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Plates.

Thursday, 11th October.

P. ALEX. PETERSON, President, in the Chair.

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

MEMBERS.

JOHN EDINGTON, JAMES F. GARDEN, DAVID M. ROBB.

STUDENTS.

CHARLES J. ARMSTRONG, JAMES G. H. PURVES, SYDNEY M. JOHNSON, EDWARD A. SULLIVAN.

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

A. ORMSBY GRAYDON, CHARLES M. ODELL, JOHN HISLOP, E. A. RHYS-ROBERTS.

The following have been transferred from the class of Students to the class of Associate Members :—

WILLIAM NEWMAN, JAMES R. PEDDER.

P

Paper No. 97.

BUILDING RAILWAYS ACROSS PEAT BOGS OR SWAMPS.

By D. A. Stewart, B.A.Sc., M.Can.Soc.C.E.

In some parts of Canada large areas of peat bogs or swamps are met with; and when locating lines for railways, the engineer frequently has to carry the line over these, or avoid them by taking a line objectionable in other ways, and in some cases it may be impossible to avoid them altogether. The following observations may be helpful to some engineer who may have to handle such work without having had previous experience in that way.

In building railways over such ground, the method of construction will, in most cases, either be to form a raft of some kind on which the weight of the track and trains will be, as it were, floated over the yielding mass beneath, or to fill in hard material until a solid bank is formed from the bottom of the swamp upwards. The use of timber trestles, being intended usually as only a temporary expedient, need not be considered here. If the swamp is at all deep the plan of filling in is both expensive and uncertain, so that the first method should be adopted whenever practicable, which will be the case almost always when the grade line can be kept down close to the surface of the swamp.

When the swamp can be drained to a depth of from two to five feet, the cheapest and most convenient plan will be to cut side ditches on both sides of the road bed, with such off-take drains as may be needed to take the water out of the side ditches, and to use the material taken out of the side ditches to make a light embankment. The body of partially dried peat between the side ditches is then sufficient to carry the light embankment with the track and trains. In this way railways have been carried over swamps so deep and soft that one man could push a pole into the muck for twenty feet or more, and pull it out again. If the depth of peat is so small that the ditches reach the firm stratum beneath, the raft becomes a more or less yielding cushion under the track.

If drainage can be got, the side ditches should not be less than three feet deep, and on account of the difficulty of working, it is not advisable to make them deeper than five feet. Unless the quantity of water to be carried off be very great, the width need not exceed six to eight feet. The off-take ditches should be made large enough to carry off the water, but it should be borne in mind that after the surface of the swamp is once dried, there will not be so much water to be carried off; and if the ditches are made wider than necessary, they will be more liable to choke than when they are so narrow that the water will have depth and force enough to scour them out.

Except where the grade line cannot be made low on account of the shape of the firm ground adjoining the swamp, a high bank is not advisable, because the additional weight only tends to sink it deeper; and, as banks made of muck tend to become wider as they settle, and should be covered on the sides as well as on the top with sand or gravel as soon as possible after the track is laid, to keep them from taking fire and burning away, the muck banks should not be made more than twelve feet wide on top for a standard gauge railway, so that the quantity got from side ditches of the size mentioned above will be ample to form the roadbed. It is usual to make the sides of the ditches vertical or nearly so, and they will stand in this way for many years without falling in, but it would be as well, if only for the sake of appearance, to have them sloped. It will prove true economy in the long run to be liberal in the matter of off-take ditches. The light moss from the top of the ditches and roots and sticks found among the muck are frequently wasted, but might as well be put into the banks, for except that they make the bank more compressible at first, they do no harm, and the work will look neater than if they are left in heaps outside. If not put into the bank, they should be burned for the sake of appearance.

The berms should not be left very wide, one and a half times the depth of the side ditch plus five feet, measured from the slope stake to the inside edge of the bottom of the ditch, would be a good rule in most cases, unless allowance is being made for a second track, in which case the width of the roadbed should be added on one side to the above. The objection to wide berms is that the weight of the bank causes the inner side of the berm to sink lower than the outside, thus forming a depression along the foot of the slope in which water collects, forming unsightly pools and softening the banks.

As the surfaces of such swamps are either level or slope gently, a surface line will always give easy grades; and the grade line should as nearly as possible be a line parallel to the surface of the swamp, thus making the side ditches of uniform size.

The swamp will settle as it is drained, and the bank as it becomes consolidated, but in ordinary cases no attempt should be made to raise them up to the original profile grades, the cost will be greater than any gain, and the additional weight may even cause the bank to break through the crust.

When the swamp is too wet to allow a bank to be made in this way, and drainage cannot be got, and the grade line can be kept close to the ground, a raft may be made of logs or brush, or both, with enough peat on top to hold the track and keep the ballast from sifting through. In this case it would be better to take the peat or muck from some distance outside the ends of the logs, as by cutting the skin of the swamp close to the road its bearing power would be diminished. One tier of logs should be laid lengthways of the road, to help to diminish the undulations of the track under trains. The cross logs should be as long as can be conveniently got and handled, so as to distribute the weight over as wide an area as possible; but there is no gain in putting down more than two or three tiers of logs, as the weight will tend to sink the raft down, and the object is to carry the track over the crust of the swamp without breaking through. But when the crust of a soft swamp has been broken, and the hole has to be filled up, if timber is plentiful and convenient, it may be used simply as filling, and will have a certain advantage from its not being softened and dissipated by the water as earth or sand would be, and in deep bogs may form a submerged raft capable of carrying the required load.

Sawdust has been used with success for filling low trestles on the Wabigoon section of the Western division of the Canadian Pacific Railway, both in cases where the banks had broken through the surface and where great quantities of gravel had been put in, but without bringing the bank as high as the original surface of the swamp, and also in one case where no other filling had been used and the surface had not been broken. In this case the trestle was about six hundred feet long and eight feet high, and soundings had been taken to a depth of sixty feet without finding firm bottom. The sawdust was spread out to slopes of three to one to distribute the weight, and track ties twelve feet long were used. Both top and slopes were covered with six inches of gravel. The sawdust settled unequally, and a watchman was kept on for four months, and the track lifted and tamped occasionally, but after that time there was no further trouble.

The culverts in such swamps should be made of wood, the banks will usually be too low for masonry culverts, and the foundations would be very expensive, pipes either of cast iron or earthenware would be liable to be broken or parted at the joints by the movements of the soil, while wood, if properly put together, would yield to such movements without injury. Being always damp, or at least the lower parts of them, they would last well, especially if made of cedar, and the banks being low, they could easily be replaced at any time.

The chief objection to railways built in this way is the excessive creeping of the rails, caused by the undulations of the track under trains. To remedy this the use of cinder ballast and ties twelve feet long was introduced on the Western division of the Canadian Pacific Railway by Mr. Whyte, the general superintendent, and these have been successful to a considerable degree. The evil might be still further lessened by the use of stiffer rails.

When the bog is too soft to carry any embankment, however light, or the grade line cannot be kept near the surface, there will usually be no other way than to fill in firm material until a solid bank is formed from the bottom up. In making estimates for this, not only should the bottom of the fill be assumed to be at the bottom of the soft material instead of the surface, but large additions should be made to the quantities so calculated, because the soft material, being displaced by the filling, will slip out sideways and carry portions of the latter with it. In many cases the division between the bog and the underlying material will not be distinct, but the one will merge gradually into the other, and in such cases the quantities of filling required will be correspondingly uncertain. The worst cases are usually where the soft muck is underlaid by soft and slippery clay. It is a common practice to get the track over such places by using timber trestles, leaving the permanent work to be done later; but when this is done, careful soundings should be taken and the method of doing the permanent work and its probable cost fully considered. This might not seldom result in the adoption of some other line, or a change of grades, which though more costly in the first place would be very much cheaper in the long run, as well as safer. It should be kept in mind that the filling of these trestles is often left until the traffic over the road is large, then not only will the work of filling be delayed by the traffic, but the latter will also be hindered, or possibly interrupted for days together, by the accidents which are almost sure to happen in the course of filling high trestles over soft ground, in spite of all the care and precautions that can be taken, and in addition to these delays there will be the cost of maintaining the trestles in a passable condition, perhaps even of rebuilding them. If all these things were taken into account, it would often be found to be really cheaper to take heavy rock work than to make high fills through these bogs; this will be understood when it is borne in mind that rock increases in bulk when broken up, that it will not take flatter slopes for being wet, as is the case with earth filling, and will not be so readily carried away by the movement of the soft material as would sand or gravel. Besides, in many cases a rock embankment would avoid the need for a culvert.

But when it has been decided to cross any such soft ground at a high level by means of trestle work, to be filled in afterwards, the permanent structure, if any, required for the passage of water, should be decided on, and the work so done as not to interfere with its proper location and construction afterwards. In neglect of this it often happens that the rim of firm ground at the edge of the bog is filled over by the material from cuttings on both sides, making the foundations of the permanent structure a matter of great difficulty and expense. Such bogs are often bounded by rocky ridges, and when these are so shaped that tunnels for the passage of the water can be driven through them without being too long, they may be cheaper as well as more secure than masonry culverts; the comparison will depend chiefly on the respective lengths of the culvert and the tunnel, and the size of the opening required. But this question should be decided before the site of the proposed tunnel is covered over. The tunnel should be located, test pits dug or borings made, and the results left on record, otherwise it may be difficult afterwards to ascertain whether the rock is suitable for a tunnel or not. If a stream tunnel is not possible or suitable the culvert will, of course, if at all possible, be placed on firm ground, beyond any danger of movement; if this is not possible, it would perhaps be better to build it strongly of wood, making it so large that a pipe or brick culvert large enough to carry the water can be built inside it after the bank has done settling. Sometimes a platform of logs is used under the fill; but if the fill is at all heavy, this is not of any use, as it will be broken up or sunk, and in any case will count only as so much filling, when it will seldom be as cheap as gravel, and will make it more difficult to keep the trestle in shape.

If clean, coarse gravel can be got, it is preferable for filling to the fine soft sand that is usually found near these swamps.

By keeping the filling spread out to the full width of the slopes from the start, it will settle more evenly and be less liable to sudden slips, which might distort or wreck the trestle; this spreading out can often be done cheaply by teams and scrapers. When the rock or firm ground at the ends of the fill slopes steeply, if the filling is ploughed off uniformly over the length of the trestle, it is apt to slide towards the middle of the trestle, and so crowd the bents; this may be prevented to some extent by filling from the middle towards both ends. In such ways, by careful watching and distribution of the filling, much may be done to preserve the trestle in a passable condition, but in all bad cases, a bridge crew should be kept on the work, and plenty of material for repairs should be kept on the ground. It will be an advantage to have as many as possible of the men working at the fill boarded close by, and arrangements should be made so that additional men can be got and accommodated, and ample material and tools procured at short notice in case of emergency.

The objections to undertaking heavy fills across soft bogs, and the precautions that should be taken when such work has to be done, noted above, apply even more strongly to the case of ponds or lakes with soft and muddy bottoms, which may be considered as bogs with their surfaces covered to a greater or less depth with water. The most valuable assistance the engineer can have will be a few good men who have had some experience on similar work.

DISCUSSION.

Mr. M. J. Butler.

Mr. Butler said his experience had been confined to swamps where the grading had been completed prior to his taking charge of the work, and ditches had been taken out for the purpose of forming the grade. The swamp was much like those usually found in the Laurentian districts of Canada, the depth of soft marly substance varying from a few feet to forty feet, the bottom being rock. Overlying the soft marly substance was a depth of muck interlaced by roots and partially rotten tree branches, etc. Suspicion having been cast upon the safety of such a road bed, it was thoroughly sounded and found as above described. To remedy the trouble the timber on the adjoining swamp was cut down, and every tree and shrub piled in "criss-cross" in every way, to tangle it up into a mat as much as possible, without spending any more labour than could be avoided. The whole length was then levelled up with mill wood and sawdust to bring the track to an approximately even grade and finally ballasted with cinders, although under the usual daily service for the past 10 years, no trouble whatever has been experienced with these bogs. In the speaker's opinion, it was an error to have cut the bog for ditches. The timber, brush, etc., should be piled on the natural surface, taking in as large an area as is practicable in order to distribute the pressure due to the weight of the trains, etc. In one or two instances that have come under the speaker's observation, piling has been attempted; but owing to the length of piles necessary and the lack of cohesion in the material of the bog, they have failed, the piling tipping over, and in one case carrying with it a high bank so as to throw the alignment fully 15 feet out of place.

Mr. A. K. Kirkpatrick.

Mr. Kirkpatrick said the young engineer in charge of a section on construction of a railway in parts of Canada and the Northern States, very often has the difficulty to contend with of building the line over peat-bogs or swamps, as described in this paper; but as a general rule, he does not remain long enough after the construction is completed to see how the work stands the traffic. If he were to remain on maintenance for four or five years, he would then see that in a great many cases work done should have been left undone. This applies especially to swamp work.

The speaker was placed in this position in 1886 during construction of the Ontario and Quebec extension, where he had charge of a section comprising seven miles of hard bottom and five miles of swamp. Immediately construction was completed, he left to take charge of other work, and did not see these swamps for four years, when they came under his supervision on maintenance of way, and he had a good opportunity of observing where and how the work had failed or withstood the traffic. These five miles of swamp might be divided into four classes, viz:—(1) Shallow bogs, eight to ten feet deep, and quite stiff peat to the bottom. (2) Deep bogs, from twenty-five to ninety feet deep and over, with stiff crust of peat from six to ten feet thick and floating on liquid muck or marle. (3) Deep bogs, from twenty-five to ninety feet and over, with thin crust of from three to six feet of peat floating on liquid muck or marle. (4) Bogs from six to thirty feet deep, with peat crust from two to six feet deep, on top of a soft grayish clay or marle.

The shallow bogs in class (1) were deemed strong enough, if drained, to be ditched, and embankment made from the material obtained. Two of these swamps have stood all right, but another one, which was covered with two feet of clay from cuttings, settled before trains were running, and had to be filled by train afterwards, since which time it has not moved. The crust in this case parted along the centre line, squeezed the underlying peat into the ditches, and elevated the berm between toe of bank and ditch from three to four feet. The berms were about fourteen feet. Another shallow bog gave way after it had stood the traffic for about eighteen months. It first showed settlement in the track along a line, making an angle of about three degrees with the centre line, causing a low spot on the north rail, and about ninety feet farther along a low spot on south rail. In picking up these low spots, cinders were used, but eventually the crust gave way, and two hundred feet of the swamp had to be filled.

In the deep swamps of the 2nd class, ditches were dug at the edges of the right-of-way, five feet wide and four feet deep, with vertical sides, leaving a five ft. berm for the fence, and the swamp was drained by an off-take ditch 3,400 long, 6 feet deep and 10 feet wide at the bottom, with sides sloped one to one. These swamps were cross-logged with the timber that stood on the right-of-way, cut into 30 ft. lengths, and laid alternately top and butt. Where the timber was thin or too light, extra timber was bought on adjacent lands, and hauled into position with lock and tackle. The centre portion of the cross-logging was covered with brush obtained from the timber used in the cross-logging, and a bank of about two feet was built on top of the material taken from the ditches. Some portions of these swamps have stood well, only requiring a little surfacing with cinders. Some places have settled about a foot for a couple of rail-lengths, and have had to be lifted with cinders, while the softer portions have settled considerably and have had to be re-cross-legged. These soft spots do not occur with any regularity, and it is impossible to locate where they will occur by observing the standing timber or by any difference in the nature of the surface.

When re cross-logging, forty foot tamarac poles, not less than five inches at top, were used, and were laid alternately top and butt, two timbers deep. The first bank was levelled off over the old cross-waying and sunken portion of the swamp at the ends of the cross-logging. This cross-logging was then covered with about one foot of muck and three inches of sand, to protect the muck and timber from fire, and the track was surfaced with cinders. The portions so treated have stood well so far—three or four years—only requiring occasionally a car load of cinders for surfacing.

Through these swamps the telegraph line has been double-poled, *i.e.*, a pole every 75 feet, as with the standard distance, 150 feet, the wires threshed up and down so that it was impossible to keep the line in repair. Even now the poles shake considerably when trains are passing.

Where an opening for water was provided, a ten foot open pile culvert was put in. A test pile fifty-five feet in length was driven, and struck a seam of hard clay or sand about two feet thick at thirty-six or thirty-eight feet, and on being driven through this seam drove from two to four feet at a blow from a 2,200 lb. hammer, with fifteen feet drop. A forty foot pile was spliced on top with dowel pin and rings, and driven to the level of the swamp with a two ft. settlement at the last below. It was decided to put eight piles in a bent, instead of four, and to drive only to the hard seam. These piles have never settled, but have had to be cut down to the lower deck of the culvert to keep a uniform top to the rail, as the track settled on either side.

Some trouble has arisen in these swamps from a greater settlement of the bank and cross-logging immediately on either side of pile structures than in any other place, and this not on account of their being put in old creek channels, because stiff portions of swamp were chosen for them, and off-take ditches made, but, as we believe, on account of the crust not receiving the same load where the opening is, and the swamp on either side pressing the underlying liquid matter to this line of least resistance. In places where a solid timber floor has been put in and a timber wall to the culvert, this extra settlement has not occurred, but the track on either side of the culvert has stood up as well as in other portions of the swamp.

Two bogs of the 3rd class were encountered, and it was deemed more advisable to pile them throughout their lengths of 1,800 and 2,700 feet than to build light banks over them, although the deepest sounding was only thirty-eight feet. The stream that drained these swamps had a good fall, and was deepened for 2,400 feet in order to drain to a depth of six feet below the surface of the bog and with a view to thickening the crust and eventually filling in the trestle. This swamp is much stiffer now than it was, but a man can still take a 25 foot tamarac pole, and shove it down its full length without any great difficulty after having got through the top crust, which is about four feet thick.

A bog of the 4th class, with a thin crust of two feet overlying a soft grayish marle, was encountered. Its length was 600 feet across and depth 30 feet, with an 18 foot bank. After cross-logging part of its length with heavy maple timber and starting to fill at full width, it was found that the marle would not support even a 6 foot bank. The filling was discontinued, and a pile trestle put in with bents 15 ft. centres and 6 piles to a bent.

A short swamp that gave way was got over by cutting all the standing timber on one acre and putting it in just as cut, without limbing, 2,000 standard of saw logs and 1,000 cords of pine slab and cinder covering, bank about 3½ feet high. This bank is still floating. Soundings were taken for ninety feet and no bottom reached.

Another instance of a swamp giving way was one crossed by a three-bent pile trestle and a bank about nine feet high, in all about 100 feet long, between two rock cuttings. The pile bents began to settle, and the trestle was filled underneath with timber laid at right angles to the bank and covered with a light coating of sand to protect it from fire. This extra weight was more than the swamp would support. The crust broke on one side and the timber stood on end. The hole was finally filled by train, 100 car loads a day for this first week, then 80 car loads a day for three weeks.

There were four other swamps, about which fear of failure was entertained. Upon these watchmen were kept and slow orders maintained, and diversions built around the swamps in case they should fail. The rails were taken and four inch cedar planks spiked to ties, breaking joint and leaving a space under centre of track of 18 ins. open. New ties were placed on top of plank and surfaced with cinders. Watchmen and slow orders were taken off, and trains resumed their usual speed. Very little settlement has taken place since.

The safest way to deal with these swamps would be to place a layer of longitudinal timbers, breaking joint, and from 25 feet to 40 feet wide, so as to lengthen the wave motion caused by passing trains, then cross-log on top of these timbers, and give a light covering of peat to fill the spaces between the logs. Add a covering of three inches of sand to protect from fire and surface with cinders, keeping grade line as low as possible or just above snow level or high water mark, and do not disturb the crust of the swamp within 175 feet of the centre line. By putting longitudinal timbers or even planking under the bank the tendency to creeping of track is reduced by the wave motion being lengthened.

Mr. Stewart does not say what the life of a twelve foot tie would be, but the speaker thinks that it would be very short on account of breaking under the rail through having too much support outside of the rail. The trouble we find is in anchoring the rail to the tie, with the present rail fastenings 44 ins. in angle-bar and slot-spiked. The spikes are cut off, or the ties split and the spikes pulled out, and after a time the corners of the slot-holes become worn and will not retain the spike. Blocks of wood, placed between the ties and under the rail, will prevent ties from creeping and piling the ballast, by spreading the resistance over more surface.

If the steel spikes become loose or are worked out or broken off for 2 or 3 joints, it is only the matter of a few trains in one direction till 12 or 14 joints are loose from the ties, as the rails pull from one end and shoving split the ties or work out and cut them off. The speaker has noticed places where the track had travelled 14 inches in this way.

Mr. C. B. Smith. Mr. Smith remarked that the mention made by the author of the difficulty always met with in filling high trestles, on account of the unequal distribution of material required, reminded him that possibly many members, not in touch with railway work, were not familiar with the Leidgerwood unloader, which is simply a small engine mounted on a flat car, next behind the locomotive, fed with steam from the locomotive, and operating a friction drum which will wind up the cable attached to the ballast plow at any desired rate, while the train can at the same time be pushed backward or forward at any rate also. A combination of these two rates of speed enabled the ballast or other material to be distributed as thinly as desired, or it can all be dumped at one spot, as would often be done in filling trestles. This method is found to be a great improvement, both in time and money, over the usual one of blocking the train and pulling the cable with the locomotive. In 1884-1886, when the Northern & Pacific Junction Railway was built from Gravenhurst to North Bay Junction (La Vase), a striking feature was the "Long Trestle" about 25 miles south of the northern end of the road. This was 4,000 ft. long, built at the north end of a 4 mile grade of 60 or 70 ft. per mile, which reached the trestle about 35 or 40 ft. above the level of a bad muskeg. The original location of this trestle was on a *tangent*, which crossed and recrossed Trout Creek several times, the intention being to divert the channel and cross the creek with about an 80 ft. span. But when the Division Engineer (Mr. D. S. Noble) began to drive test piles, he found that the located line was not a feasible one, as the muskeg would at some places adjacent to the creek not afford any bottom at all for at least 75 feet. The line was finally diverted slightly, and located well away from the creek, and crossing it once only at right angles by a Howe truss and masonry abutments founded on piles and timber grillage.

The peculiar feature, however, is that the muskeg was found on this route to have about 10 ft. of very soft material, beneath which was a layer of moderately hard clay from 6 to 8 ft. thick. Beneath this layer again was a soft bog of very great depth. The bents of the trestle have about 6 to 8 piles under them, driven 3 or 4 feet into this layer of clay, great care being taken to not puncture the layer. So that the whole structure, masonry included, is really floating, in a measure, with this layer of clay on a very soft bog beneath. A year's maintenance under quite heavy traffic of ballast trains showed that the structure was reasonably safe, there being only a few unimportant settlements at the end of that time. It is to be hoped that in the future no attempt will ever be made to fill this place in, as it is not likely that this crust would stand such a heavy load, which would in places, as Mr. Stewart shows, be an embankment at least 50 feet high. Whether the general location occasioning this structure was necessary is not certain, the location was made hurriedly by another engineer, and contracts let immediately. Neither time nor opportunity was given the division engineer to examine the location, and he was forced, as is often the case, to make the best of what seemed a bad job.

CORRESPONDENCE.

Mr. D. MacPherson.

Mr. McPherson said he had had a personal experience with such work as is referred to in Mr. Stewart's paper, in 1881 and 1882, on the construction of the main line of the Canadian Pacific Railway at a point known as Bisset's Swamp, 288 miles west of Montreal. The swamp is about 4 miles long, and a small creek traverses its whole length, winding in and out between edges of gneiss rock and crossing the line of railway several times. At the crossing points, foundations of structures reached solid rock a few feet from the surface, but between these points were level stretches of swamp covered with long grass and shrubs. The surface was apparently firm, peaty soil, and the track was built with a light bank made up from side ditches. This bank carried trains for several months, when what were called "sink holes" began to develop in several places, and often what was apparently a firm bank would in a few hours become a pool of water with bank and track out of sight. Rafts of log and whole trees with brush mattresses, were tried with more or less success, until the work of blasting out a new channel for the creek lowered the water level of the whole swamp 5 feet, after which but little trouble was had, and trains have passed safely over these submerged rafts ever since. It should be added that the depth of soft material underlying the peat crust made it impossible that these rafts could have reached bottom. The writer takes pleasure in the fact that his somewhat limited experience would appear to corroborate the theories advanced in Mr. Stewart's valuable paper.

Mr. D. A. Stewart.

Mr. Stewart, in reply to a letter from the Secretary, asking for further data, said, being pressed with work just now, at the time that he could not undertake to give the information asked for so soon as November 8th, indeed he would not like to fix a date at all.

If it were considered worth while, would it not be better to make this the subject of another paper? If anyone will consider the conditions of a trestle, say 20 to 40 feet high, resting on piles driven into deep soft mud, when gravel is being plowed off into it at the rate of 200 to 300 carloads a day, the difficulty of maintaining it in passable shape will be obvious enough. The best means of so maintaining it should perhaps have properly been included in the paper; but when it was written, he looked on this as another question.

Mr. Stewart, in reply to discussion, said:

Mr. Butler does not say to what depth the ditches in the case he mentions drained the swamp, nor does it appear that the track had actually broken through the surface.

The method described by him is a good one in certain cases, but these will be comparatively few and of small extent. Many of the swamps between Fort William and Winnipeg had only a few stunted trees and small bushes on them, and trees to form a mat would have to be hauled for several miles, and at the time the road was built there were neither sawdust nor cinders enough to be of any use within hundreds of miles.

As out of more than fifty miles of peat swamps on that road not more than one thousand feet had broken through, where the banks were low, and this only in cases when sufficient drainage could not be got, the method of draining and side-ditching might be considered fairly successful there. The bogs mentioned by Mr. Kirkpatrick were certainly very bad, and may serve as examples of what should be avoided in location when possible. The cases described by him are very interesting and useful in showing how such difficulties may be overcome when they cannot be avoided, but the methods are so expensive that they should not be resorted to except when drainage cannot be got, or where the bogs are so very soft that there is no chance of making them firm enough to carry the road by draining. And those methods are only applicable where timber is at hand.

The twelve ft. ties have not yet been long enough in use to determine their life, but it is not likely that they would last as long as shorter ones. Placing blocks between the ties to prevent them bunching has been tried on the Western Division, but their success was not held to justify the expense.

The case mentioned by Mr. MacPherson was very interesting to the writer, as showing where the crust had actually broken through, and the method of rafts had been tried, not with unmixed success. A good roadbed was afterwards made by getting sufficient drainage.

It remains the writer's opinion that careful soundings and calculations of cost when the surveys were being made would usually result in the road being built by draining and side ditching, or in finding another line.

Thursday, 25th October.

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

Paper No. 98.

NOTES ON RETAINING WALLS IN MONTREAL.

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

Having obtained some information as to the complete or partial failure of some retaining walls in Montreal during the last few years, the writer thinks that it may not be altogether uninteresting to bring this information under the notice of the members of this Society, in order that it may, if possible, induce some of them to give the results of their experience in the construction of walls, particularly of those that have proved too light, as the failure of a structure generally teaches more than its success.

Before taking up the subject, however, the writer thinks it only fair to state that neither the Chief Engineer of the Railway on which he is employed, nor the writer himself, was in any way responsible for the design of any of the walls herein alluded to as having failed.

The various cases will be taken up in the order of the numbering of the figures.

The wall shown in section by Fig. 1 (Plate I) is of dry masonry, built of stones from three feet to eight feet in length, by from ten inches to fourteen inches thick, the beds of the stones being fairly flat, but the back of the wall, in some places, seems to be rather poor, the stones being too small; the top front course was built with large, flat stones from five feet to eight feet six inches in length, but the writer has not been able to find out what proportion of through stones were used. The filling behind the wall is principally clay, a small proportion being earth and sandy clay, and was dumped from cars running on a temporary trestle.

The bank on which the filling rests has an average slope of about $2\frac{1}{2}$ to 1, and was not benched before the filling was begun; but the temporary trestle must have largely helped to keep the embankment from sliding, as it was built for a double track and was well braced longitudinally.

Indeed, possibly, this trestle, so far as it went, was better than benching, as the greasy clay would easily slide from one bench to another, unless the benches were cut down very deep; however, no doubt it would have been better to have benched the part of the slope below the trestle.

The bank under the filling is of gravel, which absorbs the melting snow in the spring very quickly, so much so that the catchwater ditch on the upper side of the slope seldom has any water in it, and there is never any sign of water passing down between the original slope and the clay filling.

The wall at the foot of the slope was built with a face batter of 1 in 12, the batter of the back being 1 in 4; and shortly after the filling was finished it pushed the wall gradually forward till the top overhung the base by about 1 in 12, the embankment rising behind the wall.

The new position of the bank and wall is shewn by dotted lines in Fig. 1 (Plate I), and is plotted from levels taken for the purpose.

Shortly after the wall was pushed forward the top was partially cleared and packed with stones and small boulders, which had rolled down the slope, to a height of about three feet, and the clay oozing in among them and hardening in the sun has kept them well in place.

Since that time the wall seems to have ceased moving forward.

About a year after this, as the clay kept flowing down the slope in the spring, the surface of the bank was levelled off, coated with good soil and sown with clover and grass which has taken root and prevented any further washing of the slope, so that the embankment now seems to be quite solid.

The wall seems to have been pushed forward, almost entirely, course by course, the stones sliding over each other. In many cases the stones of the top course overhang those of the course below by three or four inches, those of the second course do not, in general, overhang those of the course below by quite so much, but the writer noticed one stone about eight feet long in the second course which overhangs the third course by fully four inches. There is only a very short piece of the wall which has a fairly even face, and it is not far from being plumb.

The clay from the filling has found its way through the wall in many places, and no doubt helped towards making the stones slide over each other, and the vibrations caused by trains must have materially assisted the thrust of the clay in pushing the wall forward.

This wall would seem to be about the minimum thickness to retain a filling of good material, such as would stand at a 1½ to 1 slope, of the height and section shewn in firm lines on Fig. 1 (Plate I), and on a similar side hill, and was evidently too light for the clay it was intended to retain; and indeed it seems probable that it would have failed altogether, only that the side hill was able to carry off any water below the clay, and that the clay itself was of such a nature that its surface hardened quickly under the sun to which it is fully exposed.

According to "Trautwine" (edition of 1891), a dry rubble wall, eight feet high, with the given surcharge, of good material which would stand at a slope of $1\frac{1}{2}$ to 1, and on a level cross section, should have a thickness at the ground level of seven feet eight inches instead of five feet eight inches, and at the top, of four feet eight inches, instead of three feet as the wall was actually built.

The above dimensions taken from "Trautwine" would, however, have to be increased, for the clay of which the filling was made would not stand at a less slope than 2 to 1, except when dry, and, when left unprotected, will gradually wear away to a slope of 3 to 1, or even flatter towards the lower part of a high bank.

This is shewn by the dotted lines in Fig. 1 (Plate I), which looks as if the moist clay below had moved towards the wall and then pushed up the harder clay and the stones at the foot of the slope.

The sloping bank on which the filling was made would also be a cause of extra pressure on the wall since it would furnish a plane of cleavage on which the whole body of the clay while wet would tend to slide, so that, according to Trautwine, the wall should have been at least eight feet thick at the ground level and five feet four inches at the top to withstand the pressure until the clay had time to settle and harden,—indeed, it is a question if it would not have been better to have built a much thinner wall in cement mortar.

