to its bones, and falling to pieces, but that is only when it is exposed to sun and air, and when the formation of frazil is already a thing of the past. This experience convinced me that science had as yet no information to give; and that up to the present, the best authorities regarded frazil merely as a curious formation of rare and limited occurrence.

The author thinks that many are hasty in assuming that all is known about the philosophy of ice formation. Tyndall, when he overthrew the theory of Rumford, did not exhaust the subject. We know that water can be brought above its boiling point without ebullition, and we know that it can be brought below its freezing point without congealing. We know that superheating requires pressure, but how much do we know of the conditions accompanying supercooling?

The author believes that ice never forms in water without an independent nucleus; that when it appears free on the surface the nucleii are supplied by minute particles of vapour, which, becoming frozen in their ascent and falling back upon the water, form, perhaps, the very stars seen in a block of ice when melted through a lens, by the sun's rays.

That frazil, like anchor ice, forms under water seems unquestionable. Mr. Frank Gilbert, engineer, contractor for deepening the channel through the Gallops Rapids, states that he has passed in a boat over great beds of it, covering the bottom in dense masses of a spongy appearance, through which his pole swept with scarcely perceptible impediment. He also observed it upon a wire rope extended beneath the water, between his vessels, looking like bunches of iron filings lifted up by a magnet. In this case he noticed the curious fact that parts of the rope were bare and others covered with the growth, which seemed to negative the idea that the cold had been conducted through the rope. Under the circumstances it is plain that the exposure of the ends of the rope had little or nothing to do with the formation of the ice.

The conclusion come to by the author is, that frazil ice is formed in currents cold enough not only to preserve its crystals but to induce their formation.

But why should it grow luxuriantly on one spot, and yet refuse, as we have seen, to grow upon a closely adjacent spot of a character precisely similar?

Well, that is a question yet to be settled; but with your indulgence an attempt will now be made to offer an explanation.

All who have observed the action of fine drifting snow, when driven by the wind over a plane surface, such as a roof or a railway platform, will have noticed that it does not sweep along in clouds, or rolling volumes, but in long rifts or streaks, with bare spaces between. With every lull of the wind these streaks rest for a moment, to be swept away by succeeding blasts into new combinations of a similar form, according to the variations, in force and direction, of the wind.

Now it is evident that these rifts are produced by the small inequalities of the surface of the plane; that the bare places are where the wind is least obstructed; and that the snowy streaks are the eddies where its force is partially obstructed. Now if this is admitted, we are brought to the important conclusion, that if the obstructions on the plane remain unaltered, and the direction, volume and force of the wind continue unchanged, the streaks of snow with the spaces between will always occupy precisely the same position upon the plane.

If we now apply these observations to the flow of a river, we shall find a close approximation to such supposed conditions. For, taking the case of a stream with a rocky bed, we have the more or less permanent obstructions on the bottom; while, unlike the air, the volume, speed, and direction of the water are but little affected by superficial influences.

The bottom of such a river presents a confused succession of irregular obstructions, around, over and between which the water rushes in every direction possible at once, and at every variety of speed. Along its main channel, greater freedom gives the river current its highest velocity, so raising its volume at the quieter reaches that backward currents or eddies are formed at its edges.

Looking at the troubled tumbled surface such a river sometimes presents, one is tempted to believe it a hopelessly involved chaos of complicated motion; but there is no chaos there. Every movement is made under as strict a law as to which governs the piston of an engine. Every bulge or swirl that we notice at some particular spot comes from the self-same sunken rock or cranny, and each would repeat itself precisely, were it not for molecular variations, which we will not here take account of further than to note that they modify, in a minor way, the results about to be referred to.

Bearing these facts in mind, let us take a horizontal or plane section of the river.

Here we have, in the currents so intersected, instead of the long streaks seen in our snow drift, an irregular network, with meshes of every size and threads of every thickness. The threads represent the currents, and the meshes the comparatively still spaces enclosed. If we wish to present the molecular effects alluded to, they may be shown as a sort of fringe of eddies along the sides of the threads.

As in the case supposed, the general plan and position of the network is permanent, and as we know that water is a bad conductor of heat, it is plain that a sudden cooling of the water up stream would cause the threads of the network to become colder than the enclosed meshes; while the reverse would be the case on the water above becoming warmer, so that objects placed, the one in the mesh and the other in the thread, would be affected differently as to temperature.

Now for the formation of frazil.

The river is cooled down nearly to congelation; there is, we known, a very small margin to go upon at freezing point. The thermometer goes down to zero or below. The river in its efforts to part with its remaining heat steams, but its current is too rapid to freeze over; and so a supercooled current is borne down through the network. It is designated a supercooled current, because the author does not wish to commit himself to the statement that the water itself is below freezing point. Such water is always charged with minute icy particles, which may in themselves be the cause of the refrigeration of the bottom; the water charged with these particles is the current referred to.

The result is obvious; objects that present suitable nuclei in the threads are covered with a growth of frazil, while similar objects in the meshes remain bare. Similarly, on a sudden change to a warmer temperature the masses of frazil are thawed from their frail anchorage, rise, and are carried down by the stream; a phenomenon noticed by many observers. This theory also explains why frazil does not form on sandy or fine gravelly bottoms; for wherever there is any shifting of the obstructions on the bottom, there will also be changes in the threads and meshes, preventing that continuous contract with the cold current which is necessary to the formation of frazil, or so mixing thread and mesh as to bring the whole above the required temperature. To this theory, even if it is not an absolute demonstration, at least belongs the merit of accounting for all known facts in connection with the nature and action of frazil.

Frazil, as we know, appears in the form of a mass of frail particles, with very little cohesive power. It is plain then that in small quantities, or with anything like a free passage, it would pass away harmlessly seaward. It could not under such circumstances become sufficiently dense to stop even its own passage, except in eddies, wedge spaces, or "culs de sac."

Unfortunately in the St. Lawrence there are too many of all these. Every shoal or batture affords such asylums, into which the frazil graduallypacks. Fragments of ice are thrust into the mass affording new crannies for accumulation, until the flow of the stream is confined to the deeper or more direct channels. In their turn these channels will be most choked at their bends, especially where shoals or low lying islands exist on the outer side of the curve of the current and receive its centrifugal impact.

Now when we consider that the volume of a river like the St. Lawrence is not greater in winter than in summer, but rather less, and that at certain points there are floods one year, and none the next, we naturally conclude that the floods are caused by more than usual obstruction below, and not by increased volume. The trouble is, therefore, local, and may be removed without injuriously affecting other parts of the river.

We revert once more to the nature of frazil, in order to clearly point out the difference between it and surface formed ice, when in motion and floating down stream.

Surface ice may be seen in process of formation on the open channel, shooting out its lances from floating nuclei, or, more frequently, projecting itself from the shore ice under the lee of salient points. It forms thin sheets through which the oars of passing boats crash like brittle glass. All along the open channel fragments are broken off by the action of wind and wave, and float down until stopped by some obstacle. In cold weather these are either cemented together on their way or quickly consolidated when they arrive at a barrier, and thus, as a rule, is formed the surface crust over the open channel. Where the water is still or the current sluggish the opening closes smoothly by the extension of the ice from either side.

A channel closed by packing is always more or less rough, and it would be quite possible, by critical examination, to determine the relative force of the current at different places, at the time of its taking, from the degree of roughness in which it was left.

There is no evidence to show that floating ice is carried beneath the fixed ice to any great extent, except in a sttrong current. Even then the tendency to rise in packing seems nearly to balance the downward movement. Huge hummocks are formed in such places, and the obstruction to the river caused by them is due chiefly to broken sheets caught vertically, or at an angle with the surface.

The character and action of frazil are totally different. Rising in masses from the bottom, its buoyancy is so little that it floats to a considerable distance below the surface; while so small is its cohesion that when the mass becomes compacted enough to elevate its upper face above the water, it falls apart and spreads over the surface. It often attaches itself to floating ice or forms a nucleus for a new sheet of ice and should severe cold sufficiently consolidate the whole, the surface ice would be swept beneath the barrier ice, in the train of the frazil to which it was attached.

The Caughnawaga Indians, who in winter daily transport the mails to and from Lachine, state that frazil or slush ice runs only in the early part of the winter; and that when it ceases to come down, they know that the channel is closed at the upper end of the lake. If this is so, it shows either that the frazil formed below the Cascade Rapids remains fixed to the bottom as anchor ice; or, what is more likely, that being arrested by the friction of the overlying ice, it is thrust aside and jammed between the ice and the bottom, over the battures or shoals. At any rate, it goes to prove that, without an open channel, frazil is not carried down to any great extent from lake St.-Louis. As a factor in Montreal floods, therefore, we need seek it no further up than the foot of the Lachine rapids.

By keeping the channel open from these rapids down to the foot of Montreal Island, it would seem that the frazil would be carried past without serious lodgment; but as there appears as yet no means of effecting this object, our natural recourse must be to so prepare the bottom of the river so as to give as free a passage to the frazil ice as we possibly can.

As will readily be inferred, I am strongly of the opinion that the disastrous spring floods, from which the City of Montreal has suffered, are caused primarily by the choking of the river during winter, by which the area of the waterway is so reduced as to be unable to carry away the increased volume produced by the melting of the snow. Of course this is aggravated by the down flow of ice from the lakes above.

This latter difficulty it has been proposed to prevent by placing ice breakers, or rather ice-arresting piers, in Lake St. Louis, intended to keep the ice back until the barrier below has broken away.

Curiously enough, this contrivance, though one of the oldest known, has of late been received by some with so much enthusiasm, that disputes have arisen as to who had the honour of first suggesting it; not among engineers, however. It has been used in various beneficial ways, chiefly in securing an ice bridge at some dangerous spot. The latest case of the kind, known to the athor, was for the purpose of making a road upon which to haul stone and other material for the repair of the Carillon dam; a part of which had been undermined and carried away the previous year. The attempt, which was entirely successful, was made under the direction of Mr. Stark, superintending engineer of the Ottawa River Canals.

No doubt such a plan applied to Lake St. Louis would ameliorate spring floods at Montreal, if we were sure that it would entail no other consequences. But there remains a serious question; whether in so doing, the ice would not pack so heavily above as to flood the upper country, and the water obtain so great a head as to carry piers and everything else before it, and bring a worse disaster upon the city.

From the foregoing considerations it seems reasonable to conclude that the direction of any effective operations for the prevention of floods should be in the following lines:—

1st. Straightening the channels; or, where this cannot be done, enlarging them at their bends, by cutting away the inner sides.

2nd. Clearing away boulders and other elevations, on the shoals outside the bends, wherever the thrust of the stream tends to carry ice and frazil into wedge places and culs de sac, and giving the bottom a downward grade of the stream to give free egress to ice entering from above.

3rd. Removing over the whole area of the part of the river affected, all boulders, ledges and other projections of the bottom. Thorough cutting all sub-channels, as to give them a free discharge at the outlet; and benching such shallow slopes along the shoals as in combination with the surface ice afford the natural traps in which the frazil is caught.

Since writing the above, a recommendation of the Government Commission on Floods has been partially put into effect, namely, an attempt to keep open the river channel between Three Rivers and Sorel, by means of vessels fitted to break up the ice.

While very doubtful of its success as a means of preventing floods at Montreal, the author nevertheless heartily endorses the experiment. In such a difficult question the experience gained in an effort of this kind must greatly help on a solution, and may lead to other discoveries of benefit to the country, which otherwise would remain unknown.

DISCUSSION ON FRAZIL ICE.

Mr. Herschel

Mr. C. Herschel stated that the New England equivalent for "Frazil" is "Anchor ice." Anchor ice is formed in the New England rivers only at times when there is no covering of solid ice upon them, and, generally, only for the 12 to 24 hours just preceding the formation of such a covering of solid ice. For instance:—in the winter of 1885-6, the ice formed in, and went out of, the Connecticut River 4 times, giving 4 days of anchor ice, where there is usually but one. Its most distinguishing characteristics are: its low specific gravity, being nearly the same as that of water, and its adhesiveness to any protruding object in its path, as well as of the different particles, among hemselves. For instance:—some years ago it accumulated on the inlet pipe of the Detroit Water Works, in the Detroit River, which is laid in a considerable depth of water, until it threatened to or actually did shut off all supply to the city. He has seen it gather on the crest of the Holyoke Dam, and accumulate in bunches, aided, perhaps, by one or two flashboard pins, or other irregularities, until it would stop the flow of water over that part of the dam; this flow being at the time, in other parts, over a foot in depth. Mr. Herschel knows of no remedy for it, short of that which nature supplies, when she forms the covering of solid ice. Judging from the facts stated in the paper, the Caughnawaga Indians are entirely correct in their statement that frazil runs only in the early part of the winter, and its cessation to run is a sign that the channel is closed above. Where the situation is such that the channel cannot close, by reason of rapids, for example, frazil may continue to form all winter. In such cases, and if it did continue to form, the depth and regularity of the channel below would constitute the only available mitigation of the evils to be expected from such frazil.

Mr. Ranney

Mr. Ranney has never observed the formation of frazil in still water or smooth current. It is formed in rapids where the water is broken up and intermixed with air. From the foot of Crow Bay to the commencement of the Rapids (Middle Falls on the Trent), a distance of about 1000 ft., there is a current with a smooth surface. At 0° F. prisms of ice begin to form about 200 ft. down stream from the surface ice. The anchor ice begins to form as soon as the rapid commences, but does not adhere to the bed of the river until it has travelled 500 or 600 ft. down the rapid, where it commences so to settle on the bed of the river and to adhere to everything with which it comes in contact. Mr. Ranney built a mill on the Falls about 2,000-ft. below the outlet of the Bay, and formed the head of water by means of a ring dam which was filled with anchor ice, upset and forced sideways into the stream a distance of 100-ft. He has never observed anchor ice in any stream having abrupt falls, with a smooth current above and below, shewing that it requires a broken surface and cold air to form frazil. Frazil has sometimes formed an island on the very verge of Ranney Falls, with the current running at 10 miles an hour, and has remained there until the weather has moderated, while on the smooth floor of the Ranney slide it has made 2 ft. to 3 ft. in the throat with a decline of 1 in 20. On one occasion a chain cable was broken by a run of anchor ice which formed around the chain as thick as a barrel. Mr. Ranney has made bridges where the current was so strong as to prevent formation of surface ice, by placing obstructions to collect the frazil, and watering the surface. Anchor ice very soon dissolves where it is not covered with surface ice at about 20° F. He approved of Mr. Henshaw's suggestion to anchor the ice in Lake St. Louis until the river below is clear. Mill owners have to keep open channels through their ponds to the mills. He doubted whether any advantage would be derived from the straightening or smoothing of the sides or bed of the river, as anchor ice will adhere to a smooth flat-rock or slide-floor.

Dr. Bell. Dr. R. Bell considers the action described in Mr. Henshaw's paper to be secondary, and that the real origin of frazil is due to terrestrial radiation, aided by the action of the chilled water in carrying down particles of ice from the surface. Dr. T. Sterry Hunt, Prof. Carpmael, and other meteorologists concur in this latter view. He suggests the advisabilty of subjecting specimens of every variety of ground ice to careful and minute examination, so that the forms and arrangements of the component crystals may be ascertained, and thus shew whether there is such a substance as anchor ice differing essentially in origin and structure from frazil. Mr. Gilbert's observations at the Gallops Rapids strengthened the radiation theory, and the fact that the frazil formed on some parts of the rope and not on others is probably due to differences of conductivity in the bottom immediately below the rope, or to the fact that there were objects obstructing radiation above the rope. That frazil ceases to run when the channel at the upper end of Lake St. Louis is closed, as observed by the Caughnawaga Indians, is another confirmation of the radiation theory, as water must be open to the sky in order that frazil may form, and the process of formation ceases when the surface is covered with ice. The rise of frazil to the surface, and its floating down stream in large quantities, when there is a sudden change of weather, does not indicate that it has been thawed, but that the stony bottom has lost its holding power on account of the check to radiation.

Mr. Hannaford.

Mr. Hannaford's experience has led him to the conclusion that frazil ice is to be found at the foot of rapid currents and in broken and shallow water, rather than in currents of greater depth. For example, frazil ice is practically unknown in the Niagara River at the International Bridge, where its width from shore to shore is 1,800-ft., its depth 46-ft., while the current runs from 5 to 8 miles per hour. At Montreal, on the other hand, the St. Lawrence is six times wider than the Niagara River at Fort Erie, its greatest summer depth at the Victoria Bridge being only 23-ft., while the flow of water at ordinary summer level is about 2,100,000 gallons per sec., as against 1,535,000 gallons in the Niagara River at Fort Erie. This great width and consequent shallowness tends to the blockage of the St. Lawrence above Montreal. The ship channel below Montreal along St. Helen's Island, where there is a width of 1,800-ft., a depth 60-ft., and a swift current, would act as a free carrier of frazil and ice, did it not back up from below by reason of the frazil and ice grounding on the flats below the city, where the river again widens. There are two periods of high water at Montreal, the first between the middle of December and the middle of January, the second in April. If the statement is true, that frazil forms an important factor in the early winter rise, then, in Mr. Hannaford's opinion, the spring rise is clearly attributable to the ice brought down from Laprairie basin and the Upper Lakes, which chokes or gorges the channels below the city, causing the water to back up. His remedy to prevent the floods at Montreal would be to raise [illegible] buildings, yards and streets in the lowest parts of the city above the highest known or recorded level of the River.

Mr. Gzowski.

Mr. Gzowski considers that the jams and flooding caused by frazil ice might be remedied by giving the streams freer passage, removing obstructions, straightening and deepening the channel.

Mr. Brush.

Mr. Brush dissents from the theory that frazil plays much part in obstructing the flow of the river St. Lawrence. His observations have shewn that the frazil forms in greatest quantities in the rapids during the months of January and February when the water-level is steadily *falling*. The fact that there has never been a spring flood, except when the lake ice has been prematurely broken up, and has come down in large masses while the ice bridge opposite the city has remained strong enough to resist its passage, seems a conclusive proof, 1st, that however mischievous frazil may be in choking up pipes and aqueducts or the channels of small and sluggish streams, it forms no obstacle to the flow of the St. Lawrence; and, 2nd, that it is the strong surface ice which, brought down in large quantities by a strong current, and resisted by an impassable ice barrier, is carried underneath, packs the shoals, and naturally so obstructs points of the river that there is no passage for the volume of the water. To obviate these evils, either the moving of the ice must be prevented or its passage facilitated.

Mr. Lesage.

Mr. Lesage stated that the water supply of the city of Montreal was brought by an open aqueduct from a point in the river St. Lawrence above the Lachine rapids, where the river in winter is always open for a distance of seven miles to Lake St. Louis, and where immense masses of anchor ice are being daily manufactured at the bottom of the river. These masses becoming detached from the bottom are carried down stream and propelled by a S. W. wind, a large portion finds its way into the aqueduct. Various means have been undertaken with more or less success to prevent blockage. A channel was made in the border ice opposite the entrance to the aqueduct by means of gunpowder, with the effect of dislodging those spongy masses of frazil which could not be moved with a pole or other implement. Next a pier about 40-ft. in length was thrown out at right angles to the river shore a little above the entrance, with the object of diverting the current and frazil, but without success. Indeed it seemed to cause an eddy, producing precisely the contrary effect to that anticipated. In the following year a similar pier was built below the entrance, but without any appreciable effect, and the subsequent extension of this pier towards the first, until a water-way only 20-ft. wide was left, made matters still worse, and the piers had to be removed. Mr. Lesage suggested that a new aqueduct should be cut with an entrance 4,000-ft. higher up the river. Subsequently the entrance to the aqueduct was moved up to a deep bay called the Inland cut. A large basin was formed by part embankment and part crib work, which allowed the surface ice to be formed over an area of about 10 acres, and from this place the water-supply is now drawn without any further trouble from anchor ice. This seems another proof that frazil cannot form under surface ice. The entrance to the basin is about 1,500-ft. wide, and the frazil forming on the edge of the ice in the river offers no appreciable obstruction. Every winter he has observed large masses of anchor ice attached to the bed of the river, to boulders and in all places where there were eddies. The anchor ice assuming a fungus shape, gradually grows upwards. A rise of a few degrees in the temperature will cause the whole mass to break away from its anchorage, often carrying with it a boulder or any substance to which it is attached. Sometimes the river is nearly covered with these floating masses, plainly showing that they had formed in the open water of the river. The formation was most marked on cold bright days, and the frazil rose to the surface on a cloudy day with a slight rise of temperature. Experiment has shewn that the temperature of the river water at the aqueduct mouth is generally 32 ° F., and some times 31 ° F., down to a depth of 20-ft., while the temperature of the atmosphere is several degrees below zero. Every year, when ice first covers the aqueduct, frazil forms in the settling basin and is carried into the wheels, which have to be stopped a few hours until the ice has covered the settling basin.

Mr. Poole.

Mr. Poole stated that at the Acadia Colliery, Nova Scotia, the boilers are supplied with water from an artificial pond, and the feed pipe passes through an embankment at a depth of 5 feet below the surface of the water. The pipe has a movable elbow in the pond, so arranged that its inlet may be turned up at any time to the surface for examination. The open end of the pipe has attached to it a barrel from which the head has been removed. In place of the head there is a partition of coarse wire netting $\frac{3}{4}$ in. mesh, filled with sponge to filter the water going to the boilers. On the morning of the 26th November last the supply of water diminished, and the end of the pipe was turned up and examined. It was found that the netting was coated over with coarse crystals of ice and the sponges solid lumps. The pond was open the day before, but the night was clear and very cold, a high wind blowing, which died away towards morning and allowed ice to form on the surface. The flow of water through the pipe was not large, occasionally only at a rate of some 30 gallons per minute; but as the crystals of ice were uniformly distributed over the netting, and had every appearance of growing in situ, the possibility that they formed on the surface of the water and were drawn down by the current is very remote; and when it is remembered that the sponges were also frozen the evidence is almost conclusive to the contrary.

Mr. Murdoch.

Mr. Murdoch has always seen anchor ice in the bottoms of shallow rapid rivers with rocky beds, and never in clay bottoms. Frazil, which he considers the same as anchor ice, will float under the surface of running water. He states that he has found the water under the ice in Thunder Bay to be considerably below 32 ° F. At the mouth of the Saskatchewan, where the bottom is a limestone, and the banks for two miles below the rapids are 20-ft. high, it freezes from the bottom upwards until the ice reaches the level of the banks, and the river overflows. Mr. McAdams, from fourteen years' experience at the Carillon rapids, states that frazil does not adhere to surface ice formed previous to the accumulation of the frazil underneath.

Mr. Rheaume.

Mr. Rheaume stated that in many of the bays of the St. Lawrence river frazil attained a depth of 12 to 14 feet. That the cause of the Morrisburg flood was the swinging of an ice bridge between Croil's island and the shore. He had no doubt that Mr. Henshaw's suggestion for the prevention of floods would prove effective, if carried out, but doubted its practicability on account of the magnitude of the work involved.

Mr. Wicksteed.

Mr. Wicksteed discussed the causes of the floods at Montreal, and in considering the proposals brought forward in the paper for their amelioration, feared they would involve enormous cost of maintenance. He considered that the jamming of the ice was due more to the general contraction of the water-way than to individual obstruction, and desired to point out the applicability of Captain Eads's remedies for the obstruction in the Mississippi, to the case of the St. Lawrence.

Mr. Steckel.

Mr. Steckel, remarking on the origin of the word frazil, considered it to be a purely French-Canadian expression for "slush ice," and stated that frazil was also the French for forge cinders. He pointed out the propriety of adopting some term which would have but one meaning and be common to both French and English, and suggested the word "Frasis."

Mr. Sproule.

The discussions seem to point almost entirely to frazil formed on the bottom or anchor ice, as distinguished from any other form of ice, as the chief obstruction in the river channels. Probably, however, only a minor part of the frazil blocking channels has at any time been attached to the bottom. Anchor ice is not supposed to form in deep water, hence its formation is probably restricted to shoals and to a comparatively narrow border along each shore, varying, of course, with the general depth of the river at the locality. On the other hand, ice in thin sheets is forming over a large proportion of the whole area of open water, while the thermometer is below 32° F. This thin ice, varying from the thickness of paper to perhaps an inch thick, is carried downward and broken up in rapids, or is ground against the bordage ice, and the ice under which it is drawn. This process reduces the thicker surface-formed ice to fragments, and the thin films to snow-like masses, which are probably often mistaken for frazil that has been attached to the bottom ; but on close examination they will be found quite different. If it is borne in mind that according to the generally accepted theory frazil proper forms only at very low temperatures, and under comparatively restricted circumstances, while a surface film is forming daily, hourly, every minute, when the temperature is a few degrees below the freezing point, and is being carried onward constantly by a current of from one to two miles per hour, thereby allowing film after film to form in succession for weeks and months, it must seem that a very large proportion of the obstructions found in river channels must be attributed to ice formed on the surface as described.

Mr. Harris.

Mr. Harris stated his own experience went to confirm Mr. Henshaw's opinion as to the origin and means of accumulation of this ice. It might be mentioned that the railway bridge across the Gatineau river close to Ottawa was built in 1877-78, with stone piers founded on piles driven into a blue clay river bed. During the winter of 1878 it was found that although no great reduction of the water-way had been caused by the piers, yet a very rapid shove was taking place over the bed of the river adjacent to several of the piers. It had gone to the extent of removing some 5 feet in depth of the clay before it was discovered and choked by riprap. The shove undoubtedly occurred by reason of the accumulation of frazil ice clinging to the under side of the surface ice, and causing a great reduction of avaliable water-way adjacent to the piers, thereby increasing the velocity of current. Probably the stationary surfaces offered by the piers caused this accumulation to form at the time referred to.