The Fig. 1A (Plate I) shews the earth pressure according to Weyrauch's method, as published in Mr. M. A. Howe's book on retaining walls, edition of 1891; the weight of the stone wall being taken at 75 per cent. of solid stone, or 124 lbs. per cubic foot, and the clay at 120 lbs. per cubic foot; the clay filling being assumed to come only to the inner top corner of the wall, though it really pushed over to the outer top corner.

It will be seen from this diagram that the resultant pressure cuts the base of the wall near the centre, so that the wall, according to Weyrauch's theory, which takes no account of the action of vibration of passing trains, should not fail by overturning; but the horizontal component of the earth pressure is 3,900 lbs. per foot run of wall, while the vertical component of the resultant is 7,240 lbs.

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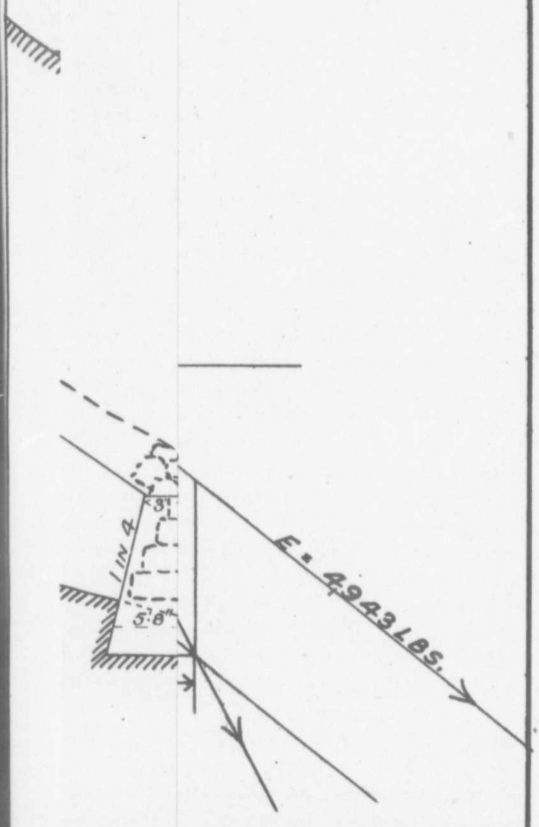


FIG. 1.

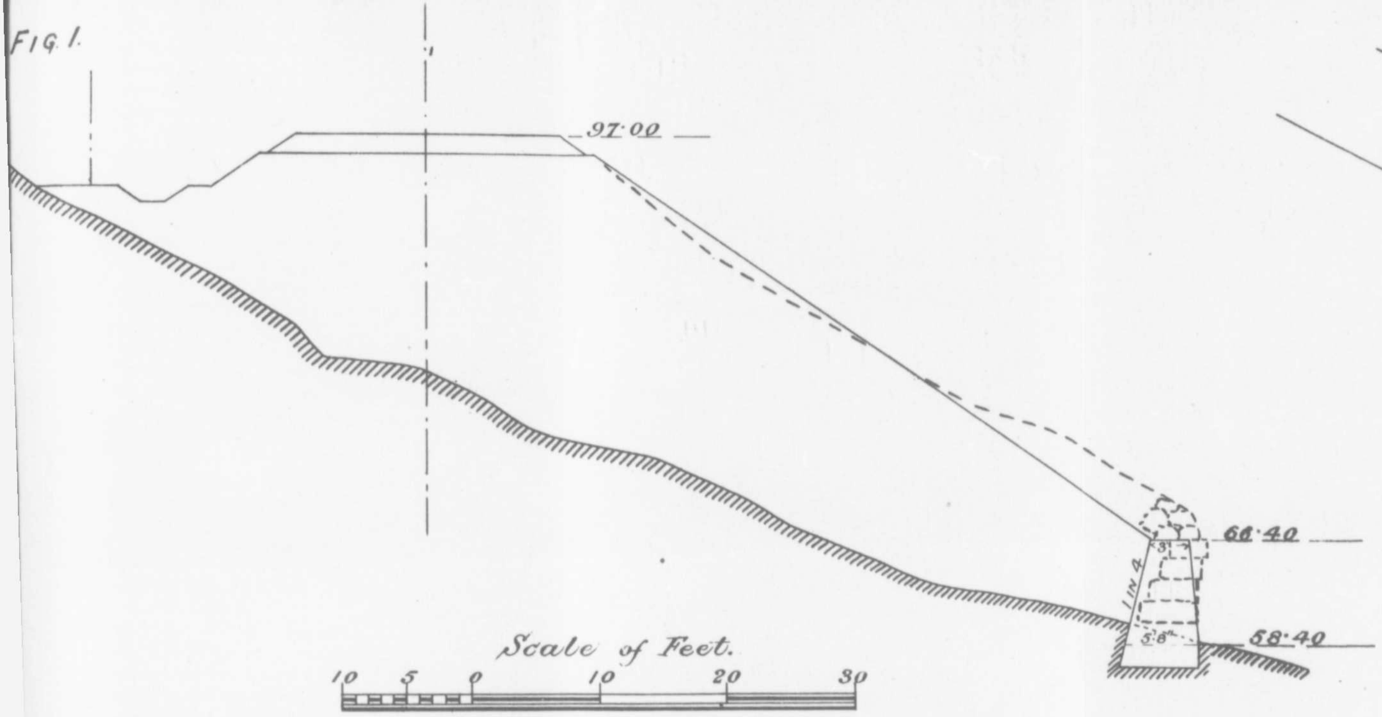
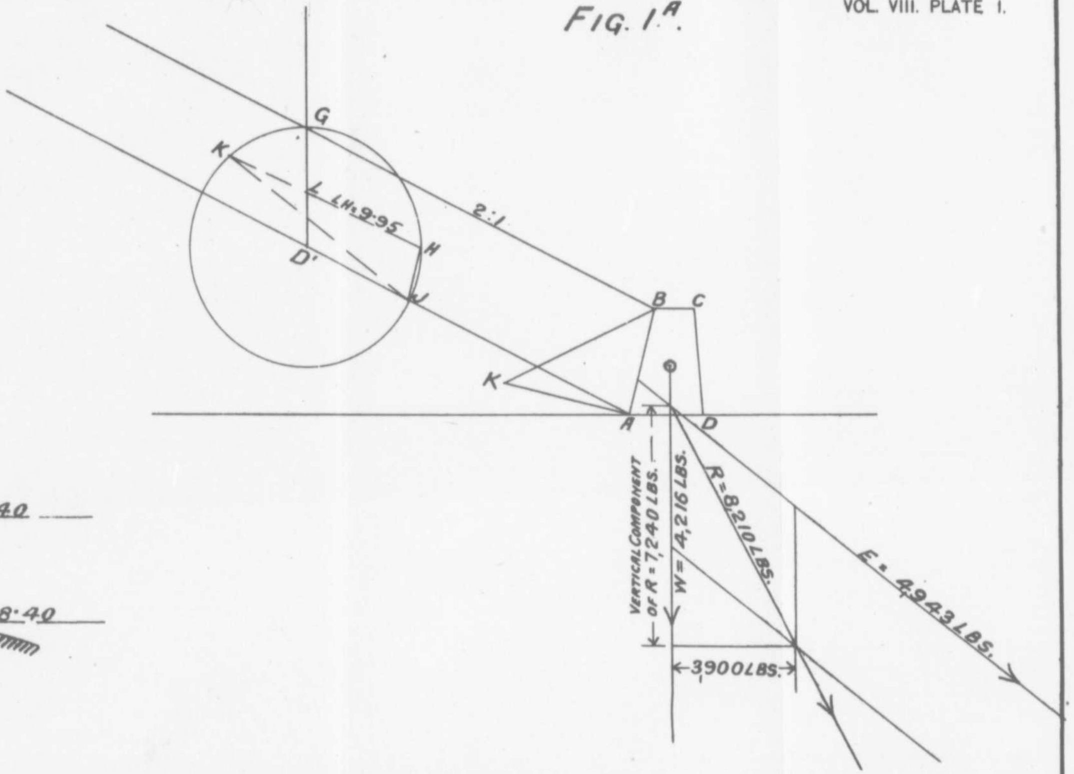

97·00
66·40
58·40
3'
1 in 4
5'8"
Scale of Feet.
10 5 0 10 20 30

FIG. 1A.


G
K
L
LH=9·95
2:1
H
D'
J
B
C
K
A
D
VERTICAL COMPONENT OF R = 7,240 LBS.
W = 4,216 LBS.
R = 8,210 LBS.
E = 4,943 LBS.
3900 LBS.

Taking friction at 0.5, which the writer will not vouch for, though it is adopted by some authors, the resistance of the wall to sliding forward at the ground level would be only 3,620 lbs., or less than the horizontal component of the thrust, without taking into account the slope of the original cross section or the vibration caused by passing trains; so that, according to Weyrauch's theory, one might expect that the wall would fail, as it actually did, by sliding forward course by course, since the various courses could not transmit the resultant horizontal thrust to the base while being liable to slide. It appears, however, that the horizontal component of the thrust decreases more rapidly than the weight of the wall for the various courses above the ground level, so much so that for a course two feet below the top of the wall, even assuming the bank to be a foot above the inner top corner of the wall, the horizontal component of the earth thrust is only 350 lbs. per foot run, while the vertical component of the resultant pressure multiplied by 0.5 is 544 lbs., so that according to theory the lower courses should have slid first. It might be fairly argued, in support of the theory, that in this case the upper layers of the clay would thaw out first in the spring, and exert more pressure as well as transmit more vibration than the frozen clay below. Had the wall been built according to the figures mentioned above as per "Trautwine," it would have had a fair margin of safety by Weyrauch's theory, and would, in the writer's opinion, have stood well enough.

The wall shown in Fig. 2 (Plate II) is also of dry rubble, with the stones even larger and the courses thicker than those in No. 1.

It retains a filling of the same sort of clay as No. 1 and also Nos. 3 and 4; but as the filling was made in the winter, a small quantity of snow was mixed with the clay.

It was built with a vertical face on account of its being next to a wooden stable; it is only forty feet long, and abuts at one end against a heavy masonry abutment.

It was pushed forward a few inches during the first spring after the filling was completed, and was then weighted down with some very large flat bedded stones placed on its top to a height of about four feet six inches.

The bank was afterwards gradually raised, behind the new stone work, with cinders, and the wall does not seem to be moving any more.

The writer has not been able to find out whether the movement of the wall was due to the courses sliding on each other or to a movement of the entire wall.

According to Trautwine's rule for a surcharged dry wall to retain the filling shown, if of good material such as would stand at a slope of $1\frac{1}{2}$ to 1, the thickness of the wall, supposing the batter on each face to remain the same, should be seven feet seven inches at the base and four feet eleven inches at the top, instead of five feet eight inches at the base and three feet at the top as originally built; but taking into account the nature of the filling, this wall should, according to Trautwine, have been at least eight feet thick at the base and five feet four inches at the top, or nearly fifty per cent. thicker than it was built.

Fig. 2A (Plate II), drawn according to Weyrauch's theory, shows that the wall should have been strong enough to resist overturning, but that, at the ground level, the horizontal component of the thrust would be 4,500 lbs. per foot run, while the vertical component of the resultant pressure, divided by 2 to give the frictional resistance to sliding, was 4,790 lbs., without taking the vibration caused by trains into account. Had the wall been built of the dimensions given above as derived from "Trautwine," it would have appeared to be quite strong enough, according to Weyrauch's theory, to resist the extra thrust from vibrations.

It seems also that this wall would have been quite strong enough to retain the filling behind it, had it been of good material such as would stand at a slope of $1\frac{1}{2}$ to 1.

The wall shown in Fig. 3 (Plate III) was also of dry rubble, built of the same class of stones as No. 2, the embankment behind it being of the same nature as that in Case 2.

The filling was made in the winter by train on a temporary trestle. The wall failed completely early in the following summer, and a part of the same wall, which gradually stepped down to a height of only two feet, was pushed down for part of its length, and the lowest part was so completely covered by the filling that no attempt was made to dig the stones out, as an extra strip of land was bought to give additional room.

Unfortunately the writer did not see any part of this wall until after it had given way entirely; but in a part of the wall left standing the writer noticed a large flat bedded stone which had been eight feet nine inches below the top of the wall, and which had been pushed forwards four inches beyond the course below it. This, together with the fact that the wall, when it failed, was completely buried by the filling, seems to shew that the stones were pushed forward and fell over each other, rather than that the wall failed by overturning, especially as a wall immediately adjoining it and built in cement (shewn in Fig. 4, Plate IV),

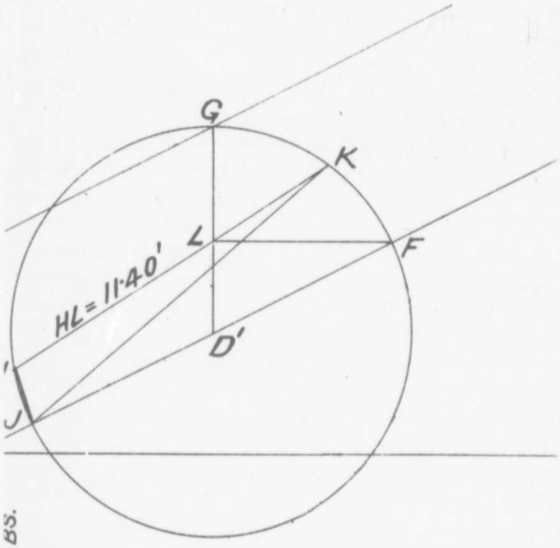

G
K
L
F
HL = 11·40'
D'
J

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FIG. 2

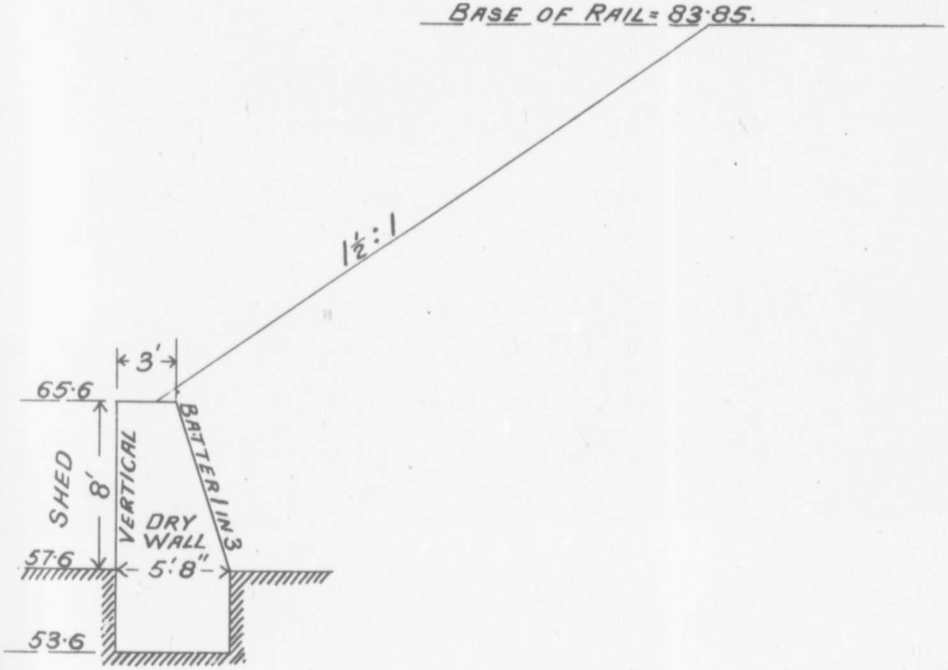
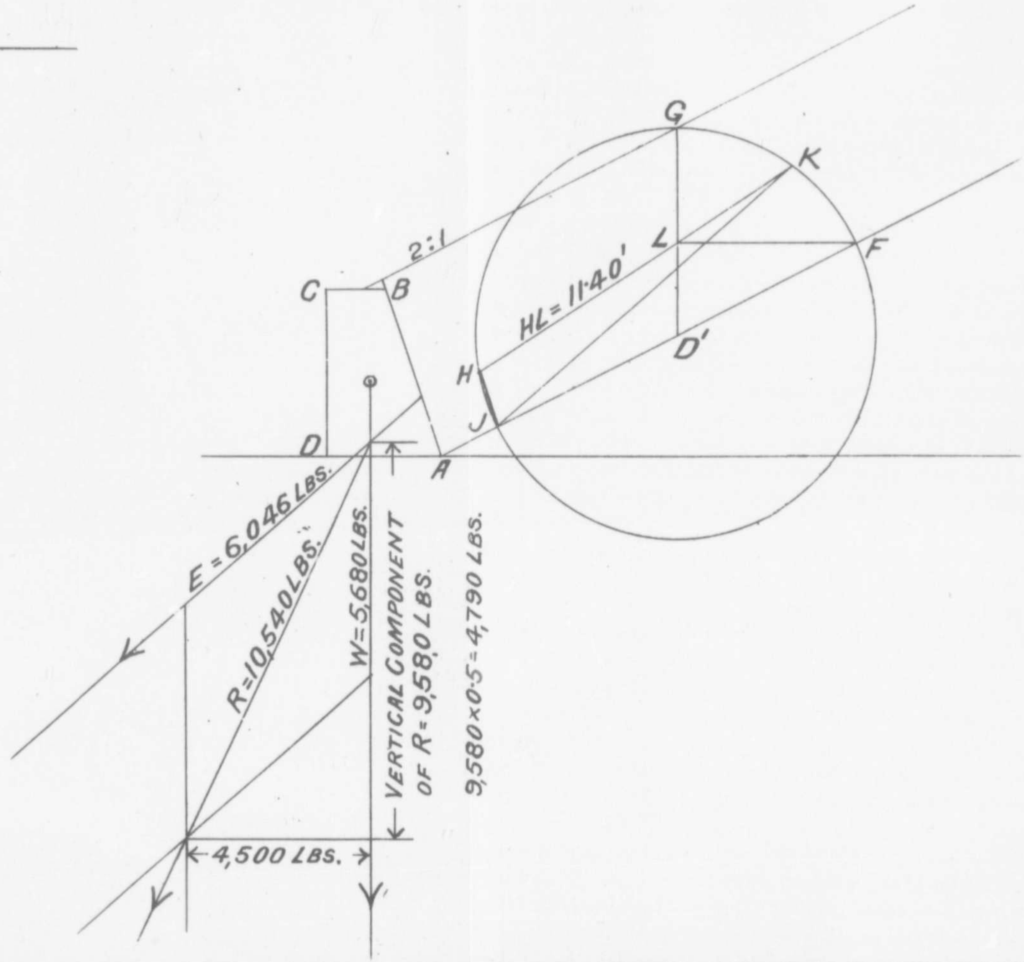
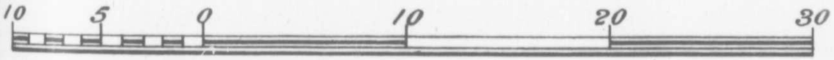


FIG. 2A



Scale of Feet.



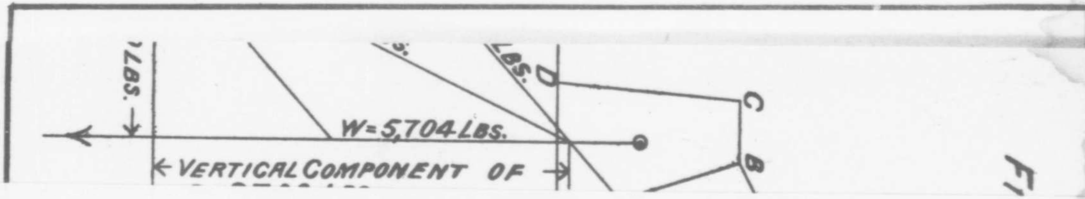

W=5,704 LBS.
VERTICAL COMPONENT OF
D
C
B

FIG. 3.

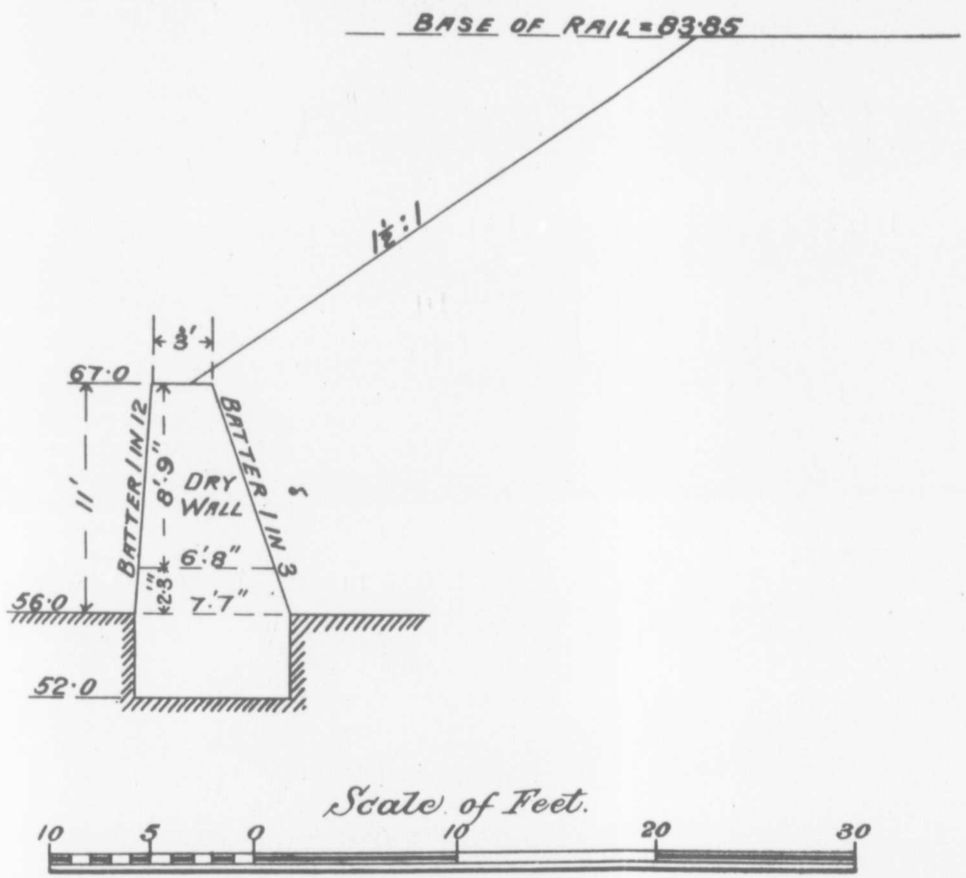
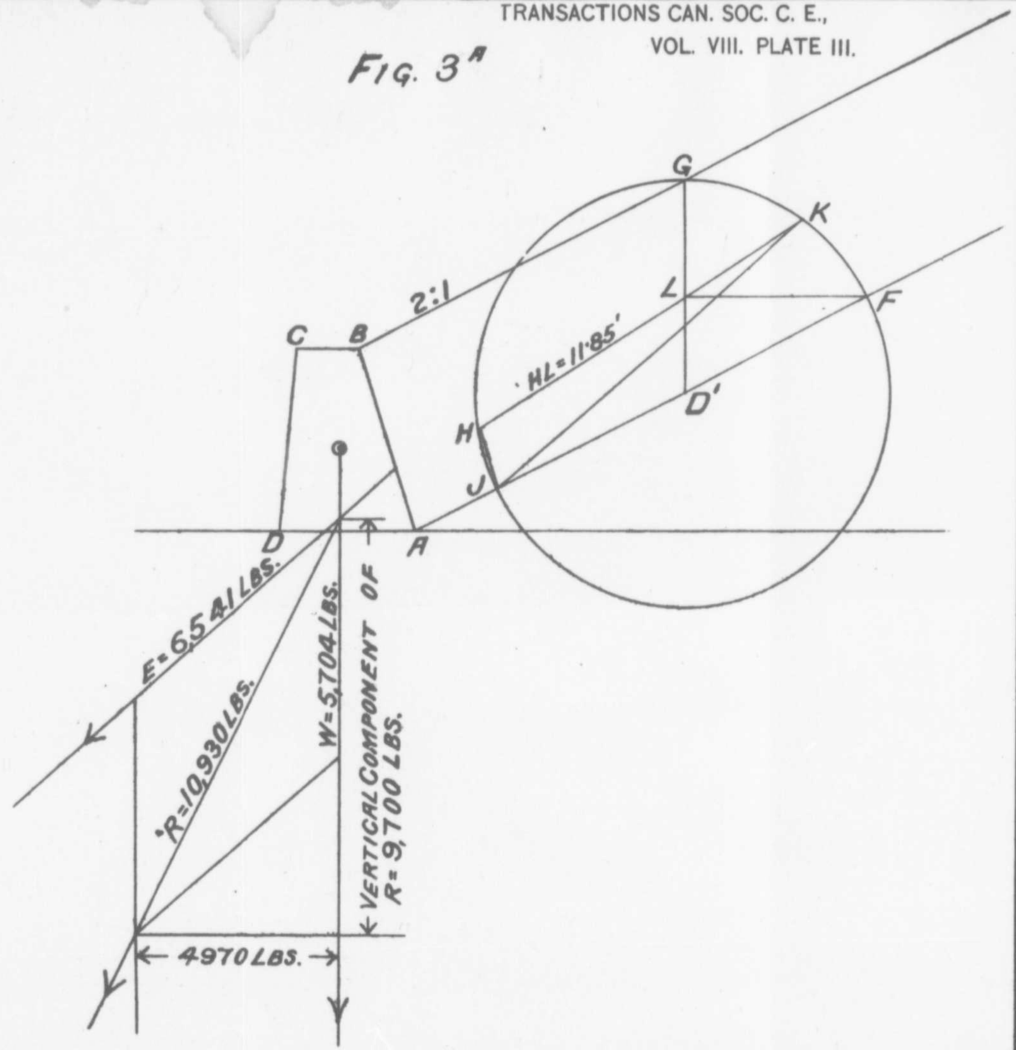

BASE OF RAIL = 83·85
1½:1
3'
67·0
11'
BATTER 1 IN 12
8'.9"
DRY WALL
BATTER 1 IN 3
6'.8"
2'.3"
7'.7"
56·0
52·0
Scale of Feet.
10
5
0
10
20
30

FIG. 3ᴬ


G
K
L
F
2:1
C
B
HL=11·85'
D'
H
J
D
A
E=6,541 LBS.
R=10,930 LBS.
W=5,704 LBS.
VERTICAL COMPONENT OF
R=9,700 LBS.
4970 LBS.

which was a little higher and not quite so thick, did not fail altogether, though it was built with a vertical face. The courses of this wall, built in cement mortar, could not, of course, slide over each other before overturning.

The sliding noticed in this case, as well as that mentioned in Case 1, seems to contradict the statement to be found in Mr. M. A. Howe's book on retaining walls, edition of 1886, page 48, that "experience "and theory prove that if the resultant cuts the base within the "*middle third*, the wall is perfectly stable, and will not yield either "by sliding or bulging, and also that the wall has a factor of safety of "at least 2."

This statement has, however, been omitted in the edition of 1891, and the writer has concluded that Mr. Howe must have found that it was not correct for dry walls, at least when they were subject to the vibration from passing trains.

Shortly after the failure of this wall the slope of the bank was found to be from $1\frac{3}{4}$ to 1 to 2 to 1 at a place where the bank had completely covered the wall.

In digging away the debris, at a place where no extra land could be acquired, considerable masses of snow were found quite hard and fresh in the months of August and September. The clay in the bank was also quite damp and greasy, and required very strong timber to retain it while the new wall was being built.

The writer noticed in one place that a $6'' \times 15''$ stick fifteen feet long, with its greatest depth against the bank which was about eleven feet high against it, was badly cracked.

This stick was well braced at the foot and at a point about eight feet up from the foot, and carried a length of seven feet of the bank. Unfortunately the writer was so busy with other work that he had no time to take proper notes of the shoring of the bank.

According to "Trautwine," this wall, if built with the same batter on front and back, should have a thickness of ten feet one inch at the base and five feet six inches at the top, instead of seven feet seven inches at the ground level and three feet at the top, as it was actually built, and Trautwine's dimensions are based on the assumption that the filling behind the wall would be of good material such as would stand at a slope of $1\frac{1}{2}$ to 1.

Considering that the filling would not stand at a steeper slope than 2 to 1, while moist, the writer thinks that, according to "Trautwine," the wall should have been at least ten feet seven inches at the base and six feet at the top, or about fifty per cent. thicker than it was built, and that it would have been better to have built a wall in cement mortar about ten per cent. thicker than the wall which failed.

The diagram 3A shows that, if the wall had been built according to Trautwine's dimensions, it should have had, by Weyrauch's theory, a factor of safety of one and a half against the stones sliding on the course above mentioned as being eight feet nine inches below the top of the wall; but this theory makes no allowance for vibration caused by trains.

Diagram 3A (Plate III) is drawn for the wall as it was actually built and for the course above mentioned.

As the wall was made with extra large stones, its weight is taken at 0.82 of solid stone, or 135 lbs. per cubic foot, the clay filling being taken at 120 lbs. per cubic foot, and being assumed to come only to the top inner corner of the wall.

The diagram shows that the horizontal component of the thrust is 4,970 lbs. per foot run of the wall, and that the vertical component of the resultant pressure is 9,700 lbs., which, divided by 2 to get the frictional resistance to sliding, gives 4,850 lbs. for this resistance; therefore, according to the theory mentioned above, the stones at this joint should have been just about ready to slide without the help of vibration.

As this wall did not fail till early in the summer after the filling was finished, when the clay was getting thawed out, it is probable that it would have been just about strong enough had the filling been of good material, deposited in layers and properly rammed behind the wall.

In view of the fact that the clay in the bank was still quite plastic and contained some snow, which might be expected to melt out gradually and make the clay still worse, and bearing in mind that a failure of the wall might derail a train and send it down the bank, and that, if the wall gave way, heavy claims for damages would have to be met, it was decided to rebuild the wall of a very heavy section, almost the same as that shown in Fig. 4B (Plate IV B), which was adopted in rebuilding the wall shown by Fig. 4 (Plate IV), the new walls in both these cases being much higher than those which failed so as to allow the bank to be widened out.

Fig. 4B (Plate IV B), drawn according to Weyrauch's theory, shows that the resultant pressure cuts the wall at ground level seven inches outside the middle third; this would leave the wall stable enough theoretically, as the foundation was good.


FIG.
B
VERTICAL COMPONENT
OF R=17,200 LBS.

FIG. 4.

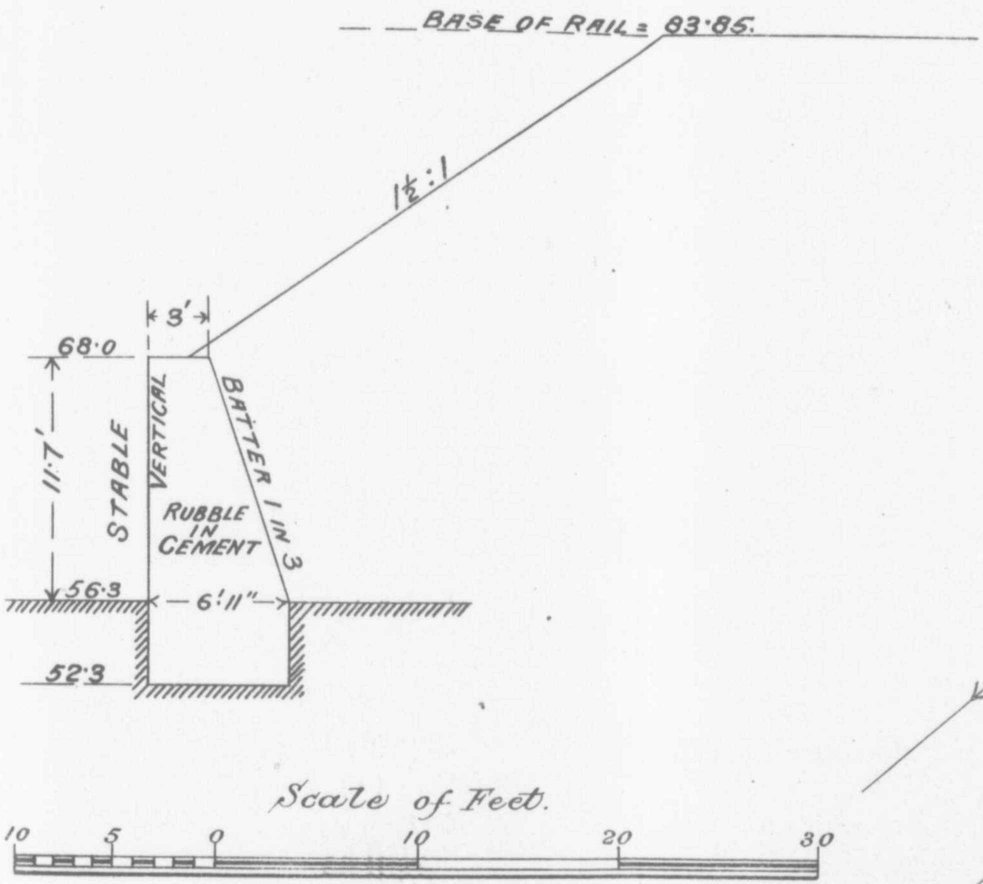


FIG. 4A

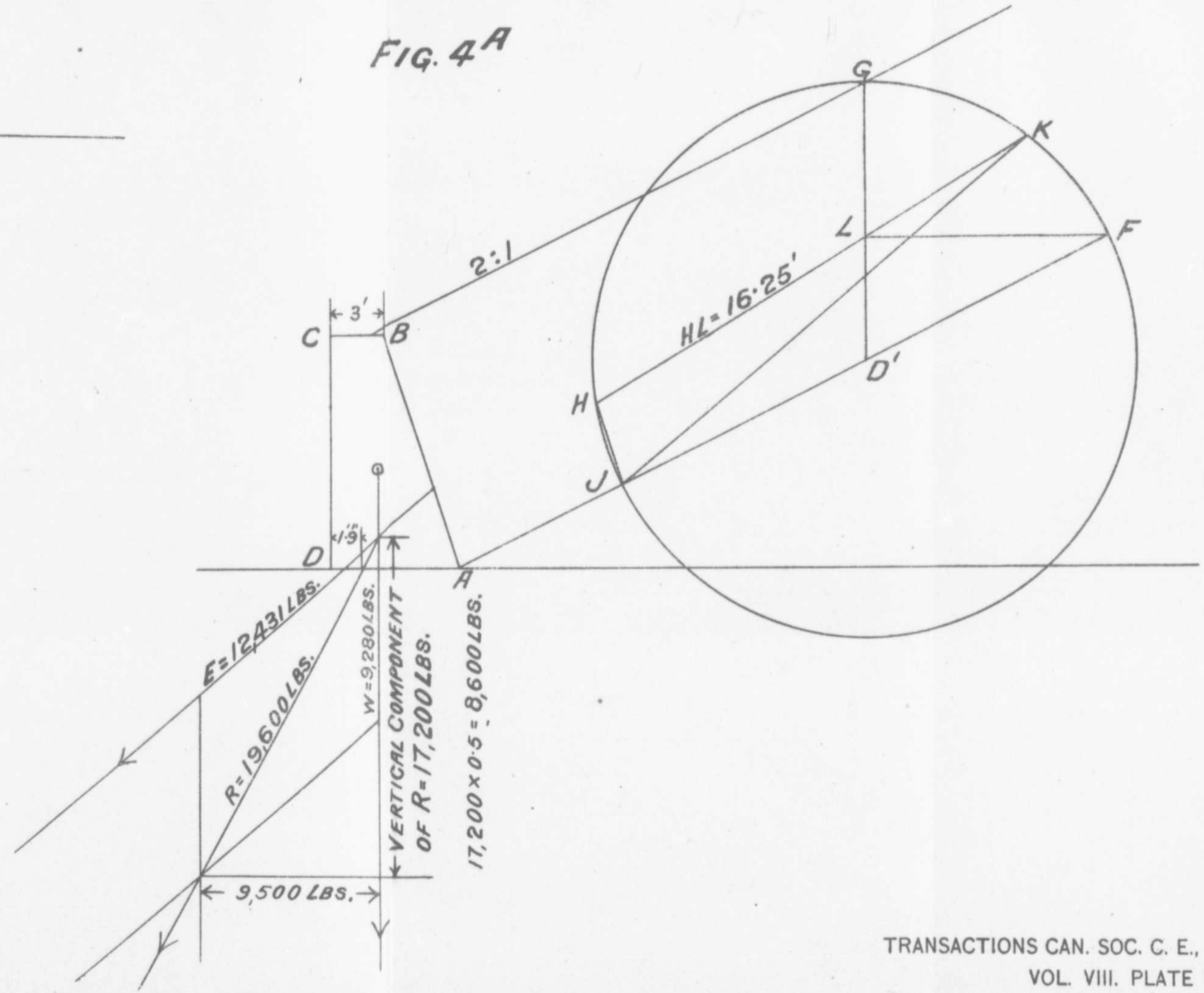


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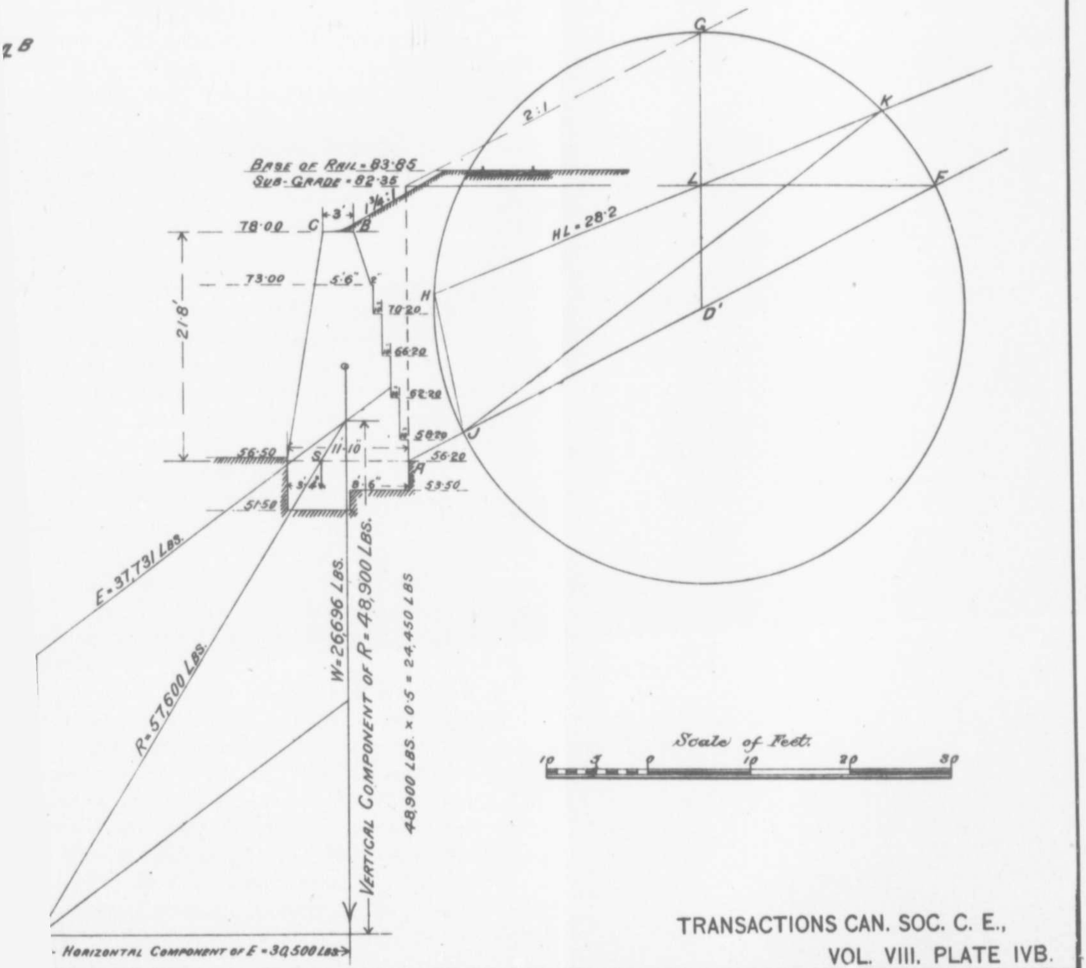
FIG. 4B



BASE OF RAIL = 83·85
SUB-GRADE = 82·35
78·00
C
3'
B
73·00
5'·6"
70·20
66·20
62·20
58·20
21·8'
56·50
S
11·10"
56·20
A
53·50
51·50
8'·6"
G
2:1
K
L
F
HL = 28·2
H
D'
D
E = 37,731 LBS.
R = 57,600 LBS.
W = 26,696 LBS.
VERTICAL COMPONENT OF R = 48,900 LBS.
48,900 LBS. × 0·5 = 24,450 LBS
HORIZONTAL COMPONENT OF E = 30,500 LBS.
Scale of Feet.
10
5
0
10
20
30

The diagram shows the horizontal component of the thrust to be 30,500 lbs. per lineal foot of the wall, and the vertical component of the resultant pressure to be 48,900 lbs., which, divided by 2 to get the frictional resistance of dry stone, would give only 24,450 lbs., as the resistance to the horizontal pressure; but as the wall was built with Portland cement mortar, there would be no danger of the courses sliding on each other.

In drawing this pressure diagram the weight of the wall was taken at 160 lbs. per cubic foot, the weight of the filling was taken at 120 lbs. per cubic foot, and an additional 2 feet was added to the height of the bank to make allowance for the train load being so close behind the wall.

According to "Trautwine," a wall of the height shown in Fig. 4B (Plate IV B), with the given surcharge, with the face batter transformed by Trautwine's method, which, in this case, adds 2 inches to the face at ground level and takes off 3 feet 5 inches from the top width in front, and with the back changed to the batter shown, which is $2\frac{1}{2}$ inches per foot for the lower part, and leaving the same quantity of masonry at the back, would be 14 feet 3 inches in width at the base and 5 feet 5 inches in width at the top.

These dimensions were considered excessive as they are about 35 per cent. greater than the standard which was used for fillings level with top of wall, and it was decided to build the upper 5 feet of the wall of the same thickness as the standard, but to give the wall a face batter of 2 inches per foot instead of 1 inch, according to the standard, thus making the wall 16 inches thicker at the ground level than the standard.

Weep holes were left in the new walls at intervals of about 6 feet, and the back of the wall was packed with small stone and spawls to secure good drainage behind the wall.

The wall shown in Fig. 4 (Plate IV) was built to retain a portion of the same bank as No. 3. Being rather higher than the highest part of the dry wall just dealt with, and as it was to be built with a vertical face because it adjoined a property line and abutted against a brick stable, it was built with cement mortar.

It was pushed forward gradually for some months before and after the failure of the wall No. 3, and would probably have failed altogether in the course of a year.

It was pushed forward about 5 inches at the top, when it was decided to take it down and replace it by the wall shown in Fig. 4B (Plate IV B), which has been already discussed.

The reasons for taking it down were firstly to secure more space by building a higher wall, and secondly to avoid the possibility of damages caused by a total failure.

According to "Trautwine," a good rubble masonry wall of the surcharge shown in Fig. 4 (Plate IV), and with the same batter at the back, should be 9 feet 5 inches thick at the base and 5 feet 6 inches thick at the top, instead of 6 feet 11 inches at the base and 3 feet at the top, as the wall that failed was actually built, and it seems certain that if Trautwine's dimensions had been adopted the wall would not have moved.

The thickness of 5 feet 6 inches at the top required for a wall with a vertical face might have been reduced to 4 feet 6 inches without weakening the wall if the front face had been given a batter of 1 inch per foot.

In the case of the new wall, with a front batter of 2 inches per foot, the neighbouring proprietor was allowed to run the roof of his stable back, and to connect it with the face of the wall, so as to keep snow and rain from getting into the V shaped space between the two walls.

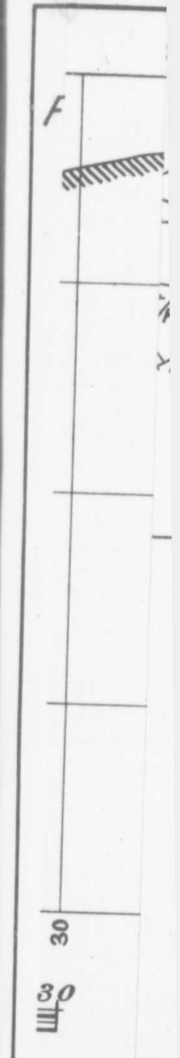
Fig. 4A (Plate IV), drawn according to Weyrauch's theory, shews that the resultant pressure cuts the base at one-fourth of its width from the front corner, and the vibrations caused by trains should throw it still nearer the front corner, so that it is possible that the small forward movement of the wall was due to excess of pressure on the foundations. The horizontal component of the thrust is about half the vertical component of the resultant pressure; but the courses could not have slipped on each other, as the wall was built in Portland cement mortar.

The new wall shown in Fig. 4B (Plate IV B) has shown no signs of failure.

It is true it is even thicker than the standard C.P.R. retaining wall, which may at first sight, as it did to the writer, seem too thick. It must be borne in mind, however, that this standard was designed not simply to retain an earth bank, but to carry and stand the thrust and vibrations of a heavy train running close up to it, either on tangents or sharp curves; and it has done this for many years and in a variety of places without any failures that the writer ever heard of.

The wall shown in Fig. 4B (Plate IV B) has, however, to stand a surcharge of 1.27 to 1, and the thrust of a soft clay bank, so that the writer thinks it is fairly proportioned.

Fig. 5 (Plate V) shews the old retaining wall on Seigneurs street between St. Antoine street and Dorchester street, where it runs diagonally up the face of the hill.



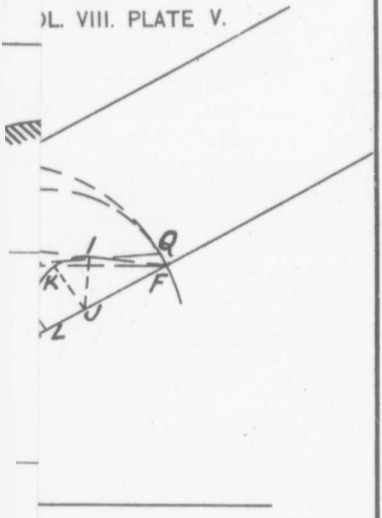

Q
K
F
J
L

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FIG. 5

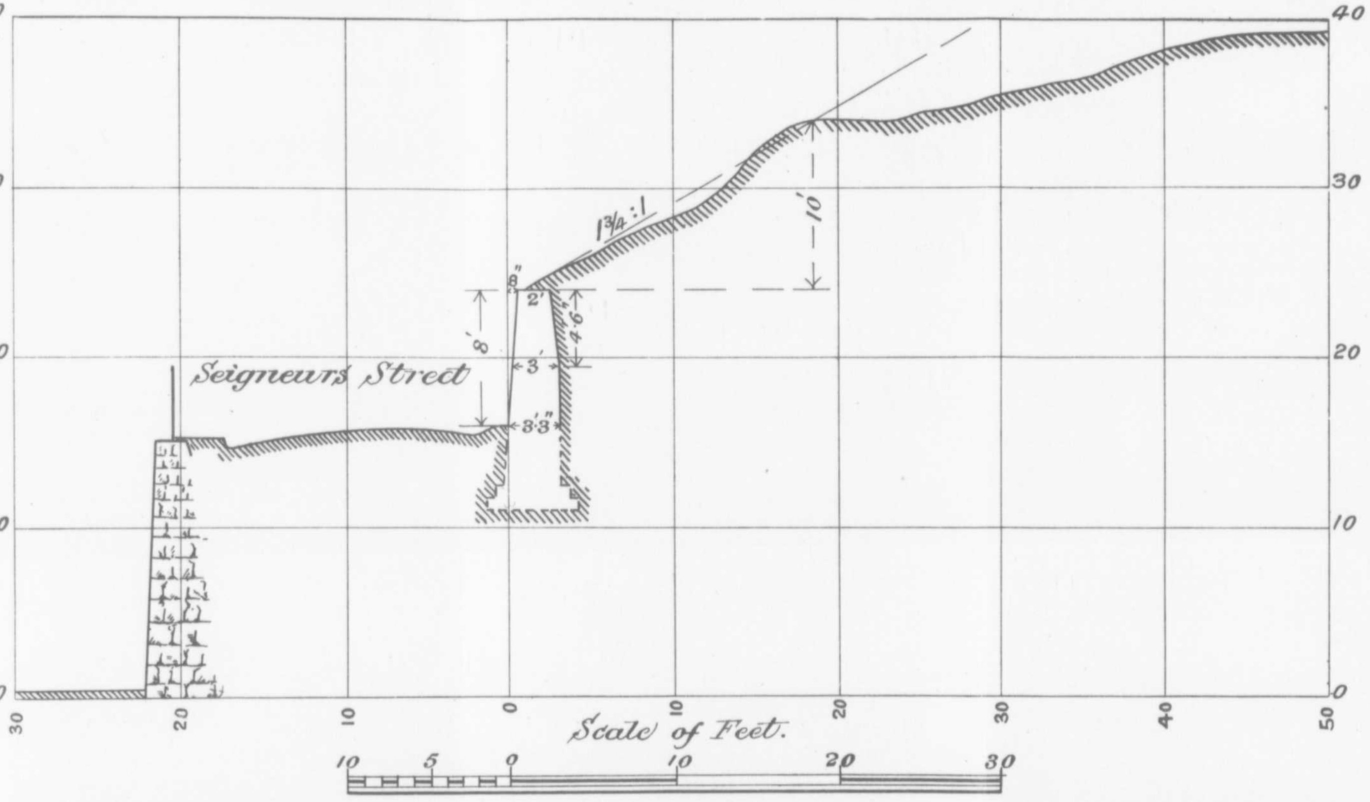
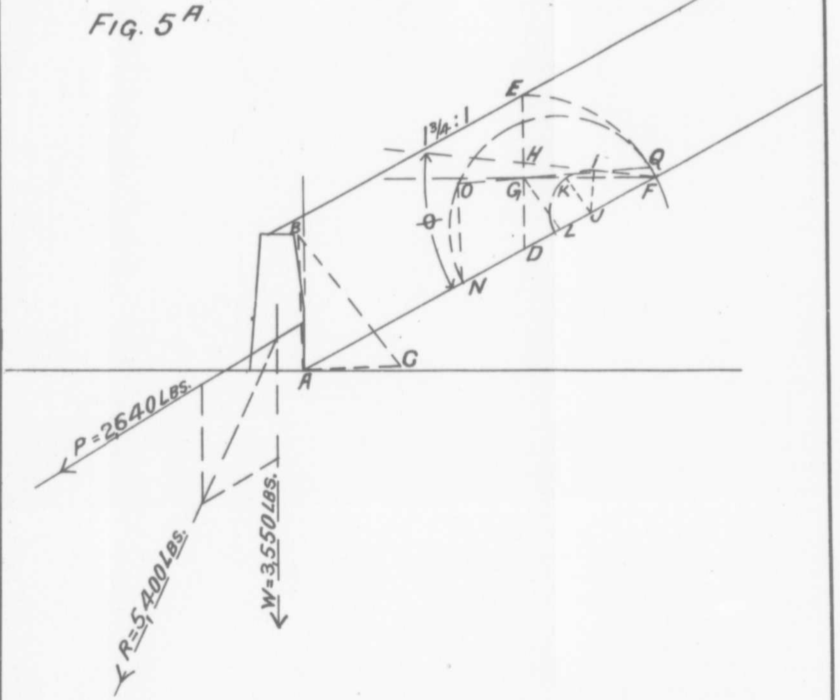


FIG. 5 A



b
a;

c
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The dimensions were taken by the writer while the wall was being taken down a short time ago, and seem rather too small considering the amount of surcharge, yet its partial failure seems to have been due to the want of proper care. Had the joints been all well raked out and filled with good cement mortar, it would doubtless have stood as long as it was wanted.

The writer understands that it was removed to make way for the widening of the street which entailed the building of a much higher new wall.

When the old wall was removed and the bank cut back, its face stood perfectly well at a slope of about $\frac{1}{4}$ to 1, apparently almost vertical, the material of the bank being mostly compact fine gravel and sand, which would stand at a very steep slope so long as it was undisturbed and protected from the weather; in fact, it looked firm enough to require a very thin wall if proper precautions were taken to prevent water from lodging behind it, and if the filling replaced at the back of the wall were well rammed so as to prevent any movement of the old bank behind.

It will be noticed that the bank retained by this wall is of a totally different nature from those already alluded to; the former is an old solid undisturbed gravel bank, the latter new clay filling dumped from cars with no attempt to spread the material in layers or consolidate it behind the walls.

The writer hopes that the City Surveyor will furnish the Society with a section of the new wall on Seigneurs street, giving the profile of the bank for some distance back from the wall.

According to Trautwine, a rubble masonry wall with a surcharge similar to that shown in Fig. 5 (Plate V), and with the given batter, should be 5 feet 5 inches thick at the ground line and 3 feet 9 inches at the top, instead of 3 feet 3 inches at the base and 2 feet at the top; however, it must be borne in mind that Trautwine's dimensions are given for a bank of clean dry sand which would exert far more pressure than the bank in question, the surface of which above and behind the wall was covered with the old sod and bound together with the roots of trees, and the material of the bank was, as already stated, very compact.

The Fig. 5A (Plate V) is drawn according to Weyrauch's theory for a surface surcharge sloping back at the same angle as the natural slope and for material standing at a slope of $1\frac{1}{2}$ to 1. The weight of the bank is taken at 110 lbs. per cubic foot and of the wall at 160 lbs; and the bank is assumed to come within a foot of the front of the wall.

The diagram shows that the resultant pressure cuts the base at about one-third of its thickness from the front corner, so that the wall should have been safe from overturning. The horizontal component of the thrust is 4,600 lbs. per foot run, while the vertical component of the resultant pressure, divided by 2 to get the frictional resistance, is 4,830 lbs.; but as the wall was built with mortar, there would be sufficient resistance to sliding of the joints—indeed, in this case, as the stones were small and not built in regular courses, the tendency for the stones to slide on each other should have been small.

Fig. 6 (Plate VI) is a section of the wall in front of the Archbishop's Palace on Lagauchetière street, from dimensions given to the writer by the contractor, who built it about 30 years ago, and repaired the portion from the entrance easterly to Mansfield street, a length of about two hundred and twenty feet, about nine years ago.

The writer was enabled to get this information through the kindness of Mr. A. Robert, the accountant at the Palace.

The portion of the wall from the entrance westerly to Cathedral street, a length of about 57 feet, has not been repaired since it was built, but bulges out at the top 4 inches at the middle of its length. The ends of this portion are well tied in by the wall on Cathedral street and by the return at the entrance, so that the unsupported length is under 50 feet.

The wall is all built in common lime mortar, and, so far as the writer remembers, the part repaired only had the front stones taken out and replaced with new mortar; the stones seemed to have been pushed out by the freezing and thawing of water lodged behind them.

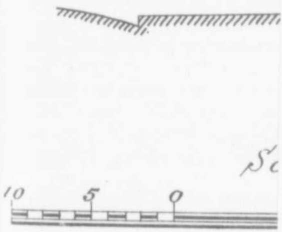
There are no weep holes in the eastern part, but it has one drain behind at the centre which discharges into the street sewer. The contractor said that he wished to have put more drains behind, but was not allowed to do so; and also said that he considered such drains much better than weep holes, which are liable in this country to get frozen up in the spring from the cold of the inner part of the wall, and that they let the frost into the body of the wall.

The writer hopes some members will give their opinion on this point.

There is no drain behind the shorter western part, but there is one weep hole at the street corner. If the dimensions given are correct, the wall is fully thick enough, and if built in cement and properly drained behind, should never have moved.

There is a thin cement catchwater drain behind the eastern portion, as shown in Fig. 6 Plate VI), which takes away the surface water from behind the wall.

FIG. 6.



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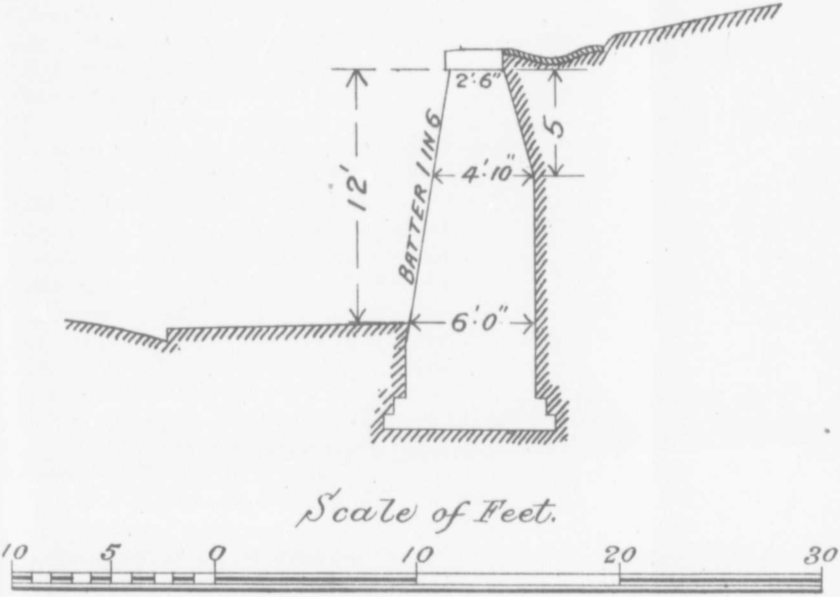

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Fig. 7 (Plate VII) is a section of the wall on the west side of Bleury street and just above Dorchester street.

It failed by bulging out on the face, and was taken down and rebuilt last year.

Through the courtesy of the Rev. F. X. Renaud, Superior of St. Mary's College, the writer was permitted to get the dimensions of this wall, and other information as to its construction, from the architects who designed it.

It appears that the architects at first advised the building of a 4 foot stone wall, similar to that which carries the present new building, which could be used for a future extension along Bleury street; however, the proprietors did not wish to go to so much expense, as they did not think of building any further in the future, and wished to reduce the cost of the wall as much as possible.

It was therefore decided to pave the slope as shown, build as light a wall as possible, and fill the V shaped space between the slope and the wall with light material, not rammed, so as to allow the water falling in the yard to percolate through the filling and run off through the drain at the foot of the slope, the drain being covered with flat tiles laid with open joints.

The wall was let by contract to the lowest tenderer, not the contractor for the new building, and the price was only sufficient to leave him $1.50 per cubic yard for the rubble backing.

The writer was allowed to see the specification for the wall. It was carefully drawn up, and provided for an ample number of headers, which were to be through stones wherever the wall was 2′ 6″ or less in thickness. It also called for 2 to 1 Portland cement mortar, made with White's or as good cement. It does not seem that the pressure of the earth filling was the cause of the bulge in the wall for which the Building Inspector had it taken down; for when it failed, the filling was not saturated with water, and there had been no time for frost to affect it.

It will be seen that the wall was about thick enough to retain the filling, for 8′ 9″ multiplied by 0.4 gives 3′ 6″ for the thickness at ground level, while the actual thickness of the wall was 3′ 3″, and the vertical pressure of the extra 10 feet in height would have been more than enough to ensure the stability of the wall, providing it were properly built.

In fact, the wall bulged out in one place where there was no filling at all behind it.

The greatest bulge was at a height of 6 or 8 feet above the level of the sidewalk, or almost as high as the top of the filling, and this seems too high to have been caused by the lateral pressure, since the greatest bulge should be about the centre of pressure.

The failure seems to have been due entirely to bad mortar, want of proper headers, and through stones and excess of mortar in the backing.

The writer examined the wall carefully after it had been almost all taken down, and could find no trace of a through stone or of a good header at all, and the wall seemed to have parted in two, the cut stone front separating from the backing.

The face was built of cut stone with a bed of only about 8 inches in depth, and the backing was of small stone with altogether too much mortar in the joints. The mortar was made of very fine dirty sand with too little lime in it, and what little there was no doubt of the useless fat lime now exclusively used in Montreal, because it is cheaper than good lime made from the black limestone which takes more fuel to burn it.

The consequence was that the upper 10 feet of the wall compressed the mortar in the backing, while the cut stone front, with its thin joints, would scarcely compress at all, and the front was forced out.

The writer has brought a sample of the mortar for inspection.

The architects protested against the way in which the wall was being built, and notified the proprietors not to pay for it; it was taken down not long after completion, and rebuilt with the money retained.

The writer believes that this wall would have stood perfectly well if a sufficient number of headers and through stones had been used, and if the mortar had been made of good cement and sand, in accordance with the specification; but thinks that it would have been better to have arranged to set the upper 2 foot portion 4 inches back from the face of the part below.

The diagram shewn in Fig. 7A (Plate VII), drawn according to Weyrauch's theory, shows that the wall would be in no danger of overturning, and that the courses would not slide on each other.

In drawing this, the masonry was taken at 160 lbs. per cubic foot and the loose earth at 80 lbs. per cubic foot.

It may be added that a part of the wall which bulged slightly is still standing.

The writer regrets that the various cases referred to in this paper are unimportant works, but thinks that, in describing them as fully as possible, the results may prove useful.

They seem to shew that Weyrauch's theory, *intelligently applied*, would be a good check on empirical rules.

7 A.

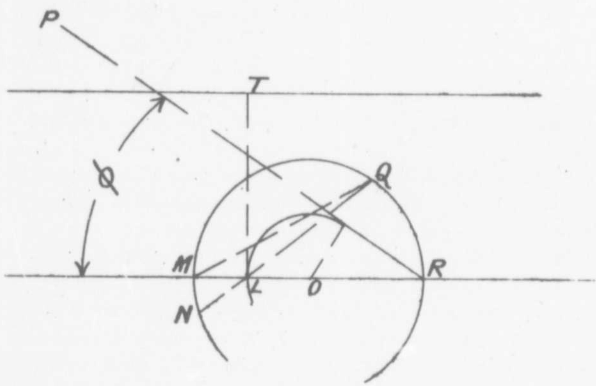


FIG. 7.