Mr. Keefer. Anchor ice, called by the French-Canadian "habitants" "frasil," and by our English-speaking river men "frozee," is so designated because it has been found "anchored" upon the bottom in open running water during extreme cold weather. When so found, it is a coarse, granulated ice of nearly uniform texture; but when it leaves the bottom, and is carried under the fixed ice of the river surface, to the underside of which it becomes attached by frost, it is found more or less mixed with fragments of thin plate ice, as well as with saturated snow and "slush" ice of a similar granulated texture, which it has picked up in its descent, and also with earthy material which it has torn up when rising from the bed of the river. It never forms upon the bottom or in the water when covered with surface ice. The name "anchor ice" is evidence of its being found at the bottom, while all other ice is at the surface, although it does not remain at the bottom as other ice does on the surface; but there is still much difference of opinion as to its origin, and even as to its formation at the bottom, among those who have not seen it there, yet know that all ice is lighter than water, and who also know that it is not *always found* at the bottom when there is ice at the surface. There are, however, persons who insist that ice is not under all conditions lighter than water, that it sometimes sinks, and that solid surface ice has been found under water. This last statement is true only when such ice has been frozen to the bottom, and is overflowed and held down by the current. Anchor ice will form on the bottom in shallow streams whenever there are about 15° of frost, or more; but in deep water it is not found until there are 40 or 50 degrees of frost. The depth at which it will form in the most severe weather has not been determined, on account of the difficulties and danger connected with the exploration. There is, however, little doubt that in the latitude of Montreal, this extends to at least forty feet, and the depth of water in which it is found is in direct proportion to the descent of the mercury and the duration of that descent. The depth or thickness of its formation on the bottom depends on the duration of the cold which, if sufficiently prolonged, would cause such a bottom growth as to raise the river out of its bed, and cause it to overflow its banks. In November Mr. Keefer has forded a shallow stream flowing rapidly over a stony bottom, having less than a foot of water, and on his return, three days afterwards, has found it impassable from anchor ice—a thin sheet of very cold water flowing over a mass of porous ice, filling the stream to the top of its banks. There is an abundant formation of "slush" ice on the surface in the main channel, at the setting in of winter, when the current or wind prevents the formation of sheet ice, which collects in masses by mutual attraction or cohesion of the spicules, the appearance of which is similar to that which is found as anchor ice at the bottom. If this be the raw material from which the growth of anchor ice is made at the bottom, the fact still remains that this ice is most abundant on the surface when there is no anchor ice at the bottom; on the other hand the growth of anchor ice at the bottom is most rapid, when and where there is no visible ice of any kind floating upon the surface. He has crossed the St. Lawrence in a canoe opposite Montreal when the thermometer was much below zero and where there was no floating ice; but the water, instead of being transparent as usual, was lead colored, thick and "sandy," with ice, invisible from the surface, flowing apparently with difficulty, as does the Missouri when loaded with sand; spicules of ice, about the size of darning needles, attached themselves to the paddle by their points, and when it was withdrawn from the water stood out at right angles to the wood—like iron filings on a magnet. In this condition of the river, the water, no doubt at the deepest point, is loaded with ice spicules to the bottom, densely and uniformly distributed throughout the whole mass, and would supply the raw material for the formation of anchor ice at the bottom whenever the latter was prepared to receive it. That it is not at all times so prepared, is evident from the fact that anchor ice is not always found when ice spicules are abundant in the water. If anchor ice is derived from ready-made ice in the water above it, the only explanation, in Mr. Keefer's opinion, is that the bottom must first become frozen before its formation can begin. Whether it be formed from the water or from ice in the water, the condition precedent is a frozen bottom. Ice will attach itself to ice or to other frozen bodies, but not to the unfrozen bed of a river. The magnetism of frost seems necessary to attract the minute particles; and when once a covering is formed a rapid congelation may take place, which will continue as long as the frozen bottom overcomes the lighter specific gravity of ice and holds the mass down. The supposition of a frozen bottom would also explain the rising of the anchor ice. When the air and the water are above the freezing point, anchor ice leaves the bottom. This generally occurs at an air temperature of about 40° F., when the water is near its maximum density, and when its colder surface current has resumed its position at the bottom, so far as these conditions do prevail in rapidly flowing water. If the rising of anchor ice were assisted by the increased density of the water which accompanies its departure from the bottom, its tendency to let go would be retarded by the now colder water in contact with it; but it is not probable that either of these conditions has any influence upon its rising or remaining. It is the change in temperature of the water, and not in its position or density, which releases the hold of the bottom on the ice, and this not by the contact of the now warmer water with the frozen bottom,—for the two are separated by a mass of ice—but by return of internal heat, in other words by the diminution or cessation of radiation from a warmer surface to a colder one, from earth to water. When the air temperature is much below zero, that of the running water is below freezing, and prevented from freezing only by its motion. The rapid abstraction of heat from the bottom by such a cold current, if intense and long enough continued, would freeze the bottom, and thus prepare the foundation for anchor ice; and whether this ice is derived in whole or in part from the disseminated spicules in the water, or is a new creation from the water, the radiation, which is an important factor in the formation of ice, is, in his opinion, the chief cause both in supplying the material and in anchoring it at the bottom, that is radiation as well as convection from the water to the colder air, and radiation from the earth bottom of the river to the colder water above it, if not also through it to the still colder air above both. As the water in a rapidly flowing river descends from the surface to the bottom, and rises from the bottom to the surface, the ice spicules must be carried down to the bottom when the thermometer is above zero, as well as when it is below it; but in the first case they do not remain there as anchored ice; and in the other case they must do so, unless anchored ice is formed out of the water at the bottom during very low temperatures. Whether anchored ice, therefore, is of surface origin depends on whether any kind of ice can be formed except in contact with the atmosphere. Doubtless some air is carried down with the current, and some may be disengaged in the process of freezing. Mr. Keefer has stirred anchor ice in twelve feet of water where it was two feet in thickness on the bottom, and bubbles (either of air or gas) came to the surface.

This form of ice is a great enemy to water-power taken from portions of the river uncovered by ice. Even in canals it forms before the surface is frozen over to an extent sufficient to clog gateways, but disappears as soon as the surface is covered by ice. A covering of ice, or any artificial covering, is sufficient to stop its formation, by preventing both convection and radiation. As it does not form under the arches of a bridge, while it may be found immediately above and below it, and as an overcast sky has been known to cause it to leave the bottom of a stream, the presumption is that radiation has more to do with its formation than convection. It has also proved an embarrassing obstruction to engineers in sinking crib work through the ice, whenever it has been deposited there from the open water above. It cannot be displaced by pressure, but must be entirely taken out or floated away. Intelligent and reliable mill-owners assert that this troublesome ice is never found in their millraces—no matter how cold the weather is, whenever the sun is shining, or whenever there is a cloudy sky at night.

In conclusion,—anchor ice, which in certain rivers or portions of rivers, is by far the most abundant formation of ice there, is not an unmixed evil—on the contrary, it is a great benefactor. All the sections of our rivers which are open water in winter are factories of anchor ice, the formation of which liberates enormous quantities of heat to temper the severity of our climate. After the slack water portions of our rivers and our lakes are covered with ice and snow, and all other sources of terrestrial heat either by radiation or convection are cut off, abundant stores of water are poured forth from the lakes into the rapid sections of the rivers, and by their conversion into ice liberate the heat they have retained in greater or less quantities, and always in the greater quantity when most needed. Mr. E. Lewis, jun., in his "Physics of Ice," says:

"To melt a pound of ice requires 142 units of heat, that is an amount which would raise a pound of water, 142 F. This is the equivalent of the molecular force exerted in solidifying the water, and the mechanical value of the two forces is the same. Expressed in figures it is the equivalent in mechanical force of the work done in lifting the same pound of ice 110,000 feet high. The melting of 20 lbs. of ice is equivalent in mechanical force to lifting 1,000 tons, nearly, to a height of one foot; or lifting two persons, weighing 300 lbs., 1,000 feet higher than Mount Washington."

The great rivers of Canada, the St. Lawrence and the Ottawa, with the large majority of their tributaries, are terrace-like in their profile, and studded with numerous lakes, as contrasted with the almost uniform slopes of the Mississippi, Missouri and Ohio, in the southern and greater portion of their length. At the outlets of all our lakes, great and small, there are rapids with water open to a greater or less extent in winter. The amount of latent heat given out in the formation of anchor ice at all these numberless "breathing holes" must give a powerful check to the duration of that same temperature under which this peculiar form of ice is so abundantly developed, especially when we remember that the colder the weather the greater the disengagement of heat, being in this respect similar to the steam blast in the Locomotive, "the harder she blows the faster she goes."

Sir William Dawson.

Sir Wm. Dawson, being called on by the President, remarked that he did not profess to know much of those practical questions which depended on the so-called *Frazil*, a term which as applied to ice did not seem to be always used in the same sense. The best term for the form of ice referred to is that of "Spicular ice," which has been used by geologists in discussing this question. Such ice consists of thin blades or needles of a crystalline character, which may either form in a separate or detached manner in water which is cooled below the freezing point, and which is agitated by the wind or by a rapid current so that the ice cannot become compact; or it may grow in the bottom in the manner in which crystalline needles form in some saturated saline solutions. In the first form the spicular ice constitutes what fishermen and boatman on the coast call "lolly," which floats in the water and is perfectly soft and mobile. In the second case it constitutes sheets, masses or shrublike aggregates of crystal attached to hard bodies in the bottom of the water. It is then called "ground ice" or anchor ice." This ground ice when it attains to certain dimensions, or when the temperature rises, may float up, sometimes carrying with it bodies to which it may be attached, and then, of course, it drifts in the same manner with lolly. Ground ice does not usually form under a covering of sheet ice; but, from the sections submitted by Mr. Kennedy, it would seem that in very cold weather spicular masses run down from the lower side of the ice in places, just as they do from the under side of the surface sheet of water in a dish of water when freezing, and these spicular growths may detain and accumulate the floating lolly drifting under the ice. With respect to the formation of ground ice proper, the principle is exactly the same as in the case of crystals forming around any hard body in a saturated saline solution. The water has first to be cooled to the point of crystallization, and when in this state it comes into contact with any hard substance, cooled by radiation or otherwise to the same or a lower temperature, it will crystallize on or around that substance, and shoot upward in needles, until broken off by violence, or until it becomes too buoyant to be any longer held down in the bottom.

The fact that it forms most readily in open water without any covering of ice, and in clear cold weather, indicates that radiation from the bottom has an important influence in its formation; but where the water is sufficiently cold it may crystallize on any nucleus presented to it; and more especially, it would seem, on metallic bodies and stones which are good conductors of heat. Hind states that on the coast of Newfoundland anchor ice forms in large masses in the sea, at depths of sixty and seventy feet, and it has been known to raise stones and anchors from the bottom, and to freeze around fish caught in nets. He also states that when the salt water has been cooled below the freezing point, the fresh water of streams pouring into it from the land is at once converted into lolly or floating frazil. In this last action there is something analogous to what takes place when water at about the temperature of 32° is tossed about in a rapid, and mixed with air at a still lower temperature, perhaps below zero. These are merely desultory observations from the point of view of a geologist; but they may serve to show that there are different kinds of spicular ice, and that they may be formed in various ways. It seems certain that several of these modes of formation are concerned in the production of the spicular ice so troublesome in our river, so that it is not prudent to limit ourselves merely to one theory of formation, any farther than the general principle that they all depend on the somewhat rapid crystallization of water, under circumstances in which it tends to form groups of spicular crystals rather than solid sheets.

Mr. Tate.

Mr. Tate remarked that whenever the water at a temperature of 32° F., or less, was passing over the river bed at a higher temperature, a formation of ice might occur after the manner of hoar frost possessing great cohesiveness and tenacity, until disturbed by a higher temperature or other forces. A thickness of 2 or 3 ft., as observed by Mr. Peterson might be thus formed, and might then be detached by the weight and possibly by fluctuations of temperature.

Mr. Dawson,

Mr. W. Bell Dawson remarked that there was one point of difference between the conditions in still water and running water that had not been sufficiently emphasized. As water attains its maximum density at 39° Fahr., the coldest water remains at the surface after reaching that temperature if the water is calm, and the ice naturally forms there. But in rapidly running water the current mixes the different parts together, and the whole volume may fall to 32° or even a little below, and it may then crystallize on the bottom or sides, or on any object in the stream. The crystals so forming would most of them be detached by the current and swept on with it, so adding to the amount of frazil in the water. With regard to the word itself, the term "fraisil" or "frasil" is correct French, and means coal-dross or cinders. It has probably become applied to the kind of ice it denotes, much on the same principle as "poudrer" is used for the drifting of snow, a word which originally referred to dust.

Mr. Guerin.

Mr. T. Guerin, after remarking upon the point of maximum density of water, stated his opinion that frazil consists of particles which must have been frozen separately; that this might be effected, the water must have been divided into separate and distinct particles at the time of freezing, which could only occur in a rapid or series of falls, where the water is violently agitated and converted into foam and spray, of which the minute watery particles are frozen, and form the frazil under discussion. He does not believe that frazil is always formed at the bottom. The lifting and displacing of anchors, and other substances, are caused by ice, which, from shoving and piling, has become so thick as to reach the bottom, and has afterwards risen with the rise of the water level, carrying the anchor, etc., with it. He does not think that the rise of frazil masses to the surface is not affected by a change of temperature. He finds it difficult to believe that the frazil was found lying at the bottom of the C.P.Ry. bridge at Lachine, especially when it has been shown that a current of 10 miles an hour, such as that in the place in question, can move loose rocks or boulders 6 feet in diameter. He has never found frazil at the bottom of lakes and rivers in any place in which it did not also reach to the surface.

Mr. Peterson.

With reference to what Mr. Guerin had stated as to frazil only forming below rapids, Mr. Peterson remarked that during the winter of 1881-82, when engaged upon the survey of the river where the present St. Lawrence Bridge is located, above the Lachine rapids, and below a long reach of slack water (Lake St. Louis), he found, when taking soundings in depths of water, varying from five feet to forty feet, that the bottom of the river was frequently covered over its entire area with frazil from two to three feet in thickness; when the sounding rod was let down upon it, the frazil was of such a consistency as to sustain the rod, which could be forced through it by a couple of strong men without much difficulty. This frazil formed during a period of intense cold, when the thermometer was below zero, the frazil would rise from the bottom, and on a mild day it could be seen jumping up above the surface of the water all over the open portion of the river, which here extends over a distance of from four to five miles. This formation of frazil and its subsequent rise to the surface occurred during the entire winter whenever a period of intense cold was followed by mild weather.

Mr. Walbank.

Mr. W. McLea Walbank was of the opinion that the Indians referred to by Mr. Henshaw did not properly understand what was meant by frazil. He spoke from experience, having crossed the river at the points in question twice daily for the past five winters, and stated that frazil formed in the Lake at both sides, and in fact almost all over the river between Lachine and Caughnawaga during the whole winter, and could be seen on the bottom on a clear day at the end of the new pier of the Lachine Canal. It always came up to the surface on cloudy days, turned upside down, and floated down stream. He also stated that it was generally known that the ice bridge had formed at Pointe Claire when the sheet ice and slush stopped coming down. Mr. Walbank did not agree with Mr. Guerin that frazil was formed from spray and foam caused by rapids, as he had often seen it form where the bottom was rough and the current strong, but no spray or foam existed.

Mr. Irwin. The temperature of the river bed cannot well be less than 32° in the case of large rivers, and is very probably higher, as it would be kept up by heat from below. The fact that large stones and masses of earth become detached from the bottom, by the floating power of anchor ice, proves that the ground below the bed of any large river is not frozen solid. How then could a stone, whose upper surface is at, or almost at, 32°, and whose lower surface is at a somewhat higher temperature, radiate cold into a body of water from which it is itself receiving cold? Is it not much more likely that such stones are only kept cold enough for ice to adhere to them, the cold in the atmosphere above the water being transmitted through the water, a theory borne out by the fact that when the air gets warmer the frazil begins to rise from below? Is it not probable that anchor ice and frazil both have the same origin, their formation being finally completed under different conditions? It has been stated that frazil did not form under ice, it is also well known that a body of ice thickens from below so that the water under such ice must be cooled enough to freeze; and, further, it is well known that quite a considerable quantity of air mixes with the water of a river while flowing, enough to purify the water by oxidation. Now, the air cannot mix with the water when it is covered with ice, and may not that be the reason why frazil does not form under ice, and that a greater part of the frazil is formed by particles of very cold air mixing with water? This being the case especially below rapids, where more air would be mixed with the water. Frazil formed in this way, being very cold, might well be almost as dense as the surrounding water (for ice contracts on cooling), and would, therefore, be easily carried to the bottom, and would crystalize most readily round any substance with a cold and rather rough surface. If forming in large quantities, and so partially able to protect itself, and not subject to too strong a current or too great pressure, what is known as a mass of frazil would be formed; but if forming in small quantities, and subject to great pressure or a strong current, the frazil will be consolidated into anchor ice. In the case of the suction-pipe referred to by Mr. J. Kennedy, the failure to prevent the formation of anchor ice may have been due to the fact that the covering did not extend over a sufficiently wide area. Particles of ice formed in the water would be carried by the suction of the pipe towards its mouth, adhering to the stones which would be kept cool by the stream of cold water, and made to consolidate by the strength of the current. Such a formation would take place slowly, but a small deposit of ice per hour would soon choke up a large pipe; how stones around such a pipe, receiving their cold from the water, could yet give up to the water enough cold to deprive it of its latent heat of liquidation, seems difficult to understand.

Mr. Francis. Mr. J. B. Francis saw no reason to change the views expressed by him on the subject of anchor ice (or frazil) in an address before the convention of the American Society of Civil Engineers, held in Montreal in the year 1881, and published in the transactions of that Society.

Mr. Kennedy Mr. J. Kennedy said he held views as to the formation and accumulation of anchor ice, similar to those set forth by Mr. J. B. Francis. He supported these views at some length, and by way of illustration and proof cited numerous facts which had come under his own observation, and had been gathered from reliable sources. Plans and sections, showing large accumulations of anchor ice in the St. Lawrence at Montreal, were exhibited.

Mr. Henshaw. In replying to the remarks made by those who have taken part in a very full discussion of my paper, it is a matter of regret that a generally recognized terminology regarding this kind of ice formation does not exist. The American and some of the Canadian critics state that what is termed frazil in the paper is known by them as anchor ice.

Now, the word frazil is, in Canada, commonly used to designate slush ice of every description, but for want of a better word, especially refers in the paper to that kind of ice, seen in a sort of efflorescence, clinging to the bottom of streams. Its origin is the same as that of anchor ice, but it detaches more readily and frequently. Anchor ice is formed when the current is too swift to allow efflorescence, and may be likened to an accumulation of roots when branches and foliage have been swept away. The objection to regelation is that it is purely a theory without a single fact to support it, except the still-water experiments of Faraday and Forbes. It seems incredible to suppose that the loosely combined masses that are seen floating can ever have been able to attach themselves to the bottom of flowing streams, even if it is assumed that the nuclei have by some means reached the necessary temperature, and still more so that particles from the surface should arrange themselves in forms suggestive of luxuriant vegetable growth.

Objections were made by some members to the description of subcurrents, apparently with the idea that it was original. It was, of course, only stated as an incontrovertible fact, in order to show the manner in which the river bottom could become refrigerated. To prove that these currents do and must exist, and that in unchanging river bottoms they must be permanent, it is only necessary to invoke the law of persistence of force, which lies at the base of all physical science. A current then highly charged with ice particles, formed under a very low temperature, must have a strongly refrigerating effect, and this has only to be demonstrated in order to account for a natural growth of ice below the surface or on the bottom.

Interchanging currents in running streams are mainly offshoots from the subcurrents and the consequent reflex action; their strongest action is from below, and their intensity is proportioned to the obstructions met by the subcurrents. When there is no subcurrent there is no formation either of frazil or anchor ice. In lakes or ponds the interchange is due to waves or ripples, and the weak action of such currents would not permit the formation of ice at any considerable depth, unless aided by artificial currents, such as those produced by the supply pipes of waterworks, where, according to Mr. Herschell, Mr. Poole, and others, the ice has formed in large quantities. The theory of radiation is attended with as great difficulty as that of regelation, for while there is no trouble in accounting for hoar frost by radiation through the air, the denser medium supplied by water would render it very doubtful in the case of frazil, even if the still more important difficulty of a surface more or less ruffled or uneven were thrown aside.

31st March, 1887.

Mr. JOHN KENNEDY, M. Can. Soc. C.E., Vice-President, in the Chair.

The discussion upon Mr. G. H. Henshaw's paper on Frazil ice occupied the evening.

14th April, 1887.

THOMAS C. KEEFER, C.M.G., President, in the Chair.

It was announced that Ambrose Duffy had been transferred from the class of Associate Members to that of Members.

The following candidates were balloted for and duly elected as

MEMBERS.

John Dyer.
John Randolph Hersey.
Armitage Rhodes.

ASSOCIATES.

Thomas Briggs Brown.
George Reaves.
Joseph Rielle.
John Taylor.

STUDENTS.

William J. Carmichael.
Louis Henry Chaperon.
Francis W. W. Doane.
Robert E. Hunter.
Peter L. Naismith.

Paper No. 2.

CONSTRUCTION OF THE CANADIAN PACIFIC RAILWAY GRAIN ELEVATORS.

By Stuart Howard, M.Can.Soc.C.E.

The Grain Elevators lately constructed by the Canadian Pacific Ry. Co., in the City of Montreal, are located south of the old Quebec Gate. Barracks, now the Dalhousie Square Station, and above the wharf belonging to the Montreal Harbour Commissioners. This property has been reclaimed from the river, the front being protected by cribwork, and the space filled in with stone, debris and clay.

There are two Elevators, 210 feet long and 80 feet wide, built on the old river slope over the Harbour wharf. It was thought expedient to pile the foundations and not to trust to any unsound bottom, as the total weight of each building, including masonry, timber, and a full elevator of 560,000 bushels of grain, amounts to a little over 40,000,000 lbs. The area is divided into 102 bin spaces, each about 12 ft. square. Each bin is supported upon a pier of masonry, and the weight upon the pier is 497,000 lbs., equal to 70 lbs. on each sq. inch of concrete foundation.

A retaining wall, 12 feet wide at the bottom, 22 feet in height above the wharf level, and 5 feet below it, containing 7½ cub. yds. per running foot of wall, has been constructed from the masonry of the Brock Street Ramp to the eastern elevator, a length of 118 feet; then for the eastern elevator a length of 208 feet; and between the two elevators a length of 230 feet. From the west end of the westerly elevator the same section of wall is built to Barrack Street, and after a gap of 50 feet leading to a double ramp, it is again continued to Fripponne Street, on a grade of 1 in 20 to the level of the Harbour revetment wall. The new level of Water Street being 10 feet above the old level, this retaining wall was built to support the earth filled in at the back, in order to make the new street, which is carried some distance south of the old river bank.

Piles were used in the entire foundations of the elevators and connecting buildings, the front wall or that nearest the river having three rows, and the back and end walls two rows placed at 3 ft. centres. Each pier, of which there are 80 in each elevator, is built upon a cluster of 9 piles; the engine and boiler beds, and the chimney, also rest upon a pile foundation. The piles were driven in by means of a driver worked by steam, with a fall of 20 feet, the ram weighing 1400 lbs. They were cut off 9 inches above the bottom of the trenches, which were 2 feet deep, the whole of these excavations being filled in to the level of the natural ground surface with well rammed concrete, composed of 2 parts of sand, 1 of White's Portland cement, and as much stone as was required to fill all the voids. On this foundation, which extended 12 inches beyond the walls on either side, the masonry was commenced. The front wall is 6 ft. wide and has a concrete bottom width of 8 feet, the footings being 7 feet and the wall 6 feet wide. The back and side walls are 4 feet in width and the concrete 7 feet, the latter being further strengthened by buttresses 4 feet wide, placed every 25 feet, and bonded into the piers, in order to resist thrust of the outside earth. The piers are 4 feet square with two-6 inch footings, the concrete being 7 feet square. These are finished off at a level of 23 ft. 8 ins., and the copings of the walls are 34 ft. above low water. Earth is filled in to a level of 9 inches below the top of the piers, the space up to the street level being utilized as a sort of cellar to contain the iron receiving tanks and the bottom of the elevating legs used for raising the grain from these tanks to the top of the building for distribution into the different bins. It will readily be seen from the foregoing description that the foundations up to the street level were necessarily very deep and expensive, the height from the wharf to this level being 22 feet. A casual observer approaching from the Station side would imagine the foundations to be only of an ordinary description, until on looking over the retaining wall described above, a solid wall of masonry 22 feet in height is seen. The total quantities of piling, concrete and masonry in the two elevators, revetment wall, engine, boiler, and chimney foundations were 43,389 lineal feet of piles, 1,362 cub yds. of concrete, 16,187 cub. yds. of masonry, and there were over 40,000 cub. yds. of excavation and filling, the cost amounting to $10,847 for piles driven, $10,554 for concrete, $125,450 for masonry, and $8,000 for earthwork, making a grand total of $154,851 for work now covered up and hidden from view, and presenting only a fine face of masonry wall to the river.

On each pier four 12 ins.×14 ins. posts, 26 ft. 6 ins. long, are placed and kept one inch apart by wooden keys, the whole being thoroughly bolted together. On these posts and morticed into them are two 12 ins.×12 ins. caps, and above them two 12 ins.×14 ins. pieces are also keyed and bolted and strengthened by 8 ins.×8 ins. braces set at an angle of 45°, and tenoned into the posts. These caps run from front to back, resting also upon two 12 ins.×14 ins. posts on the copings of the walls. On these timbers and running longitudinally are two 12 ins.×16 ins. timbers placed midway between the posts, forming mouths at the centre of the bin; 12 ins.×14 ins. longitudinal pieces placed directly over the posts, also thoroughly braced with the four cross timbers, carry the bin walls. The posts around the building and on the copings are immediately opposite those on the piers, and are two 12 ins.×14 ins. timbers.

The railway tracks (two in each building) are carried by 12 ins.×14 ins. stringers, directly under each rail, resting upon 12 ins.×12 ins. timbers opposite each cluster of posts, and thoroughly braced with 9 ins.×9 ins. pieces. The flooring is supported on 3 ins.×12 ins. joists at 24 ins. centres, laid upon 8 ins.×12 ins. longitudinal pieces let into the sides of the posts and well bolted to them. The bin walls are constructed of 2 ins.×6 ins. planks, and the outer walls of 2 ins.×8 ins. planks, laid one upon the other, breaking joint, and well spiked with 5 inch spike nails, every 15 inches. The bottoms are at an angle of 45°, with an opening of 12 inches square in the centre, resting on the 12 ins.×16 ins. longitudinal timbers, to the underside of which the castings for the revolving spouts are fixed. These bins are 50 feet in depth with a ladder in the corner of each made of ¾-in round iron, flattened at the ends, and placed between the planking. The inside bottom of each bin is lined with iron to prevent the planks from wearing away by the friction of the grain. There are 102 bins in each elevator, of which two are lost, one being used for the staircase, and the other for the driving belt. The remaining 100 have a total capacity of 560,000 bushels.

The cupola or central portion at the top is reduced to a width of 49 feet, and so that it may have a solid bearing and not be dependent upon the shrinkage of the bin walls (as the upper stories in elevators formerly rested immediately upon the bin walls), it is carried by 10 ins.×10 ins. posts set in the corners of the bins, and resting upon the posts on the piers, and held by iron straps passing round them and through the bin wall. There are four stories above the bins, the framework being posts 10 ins.×10 ins., with caps 10 ins.×10 ins. braced with 6 ins.×6 ins. pieces, and running through the length of the building are 10 ins.×10 ins. timbers, also thoroughly braced. The floor joists are 2 ins.×10 ins. at 18 ins. centres running lengthwise of the building, the flooring being 1¼ ins. thick. The rafters are 2 ins.× 8 ins. at 16 ins. centres resting on 6 ins.×10 ins. plates. The roof is ¼ pitch, covered with one inch boarding and Canada plate. A staircase with 104 steps, 3 ft. 6 ins. wide, risers 8 inches and 9 inch treads, is placed in the S.E. corner of the building and carried by upright posts 6 ins. square, being thereby made independent of any shrinkage of the bin walls; this leads only to the level of the top of the bins. Above this are two other staircases from floor to floor, one at each end of the building. The timber in the elevator above the foundations amounts to about 1,250,000 ft. B. M. The elevator is supplied all through with speaking tubes and gongs, and well protected in case of fire by pipes connecting with the engine room. The pressure of water is supplied from the City, and in case of necessity worked by a Northey pump of 120lb. pressure, connected with the engine, branches with hose and nozzles being laid on each floor. The whole exterior of the walls is covered with corrugated iron 26 gauge, the corrugations on the cupola and lower part being vertical. On the bin walls horizontal iron fire escape ladders are also provided.

The upper story of the cupola contains the machinery. The shaft carrying the pulleys, being from 6 to 5 inches in diameter, is made in sections, bolted together and supported by cast-iron brackets, on a strong timber frame. The driving pulleys, of which there are nine in all, four for the south elevating legs and five for those on the north or track side, are 5 feet in diameter and 22 inches face, they are fixed to movable sleeves through which the shaft passes, and are thrown in or out of gear by strong clutches worked by levers with screw bar attached, and operated by means of wheels turned by hand. The legs on the north side are set in motion by belts running over pulleys on the main shaft, tightened by tightening wheels attached to a frame, and worked by ratchet gearing. The elevating legs are made of 2 ins. T and G plank, screwed together, forming a box with an internal dimension of 12 ins.×24 ins. running from the bottom of the receiving tanks to the top of the building. The belt to which the buckets are fixed is inside, and passes round a wheel 24 ins. in diameter at the bottom and the 5 ft. diameter pulley on the main shaft at the top of the building. The bottom wheel works in a cast-iron frame, and can be lowered or raised at pleasure by a ratchet. The belts in the elevating legs are 256 feet long and 20 inches face, the buckets being 18 ins.×7 ins.×7 ins. placed every $15\frac{1}{2}$ inches, and bolted to the belt. Each bucket holds $\frac{1}{5}$ of a bushel. Thus, as the pulley makes 36 revolutions per minute, the belt travels at the rate of 569 feet per minute each leg being able to raise 5,250 bushels per hour. Before proceeding to show the method of manipulating the grain, it may be well to describe the power used for setting the machinery in motion.

The Boiler House is a substantial brick and timber structure, 40 ft.×47 ft. placed midway between the elevators, with a height to the eaves of 20 feet, the roof sloping each way, and surmounted by a good ventilator. It contains at present three boilers 5 ft. 6 ins. in dia. and 15 feet long, with fifty-six $3\frac{1}{4}$ ins. tubes and a fire-grate 4 ft. 6 ins.×6 ins. They were built at the Montreal shops of the Canadian Pacific Railway.

The boilers are placed upon a strong timber foundation of two thicknesses of 6 ins. timber, placed on 10 ins.×10 ins. caps, mortised on to piles placed at 3 ft. centres, driven through the 22 feet of earth filling over the wharf level, into the solid ground below, and which are at least 30 ft. long.

The steam from the boilers is conveyed to the engines, which are placed in buildings 24 ft.×40 ft. adjoining the elevators, by a 6 inch pipe laid in a wooden box, containing also the feed pipes for the boilers and the exhaust pipes. The engine of No. 1 elevator is a Wheelock Horizontal Engine with condenser attached, making it equivalent to 175 horse-power. The cold water for the condenser is pumped by a Northey pump, direct from the River through an eight inch iron pipe, passing under the revetment wall and into a well at the river front in the wharf cribwork, the water entering by a hole cut through the front timbers, 12 inches below low water. Inside the well a foot valve is placed to equalize the pressure. The waste water is run through an ordinary 9 inch sewer pipe, laid in the same trench as the water pipe, but carried down stream on approaching the river. The dimensions of the engine are, cylinder 20 ins.×46 ins. with a fly wheel of 16 ft. diameter, making 65 revolutions per minute. This is reduced to 36 by means of cogwheels 5 ft. 4 ins. and 9 ft. 4 ins. in diameter, the pitch of the teeth being 5 inches. The flywheel is on the 10 ins. driving shaft, to which the driving pulley with face of 48 inches and 7 ft. in diameter is attached. The main belt, 46 inches wide, of 6 ply rubber, made by the Canada Rubber Co., 250 feet long, passes round it, and over a 7-ft. pulley wheel on the main shaft at the top of the elevator, setting in motion the machinery for driving the elevating legs.

Between the two tracks is a platform 4 feet above the rails, and 11 feet wide, and below this are five receiving tanks made of 2 inch T and G planks, and lined inside with iron, set in wrought iron tanks and placed on the level of the piers. These tanks are 35 feet centre to centre, or as nearly as possible opposite the car doors. At the level of the rails and extending up to those nearest the platform are iron gratings. The cars can be moved about at pleasure by means of a hawser wound round a capstain, and attached to the front of the cars. When the grain is ready to be unloaded, it is effected by a wooden shovel, with 2 handles attached (in shape like a railway scraper) with a rope connected to it, and wound round a drum working automatically on a shaft fixed to the posts over the platform and running the whole length of the building. There are five of these shovels, one over each tank; the shovel is drawn into the car, and as soon as the tension is taken off the rope, a small hammer falls, and the drum is turned, winding up the rope, and scraping the grain from the car's door, down on to the grating through which it passes into the tank, the sides of which are at an angle of 45°. It pours then through a small door at the bottom, immediately under the elevating legs, the buckets scooping it up, and elevating it to the top of the building, where it is discharged into a receiving hopper. From this it drops into the weighing hopper, of a capacity of 30,000 lbs., or 500 bushels of grain. The shovels have an unloading capacity of one car of 600 bushels in 15 minutes, in most cases 5 cars per hour, and as there are five shovel machines with two drums on each, the total number of bushels that can be unloaded per hour, with all the machines working, amounts to 30,000 bushels. The scales used are those made by the Fairbanks Scale Co., and are nine in number, with a weighing capacity of 40,000 lbs., an accurate account of the grain weighed being kept. Under each weighing hopper is a circular table, around which are fixed a number of wooden spouts leading to the bins belonging to its particular radius; the grain is therefore discharged through a revolving spout, fixed to the bottom of the weighing hopper, and placed opposite any particular spout, leading to the bin required to be filled. There are four legs on the south side similar to the five on the track side, so that grain can be taken from any bin, run into one of these tanks, elevated, and put into another bin. By dropping it, and continually passing it on, it is possible to take grain from a bin at one extreme end of the building, and put it into one at the other.

The grain can be thoroughly cleaned by being passed through a separating machine, the smut and dust dropping into a receptacle for that purpose. The air is conducted from the cellar through a tight wooden box, the draught being caused by two fans, 4 ft. in diameter, each making 625 revolutions per minute. There are two separators, one at each end of the building, and on the same floor as the scales and weighing hoppers.

Two spouts on the lower floor are used for loading cars, and the discharge is so great that a car of 600 bushels can be filled in three minutes. On the lower floor is a 4 inch shaft, connected to the main driving shaft, and running longitudinally, supported on iron standards, the centres being 18 inches above the flooring, which is utilized for driving the conveyor belts. The conveyors are carried across the wharf on trestles, formed of 5 ins.×8 ins. timbers, resting on sills bolted to posts, the bents being well braced and bolted and placed at 42 ft. centres. The chords are of two 3 ins.×8 ins. pieces strengthened by braces and straining beams, keyed and bolted to the chords. On these rest the floor joists 2 ins.×8 ins., 11 ft. long and at 3 ft. centres, the flooring being 2 ins. thick and 11 feet wide. The upper portion is made as light as possible, being a simple framework supporting convex rollers 38 ins. long, placed at 6 ft. centres, there being two rows, 14 inches centre to centre. The grain in transit is protected by a tarred canvas covering, fastened to circular iron bands 3 inches wide and $\frac{1}{2}$ an inch thick, placed 18 feet apart, and supported also between these at every 3 feet by $\frac{3}{4}$ inch bars bent to the same radius, namely 36 inches. Openings with flaps are opposite every roller, so that the journals can be oiled from the outside, a space being left between the covering and the outside of the floor to admit of decent footwalks protected by hand railings, which lead across the entire structure from the elevator to the tower.

On a small shaft in the elevator is a 48 ins. diameter pulley, face 38 ins., on a loose sleeve, worked with a clutch, and set in motion by a reversible bevel gearing, so that the conveyor belt can be run either in or out of the building for loading or unloading vessels. The conveyer belt is 36 ins. wide, 515 ft. 6 ins. long, of 4 ply rubber, and is carried on a level over the convex rollers, the grain being dropped on to it from the bins above through a small hopper. The belt is bagged at this particular point so as to run the grain on the centre. The conveyer belt travels at the rate of 455 ft. per minute, and its capacity is about 9,000 bushels par hour. The transit of grain should be seen in operation to be realized as the idea that wheat and other grain, and especially peas, can be carried along on a flat and level belt without running over the sides, is a wonderful fact. The grain after passing into the tower, which is at the river end of the structure, is discharged into a small hopper, to the bottom of which is fixed a rotating iron spout, capable of being raised or lowered so as to suit the height and position of the vessel's hatches, which it drops into the ship's hold. There are two conveyers to each elevator placed at 146 ft. centres, which are made as light as possible, the whole structure being put together with bolts, as they must be removed from the wharf as soon as navigation closes, and before the river rises. In the towers are horizontal tighteners, around which the belt passes, fixed to a movable iron frame, and worked by hand.

The Halifax elevator, as also the million bushel one in Boston, have conveyors on this principle. During a visit to the latter place, the author had the pleasure of seeing peas carried by a conveying belt out to the ocean steamers. Here the conveyer was over a quarter of a mile in length, and built not in one straight line but around corners, the grain being thrown from one belt on to another. The motion of the belt was transmitted by means of a bevel wheel keyed on to the shaft of the pulley wheel at the extreme end, and set into another on the adjoining belt, at right angles to the centre, and at the angle of the turn. The last portion of the conveyer is built down the centre of a wharf with vessels on either side, and at certain distances on each side of the structure are receiving hoppers with spouts attached, under which the vessels are placed.

Movable trippers are placed under the belt, lifting it up some little height above its level. The grain ascends the incline, and being shot forward by its velocity over the summit, falls into any particular hopper, opposite which the tripper is placed, and is conveyed into the vessel's hold.

The chimney rests upon a pile and concrete foundation, with forty-nine piles at 3 ft. centres, the concrete being 21 ft. 6 ins. square. Up to the level of the street is carried a solid mass of masonry 20 ft. square at bottom, 22 ft. 6 ins. high, and 15 ft. square at the ground or street level. The ashlar work is carried up to a height above the street of 19 ft. 3 ins. with a heavy chamfered coping. From this the brickwork starts, with a square base of 12 ft., rising to a height of 132 feet with a batter on each face of 1 in 47½. The walls are 48 ins. in thickness at bottom, with an air space of 12 inches, which is carried up to a height of 100 feet, the wall being reduced alternately 4 inches on either side of this space at every 25 ft. of height, up to the point at which it is vertical, the walls being there 16 and 20 inches thick. The top is surmounted with an iron cap, weighing over a ton, which is thoroughly bolted down to the brick-work. It was made in eight sections and bolted together in place. The shaft is 4 ft. square inside measurement, and up to a height of 40 ft. above the stonework is lined with 8 inches of firebrick. The walls are bonded together with iron bands, and iron steps are built into the brick-work in one corner the whole height of the chimney.

In connection with this work it should be stated that Mr. P. A. Peterson, M.Can.Soc.C.E., was the chief-engineer, and Mr. S. Howard, M.Can.Soc.C.E., the engineer in charge.

From the drawings accompanying the paper, Plates I and II have been prepared.

DISCUSSION.

Mr. Butler. The loads permitted to each square inch of foundation are rather greater than is usually considered advisable. The Bismarck Bridge, on clay of a very hard and compact nature, is limited to 39½ lbs. per square inch; the Niagara Cantilever, on massive boulders, with a concrete monolithic base, is limited to 41 lbs. to the square inch. The foundations of the Capitol building at Albany are loaded to a much greater extent, and as they rest on clay, and have shewn no serious settlement, it may be safely assumed that the Bismarck and other bridges have an unusually large factor of safety. The pressure on the clay at the foot of the basement walls at the Albany Capitol is in some places as great as 166 lbs. to the square inch. Provision has been made for the removal of the dust; this is a very necessary precaution (too often neglected), as there can be no doubt that finely disseminated dust when brought into contact with a flame, from a candle or lamp, will explode with great violence. Would not the same result be obtained more cheaply, with powerful exhaust fans for the conveyers, on the principal of pneumatic transmission, as is now secured by the conveyer belt?

Prof. Bovey. Endless bands for the conveyance of grain were first employed in the Waterloo Dock Corn Warehouses, Liverpool. These warehouses line three sides of the dock, and the distance over which the grain can be carried on bands is nearly 1⅓ miles. The superiority of this mode of conveyance was demonstrated by Mr. P. Westmacott, M. Inst. M.E., in an elaborate series of experiments, which shewed that with an 18-ins. band, 1·02 H.-P. were required to convey 50 tons of grain per hour through a distance of 100 ft., as compared with 25 H.-P., with a tubular screw in revolving casing, and 18·38 H.-P. with the common screw in stationary casing. The warehouse 18 ins. bands ("made of 2 plies of stout canvas covered with vulcanized india rubber") are driven by 8 H.-P. hydraulic engines, which receive the pressure from an accumulator in the central block. The engines at 25 revolutions per min. give a band discharge of 60 tons per hour, and in the same time use 120 cub. ft. of water, costing about one-fifth of a penny per cub. ft. At the same speed a 6 H.-P. engine with a 12 ins. band will convey 25 tons per hour, and use 75 cubic ft. of water. In the experiments it was also found, "that the maximum band speed was 8 ft. per sec. for light oats, bran, flour and similar grain, 9 ft. per sec. for heavy clean grain, and a still higher speed for peas." Corners are easily turned by the band, being raised at any given point by means of a simple piece of mechanism, so that the grain runs up-hill towards the ridge, leaves the band, and is received into a curved spout, which leads it away in any required direction. This method of changing the direction of the moving grain has proved more effective than the air blast or brushes. A great deal of fine dust is thrown off, and is liable to injure the machinery unless protected. The grain is distributed over the floor by means of a fan, which receives it from a spout leading to its upper surface. A large amount of valuable information on the subject may be obtained from Mr. Westmacott's paper read before the Institution of Mechanical Engineers, England. It would be of interest and value if Mr. Howard could give data as to the power required to carry the grain it the C. P. Ry. Elevator, and as to the best speed at which it should be carried. The endless band system is often made use of for the conveyance of broken stone, charcoal, and many other kinds of material.

Mr. Howard. It is somewhat difficult to estimate the cost of handling grain, as the delivery and discharge of grain is so very uncertain. There may be days when the machinery is running to its full capacity, at other times very little business may be done, and yet the boilers must be kept going, and the wages of the employés paid. The cost for four weeks amounted to $1130.25, and during that period 238,812 bushels were received, and 308,863 delivered into vessels, at a total cost of 1-5th of a cent per bushel; at other times the cost has been $\frac{1}{8}$ of a cent, and again nearly one cent.

Taking each H.-P. expended at 2 cents per hour, the cost for the steam shovels (using, say 10 shovels, requiring an expenditure of 15 H.-P.), in unloading 15,000 bushels, is 15 cents, that is one cent for every 1000 bushels; the cost for the elevating legs, at say 10 horse-power for each, is 20 cents, elevating per hour 8790 bushels, that is one cent for every 440 bushels; there is also the capstan cost, and the cost of cleaning and moving from bin to bin. Thus the total H.-P. may be taken at for shovels 15 H.-P., capstan 7, fans 6, making, with 90 for legs, a total of 118 H.-P. equivalent to $2.36 for 79,110 bushels, or 335 bushels for one cent. This is a very extraordinary cost, as it is upon the assumption that everything is working satisfactorily and to its full capacity; even taking it at one half, the cost will be at the rate of 167 bushels for one cent.

The conveying of grain to the vessels is slightly different, and from the following result it is seen that with a small additional horse-power, and an increase in width of belting, the amount carried is considerably increased, and the cost of handling very much reduced. The discharge from the bins is only about 6000 bushels per hour, and it is seldom that more than two bins are discharging at the same time, so that a 42 inch belt would be the most economical. Taking the cost of handling at two cents per horse-power, a 24-ins. belt takes four horse-power and delivers 4000 bushels; or 1 horse-power for every 1000 bushels, costing one cent for every 500 bushels.

A 30 inch belt takes 52 H.-P., and delivers 6000 bushels; or 1 horse-power for every 1150 bushels, costing 1 cent for every 600 bushels.

A 36 inch belt takes 7 H.-P., and delivers 9000 bushels; or 1 horse-power for every 1285 bushels, costing one cent for every 643 bushels.

A 42 inch belt takes 94 H.-P., and delivers 13,000 bushels; or 1 horse-power for every 1380 bushels, costing one cent for every 690 bushels.

A 48 inch belt takes 12·5 H.-P., and delivers 18,000 bushels; or 1 horse-power for every 1440 bushels, costing one cent for every 720 bushels.

The power required to work the Archimedean screw, formerly used for pushing along the grain in mills, is so great, and the result so small, that it has been of late years entirely superseded by the flat belt; it would be entirely out of place where the conveying structure has to be removed yearly, the weight being so enormous, and the fixtures in connection therewith requiring such careful adjustment. For instance, a screw to carry the same amount of grain as a 36 inch belt, viz., 9000 bushels per hour, and at the rate of 450 feet per minute, would require a diameter of 24 inches, or 12 inches pitch, and should make 300 revolutions per minute, with an expenditure of about 40 horse-power.

The ordinary charges are:—

1½ ct. per bushel for winter storage.
1 " " summer storage, 15 days.
¼ " extra for every 10 days after.
⅛ " turning, and ½ cent cleaning.

Mr. Butler, in his remarks, must have overlooked the fact that the piers rest upon piles. The weight is distributed over nine piles, and as they were mostly over 12 inches in diameter, or say at least 130 square inches, or perhaps more, this would be equivalent to 423 lbs. per square inch of pressure; they were driven into the solid foundation of the river bed, and Rankine allows 1000 pounds per sq. in. for piles driven home, and 400 in ordinary ground, so that there is little fear of the building settling.

28th April, 1887.

JOHN KENNEDY, Vice-President, in the Chair.

The following candidates have been balloted for and duly elected as

MEMBERS.

ROGER ATKINSON.	PHILIP L. FOSTER, B.A.SC.
FRANCIS ASHLEY HIBBARD.	ARTHUR THOMAS TIMEWELL.

ASSOCIATE MEMBER.

PIERRE ALFRED PERRON.

ASSOCIATES.

JAMES FERGUSON ARMSTRONG.	GEO. M. DAWSON, PH. D., F.R.S.C.

STUDENTS.

NOEL EDGELL BROOKE.	HENRY MARTYN RAMSAY.
JAMES HERRICK MCGREGOR	ONÉSIME SIMARD.

Paper No. 8.

FOUNDATIONS OF THE ST. LAWRENCE BRIDGE.

BY G. H. MASSY, B.E., M.CAN.SOC.C.E.

In the autumn of 1881, the Atlantic and North Western Railway Company decided to build a bridge across the St. Lawrence, in the vicinity of Montreal. Accordingly, in October, 1881, surveys were made at several places. The first line surveyed was at the Lachine rapids, crossing Heron Island. The river here proved to be very wide, but in other respects a tolerably favourable line was obtained. The next survey was made in November at the Nun's Island. This line shewed deep water and a wide crossing, worse in every respect than the line at Heron Island. The third and last survey was made where the bridge now stands. At this point the sounding shewed the existence of an irregular reef about 500 feet wide, extending from the north shore to the main channel, with a depth of from 5 to 20 feet of water. The current here runs at a speed of from 2½ miles to 6 miles per hour at low water, and from 4 to 9 miles at high water, the difference between high and low water being about 6 feet.

The soundings were taken from a boat allowed to float down stream over the points where soundings were required. At a given signal from the man at the lead line, the exact position of the lead line was fixed by means of two transits on shore. In order to avoid any possibility of confusion or mistakes, each sounding was numbered, and the man in the boat who booked the sounding, held up a card with the unit figure of the sounding, so that both transit men and the man in the boat checked the number each time; by this means from 3 to 15 soundings were taken, according to the velocity of the current, each time the boat dropped down stream; the direction and velocity of the current were taken by floats in a somewhat similar manner, but the position of the float had to be taken at fixed intervals, say half a minute apart.

These soundings when plotted gave full information as to the surface of the river bottom, and from these soundings seven trial lines were laid down and the position of the piers marked. A scow was then moored over the site of the piers, and borings taken with an ordinary steel rod 1½ in. diameter furnished with a screw bit.

This rod answered very well, except at places where the depth of the water exceeded 25 feet, with a strong current, when it was found necessary to protect the rod by means of a tube of 6 ins. diameter, 20 feet long, through which it was passed. The borings shewed bare rock near the north shore, but towards the centre the bottom was covered to a depth of several feet with gravel and hard pan. The rock forming the bottom of the river is mostly Utica shale, interspersed with veins and floors of trap; above this formation the blue limestone appears on the south shore.

This was the amount of information furnished when it was decided to call for tenders. However, nothing further was done in the matter until August of 1885, when one or two other lines were tried, and the Company in the following November let the contract for the masonry, in which it was stipulated that the work should be finished by November 30th, 1886, thus giving 12 months for its completion.

The specification allowed the contractor to use "cofferdams or sink bottomless caissons fitting closely to the rock, into which he can deposit Portland cement concrete to a depth not exceeding ⅓ of the depth of the foundation from the surface of the water; when the concrete is perfectly set the caisson may be pumped out and the masonry commenced from its surface."

The latter plan was adopted as being a much more expeditious method than that of cofferdams. During the winter of 1885-6 stone was cut for the masonry and broken for concrete, caissons and scows built, and all made ready for spring.

The abutment on the north shore, and piers Nos. 1 and 2 were built during March, April and May. On the 12th of May the first caisson was brought down for No. 4 pier. The foundation here was bare rock, so that all required to be done was to get the caisson into place and commence concreting. The caisson was towed out of Lachine harbour by two powerful tugs, both tugs pulling up stream, thus allowing it to drop slowly down with the current. The caisson was built of 12 × 12 in. timber, spiked together by rag bolts, and braced at every 10 ft. with 12 × 12-in. braces, as shewn on Plate III; the joints were caulked and made water-tight; about five of the upper courses of timber were fastened to those below by long screw bolts, so arranged that by turning the bolts they could be taken out and the upper courses of timber detached after the pier was built, thus removing all timber which would otherwise appear above water.

Three strong posts were built into the front of the caisson to which the anchor cables might be attached, and two similar posts at the stern end to which guy ropes might be fastened, when the caisson had to be twisted round so as to get it at right angles to the bridge centre line. A scow measuring 23 × 70 feet was placed on either side of the caisson, and two timbers stretched from scow to scow crossing the caisson at the bow and stern; these timbers were made fast to the caisson by chains and the ends jacked up from the decks of the scows so as to lift the caisson several feet out of the water, thus lessening its draught. This was found necessary in order to avoid striking boulders or rocks on its way down.

The caisson carried three anchors weighing 4 tons each, and each scow carried one weighing one ton; the chains attached to the 4 ton anchors were formed of 1¼ in. links, and the steel wire ropes used were 1¼ in. and 1½ in. diameter. The chain for the smaller anchors was made of ¾ in. iron. The total number employed on the contract were twelve 4 ton anchors and twelve 1-ton anchors with 2 miles of chain cable and 2 miles of steel wire rope. When the caisson was about 600 feet above the site of the pier, the three heavy anchors were dropped, and the whole draft of scows and caisson allowed to hang on the first, so as to make certain of its having taken hold in the bottom; this chain was loosened and the second tested in a similar way, and then the third anchor, so that each caisson had always three anchors out, any one of which was capable of holding it, besides the smaller anchors from the scows kept in reserve. The anchors from the caisson were not in one line, but spread a little, so that by loosening one chain and keeping the others tight the caisson could be placed directly over the site of the pier. The caisson was thus lowered down to the bridge line.

Towards the north shore the current ran very oblique to the bridge line, thus necessitating the swinging of the caisson round, in order to bring it into position; this was often a slow operation, as the moving of the caisson round generally threw its centre north or south of the site of the pier. As however there was an allowance of 5 feet between the inside of the caisson and the masonry of the pier all round, it was considered sufficiently accurate if the caisson was placed within 6 inches of its intended position. It required about one day to place each caisson.

The foundation of piers 4 and 5 was bare rock, and therefore when the caisson was placed over the site of the pier it was loaded down with ashlar laid along the top timbers.

The next operation was to prevent any current passing between the bottom of the caisson and the rock, by placing sheet piles of 3 inch plank all round the bow and spiking them to the caisson.

A curtain of canvas fastened round the inside of the caisson, at a distance of a few feet from the bottom, was spread over the rock and loaded with bags of concrete; this was necessary in order to prevent any current from washing over the concrete and separating the cement.

When this was finished the concrete was prepared by mixing Portland cement and sand in the proportion of one to one; to this was added as much broken stone as would make the whole into a mass of stone whose interstices were filled with mortar, the whole being thoroughly mixed. The stone was broken to pass through a 2½ inch ring. The proportions were about 3 of broken stone, 1 of cement and 1 of sand. This concrete was lowered into place by means of an iron box, holding 2½ yards; the box was constructed of iron ¼ inch thick, with a floor hinged about 2 ft. 6 ins. from the bottom, and opening at the centre; by turning a lever this floor was allowed to fall, permitting the concrete to slip through, but being still protected from the action of the water by the sides of the box; in this manner, with two gangs by day and two at night, 80 yards could be placed in 24 hours.

When the concreting was finished the caisson was left for 2 or 3 days until the concrete had set, when the water was pumped out the concrete levelled off and the masonry commenced.