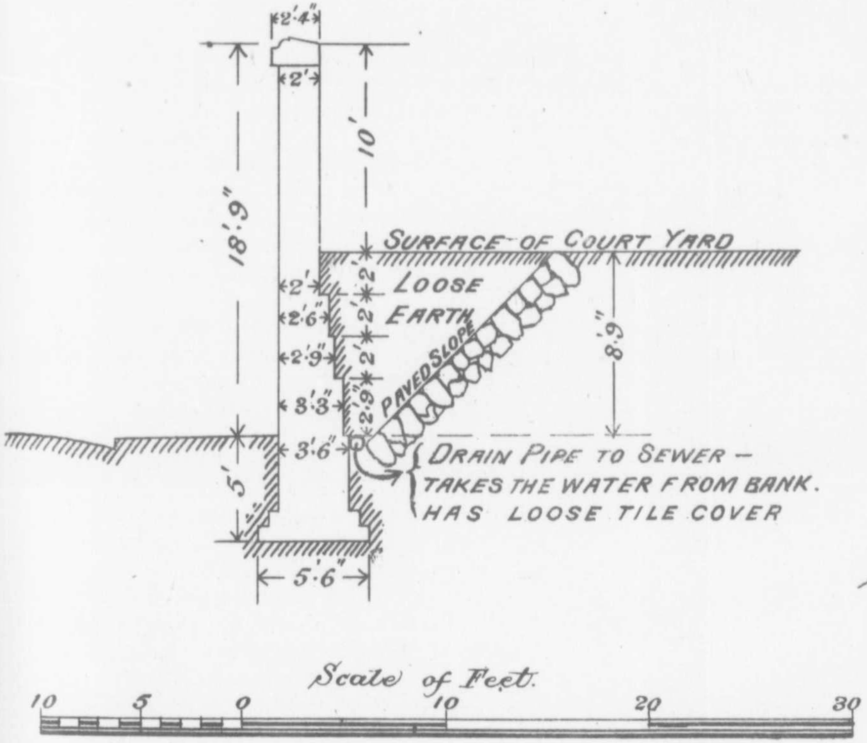
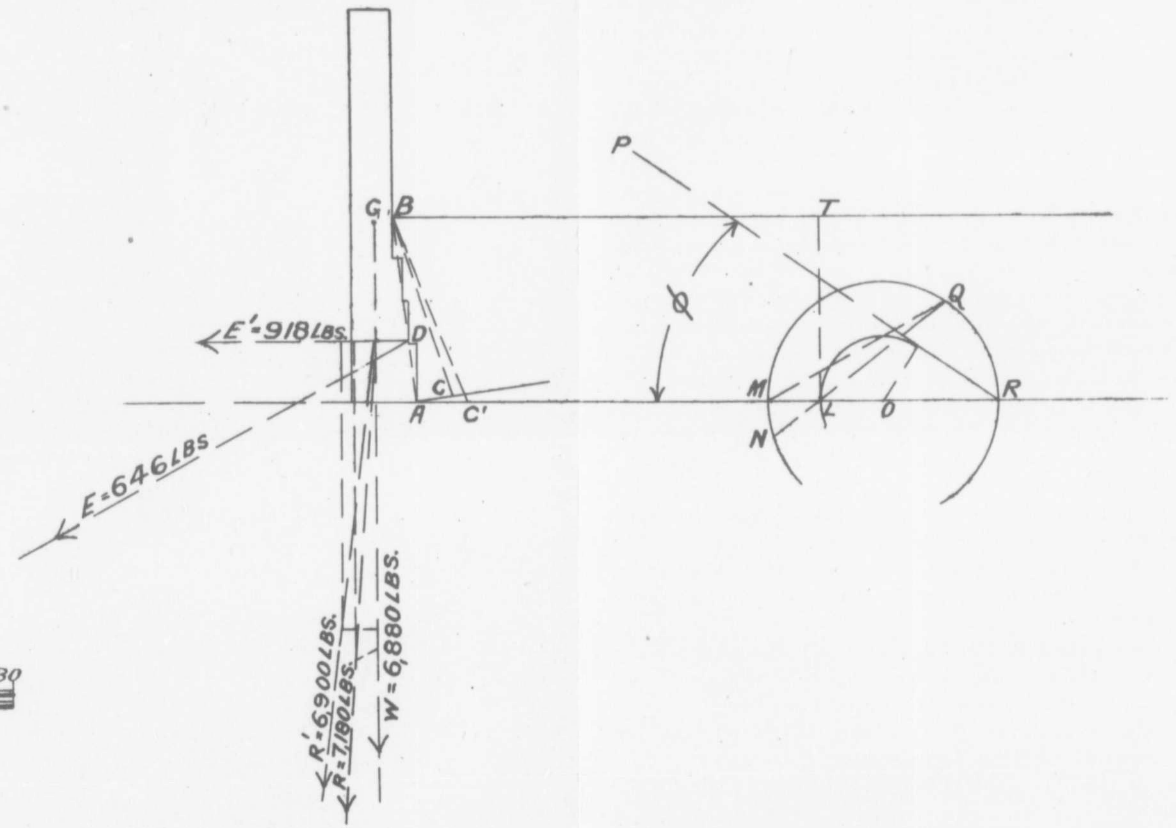

2'4"
2'
10'
18'9"
SURFACE OF COURT YARD
LOOSE
EARTH
PAVED SLOPE
2'
2'6"
2'9"
3'3"
3'6"
8'9"
5'
5'6"
DRAIN PIPE TO SEWER — TAKES THE WATER FROM BANK. HAS LOOSE TILE COVER
Scale of Feet.
10 5 0 10 20 30

FIG. 7A.


G B
E' = 918 LBS.
D
C
A C'
E = 646 LBS
R' = 6,900 LBS.
R = 7,180 LBS.
W = 6,880 LBS.
P
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This theory assumes that the filling is without cohesion, and that its free surface slope would be a plane surface.

This seems to be the worst condition that a filling could assume, and that is what is to be guarded against in the case of embankments made by dumping from trains on a trestle.

In the case of a wall intended to retain a natural bank, part of which is to be cut away, nothing but experience and good judgment will be proper guides in determining how far theory may be departed from, and these would require to be supplemented by a thorough knowledge of the nature of the bank.

A natural bank, like that at Seigneurs street, only requires to be properly drained, and to have the material replaced behind the wall well rammed, so that the new face may not gradually loosen and press forward till at last there will be as much pressure against the wall as from a new bank ; if these precautions are carried out, a very light wall might be used.

The writer is well aware that such an eminent authority as Sir Benjamin Baker, whose practical rules are so good, seems to think that theory is entirely at sea with regard to retaining walls, if one may judge from his book on the lateral pressure of earthwork published by D. Van Nostrand in 1882.

With all due deference to this distinguished engineer, the writer thinks that he is a little hard on theory.

Many of the failures mentioned in his book were due to bad foundations ; such cases as these require quite different treatment from those where the foundation is solid, and should be kept quite separate.

Without attempting to criticise the book above mentioned in full, the writer may mention that on pages 26 and 34 Sir Benjamin obtains the pressure against two walls by calculating the moment of stability of the walls after they had been pressed forward considerably. Surely this is not fair to theory, since the force required to start a wall and push it out of plumb would be much greater than that finally required to push it down when leaning; and, besides, it is reasonable to assume that the pressure would be relieved by the forward movement of the wall, unless the filling had no cohesion, and unless it were kept up to its original level.

Again, on page 49, referring to cracks in clay over tunnels, the cracks being probably along the line of least resistance, he assumes this to be Coulomb's line of least resistance, and argues against his theory because the cracks had a slope of ½ to 1.

There does not seem, however, to be any very good reason for doing so since Coulomb's theory did not take into account the cohesion of the clay; and, besides, the writer thinks that the case of a mass of clay over a tunnel is not quite the same as that of a bank against a retaining wall with a plane face.

In conclusion, the writer would ask his fellow-members to bear in mind that this paper has been written rather too hurriedly for proper consideration, and trusts that they will give as much information as they can on the subject.

ROUGH TESTS OF THE FRICTION OF A FLAT BEDDED GREY LIMESTONE FROM MONTREAL QUARRIES, WITH ITS NATURAL FACE ON THE NATURAL FACE OF A LARGE FAIRLY LEVEL STONE OF SAME DESCRIPTION.

25th October, 1894.

The faces had no abrupt square projections, and no projections seemed to be more than $\frac{1}{4}''$ above or below the average face.

The smaller stone was not weighed until after the tests were over, and it was then found to weigh almost exactly 60 pounds.

Sometimes on pulling the smaller stone it stuck, and took about 42 lbs. to start it, $= 60 \times 0 \cdot 7$.

1. On first trial, it took from 35 to 36·7 lbs. to start the 60 pound stone and from 23·3 to 26·7 to keep it moving.

2. On second trial, on a very uniform faced but rough stone, it took from 35 to 40 lbs. to start and from 28·3 to 31·7 lbs. to keep the small stone moving.

3. On a new stone step, bush-hammered, it took from 31·7 to 36·7 lbs. to start the smaller stone and 20 lbs. to keep it going.

4. On jarring the 2nd large stone with a crow bar, it took from 30 to 31·7 lbs. to start the smaller stone and about the same to keep it moving.

5. On jarring the 2nd large stone with a wooden bar, it took about 31·7 lbs. to start the smaller stone and keep it moving.

On tilting up the larger stone, the angle of repose was found to be about 42° to 45°, but the smaller stone slipped quickly.

Summary.

1. 0·58 to 0·61 to start and 0·39 to 0·44 to keep moving.
2. 0·58 to 0·67 to start and 0·47 to 0·53 to keep moving.
3. 0·53 to 0·61 to start and 0·33 to keep moving.
4. 0·50 to 0·53 and No. 5, 0·53 to start and keep moving.

Thursday, 8th November.

P. ALEX. PETERSON, President, in the Chair.

The discussion on Mr. Stewart's paper on "Building Railways Across Peat Bogs or Swamps" occupied the evening.

Thursday, 6th December.

P. ALEX. PETERSON, President, in the Chair.

Paper No. 99.

TRANSPORTATION ON OUR INLAND WATERWAYS AND CANALS.

By A. L. HOGG, M.Can.Soc.C.E.

This is a subject of much importance. Only a few weeks ago, a convention was held at Toronto, to discuss and to forward any practicable scheme to connect our great Inland Lakes with the sea-board. A system of deep waterways was discussed, via the St. Lawrence and Hudson Rivers. The great cost of such a scheme, based upon the customary lockage system, would undoubtedly involve its promoters in ultimate financial disaster *à la* Panama, and there the matter rested, in so far as the convention was concerned, and since then, with the exception of a few casual remarks from an occasional correspondent in the local press, we have heard nothing more of it.

While improvements are constantly being introduced in our methods of transport by land in all its various branches, very little apparently has been accomplished in the meantime to improve our methods of transport in connection with our waterways; methods that were introduced two or more generations back are still in vogue to-day. In this field of engineering we seem inclined to follow too closely, and sometimes blindly, in the footsteps of the early engineers, content to accept their plans and details for our modern works of this class without question, not presuming, or perhaps fearing to alter designs which have answered the requirements so well, and have withstood the test of years. It is always prudent to let well enough alone; but in this particular the time has arrived for an advance to keep up with the age we live in. The writer proposes, through the medium of this paper, to suggest for discussion one important innovation to the existing methods in our canal transport. The principal reason for the introduction of this innovation is the vital one of cost, as compared with the lockage system, and if it can be made to work as efficiently, so much the better, ensuring to the promoters and shareholders a reasonable return for capital invested, by virtue of the immense reduction in the estimates.

At various times, in watching the progress of vessels through a series of locks in our canals, it has occurred to the writer that here might be an opening for improvement, in substituting some other arrangement to overcome summits than that of climbing by an ascending and descending ladder of locks, and now proceed to describe the scheme proposed as an offset to the lockage system in our canals and waterways, for the transfer of vessels, over summits from one water level to another. The accompanying drawings illustrate a system of skidways, combined with pontoons and slips, applying the principle employed by the French, in their "Chemin de Fer Glessant," between the sliding surfaces of the ways, to eliminate friction as far as possible, when the vessel is being drawn up the incline, or to act as brake power, when being let down the incline as desired. To utilise to greatest advantage this system of skidways, the engineer must secure a suitable site; gently sloping hill side is the most favourable for the purpose, as then the work of grading up the ways, being mostly surface work, gives greatest strength with least expense. There are a variety of ways, in which these skids can be placed according to the nature of ground selected for site, but the simplest form of their use would obviously be up and down in one direction.

A most important consideration in the choice of a site for these skidways is that they should be located near a stream of sufficient volume to operate the hydraulic appliances efficiently, and failing such volume, a storage reservoir can be constructed at a convenient point on the hill side, to be supplied from the nearest streamlet or gathered from springs and surface drainage. It is most essential in a design for these skidways to have an absolute plane surface between the sliding ways.

The utilisation of these ways in connection with dams and weirs, for the improvement of natural water-courses, especially in mining or isolated districts, as are found in the Kootenay District of British Columbia and many other parts of the interior of Canada, would be an economical means of local transport to the highways of trade for the products of these districts, and thereby develop the country, and benefit our mining and other interests which have been sadly neglected —and which are in much need of some encouragement.

Some may doubt the practicability of handling loaded vessels in this manner. Those may be referred to an article by Sir Benj. Baker, on Ship Railways, in the *Nineteenth Century Magazine*, of March, 1891, as to what has been done in that way. The following is an abstract:

" It is very rare in engineering problems to find that what has been " done successfully on a small scale is impracticable on a large one; " but rather the reverse is the truth.

" The same truth, that with modern appliances and increased ex- " perience, engineers of the present day encounter less difficulty in " carrying out large works than their predecessors successfully sur- " mounted in dealing with small ones, holds good of steamboats and " countless other things, and doubtless will hold good as regards ship " railways.

" But, after all, a ship railway adapted to modern vessels is but a " new combination of mechanical contrivances, every one of which has " been well tested singly to at least as severe an extent as it would be " tested in the combination. Thus, in the case of a ship railway the " vessel has to be lifted out of the water, and it has to be hauled along " a railway, on a properly constructed car. It is necessary in order to " prove the above proposition, therefore, to show: (1) That heavy " vessels can be floated over and blocked on a submerged cradle, and " that the cradle and blocking will carry the ship safely when moving " along the railway. (2) That the vessel and cradle can be lifted to " any required height out of the water to rail level. (3) That the " rails and sleepers will support the heavy rolling load. These points " will now be dealt with very briefly in the light of past experience.

" A vessel's home is upon the water, but she is built on land, and " she has to return there whenever the slightest repairs to her hull " have to be effected. She must be strong enough, therefore, for both " conditions—ashore or afloat. It is now seventy years since the first " great improvement was made, by the introduction of what was known " as the 'Patent Slip' by Mr. Morton of Leith, where the ship was " floated over a submerged cradle, blocked thereon, and hauled up an " inclined railway by mechanical power. During the past seventy " years thousands of vessels, up to three thousand tons in dead weight, " have been so hauled out of the water, over a short length of railway, " without the slightest difficulty or structural injury—and as a result " of past experience, no reasonable doubt need exist as to practicability "of constructing a cradle capable of carrying a vessel over any length "of railway with safety, certainty and despatch. It has been equally "demonstrated by past experience that heavy vessels can be satisfac- "torily lifted to any required height out of water. The largest dock "in existence, known as the 'Bermuda Dock,' was built about twenty- "five years ago, of sufficient power and capacity to lift ironclads weigh- "ing 10,200 tons clear out of the water. Of more recent design are "the 'Depositing Docks' of Messrs. Clark & Standfield, where the "vessels are lifted by pumping out submerged pontoons, and are "deposited on fixed staging, and it is stated that the operation occu- "pies only about twenty minutes. As an illustration of the great "strength of ships, it may be mentioned that at the Nicolaieff Dock, "the steamship 'Russia,' about 3,000 tons in weight, and 334 feet in "length, was lifted out of the water by pontoons extending only for a "length of 174 feet under her keel, thus leaving both ends of the "vessel unsupported, and that, notwithstanding this great overhang, "no sign of structural weakness was exhibited.

"As regards the ability of the ways and sleepers to carry the load of "a ship and cradle, in the manner proposed, little need be said in this "age of advanced mechanical appliances."

Having thus, by an appeal to past experience in connection with the raising of ships and the haulage of heavy loads, justified the statement that, after all, these skidways are but a new combination of old contrivances, we may proceed to consider briefly the application of those methods in the case now under consideration as an alternative for locks in our canals and waterways.

The object of the proposed innovation is to cheapen the cost of works of this class, and so place enterprises of the kind in the first rank, as paying concerns, and thereby secure the confidence of the investing community and to demonstrate that the capital required for its construction could not be better employed. There are many places in Canada where the natural topography of the country would permit of these skidways being constructed in connection with dams and weirs, connecting the natural water stretches at a comparatively small cost, considering the great advantages derived to the country at large, in the development of these otherwise waste places where minerals abound, as phosphate, iron, stone and lumber and valuable ores of all descriptions that are awaiting transport to the markets of the world, and which at present lie buried and unproductive. The accompanying drawings show two methods of handling vessels on these inclines.


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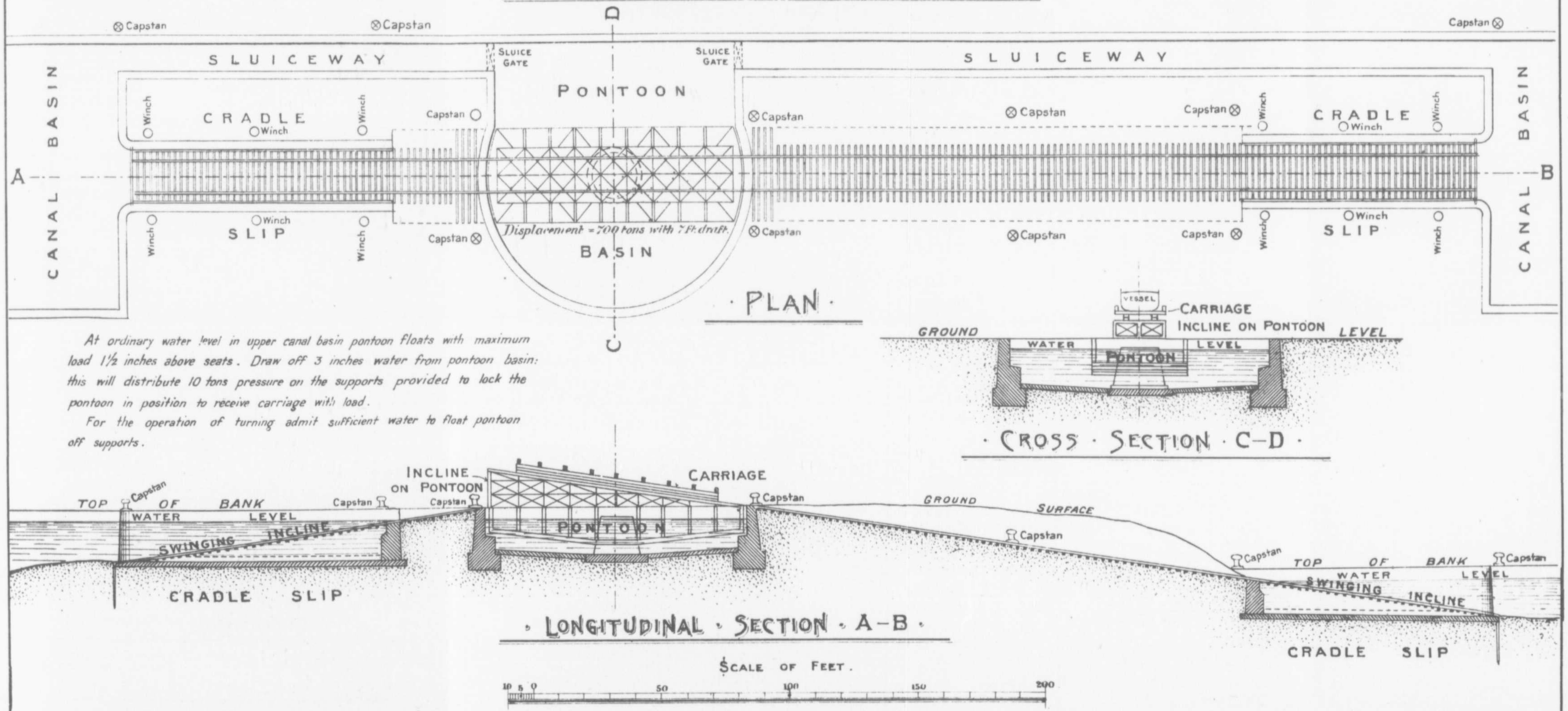
No 2

· Sketch · for · SKIDWAYS · with · PONTOON · TURNTABLE ·
· proposed · as · an · alternative · for ·
· Locks · in · Canals ·

A. L. HOGG, C. E.



In No. 1 it is proposed to raise the vessel to the incline by means of pontoons, to which is attached a swinging gridiron, consisting of a very stiff combination of longitudinal and cross girders made of steel and firmly rivetted together, and which when swung to the angle of the incline is supported at intervals by iron chock-blocks and stays underneath, worked by hydraulic power, so that the gridiron then in effect constitutes a solid part of the main skidway.

Hydraulic power is also to be provided for pumping pontoons, and the working of capstans and winches for manœuvring the vessels on the ways; at the ends of the incline cradle, slips are provided to expedite the work of placing the vessel on submerged cradle over-ways, and properly securing it before being hauled up incline. These slips have also attached a swinging gridiron, similar to those in the pontoons described above. The cradles, like the gridirons, are formed of a rigid combination of steel girders carrying keel-blocks and sliding bilge-blocks of the usual lifting dock type.

The order of procedure in raising a vessel and transferring it across the skidways would be as follows: for plan No. 1:—The vessel is floated into the pontoon or cradle slip, "as the case may be," over the submerged swinging incline and cradle; then sufficient water is pumped out of the pontoon to bring it to the level of the incline where it is secured, and the vessel with cradle on gridiron properly blocked, the whole is then mechanically swung to the angle of the incline. The ship and cradle would then be in position to be hauled along the ways on to the incline and transferred to the other cradle slips at foot of incline, and there placed in the water to resume her voyage by a converse operation to that used when being raised to the incline at the other end of the way.

Plan No. 2, in so far as regards the ways and cradle slips at foot of inclines, is similar to that in plan No. 1, as to design and operation, the only difference being the introduction of a floating turntable at the summit of inclines, which removes the necessity for expensive pumping machinery required in pumping the pontoons used in plan No. 1.

Sir Benjamin Baker states that various plans have been proposed from time to time for the quick and efficient blocking of the curved surface of a vessel's hull to the flat top of the cradle. Hinged bilge-blocks, hydraulic rams, elastic bags filled with air or water, and many other such contrivances have been suggested, but the present universa practice in docking, or in launching a ship, is to use simple wooden keel and bilge blocks. In docking a vessel, nearly the whole of the weight comes on the keel blocks, and the bilge blocks are few in number, and extend only for about the middle third of the ship's length. In launching a vessel, the weight is transferred from the keel-blocks on to the launching ways on each side of the same, by means of a couple of narrow cradles or bilge logs of hard wood, packed up to the hull of the vessel by soft wood filling. These cradles carry the ships down the too often imperfectly bedded inclined launching ways at a speed of some twelve miles an hour. As the vessel is leaving the launching way, her stern is waterborne, whilst the bow is pressing hard on the shore, but yet it is the rarest thing for any mishap to occur to a vessel even under this singularly rough treatment.

The best way of blocking a vessel on the cradles will be quickly determined after a few weeks' experience, but in the first instance, the well tried one, of timber keel and bilge blocks, cannot be far astray.

The following extracts from Trautwine, relating to the laws governing moving bodies on inclined planes, will assist to an understanding of the subject:

Sliding force	(parallel to surface of plane)	= W, × Sin M N O.
Pressure	(perp. " " ")	= W, × Cos M N O.
Friction	(parallel " " ")	= W, × " " × co-eff. of fric.

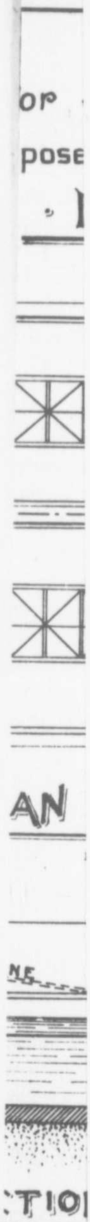
Friction does not vary as the angle of the plane, but as the cosine of that angle, or in the same manner as the perpendicular pressure varies. Suppose we desire to slide a vessel of say 600 tons, in the manner proposed, up an inclined plane, sloping 8° or 14 feet in 100 feet, we have to overcome the parallel sliding force and the friction.

W
Sliding force = 600 tons, × nat. sine 8°.
= 83.52 tons.

W
Friction = 600 tons × nat. cosin 8° x co-eff. of friction.
= 600 .9903 × .14 prop. of friction to pres.
= 81.79 tons.

combined force to overcome = 81.79 + 83.52 = 165.31 tons.

This force but balances the downward tendency of the load together with its friction, and in this condition it is plain that to impart motion to the now unresisting load we must apply some additional force. We desire again to slide the load down the plane, what force have we to employ? Here nothing resists but the friction, viz.: 81.79 tons, and the sliding parallel force helps to the extent of 83.5 tons,

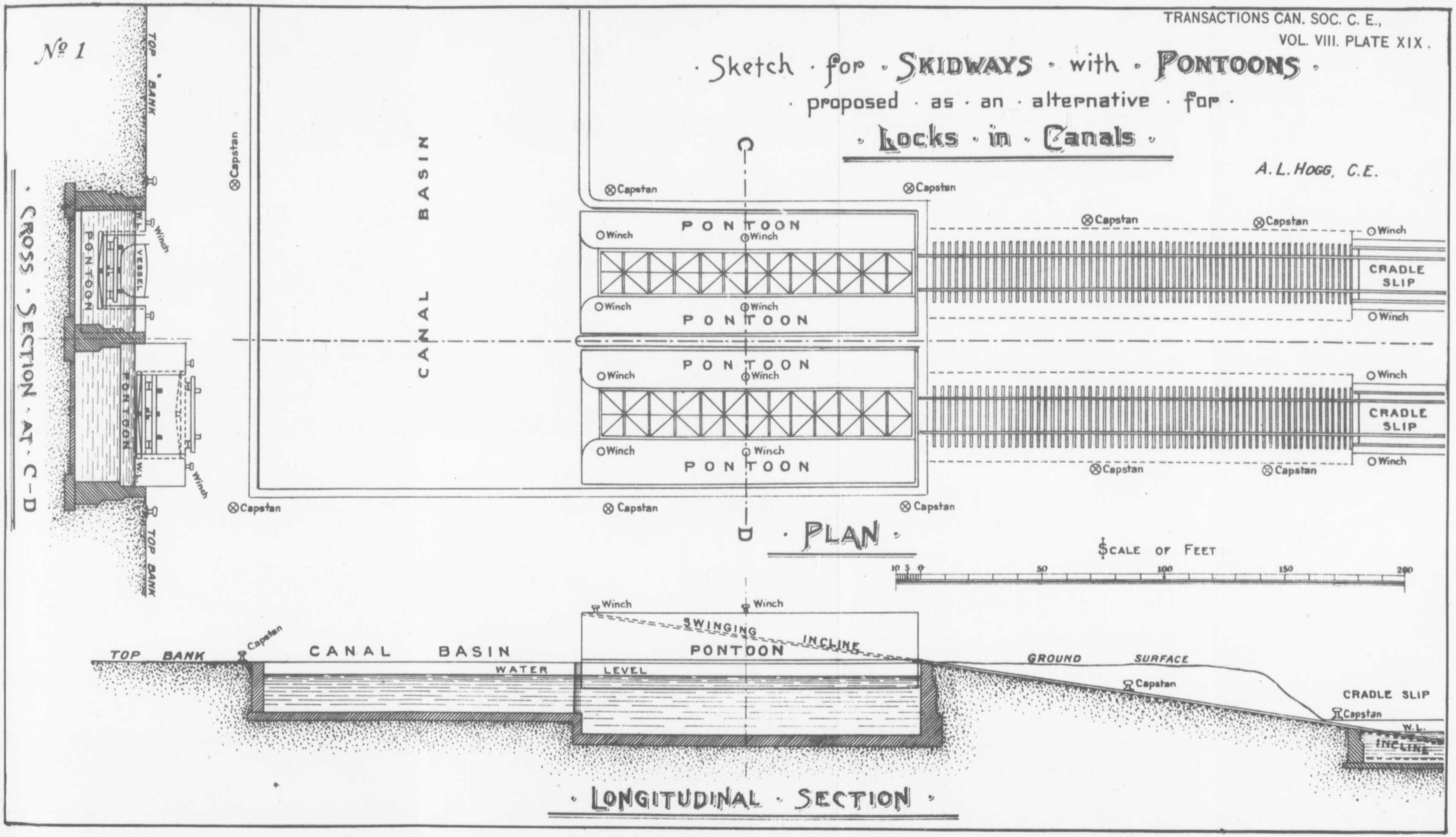


TRANSACTIONS CAN. SOC. C. E.,
VOL. VIII. PLATE XIX.

No 1

Sketch for SKIDWAYS with PONTOONS proposed as an alternative for Locks in Canals

A. L. HOGG, C.E.



therefore in this case we would have to apply about 1.73 tons of break power to keep load from sliding down the plane.

It has been stated that the main object of the author in bringing forward these skidways was the vital one of cost, as compared with the lockage system. In the first place, where a series of locks would be necessary, these ways could be put in at half the cost of locks. Secondly, the greatest saving would be effected in the reduced quantities in excavation, and earth-work in the canal as a whole. The skidways can be lengthened with very little additional expense, for the purpose of placing the centre line of the canal proper on the contour of minimum excavation ; by this means the quantities can be considerably reduced, which, taken with the saving effected in dispensing with locks, together would make quite a respectable showing.

Where one lock only is required to overcome a summit, these skidways can offer no advantages over the lockage system.

In conclusion, the writer hopes that this important subject will meet with some consideration from the members of the Society, and draw out such discussion as the subject deserves. Although an innovation, it may be the means (through discussion) of bringing to light some practicable scheme to accomplish the object in view. In which case this paper will not have been written in vain, nor love's labour lost.

At the Shipbuilding Yards of Messrs. Blackwood and Gordon, at Port Glasgow on the Clyde, a cheap and well arranged hauling slip is to be seen in operation. No accident of any importance has occurred from its use since it was constructed some years ago. Steamers 250 feet in length are frequently hauled up on this incline and blocked for repairs. The hauling gear was designed especially for the work by the master mechanic, and works smoothly.

DISCUSSION.

Mr. H. Irwin.

Mr. Irwin said he understood from an interview with Mr. Hogg, that the system proposed by him was intended only for small canals to be used as feeders to railways and larger canals, though in the first part of the paper under discussion, Mr. Hogg refers to such large undertakings as the Panama Canal and a deep waterway from the Great Lakes to the Atlantic. It is difficult to arrive at any definite conclusion as to the system proposed without any comparative estimate of the cost of the various structures which are so briefly described, but it would seem certain that the pontoons, turn-tables and boat carriages shown in the drawings could not be made to handle boats of more than 200 or 300 tons capacity, except at such a cost as would prevent the system from being worked economically.

As to the "Chemin de fer glissant" idea, it does not seem that this scheme has been a commercial success as yet. When the experimental railway was exhibited, the track was arranged so that there was a down grade from each end towards the centre, so that when the water was let into the "patins" the train started of itself, and the propelling turbines were then able to increase its speed and carry it over a summit; but it would seem that the system employed would be unable to start a train up a grade, for the propelling turbines could not set the train in motion without first letting the water under the "patins," when the train would at once begin to slide back down hill. As all boats using Mr. Hogg's system would have to be started up heavy grades of from 10 to 15 per cent., it would seem impossible to apply the "Chemin de fer glissant" principle to them. But even if it could be applied, the saving would be very small in comparison with the cost, for in going up a grade such as of 14 per cent., the greater part of the resistance to be overcome is due to the grade. Taking for an example a boat weighing, with its load and carriage, 600 tons, assuming the friction under the "Chemin de fer glissant" system to be only 1 pound per ton as claimed for it, and the frictional resistance of a carriage on wheels running on a track of rails to be 8 pounds per ton, on a 14 per cent. grade, the resistance under the former system would be made up of

		tons.	
frictional resistance	600 lbs.–	0.3	
grade resistance		84.0	
	Total	84.3	tons

while under the latter system it would be

frictional resistance	4,800 lbs.–	2.4	tons
grade resistance		84.0	
	Total	86.4	tons

being a gain of only 2.1 tons, or 2.4 per cent. in favour of the former system, which entails the use of very expensive machinery, intended for light and high speed vehicles, and has not yet proved to be a commercial success.

It appears from the records of the Morris Canal in the United States, which is or was operated by means of planes used by boats up to 100 tons capacity, that a plane costs about as much as a flight of six locks of about 6 foot lifts, but that it requires much less water, even when water power is used, to draw the boats up the plane; and boats going up a plane are moving towards their destination. The planes also require much less time for transferring boats than is necessary for lockage. The Stanhope plane on the Morris Canal only required 3,180 cubic feet for the water wheel to draw a boat up the incline, and only 90 cubic feet to let one down, while a flight of locks in the same place would have required 72,240 cubic feet for passing a boat up. The time by the plane was 5 minutes 30 seconds to go up and 2 minutes 30 seconds to go down; while 96 minutes would be required to pass a flight of locks.

The speaker understands very well that small canals cannot compete with railways in carrying goods; but as there are places where a small canal operated by planes might be very useful, he would propose a different scheme from Mr. Hogg's for getting over a summit or for passing from one grade to another. This scheme would consist in having a platform long enough to take the pontoon or frame for carrying the boat. The platform would be capable of tilting on a horizontal axis placed at right angles to the tracks at the centre of the platform, the ends of the platform to be raised or lowered by hydraulic jacks. One of these platforms would be placed at each end of the plane and one at the summit and each change of grade. The speaker thinks that these platforms would overcome the difficulty of passing from one grade to another in the case of boats up to 200 tons capacity, and by running the boats suitably past the centre of the platform the weight of the boats would do the greater part of the tilting, the jacks at the ends being used to control the motion. Possibly the platform principle might be applied to all sizes of canal boats. Members who wish to look further into this matter will find some information in the Scientific American Supplement, Vol. 15th, Feb. 24th, 1883, page 5943; Vol. 19, May 9th, 1885, page 7786; Vol. 20, July 4th, 1885, page 7911, and in the American Engineer & Railroad Journal (Van Nostrand), December, 1894, page 555.

Mr. W. J. Sproule.

Mr. Sproule said he thought that a member who proposes such a scheme should give more information respecting the method proposed for working it. There is very little given as to the way the vessel is to be got out of the water or into the water. The vessel seems to be lifted on a barge and then tipped up at one end, which would necessitate an arrangement for lifting more complicated than the method proposed for the Chignecto Ship Railway. He could see no improvement in sliding a vessel. He thought that for the credit of the Society, a member who proposes a scheme in which the only novelty seems to be the sliding of the vessel on skids instead of transporting it on wheels, if indeed this be a novelty, should give sufficient details and figures on which to base a claim that the novelty would be an improvement.

CORRESPONDENCE.

Mr. G. H. Webster.

Mr. Webster said he was glad to receive Mr. Hogg's paper on "Transportation on our Inland Waterways and Canals," and trusted, that it would be the means of directing the attention of our members to a subject which is of great importance to Canada.

As a resident of the North-West the writer is particularly interested in any scheme which may be devised to overcome existing difficulties in the way of developing navigable channels in our rivers. There is probably no part of Canada more interested in securing means of cheap transportation to the seaboard for grains and other farm produce, and the return shipments of merchandise, than the Province of Manitoba and the North-West Territories; but the difficulties in the way of securing the cheapest of all known means of transportation, namely, by water, has prevented attention being directed to the great possibilities of this Territory in that direction.

Before anything can be done, however, to render available, for the use of commerce, the great natural arteries of this part of the Dominion, some plan on the lines suggested by Mr. Hogg must be substituted for the old canal lock. We have rivers of great length penetrating the most fertile lands in the world. Many of these rivers are now navigable for a month or two in the spring, but the summer flow of water in them is too low to admit of the use of the ordinary canal lock in passing dams or weirs, but the supply of water is quite large enough to enable them to be made navigable during the open season, by means of dams and weirs, if vessels could be lifted over these obstructions in some quick and easy way without using the water stored up by the dams for other than power purposes in operating the lift.

As a contribution to the literature on this subject, the writer sends a clipping from the *Railway Review*, giving an illustration and description of a tramway built, "to connect the Marne river with the l'Ourcq canal, both passing near the city of Meaux, France, but without any communication between them. The distance requiring to be traversed when going in the ordinary way is more than sixty miles from the canal to the river, while the actual distance between them at Meaux is less than half a mile. To avoid this long detour, M. Fournier, a water-way contractor, decided to connect the two water courses at his own expense, and chose a place called Beauval upon the river Meaux, just below the dam of the low farms. The distance from the canal to the river is less than half a mile at this point, and the difference in level is about 40 feet. It would take four or five locks of the common kind, which would be very expensive and require a quantity of water that could not be obtained. It was, therefore, necessary to find a different arrangement, and the present project was adopted.

"Two basins have been constructed at each end of the road in direct communication with the corresponding water courses. These two basins are connected by a double track railway of different heights, upon which runs a car or cradle carrying the boat, as shown in the accompanying illustrations. The boat is brought into the basin, placed upon the car, and hauled to the other basin by means of a cable running over a toothed wheel geared with a ratchet-rail laid in the center of the track. The power is supplied by a turbine operated by water taken from a dam in the river at this point. The building erected for this purpose has room for six turbines, but at present only one is used.

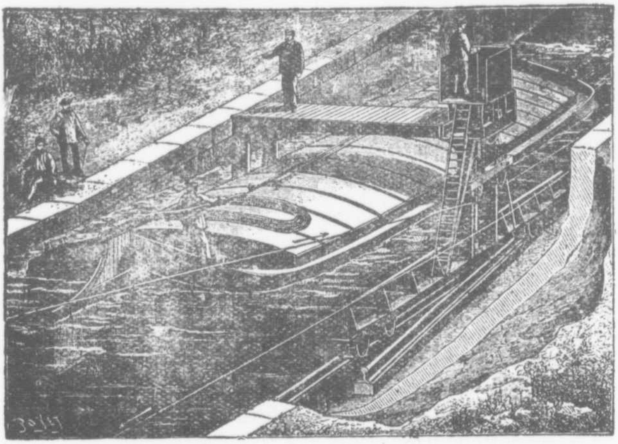


Fig. 1.—INCLINE RAILWAY FOR TRANSPORTATION OF BOATS.

"This car or cradle is shown in Fig. 1. It is composed of two T-iron beams held by cross beams forming a frame 75 ft. in length. This frame is laid upon two trucks, each having two axles about 6½ ft. apart.

"The boat is loaded directly upon the frame; as these boats are 90 ft. long, they project about 6 ft. beyond the frame at each end, but this has occasioned no inconvenience.

"A bridge is built over the center of the car. This framework has upon the side, as shown in Fig. 1, a system of pulleys that carry the cable. The cable is half an inch in diameter ; it is moved at the rate of about 50 feet per second.

"In the old method of towing, a chain was used, but it does not give good results. The chain vibrates violently, often breaks, and sometimes leaves the pulleys. It has been advantageously replaced by the ratchet-rail. The ratchet-rail is attached to rail ties and upon walls of masonry in the mill race. The rails that the car runs upon are of the Vignole type, weighing 90 pounds per meter. The ties are very strong, and placed near together so as to support the heavy loads. The track supports 14 tons per wheel of the car carrying a loaded boat. The gauge of the track is about $6\frac{1}{2}$ feet.

"The track goes out of the lower basins with a heavy grade, which is that of the bottom of the basin. The grade is 4 per cent. in the basin and 6 per cent. at the top.

"The wheels of the two trucks do not run upon the same rails in the basins, the truck that occupies the lowest position according to the natural grade at the bottom runs upon a specially raised track, in such a way that it is always upon the same level as the other truck. The auxiliary track is inside the normal track in the basin ; the gauge is not so wide. The wheels are so made that they can run upon either track. The rear truck runs upon the narrow track by its inside tires; when it goes out of the basin, it runs upon the normal gauge on its outside tires. The forward truck, on the contrary, at the departure from the basin runs upon its inside tires upon the normal track at a lower level. This arrangement maintains the boat in a horizontal position, and it runs upon the normal track to the other basin, where it again finds the wide track, and runs upon its outside tires. This arrangement is represented by Fig. 2.

"As can be seen, there are a series of ingenious arrangements which, joined to the very new application of ratchet railways for hauling boats, is particularly interesting."

Mr. Webster suggests that this is a subject of such national importance that it should receive attention from the Dominion Government, and that one or two of our leading hydraulic engineers should be sent to France and other countries, where great attention has been paid to the improvement of rivers, to examine and report on the latest methods adopted for overcoming the difficulties in the cheapest and most practical way.

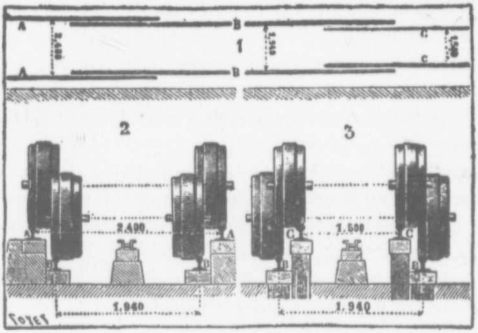


Fig. 2.--PLAN OF RAILS.

In earlier days waterways were the principal means of transportation for general commerce in the old world as well as in America, but since the introduction of railways, the small, slow-going inland canal has been neglected. A renewed interest is being taken in them now, due to the low margin of profit in producing grain and products of the mine and forest. Great improvements have been made in the capacity and speed of vessels for canal and river navigation, but the old, wasteful lock remains in all its original glory, and why? probably, for no other reason than a prejudice against removing a vessel from its native element for fear that it might thereby be subjected to injurious strains. But surely the lessons learned in the use of marine railways of short length and in dry docks should make it plain that such fears must be unfounded, and this should be particularly true in reference to the small vessels which would be used in rivers in all parts of Canada, which might so easily be made navigable if their slender supply of water was not to be used for lockage purposes.

Under the system in vogue it is very necessary, in considering the question of constructing a canal or improving a river, to know that there is a plentiful supply of water for such loads as may be required and to maintain the surface level of the upper reaches at a fixed minimum elevation. No doubt, a large number of promising enterprises of this kind have had to be abandoned for lack of water supply. Now, if this feature can be eliminated by following up Mr. Hogg's suggestion and designing a successful lift, slide or tramway, whichever it may be, it cannot fail to prove of immense benefit to the cause of cheap transportation.

Mr. Wicksteed said he had read the paper with interest, and it suggests some thoughts to him: 1st. Would the author's inclined planes and apparatus be in ordinary cases any or much cheaper than a lock or flight of locks? 2nd. Would not the amount of time consumed in raising, keel blocking, skidding and lowering the vessel be a very serious offset against such a possible saving in first cost? The writer is under the impression that where lifts or inclined planes have been used or experimented upon, it has been with a view to economising the consumption of water rather than reducing first cost. With regard to the strains on a vessel's hull in being lifted or carried, the writer would point out that in launching or locking, the vessel does not carry a 3,000 or 4,000 ton cargo. To dock a loaded vessel has always been looked on as a very dangerous operation. Such vessels as are in use upon the lakes with very flat bottoms, square bilges and small depth of hold would seem to be particularly ill adapted to being "monkeyed" with under such conditions. Mr. H. K. Wicksteed.

Referring to the problem of connecting Lakes Huron and Erie with the seaboard, the writer quite fails to see any analogy between it and the ill-digested Panama Canal project. In the former case, the question is one merely of cost, of doing on a large scale what had been repeatedly done on a small one. In the latter project, there are, on the other hand, tremendous engineering difficulties, no feasible plan for grappling with which had ever been formulated at the time work was commenced. There were absurdly inadequate estimates and extravagance, bad judgment and corruption at every turn. What scheme, small or large, could hope for success under such conditions?

What the farmer in the West needs is not the straightest or the most direct, or the most romantic, or even the quickest road to market,—it is the one by which he can reach it *cheapest*, and that route is *via* the Great Lakes, the Ottawa and Montreal.

The farmer and the grain buyer and shipper of the Western States recognise this great principle. The same classes in Manitoba do not, but are led away by the visionary hope of rendering themselves independent of the East, with the help of the common *per se*, of diverting the trade of the northern half of the continent through their territory from existing channels, instead of enlarging and improving those channels to the extent of their needs.

Mr. Allison said the remarks in the second paragraph of the paper on the alleged backward condition of water transport appear to be somewhat wide of the mark. Surely (to mention only a few things) Mr. J. L. Allison.

the improvement to the St. Lawrence, the locks on each side of the Sault Ste. Marie, the improved harbours, the fleets of large steamers on the Lakes, and the improved facilities for loading and unloading grain, coal, ore, etc., represent no inconsiderable advance on the water transport of "two or more generations ago."

The author claims great economy for his system, but it must be remembered that it applies only to that part of a canal in which the difference in level is overcome, or where the locks would be placed. It is unusual for the cost of the locks, in a canal of any considerable length, to represent more than one-third of the total cost. If, then, the skidways "could be put in at half the cost of the locks," the saving in first cost would not be more than one-sixth, scarcely an "immense reduction." In order to secure even this economy, the whole difference of level would require to be collected on "gently sloping hillside."

The author's claim that the use of these ways would lead to the more economical location of the rest of the canal does not seem to be well founded, as the location of the summit level would be governed by the same conditions as would hold in case locks were used.

This system depends for its success on the presence of a film of water between the fixed and sliding surfaces. The principle has been applied on a small scale by M. Girard, and later by M. Barre, in the "*Chemin de Fer Glissant*," but is it not putting the case over favourably to say that it is "employed" by the French? The principle has been experimented with for the last thirty years, but can scarcely be said to be "employed" by the French any more than the Boynton Bicycle Railway can be said to be "employed" by the Americans.

As per details.—The first plan proposed makes no provision against the tilting and rising or falling of the pontoon if a vessel were moved off or on. By the second plan this trouble would be avoided, as the turn-table would have end bearings; but each vessel would be turned about and would have to be turned in the water. This would make necessary a turning basin at each, or at least at one end of the ways, and would be a cause of delay to the vessel and to any other that might be approaching the ways from the opposite direction.

Mr. A. L. Hogg. In replying to the questions and criticisms brought forward in the discussion upon the above subject, the author desires first to express his thanks to the members of the Society for the courteous manner in which his paper had been received, notwithstanding its many defects. His suggestions offered were treated with great indulgence, considering the meagreness of the details submitted for information. The writer might have elaborated more, had his idea not been to bring out, in course of discussion of the subject, the suggestions of others which might lead to a practicable scheme being worked out in detail, with estimates, etc., complete of the various structures introduced. It is a very simple matter for anyone to estimate for himself, from the description and sketches submitted, when once the material to be used in its construction is known, and the maximum capacity of the vessels and machinery required to operate same are determined upon. It ought to have been explained, on presentation of the paper, that the designs shown for illu tration were got up for vessels not to exceed 300 tons capacity, and to be applied to the improvement of our rivers and inland waterways, and not to canals proper.

The writer grants that great strides have been made within recent years in the direction indicated by Mr. Allison, but none in the way of utilising existing natural water courses, to which this scheme of skid-ways is more particularly directed.

The system does not depend for its success on the presence of a film of water between the fixed and sliding surfaces of the ways; this method was only suggested as one means, amongst a host of others, which might be employed to eliminate friction, as far as possible, without introducing the propelling apparatus employed in the "*Chemin de Fer Glissant,*" to haul the loaded vessel over the ways; for this purpose, capstans are provided at short intervals along both sides of the ways.

In Plan No. 1 provision is made against raising or tilting of the pontoons, when load is moving on or off, in the following manner, viz:— The pontoon, with maximum load upon it, is raised to the level of the ways, where it is held securely in position, being anchored at that level, under a strain equal to the maximum load that it is designed to raise and carry. Against side-tilting, provision is made by guide-ways cut into and fitted on top of side-walls of the basin.

The swinging platform proposed to be introduced into the cradle slips at foot of ways, and into pontoons employed in Plan No. 1, may be operated by levers, or chains, by winches, hand worked, or by hydraulic power; in this way there should be little or no difficulty in raising vessels on to the ways, preparatory to being hauled across same.

Mr. Irwin proposes "Tilting Platforms" to overcome summits and changes of grade; this arrangement could be applied to take the place of the "Turn-table" in Plan No. 2, thereby doing away with the objection made against it, and would cause less delay to approaching vessels entering the slips.

THURSDAY, 20TH DECEMBER.

GRANVILLE C. CUNINGHAM, Member of Council, in the Chair.

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

MEMBERS:

JOHN P. BURNYEAT, JAMES B. SPENCE,
EDMUND J. WALSH.

ASSOCIATE MEMBERS:

DAVID OWEN LEWIS, GEORGE ROSS,
LEWIS HOWARD WHEATON.

STUDENTS:

HENRY J. LAMB, ROBERT G. REID, Jun.,
ANGUS SMITH.

The following have been transferred from the class of Students to the class of Associate Members:—

ARTHUR EDWARD CHILDS, HORACE B. KIPPEN,
CHARLES R. F. COUTLEE, RICHARD S. LEA,

The discussion on the affairs of the Society and on Mr. Hogg's paper on "Transportation on our Inland Waterways and Canals," occupied the evening.

Thursday, 3rd January.

P. ALEX. PETERSON, President, in the Chair

Paper No. 100.

THE RESISTANCE OF PILES.

By HENRY F. PERLEY, M.Can.Soc.C.E.

Piles are used under varying circumstances:—(1) to form a foundation where the soil is of such a nature as to preclude the super-imposing of a structure on it, but which, by the use of piles, is compacted to such an extent as to afford sufficient resistance to a sinking or settlement of the piles which carry the load; (2) as a ready means of obtaining a foundation where a loose or soft stratum overlies a firm and compact material, to or into which the piles are driven and derive their support; (3) to serve as columns of support, as in the case when driven in clusters, or singly, as in pile-bridging and wharfing, where the piles are capped and carry only the superstructure, and a dead or a live load, but are subjected, it may be, to the lifting power or action of ice; (4) where they are driven to form a coffer-dam, and are not subjected to any vertical pressure, their object being to provide a water-tight structure, strong enough to resist the unequal side pressures to which they may be subjected; and (5) to form a retaining or revetment wall.

The resistance to which a pile is subjected is of a two-fold nature,—(1) that which it meets with whilst being driven, and (2) that which it offers in sustaining either a vertical load or a lateral pressure

In the literature on "pile-driving," the subject appears to be treated in a very profound manner, and we have no end of wonderful calculations and still more wonderful formulæ to perplex the brain of the practical man, and needlessly worry him with their purely theoretical assumptions, complex forms, and variable constants; and all the more so, seeing that the formula which might apply in one case would not apply at all to others, and thus the adoption of the majority of the formulæ to be found in pocket-books and manuals is to be deprecated.

With regard to the resistance a pile offers in sustaining a load, a complication ensues, as it may be so placed that *two* different resistances have to be borne by it. In a foundation pile, whose head is on a level with the surface of the ground, and thus is supported throughout its whole length, the resistance experienced in driving is, in some degree, a measure of the resistance to settlement, and a greater load per square inch can be imposed on it, because it is a column supported at all points in its length against flexure and rupture, both of which actions are modified and, it may be said, greatly modified by the nature of the ground or soil into which the pile is driven; for it stands to reason that a pile which has passed through a comparatively soft stratum, and then penetrated a hard stratum, cannot support the same load that it would were it driven into a stratum solid throughout. Then again—take the case of a pile in a bent of a pile-bridge. Here we have a pile which is to be driven x feet into the earth, and to stand y feet above its surface, unsupported, except in so far as it may be tied to other piles by walings, braces, or caps. The resistance of the y portion of the pile is its ability to support as a pillar or column the dead and live load imposed on it, and to transmit such pressure to the x portion, to be met by the resistance afforded by the ground or soil into which it is driven.

The resistance to the downward movement of a pile is (1) that which is opposed by the displacement of a mass or quantity of earth equivalent to the cubic contents of the driven portion of the pile; (2) the frictional resistance which exists between the ground and the pile, such resistance varying with the nature of the soil or ground, the depth driven, and the superficial area of the pile in contact with the earth; and (3) the ability of the pile to withstand crushing, rupture, or deformation of any kind whilst being driven, or at any time during its use.

Supposing a pile 12 inches square to be driven 15 feet into the ground, then there must have been 15 cubic feet of earth displaced, for which room can only be found by a partial rising of the surface, and by a compacting or a compression of the earth surrounding the pile. The superficial area of the portion driven is 60 square feet, and therefore each superficial foot of pile surface displaces $\frac{15}{60} = 0.25$ cubic foot, equal to a film of earth 12 inches square and 3 inches thick. The density or compactness of this film is dependent upon the character of the earth or ground into which the pile is driven, and no doubt the resistance to the downward movement of the pile during driving, and its stability afterwards, are due, to a greater or less extent, to the frictional resistance set up by this compressed film,—a resistance equal to the greatest load or weight which the pile would support up to the moment when a movement or settlement takes place, always assuming that the load is not greater than what would crush and destroy the pile.

There is a great difference between *a dynamic force* and *a static pressure*, the former being represented by a blow from a ram falling from a height, producing an effect in a minute portion of time ; and the latter by a load, applied, it may be, gradually during a longer or shortened period, or in increments defined or undefined as to amount.

As an illustration, the following data is assumed :—

Weight of ram,	2000 lbs.
Fall of ram at last blow,	5 feet.
Set under last blow,	0.5 inch.
Length of pile driven in ground,	20 feet.
Dimensions of pile,	12 × 12 inches.

From these data the dynamic force, or the "energy" of the ram developed at the moment of impact, and imparted to the pile, will—using the well-known formula for energy, $\frac{wv^2}{2g}$ amount to 10,000 foot-pounds, or the amount which would sink the pile to a depth of *one foot* in a stratum offering a resistance of 10,000 lbs. to the descent of the pile in that distance. In the data assumed the pile was driven to a depth of 0.5 inch only, or the resistance to the downward movement was so great that the energy developed was only sufficient to cause a "set" of 0.5 inch, under the last blow of the ram falling from a height of 5 feet; hence the actual amount of energy displayed becomes $\frac{10,000 \times 12}{0.5} = $ 240,000 foot-pounds. This amount has a two-fold signification, for it represents (1) the frictional resistance of the earth to the descent of the pile ; and (2) the load which the pile will bear without settlement.

It is assumed that the pile has been driven to a depth of 20 feet, and further assuming, for the sake of simplicity, that the point of the pile does not support any portion of the load, then the area in contact with the earth will be $20 \times 1 \times 4 = 80$ superficial feet, then $240,000 \div 80 = 3000$ lbs., or the average resistance of the earth per square foot of the driven surface.

The area of the pile is 144 square inches: then $240,000 \div 144 = 1667$ lbs. per square inch, which is in excess of the weight, as a permanent load, to which the pile should be subjected. Assuming a factor of safety of 8, the load becomes 208 lbs. per square inch.

In 1849, Major Sanders, U. S. Engineer, deduced from his experiments at Fort Delaware, "that a pile will safely bear, without danger of a further subsidence, as many times the weight of the ram as the distance which the pile is sunk the last blow is contained in the distance through which the ram falls in making the last blow, divided by *eight*," .... or expressed as a formula,

$l = \frac{wh}{8d}$, when w is the weight of the ram, h the fall in inches, d the distance sunk by the last blow, and l the safe load.

Applying the assumed data to this formula, we have :

$\frac{2000 \times 5 \times 12}{8 \times 0.5}$ = 30,000 lbs., and if this amount be multiplied by 8, we get 240,000 lbs., or the amount derived from the calculation for energy.

During the driving of a pile, the earth surrounding it is in a state of motion or vibration, and if the blows of the ram follow in quick succession, as in the case of a steam pile-driver, the particles of earth are kept vibrating and the tendency to settle is prevented, and thus the pile may be driven deeper and more quickly than by the usual machine worked by hand power, by which the blows are rendered at comparatively long intervals. It is well known that a bolt can be driven more quickly into a hole smaller in diameter than itself in timber, when *two* hammers instead of *one* are used, because the fibres of the timber are prevented from "setting" or hugging the bolt by the rapid succession of blows to the same extent they would otherwise do. A heavy ram falling from a small height will do better and quicker work than a lighter ram falling from a greater height, and a greater number of blows per unit of time can be given; and besides this, the chances of brooming or crushing the head of the pile are reduced to a minimum, hence the successful use of the steam pile-driver.

In the construction of works for the extension of the dockyard at *Portsmouth, England, it was found that on the resumption of pile-driving after an interval of some hours, the "set" of the pile was invariably much less than that observed on the cessation of driving, the fall of the ram being the same; and this result was accounted for in a great measure by the fact, that during the process of driving, the ground was to a great extent disturbed, and the vibration of the pile caused the hole from the surface downward to be slightly enlarged, thus relieving the pile from the full frictional resistance. On the

* Proceedings Inst. C. E., Vol. 64, p. 164.

cessation of driving, the ground settles or expands, and thus grips the pile to such an extent as to materially increase the frictional resistance. To determine the amount of increased resistance accruing from quiescence, special observations were made on a number of piles, the driving of which had been completed before closing the work for the night. On the following morning *one* test blow was given, and the resulting "set" compared with that of the previous evening; and it was shown that 39 beech piles, which had an average "set" of 0.054 ft. on completion of driving, when tested the following morning, gave an average set of 0.0234 ft., showing an increased resistance of 2.3 to 1.0. Seventy-four fir piles, which had an average "set" of 0.0306 ft., gave, after an interval of 14 hours, an average "set" of 0.013 ft., or an increased resistance of 2.81 to 1.0. Using these "sets," the data previously given, and Major Sanders' rule, we have:

For beech piles,	safe load	at night,	23,148 lbs.
do	do	do	in morning,	53,380 "
For fir	do	do	at night,	34,090 "
do	do	do	in morning,	90,154 "

An examination of these results shows the great amount of uncertainty connected with the determination of the safe load which should be imposed on a pile, for it may be either under or over-loaded, when the night or morning "set" is taken as the correct factor, and it is this action which renders all the formulæ for determining the resisting to a great extent hypothetical.

Besides the resistance to further downward movement due to the dead and live loads, a pile in some instances has to withstand in cold countries an upward or drawing movement due to the action of ice, by which, as in the case of pile-bridging or wharfing, it is encompassed.

In tidal rivers or harbours where the ice is in constant motion, a film or coating forms on the surface of piles against which the moving ice rubs, and therefore does not produce any injurious effects; but a different action takes place when piles have been driven in bodies of still-water in which an increase in volume is caused by an influx of water, and consequently a rise in elevation ensues. In rivers and small lakes, where their volume is augmented by the melting of snow, etc., the ice surrounding and adhering to a pile acts as a platform which is raised by the influx of water; and if the lifting power displayed is greater than the resisting power of the pile to withdrawal, then an upward movement must take place; but where the pile has an excess of resistance, the ice fractures and breaks away without causing damage.

Ice, we know, is water in its solid form, and we also know that its specific gravity is less than that of water, or as 0.9175 to 1.0;—or, in other words, a cubic foot of ice weighs 57.33 lbs., as against 62.5 lbs. the (accepted) weight of a cubic foot of water; and the lifting power of ice under the influence of rising water is therefore 62.50—57.33 or 5.17 lbs. per superficial foot, *one foot* thick.

According to a paper by Mr. J. F. James, M. Inst. C. E.,* the adhesion of ice to timber is 29.43 lbs. per square inch. Trautwine states that the adhesion ranges from 30 to 40 lbs. per square inch.

There is not any doubt but that the power to draw a pile is much less than the power to drive it, especially in the case of a round pile, which is tapering, and when once started is free to be moved easily upwards.

Mr. James made a number of experiments on the "Force required to draw a pile," with what may be classed as rods, ranging from 1 inch to 2 inches square, 1 to 2 inches in diameter, and 3¼ by 1 inch in section; and from the results of 40 experiments he determined a coefficient C to be 0.3285, or that the power required to draw is to the power required to drive as 0.3285 to 1. Thus, in experiment 17, a pile 1¼ inches square was driven by a ram weighing 22.5 lbs., falling 7.2 feet at the last blow, the "set" being 0.895 inch, the driven length being 18.5 inches, and a force of 727 lbs. was exerted to draw it. Using Major Sanders' rule, omitting the factor 8, and the foregoing data, we have $\frac{22.5 \times 7.2 \times 12}{0.895} = 2171$ lbs. as the resistance to downward movement. The force to withdraw was 727 lbs., and $\frac{727}{2171} =$ 0.335, which represents the co-efficient in this case.

In the removal in 1880 of the coffer-dam used in connection with the construction of the Albert Dock, Hull, England, in which piles were driven with a ram weighing 2240 lbs., falling on an average 5½ feet, the "set" at the last blow averaging 0.625 inch, and the driven length averaging 18¼ feet,—it was found that the average force to withdraw a pile was 75,869 lbs.

Now the "energy" developed, using the foregoing data, was 236,384 lbs. and $\frac{75,869}{236,384} = 0.321$ as the co-efficient in this case, which may be assumed agrees with those found by Mr. James.

Assuming a pile 12 inches square, and the adhesion of ice to timber

* Proceedings Inst. C. E., Vol. 41, p. 191.

at 30 lbs. per square inch, then the total force which can be exerted by ice one foot in thickness will be $(12 \times 4) \times 12 \times 30 = 17,280$ lbs., and the area of ice to be acted on by rising water to just move the pile will be $\frac{17,280}{5.17} = 3,342$ superficial feet, *one* foot thick; or the pile must stand isolated in the centre of a sheet of ice 58 feet square, which seldom obtains in practice.

The only satisfactory way of arriving at the load piles will carry with safety is to test the ground into which they are to be driven, by loading one or more, which have been driven to what is considered a sufficient depth, with dead weight until settlement takes place, and from the results obtained to determine the final "set" for the remainder of the piles. Such a course is really only necessary where piles are classed as "bearing" piles, and not when they are used as "retaining" piles, as in a coffer-dam, etc., in which case it is only requisite that they be driven to a sufficient depth to ensure a water-tight enclosure, and are large enough and strong enough to render the service expected from them.