Very little pumping was required to keep the caisson dry.

The anchors were never removed until the masonry was above water level.

In sinking the caissons it was necessary to take into account that water might get between the concrete and the rock, and thus place the caisson is the same position as a tub which, being sunk in the river with its edge above water and then bailed out, would be in danger of rising and floating bodily away.

Over the foundations of Nos. 6 and 7 piers there was a considerable deposit of gravel; this was partially removed before the caisson was brought down, by means of a large rake worked from two scows anchored over the foundation. The rake was hauled up stream along the sides of the scows by men, then dropped and pulled down stream by a horse and windlass.

The head of the rake was formed of an iron bar about 2½ inches × 2½ inches, and 5 ft. long, on which steel teeth 1 in. by 2½ ins. were fastened, and the whole attached to a long handle. This arrangement removed a quantity of loose stones and gravel; the remainder was taken out when the caisson was in place, by means of a "Hayward excavator."

The next foundation commenced was for No. 8 pier. The surface gravel was raked off and the caisson placed.

The rock here was covered with 4½ feet of hard pan, so tough and hard that the Hayward excavator could make little impression on it. An ordinary clam shell dredge was tried, but without success; recourse was then had to dynamite, and holes were drilled to a depth of 2½ feet at different places and charged; small quantities of hard pan were loosened in this way by each explosion.

There weeks were occupied at this work with little effect, when a long iron bar was made with a chisel edge of steel at one end and a ring at the other. The bar was about 25 feet long and weighed 1,700 lbs.; this bar was hoisted up vertically some 10 or 15 feet by an ordinary pile driving engine, and allowed to drop with its full weight. By this means the remainder of the hard pan was loosened, and then removed by the excavator.

From the experience gained at No. 8, it was decided to procure dredges for the remaining foundations, and, accordingly, dredges No. 5 and 6 were hired from the Harbour Commissioners; these worked in a most satisfactory manner, and notwithstanding the hard, tough character of the material to be excavated, Nos. 9, 10, 11 and 12 caissons, were brought down and placed without much difficulty.

Some of these were only partially built at Lachine, the remaining courses of timber being added when the caisson was near the foundation for which it was intended, as the water was shallow just above the site of several of the foundations.

At No. 14 the foundation was covered with 14 feet of hard pan, requiring the constant employment of No. 6 dredge from June 22nd until August 6th.

The distance from the foundation to the surface of the water at this pier was about 33 feet, and the current was 4 miles per hour.

Previous to dredging, a guard crib was sunk in front of this foundation 8 feet wide at bow, 26 feet at the stern, and 26 feet long, with its lower end 3 feet above the bow of the caisson (when in place), i.e., just far enough above to clear it, thus forming an eddy in which the dredge could work without much obstruction from the current. This crib was placed in position in a similar manner to the caissons, with the exception that one of its anchor chains was secured to an iron bolt on shore.

This caisson was so deep and required so much loading that rails were used as well as stone to sink it. Some of the rails were placed along the outside near the bottom, and the remainder rested on the cross timbers inside.

At this and several of the other foundations the electric light was used at night and also in the daytime under water, to assist the divers in clearing the foundations and placing the bags of concrete round the edges of the caisson.

No. 13 pier was always looked upon as the most difficult. It stands in 28 feet of water and at the swiftest part of the current, and on it is to rest the cantilever spans of 408 feet each. It was of the greatest importance that the foundation should be first class in every way, so as to avoid any possibility of settlement when the weight of superstructure came on it. The pier is much larger than any of the others, and the placing of the caisson required much care.

A guard crib was also sunk in front of this similar to that used at No. 14, but a little larger, being 30 feet wide at the stern. This crib was brought down when about half built in a manner similar to that used for bringing down the caissons, being placed between two scows and supported by cross timbers. No. 13 pier stands directly in the centre of the main channel, the current here being so strong as to sweep off all loose material, leaving the bottom bare rock, and thus affording little chance for anchorage.

Accordingly a "dead man" was placed on a projecting point on the south shore, about 1,700 feet above No. 13 pier. This "dead man" consisted of a 16 in. pine log, let into a trench excavated purposely in the limestone; both ends of the log were well loaded down with stones, and round the centre the 1½ wire rope was lapped and secured. The other end of this rope was rolled in a coil on the deck of a scow anchored about 400 feet above the site of No. 13 pier. The scows attached to the crib carried three four-ton anchors, and two one-ton anchors, these large anchors were dropped as the crib floated down, and as it passed the scow the end of the 1½ wire rope was taken on board and secured to the "snubbing posts." Thus, the crib had three 4-ton anchors, and the wire rope; two of the anchor lines passed through the front timbers of the crib a few feet from the bottom, thence upwards, to above water level, then over another cross timber, and round the snubbing posts, and the other two lines passed directly above water over the front timbers and around the posts.

As the line from the "dead man" passed diagonally across the steamboat channel, it was necessary to load it down so as to avoid any risk of accidents to passing vessels; for this purpose 3 heavy pile hammers were used, tied together and dropped over the line at the centre of the channel. The breaking strain of the 1½ inch rope was about 30 tons. The crib was thus lowered, so that her stern remained about 10 feet above the position of the bow of the caisson when in place.

The crib was here completed and sunk, and when the caisson was floated down and dropped behind the crib, it required to be forced *down stream* to get it into place, so strong was the eddy formed by the protection crib. The bottom was bare rock, perfectly clean, so that when the caisson was sunk concreting commenced at once.

It was in connection with this pier that the greatest loss of plant was sustained by the contractors. No. 5 dredge was brought over to try the nature of the bottom before the protection crib was sunk. A scow was moored alongside and secured to the dredge; the action of the current on this scow swung the dredge round, and after swinging for a time she broke away from her anchor and dropped swiftly down stream, till meeting with a more shallow part of the river, the "spuds" came in contact with the bottom, and the dredge went over on her side, where she now remains, the men on board having a narrow escape from drowning. As soon as the piers were finished the caissons were well protected from the action of the current by rip-rap to within a few feet of low water level.

Some curiosity being felt as to the power required to hold No. 13 caisson in the heavy current, some experiments were made with two models one four times the section of the other. The models were held in the current, and the strain on the line holding them measured. By observing the strains in currents of different speeds, it was found that the force varied as the cross section of the caisson, and as the square of the velocity of the current, from which the calculated holding strain on the large caisson in the main channel was estimated to be from 60 to 100 tons, being subject to serious fluctuations due to shearing from side to side.

Before sinking No. 12 caisson, an anchor crib was placed about 1,500 feet above the site of the pier to which one of the chains was attached. The crib was 12 feet wide by 25 feet long, and filled with stone.

In depositing the concrete two different sized boxes were used, one holding 2½ yards, the other 1 yard. The smaller box was found convenient for filling corners and places where the large one could not pass; but the large box was chiefly employed, as the concrete deposited by it appeared superior to that deposited by the smaller one.

An experiment was made by mixing sand, Portland cement and broken stone, in the proportion used for concrete. Some of this was mixed with water and placed in a sack, the remainder was filled dry into a similar sack, and the whole submerged into the river. After twenty-four hours the sacks were examined, when it was found that the concrete submerged in a dry state was quite unset, while the other had commenced to harden. The sacks were replaced in the water and left for several days, and, when again examined, the dry concrete was found in the same unset state, while the other was quite hard. Both sacks were left in the air for a month; the wet concrete continued to harden, the other became quite dry and loose. This experiment was repeated, but with the same curious result.

On pumping caisson No. 14 the concrete was found not to have set, and to be nearly of the temperature of newly slacked lime, while an unusually large amount of laitance was deposited at the lower end, in a space left for the pump. The caisson was allowed to fill again, and the temperature of the water inside observed daily, when it was found to be several degrees higher than that of the water in the river. At the end of six days the temperature had cooled down, when the caisson was again pumped, and the concrete found to have set.

No swelling or cracking of the concrete, which always accompanies the action of quicklime, was observable.

The quantity of concrete in the foundation was 890 yards, made from several different, but all good, brands of Portland cement.

Although there was a slight rise of temperature in the concrete of some of the other foundations, No. 14 was the only one which caused any inconvenience.

The Chief Engineer of the above work was Mr. P. A. Peterson, M. Can. Soc. C. E.; Mr. Massy, M. Can. Soc. C. E., being the engineer in charge.

From the drawings accompanying the paper, Plate III has been prepared.

DISCUSSION.

Mr. Dodwell. Mr. Dodwell said that the Society was indebted to the author for a capital paper on a most interesting and important work. It was a work in which he took a special interest, having assisted the author in the winter of 1881 and 1882 with the surveys, soundings and borings referred to in the paper.

The heating of the concrete referred to by the author had been pretty well discussed, but before leaving it he would just like to ask the author what degree of temperature had been reached—he understood him to say he had used thermometers—and how long this temperature, whatever it was, had been observed to last. While building the bridges at Ste. Anne and Vaudreuil, he had heard of this instance of the heating of the concrete at Lachine, and he had, therefore, kept a good look-out for similar action. Nothing of the kind had, however, been observed. The cement used at the Ste. Anne and Vaudreuil bridges had been almost exclusively "Johnson's," the same, he believed, as had been used at Lachine. Something over 7,000 barrels had been employed, and the only peculiarity he had noticed in connection with it was a somewhat heavy efflorescence from the joints of masonry laid in the winter. He had frequently before observed an efflorescence from masonry and brickwork, but rarely if ever as excessive as in this case, and the deposit was generally an insoluble salt of lime, such as the carbonate. Here, however, the deposit was highly soluble, and, from its taste, he believed it was chiefly composed of Sulphate of Soda. He had collected a quantity of it, and was having an analysis made. It did not seem to have any prejudicial effect on the cement, for the joints were nearly as hard as the stone.

There were one or two other points in the paper upon which he would like a little information.

He noticed in the diagram exhibited that the stern of the caisson was framed to a sharper angle than the bow. It appeared to be about 60°, while the bow was 90°. Doubtless, in a current such as the work in question had to contend with, the sharpening of the stern of the caisson served to lessen very materially the shearing and swinging from side to side of the caisson, which the author had spoken of, and it would be interesting to know exactly what angle was the best suited for this purpose. Perhaps the author could state how his caissons came to be framed to the angles shewn on the diagram; why, for instance, the stern angle was not 10° more or 10° less than that actually adopted.

Several of the piers, standing in the deepest water and in the strongest current, were built directly on the bare rock. He would like to ask the author whether in these cases any precautions had been taken to roughen or step the rock bottom so as to give the concrete a better hold, and prevent the pier with its caisson and concrete base from sliding bodily down stream. If this had not been done, it became a vitally important question whether the *vis inertia* of the pier, aided by friction, was sufficient to withstand the pressure of from 60 to 100 tons, which the author had stated as the probable effect of the current on the caisson.

With regard to the large harbour dredge that had been sunk and lost, he happened to be on the work the day the accident occurred. He was in company with the chief contractor on pier No. 7 or 8, when they heard the dredge whistle in a very alarming manner. They at once knew that something was wrong, so jumping into their boat they made all haste in the direction of pier No. 13, where the dredge was working. Before they had proceeded far, it became evident that the dredge had broken from her moorings, and by the time they had got within a couple of hundred yards of her, the "spuds" had struck the bottom and she had heeled over and sunk. It was quite an exciting five minutes. He would merely like to ask the author whether any steps had been taken to raise or remove the dredge, and, if so, with what success. Lying as it did almost in mid-channel, it was a serious source of danger to steamers running the rapids, and one which the Harbour Commissioners would hardly approve of leaving.

Mr. MacPherson.

Mr. D. MacPherson remarked that, in reference to the rule for force of resistance to currents, deduced by Mr. Massy from experiment, and the theoretical rule given by Prof. Bovey, it appeared evident that any such rule must be materially modified, not only by the size, but by the shape of the resisting body, and he wished to know if, in the opinion of Prof. Bovey, such was not the case; if so, to what extent was this force modified by the caissons of the St. Lawrence bridge being made with an angle of 90° at the bows instead of being rectangular in plan.

Prof. Bovey.

In order to measure the resistance R to the motion of a body, wholly or partially immersed in a current, it is usual to employ the empirical formula, $R = C. A. w. \frac{v^2}{2g}$

A being the transverse sectional area of the immersed portion of the body, w the specific weight of the fluid, v the *relative* velocity of the current, and C a coefficient depending principally upon the form of the immersed body. When a body is moving in a current of very great width, the following approximate value may be assumed for C :–$\frac{11}{10}$, for a prism with square ends having a length from three to five times the least transverse dimension; 1 for the same prism with a tapering stern; $\frac{1}{2}$ for the same prism with a tapering stern and a triangular or a semi-circular prow; $\frac{1}{3}$, for the same prism with a tapering stern and a prow with a plane face at 30° to the horizontal; $\frac{1}{6}$, for the fastest ships.

The values of C are further modified when the width of the current in small, and also by waves.

The effervescing and the slow setting of the concrete, alluded to by Mr. Massy, were doubtless due to the presence of an excessive amount of unslacked lime, and must be attributed to the bad quality of some of the brands of cement which were employed in the mixture.

12th May, 1887.

JOHN KENNEDY, Vice-President, in the Chair.

The following candidates were declared to have been balloted for and duly elected as

Members.

George Arthur Bayne.
William Edward Gower.
Francis J. Lynch.
Ernest Marceau.
John Page.
Richard Birdsall Rogers, B.A.Sc.
Frank Linn Somerville.
Toussaint Trudeau.

Associate Members.

Professor Joseph Haynes.
Charles Hodgson Ostler.

Associates.

Wilfrid Theodore Skaife, B.A.Sc.
Wallace Cuthbert Trotter.

Students.

John Holden Antliff.
Conway Edward Cartwright.
Joseph Narcisse Alf. Hamel.

THE SUPERSTRUCTURE FOR THE ST. LAWRENCE BRIDGE.

4.

By J. W. Schaub, M.A.Soc. C.E.

The St. Lawrence Bridge was first outlined, about five years ago, by Mr. Peterson of the Atlantic and Northwest Railway Co., but it was not until the November of 1885 that the contract for the Superstructure was awarded to the Dominion Bridge Co. of Montreal, with Mr. C. Shaler Smith as consulting engineer, and Mr. P. Alex. Peterson as chief engineer for the Railway Company. The designer of the bridge is the late Mr. C. Shaler Smith; Mr. Frank D. Moore, as chief assistant engineer, having full charge of the calculations and the details.

In adopting the lengths for the different spans at the selected crossing of the St. Lawrence River, there was no precedent to guide the designer, excepting the lengths which had been adopted for the Victoria Bridge, which are as follows:—24 spans each 240 feet centre to centre of piers, with one channel span of 350 feet centre to centre of piers. In the St. Lawrence Bridge there are eight spans of 240 feet centre to centre of piers, two spans of 269 feet centre to centre of piers, and two channel spans of 408 ft. centre to centre of piers (see Plate IV).

The St. Lawrence Bridge begins properly at the first crossing of the Grand Trunk Railway, which is by an 80 ft. through girder. The next crossing is the Canal, which is by a swing bridge 240 ft. long. The general design of this swing bridge is of the triangular pattern, known in Mr. Smith's office as the "Menomonee" type. This swing has a rim-bearing table, turning on 34 wheels which are placed on a circular track, and operated by hand power or steam power from the centre. There are two classes of draw spans, rim-bearing and centre-bearing, the centre-bearing being used for spans of short lengths up to 150 feet. For spans of longer lengths, it is customary to use the rim-bearing, or the rim-bearing and the centre-bearing combined, it being easier to operate the rim-bearing swing for longer lengths. The first span of this pattern (the triangular) was designed by Mr. G. H. Pegram, M.A.S.C.E., formerly assistant to C. Shaler Smith, for the Chicago, Milwaukee and St. Paul Railway. The advantages in this form of swing are in having low inclined chords at the ends, which aid in deflecting a possible derailed car which might strike the bridge, and which also reduce the area exposed to wind pressure at the ends of the arms, making it easier to handle during high winds. The supposed advantage derived by avoiding all counter strains in this form of bridge, which Mr. Pegram had at first supposed to be the case, is not obtained. One particular feature in this span are the rocker links at the centre, which tend to equalize the pressure on the turntable, making the strains on the centre posts at all times alike in any one pair (see Plate IV). The ends of the arms, when the draw span is closed, rest on the crowns of inclined beds, which are set at a proper elevation to give the reactions necessary for a beam continuous over three level supports.

The heights at the ends are determined by calculation, and ample margin is allowed for any discrepancies in these heights due to unequal expansions from temperature, lack of uniformity in the elasticity of the material, or any imperfections in the workmanship.

After crossing the canal, we come to the river spans proper, which consist, first, of three 80 ft. deck plate girders, then the eight 240 feet deck spans.

It might be stated in regard to the plate girders used in the St. Lawrence Bridge, that they are all provided with rockers at the end supports, so as to allow any vertical movement in the girders themselves, due to deflection from passing loads, or to neutralize any imperfections in the workmanship which would tend to bring any undue pressure on the bed plates or expansion rollers.

This has been Mr. Smith's late practice for all girders above 50 feet, and was first used for the Denver and Rio Grande Railway in 1884.

The general design of the deck spans is the double intersection Pratt Truss.

The two systems are entirely independent of each other throughout (see Plate IV). Where the diagonals cross the vertical posts, there is a pin running through the post, dividing the ties into two lengths. It is a matter of regret that this practice has been used so indiscriminately by the Engineers in the States, without any regard to its pernicious effects. This has been the case, for example, in such large structures as the Plattsmouth bridge, in which there are posts 50 ft. long on centres, divided into half lengths by the ties crossing at their middle, without any provision for the effects of distortion due to strain in the members; the effect of a load coming on a structure framed in this manner can be easily shown (see Plate IV). Supposing the trusses to be cambered when there is no strain in any member, the intersection of the tie is at some point below the centre of the post. Now, when the load comes on the span, the chords tend to become horizontal, the posts tend to become vertical, bringing the intersection of the ties with the posts more and more towards the centre of the post, until finally, when the entire camber is taken out of the truss, the intersection must necessarily be at the centre of the post; the amount of this movement depends on the length of the panels and the depth of the truss. In the 240 feet spans of the St. Lawrence Bridge, this movement amounts to about $\frac{1}{4}$ in. and has been provided for by making the holes in the posts 1-in. larger than the pin, thus allowing ample movement for the pin when the load comes on the bridge. This movement can be noticed in a structure at any time when the pin is free to move, as in the St. Lawrence Bridge. Where the pin is not free to move the distortions must necessarily take place in the members themselves; and, moreover, this practice is questionable where it has been done with a view to figure the posts for half their total length, and consider them as fixed ended where they are held by the diagonals at the centre.

The next portion of the bridge to be considered are the two 269 feet spans and two 408 feet spans, forming four continuous spans over five supports (see Plate IV). There were two designs proposed besides the one that was finally adopted (see Plate IV). The design as adopted was known in Mr. Smith's office as the "Flying Cantilever," and was first proposed for the Storm King Bridge over the Hudson River, in State of New York. As used in the St. Lawrence Bridge it is, properly speaking, no cantilever bridge, as the spans are continuous. The cantilever principle is used here for erecting the bridge only, which is built out from the piers on each side, the ends being joined at the centre when the final coupling is made and the spans become continuous over five supports. The advantage of the cantilever principle is only a saving in the erection, there being no saving in the weight, as there is merely a different distribution of the material from what there would be in ordinary disconnected spans. In a continuous girder there is necessarily a saving in the weight over the piers, as was the case in the St. Lawrence Bridge, but the saving in the mode of the erection is the principal item to be considered here. The advantage of using two centre piers instead of one would have been a considerable saving in the cost of erection, but not sufficient to counterbalance the increased cost of the extra masonry; this was the principal reason why one centre pier only was used instead of two, as shown in Plate IV.

In speaking of cantilever bridges, it might be here stated that the first cantilever bridge built in America was the Kentucky River Bridge, built by Mr. C. S. Smith in 1876. Mr. Smith also built the Minnehaha cantilever in 1881, long before the Niagara cantilever was ever thought of. The Kentucky River Bridge is a wonderful structure, from the fact that it is really the first continuous pin connected girder that was ever built in America, and is remarkable also from the fact that instead of being continuous over four supports (Plate IV) it had its points of contra-flexure fixed by cutting the chords after the bridge was erected. In a letter of Mr. Smith's, written two years before the bridge was built, he says: "I feel so confident of my calculations of the continuous gir- "der that I now propose to cut the chords at their points of contra- "flexure, thus fixing these points beyond a question of doubt." This statement was the forerunner of the Kentucky River Bridge, in which the points of contra-flexure were fixed at.* (See Plate IV.) These points of contra-flexure could have been fixed in the river arms instead of the shore arms, and it is a curious fact that they should not have been fixed in the river arms, as was subsequently done by Mr. Smith in the Minnehaha cantilever, where the point of contra-flexure is fixed in the centre of the river span, there being two shore arms and two river arms without any mid span hung from the ends of the river arms, as in the Niagara and St. John cantilever bridges.

In regard to the Kentucky River Bridge, the question might be asked:—How is the expansion of the river span—that is, that portion of the bridge between the towers—provided for, inasmuch as the trusses are rigidly fixed to the towers? The towers must necessarily deflect longitudinally when expansions take place, and here the deflection in the towers from temperature, and also from the effect of a train of cars skidding on the rails, with brakes set, has been provided for in proportioning the sectional areas of the material in the towers. When the bridge was tested, a train of freight cars, moving at forty miles per hour, was brought to a dead stop on the bridge. Of course it was anticipated that a movement would be noticed in the towers, in the direction of the moving train, and provision was made for measuring the amount of this movement. However, the friction of the wheels skidding the whole train along the bridge had no apparent effect on the inertia of the large mass of the material in the bridge itself, and the only movement that was noticed was at the moment the train first came on the bridge, when the first tower deflected towards the advancing train simply owing to the deflection of the shore spans; and as soon as the entire bridge was covered the towers resumed their normal positions.

In any beam continuous over any number of supports, when any flexure takes place $\frac{1}{R} = \frac{M}{EI}$ in which,

M, is the bending moment at any point in the beam.

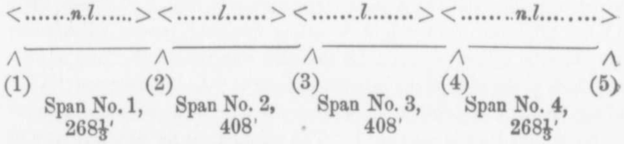
R, is the radius of curvature of the beam at that point.

E, is the modulus Elasticity of the material.

I, is the moment of inertia of the cross-section of the beam at that point.

By assuming all the supports to be level, and assuming "E" and "I" to be constant, the Theorem of Three Moments may be obtained, and is given in all text books on Applied Mechanics. However, it was not until September, 1875, that Professor Mansfield Merriman gave, in the London Philosophical Magazine, the formulæ for a beam continuous over any number of level supports, which are at all practicable. These formulæ are as follows:

Formulæ for obtaining pier moments and reactions, as applied to the four continuous spans in the St. Lawrence Bridge:—



"m" is the number of any pier.

"r" is the number of any loaded span.

M is any pier moment.

s is the total number of spans=4.

The Pier Moment when $m < r + 1$. is given by

$$M_m = \left(\frac{C_m}{l}\right) \times \frac{A\,c_{s-r+2} + A_1\,c_{s-r+1}}{C_{s-1} + 2(n+1)\,C_s}.$$

When $m > r$,

$$M_m = \left(\frac{c_{s-m+2}}{l}\right) \times \frac{A\,c_r + A_1\,c_{r+1}}{c_{s-1} + 2\,(n+1)\,c_s},$$

in which

$$\left.\begin{array}{l} A = P\,l^2_r\,\{2\,k - 3\,k^2 + k^3\} \\ A_1 = P\,l^2_r\,\{k - k_3\} \end{array}\right] ; \qquad k = \frac{a}{l_r}.$$

P denoting the load in any span.

l_r, denoting the length of that span.

a = distance from nearest left hand support to the load "P," which is necessarily a concentrated load; c is a number, and in present case,

$$c_1 = 0 : c_2 = 1 : c_3 = -(2 + 2\,n) = -3{\cdot}3154.$$
$$c_4 = 4 + 3 + \{n \times (4+4)\} = +12{\cdot}2616.$$

SHEARING FORCES.

$$S_r \text{ (in loaded span)} = \frac{M_r - M_{r+1}}{l_r}. + q$$

$$S_{r+1} \text{ (in loaded span)} = \frac{M_{r+1} - M_r}{l_r} + q_1.$$

$$S_m \text{ (in unloaded spans)} = -\frac{M_m - M_{m+1}}{l_m}.$$

$$S_{m+1} \text{ (in unloaded spans)} = \frac{M_m - M_{m-1}}{l_{m-1}}.$$

in which $q = P\,(1 - k)$; $q_1 = P \times k$.

S_r denotes the shearing force immediately to the right of the nearest left hand support, and S_{r+1} denotes the shearing force immediately to the left of the nearest right hand support of the loaded span.

S_m and S_{m+1} apply to the unloaded spans in the same manner.

The above formulæ are given by Dubois in the "Strains in Framed Structures," page 135, but unfortunately the signs + and − should be reversed.

The principles of the design for the four continuous spans, upon which the calculations were based, are the strains from dead weight which are calculated as a cantilever each way from "W" (see Plate IV). After the dead weight is swung complete, proper adjustments are made by means of adjustable ties each way from "W," and adjustable beds at the ends of the balancing spans at "A;" the section "XY" of top chord is rivetted in place when the four spans act as continuous as far as live load is concerned. The calculations for live load strains were then made in accordance with the formulæ before given for a girder continuous over level supports, and the two were combined.

The objections to any continuous girder are: 1st—the modulus of elasticity "E" is not constant; 2nd—the moment of inertia "I" is not constant; 3rd—the supports are not necessarily level. These objections will be discussed in order.

1st.—The modulus of elasticity, as is well known, has wide margins of variation in the same material, but by rigid inspection of the material at the mill this variation may be reduced to a minimum. Mr. Bouscaren gives the margin for variation of the modulus of elasticity of iron in general from 23,000,000 to 28,000,000. For mild steel, which is a far more homogeneous metal than iron, this margin may be very much reduced. It is to be regretted that no experiments, of sufficient extent, have been made with a view to determine the margin for variation of the modulus of elasticity in steel. Of course slight variations in the percentage of carbon in steel produces wide margins in its ductility, but a rigid inspection at the mill can guard against this. In the St. Lawrence Bridge great care was taken in securing a mild uniform steel with an ultimate strength of about 60,000 lbs. and a ductility of 18 per cent. in 12 diameters. The tests subsequently made on some of the full-sized members at Pittsburg, Penn., shewed the material to be the same as when tested in small specimens. The material was found to be all that could be desired, and the Steel Company of Scotland deserve great praise in furnishing a uniform steel, a material not easily obtainable. Their mode of manufacture is the Siemens Open Hearth process.

2nd.—The moments of inertia in the formulæ are assumed constant, and give results which are entirely on the safe side, the stresses being greater than they actually would be, especially over the piers.

3rd.—The supports which may be assumed to be out of level can at any time be adjusted by means of the adjustable beds at the ends of the balancing spans at A (see Plate IV), and any inaccuracy in the distribution of dead weight can at any time be noticed in the variation of the strains in the ties at the centre of the channel spans at "W."

The three objections to the continuous girder are very serious, and would have undoubtedly been sufficiently strong to have prevented the use of a continuous girder for these spans, had it not been for the conditions under which this design was made. A consideration of these will at once shew that the problem for closing the two channel spans was certainly solved in the most scientific manner, when it is borne in mind that the positions of the piers were all fixed, and it was considered unadvisable to use false-work in raising the two channel spans.

The trusses for the continuous girders, it will be noticed, are of the double intersection type, as in the eight 240 ft. deck spans. A question might be raised as to the possibility of making correct calculations of the strains in the curved portions of the channel spans, inasmuch as the two systems here combine their strains one into the other. It would be impossible to do so if the calculations were made for each system separately, but here the calculations for the two systems were carried through together, and the work was very much simplified by using the graphical methods entirely, for calculating the strains in the continuous girders for the St. Lawrence Bridge. As to the methods used in the calculations, the author wishes to say that Mr. Moore, of St. Louis, has recently prepared a lithograph, which shews all the essentials necessary to understand the methods used in a very concise form, consequently, full details as regards the calculations will be omitted.

The unit stresses used in the details are essentially as follows:

Steel @ 12,000 lbs. per square inch for tension.
Iron @ 8,000 " " " " " "

The only tension members that are iron are counter-rods and the wind bracing. For the wind bracing a higher unit stress was used. The compression members were all figured by the "Rankine-Bouscaren" formulæ, which are certainly the best formulæ in use, as they give results which agree more nearly with the results obtained from actual tests than any other formulæ. As used in the St. Lawrence Bridge the formulæ for steel are:—

$$P = \frac{10000}{1 + \frac{l^2}{36000 \times r^2}} \quad \text{for fixed ends.}$$

$$P = \frac{10000}{1 \times \frac{l^2}{24000 \times r^2}} \quad \text{for one fixed end and one pin end.}$$

$$P = \frac{10000}{1 + \frac{l^2}{18000 \times r^2}} \quad \text{for two pin ends.}$$

These formulæ are so well known that no explanation is necessary. The 10000 lbs. for steel in the numerator is substituted for 8000 lbs. for iron, as given by Mr. Bouscaren in his report to the Board of Trustees of the Cincinnati Southern Ry. As the matter of guard rails in railway bridges has now become so very important, it would perhaps be well to say that when the St. Lawrence Bridge is completed, a train of cars could be run off the track for the entire length of the bridge, without the passengers being aware of it. The ties are spaced with 4 inch openings, and the wheels are guarded by two heavy guard rails on each side of the track. The only accident that could possibly happen to a train of cars on this bridge is, that they might be blown bodily off the track, provided a western cyclone should happen to visit this section of the country, which is not at all probable.

DISCUSSION.

Mr. Butler.

Mr. Schaub's very interesting description cannot fail to be received with pleasure by the members of the Society. It is to be hoped that the description given is but the prelude to a more elaborate monograph, giving in full details all the particulars relating to the design of the bridge, similar to the admirable papers prepared by Mr. Geo. S. Morrison on the Plattsmouth and Bismarck bridges, and by Mr. Schneider on the Niagara cantilever.

The novel and interesting features of this bridge are, of course, the continuous girder of such great length resting on five supports, and the pleasing and ingenious method of passing from a through into a deck bridge. In the absence of the plates it is a little difficult to follow the description clearly. It seems that Mr. Schaub has drawn attention to an important defect in the construction of double intersection Pratt Trusses, and one which Mr. Butler had never seen alluded to before. In all such bridges, each system is supposed to act independently, yet it is perfectly obvious that where the long diagonal is coupled to the post of the other system ("When the pin shall fit its hole within the $\frac{1}{50}$th of an inch"), unless the workmanship is mathematically correct, the whole or a part of the load may be transferred to the post of the other system, or else so pull the post out of its place that the other half of the diagonal may do its work. The function of the pin at the centre of the post should be merely to couple the two halves of the diagonal, and to hold them in place, thus preventing the excessive vibration that would naturally occur in such long slight members. In view of the fact that rails 60 and 90 feet long have been rolled, would it not be better to have these long diagonals rolled in one piece, and hold them against the side of the posts by some simple device, thus obviating the necessity of pin and hole, with its reduction of section and expensive reinforcing of all long posts.

Of course, it may be said that the pin also seems to shorten the post, but when provision has been made for the effects of the distortion, due to the cause mentioned by Mr. Schaub, it is difficult to see how it could be so considered. His point therefore seems well taken in questioning the practice of "figuring the posts for half their total length, and consider them as fixed ended, when they are held by the diagonals at the centre."

Owing to the necessary alternating stresses, to which many of the members in a continuous girder are subjected, it would seem that this was a case peculiarly well adapted for the use of Laundhardt's and Wayrauch's formulæ.

The designers of the St. Lawrence bridge, by their adoption of mild steel throughout, have disarmed criticism, and have created a valuable precedent on this Continent.

The steel used in the Bismarck bridge for compression members had an ultimate strength 80,000 to 90,000 pounds per sq. inch, with an elastic limit of from 49,600 to 65,000 lbs. per sq. inch, with an elongation of from 12.75 to 21.25 per cent. in eight inches.

The steel used in compression members of the Niagara cantilever ranged from 79,300 to 89,980 to the sq. inch for ultimate strength, with an elastic limit of from 49,450 to 65,780 pounds to the sq. inch, with an elongation of 18.25 to 22.75 per cent. in eight inches, and a reduction of area of 41.2 to 37.7 per cent. Such high grade steel was very difficult to get, and consequently cost very much more than a milder type would have done.

The recent experiments in England, on the effect of cold on steel axles, also go to show the disadvantage of the higher grades of steel where subjected to extremes of temperature.

It would be interesting and valuable to compare the weight of channel span with the 400 ft. span of the Bismarck Bridge, noticing also the deflection under a similar test load to that adopted in the testing of that Bridge.

Mr. Bouscaren. Mr. Bouscaren saw the designs for this bridge at the time they were being prepared in the office of his late friend Shaler Smith.

Whatever may be said as to the economy of the general plan, Mr. Bouscaren thinks that it solves the local difficulties which had to be contended with, in a very elegant manner, and is well worthy of the name of the designer.

He was very glad to see the tribute paid to Shaler Smith, as one of the earliest promoters of the use of cantilevers in bridge construction in the United States.

The idea of fixing the points of contra-flexure in continuous girders was first suggested by Professor Cullman in the first edition of his graphical statics; it was subsequently applied by Gerber and other European engineers, as early as 1866 and 1867. Its first advocate in the United States, he believed, was Louis Nickerson, of St. Louis, known by his ingenious experiments on glass beams; but to Shaler Smith belongs the claim of priority in its application, as made in the Kentucky River Bridge in 1876. Speaking of this structure

Mr. Schaub says: "These points of contra-flexure could have been "fixed in the river span instead of the shore arms, and it is a curious "fact that they should not have been fixed in the river span." Having co-operated with Shaler Smith in the designing of this bridge as "principle Engineer of construction" on the Cincinnati Southern Railway, he would ask to be permitted to explain why the hinges were placed in the shore spans.

One of the principal objects sought in fixing the points of contra-flexure is to avoid the reversions of strain, which take place in the different members of the continuous truss with the displacement of the load. In a continuous girder of three equal spans, it is quite clear that this object is better served by hinges in the shore spans, whereby the directions of strains are fixed in *two spans*, and reversible *in one* only, whereas the contrary would be the case if the hinges were located on the middle span.

It is only when the shore arms are much shorter than the middle span, and the initial strains in the short spans from the dead weight of the middle span preclude reversion to a very large extent, that the hinges in the middle span become advisable in point of economy. Such is the case in Mr. Schneider's bridge over the Niagara.

Mr. Dawson.

The theorem of the three moments was discovered by M. Bertot in 1855. In applying it to a continuous girder of any number of spans, it takes the form of a number of simultaneous equations, and the general solution of these is due to Clapeyron. The theorem in its original form assumes the load to be uniformly distributed over the extent of each span. This is satisfactory for rivetted structures to which it was first applied, but is not convenient in the case of pin trusses in definite panels, where the loading is at isolated points, and usually varies from one panel to another in the course of the same span. A modified form of the equation makes it applicable to the case of isolated loads. It has always seemed to Mr. Dawson safer to work directly from the general equation, rather than to use formulae derived from it.

It is very desirable that a bridge in which the chords are cut should not be called "continuous," as the cutting of the chords is the essential difference between a continuous girder and a cantilever. The advantages of doing so are, that reversed strains, for which pin trusses are less adapted than rivetted work, are almost entirely avoided, that any slight inequality in the levels of the piers, due to inaccuracy in setting out or to settlement afterwards, does not affect the stresses as originally calculated, and also that the expansion for temperature takes places under better conditions.

The cantilever principle is eminently applicable to pin trusses, as they have hinged joints already supplied by the pin connections, and there is greater difficulty in making them act satisfactorily under expansion for temperature when they are continuous than in the case of rivetted girders.

The method of allowing a continuous girder to act as a cantilever during erection is a favourite one in France, and presents undoubted avantages. It is there used in erecting high viaducts, which are pushed forward from one bank as built, the forward end acting as a cantilever for the whole length of a span, until the next pier is reached.

With regard to the effect of a variation in the moment of inertia of a girder, a gradual change in the depth appears to have no appreciable effect in modifying the stresses. In taking out the stresses in a draw span of 396 feet total length for the Sault Ste. Marie Bridge, in which the top chord has an inclination of nearly 1 in 12, the moments at the centre and the reactions were calculated directly from the theorem in question with the assumption it involves, and yet in working out the stresses in the individual members by the graphical method no appreciable error could be detected in the closing of the figure.

It seems safe to say in such a case that the stresses as thus calculated are within one per cent. of the absolute truth, as far as the questions of theory involved are concerned. In the case of a swing of the triangular design, such as that erected over the Lachine Canal, the want of coincidence might well be greater, owing to the more rapid variation in the depth of the truss. The problem of the distribution of the weight of the swing, when open, around the rim of the turn table, is one of much interest, and would deserve separate discussion. In the Sault Ste. Marie swing, designed by the Detroit Bridge and Iron works, this has been attained by bringing the weight down upon radial beams in the drum which, so far as this particular object is concerned, is an excellent method.

Mr. Dawson then expressed the wish that further explanation should be given with regard to the expansion of the Bridge from temperature; and also the effect in modifying the strains of the adjustment as between the dead and live loads.

Mr. Blackwell. The works with which Mr. Schaub is connected have established a most elaborate system of annealing, and it would be interesting to learn the general result as regards the percentage of elongation in the mild steel used in the St. Lawrence Bridge.

Mr Tate. What is considered to be the maximum inch-stress, to which the metal is subjected in the arms of the Bridge from the centre piers during erection, and before any connection is made with the adjacent arms? What the maximum unbalanced load that the arms from the centre pier may safely bear during erection, and before any connection with adjacent arms?

Mr. Peterson.

Mr. Peterson stated that he had listened with considerable interest to Mr. Schaub's paper, which he read at the last meeting, and thought that he deserved the thanks of the Society for the trouble he had taken in this matter, as it requires a very great effort in these pushing days for a busy man to sit down and write a paper.

He had always intended to prepare a paper himself, covering the entire question of the bridge, and hoped to have had Mr. C. Shaler Smith's assistance upon the continuous portion of the superstructure, the general design and detail of which are due to him. He regretted exceedingly that Mr. Smith had not been spared to see it finished.

At present, he proposed to give a sketch of what was done before the date at which Mr. Schaub takes up the matter, and to state some facts regarding the early history of the work which Mr. Schaub had not been in a position to become acquainted with.

On receiving the appointment of Chief Engineer of the bridge in September, 1881, a report on the bridge was submitted to Mr. Peterson, together with a rough chart made by the late Col. Roberts, past president of the American Society of Civil Engineers, who had been employed by the late Sir Hugh Allan, the then president of the Northern Colonization Railway, and who was about to undertake the construction of the Canadian Pacific Railway.

Col. Roberts reported very fully, and made estimates upon a great number of crossings, but gave a preference to the crossing at Ile Heron; and for this reason, as well as from the fact that the company had purchased a considerable tract of land near what would have been its Northern terminus, the Directors desired Mr. Peterson first to make a survey of this crossing. He made careful surveys of this crossing, of one at Nun's Island, of another below the Victoria Bridge, and lastly of the present crossing at Caughnawaga, which Col. Roberts had not examined. After thorough surveys of all these crossings had been made, and careful estimates had been prepared, he found the Caughnawaga line to be very much the cheapest. His estimate for a double track bridge from grade to grade for the Ile Heron line was $2,176,475; for the Nun's Island line $2,946,186; and for the Caughnawaga line $1,407,373.

He reported in favour of the Caughnawaga line, as he considered it preferable from an economical point of view, as well as from its position, which gave the shortest line between the west and the Atlantic seaports, and at the same time an easy entrance into Montreal. This report was adopted by the Board of Directors, in January, 1882, and plans were approved by the Railway Committee of the Privy Council in the following April.

This design had ten deck spans of 300 feet in the clear, and one through span of 330 feet, with a clear headway of 60 feet above ordinary summer water. The bottoms of the deck spans were placed 30 feet above ordinary summer water.

Although he adopted 300 feet spans at this time, he was well aware that it was not the most economical design. This length was chosen in order to obviate any difficulty in connection with the Government approval of the plans, as the directors were under the impression that there would be a considerable amount of resistance to bridging the river at this point, on account of the damage which it was supposed by some would be caused by the holding back of the ice, and the flooding of the country above, while it was also suspected that objections would be made by the lumbermen as interfering with the running of rafts.

No further steps were taken towards the construction of the bridge until the spring of 1883, when, after seeing the ice pass out, new plans were submitted to the Government, with 12 spans of 250 feet, and one of 330 feet. The latter length was required for the channel span by the charter, which gave a saving of about $75,000. This arrangement of spans was objected to by the pilots engaged in running rafts down the channel, and in order to meet their views, Mr. Peterson arranged to change the plan to eleven spans of 268, and one span of 340 feet, but nothing further was done towards commencing the work at that time.

Mr. C. Shaler Smith was called in as consulting engineer for the superstructure in the summer of 1884. He apprehended much greater difficulty in the construction of the piers in deep water than Mr. Peterson did, and suggested that in place of the eleven spans of 268 feet, and one span of 330 feet, then proposed by the latter, there should be introduced two spans of 258 feet and two spans of 408 feet over the channel, thus getting rid of one deep water pier, and probably one year's time in the construction of the Bridge; the complete design thus embraced eight spans of 252 feet, two spans of 269 feet, 10 ins., and two spans of 408 feet, centre to centre of piers in each case. With these arrangements the 252 feet span extended further over the shore than Mr. Peterson considered safe, on account of the tendency of the ice to shove on the shore and lift the span out of position. To obviate this, the 252 feet spans were changed to 242 feet, which gives the arrangement of the spans as it has been executed.

Tenders were not called for the construction of the work, until a year after this, September, '85, when Mr. Peterson asked in his specification for prices based upon the following arrangements: eight spans of

242 feet, two spans of 269 feet, 10 ins., two spans of 408 feet all centre to centre, and also nine spans of 268 feet, two spans of 269 feet, and one span of 340 feet centre to centre, stating at the same time that tenders and plans would be received for any other arrangement, providing the position of the east pier of the channel span was not changed, and that no piers were placed closer than 242 feet centre to centre. Plans were sent in by the Union Bridge Co. of New York, the Dominion Bridge Co. of Lachine, and the Phœnix Bridge Co. of Phœnixville.

The Dominion Bridge Co. sent in a tender, based upon the arrangement of the long spans suggested by Mr. C. Shaler Smith, and this was accepted; but before the contract was signed, Mr. Peterson had the floor system changed, so as to place it between the trusses, instead of on top, as he considered this would make a much more compact bridge, and by the arrangement the top chords would form admirable guard rails, and render the bridge absolutely safe for a derailed train, while it would, at the same time, improve the appearance of the structure. With this latter view, he also had the top chords in the curved portion, where they were built of eye bars, cased in so as to give them a uniform width and appearance throughout.

The adoption of the two 408 feet spans did away with one pier in deep water, which Mr. C. Shaler Smith convinced the Directors was a very important consideration in the rapid completion of the work. He thought that the greatest difficulty and delay would be in the construction of the deep water piers. Mr. Peterson was not of this opinion, and apprehended no great difficulty in the work, nor did he apprehend that there would be any serious difficulty in erecting the channel spans from false works in the river. The result would go to prove that the fears entertained, regarding delays likely to arise from the deep water piers, were to a great extent groundless, as the masonry was finished nearly a month in advance of the contract date, viz., 30th November, 1887, whereas the superstructure, about which it was supposed there would be no difficulty, is not at this date completed.

Prof. Bovey. The method of equalizing the pressure on a turntable, by means of a rocker-link, was adopted in 1878, in the truss of a counterbalanced swing-bridge, erected by Messrs. Cunningham and Keepers of the Milwaukee Bridge and Iron Works. The posts over the main bearings are inclined and rivetted to a strong plate, which carries a pin B. The top chords and bars are attached to a pin A. AB is a short link which transmits the whole load to the main posts, and, however unequally the arms may be loaded, there will be an even distribution of pressure on the turntable. Imperfection of workmanship will modify this result to some extent, which could only be absolutely true when the line of action of the resultant load coincides with the axis of the link and bisects the angle between the inclined posts.

What the author calls the Rankine-Bouscaren formula would, perhaps, be better described as Rankine's modification of Gordon's formula, the coefficients being those adopted by Bouscaren. Rankine substituted the ratio of length to least radius of gyration, for the ratio of length to least dimension in Gordon's formula, and thus eliminated the variation due to a change of sectional form.

Very elaborate calculations seem to have been made in order to determine the stresses in the different members of the double-intersection trusses; but it is certainly impossible to determine these stresses with any degree of exactness, and under a moving load the diagonals are subjected to wide variations of stress, and, therefore, require a proportionately greater sectional area. The live loads to be allowed for are also continually increasing, and it seems useless to calculate for a particular distribution of loads on engine wheels. Indeed, the opinion seems to be gaining ground that it would be practically as good to design a bridge for a uniform load, say of 3,000-lbs. per lineal ft. with an excess of 25,000-lbs. concentrated at the head. Floor-beams and short spans may then be designed for two loads of 40,000-lbs. on a 14-ft. wheel base (or on axles 7-ft. apart). One great objection to almost all pin-connected bridges is that the safety of the bridge depends upon the strength of individual members. This has been made painfully evident by recent bridge accidents, which would certainly not have occurred, had the members been rivetted together and made, to some extent, mutually dependent as is the common practice with European engineers.

The most striking feature, and the one most naturally subject to criticism in the St. Lawrence Bridge, is the bold and novel method adopted for passing from the deck to the through spans. The design originally proposed by Mr. Peterson, the chief engineer, in which the piers for the deck spans were to be carried up sufficiently high to support the ends of the ordinary disconnected trusses, certainly possesses many substantial advantages. It does away with the necessity of curving the lower chords at the haunches, and, therefore, also with the precautions which have had to be taken in providing against the excessive straining which such curving induces.

It would be interesting to know why the original cantilever design was departed from, and the continuous girder system adopted.

The former possessed the advantage of rendering possible a definite determination of the stresses, while in the latter the movement of the points of contra flexure under a live load considerably complicates the problem, and renders its solution extremely difficult.

The formulæ given by Mr. Schaub for the moments and shears in the case of continuous girders are based on certain assumptions. Recently, in a paper before the Royal Society of Canada, Professor Bovey has deduced formulæ somewhat simpler and more easily applied in practice, the assumptions being the same.

The bending moment upon the r-th pier counting from one end, under a load upon the r-th span, there being n-spans in all,

$$\text{is } \frac{a_r}{a_{r-1}} \cdot \frac{B - cA}{bc - 1} \text{ if } q < r$$

$$\text{and } \frac{a_{n-q+1}}{a_{n-r+1}} \cdot \frac{A - cB}{bc - 1} \text{ if } q > r$$

$$\text{where } A = \Sigma \frac{wp}{1}\left(l^2 - p^2\right), B = \Sigma \frac{wp}{l}\left(l - p\right)\left(21 - p\right),$$

$$b = 4 - \frac{a_{r-2}}{a_{r-1}} \text{ and } c = 4 - \frac{a_{n-r}}{a_{n-r+1}},$$

the co-efficients a being determined by the law,

$$a_1 = 1, a_2 = x, a_3 = 4a_2 - a_1 = 4x - 1, \ldots a_r = 4a_{r-1} - a_{r-2}$$

It also at once follows that the bending amount at any pier is a maximum when the two adjacent spans and then every alternative span, counting in both directions, are loaded and the remainder unloaded. The inclination of the neutral axis has been neglected in the calculations of the St. Lawrence Bridge, but the modifications introduced thereby would in all probability be too small to be of any serious account.

Prof. Burr.

The paper of Mr. Schaub and the diagrams of Mr. Moore present the consideration of a quite remarkable structure and a bold piece of engineering. The circumstances of the location certainly justified and even necessitated a type of structure, which should obviate the use of false works in the channel spans, but just what conditions compelled double intersection triangulation in which uncertainties in web stresses may reach anywhere from 10 to 25 per cent. of their values is not clear. It is undoubtedly a simple operation to assign definite duties to each system, and compute the resulting stresses, but the latter possess largely imaginary values in many of the web members.

It is a well known analytical truth, that an exact determination of stresses for such a structure is an absolute impossibility. Their real values cannot be demonstrated, and many of them may vary between comparatively wide limits. Ten years ago limited facilities in producing and handling large members justified a loosely approximate division of stresses, with sufficiently low working stresses, but the example of a two truss 550 ft. span, designed to carry a double track railway, two roadways and two sidewalks, by American engineers, with one system of triangulation only, leaves scant reason for a double system in such a structure as the bridge at Lachine.

The double system stresses are not only indeterminate in amount, but give rise to excessive metallic fatigue by the quick transitions of alternately heavy and light concentrations from one system to another.

The combination of the cantilever principle for the fixed load, with that of continuity for the moving, is open to serious objection with a simple form of truss; but where there is added the uncertainties of form already considered, together with the super-addition of positive omission in the computations, the objections do not decrease. The very approximate character of continuous stresses in fixed spans, and under conditions favourable to the truss, are too well known to require specific consideration, as indeed, Mr. Schaub clearly shows; in the present instance, however, some very complicating conditions were introduced in the design, and appear to have been entirely neglected in the computations.

Mr. Schaub gives various familiar formulæ for the moments and shears under continuous girders on the assumptions that the co-efficient of elasticity and moment of inertia are constant, also that the supports are all on the same level, also that the girder is *straight between supports.* The latter condition, it will presently be seen, has considerable meaning. The co-efficient of elasticity, even in mild steel, will vary from 5 to 10 per cent. either way from a mean value in the same structure, and the moment of inertia ordinarily varies much more. But Mr. Schaub is probably correct in assuming that the consequences are not very serious, so far as these items are concerned. It is safe to assert, however, that the derangement of stresses arising from unequal settlement and simultaneous variety in temperature, which will at times exist throughout the structure, will very frequently be far beyond the reach of the adjustable supports at the ends of the balancing spans.

The only effective adjustment is an absolute fixedness of stresses in a design that will not permit their variation.

There can be no doubt that the omission of the fact that the girder is not straight between supports throws a very grave element of doubt over the results of the computations for the moving road. Instead of using the common form of the theorem of three moments for the straight girder, the following form should have been employed if E and I be assumed constant:—

$$u_{1a}\overset{a}{\Sigma} P\, l_a\left(1 - \frac{z^2}{l^2_a}\right) \quad + u_{1c}\overset{c}{\Sigma} P\, l_c\left(1 - \frac{z^2}{l^2_c}\right) z$$

$$+ 3\left(M_a\, u_a\, x_a + M_b\left(\overset{1}{u_a}\,\overset{1}{x_a} + \overset{1}{u_c}\,\overset{1}{x_c}\right) + M_c\, u_c\, x_c\right) - 0$$

l_a and l_c are adjacent spans, and z is the horizontal co-ordinate of the point of application of P from the extreme end of either span.

$$u_a = \frac{2}{l^2_a}\int_o^{l_a} u\left(l_a - x\right)dx; \quad \text{and } x_a = \frac{\int_o^{l_a} u\left(l_a - x\right)\ x\,dx}{\int_o^{l_a} u\left(l_a - x\right)\,dx}$$

In these formulæ "u" is the varying cosine of the inclination to the horizontal of a curved line drawn through the centres of gravity of all the normal sections of the truss chords. The values of u_a and x_a are typical of all u's and x's in the moment formulæ.

As the 408 ft. spans are through and the adjacent spans deck, the line passing through the centres of gravity of the truss chords in the two adjacent spans is sharply curved in the vicinity of the pier, between the two spans; hence "*u*" would have a value very considerably different from unity for a long distance on either side of the pier just mentioned, so that the omission of its consideration in the computations will materially affect the results. As a matter of fact, however, if the proper varying value of "*u*" had been introduced in the formulæ, and the resulting moments and reactions determined accordingly, it is not improbable that the complications in the results would have justified the rejection of the plan. It does not appear to be good engineering or proper design to omit such considerations. It is very true that the safety of the structure is not endangered by such action, but it is equally true that where types of structures can be used, in which the computations of exact stresses is easily secured, and the proper disposition of the metal to meet them is perfectly under control, such types should be selected.

Prof. Burr does not agree with Mr. Schaub, either that it is common practice among American engineers to place pins at the centre points of posts in perfectly fitting pin holes, or that the practice is pernicious in the few cases in which it has been done. The movement of the pins, which he mentions, has taken place in a large pin hole, such as is used in the St. Lawrence Bridge, is probably due to another cause than that of the deflection of the bridge with the consequent relative movements of its parts. Eye-bar members in double lengths will never lie in a straight line, but the centre pin will lie below the line joining the pins at the extremities, in consequence of the weight of the eye-bars, their heads and the pins, since the latter have no support; and they will lie further below that line, when the bridge is free from the moving load, than when it is covered by it. It is not improbable that the difference in elevation of this pin, under the two conditions of loading, would amount to nearly a quarter of an inch in the case under consideration. It is by no means improbable, therefore, that the larger part, perhaps the entire movement which he mentions, is due to this cause.