Engineers, as a rule, when dealing with pile-driving, are too apt to follow a well trodden path by specifying hard and fast requirements, irrespective of the service a pile has to perform; and, in the opinion of the writer, full consideration of such service should be given before a specification is completed. In explanation of this, the following is offered: A masonry pier supporting the ends of two iron trusses of 150 feet span is to be built on a pile foundation comprising 60 piles, capped and covered with two tiers of timber 24 inches deep. Now, the dead load to be borne by 60 piles will be equal to the timber caps and flooring, the masonry pier, a proportionate part of the trusses and track; and the live load will be equal to that of the heaviest train which can be placed in one span, which, though intermittent in its action, must be provided for. Assuming the weight of the dead and the live load to amount to 1,800,000 lbs., the weight to be borne by each pile will be 30,000 lbs. Using *eight* as a factor of safety, the "energy" to be developed by the ram employed will be 240,000 foot-pounds. Using previous data as to the weight of ram and fall, it can easily be determined from Major Sanders' rule that a "set" of 0.5 in. will be required. Now, if it be specified that the piles shall be driven by a ram weighing 2000 lbs., falling from a height of 5 feet, until a "set" of 0.5 inch is obtained at the last blow, or is the average of a specified number of last blows, then reliance can be placed on the piles so driven.

CORRESPONDENCE.

Mr. H. A. Gray. Major Henry A. Gray states that he is very much interested in Mr. Perley's valuable and practical paper on "The Resistance of Piles," and would say that recently quite an improvement has been made in the method of driving piles, which would come under Mr. Perley's heading of "the resistance which is met whilst the pile is being driven." Two years ago extensive pile driving was done by the Department of Public Works of Canada as protection work when widening the River Sydenham, at Owen Sound, to increase the harbour area. Previous work at this place had shown the difficulty of driving piles through the sand and other compact material, found there, of sufficient length to allow the lower ends to be below the depth required to be dredged in the harbour. A very clever mechanic, a partner of the firm of contractors for the protection work, Captain James Canan, consulted with Major Gray, and conceived the idea that he could improve upon the method of using a jet alongside the pile, while being driven, to displace the material through which the pile had to pass, and in fact construct a machine which would bore the hole for the pile, and, before the hole thus bored could fill in, insert the pile in place and to its required depth. After trials Captain Canan succeeded beyond all expectations, and, as a result, the following facts will be of interest.

Fender piles of rock elm 40 feet long, 12″ × 12″ square, with ordinary pile-driving machine, *i.e.*, ram 2,000 lbs. weight, fall 20 feet, pile pointed and iron ring placed around head. After 200 blows given in from 35 to 40 minutes, split below the ring and a piece one foot in length had to be cut off the top of the pile and the ring replaced. After 15 more blows the pile could not be driven any further, and three feet three inches still remaining above the proper height of the pile work had to be cut off.

With the use of the boring machine the same sized pile, viz., 40 feet long and 12″ × 12″ square passing through the same material was put down its full length, without the use of a ring, in three minutes, perfectly perpendicular, in line, and close up against the other work, and to exactly the required height with nothing to cut off the top. Only the weight of the hammer resting on the head of the pile at first and then settling into its full depth, a few light blows were given, the hammer not being hoisted more than 2 feet in the leaders to complete the work. Eighty to one hundred piles penetrating 20 feet in depth have been driven by this method in one working day of 10 hours.

It may be remarked here, for comparison, that the United States Army Engineers (Vol. 1889, Part 4) gives a day's work of pile. driving, with use of jet, material, sand with pockets of gravel, average penetration 18.9 feet as from 20 to 34 piles.

A short description of the boring machine may be of interest The inventor states that it consists essentially of a shaft to which a turbine and an Archimedian screw are fixed and contained in a casing supplied with water under pressure, and having openings arranged in such a manner that the water forced into the said casing will in escaping act upwardly against the soil loosened by cutting blades fixed near the end of the shaft. These blades are set at such an angle that they will not only cut into the soil against which they are pressed, but will elevate the loosened soil so cut. They are made detachable, so that they can readily be removed and sharpened or replaced by new ones. Suitable mechanism is provided, by which the boring tool is readily lowered to the bottom of the water, and as easily withdrawn after it has performed the work. Simple mechanism is also provided, by which the pile is guided and lowered into the hole prepared by the boring machine.

The great advantage of this machine is that the piles are driven their full length, perfectly straight, perpendicular, and in line, without twisting or buckling and without damage to the heads, and at a considerable saving of time and expense in the operation.

With respect to that portion of Mr. Perley's paper in which he gives the power of ice adhering to and surrounding a pile to raise it by the influx of water underneath, acting as a platform, Major Gray would state that, having had considerable difficulty in keeping a level railway track on a pile-bent structure, at Catalone Lake, Cape Breton, from the same cause, he inverted the piles, and by this means reduced the friction upwards (or adhesion), and the ice becoming free thus prevented the piles from being disturbed.

Mr. Kerry said it appears to the writer that Mr. Perley has Mr. J. G. Kerry.

briefly covered the whole subject in the statement that the resistance depends upon the friction between the ground and the pile.

Mr. W. M. Patton, of the Virginia Military Institute, a civil engineer of wide practical experience, states in a book recently published on "Foundations," that the bearing power of a pile depends on the crushing resistance of the soil under its end and the friction between the sides of the pile and the surrounding earth, and suggests that a series of constants might be calculated from experiments giving the friction co-efficient of the various soils. He might perhaps have disregarded the crushing under the end of the pile, as piles are frequently pointed, and blunted piles may wear to a point in driving, and have said the resistance depended upon the friction only. That no dynamic calculation should be depended upon appears clear from the entirely different action of driven piles after a few hours rest, and from the fact that few piles are subjected in practice to dynamic stress. There are numerous experiments on the resistance of bearing piles, and it would seem possible from these to draw up a table of earth friction co-efficients to accompany the various other tables we have of earth constants, and the use of which would reduce the question of the bearing power into the multiplication of so many square inches by a constant. Though the variations of quality in soils are innumerable, it would not seem difficult to choose a constant which would be on the safe side, especially if a competent man were sent out to examine the site instead of the ordinary "pile inspector." That the bearing power depends upon friction only is everywhere admitted, but it has not yet passed into practice, as the common practice of "splicing" piles will illustrate. It very frequently happens when a pile is going very easily in a bottomless swamp, that a drift bolt is partially driven into it, and another pile placed on top of it, having a hole bored in it to receive the end of the drift bolt, and the whole "spliced pile" driven down, with the frequent result that the second pile jumps off the top of the first which is thus practically lost. In such situations, if the above hypothesis be correct, two piles driven side by side would have a bearing power equal to that of the double length pile, even if it were successfully driven, while all the cost of iron and splicing and all danger of complete loss of the first pile would be obviated.

DISCUSSION.

Mr. Smith said :—Mr. Perley has given us a very interesting paper ; there are few topics of more value to the Civil Engineer than full knowledge on the bearing power of piles, and while we may never attain full knowledge, yet discussion will surely bear good fruit. Mr. C. B. Smith.

Piles may be driven in at least six different ways :

(1) By a drop hammer falling free.

(2) By a drop hammer, fastened to a line.

(3) By a water jet.

(4) By insistent weight and vibration (in soft soils).

(5) Steam hammer.

(6) Gunpowder drivers.

The 1st and 5th are the usual methods, although water jet driving is largely used under certain conditions. We are, however, limited evidently in the application of formulæ to methods 1, 5 and 6, as Nos. 2, 3 and 4 introduce unknown variables.

Now, Mr. Perley has met with many astonishing results, and it seems somewhat surprising that he should have put so much labour on results all resting on the rule which he has selected as the object of his use, and, at the same time, condemnation.

This rule of Maj. Sanders is merely an expression that the whole energy developed in the fall of a hammer represented by $w \times h$, is equal to the bearing power of the pile, *i.e.*, the resistance it has offered against being driven, by the penetration, or in a formula :

$$w \times h = s \times d \text{ or } s = \frac{wh}{d} \text{ or a safe load with}$$

$$\text{factor of safety of } 8 = \frac{wh}{8d}.$$

This is really the simpler form of Weisbach's formula, which Maj. Sanders adopted. There are something like 17 formulæ for the bearing power of piles in use ; of these, there are three which eliminate all but the known variables. They are :

(1) Weisbach, or Sanders—

$$\text{safe load} = \frac{1}{8} \times \frac{12wh}{s}$$

(2) Trautwine—

$$\text{safe load} = \frac{1}{8} \times \frac{46w\sqrt[3]{h}}{s+1}$$

(3) Wellington's—

$$\text{safe load} = \frac{1}{6} \times \frac{12wh}{s+1} \text{ for drop hammer.}$$

$$\text{safe load} = \frac{1}{6} \times \frac{12wh}{s+\frac{1}{10}} \text{ for steam hammer.}$$

in all of which w=weight of hammer,
h=drop in ft.,
s=penetration in inches,
being the average of the last 3 or 4 regular penetrations.

Now let us consider what these formulæ mean:

No. 1 simply states that the *static resistance* is nothing, which is absurd, because when $s = o$, then the safe load = infinity, and for very small values of s, the safe load given is far too great.

On the other hand, No. 2 recognises the fact that it takes something to start a pile before it begins to move.

In the third formula this is farther and intelligently expressed as

$s+1$ in drop hammer,
and $s+\frac{1}{10}$ in steam hammer,

because in the latter case the vibration set up has not time to get fully over before the next blow occurs, and the grip of the surrounding earth is ∴ less. Now, when s is small we are not sure whether the toe of the pile is brooming or not, and should look on very low values of s, of less than $\frac{1}{4}''$ for steam hammer and $\frac{1}{2}''$ for drop hammer, with suspicion.

Let us now consider some of Mr. Perley's troubles in the light of a formula which has not the absurdity of giving infinite values for zero penetration.

First of all, in the 4th paragraph, he distinguishes between piles fully and partly driven in the soil. Now, if we use Wellington's formula, all this danger of piles failing as pillars will disappear. Let us assume $\frac{1}{2}''$ penetration as a minimum for 2000-lb. hammer and 20-ft. drop,

$$\text{his safe load} = s = \frac{2wh}{s+1} = \frac{80000}{1.5} = 53333 \text{ lbs.}$$

Now, supposing a pile standing 15 feet *unsupported* out of ground, which I presume would be considered a reasonable maximum, using Gordon's Pillar formula:

$$\frac{w}{s} := p = \frac{f}{1 + a \frac{l^2}{h^2}} \quad \text{now in a 12'' pile} \quad s = 113 \text{ sq. inches.}$$

$$\therefore w = \frac{113 \times 5000}{1 + \frac{1}{250} \times 225} = 300{,}000 \text{ lbs.}$$

as the breaking load, or a factor of safety of 6. The author has tested large numbers of pine, oak and fir pillars at McGill, of 15 diameters, and has found Gordon's formulæ erred always on the safe side.

Therefore, we may conclude that under ordinary conditions, a pile will stand as much as a pillar as one would care to have it bear as a pile. This safe load of 53,333 lbs. = 472 lbs. per sq. inch is, therefore, all we need consider, and the two resistances are, after all, only one.

The energy of fall of a hammer, even neglecting all outside losses, is consumed after reaching the pile in many different ways:

(1) By brooming the top and bottom of piles.

(2) By bouncing the hammer, which can be largely avoided, however, by lessening the fall when it occurs.

(3) By compressing the pile within the elastic limit.

(4) In overcoming the static grip of the surrounding earth.

(5) In causing the pile to penetrate.

Now the last two only can be considered as representing how much the pile will again need to start it.

It is evident therefore that:

$W \times h =$ energy of fall is far greater than facts would justify in estimating the ultimate load on a pile, and numberless records will bear this out as will be given later on.

In the 1st calculation Mr. Perley tries to reconcile 240,000 ft. lbs. of energy with a safe load of 30,000 lbs. and factor of 8, whereas by Trautwine's rule

Safe load would = 20950.

and by Wellington's $\frac{2\,wh}{S + \frac{1}{10}}$ Safe load = 18110.

which are certainly nearer a factor of eight to the actual amount of energy delivered to the pile in useful work than the 30,000 lbs. given by Weisbach's rule.

Again, near the bottom of page 3 we find the following results, which are certainly probable and in line with numberless observations of the same kind :—

	Sanders
Load on beech piles, evening	23,148
Load on beech piles, morning	53,380
Load on fir piles, evening	34,090
Load on fir piles, morning	90,154

If these had been calculated by Wellington's formula

$$S = \frac{2\,wh}{S + \frac{1}{10}}$$ we would get:

	Wellington
Load on beech piles, evening	26,666
Load on beech piles, morning	52,660
Load on fir piles, evening	43,480
Load on fir piles, morning	80,000

by which we see there would not have been quite so much discrepancy if a formula had been used which does not range up to infinity in its safe loads.

These cases are quite frequent, and it is evident that the lesser load of the two should be taken in each case, because should the pile be driven again the next morning, the penetration after the first blow or two would have probably become again the same as the evening before.

No formula can cover the case of piles becoming more solidified in their place by the effect of time, and we should be satisfied with a formula which is always reasonably on the safe side at the time the driving ceases.

Again on page 4. The maximum supporting power by Wellington's formula would be using $\left(S = \frac{2\,w\,h}{S + \frac{1}{10}}\right)$ 1,954 lbs instead of 2171 lbs. and 200,400 lbs instead of 236,384 lbs., in each case being less than by Sanders' rule and more in accord with analogous cases, for it seems rather a large proportion to say that it takes 3 times as much to drive a pile of nearly uniform diameter as to pull it, when we consider that the force required to pull long wire nails out of soft pine or basswood is nearly as great as that required to drive them in. This has often been tested at McGill, and can be depended on. Again, just at the end of the paper, he calculates a pile under certain conditions will be safe with 30,000 lbs. Wellington's rule for same conditions gives safe load $= \frac{2000 \times 2 \times 5}{0.5 + 0.1} = 33{,}333$ lbs., which is practically the same.

To sum up the whole case, it would seem evident that Mr. Perley, while on the whole condemning formulæ, has demonstrated his disbelief in them by using one so weak in its construction as to constitute it a vulnerable object of attack.

It gives inordinately high values when the set is small, and only comes down out of the clouds when the set is ½″ or over, and is not at all applicable when we consider drop-hammer records, it being useful only in steam hammer driving for large penetration, which is too limited a range for use on this continent where drop hammer driving so largely predominates.

If we turn now to Trautwine's and Wellington's formulæ, we find them conservative under suspiciously small sets.

In fact, the concensus of opinion seems to be that

$\frac{2\,wh}{S+1}$ or $\frac{2\,wh}{S+\frac{1}{10}}$ is a simple safe rule under all ranges of conditions of drawing by drop or steam hammer, and while Mr. Perley has done well to bring such an important matter before the Society, he has hardly stated the case fully in the light of all evidence, when he criticises on the basis of Sanders' or Weisbach's formula, in place of Trautwine's, or more particularly Wellington's.

It will be observed that while Wellington's formula is peculiarly applicable for a drop hammer under small penetrations, Sanders' rule fails completely, as the subjoined table will show.

Place.*	Material.	Wt. of Hammer.	Drop.	Penetration.	Actual sustaining Power.	Safe Load, Wellington.	Safe Load, Trautwine.	Safe Load, Sanders.
Neuilly Bridge, France.	Gravel	2,000	5′	.016″	105300	19,700	20,000	938000
Hull Docks, England.	Mud	1,500	24′	2′	45,000 to 56,000	24,000	8,340	27000
Royal Border Bridge.	Sand and Gravel	1,700	16′	.05″	156800	53,700	23,200	816000
Phil. Experiments	Mud	1,600	36′	18″	14,560 to 20,120	6,060	1,600	4800
U.S. Test Pile.	Silt and Clay	910	5′	.375″	59,600	6,620	7,075	16200
French Rule.	--	1,344	4′	0	56,000	10,742	12,500	Infinity.

* The basis of this table is taken from a book by *Engineering News*, al "Piles and Pile Driving."

This table also points out clearly that, from actual tests made, the Wellington formulæ are safest to use, and that Trautwine's is a good second.

Mr. W. J. Sproule.

Mr. Sproule said he would remark, in case the young members should get alarmed at all this talk about formulæ, that they had driven a great many piles in Montreal harbour, and had never bothered themselves very much about formulæ. They usually put in piles about 15 inches in diameter and drive them until they go about an inch per stroke, or sometimes until they will go no farther. He had no doubt that formulæ are useful in a great many cases. In this case the foundation is usually good, and the capacity of the pile as a pillar (it being 30 ft. to 40 ft. long unbraced) as well as the length of spans between piles, with regard to the strength of caps, stringers and planking and consequent cost, were largely the determining elements as to the number of piles driven in a given area. The wharves are often heavily loaded with steel rails and pig iron, and none have yet failed by the piles giving way.

Mr. C. B. Smith.

Mr. Smith said that because they have a good soil and have driven piles down and they stayed there, is no reason to suppose that formulæ can be done without.

Mr. W. J. Sproule.

Mr. Sproule said he only wished to give the practical side of the question. He did not wish the younger members to give undue prominence to the theoretical side first. As Mr. Smith says, they have a good foundation, or else they would have had to take the formulæ into question. They did not have to deal with it in that way because they have a good foundation, and it occurred to him that so much formulæ might alarm the younger members unduly. If he had much piling to do in any place, he would endeavour to ascertain the nature of the material by borings. One thing he did not understand was the statement that the bottom of the pile has nothing to do with its bearing capacity. In parts of the cemented material in the bottom of Montreal harbour the resistance under the bottom of a pile might nearly equal its bearing capacity as a pillar thirty feet long.

Mr. Wm. Kennedy, jun.

Mr. Kennedy, speaking of the machine which Mr. Gray describes, said there is a water wheel about 5 inches in diameter placed in a case. This case is cylindrical with a flat top and cone-shaped bottom. The top has an opening say 2 or $2\frac{1}{2}$ inches diameter to receive a pipe or hose which carries the water supply to the water wheel, and the lower or cone-shaped end (apex downward) has holes near the apex for discharging the water after passing through the water wheel. The water wheel shaft, which is vertical, is extended downward, passing through the cone at the small end. On the extreme lower end of the shaft is fixed a two-blade cutter about 8 inches diameter, resembling a two-blade propeller wheel.

The machine when ready to work is placed in position where the pile is to be driven, and the water wheel with the cutter is made to turn rapidly by means of water supplied through a hose from a powerful steam pump. Provision is made for lowering the machine as fast as the cutter works into the ground. In the meantime, the earth, clay, etc., disturbed by the cutter is carried upwards by the escaping water from the water wheel forcing its way to the surface. The cutter is sufficiently large, together with the action of the discharged water, to make the hole large enough to pass the water wheel case, and also leave space around the case for the uprising water mixed with the excavated material.

This machine is unsuited for a bottom where large stones would be met with, and also, for obvious reasons, unsuitable for pure sand.

When the pile is to be put in, there is generally a stroke or two at the end of the hammer just to settle it down. It falls in as described by Mr. Gray. At first when the pile is put in, it runs down a considerable distance.

Mr. Kennedy said it was a very cheap way of driving piles. The piles were put in very rapidly. The average work is from 80 to 100 piles, so that this method claims to be four times as efficient as the water jet.

Mr. W. McLea Walbank.

Mr. Walbank said he had intended to make some remarks on Mr. Perley's paper, but had not had time to prepare them. He had had a considerable experience in pile driving. He had noticed a great difference in the soil even on the same site. He had driven piles that went down and remained perfectly firm, while other piles driven in close proximity (a few feet away) under apparently the same circumstances would not remain permanent, but when the "monkey" was raised would follow it for two or three feet, due, he believed, to compressed air, because the only way he could get the pile to remain down was to bore a hole in the ground beside the pile and let the air escape, when all trouble would end. He also noticed that in some cases piles sink much deeper than in other cases within a few feet of each other under similar conditions of driving. In his practice he would prefer if possible to get the piles down to a good bearing, rather than trust to the friction of the soil on the pile. He would not put a sharp point on the pile unless in soils too hard to drive without brooming the end, and in that case would provide an iron shoe.

Mr. Henry F. Perley.

Mr. Perley in reply stated that when preparing his paper, he examined the formulæ extant, and acquainted himself with the opinions of others relative thereto, and found such a diversity to exist as to make their application to any particular case a somewhat doubtful proceeding.

Mr. Perley notes that Mr. Smith takes exception to Sanders' formula as giving infinity when the penetration is *zero*, and submits results obtained by the use of Trautwine's and Wellington's formulæ, and yet their correctness was, not very long ago, the subject of dispute and discussion between the authors named, each claiming that the formula of the other was wrong and the results obtained by its use incorrect.

In these formulæ there appears in the divisor the factor + 1, which, according to Mr. Wellington, has been added because "there is an extra initial resistance in getting a pile under way, and is intended to give the nearest feasible equivalent for the effect of that extra resistance in modifying the mean resistance to penetration. With individual piles it may or may not be a little more or less."*

If this factor + 1 be omitted, these formulæ will come under Mr. Smith's condemnation as absurd, and it may fairly be assumed that + 1 was purposely added, so that when the "set" is suspiciously small, the results obtained would be prevented from extending into infinity, and —what is worse—absurdity. Relative to this Mr. Wellington states that:—

"In most of the formulæ, L is inversely as S, which plainly cannot be correct, as when $S = 0$, L becomes infinitely great. To avoid this absurdity, Trautwine adds to S the constant 1 inch, which seems to us the true principle." †

Mr. Smith claims that Mr. Perley has hardly stated the case when he criticises on the basis of Sanders' formula in place of Trautwine's,

* Piles and Pile Driving, edited by A. M. Wellington, p. 10.

† Do Do Do Do p. 29.

or more particularly Wellington's. Sanders' formula is simple, easy of application, and gives within the range of the "set at the last blow" to which piles are practically driven on work, and not theoretically in the office, results which are trustworthy. Wellington's formula has been attacked by Trautwine as being inferior and incorrect, the reply being :—

"We distrust all formulas which, like Trautwine's cube root formula, are not only unsupported by, but in direct and complete antagonism to, theory." *

In considering this matter, it can be assumed that the action of dividing a pile into a resisting medium is analogous to that of a projectile on, let us say, an armour-plate, the energy required to effect penetration or perforation being determined by artillerists from the formula $\frac{WV^2}{2g}$. Now Sanders' formula is a modification of the foregoing, and is therefore based on true principles. It is true that if infinitesimal "sets" are used, the results may be misleading, and so they must be in any formula ; but, as previously stated, piles are not, and cannot be, driven to minute fractions of an inch, and the question of infinity may be dismissed.

Mr. Smith, in treating of the results obtained at Portsmouth Dockyard, failed to comprehend Mr. Perley's remarks thereon, which were that an examination showed the great amount of uncertainty connected with the determination of the safe load...when the night or morning "set" is taken as a factor ; and the uncertainty of the results are as fully demonstrated by Wellington's formula as by Sanders'.

Mr. H. A. Gray's letter refers to "pile driving," a subject not touched by Mr. Perley, but what he has written is interesting and worthy of record, especially when read in conjunction with Mr. Kennedy's clear explanation of the apparatus used. What would have made Mr. Gray's letter more valuable would have been information, whether, after the piles had been placed, any trial was made after a lapse of time to ascertain if they sank, and to what extent, under a blow or blows of a hammer. This, Mr. Perley has learned from Mr. Gray, was not done.

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* Piles and Pile Driving, edited by A. M. Wellington, p. 30.

PRESIDENT'S ADDRESS.

Address of P. Alex. Peterson, President Canadian Society Civil Engineers, on leaving the Chair at the close of Annual Meeting, January 25th, 1895.

One of the duties of the position to which the Society, a year ago, elected me, is the delivery of an address at the close of my term of office. It has been customary for the Presidents of Sister Societies to give a general review of the professional progress and scientific advancement in subjects which allude to our profession, but sometimes a President has chosen a subject which he assumed would be of interest to the members of the Society, and at the same time a record of the progress of some great work, which he considered he was in some special degree qualified to speak of; so instead of giving a general sketch of professional progress during the past year, I have decided to give a review of what the Canadian Pacific Railway Company has done since 1886, in the way of re-construction.

You are all aware that the Canadian Pacific Railway Company took a contract from the Government on 21st Oct., 1880, to complete the Railway to the Pacific Coast in ten years, and that the work was pushed on with such energy that trains passed from tide water to tide water in November, 1885. In carrying out this work through an almost inaccessible wilderness, it was decided to construct a large amount of temporary work, which would carry the traffic safely for some years, and at the same time be of material use in the economical construction of the permanent works. This method of carrying out the work enabled the Company to open the line five years earlier than it could otherwise have done; it saved a large amount of money in first cost and in interest, it will save a large sum in ultimate cost, and it enabled the Company to earn $20,000,000 in the year fixed for the completion of the contract.

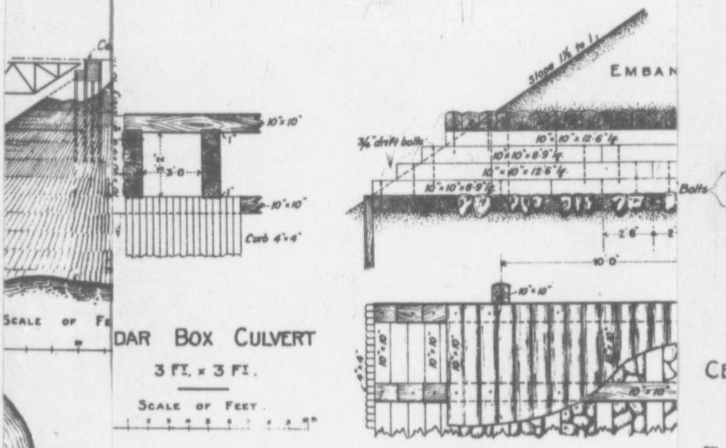
The temporary work put in the roadbed consisted principally of long and high wooden trestles to cross large ravines, small pile trestles to cross small streams, and wooden bridges with the substructure of piles or wooden cribs, and the super-structure of wooden trusses with spans varying from 30 feet to 180 feet in length to cross important streams and large rivers.

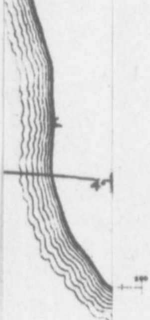
FILLING TRESTLES.

On the Eastern Division between Cartier and Nepigon, and on the Western Division between Fort William and Winnipeg, where square timber could not readily be obtained, round timber cut in the nearest valley along the line was used, and the work was of a more temporary character than where good timber was obtainable, consequently the work of replacing it was commenced at an early date, and this was especially the case when the structures were long and high and required two or three years to fill. The Big Pic trestle on the Eastern Division 800 miles west of Montreal, which was 1300 feet in length and 70 feet high at the western end, and required nearly three seasons to fill, contained 172,123 yards. To have filled this trestle would have taken five seasons, if done by the ordinary hand dump car method, and would have cost not less than $94,668, whereas, the work only cost $36,770, or 16¼ cents per cubic yard, leaving out the cost of the trestle, a saving on that trestle alone of $57,898, besides allowing the line to be opened five years earlier. On this same Division another large trestle, No. 799, 800 miles west of Montreal, was commenced in 1890 and finished in 1893, requiring 100,000 cubic yards. This was filled at a cost of $15,000, or 15 cents per cubic yard. At the time of construction it could have been filled only by borrowing rock at a cost of $159,600, or $2.85 per cubic yard. There have been filled on this Division 535 trestles, having a length of 86,138 ft., and requiring 4,095,612 yards of material to fill them, on which, not counting interest saved on capital, there has been saved to the Company at least one dollar per cubic yard, or $4,095,612, by putting in temporary structures and making banks by train with gravel and sand instead, or rock, or even earth from long haul cuts by horse cars.

Where trestles have been built over good solid ground or rock, not under water, the filling has been easily done; but in some places, with bad foundations, this filling has been attended with serious difficulties, and in certain cases on the Government sections, the risk of stopping traffic was so great that it was considered advisable to change the location of the line. In many instances a certain amount of risk had to be run, and was provided against in the way of having timber on hand ready to repair the track, so as to avoid an interruption to the traffic; and so successfully has this been done, that in no case has traffic been interrupted for more than a few hours at any one time. In one case at structure No. 740 on the north shore of Lake Superior 820 miles west of Montreal, a trestle 800 feet long and 40 feet high had a culvert built under it, and was nearly filled when the central portion dropped down about 14 feet, carrying the centre of the culvert down, and leaving the outer portion of the slopes and the ends of the culvert in position. This culvert and embankment were built on a coarse gravel foundation, under which there must have been a hollow space, below the depth to which the piles had been driven, covered with a crust that was thick enough to carry the trestle and its load, but not strong enough to support the gravel bank.

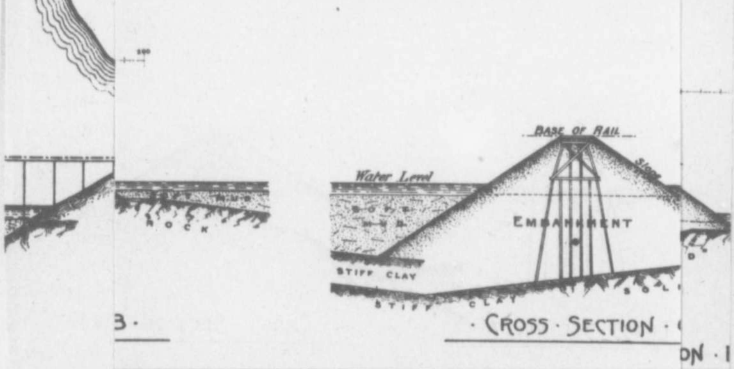
On the Western Division between Fort William and Winnipeg, in a great number of places the trestles were built through lakes, the water being of various depths over soft black peaty material often from fifty to seventy feet deep on a bed of sloping rock. In other cases the same character of bottom would be found, but without the sloping rock. In the case of the sloping rock when the trestle was nearly filled, the whole bank has slipped bodily down the slope into the lake. In other cases when the material was nearly up to the level of the track, and before the banks had run out to the proper slope, the lower portion would slide out, carrying with it the full width of the made bank at the top, see Plate IV, the bank sometimes carrying with it a great part of the trestle, and always very much distorting the alignment, so that new piles had to be driven or put in place in order to maintain the traffic. Another form of trestle that was met with, was when deep lakes had to be crossed, where, from the nature of the rock on which the trestle stood, it would be dangerous to run the risk of the filling sliding down a steep slope, and carrying the trestle with it. Here there was nothing to do but divert the track, and in some instances it was found that a better and cheaper line was close at hand, which avoided the fill altogether. In other cases it seemed that the deepest portion of the lake had been chosen, and that by judicious change of location enough rock could be obtained on a better line to fill the shallower crossing of the lake. In other places the Government had put quantities of cross-logging, where there was no possibility of the logging supporting the bank that was to go in, and when earth was put upon it, the logs would sink in the centre, and cause the ends to bend upwards, and so allow the bottom to assume a curved form, which would slide down on the sloping rock. A great deal of expense had been gone to by the Government in putting in cross-logging under banks as much as fifty feet high, with soft bottoms through which it would settle, some of which the Company removed before attempting to

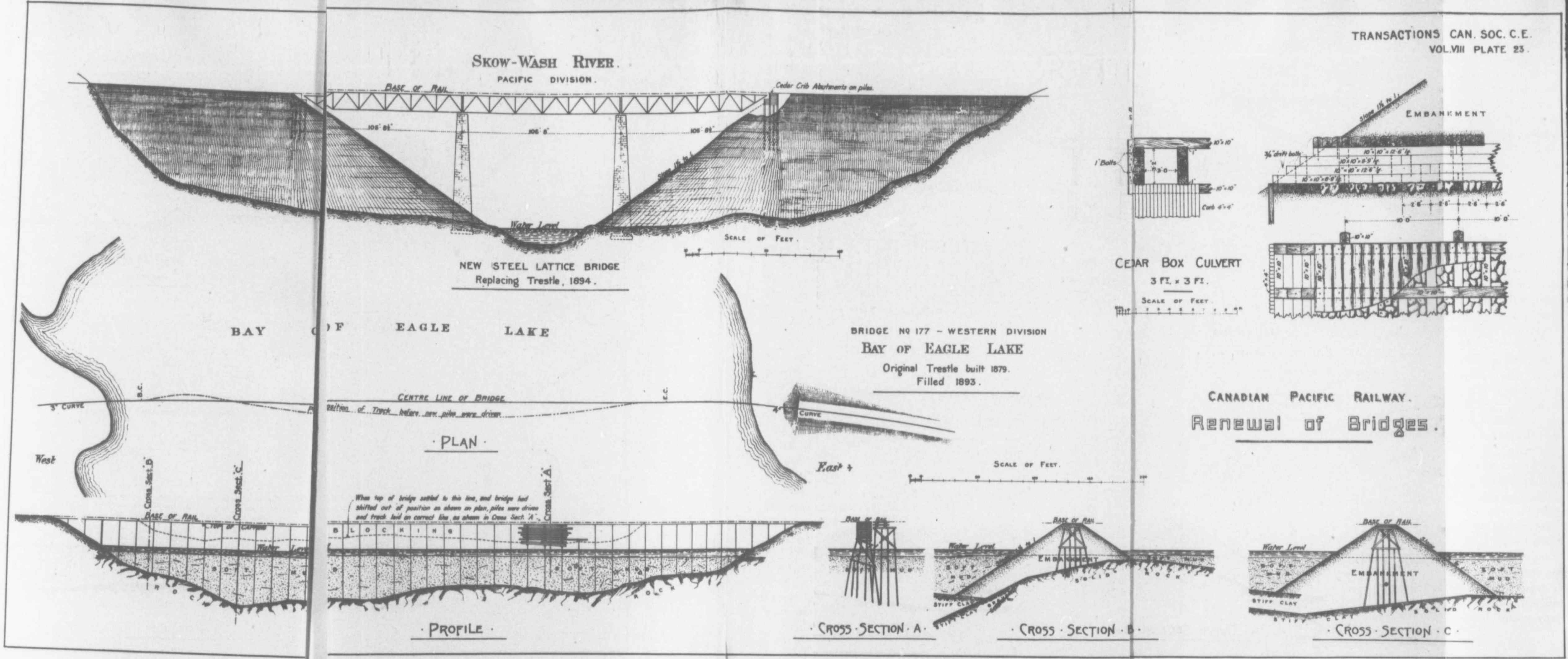




CANADIAN PACIFIC RAILWAY.