The almost indefinitely small movement of the centre of the column, in the case of the closely fitting pin, would affect the column alignment much less than the incidental results constantly occurring in the shop, in the very best of work, and the resulting derangement of stress in the column is probably too small to be worthy of any serious consideration.

One point in connection with this work is of the highest importance at this period of transition from iron to steel in structural work; and the course of the designers of this bridge is a wise one in selecting a very mild grade of steel wherever that metal was employed. The almost universal practice of using steel of 70,000 pounds ultimate tensile resistance or eye-bars, and 80,000 pounds ultimate resistance for the steel in columns, is as yet open to some criticism. The working stresses in these high steels are taken at a value proportionate to their ultimate resistance. While this ought to be a safe rule to follow, if our experience were sufficiently extensive to confidently control the effects of shop processes and manipulations in the production of finished members, bridge members of these high grades of metal, free from internal conditions of stress, which in some cases militate very seriously against their ultimate resistances, cannot yet be produced. It is far wiser and better engineering, therefore, to use mild steel with corresponding values for working stresses, as was done in the case under consideration.

Tensile steel with an ultimate resistance of 62,000 pounds per square inch, and compression steel running from 65,000 to 70,000 pounds per square inch in ultimate tensile resistance, will give finished bridge members of a thoroughly reliable character, and it is in all probability much safer to use higher working stresses with such metal than with the higher grades of steel, which have been very generally used.

It is matter of congratulation, therefore, to the engineers of this structure, that they have selected a material which can be confidently relied upon in the performance of its duties.

Mr. Butler's suggestion to make the long diagonals in one length is generally carried out where the lengths do not exceed forty-five feet. In this country it is more convenient to use shorter lengths, say thirty-five feet. In general, all lengths in the Lachine Bridge had to be confined to about forty feet, which necessitated splicing all members above that length. In the 520 feet span of the Ohio River Bridge at Cincinnati, it was specified that the long diagonals should not be coupled by a pin through the post, and here the coupling was made by a pin a short distance away from the post, obviating all the objections to making the long diagonals in two lengths.

The use of the Launhardt formulæ, as Mr. Butler suggests, being well adapted for the continuous spans in the Lachine Bridge, is very questionable.

The Launhardt formulæ are based on a few experiments made by Wöhler on small specimens in tension only; from which Launhardt and Weyranch deduced the formulae for working stresses acting in opposite directions. The formulae are, as used by Mr. Joseph M. Wilson, M. Am. Soc. C.E., Consulting Engineer P.R.R.:—

For pieces subject to compression only or tension only,

$$(1)\ \mathrm{a} = \mathrm{u}\left(1 + \frac{\text{minimum stress in member}}{\text{maximum `` `` ``}}\right)$$

For pieces subject to stresses acting in opposite directions,

$$(2)\ \mathrm{a} = \mathrm{u}\left(1 + \frac{\text{maximum stress of lesser kind}}{2 \times \text{max. stress of greater kind}}\right)$$

in which

a = permissible stress per square inch, either tension or compression.

u = for doubled-rolled iron in tension per sq. inch, 7500 lbs.

u = for rolled iron in compression, 6500 lbs.

The Launhardt formula as used by the Union Bridge Co., for the Kentucky and Indiana Bridge over the Ohio River at Louisville, is:—

For pieces subject to stresses acting in either one or opposite directions.

$$\mathrm{a} = \mathrm{u}\left(1 + \frac{\text{minimum stress in member}}{2 \times \text{maximum stress in member}}\right)$$

which is identically the same as formula (2) given by Mr. Wilson, the minimum stress in any member becoming the maximum stress of the lesser kind when the minimum stress is negative and the maximum stress positive. The formula as used by the Union Bridge Co., for members subject to stresses acting either in one or opposite directions, is entirely wrong. It should have been applied to members subject to stresses acting in opposite directions only. For members subject to stresses acting in one direction only the formula (1) should have been used. The use of the formula as given here, inasmuch as some tensile members in steel are allowed to be strained above 18,000 lbs. per square inch for a working stress, is questionable. The experiments of Wöhler should be extended to members subject to stresses in opposite directions before any formulae which so materially affect the unit stresses are employed.

In comparing the weight of one of the 408 feet channel spans of the St. Lawrence to the 400 feet span of the Plattsmouth bridge, it might be said that the former will weigh fully 400,000 lbs. more than the latter.

Mr. Bouscaren's statement with regard to the fixing of the points of contraflexure in the shore arms of the Kentucky River Bridge, to preclude a reversion of strain, is only correct after the bridge was swung complete. During the erection a reversion of strain must occur in the shore arms, and was provided for in the Kentucky River Bridge by adding sufficient section in the chords to allow the erection to proceed as a cantilever. It is easy to see that a large percentage of the metal in the chords near the points of contra-flexure of the Kentucky River Bridge had to be introduced, which was not required after the bridge was completed. This fact is what led Mr. Smith to fix the point of contra-flexure where the use of extra metal for erection as a cantilever would be avoided, as he did in the Minnehaha cantilever in 1881.

In reply to Mr. Tate's question:—"What is the maximum stress developed in the cantilever arms during erection?" The maximum stress per square inch is developed in the cantilever arms next to the flanking (balancing) spans; and occurs in the curved portion of the top chord in the second panel from the pier. Here the stress amounts to 20,900 lbs. per square inch when the cantilever is built out, with the traveller and hoisting engine standing at the end of the arm.

The maximum unbalanced load which the arms from the centre pier may safely bear during erection, and before any connection with adjacent arms is made, depends solely on the width of the base which is used for erecting that portion over the centre pier. There is nothing in the construction of the trusses themselves to give any base whatever; thus nothing else remains but either to use one or two temporary cribs, so as to give the necessary base, or to employ false work immediately next to the pier on both sides in line of the bridge. The latter method is the one which has been finally adopted by the Dominion Bridge Co. It might here be said that it was Mr. Smith's intention to use one or two cribs in line of the bridge to assist in balancing that portion over the centre pier, until the final coupling was made.

In regard to Mr. Dawson's statement in referring to the formulæ used for calculating the stresses in the continuous girders, it might be said that there is no possible objection to using these formulæ as long as they are known to be correct. They are derived directly from the "Theorem of Three Moments," and they certainly simplify the work very much, when using concentrated loads. Mr. Dawson's distinction between continuous girders and cantilever bridges is too sharp. A cantilever bridge such as the Niagara is simply a continuous girder, with fixed points of contra flexure. The cantilever principle is simply a step forward in the science of engineering, from the continuous girder. Mr. Dawson's objection to using pin connected trusses for continuous girders, owing to their unsatisfactory condition for expansions due to temperature, would not hold if expansion rollers are provided where needed, and if also provision is made for the strains produced by the friction of the rollers themselves. These same provisions would have to be made in any form of girder, whether rivetted or pin connected. Mr. Dawson calls attention to the rapid variation of the depth of the trusses of the swing over the Lachine Canal, as to its effect in the calculation of the strains, inasmuch as "I" the moment of inertia is assumed as constant. He also cites the fact that the 396 feet draw span of the Sault Ste. Marie Bridge, with its top chord at an inclination of 1 in 12, gave no appreciable evidence of an error in assuming "I" the moment of inertia of the cross section to be constant, inasmuch as the diagram of forces closed.

The fact that the diagram of internal forces closes does not prove the assumptions made in regard to the Theorem of Three Moments to be correct. In fact, any external forces whatever may be assumed to be acting, and as long as they balance, they may be applied to a structure of any form, and a diagram of internal forces which also balance may be obtained.

The assumption that "I" is constant involves an error in obtaining the reactions only, which is entirely on the safe side, as previously stated; but no amount of inclination in the chords of the draw span would prevent the diagram of internal forces from closing as long as the external forces are balanced.

The method used for annealing the steel bars for the St. Lawrence Bridge is the same practically as used by all manufacturers in the States, namely, heating the bars to a low cherry red in a gas furnace, the flame not striking the bars. The temperature is not a high one, as the bars take, perhaps, a whole day to become properly heated, when they are drawn out on a sand bed, and allowed to cool under the sand. The results obtained by the Edge Moor Iron Company shew that the bars may be allowed to cool without being covered, but it would certainly be preferable to allow them to cool in sand or some similar material. The effect of annealing is to restore the molecules to their normal conditions, and to make the metal more ductile and homogeneous. The extensive experiments made by the Edge Moor Iron Company on the steel bars for the East River Bridge shew that annealing reduces the ultimate strength and increases the ductility. The eye-bars used in the St. Lawrence Bridge are made by the Kloman process; that is, the metal in the head is rolled thicker than the body of the bar, which leaves a lump on each end of the bar, from which the head is forged under a steam hammer.

The Rankine formula for compression members is certainly a modification of Gordon's formula, but the introduction of the least radius of gyration in place of the diameter in such a vast step in advance of the Gordon formula, that the Rankine formula now stands alone.

The Gordon formula is an empirical formula, framed to suit the experiments of Mr. Eaton Hodgkinson, made in connection with the building of the Conway and Britannia Bridges. Now, when the Gordon formula is applied to other sections than those used by Mr. Eaton Hodgkinson, the results are not correct. Why? Simply because in the Gordon formula there is no variable dependent upon the Moment of Inertia of the cross section, a very important element, when it is remembered that a long column must be designed to resist flexure as well as direct thrust.

Mr. Burr's objection to the double intersection type of truss must also hold good for any ordinary discontinuous span. Why the web strains in this form of truss should be uncertain within limits ranging from 10 to 25 per cent. Mr. Burr does not make clear. With long panels, such as those used in channel spans of the St. Lawrence Bridge, quick transitions of alternately heavy and light concentrations, from one system to the other, cannot take place. To be sure, a single system would have been desirable, if other conditions could have been ignored. A single system would have required very much longer panels, which would have made the curves in the chords a series of straight lines, the effect of which would be anything but pleasing to the eye. Longer panels would have necessitated using built stringers in the place of rolled beams, an objectionable process in this country as rolled beams are very much cheaper than built beams.

Mr. Burr says:—"It is undoubtedly a simple operation to assign "definite duties to each system and to compute the resulting stresses, "but the latter possess largely imaginary values in any of the web members." If Mr. Burr will examine the diagrams of Mr. Moore, he will find that where the two systems do combine, they are united by an equalizing link, the direction of which is fixed, not arbitrarily, but by working back from a neutral point in the span where the shearing force is zero, for a position of the load which is known to give the maximum. This operation is carried out independently for each system. A mean, which is the result of the maximum, fixes the direction of the equalizing links. They are held in position by proper construction, and prevent any ambiguity in the value of all the stresses calculated thereafter.

If Mr. Burr would give his formulæ more clearly, that is, the formulæ which he says should have been used for calculating the moments and shearing forces for the continuous girders in the St. Lawrence Bridge, it might be possible to make a comparison, with a view to determine exactly how much error is involved in assuming the beam to be straight between supports. If there are any formulæ that are more accurate, and at the same time as practical as those that were used, it would be of interest to know them. There is no structure in existence in which the formulæ Mr. Burr gives have ever been employed.

It has been shewn with sufficient clearness that distortions must take place in the members themselves, in a structure where the diagonals are held by a pin to the post at the centre. It is a matter of simple computation to determine exactly where the diagonals cross the post when the truss is cambered. In the 240 feet deck spans, the point of intersection of the diagonals with the post is exactly ¼ in. below the middle of post when the truss is cambered. The diagonals do sag where they are free to sag, but this is altogether another consideration. The practice of fixing the diagonals to the posts, at their middle, is comparatively a new one, but it is only necessary to look among the more recent structures, built in the United States, to establish its popularity.

26th May, 1887.

Mr. T. C. KEEFER, C.M.G., President, in the Chair.

The discussion upon M. Schaub's paper on "The St. Lawrence Superstructure" occupied the evening.

9th June, 1887.

MR. T. C. KEEFER, C.M.G., President, in the Chair.

The following candidates were declared to have been balloted for and duly elected as

MEMBERS.

THOMAS OLIVER BOLGER.	PETER GRANT.
HERBERT CHARLES BURCHELL.	MALCOLM HUGH MACLEOD.
WILLIS CHIPMAN.	CHARLES PERCIVAL METCALFE.
ARTHUR EMILE DOUCET.	JULIUS W. SCHAUB.
HIRAM DONKIN.	

ASSOCIATE MEMBERS.

HENRY BANNISTER.
HUGH WILSON.
HARTLEY GISBORNE.

ASSOCIATE.

ROBERT GILLESPIE REID.

STUDENTS.

JAMES FITZGERALD.
ROBERT TODD LOCKE.

5.

THE WARMING, VENTILATING AND LIGHTING OF RAILWAY CARS.

By J. D. BARNETT, M.CAN.SOC. C.E.

A more unsatisfactory question than that of railway car heating and ventilation it would be difficult to find. Not only do car designers disagree, but the passengers have ideas and wishes so diametrically opposite that a satisfactory solution does not at present seem possible. Do not expect it from the author, who will esteem himself happy if he succeeds in conveying a fairly clear idea of the problem, and of those recent attempts at its solution approaching nearest to success.

The problem, considering the wide and rapid variations of a North American climate, is certainly a double one, although experience and the Patent Office records shew that each factor is usually attacked singly; and at first it will perhaps be better so to look at the subject.

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The requisites of a good heater are :—

(*a*) That it give out heat sufficient in amount.

(*b*) That it be safe from fire risk, scalding, &c.

(*c*) That it be frost proof.

(*d*) That it be controllable without too much attention.

(*e*) That if it be part of a continuous system, it may be detachable without rendering it useless, and that it may have a variability of from two to fifteen cars.

(*f*) That its heat be distributed equally throughout the car, and close to floor.

Ordinary stoves are wanting only in *b* and *f*, and Spears encloses his hot-air stove in a close-woven, heavy wire netting, slightly elastic, yet strong enough to fill requisite *b* ; stoves manufactured from wrought-iron—instead of thin, cheap cast iron—having common-sense doors, and located in centre of length of car, come very near satisfying all requirements.

Steam heating—at low pressure—with the heat supply located in a portion of the train not occupied by passengers, fills all requisites except *c* and *e*, the more recent inventions being endeavours to meet these particular requirements.

The Martin system receives its steam supply from the locomotive. It has for distribution, one through or continuous train pipe under each car, with a metallic double-ball-coupling and expansion-sleeve for connection at each end, and a double vertical line of piping (for heating purposes) on each side of car below seat level, having, however, no provision for keeping car warm when it is not attached to locomotive, or coupled up to station steam warming pipes, or to external portable boiler. Similar crude attempts at steam warming have been made ever since Stephenson's day. The metallic flexible coupling for the through pipe appears to be its distinctive feature ; but it is open to doubt if a claim for originality could be sustained should this patent be subjected to legal test. (See historical notice in "The Artizan," July 1st, 1863, page 147.)

The cost of equipment is $200 for engine, $200 for ordinary cars, and $250 for sleeper and parlour cars.

The Sewall and Emerson systems appear in many respects to be identical. They draw their steam supply from the locomotive, and use a hot well under the car to receive the water of condensation. Below the well a fire is placed when the car is standing detached, the car heating pipes being arranged so as to give independent circuit with this reservoir boiler. The auxiliary source of heat—be it coal fire, oil lamp or gas jet (and all have been used)—is dumped, or otherwise dispensed with, as soon as the car is to be coupled up with train, thus meeting requisite *b*.

Many-ply rubber-hose is used to allow of adjustability in the continuous couplings. The expense of renewing each hose may amount to $3 or $4 per year. Sewall has a simple and effective metallic hose coupling, locking by gravity, and readily separating when cars become detached, which will permit of a free interchange of cars with foreign railways on through runs. Emerson has apparently not given this most important point any special attention, and as each car with his equipment, has an independent outlet by pet-cock for the excess of steam and water, there is produced with this arrangement a vapour sometimes obscuring the windows, and the annoyance of a constant drip of water has been noticed. Sewall has a small opening in the through steam pipe to atmosphere at end of last car only, the excess of water in hot well under each car being discharged intermittently by self-acting trap.

The continuous circulation and its control (when car is detached and fire is put under hot well) cannot be said to be perfect with either system, Emerson having to use a second series of pipes on car roof to act as a condenser or cooler, while the Sewall slowly loses its water supply, from the permitted escape of steam through a pin hole at end of the continuous pipe.

The pounds of steam condensed to water per car per hour are variously given, the independent tests (far too limited in number) shewing higher figures than those given by the patentees. The Chicago, Minneapolis & St. Paul Ry. Co. obtained an average of 75 lbs. at temperatures between 20° and 40° above zero; but even their careful experiments will not permit an approximation to the weight of steam required with high winds, and temperatures from 20° to 30° below zero. It may be deduced from some experiments with these systems, and a locomotive with a boiler so large that it is not generally worked up to its maximum capacity, that 1 lb. of soft coal burnt in its fire-box will radiate an amount of heat equal to 2 lbs. of anthracite burnt in the car; therefore, after allowing a margin for fuel used when car is detached from locomotive, the total or annual cost for fuel, when the rolling stock is fully equipped for steam heating, will be but one-half of that now paid for hard coal, ranging at present on various railways from $35 to $55 per year per car.

There is no information as yet, nor can any be obtained until next winter, as to the continued action of "traps" in getting rid of local condensation at extremely low temperature.

Hot water heaters—that is to say, the contained coil and vertical boilers of Owen, Baker, Smith, Johnson, Coughlan, Salmon, etc.—fill all requirements, except "*b*" and "*c*," and various schemes have been tried and suggested to overcome these defects, such as enclosing the whole in a metal safe with self-shutting doors, or making the water-crown of stove boiler of thin cast-iron, so that it shall, in case of accident, instantly fracture, thus drowning the fire, or arranging that derailment open a reservoir of chemicals which shall discharge into and kill the fire. The dead weight of the safe and its contained stove would be dangerous in time of collision; self-quenching arrangements cannot be depended upon if left disused, say, for twelve months; and it is possible that the escaping vapours and acids might prove quite as dangerous to life as hot cinders would.

Exhaust steam from the locomotive cylinder and from the brake air-pump have been slightly experimented with as a source of car heating; but the water carried in suspension is so large in amount and so difficult to get rid of, as to discourage any hope of success in that direction, in Canada, unless it be by the use of the Williams patent, recently experimented upon by the Central Vermont Railway, in which the old pipes employed in single circuit with a hot water heater are utilized. The single circuit is broken, and the pipes on each side of each car are connected under the platform by flexible hose, so that there is opportunity for complete circuit down one side of train and back the other, when the two hose under platform of last car are coupled together.

Exhaust steam from the locomotive, from the air-pump, or from the vacuum-pump, is admitted at forward end of this pipe circuit, and a vacuum-pump is attached at return end (also on locomotive). It is claimed that the vacuum-pump will clear the pipes of all vapour of water of condensation, however many convolutions or "pockets" there may be in the whole circuit.

Its main defect is its complete dependence on the locomotive (or other detached boiler) for heat, and its dependence on the pump to prevent failure by frost.

Mr. D. H. Neale, New York, writes (since the "advance proof" of this Paper was issued) "that a train heated by exhaust steam from the locomotive has been running between Glasgow and Aberdeen for the last two winters, with very satisfactory results, using a cast-iron radiator of a simple form under each seat. When the locomotive is first attached to the train line, steam is turned on until the coaches are warmed, after which a small portion of exhaust steam is found quite sufficient to keep up a comfortable temperature."

Stoves underneath the car frame have been used; but the supply of heat—with the hot air system—is not always adequate, and the gases of combustion are liable to get into the hot-air flues. With these defects, and a first cost about double that of a similarly equipped car with internal stove, the risk from fire is not removed, and cars so fitted have in accidents been destroyed by fire. External heaters for hot water or steam are more effective, but the fire risk is not removed—it is only in part lessened.

The Gold system is practically a storage, rather than a continuous heating system, and has been used only on suburban railways (900 cars). A 3½-in wrought iron tube is almost filled with brine (water and salt), then sealed up, and laid horizontally within a 4-in. steam pipe, so that when steam is admitted into the annulus between the two tubes, it not only radiates externally but heats up the contained brine, thus charging a reservoir, which when steam is cut off continues the radiation by parting slowly with its rapidly absorbed heat, so that, for instance, with an external temperature just at freezing, a street car will retain a comfortable warmth for two hours. To suit ordinary train service it is proposed that the reservoirs shall be charged when the locomotive is running down grade and has steam to spare. The defects of this system are a difficulty in obtaining flexible couplings for high pressure steam, and the risk of scalding in case of accident; and the fact that failure of locomotive would eventually result in freezing out the passengers prevents it from being considered a practical scheme for long through runs or for isolated branch trains.

VENTILATION.—Having continuous steam-pipes throughout the car, the question of ventilation in winter is not a difficult one, a few small inlets close to pipe, with wide-open exhaust-ventilators in roof, giving free exit, are conditions fairly conducive to health and comfort.

The many and variously designed stoves, with passages in or around them, through which air is forced from Cowl or Bellmouth on top of roof when train is in motion, and thence through hot air flues provided with foot registers the length of the car, have not proved a success, being deficient in heat and at the same time making the air too dry. Heat radiated is far more comfortable and healthy than heat delivered by convection.

The *minimum* supply of fresh air required to keep a car carrying 60 passengers, in sweet and healthy condition is 1,000 cubic ft. per minute, and the more this amount can be increased (without inducing draughts) the better.

For summer service a narrowing opening at front end of car under platform hood will no doubt admit enough air when car is moving; but it is not sufficiently diffused, a draught being felt about the 4th or 5th row of seats, which fine wire screens or adjustable louvre boards fail to get rid of. A roof cowl, of almost any pattern, open to front of train will force sufficient air in, and it can be distributed at various points in ceiling, sides or floor, according to the number of distributing pipes and adjustable registers used, but the air there collected is far from pure, the dust not only annoying the passengers, but settling in the pipes, and eventually choking up the passages. Fine wire screens reduce the air pressure out of all proportion to the dust they exclude, and have no effect on smoke, sulphur, etc., from engine, which is apt to trail over the train, especially in woody country and in cuttings. Thirty-three years ago air was so forced through water-spray, the resultant inky colour of the water proving that it performed its work well; but the apparatus occupied too much space, and in damp weather the car was too moist for comfort. Ruttan of Cobourg passed the air over water. This proved not so effective, but the car was dryer; yet his system collected so many impurities in the purposely contracted passages, that it was not used with success on long trips. A double roof with the open space between, bell-mouthed at each end, and the lower roof perforated, will act as efficiently as a distributing flue in securing full admission of air (and a double roof insures a cool ceiling), but it is no nearer to the securing of clean air, and much increases the fire risk. A fan, worked from the car axle, drawing its air supply through gauze-covered opening in the *side* of car, passing it over an ice box, distributing it around top of car from a 6 in. tube and exhausting through the floor, has proved very effective when the car was running at full speed; but when going slow, or climbing grades, it did not give sufficient supply, and passengers were provoked to break the windows which (necessarily in this as in all artificial systems) had been fastened down. It should not be forgotten that all similar schemes result in a car being oppressively close when it is not in motion.

There are several patents for taking air in front of the engine, warming or cooling it there as required, and forcing it to each car through a continuous train pipe by an independent steam motor. The bulk size of the apparatus involved will probably discourage experiment in this direction until all other possible expedients have failed.

For purifying the air there seems be no scheme equalling that of W. D. Mann, who says, "taking my cue from nature's provision in the human nose...... I have adopted a 'nose' through which all air is obliged to pass. This consists of a mass of 'excelsior' (fine wood shavings like hair), held loosely by spindles of wire, and kept moist by the melting of ice over it...... the air being first discharged directly on the surface of a large pan of water, the product of the melting ice."

LIGHTING.—The existing sources of artificial light are candles, oil, gas (coal, oil, water), and electricity. Candles are wanting in brilliancy, cleanliness and safety, and are not now used. Oil has been roundly abused in the public press and in some State Legislatures; nevertheless mineral oil of 300° fire or flash test is, all things considered, a safe source of light—absolutely so if there be no other source of fire in the car than the lighted lamp itself. Certainly there are but few, if any, cars destroyed by fire in summer, when the increased train service partially balances the fewer hours per night that lamps have to burn, and, if steam warming be adopted, all trains will, in winter, be as safe from fire risk as they now are in summer.

Coal-gas carried within wrought iron reservoirs, under a pressure of about 230 lbs. per sq. in., gives a brilliant light, and a reservoir 10 ft. long by 1 ft. diameter will hold sufficient gas to run a 5 ft. burner 50 hours, or the car for 10 hours. The first cost of fixed plant for compressing and storing coal-gas is heavy, varying from $2,300 to $18,000 per station (not including cost of gas producers), and there is a large daily expense in running the plant in addition to a serious loss of gas, when it is under compression, due to its condensing into a troublesome gummy liquid, which interferes with the action of all the mechanical fittings and the self-acting pressure reducing valve, as well as with the efficiency of the small distributing pipes.

The Pintsch system gets rid of some of these troubles by using gas manufactured from crude petroleum, or other natural hydro-carbon, which, in addition to being less sensitive to low temperatures, to loss by compression, and to gummy condensation, gives a clearer white light of higher illuminating power; the economy resulting from the use of this system compared with that of coal-gas is marked. It has but one drawback, viz., that each charging station must be equipped with a complete gas *distilling*, as well as gas compressing apparatus, otherwise, special gas storage tanks on wheels must be regularly transported to the distributing points, from the central manufacturing and compressing depot. English experiments shew that colza oil costs per lamp per hour 1.25 cents, and the Pintsch light only ·652 cents.

In electric lighting there have been experiments with primary (or chemical) batteries, secondary (or storage) batteries, independent dynamo, and dynamo taking its power from a revolving car axle. A dynamo deriving motion from an independent engine is costly, requires the constant attendance of a skilled man, and is useless when detached from the train; hence the attempt of Messrs. Houghton & Stroudley and others, who combined a secondary battery with a dynamo driven from a car axle, their action alternating, or even if required supplementing each other, the mechanical details being so arranged that the batteries could not play back into the dynamo when it was running at slow speed; the axle could also revolve in either direction without interfering with the efficiency of the combined apparatus, the whole of which was carried in the guard's van. It is recorded that trains so equipped, made on the Brighton Railway 2,352 trips in 11 months without failure, but at the present date this Company are reported as experimenting with the Pintsch gas light.