Renewal of Bridges.




SKOW-WASH RIVER.
PACIFIC DIVISION.
Base of Rail
Cedar Crib Abutments on piles.
105' 8½"
105' 8"
105' 8½"
Water Level
SCALE OF FEET.
NEW STEEL LATTICE BRIDGE
Replacing Trestle, 1894.
CEDAR BOX CULVERT
3 FT. × 3 FT.
SCALE OF FEET.
EMBANKMENT
BAY OF EAGLE LAKE
BRIDGE No 177 – WESTERN DIVISION
BAY OF EAGLE LAKE
Original Trestle built 1879.
Filled 1893.
CANADIAN PACIFIC RAILWAY.
Renewal of Bridges.
CENTRE LINE OF BRIDGE
Position of Track before new piles were driven
CURVE
·PLAN·
West
East
SCALE OF FEET.
Cross Sect. B
Cross Sect. C
Cross Sect. A
When top of bridge settled to this line, and bridge had shifted out of position as shown on plan, piles were driven and track laid on correct line, as shown in Cross Sect. 'A'.
BASE OF RAIL
BLOCKING
SOFT MUD
ROCK
·PROFILE·
·CROSS·SECTION·A·
Water Level
EMBANKMENT
STIFF CLAY
SOLID ROCK
·CROSS·SECTION·B·
Water Level
EMBANKMENT
STIFF CLAY
SOFT MUD
·CROSS·SECTION·C·

make the embankment. In such cases cross-logging is worse than useless, as it cannot support the bank, and sinks at the centre, allowing the outer ends to turn up, so as to form a blunt edge as it were, which pushes out the soft material underneath to each side.

Cross-logging is only of use when a low bank is to be carried on top of soft material, which is not quite able to sustain the load. Then the cross-logging will broaden the base and furnish a lighter material to reach the desired height; but when the bottom is so soft that the bank will go through it to a solid bottom, then the cross-logging is a serious disadvantage to the work, as it increases the tendency of the bank to slide out sideways. In some cases where the risks of filling were so many, and the danger of interruption to the traffic so serious, there being no chance to put in a temporary track without great delay, diversions were made. In all such cases shallower crossings were found, and the rock from the excavation made the fills. Of course the cost was greater than if a proper location had been made at first, but a good line has now been obtained, and one from which no further trouble or expense can arise. A little more care in locating the original line would have avoided the necessity for these changes. This emphasizes the necessity for greater care in the location of railways. No class of Engineering is more neglected than location. Any Engineer who can run a transit is often thought good enough to locate a line; but after the line is built, the mistakes are found, bad bottoms as just described are discovered, and sharp curves and steep grades are put in the line that might easily have been avoided, and, as a consequence, either the line has to be worked at heavy expense, or large sums of money have to be expended to build the line over, so that greater loads can be hauled and the line more economically worked.

The filling of some of the trestles on the section between Fort William and Winnipeg required the utmost care and the strictest supervision so as to avoid any serious interruption to the traffic. At trestle No. 226A, east of Barclay Station, 1,248 miles west of Montreal, sawdust was satisfactorily used for filling under the following circumstances. A pile trestle 335 ft. long and 8 ft. in height across a soft spot in a swamp between two clay hills required filling, and had the bottom been able to hold up the bank, only 2,880 cubic yards would have been required to make the embankment. Soundings were taken through black muck and soft clay for 60 feet without finding a hard bottom. Filling was commenced on the 30th July, 1891, and when 864 cars or 6,912 cubic yards had been put in, the track dropped on the

8th August about four feet over the whole length of the trestle. The track was raised and the filling was carried on till the 31st October, at which date 6,825 car loads had been put in, equal to 54,600 cubic yards, or 51,720 cubic yards more than was required to fill from the surface to subgrade. By this time the banks at both ends of the trestle had broken through, or rather had been carried down by the settlement that took place under the trestle, and the filling sank faster than it could be put in. The track was then below grade for a distance of eight hundred feet, and eleven feet below subgrade at the lowest place. This settlement took place by sudden drops of from six to seven feet, but was kept passable by cutting down the track on each side of the lowest point;—as the bank never fell more than 11 ft. below grade, which was the level of the water in the marsh;—and by filling in with sawdust, so as to enable the heavy wheat traffic to be carried over without assistance from a pusher. The track was raised to within six feet of grade, and the approaches cut down so as to make two per cent. grades, over which the ordinary traffic passed without difficulty. During the winter the sawdust filling gave no trouble, so in the spring it was decided to complete the bank to within a foot of the required height, and to cover it with a foot of gravel. The sawdust proved so satisfactory that it was decided to raise it three feet higher than the original trestle, in order to improve the grade at this point, which is near the east end of Barclay siding. The bank as filled has not shown any appreciable settlement and has remained in perfect order.

Bridge No. 169, 1,250 miles from Montreal, was a pile trestle 596 feet in length and nine feet high, built across a swamp, where soundings, or rather borings, were taken for sixty feet in depth without finding hard bottom. Previous experience in similar places showed that great expense would be entailed in attempting to fill this place with gravel, and that serious interruptions to traffic might be expected. Sawdust having been used with success on No. 226A above mentioned, it was decided to try filling this trestle altogether with sawdust, and to spread the weight out as much as possible by using flat slopes of 3 to 1. The sawdust was brought from Keewatin in box cars, containing 45 cubic yards, by freight trains each day, as the cars were filled by shoots leading from the mills and left on siding near by to be dumped by special work gang sent out when siding was filled. The time required to fill the trestle was about three months. The sawdust was covered with a foot of ballast, and has remained in perfect condition, except 75 feet of the track, which required lifting and tamping for the first three months, probably due to the fact that the sawdust was thrown in loosely and not packed as at No. 226A. It has since shewn no signs of settlement and has given good satisfaction. The quantity of sawdust used was very little in excess of the quantity calculated from the cross section, showing that sawdust shrinks less than earth for a bank of the same dimensions, and it may be interesting to know that the sawdust bank yields less under a passing train than the trestle, and has less spring in it than a muck bank built over a swamp of the same character.

Trestle No. 177 across a bay of Eagle Lake was 634 feet in length and 23 feet above the surface of the water, built with frame bents on piles which were driven through very soft mud and clay overlying rock at depth varying from 20 feet to 40 feet. The rock sloped to the north at the west end and to the south at the east. A thick mattress of logs was, in the original construction by the Government, put in between the piles, or the piles were driven between them for the purpose of assisting to support the bank and to stiffen the piles, standing as they were in such very soft mud. Fearing that the mattress, which extended about fifty feet on each side of the trestle, in settling at the centre and turning up at the ends, would slide on the bottom and so wreck the trestle, it was decided to cut, from the ice during the winter, the mattress just outside the piles, as the simplest method of avoiding the danger likely to arise from the presence of the cross logging, on such a very soft bottom. Filling was commenced on 8th August, 1892, was carried on up to the 27th of the same month, up to which time 1,284 car loads had been put in, nearly all of which had been hauled by horses and scrapers to the edge of the cross logging left between the piles, and dumped over the ends of it so as to form two banks, or walls, outside of the trestle, and to mak- as much as possible of the bank, with the least interference with the trese tle. In spite of this precaution the trestle sank two feet on the last mentioned date, and went out to the south about four feet, and continued sinking and going out of line steadily till, on the 29th September, when 4,674 cars or 37,392 cubic yards had been put in and hauled out by horses and scrapers, the bridge had settled 18 feet and was 12 feet out of line. It had been kept passable all this time by blocking up over the caps, as shown on Plan No. IV. Piles were then driven to the northward on the old line and the track placed in its original position. Filling was commenced again on the 3rd October, and continued to the 23rd, at which date 7,291 cars had been put in, and the new piles were as much out of line and had sunk as much as the old bridge had on the 29th September, and had of course during this time to be kept blocked up to keep the bridge open for the heavy wheat traffic. Filling was now stopped for the season, and new piles were again driven and the track moved over into line. What remained of the old bridge was now 38 feet out of line. During the winter and up to the 2nd May, no more than two feet of settlement took place. Filling was recommenced on the 2nd May, and by the 9th May, 866 cars had been put in, when at 5 p.m. the bridge sank an average of 8 feet over 28 bents. At 1 p.m. on May 10th the track was passable and passenger train No. 2 crossed on time. On 10th and 11th of May, 305 cars were put in, and at 6 p.m. on the 11th the bridge sank an average of 8 feet over 18 bents, and though it rained heavily all night the track was passable at 9 a.m. the next morning.

On May 16th, when 371 more cars had been put in, the trestle again sank about 8 ft. over the same 18 bents, and went out of line 10 ft. to the south; but the track was blocked up, and made passable by one o'clock on the morning of the 17th, and all trains passed on time. Between May 17th and 20th, 544 more cars, or 4,352 cubic yds., were put in, when the trestle sank again about 8 ft. over the same 18 bents at one o'clock p.m.; track was, however, passable at 8 p.m. on the same day.

At 5 p.m. on May 23rd, when 442 more cars, or 3,536 cubic yds., had been put in, the trestle sank about 7 ft. over the same 18 bents, and went out 10 ft. to the south; but by 11 p.m. on the same day it was ready to pass trains, requiring something less than one hour to raise it each foot over the 240 ft. Three hundred and seventy-four more cars had been put in up to 5 p.m. of the 25th of May, when the trestle sank for the sixth time seven feet over the same 18 bents, causing a stoppage of the line at this point for seven hours. On 27th May, after 284 more cars, or 2,272 cubic yds., had been put in, this bank was within six feet of the grade, and by cutting down the approaches it was possible to lay the track on the filling. This was done and the filling stopped, so as to allow the bank to set and solidify. Work commenced again on the 21st of August, and between that date and the 9th of September, 788 cars were unloaded in small quantities at a time, and the bank brought up to grade 18 ft. wide at base of rail.

Between 9th September, 1893, and 31st July, 1894, the embankment settled about 2½ ft. at the lowest point. On the latter date 96 cars were unloaded, which brought the track up to grade and bank 16 ft. wide at base of rail. Since that date no appreciable settlement has taken place.

The filling of the trestle has been given in considerable detail in order to give a clear idea of the difficulties that are encountered in filling on a bad bottom and sloping foundation, and to show what can be done in the way of keeping such a structure passable in the face of such difficulties, caused by the sudden sliding out into the lake of the original bottom of clay and mud overlying the hard bottom, and carrying with it the filling which rested upon it. The track sank in the autumn of 1892, 40 ft., and in May, 1893, 52 ft., besides smaller settlements that were going on all the time, and yet traffic was maintained, the greatest detention to any passenger train being eight hours, when the track sank at 6 p.m. during a heavy rain, and was ready to pass the train at nine a.m. next morning.

The estimated quantity of filling required for the trestle was 100,000 cubic yds. The total quantity put in was 96,000 yds., which cost $41,637.00.

When the foundations are good, the filling of a large trestle is attended with little or no risk. Settlements of trestles on apparently good foundations, however, occur, which it is difficult to account for, such as that at Big Pic, where, after the trestle had been filled some time, the bank and trestle subsided six feet in one night, and, as far as could be seen, no disturbance of the surrounding ground took place, nor has any further settlement taken place in the past five years.

Between Winnipeg and Donald, a distance of 1,024 miles, there are not many large trestles; a few of the large ones west of the summit of the Rockies have been filled, the policy adopted being to fill long, shallow ones, and so to reduce the length of wooden floors as much as possible with the least amount of money, except in certain cases where transfers could not be made or diversions readily built. West of the Summit most of the trestles filled were situated on sides of hills, and required retaining walls to hold the banks and prevent the slopes from running down into the Kicking Horse River.

From Savonas to Port Moody, a distance of 213 miles, built by the Government, a large amount of work has been done, 27,746 ft. of trestles having been filled. In all cases the streams are carried through the banks in stone arches or box culverts, and where grasshopper trestles were built and no drainage required, and there was no room to extend the slopes on account of the steepness of the banks, stone retaining walls were constructed and generally filled in behind with stone debris.

In many cases the sites of the trestles were changed and thrown into the banks, so as to take out curves and at the same time enable the filling to be made without building expensive retaining walls. This has been carefully studied and economically carried out, the line having been thrown in just enough to furnish filling for the trestles, and thus material was obtained close at hand, and the quantity required was reduced by throwing the fills up the hillside and placing more of the track on solid ground.

PNEUMATIC DUMP CARS.

The material used in filling trestles on the Eastern and Western Divisions was loaded with steam shovels on flat cars and unloaded by means of the ordinary ballast plow, drawn over the length of the train by the locomotive. On the Pacific Division a large portion of the work was done in the same manner. Where the filling was on side hill, a one-sided, or side hill, plow was used, and on straight track worked fairly well, but on sharp curves it caused a great deal of delay, and very materially increased the cost of the filling. In order to overcome this, all the various dump cars in use were examined in the latter part of 1891, and inquiries made from the principal manufacturers of cars and the leading Railway Companies and contractors in the United States, when it was found that there was not in use in any place a dump car that would answer the purpose, viz., one that could be unloaded without sending men along the track over the high trestles to do the work, which would have been slow and dangerous, and in order to avoid this, the question of operating dump cars by power, obtained from the locomotive, using either steam or compressed air, was then considered, when it was found that a plan for using compressed air had been patented in the United States, but had not been put into use. From this design as a basis. and after a number of important changes had been made on it in the Canadian Pacific Car Department, fifty cars were built in the Company's Car Shops in the Spring of 1892, and sent to the Pacific Division, where they gave the most complete satisfaction; trains of twenty cars being regularly unloaded, and brought back into position ready to return to put in half a minute, which, of course, very materially reduced the cost of the filling. This, it is believed, is the first instance where dump cars on Railway Works have been unloaded by means of compressed air.

HYDRAULIC FILLING.

Two large embankments, one containing 66,000 yds. and the other 144,000 yds., have been made by hydraulicing gravel from adjoining hills. The first embankment was filled at a cost of $5,839.51, of which amount $2,862.43 was for labour, and the balance, $2,977.08, was for plant and material used in boxes, etc. The iron pipes, monitors and part of the material in the boxes can be used again, and in fact are now in use at the second embankment, so it was considered fair to charge only 20 per cent. of the plant against the cost of filling, which reduced the total cost to $4,715.33, or 7.15 cents per cubic yard.

The second embankment is now being successfully made. The water is taken from the stream, which runs down the valley that has to be filled, at a point about 584 feet up the hill side, and 353 ft. above grade, or at an elevation of 125 ft. above the pit from which the gravel is taken for filling the ravine. The water is carried in a 15 inch pipe to a giant or monitor, such as is used in hydraulic mining. This monitor is generally worked with a five-inch nozzle, and throws a powerful stream against the gravel bank, washing the gravel and boulders down into a flume which has a grade of from 11.5 feet to 25 feet per 100 feet. This stream will carry down on to the dump 750 cubic yds. in 10 hours. One man is required to work the monitor, another is at head of sluice, and two along sluice to start and keep moving boulders that can pass down the flume, but are liable to lodge on a flat side, and three men are required to direct the material as it comes from the flume and to put in brush at the outer edges, so as to prevent the water from cutting channels in the slopes. Old sleepers taken out of track have been used for this purpose most successfully, by simply placing them on the outer edges of the bank, and when the gravel is raised up to the top of them, a new row is laid down on the lines of the slopes, and so on, new lines of ties being put in for each six inch rise of the bank. There are a number of places on the line where this method of filling is to be adopted.

RETAINING WALLS.

Large numbers of retaining walls have been built along the Fraser and Thompson Rivers at grade to replace the grasshopper trestles, and long structures of crib wharfing put in by the Government. Some of these walls are 100 ft. in height, and have in all cases been built of concrete mixed with large stones, generally found at or near the site of the wall. This work has been done in the most economical manner possible, by intelligent labourers, specially instructed as to how such work should be built. When these walls were commenced, Portland cement cost on the Pacific Coast $5.50 per barrel of 400 lbs. It was therefore desirable to use as little of it as possible, and yet enough of it had to be used to cement the stones in the most thorough manner. Large angular stones, as they came from the quarry or as they were picked up along the track, were first laid down on their largest beds on the foundation; cement mortar, three of sand to one of cement, was then put into the bottom of the angular spaces, and into this mortar small angular stones taken from rock slides were mixed, and into this mixture larger angular stones were carefully rammed, the angular point downward, so that they nearly touched the first large stones laid; when the large spaces were filled and the course levelled off, grout was poured on to fill any vacant spaces and to more thoroughly cement the whole mass together. This method required less than one-half the cement used by ordinary masons in building rubble masonry, and as it was done by labourers, there was the large saving in the labour as well as in the cement, and the work is certainly very much better than the average rubble built by masons. When there was room to build retaining walls at the bottom of the slopes, and when they could be built with a batter of as much as 1 to 4, dry masonry was used.

WATERWAYS—STONE.

At most of the fills it has been necessary to provide waterways in the form of bridges, stone arches, stone box culverts or cedar box culverts, the exception being where tunnels were made in rock points at one side of the fill. This has been found economical, and has been carried out wherever possible, the cost of a tunnel six feet by eight feet being about $9.00 per lineal foot.

Where the line is carried on side hill ground, over a deep valley, with a stream at the bottom, the stream, instead of being allowed to follow its natural course down the valley, and to pass under a bank requiring a culvert, say 200 ft. in length; has been tapped at an elevation a little above the rail level, and the water carried along the side of the valley in a ditch and over the bank, just under the rails. In many cases this method has proved very satisfactory, and of course economical, a culvert 20 feet long, of light construction, on a good foundation, taking the place of one 200 feet in length, of heavy construction and probably on a soft foundation.

Where waterways under heavy banks have had to be provided, and where covers were easily obtained, three feet by four feet box culverts have been built, with masonry constructed as already described for retaining walls, great care being taken to use the best cement and to fill all spaces between the stones. Where a three feet by four feet box culvert was not quite large enough to carry the water, or where covers were not easily obtained, small arches have been used, the arch ring being built of rubble laid in cement. These arches in most cases have cost less than box culverts, as the stone for the entire arch, except coping and outer ring of arch, was generally found either on the site or at the end of an adjoining rock cut, whereas the covers for the box culverts would have had to be specially quarried, and often hauled long distances, which very materially increased the cost of the culvert, and where this was the case, arches were always adopted.

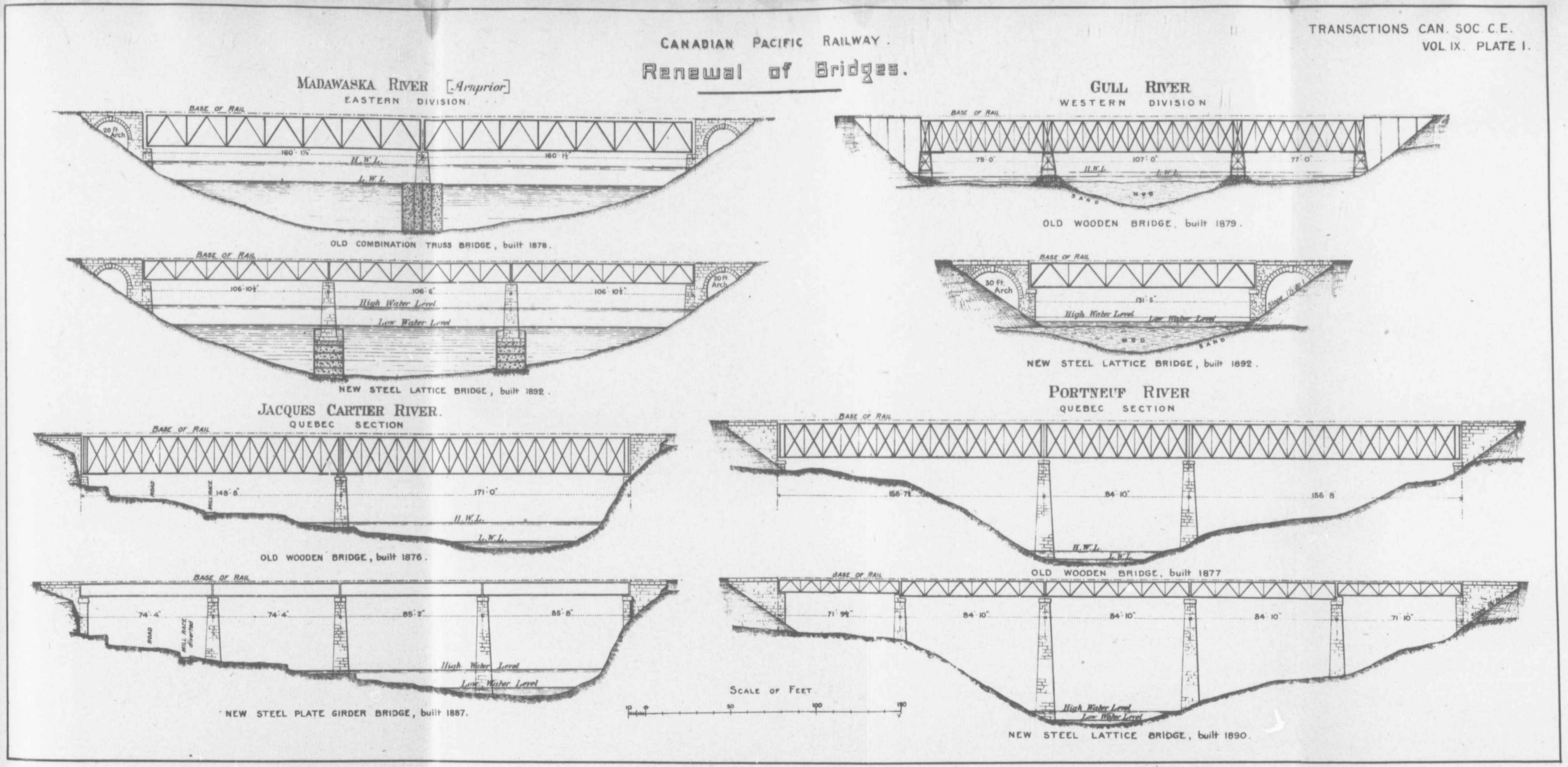
In places where a waterway of from 20 feet to 30 feet in width was required, arches have been adopted in preference to short iron spans of any kind, when the cost was not much in excess of the spans. Arches have always been found to be cheaper, where provision was made for double track. Semi-circular arches have been found to be much more expensive than flat arches, as the wings to catch the slopes for flat arches are very much smaller, and as the width of water-way is what is wanted in most cases, many flat arches have been built. For a 14 feet arch under a 46 feet bank for instance, the quantities are as follows: for single track flat arch 639 yards, and semi-circular arch 805 cubic yards, for double track flat arch 697 cubic yards, semi-circular arch 897 cubic yards, the distance from bottom of stream to springing being the same in both cases, as also the depth of foundation. Semi-circular arches on high walls have been used under the heavy fills in the deep valleys that run into the Fraser, as the streams in these valleys at times carry down timber debris, which is liable to jam at the entrance of the culvert; and as the streams have rapid falls, a culvert might soon be flooded up to its top, and for this reason culverts are built with high waterways, wherever it is considered safe to put in an arch. Great care is required in fixing the dimensions of water-ways in the mountains, for even after years of study of a stream, and when it is thought that it has been seen under all conditions of flood, something happens to upset all former experience and conclusions. A slide often takes place up in the mountains, which may turn two streams into one, and send down with that one a large amount of timber debris, which formerly, but to a lesser extent, came down some other stream, and afterwards the small stream becomes the larger one, and *vice versa*.

CEDAR CULVERTS.

There are many places on the line where stone structures for water-ways would have been expensive on account of the great distance which the stone would have to be hauled, and in other places, foundations for stone structures would have been very expensive, and it became necessary to substitute something else. Iron pipes were expensive, and required a very long haul. Earthenware pipes were cheaper, but also required the long haul, and in some cases were found to be affected by the frost. Wooden culverts built of cedar timber, of which we found large quantities along the line, seemed to meet the requirements: 1°, the timber is cheap; 2°, there was in all cases a very much shorter haul than that required for stone, iron or earthenware; 3°, it required a much less solid or uniform foundation; a settlement of a few inches more at one point than another did it no harm, and cracks that would have seriously injured stone, iron or earthenware from such a settlement did not arise in cedar timber, its elasticity permitting considerable settlement without any injury to the structure. As to its permanency, there is no question but that cedar will last at least fifty years, quite as long as much of the stone that is found on many railways. There is a cedar fence on the Aylmer Road, between Ottawa and Aylmer, that in 1876 was fifty years old, which was then being taken down to straighten it up, the owner of which said that he would take off the bark and rebuild the fence, when he considered it would be good for another fifty years.

A cedar log is to be seen in the Stanley Park at Vancouver, British Columbia, in a good state of preservation, on which a tree of 10 feet 6 inches in circumference has grown with one fork of the roots on one side of the tree and one fork on the other side. Similar trees to the one growing on the cedar in the same place have 168 rings, showing them to be 168 years old. There is a hollow cedar log in the same Park 4 feet 6 inches in diameter, the shell being six inches thick, which is quite sound. Over this log is growing a spruce tree, which measures 13 feet 6 inches in circumference at eight feet above the log, and at 14 feet above the log it is 12 feet in circumference, which is 192 years old. From this evidence of the lasting quality of cedar in different situations, it is fair to assume that cedar culverts will last at least 50 years, and that they may be considered permanent work; for the saving in interest on the extra cost of iron or stone will renew these structures if necessary much sooner than at the end of fifty years. Cedar culverts have been put in where the banks are twenty feet and under, and where bad foundations or excessive haul rendered the use of stone, iron or earthenware too expensive in comparison with cedar at the point in question. These culverts, generally three feet by three feet inside measurement, are made of 10 inches by 10 inches square timber, and in some cases double or treble, side by side. The timbers are securely treenailed


AY
RAIL
RAIL


TRANSACTIONS CAN. SOC. C.E.
VOL. IX. PLATE I.
CANADIAN PACIFIC RAILWAY.
Renewal of Bridges.
MADAWASKA RIVER [Arnprior]
EASTERN DIVISION.
BASE OF RAIL
20 ft Arch
160' 1½"
160' 1½"
H.W.L.
L.W.L.
OLD COMBINATION TRUSS BRIDGE, built 1878.
BASE OF RAIL
106' 10½"
106' 6"
106' 10½"
20 ft Arch
High Water Level
Low Water Level
NEW STEEL LATTICE BRIDGE, built 1892.
GULL RIVER
WESTERN DIVISION
BASE OF RAIL
79' 0"
107' 0"
77' 0"
H.W.L.
L.W.L.
SAND
MUD
OLD WOODEN BRIDGE, built 1879.
BASE OF RAIL
30 ft. Arch
131' 5"
High Water Level
Low Water Level
MUD
SAND
NEW STEEL LATTICE BRIDGE, built 1892.
JACQUES CARTIER RIVER.
QUEBEC SECTION
BASE OF RAIL
ROAD
MILL RACE
148' 8"
171' 0"
H.W.L.
L.W.L.
OLD WOODEN BRIDGE, built 1876.
BASE OF RAIL
74' 4"
74' 4"
85' 2"
85' 8"
ROAD
MILL RACE diverted
High Water Level
Low Water Level
NEW STEEL PLATE GIRDER BRIDGE, built 1887.
SCALE OF FEET
10
0
50
100
150
PORTNEUF RIVER
QUEBEC SECTION
BASE OF RAIL
156' 7½"
84' 10"
156' 8"
H.W.L.
L.W.L.
OLD WOODEN BRIDGE, built 1877
BASE OF RAIL
71' 9½"
84' 10"
84' 10"
84' 10"
71' 10"
High Water Level
Low Water Level
NEW STEEL LATTICE BRIDGE, built 1890.

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and bolted, and upright timbers are fastened to the outside at intervals of about four feet, so as to prevent the water from following along the outside of the walls, and so endangering the structure. See Plan No. IV.

BRIDGES.

The great number of long high trestles requiring waterways from 80 feet to 100 feet in width, with the rail 80 feet to 100 feet above bed of stream, led to the adoption of the following structure, which is considered to be that which most satisfactorily fills the requirements of the case: three spans of one hundred feet, with two piers, and the ends of the outer spans standing on cedar cribs founded on piles. By this plan we get a good, safe, substantial structure at a present cost of the piles and cedar cribs, against the two short stone abutments, effecting a saving of $14,000 for 80 feet height. By the time the cribs and piles require renewing, the bank will have settled, so that masonry can be built upon it instead of through it; and leaving the question of interest aside, there is a saving of 1200 yards of masonry, or $13,500 at each bridge, and the structure is equally as good for all practical purposes, and will require no more looking after than if it had all been built in stone, as an inspection is made of all structures at least once every month. See SkowWash River, Plate IV.

In rebuilding structures over that portion of the Eastern Division lying between Carleton Junction and Sudbury, a distance of 295 miles, and on the Western Division between Fort William and Winnipeg, a distance of 428 miles, masonry has been built for double track, and of course this consideration materially changes the character of the structures that have been adopted. Stone arches have been more frequently used here than on the single track sections, on account of their economy over small truss spans. On single track, where the cost of truss and arch was nearly the same, on double track, the arch would be very much cheaper, as the difference between a 25 feet arch, single and double track, say in 30 feet bank, is only 16 per cent., whereas for the same span of iron on masonry abutments the excess is never less than 45 per cent. For a 25 feet arch in 20 feet bank, the difference between single and double track is only 32 per cent., whereas for the most economical girder the excess of double track over single is never less than 80 per cent. The arch requiring only 13 feet of additional length of barrel, or centre portion of the arch, whereas the truss requires an additional span and 47 per cent. more masonry. This is, however, offset by the fact that the expenditure for the arch must be made at once, whereas the trussand some of the additional masonry required for it may be postponed till actually required, but the economy of the arch is so great that it has been put in wherever possible.

An important part of the reconstruction has been the replacing of wooden bridges with structures of stone and steel. Wooden bridges have been carried over as long as they could be rendered absolutely safe. In most cases where a bridge showed the slightest sign of weakness, or when it was thought from its age that it might be becoming weak, it was strengthened by putting pile bents under the second panel point from the end, thus reducing a hundred foot span to one of 60 feet, and of course strengthening it in like proportion. The structure was then carefully watched, and renewals commenced, so as to have the new bridge in before the old one was worn out.

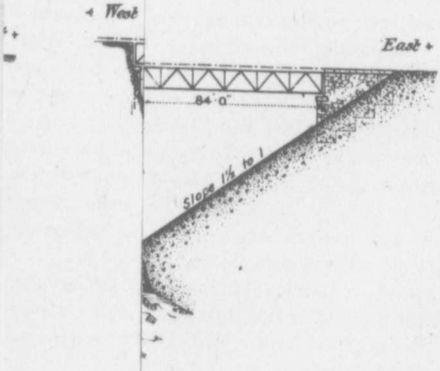
In renewing the work on the old sections of the line, as, for instance, between Quebec and Montreal, it was found that considerable economy could be effected by the use of short spans, without at all interfering with the waterway or with the passage of ice, timber, etc.

The Jacques Cartier bridge, as originally built by the Quebec Government, had one 170 feet span and one 140 feet span on masonry abutments and pier. To rebuild these spans in steel would have cost $25,629. By adopting two 85 feet spans and two of 74 feet the cost was only $21,105.39. This of course included additional masonry piers, and also the diversion of a mill-race, which was under one of the spans, where it was required to build the pier. The short plate girder spans require much less care and inspection than the longer spans, and are much cheaper to maintain. See Plan No. I.

At Port Neuf the old bridge was built with one 80 feet span over the stream and two side spans of 150 feet. One of these large spans was adopted on account of the bad character of the foundation, but it was found economical to put in two 75 feet spans in the place of each of the 150 feet spans, and to carry the bad foundation down to the hard bottom, and drain the surrounding ground, as the renewal of the original spans would have cost $25,600.98, and the work was done for $22,169.37, and a better structure obtained. See Plan I.

At Arnprior, which is on the section built by the old Canada Central Railway, and as mentioned above—being between Carleton Junction and Sudbury — has all new structures built for double track, two old combination trusses of 150 feet required renewing. The centre pier on wooden crib was in 39 feet of water, and was continually settling, so that a new pier was required. It was found that to build a new pier

NSACTIONS CAN. SOC. C.E.
VOL. IX PLATE III.



PACIFIC R

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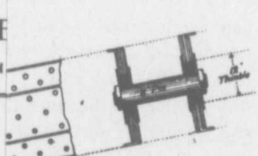

ALE OF FEET.

100

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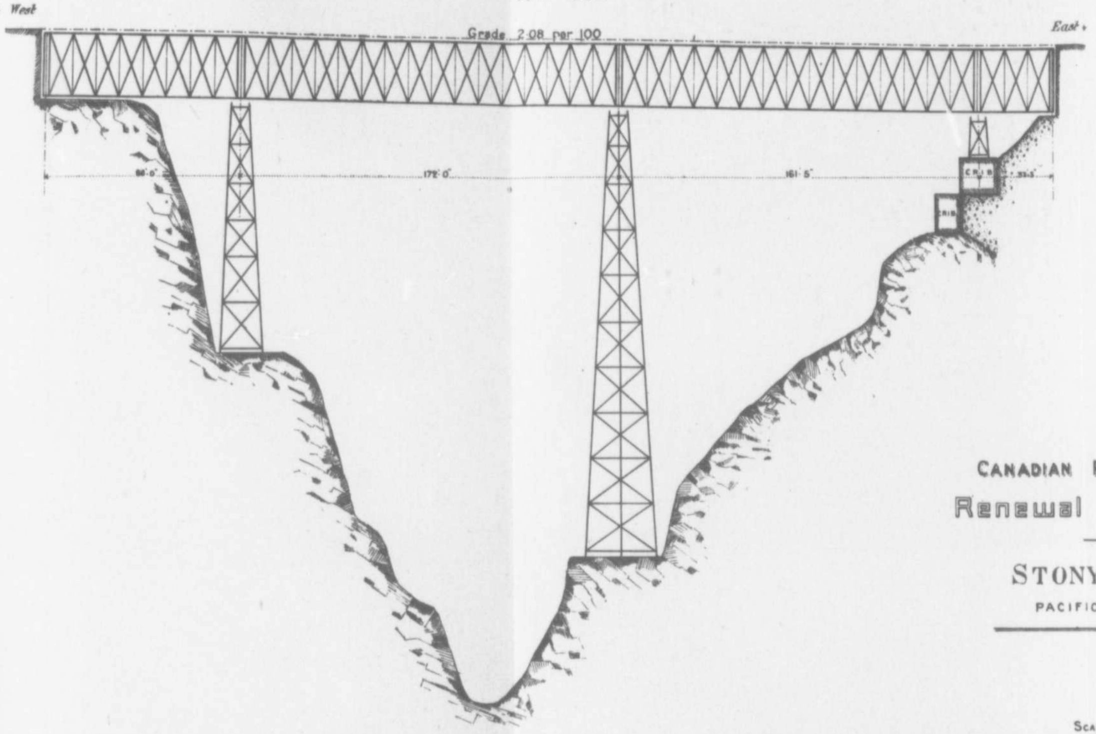
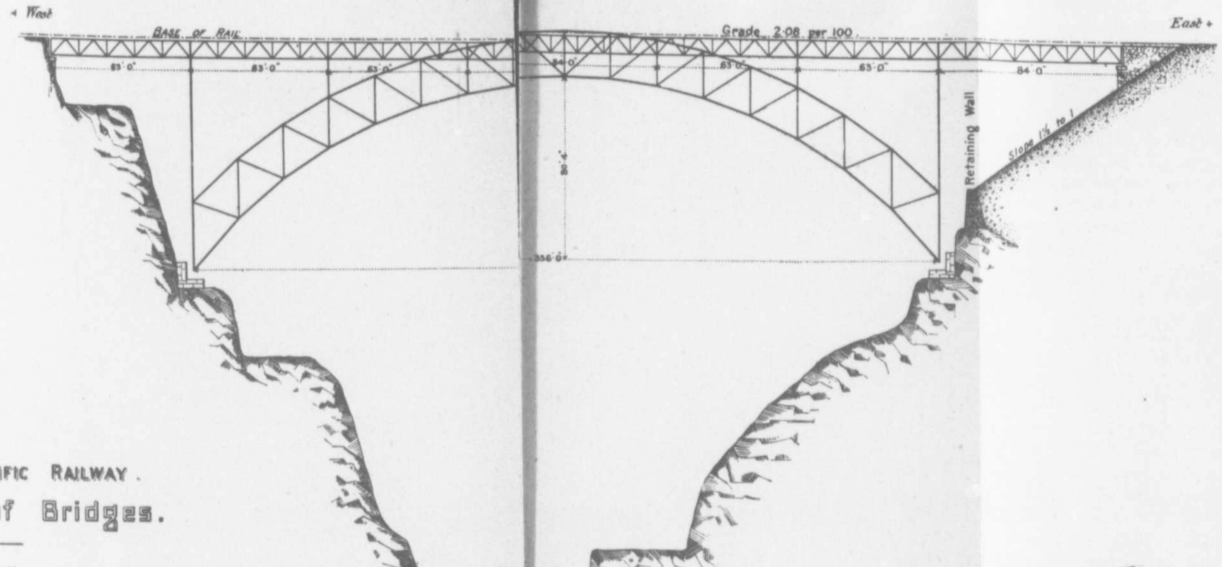
4 FT.

ORIGINAL WOODEN BRIDGE
built 1885.



NEW STEEL ARCH BRIDGE
built 1893.



CANADIAN PACIFIC RAILWAY.

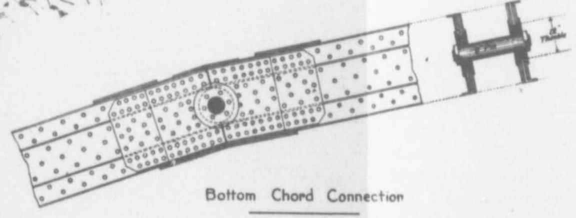
Renewal of Bridges.

STONY CREEK

PACIFIC DIVISION.

SCALE OF FEET.

10 0 50 100 150



Bottom Chord Connection

SCALE.

for double track and single track spans, the cost would be $36,149.15, for the bridge complete with double track spans $60,978.95, and that by putting in two new double track piers and three 100 feet spans for single track, the cost would be only $32,093.61, and with the bridge complete for double track $45,687.20. The abutments were built in the early days of Railways, when economy was not very much considered; they were 21 feet wide between the parapet walls, which were four feet thick, so that by removing these walls back to the ballast wall, we obtained an abutment 29 feet in width, wide enough for a double track bridge.

The piers of this bridge were put in by sinking bottomless caissons through the water and the mud, which overlaid the rock to a depth of 39 feet. This mud, which was three feet thick, was removed by divers, and concrete to a depth of 20 feet was deposited inside the caisson through the water. When the concrete was all in, the water was pumped out and masonry built on top of it. Each pier contained 257 yards of masonry, and cost $2,661.50, or $9.50 per cubic yard. The excavation in the caissons under water cost $372, or $6 per yard. See Plan No. I.

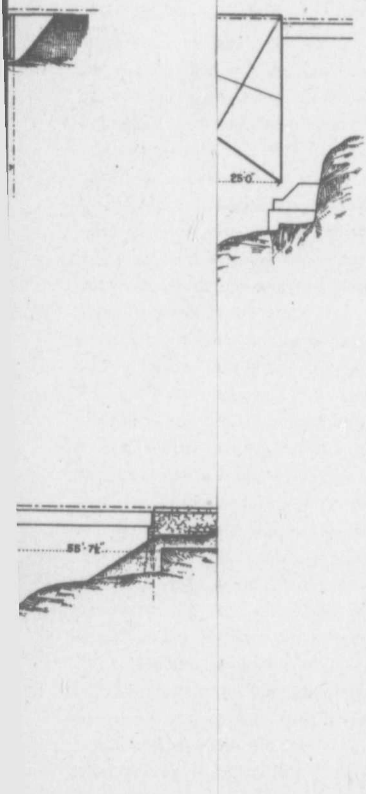
The Gull River bridge on the double track section between Fort William and Winnipeg, as built originally in 1880 by the Government, was composed of one span of 100 feet, two spans of 80 feet, and eighty-five feet of trestle. The cost of replacing these three spans in 1891 in masonry and steel, that is, with masonry complete for double track, and steel for single track, would have been $41,600, and complete for double track, $55,800; but by using one span of 130 feet with stone arch abutments of thirty feet span, the cost was $33,166, and to complete for double track the cost will be $41,260. The base of rail on this bridge is 23 feet above low water. The bed of the river is composed of fine sand, and the masonry was founded on piles, capped with timber below lowest water. See Plan I.

The Stony Creek bridge on the Pacific Division, near the summit of the Selkirks, built in 1885 over a chasm 300 feet deep, has been replaced by a steel arch of 336 feet span. The wooden structure was composed of continuous Howe trusses of 33 feet, 161 feet, 172 feet, and 86 feet, supported on wooden trestle towers, and would have been serviceable for some time longer, as the timber, which was Douglas fir, was in good condition; but the Management, in view of the difficulty of replacing such a structure in case of its being burnt, and of transferring the traffic over such a chasm, decided to rebuild it in steel in

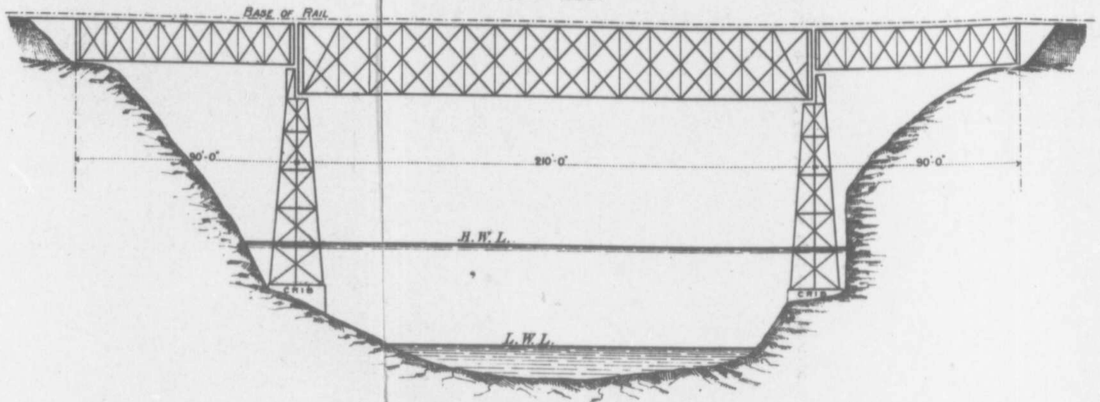
1893, and fortunately this was done before the fire of 1894, which swept over the western end of this structure and under it, destroying everything in its way that would burn. The walls of this ravine consist of decomposed mica schist, broken by numerous veins of quartz, upon which a good foundation could not be obtained or made. It was therefore decided to put in a span of 336 feet in the shape of a three-hinged arch, with one span of 60 feet at the west end and one span of 80 feet at the east end, and to build this arch outside of the old structure, it being impossible to improve the crossing by any change of location. Very inexpensive foundations were required with this arrangement, and by placing the trusses of the arch outside of the girder, and carefully fitting the floor beams to the old spans, it was possible to place the arch in position without cutting out rods or braces to such an extent as to weaken the old trusses or interfere with the traffic. The arch was erected on a light false work, and by using six inch pins at the connections with 12 inch covers or thimbles, on which the chords bore, as shown on Plan No. III, the connections were made very readily, no field riveting being required at the connections, except on the lateral bracing which covers the joints at top and bottom. The estimate based upon the Company's Standard Specifications for a 380 feet span and one span of 80 feet was $82,824, and for a 336 feet arch, one 80 feet and one 60 feet girder, $77,360. As this bridge is on a grade of 2.08 per 100 with a curve on the western end of the span, the standard load was increased by 25 per cent., which brought the cost of the structure to $96,075.67, of which $74,032.88 is for steel and the balance for masonry, retaining walls and floor.

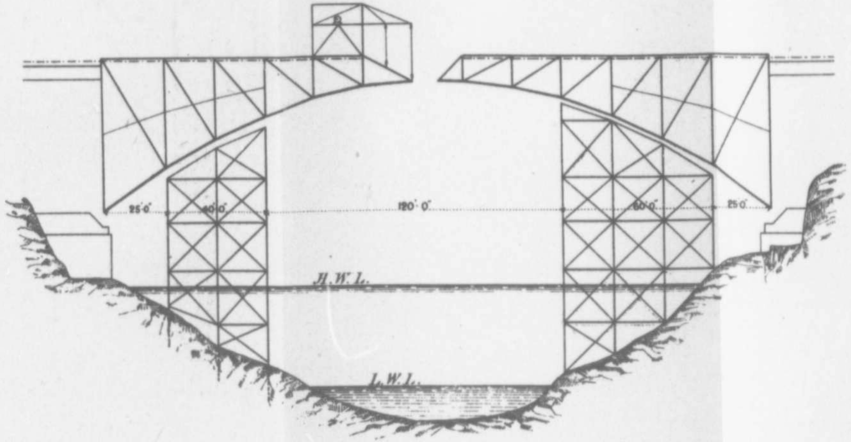
The Salmon River bridge, put in by the Government, over the mouth of a rapid stream on the Fraser River, 137 miles east of Vancouver, was composed of one 200 feet span double intersection truss and two spans of 80 feet. The double intersection truss gave out before the road came into the hands of the Company, and was supported by braces and straining beams. This class of truss, designed with a minimum of iron and a maximum of wood in the web members, on account of the great cost of iron on the Pacific Coast, did not prove satisfactory, and required strengthening or supporting in nearly every case before the Company could run heavy engines over it. With similar spans these trusses have only about one-half as much iron in the web members as an ordinary Howe truss; in this truss the proportion was as 9 to 16. The river at the point of crossing is very rapid, and false works would have been difficult to erect and maintain, so it was decided to put up a hinged arch of 270 feet span and three spans of 50 feet, estimated to

CAN. SOC. C.E.
OL. IX PLATE II.

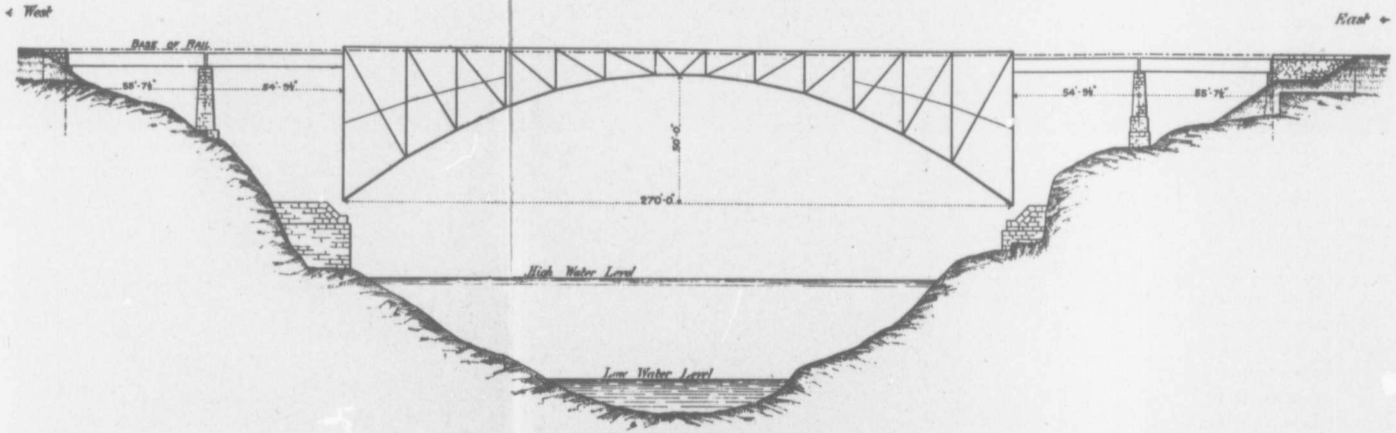


ORIGINAL WOODEN BRIDGE
built 1883.





Falsework, and Mode of Erection.



NEW STEEL ARCH BRIDGE
built 1893
on site 34 ft. South of old bridge.

CANADIAN PACIFIC RAILWAY.

Renewal of Bridges.

SALMON RIVER

PACIFIC DIVISION

SCALE OF FEET.

10 0 50 100 150

cost $44,413. To rebuild the structure with one span of 160 feet, one 80 feet, one 70 feet and one 60 feet, the cost was estimated at $55,-807. When excavating for the foundation of the west abutment in mica schist, similar to that at Stony Creek, an extensive slide took place, which necessitated greatly increasing the quantity of masonry and lengthening the gap to be covered, so that the bridge, as built 34 feet south of the old structure, is made up of one 270 feet hinged arch and four 50 feet plate girders, the cost of which was $57,966. The arch was erected as a cantilever, as shown on Plan No. II.

In giving this very general idea of the character of the work done, and in showing to some slight extent the economy that has followed the use of temporary work in the original construction, I have trespassed longer upon your patience than I intended. Much that would be very instructive has had to be passed over entirely, and none of the work has been more than touched upon.

In conclusion, I would like to impress upon our younger members the necessity that exists in this new Country for the practice of economy in all the works they happen to be engaged upon.

We have a great work to do in building up a Country which stretches from the Atlantic to the Pacific, filled as it is with great natural resources of all kinds awaiting development, and but little money to do it with; and if we can so carry out our works that they are good and substantial, and at the same time cheaply constructed, so that the Capitalists who furnish the money can get a fair return for its use, we may expect more money from them, and other works will be carried out that will give employment to Engineers and prosperity to our Country. It is quite an easy matter to build an expensive structure, but it is an Engineer's duty to build an effective structure for the least possible cost, and after his design is made perfect as to its stability, he should proceed to remove from it everything that is not absolutely necessary and that has no duty to perform, remembering that he must never build ornaments, but that good and wise construction will be ornamental in itself.

Finally, you must also remember that your success in life depends on your capacity and willingness to take infinite pains with everything you are called upon to carry out. You must be in downright earnest about your work, and, above all things, you must be absolutely and entirely honest in every respect, never letting your convictions or opinions be warped in any way for any consideration, and then, if you may not always command success, you will at least deserve it, which is often better.

OBITUARY.

JOSEPH LENNON UNSWORTH was born in Liverpool, England, on March 12, 1840. His father, James Stanley Unsworth, was in the employ of the Grand Trunk Railway, and his mother was a sister of the celebrated composer of music, John L. Hatton. Mr. Unsworth was educated in Montreal and St. Hyacinth, and on leaving college in 1855 entered the service of the Grand Trunk Railway Co. as an apprentice, in the mechanical department at Longueuil, under Mr. W. S. Mackenzie, then the locomotive superintendent. He remained in the service of the Grand Trunk Company in various capacities till March, 1872, when he was engaged upon the construction of the Intercolonial Railway between Rivière du Loup and Causapscal, and in November, 1874, on its completion, he took charge of the locomotive department at the former station, its then western terminus. In November, 1881, he was appointed mechanical superintendent and storekeeper of the Canadian Government Railway in Prince Island Edward, and in May, 1888, became superintendent. He held this appointment at the time of his death which took place September 10, 1894, at Charlottetown, P.E.I. He became a Member of the Society, January 6, 1888.

FREDERICK AYSHFORD MILBANKE WISE, second son of Mr. John Robert Wise of Highfield House, Exmouth, Devon; H. M. Consul General to Sweden, was born on the 31st July, 1833. He was educated at Cheltenham College for the East India Company's Engineers, and passed the examination for the Indian Staff Corps College at Addiscombe.

On the advice of the late Mr. James Bell Forsyth of Quebec, he gave up the idea of service in India, and came out to Canada in 1852. He was at once appointed by the Hon. John Young (then Chief Commissioner of Public Works) to the staff of Mr. Samuel Keefer, Past President Can. Soc. C.E., and was engaged in making surveys for a projected canal at Sault Ste. Marie. He was subsequently employed on the location and construction of the Grand Trunk Railway, being connected with the work until its completion.

In 1858, Mr. Wise was appointed by Mr. Walter Shanly, M. Can. Soc. C.E., to construct the Kingston Branch and other works, occupying a period of over two years. He enjoyed the esteem and friendship of that distinguished gentleman—who was then Chief Engineer of the

Grand Trunk Railway—a friendship which only ended with Mr. Wise's life.

In 1861-2 he was engaged in making surveys and plans for the proposed Harbours of Refuge on Lakes Erie and Ontario, under the Hon. Hamilton H. Killaly, C.E., with whom he subsequently served on the Military Commission.

In 1864 Mr. Wise was appointed engineer of construction on the Erie & Niagara Railway, and on its completion was transferred to the Buffalo & Salamanca Branch of the Atlantic & Great Western Railway.

During the reconstruction of the Prescott & Ottawa Railway in 1866, under Mr. Thomas Reynolds, Mr. Wise was resident engineer of the works. He also built the Chaudière Branch of that railway. About this time he was requested by the Council of Ogdensburgh, N.Y., to prepare a report and plans for the sewerage and water works of their town; and he was also employed by the United States Government to make a survey and plan of Ogdensburgh Harbour, with a view to its improvement.

In 1872 Mr. Wise was engaged by Mr. T. C. Keefer, Past Pres. Can. Soc. C.E., as resident engineer on the Ottawa water works, then in course of construction, and had charge of the aqueduct, masonry, bridges, etc., etc He was appointed in the same year engineer of the Rideau Canal; and by permission of the Government continued his connection with the water works until their completion. The manner in which the duties entrusted to him were performed elicited the warm approval of his chief, whose confidence as an engineer he retained to the last. To quote Mr. Keefer's forcible words: "He was a man of sound judgment,—one who could neither be bought nor bamboozled."

During his long and judicious administration of the affairs of the Rideau Canal, that line of navigation was greatly improved, and the works placed throughout in efficient condition. Mr. Wise also planned and constructed the Tay Branch, which forms a part of the Rideau Canal system.

The writer, who enjoyed Mr. Wise's friendship for a period of over forty years, may be permitted to add that the effects of his early training were abundantly evident in every act of his life. He was a lover of athletic sports—and was distinctly endowed with artistic talents, as shown in all his drawings and sketches, some of which were of very considerable merit. He was a close observer, and had a retentive memory, so that his views on almost every subject connected with the profession were in accordance with sound common sense combined with skill and experience. His opinions were of much value on hydraulic works. His individuality was most marked. Nothing could swerve him from the straight line of duty, and yet in carrying out the various important works with which he was entrusted, he had the happy faculty of securing their proper construction without losing the personal friendship and esteem even of those whose interests suffered by his firmness and rectitude. In short, he was an excellent specimen of that class of educated and honourable Englishmen which has done credit to our profession in every quarter of the globe.

Mr. Wise was one of the original members of this Society, having joined in its formation on the 20th January, 1887. His health had been failing for some time before his death, which occurred rather suddenly at Ottawa, on the 3rd July, 1894, where, for nearly twenty-two years, he had filled the position of superintending engineer of the Rideau Canal.

HENRY YATES was born at Walton-le-Dale, near Preston, Lancashire, England, his father having been engaged as engineer and contractor on parts of the Liverpool & Manchester Railway. Mr. Yates was educated at a private academy near Liverpool, and his father dying when the son was young, he was apprenticed to the famous firm of Nasmyth & Gaskill, engineers, of the Bridgewater foundry, near Manchester. Mr. Yates made rapid progress in his chosen profession, and after completing his apprenticeship he was one of a number of young engineers recommended and sent out by Mr. Nasmyth to France, to assist in the construction of the first railway there between Paris and Rouen. He remained in France until 1846, when, returning to England, he was employed in the locomotive works of the London & Southwestern Ry., as superintendent over the construction of their new engines and other plant for the line. He remained in this position until 1853, when he was engaged by Mr. C. J. Brydges, the managing director of the Great Western Railway of Canada, to come to Canada for a term of years, receiving the appointment of chief locomotive superintendent and mechanical engineer of the whole line. In 1857 he entered into an arrangement with Captain Barlow to complete the Buffalo & Lake Huron Railway, and held the position of chief mechanical superintendent and engineer. Five years afterwards he became chief contractor for the maintenance of the permanent way and the whole of the works between Buffalo and Goderich. In 1861, when Sir Edward Watkin became president of the Grand Trunk Railway, Mr. Yates was offered and accepted the appointment of chief engineer of the whole of that railway and its branches, a position which he held until 1866. Afterwards he was engaged more or less as engineer and contractor for and on works in connection with the Grand Trunk from 1880 to 1886. The Michigan Air Line Railway was surveyed, located and completed under his supervision as chief engineer, an important work for which he received much deserved praise. Since then he had not been actively engaged except in consultation and advice afforded to those interested in the railways of Canada. During this active career of 35 years in Canada as civil and mechanical engineer, Mr. Yates had invented several important and profitable patents, as applied to locomotives. In 1869 he formed a partnership with the late John H. Stratford for railway supplies, and their operations were crowned with success.

Mr. Yates was a member of the Institute of Mechanical Engineers of London, England. In 1851 he married Emily Sapey of Chertsey, Surrey, England, who survives him, together with three sons: Mr. Herbert Yates, C.E., of this city; Mr. Wynn Yates, contractor of Detroit; and Dr. H. B. Yates.

Mr. Yates was elected a Member of the Society, December 19, 1889.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.		Date of Membership.
Duchesnay, Edward Z	Vancouver, B.C.	May 23, 1895
Keating, Edward Henry	City Hall, Toronto.	May 23, 1895
O'Dwyer, J. Seabury	Granby, Que.	A.M. June 25, 1887 M. May 23, 1895

ASSOCIATE MEMBERS.

Bickerdike, Robert, Jun	P.O. Box 94, Montreal.	S. Dec. 6, 1888 A.M. May 23, 1895
Casgrain, Joseph P. B	180 St. James St, Montreal.	May 23, 1895
Crompton, Arthur	Hamilton, Ont.	May 23, 1895
Richardson, George Henry	Revelstoke, B.C.	S. Feb. 24, 1887 A.M. May 23, 1895

STUDENTS.

Angus, William F	240 Drummond St., Montreal.	May 23, 1895
Baker, Hugh C	93 University St., Montreal.	May 23, 1895
Dibblee, Harrie Miles	Woodstock, N.B.	May 23, 1895
Greig, Alex. R	Westmount, Que.	May 23, 1895
McGillivray, Archibald	New Westminster, B.C.	May 23, 1895
Moodie, Kenneth	McGill College, Montreal.	May 23, 1895
Robins, Sampson P	513 N. Dame St., Montreal.	May 23, 1895
Rogers, Robert P	Grafton, Ont.	May 23, 1895
Scammell, J. Kimball	St. John, N.B.	May 23, 1895

CHANGES AND CORRECTIONS.

MEMBERS.

Hislop, John	Eagle Eagle Co., Col.
Hyndman, Patrick Kennedy	Stafford Villas, Sarnia, Ont.
Krouglicoff, Nicholas	Wludiwostock, Siberia.
Osler, Charles Hodgson	168 Rideau St., Kingston, Ont.
Shewen, Edward T. P	Dept. Pub. Works, St. John, N.B.

ASSOCIATE MEMBERS.

Going, Alvah Seymour	Cor. Hillside Ave. & Cook St., Victoria, B.C.

HAYCROFT, JAS. ISAAC................Fontenay, Woollahra, Sydney, N.S.W., Australia.
PEARSE, THOS. E. E..................Box 524, Pittston, Pa.
WARNER, WILLIAM GEORGE............36 Toronto St., Toronto.

STUDENTS.

DAWSON, A. S........................Care of Messrs. Moore & Co., 95 Milk St., Boston, Mass.
DOMVILLE, JAMES W..................9 Drummond St., Montreal.
DUFRESNE, ALEX. R..................McGill University, Montreal.
HARE, GEORGE C......................McGill University, Montreal.
HAULTAIN, H. E. T...................
MOONEY, GEORGE W...................269 University St., Montreal.
WAINWRIGHT, JAMES GEO. R..........Engineers' Dept. G.T.R., Hamilton, O.
WALLACE, JOHN WM. MARTIN.........1124 City Hall Ave., Montreal.

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