The system of electric car lighting, of which we have most exact information, is the Julien secondary battery; it has much less dead weight than the Plante, Faure and other early patents, and it can be charged from any electric source. Its standard cell has 19 plates, and weighs 27 lbs., or, with rubber box and connections, 34 lbs. In order to find the total weight required per car, divide the desired candle-power of the lamp by 2, and this will give the weight of battery per lamp hour. Thus 16 c. p. lamps require 8 lbs. of battery, and 10 lamps 80 lbs., or per night of 10 hours 800 lbs. Allowing 20 per cent. for contingencies the ten 16 c. p. lamps for one night's duty call for 960 lbs. weight of cells, or with connections 1,200 lbs. per car extra weight to be hauled (as a minimum).

The cost, as submitted by the Julien Co. in their recent offer to the New York Central Ry. Co., and actually charged to the Wagner Car Co. for equipping the "Olga," is

60 cells at $13	$780
Wiring, boxes, and lamp fixtures	150
Total cost	$930

The daily cost, using the figures obtained from the Boston and Albany Railway, is

60 cells at $13 = $780, depreciation at 30 p.c. =	$234.00
24 lamps at 85c. = $20.40, each lamp lasting 2 months, 6 renewals at $20.40 =	122.40
Charging battery 365 days at 75c. =	273.75
Interest on $9.30 at 4 p.c. (cost of installation) =	37.20
Total cost of 24 lamps per year	$667.35
Cost of 24 lamps one day	1.83
Cost of one lamp per day	0.76

The batteries will probably last longer than 3 years, although actual experience with them covers little more than 2½ years; the negative plates never give out, and the positive plates have not yet done so, whatever the violent motion inseparable from railway travel may yet result in.

The weight of this installation will exceed one ton, and should the exigencies of train working require that a second set of cells be kept for charging, while the other set are in use, the cost for a car as fully lighted as the "Olga" would exceed $1,700.

The North British Railway Co. has artificially lighted a train performing much tunnel service by electrically charging an insulated central rail with which circuit to coach lamp wires is made automatically by wheel coming in contact with the raised rail at entry into tunnel. The rail drops and circuit is broken at exit from tunnel, thus the lamps are alight only when train is within tunnel.

To sum up:—it may be said, that if boiler-power can be supplied, there are no great difficulties under average conditions in heating a train by steam supplied from the locomotive. Boiler power in midwinter on any other than short local runs is, however, rarely in excess of absolute needs, and if boilers large enough are built the locomotive will be so much heavier as to probably call for the strengthening of bridges, &c. If compressed gas be used for lighting, it can readily be adapted as a source of heat, in connection with any system of steam circulation or water pipes.

Ventilation, in winter when steam pipes are used, taking air supply through sides of car close to pipes, and keeping exhausts open in raised roof, is easily accomplished. In summer it is different, and some artificial means for supplying, cleansing, and distributing a large amount of air is necessary. Such schemes will not work if passengers have the option of opening side windows, thus destroying the artificial currents. There are strong objections to machinery, as it must not be recognized as such by the passengers, must not be too expensive, must not require too much attention, nor be liable to derangement.

It is known to all familiar with the plenum system of ventilation (air forced in by fan)—as adopted for the Houses of Parliament and for Public Buildings at Washington—that it is not satisfactory, although the conditions are much more favourable to success than those limiting the ventilation of trains.

Induced currents by air-jets, worked from the brake air-reservoir, may yet accomplish this work satisfactorily.

The ejectors would be very small and distributed over the whole area of the coach at such points as experiments may determine, and acting on the contained air within the coach by suction would permit of the fresh air being received both summer and winter at the same point, viz., at *sides* of coach where it can be obtained (without special filtering) in the purest condition. In winter these ejectors would not be required.

If each passenger is to be allowed to do what is right in his own eyes, it is probable that side windows hung so as to swing vertically, instead of to lift horizontally, would keep out more of the cinders, etc.

For lighting, oil and oil gas are safe enough, and ignoring the question of interest on the heavy first cost of the equipment, the actual daily outlay for gas would probably be less than for oil (taking all breakages of lamps, etc., into consideration.)

Electric lighting—cool, safe, and pure—is as yet somewhat uncertain in effect, too expensive in first cost, and calls for too highly paid skill in attendance, to be generally adopted.

Not only for economy in the use of light, but also for cheerful effect in daytime, the internal "finish" of cars should be in light coloured woods, and with the object of lessening fire risks, the "finish" should be, where possible, in wood rather than in woven fabrics.

Cars wholly framed in metal, whatever be their relation to fire risks, are not likely to be a success for passenger service, because of the difficulty in deadening the annoying vibrations and noise incident to motion.

The last few months have been prolific with car heating patents, many of which could not yet be said to have reached the experimental stage. One attempt by Mr. Wilder kept the old hot water heater and its pipes intact, but an additional wrought iron drum was added under the sills, to which the water circulation pipes were coupled, so as to make the drum part of the coach circuit. A through train steam-pipe from engine (by branch under each coach) admitted steam into a coil within the drum, thus heating up the water and putting it into circulation throughout that coach. When coach was detached and standing, the heater could be lighted up, and circulation maintained as at present.

DISCUSSION.

Mr. Wallis remarked that the warming of railway cars is a subject to which, on this continent especially, much attention has been given.

The use of ordinary stoves has been unsatisfactory, from the difficulty of maintaining an equable temperature, and in first class coaches, at any rate, they have, on most railways, given place to various systems of diffusing heat through the medium of water at a temperature of about 212° Far. The hot water system with independent heaters is, no doubt, a considerable step in advance of the stoves, perhaps as much so as the stoves are in advance of the foot warmer used in Great Britain and other milder climates; but like the stove, it has one serious objection which has existed since its inception, and has become prominent, and made the question of car warming of vital importance, during the past winter. The lamentable accidents in which the car heater has figured so conspicuously and unfortunately, and to the use of which the lives of many sufferers are believed to have been sacrificed, has brought into prominence a crop of arrangements or systems, many of which the author of the paper has fully described. These systems seek to establish a central source of heat in the fire box of the locomotive, and thus to reduce the number of disastrous possibilities to a minimum.

That the principle is a correct one, there can be no doubt.

During the past winter, on several railways, steam has been successfully used with some of the systems mentioned, and most of those present have seen the same in operation on the New York elevated railways. While, however, the principle appears sound, the working out of the same is attended with difficulty. The one central source of heat may fail and in a northern climate with storms of snow and spells of intense cold, the result may be but a remove from that which the system is intended to avert.

Clearly then there must be auxiliary sources of heat, and the system which most successfully combines the two (that is, the Central and Auxiliary) will find most favour with the officers of railways. It is too well known that the maintenance, in proper working order, of devices, which are used only in cases of emergency, is difficult; and this fact, and the apparant necessity of such a device, is the great drawback to the use of steam from the locomotive.

The question of first cost is an important one, and this would suggest the use of the piping forming the present generally adopted hot water system.

The further difficulty which may arise from the inability of the locomotive to furnish the necessary steam, in long through trains, will have to be met either by a reduction of train load or an increase of the power of the engine, which in either case is serious, having regard to the radical nature of such a change on railways fully equipped at present.

The author's estimate of economy to be derived from the continuous system is rather a high one.

The mean temperature at Montreal for the six winter months, from November to April inclusive, is, as nearly as possible, 20° Far. (See Prof. McLeod's meteorological reports), and if the water of condensation amounts to 75 lbs., at temperatures ranging from 20° to 40°, an evaporation say of 6 lbs. of coal, which is fair locomotive practice during winter, would account for 13 lbs. coal per car per hour, or about 7 per cent. more than that actually now used for haulage.

Making due allowance for the preparation of the cars a reasonable time prior to their occupation, the consumption of coal for the year, that is, for the six winter months during which coal would be used, would be 8 tons, or say $30 per car.

In a continuous system of heating, the constant interchange of cars between railrays, makes a universal coupling essential, and before much headway can be made such a coupling will have to be agreed upon. The coming winter will no doubt see much done by way of experiment to solve this important question.

As long as such a difference of opinion exists on the part of railway travellers, as to what constitutes comfort in the shape of ventilation, it would seem hopeless to insist upon the adoption of devices, whose object can be rendered nugatory at the will of the individual.

Those who hold somewhat extreme views on this question are apt to mistake rise of temperature for imperfect ventilation.

The railway car of this continent is of a construction to be easily ventilated. The end doors, the side and upper deck windows, all form excellent passages of ingress and egress for the air, which can be admitted in greater or less quantity, as required.

In car lighting, one advantage in using oil is that a high fire test oil may be obtained (300° flashing point) at a reasonable price. Such oil will not a cause a fire, though it would feed one started from another cause; and in illuminating power it is equal at 20c. per gallon to gas at 45c. per 1000 cubic feet. An ordinary car roof lamp of the double type burns from 2 to 4 oz. of oil, and a highly lighted car, therefore, only costs 25c. per hour for its light.

There is no doubt excessive comparative wear and tear of lamps; but with all this there is a great margin of cost in favour of oil, which is one of the good things nature has provided.

Mr. A. T. Drummond. The subjects, especially of the heating and lighting of railway cars, which Mr. Barnett discusses, have received more than usual attention from the public during the last few months, in consequence of the terrible disasters at White River Junction and Dedham.

With regard to the heating of cars, the popular verdict, without doubt, favours heating by steam derived from the locomotive, as being absolutely safe from the dangers of fire in the event of collision or other disaster. The system also produces an uniform, pleasant heat, under easy control. The inventor of the Baker heater contends that he can furnish a self-acting furnace, which can be charged with coal in New York, and will not require to be opened for recharging or any other purpose until such a distant point as Chicago is reached. He also contends that such a furnace can be made so strong and be so securely guarded, as to resist fracture, and retain the coal in case of any accident whatever. This, in Mr. Drummond's opinion, is not possible. It is not the ordinary, if the term might be used, but the extraordinary accidents, where the complete collapse of the cars is probable, that have to be most guarded against. No stove, however strong, or however well cased in an iron jacket, is altogether proof against the effects of such disasters, and the very weight of the stove is an element of danger when it is displaced by the overturning of the car at the embankment or bridge, or by the collision. Nor is a heater suspended under the car less source of danger. What must be avoided is any system which, in the case of the complete collapse of the car, would permit of live embers being scattered broadcast over the car furnishings and debris.

Whilst, however, the popular verdict is in favour of steam derived from the locomotive, the railway manager has not only its practicability but its economy to consider. Its practicability is now becoming less of an experiment, and more of a certainty. There are still some minor difficulties which further experience will readily overcome. Various railway managers and superintendents, after actual trial, have testified in its favour, and the superintendent of motive power on the New York, Lake Erie and Western railway goes even so far as to say that "unless the outside temperature is below zero, warming a train of cars by steam on a railway of an average gradient will not increase the draft on the locomotive one per cent.; the size of the train has nothing to do with it." As to its cost, the result of the enquiries made by the Massachusetts and New York Board of Railroad Commissioners appears to prove that it is little, if any, more expensive than present methods. Abundant warmth, it was shewn by continuous experiments, was obtained even when the temperature was 20° below zero, and only a moderate pressure was required, ranging on one railway from 2½ lbs. to 5 lbs. when the thermometer varied between 5° and 13° below zero. The Intercolonial Railway authorities fear, after the experience of the past winter, when trains were snow-bound for several days, that cars heated by steam from the locomotive might be placed at a grave disadvantage if detained in a snow drift. It is, however, impossible to foresee every such contingency, and even for the ordinary heater it is not usual to carry several days' supply of coal.

It is said that the Boston and Albany through New York train is heated from the locomotive in twenty minutes, and it is claimed by the Martin System people that eight cars can be thus heated without any loss of power to the locomotive. On the other hand, they also claim that when once a car is properly heated, it will remain comfortable for at least half an hour after being cut off and side-tracked. These are important points regarding which some further experience is needed.

The subjects of lighting and heating must, however, be considered together by railway managers if accidents from fire are to be prevented. It is merely taking away one risk of fire, if steam from the locomotive is employed as a heating agent, whilst oils or even gas are still retained for lighting purposes.

Mr. Drummond does not agree with Mr. Barnett, that for lighting cars, oils or oil gas are safe enough, and that mineral oil of 300° fire test is absolutely safe, if there is no other source of fire in the car than the lighted lamp itself. Though claimed, it has by no means been established, that a sudden shock to the car would necessarily at once put out all such lights in it, and thus quickly remove the source of danger. There is some evidence to the contrary. Now, the swaying of a Pullman sleeper, in the event of its being precipitated from the track, would be liable to bring inflammable material like curtains and bedding into contact with the lighted lamps, and if they should take fire, such fire would increased fuel should the oil have become scattered over the car by the breaking of any of the lamps. It may be urged that the occurrence of extraordinary accidents is assumed, but it is these very extraordinary cases that have most to be provided against, as when they occur, the loss of life is greatest.

Gas is open to a similar objection in case of collision or derailment and it has this greater objection that, if the reservoir of highly compressed gas should be burst open by the shock, as is probable, a large amount of very explosive material would be let loose.

The only absolutely safe means of lighting, at present known, appears to be the electric light, and considerations of expense can alone prevent its general adoption. It does not add to the heat of the car, is under immediate, easy control, has the advantage of cleanliness and freedom from unpleasant odours, and gives a steady, agreeable light. The first cost in fitting out a car with it is considerable, in fact, much more than it should be. In railway economy, however, safety should be a consideration long prior to that of expense.

Mr. McIlwain.

Mr. McIlwain fully endorses the remarks of Mr. Barnett, regarding the difficulty of obviating all the objectionable features of car heating and lighting, and having taken up this question has much pleasure in giving some of his experience. He has made a number of tests with the object of finding a system of heating and lighting, that combined safety with efficiency and economy.

In all the experiments, where the heating of the cars was affected by burning coal, whether the heat was diffused by means of hot water steam, hot air, or by direct air contact and radiation, a practically indestructible fire pot was employed. He found that this kept the coal from being scattered, if upset or detached in case of accident; but the combustion products escaping through the air openings, necessary to maintain combustion under normal conditions, are of such a high temperature as to ignite wood or debris piled on the fire pot. In one instance, the sides of the fire pot set the wood, upon which it had fallen, on fire.

Water calculated to extinguish the fire automatically, in case the stove is upset, could not be relied upon under all the different conditions that may exist in a wreck. Fire extinguishing devices, that automatically generate carbonic acid, are not safe, and also not as effective in cooling a bed of incandescent anthracite as they would be in extinguishing a wood fire.

Further, whoever has witnessed the terrible rapidity with which carbonic acid destroys human or animal life would object to the introduction of a carbonic acid extinguishing device. The presence of a large mass of red hot anthracite seems almost incompatible with safety.

Steam heating would abolish all danger of a fire in case of accident; but the difficulties this climate offers to the mechanical execution of this plan seem almost insurmountable, and if accomplished, the drain on the Locomotive, and the cooling down, if a car is detached from the train, add further troublesome features, not yet fully overcome.

Mr. McIlwain is now testing a device invented by a German chemist, which promises well if it proves successful in practice. He hopes to be able to speak more positiveiy on this in the near future.

Regarding the lighting of cars, he concurs with Mr. Barnett that 300 per cent. test oil is practically safe (as there are no authenticated cases where life has been lost or property destroyed in railway accidents, caused by the use of oil of this description), and with some of the modern burners, an illumination of the car can be produced that cannot be excelled by the electric incandescent.

The simplicity and absolute reliability of oil lighting is another strong point in its favour. The electric incandescent in railway cars has made such a poor show, especially in view of reliability and economy, that it can only be considered to be in its first experimental stage.

Secondary batteries lose their efficiency readily, and this with their enormous weight and first cost has greatly diminished the adoption of the storage system.

Dynamos want attention and power, and more of both than the light they furnish is worth.

Chemical batteries consuming zinc have been mentioned and advertised as being the true electric generator for car lighting; careful tests have shown it to be much more expensive than oil lighting, in fact entirely out of the question, as far as practical work is concerned.

He does not look upon gas lighting in as favourable a light as Mr. Barnett. Oil has a freedom from complicated construction and plant that may get out of order; oil is independent of any definite source of supply, always ready, can be handled by the brakeman or porters, is just as safe as gas, and if there is a difference of price in favour of gas, it is so small as to be of no consequence in view of the many desirable qualities oil possesses.

The extended interest and research, that have been caused by the deplorable loss of life in last winter's accidents, will no doubt result in methods of heating cars much more safe than those now in use.

VENTILATION.—After trying almost every known device for ventilating cars, all of which have failed in the one important feature, i.e., in giving the same (or nearly so) amount of ventilation when the car is standing still as when moving, Mr. McIlwain has arrived at the conclusion that the coming system of ventilation to be successful, must be one that will fully give the necessary amount of fresh air circulation under all conditions. This can, in his opinion, be accomplished by automatic arrangement, whereby in warm weather, when the car is at a standstill, the ventilators will be open to their fullest extent, and gradually reduced as the momentum of the train is increased, until at last the minimum amount of air required to properly ventilate a car will be admitted only, and the reverse as the speed is reduced. Inventive ingenuity will be adequate to accomplish this, when it is found that the ventilation of railway cars is as important as automatic drawbars, or continuous power train brakes.

Mr. G. Gibbs. Mr. Gibbs, of the Chicago, Milwaukee and St. Paul Ry., fears that he can at present add little of value to the published accounts of their experiments last winter. These were very far from complete, on account of the limited range of temperatures encountered. The highest recorded temperature at which test was made was 40 ° Far., and the consumption of steam was 70 lbs per car per hour. At 30 ° the amount rose to 85 lbs., and at 10 °, 100 lbs. Except at these temperatures no reliable figures can be given. A "heating-up" test, however—standing— at 10 ° below zero was made, and it took 285 lbs. of steam per car to bring the inside temperature up to 70 ° Far., and three hourstime. If the total condensation is divided by three, 95-lbs. is obtained as average consumption per car per hour. At present there hardly seem sufficient grounds for deducing from this figure one for running test under same temperature condition, as the further loss of heat due to the motion of train would much depend upon the build of the coach, the principal losses occurring from leakage and not from conduction.

It would be exceedingly interesting to be able to work out an approximate law for steam consumption at various temperatures. Mr. Barnett suggests in a letter that the condensation may increase in a geometrical rather than arithmetical ratio with temperature fall. Mr. Gibbs is inclined to doubt this, however; in fact, he hopes that the condensation will not be as great even as in inverse ratio of temperatures. He has been led somewhat to this conclusion from the fact that considerable heat must be wasted at the moderate temperatures of the tests, while with care at low temperatures much of this would be saved, at the expense of good ventilation, however.

Running over some of the points made in Mr. Barnett's excellent paper:—

He entirely agrees with him in what he says, in reference to stoves, encased or otherwise, or other individual heaters outside or in; also in regard to use of steam from exhaust of locomotive cylinders, air-pumps, etc. He has maintained that one of the most vital points connected with continuous steam heating was in dealing with the water of condensation. The rapidity with which water issuing hot from parts of a locomotive will freeze in the severe Nerthern climate, is almost inconceivable; and he, therefore, lays great stress upon the perfect action of the "trap" used, and would give it the least possible work to do by using the dryest steam.

He has been in favour of wholly metallic couplings between cars, but after some experience with these, believes that the purpose can be more satisfactorily accomplished, by securing flexibility by the use of stout steam-hose, having couplings arranged to permit of very readily replacing a broken hose by an extra one always carried at hand.

In practical train operation, there are certain to be some complications introduced by use of continuous heating; but Mr. Gibbs feels convinced that the operating department can deal with these, if it is supplied with a mechanically good arrangement. As might be naturally supposed, the arrangements on the market at present are far from perfect or well thought out.

There is a good field for inventors in this direction, to devise a simple coupling, traps and means of regulating radiating surface for varying degrees of cold, and, as far as possible, for needful ventilation. Beyond this, the so-called "systems" amount to nothing, and the expectation that railroads will pay exorbitant prices for the privilege of using what is already theirs is certainly doomed to failure.

His company is about to embody in a new arrangement being prepared for next winter, a scheme for good ventilation, but the details have not been sufficiently worked out yet to be made public.

Mr. Gibb, agrees with Mr. Barnett in his remarks about use of 300° fire-test mineral oil for lighting. He considers it perfectly save from the danger of setting the car on fire, under any condition of collision wreck, provided no other source of fire is at hand. The difficulty of inflaming the grade of oil is well known to any one handling it, and the slight shock necessary to put out all lamps using this oil can be easily determined by experiment.

Mr. Barnett.

Mr. Barnett, in reply, said the estimated economy in fuel by steam-warming was based upon experiments carried out with locomotives hauling short trains (therefore, having light fuel consumption per sq. ft. of grate surface, and excellent evaporation per lb. of soft coal burnt), and in districts to the south and west, where the average temperature was milder than in the province of Quebec but not so mild as to result in any appreciable reduction in the amount of hard coal used in keeping heaters alive night and day.

The explanation of this apparent anomaly is in the fact that hard coal is not readily combustible, and will not keep alight when in contact with a cooling metallic surface, unless a certain intensity or activity of combustion is maintained in excess of that absolutely required for heating purposes, thus occasioning a waste in the use of hard coal that locomotive steam heating would probably avoid.

Also, aside from the higher market price of hard coal, its evaporative duty, when burnt under similar conditions, is but 74 per cent. of that achieved by soft coal. (See author's paper April, 1886, in Proceedings Canadian Institute, Toronto.)

The desired universal coupling will probably be found in the Sewell patent, if it can be effectively cleared of the water of condensation. Whether this be so or not, it is at present the best coupling offered for light steam pressures.

Mr. Gibbs very properly qualifies his belief that the water of condensation (at present the only satisfactory measure of the amount of heat taken from a locomotive) will not—at extremely low temperatures—increase even "in inverse ratio," by saying that the free mouvement of air through the car required in his experiments at medium temperatures would not be allowed in winter. Granting that a restriction may be to some extent permissible, there is no physical reason why the air in a car should not be changed as frequently in mid-winter as at any other season when artificial heating may not be required. The demands of a healthy body are practically the same in all seasons, although in mid-summer we may desire positive draughts because of their cooling influence.

The difficulty of inflaming high grade mineral oil may be tested any time by dropping a mass of saturated cotton waste, when in full blaze, into a barrel of 300° oil, with the invariable result of the oil putting the fire out at once. There is no authenticated case of such oil being the primary cause of destruction by fire of any car in any railway accident on this continent.

Mr. Drummond is correct in saying that a heater suspended underneath the car is no less a source of danger. The P. & R. Ry. have had at least two coaches so equipped burnt up in accident, and the B. & E. Ry. one.

The statement he quotes, that steam warming will not increase the draft on the boiler one p.c., cannot be sustained. A coach to carry 60 passengers requires from 126 to 140 supl. feet. of pipe surface for steam, or 200 ft. for hot water, with an average temperature of 160° F. Where steam is used for the warming of domestic dwellings, despite the facts that walls are thick, and double windows and doors are used, the condensation averages $\frac{1}{3}$, often raising to $\frac{1}{2}$ a lb. per ft. per hour; and it is self evident that a coach having its doors often opened, and a large glass surface to radiate heat, will suffer a much greater condensation. Using, however, the small figure of a $\frac{1}{2}$ lb. per sq. ft., the condensation over 140 ft. will total to 70 lbs. per hour, or per 10 coaches 700 lbs., which is 1 p.c. of 70,000 lbs., equivalent to an evaporation of 7,000 galls. and the burning of more than 5 tons of coal per hour. If 2,000 galls. are to be evaporated, the locomotive must not stop during the hour, so that its artificial blast may draw air enough through the small grate to consume this large amount of fuel.

That steam, at such low pressure as 2 to 5 lbs., will warm a train, or that the fractional opening of an ½ in. valve will pass steam enough, is no proof that the consumption of steam is small in quantity, or that there is no loss of power to the locomotive; all tests of the definite amount condensed contradict this statement.

It is the heavy expense and necessity for skilled attention that will restrict the use of the Electric light on trains. Even when primary batteries are used as a source of electricity for equal candle power, the cost is equivalent to coal gas at $3.25 per thousand feet; there is a possibility of risk to life, for it is not yet proven that a charged storage battery—or even a primary battery—is not a source of danger to passengers at time of a passing thunder storm.

It may be remarked that in all discussions on the cost of lighting by Dynamo, worked from coach axle that have come under Mr. Barnett's notice, the factor of expense involved in giving motion to the machine is ignored, it being tacitly assumed that the resistance to the train is not increased, although a Dynamo so coupled up is a most effective electric brake.

The extreme cost for lighting the "Olga" is qualified by the consideration that it is to some extent an advertisement, its 24 electric lamps when all alight giving 384 candle power, 120 candle power being enough to permit reading in any part of an ordinary coach. This may be obtained by 8 oil lamps, using argand burners of 15 candle power, which is about the quantity of light given out by a first-class argand student lamp. The consumption of about one pint of oil per hour will develop 120 candle power.

There may be risk in the presence of reservoirs of compressed gas in time of accident; but although the Pintsch systsm has been used in Germany since 1770, and 40,000 vehicles are now equipped with it, no case of injury to life or property in time of railway accident is attributed to it.

Mr. McIllwain's statement as to lack of success in electric lighting is probably limited to experiments made on this continent; the Pacific Railway Co. having made more than any other railway, and the Co. is still experimenting.

That special ventilation is not required when car is standing, is open to question. It is often asked for by passengers, and the conditions of the problem are such as to scarcely justify elaborate machinery or extensive outlay to attain perfect ventilation, only when the coach is in motion. If train motion is to be a factor in the equation, the outlook at present suggests but a qualified success in the supply of fresh air at low train speeds.

At the conclusion of the discussion on Mr. Barnett's paper, Professor Leeds, of Harvard University, described a method of water purification with special reference to aeration, precipitation and mechanical filtration.

OBITUARY.

Harold Waldruff Keefer was the youngest son of Mr. T. C. Keefer, President of the Society. He was educated at Ottawa, and at Lennoxville, afterwards entering the Royal Military College at Kingston, with the first batch of Cadets, which are known in the College as the old Eighteen, and graduated with honors in 1880. When at the Military College, he was Sergt. Major of the Cadets, and received on leaving a handsome sword for good conduct. With the Cadets he was a general favorite from his kindly disposition and manly bearing, which here as in after life endeared him to all with whom he came in contact. Shortly after leaving the Military College, he accepted a position as Assistant Engineer on the Kansas City, St. Joseph & Council Bluffs Railway, where he won the good opinion of all connected with the Railway. On the news of his death reaching St. Joseph, a meeting of the officers and employees of the Road was held, at which the following resolutions were adopted: "Whereas we have heard with profound sorrow of the death of our friend and former associate, Harold W. Keefer, and whereas we recognize in his life an example of industrious application to, and conscientious regard for, the interests of those in whose service he was enlisted—and we noted with pleasure his rapid advancement to the higher ranks of his chosed profession—and whereas in his social life his varied information made association with him beneficial and instructive, while by his cheerful disposition and manly frankness he won his way to the hearts of all who knew him. Therefore resolved that in his sudden and unlooked for death, we read the lesson of life's closing chapters for us all, and we bow our heads in reverent submission to the will of Him, who ruleth the universe and doeth all things well. Resolved, that we tender to the father and family of our deceased friend our heartfelt sympathy in their untimely bereavement and grief."

After leaving the Kansas City, St. Joseph & Council Bluffs Railway, he was engaged as Assistant Engineer in the construction of the Canadian Pacific Railway on the North Shore of Lake Superior, and afterwards on the construction of the Canadian Pacific Railway Short Line, between Smith's Falls and Montreal. It was while discharging his duty in connection with the latter work, that he lost his life by falling from the Vaudreuil Bridge, on the 21st of January, 1886; he bore up bravely after the accident, but succumbed at last from the effects of the internal injuries he had received. He was very manly in his tastes and feelings, being very fond of outdoor sports and military life, and was at the time of his death, Lieut. of the Princess Louise Dragoon Guards. He was very warm-hearted and generous in disposition, with the high sense of honor and feeling of a true gentleman. In all his work he was very conscientious and painstaking; and though cut off at the early age of 28 years, he showed professional ability that would have placed him, had he been spared, in the front rank of his profession.

Thomas Guerin was born in the Glen of Aherlow, county Tipperary, Ireland, A.D. 1818, and died in Ottawa on Saturday, the 7th May, 1887. He received his education in Trinity College, Dublin, and came to Canada in 1843. He was appointed lecturer in Mathematics and Natural Philosophy in McGill College, in 1847. The following year he was married to Miss Mary Maguire, of this city. Having studied law, he was admitted to the Bar of Montreal in 1852; but preferring scientific pursuits he never practised law, but devoted himself to Civil Engineering. He was on the engineering staff of the Grand Trunk Railway from the time of its location to its completion. He then located the Piles Railway and the first section of Lake St. John Railway. Mr. Guerin now went abroad for some years, and during this time was resident engineer on the Guines and Matanzas Ry. in Cuba, located and constructed the Launceston and Deloraine Railway in Tasmania, besides several other roads and bridges for the Government of Victoria. Returning to Canada in 1864, he received an appointment on the engineers' staff of the Department of Public Works, which he held for nine years, and then resigned to become resident engineer on the Oakland Harbour Improvements for the United States Government. Mr. Guerin competed successfully for a prize offered by the Chili Government, for the best means of measuring and distributing water for irrigation purposes, and invented a module, which was extensively used in irrigating the land in Chili and Peru before the late war. He also invented a sewer and sink trap to prevent the escape of sewer gas. Mr. Guerin returned to Canada in 1880, and from that time to the date of his death was connected with the Department of Public Works. From time to time he contributed papers of professional interest to various engineering journals.

Mr. Guerin took great interest in the formation of the Canadian Society of Civil Engineers, and was elected a member at the preliminary meeting, held on Jan. 20th, 1887.

His profession was a labour of love to him; his mental attainments were cultivated by long years of constant study, which had made the paths of science easy and pleasant to him; and when death came, it found him busy in the faithful performance of his duty.

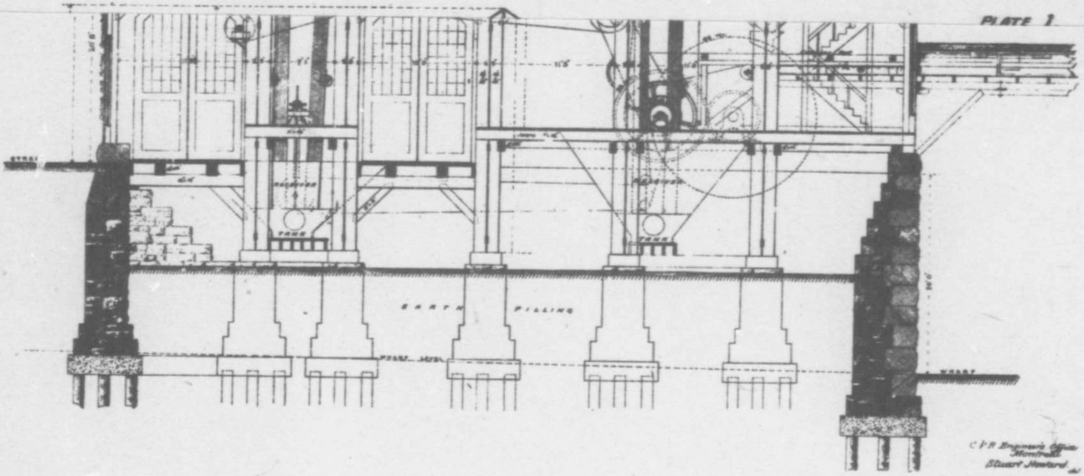
Like many men of refined temperament, he was of a retiring disposition, but his rare gifts commanded the admiration of those who had the good fortune to know him. He was distinguished for a nobility of character rarely met with. Decided in his principles, strong in his reasoning, a faithful member of the Roman Catholic Church, he was ever amiable and just to all. He leaves a widow, four sons and one daughter to cherish his memory.

End of Part I, Vol. I.

INDEX TO THE TRANSACTION.

1887—March to June.

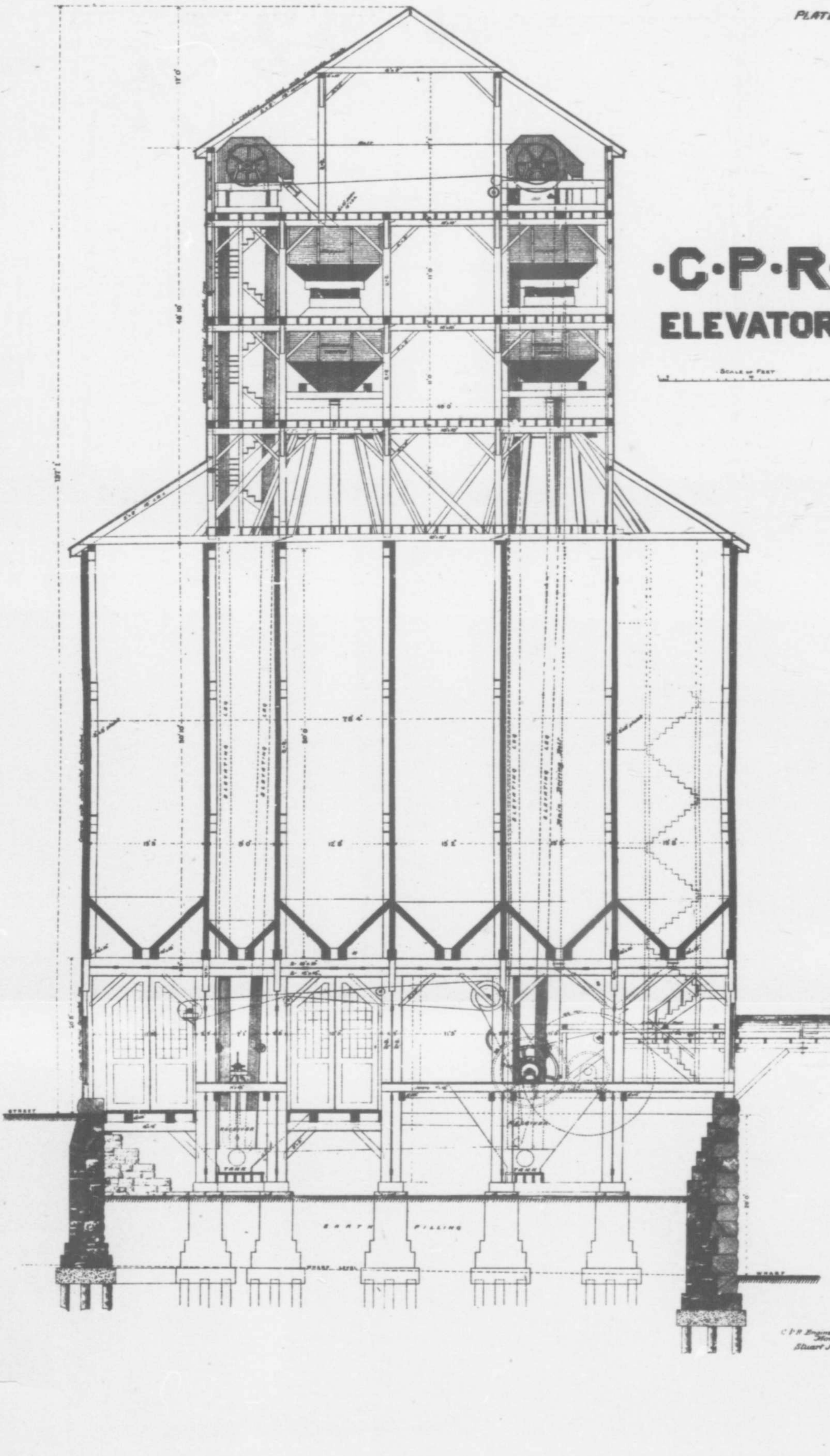
PLATE 1.



C P R Engineer's Office
Montreal
Stuart Howard del

PLATE 1.

·C·P·R· ELEVATOR



C P R Engineer's Office
Montreal
Stuart Howard del

PLATE 2

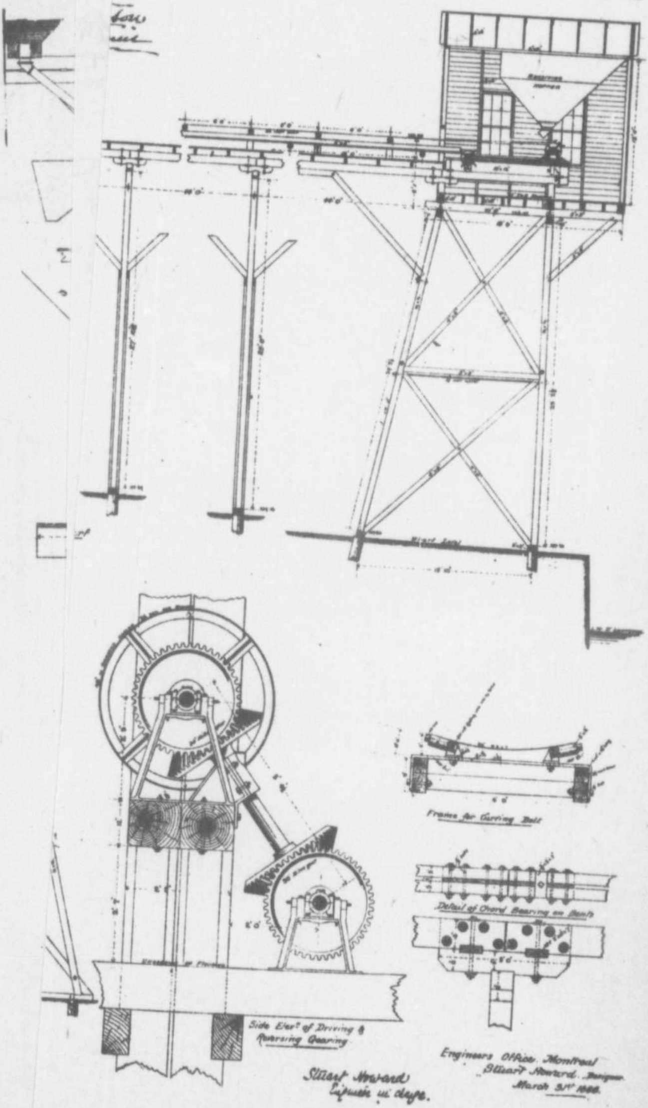

Receiving Hopper
Frame for Cutting Belt
Detail of Chord Bearing on Posts
Side Elevn of Driving & Reversing Gearing
Stuart Howard
Engineer in charge.
Engineers Office. Montreal
Stuart Howard. Designer
March 31st 1888.

PLATE 2

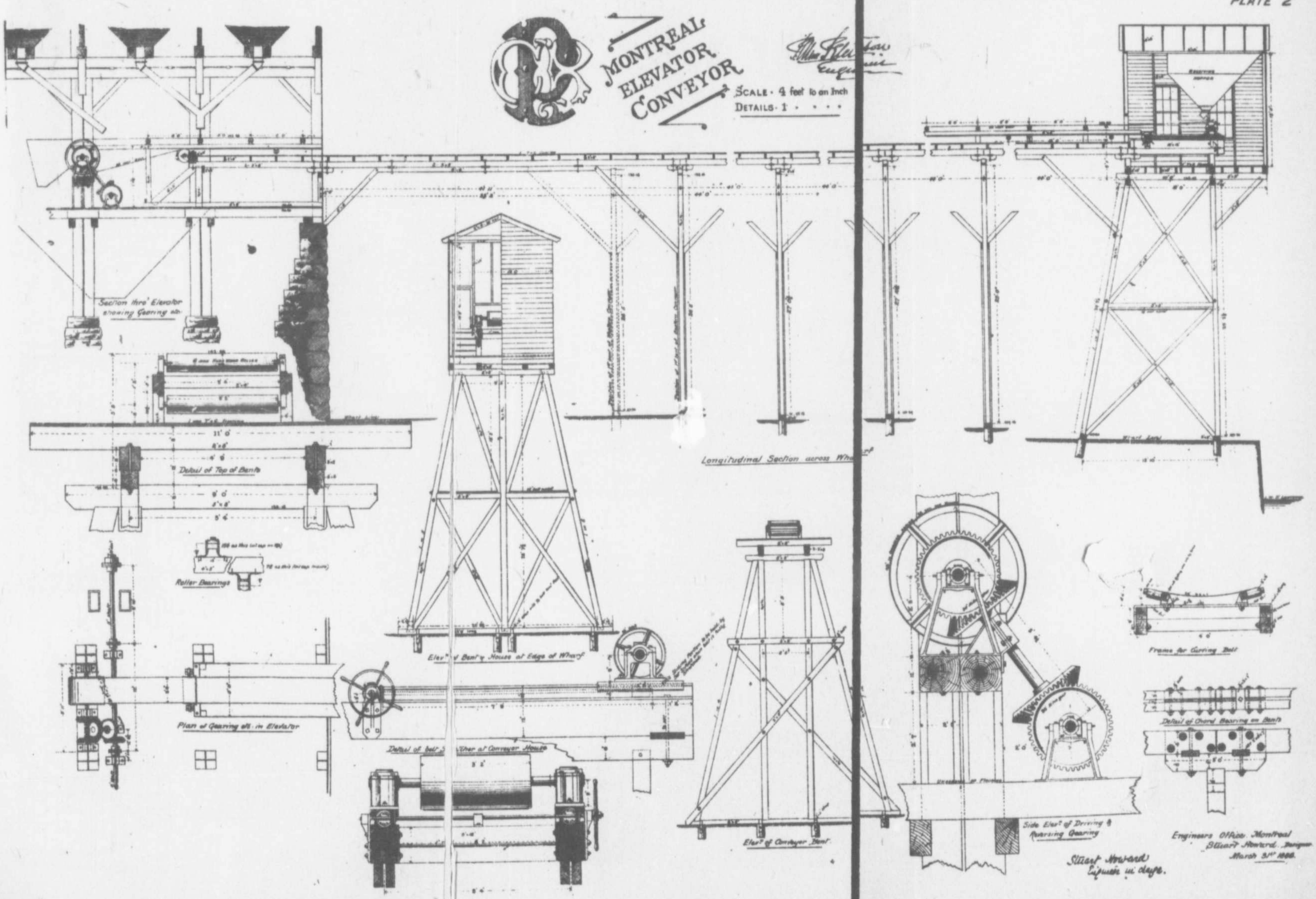
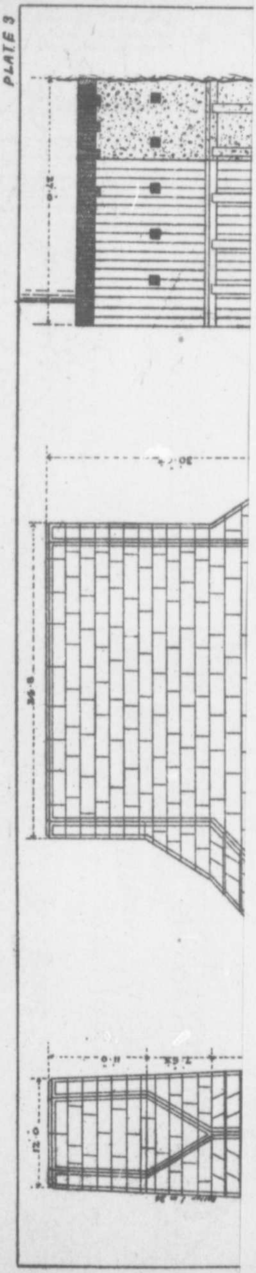
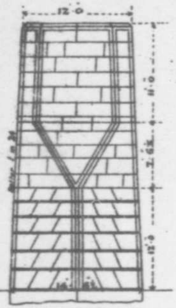

MONTREAL
ELEVATOR
CONVEYOR
SCALE · 4 feet to an Inch
DETAILS · 1 · · · ·
Engineer
Section thro' Elevator showing Gearing etc.
Detail of Top of Bents
Roller Bearings
Plan of Gearing etc. in Elevator
Elev. of Bent & House at Edge of Wharf
Detail of belt tightener at Conveyor House
Longitudinal Section across Wharf
Elev. of Conveyor Bent
Side Elev. of Driving & Reversing Gearing
Frame for Carrying Belt
Detail of Chord Bearing on Bents
Engineers Office Montreal
Stuart Howard Designer
March 31st 1888
Stuart Howard
Engineer in charge.

PLATE 3

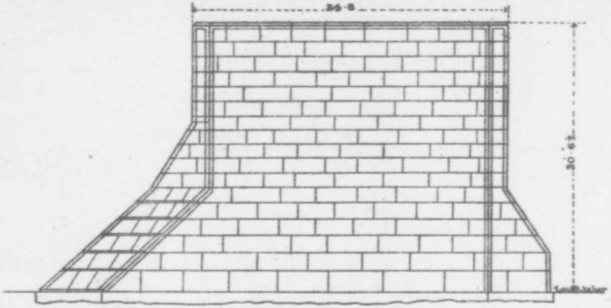


S.

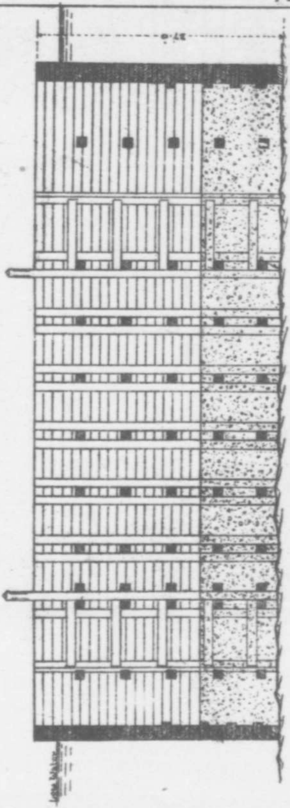
PLATE 3



Front of Pier



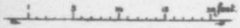
Side of Pier.

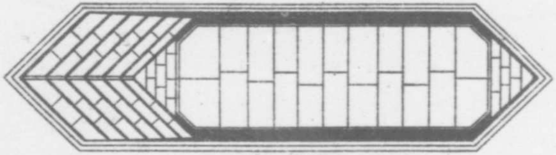


Longitudinal Section of Caisson.

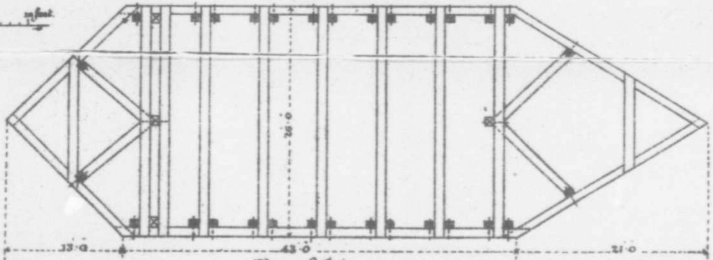
St. Lawrence Bridge.

Pier and Caisson No. 13.





Top of Pier.

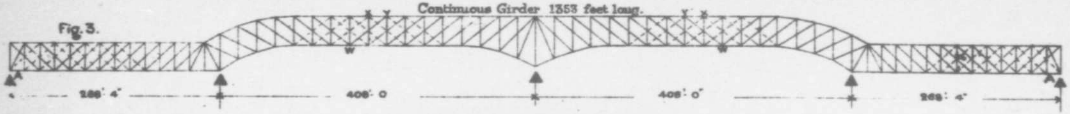


Plan of Caisson.

F.C.

Continuous Girder 1353 feet long.

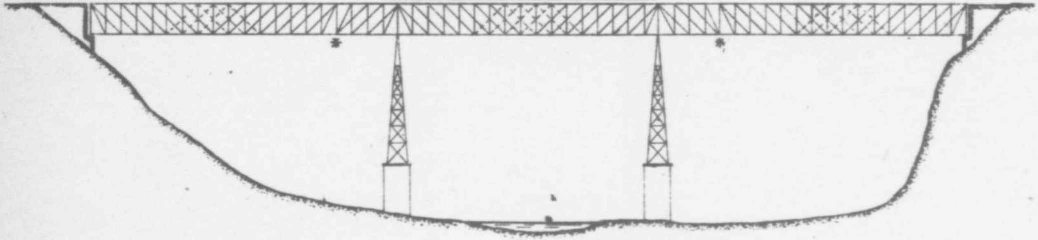
Fig. 3.



KENTUCKY RIVER BRIDGE.

Length 1138 feet. Height 276 feet.

Fig 4.



* indicate Points of Contra-flexure [fixed].

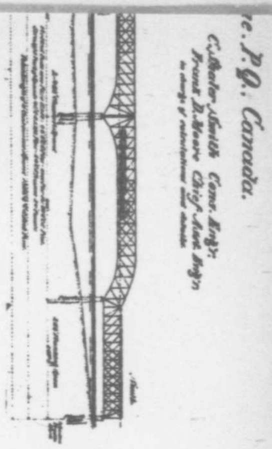


PLATE 4

LACHINE CANAL

Draw Bridge.

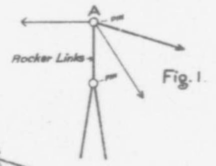
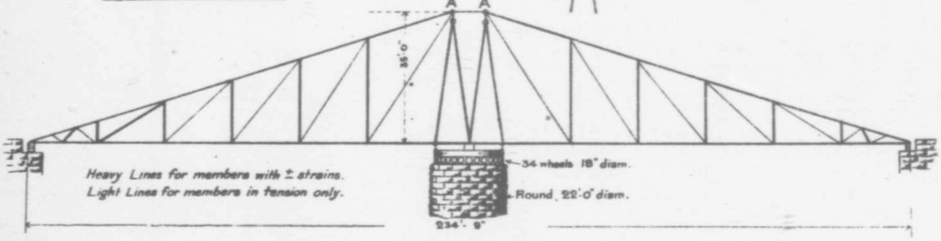


Fig. 1.



Heavy Lines for members with ± strains.
Light Lines for members in tension only.

ST LAWRENCE BRIDGE.

8-240 feet Deck Spans.

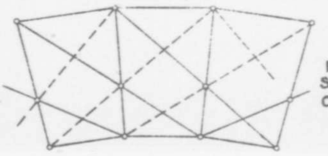
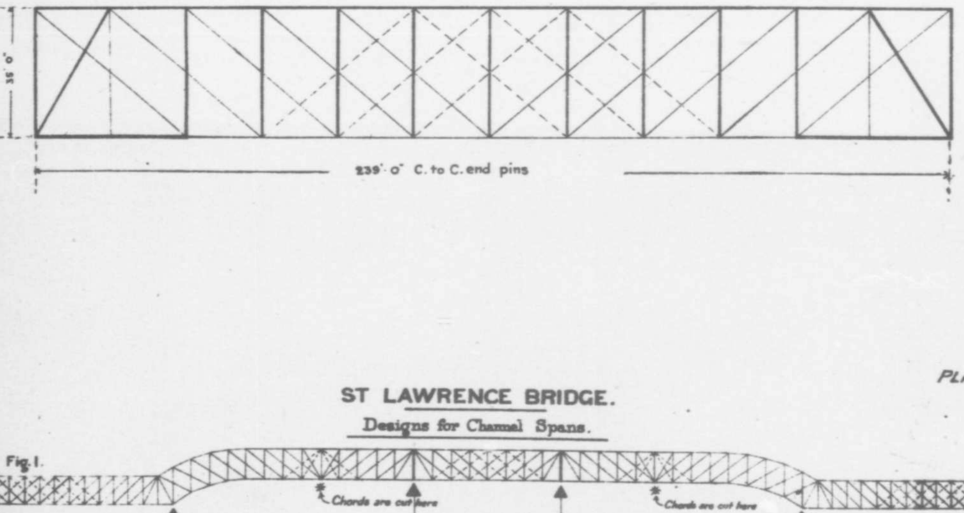


Fig. 2
Shewing Framing for
Camber in Trusses.



239' 0" C. to C. end pins

PLATE 5

ST LAWRENCE BRIDGE.

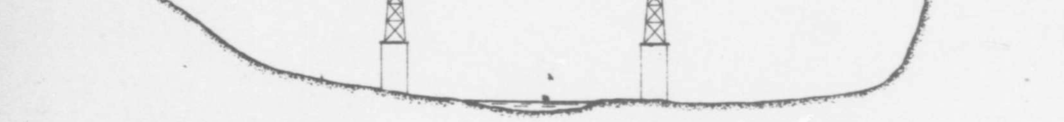
Designs for Channel Spans.

Fig. 1.

Fig. 2.

Fig. 3.

Continuous Girder 1353 feet long.



KENTUCKY RIVER BRIDGE.

Length 1136 feet. Height 276 feet.

Fig. 4.

* Indicate Points of Contra-flexure [Fixed].

St. Lawrence River Steel Bridge over Lachine Rapids - A. & N.W. Ry. at Lachine. P.Q., Canada.

P. Alex. Peterson Chief Engr.
Dominion Bridge Co., Job Abbott Prest. } Contractors.

C. Shaler Smith Cons. Engr.
Frank D. Moore Chief Asst. Engr.
in charge of calculations and details.

General Elevation.