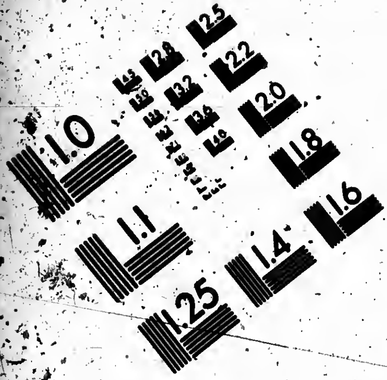

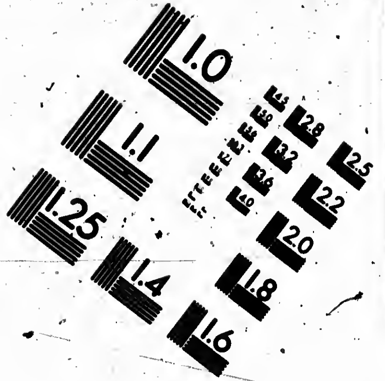

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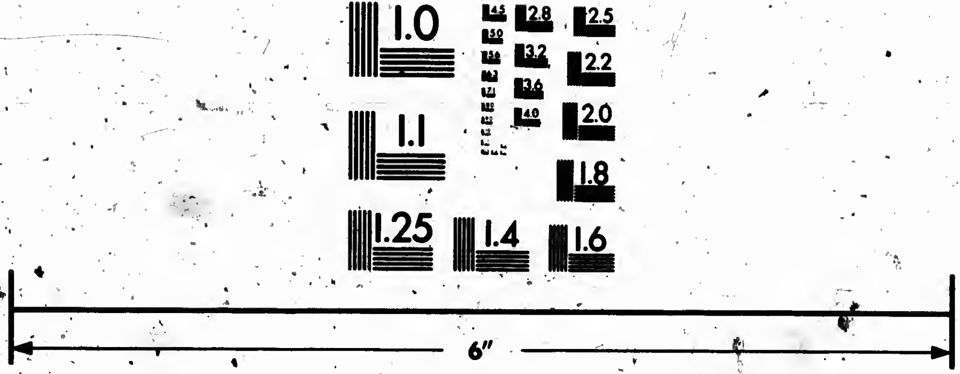

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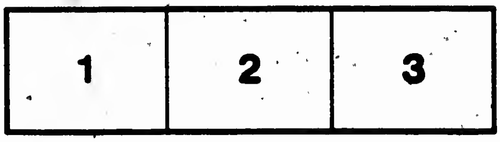

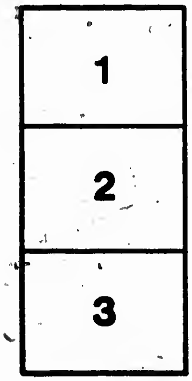

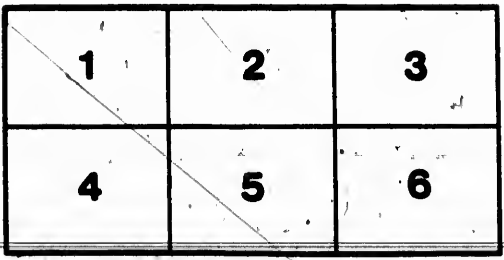

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Canadian Society of Civil Engineers.

ESTABLISHED 1887.

TRANSACTIONS.

This paper will be read on Thursday the 12th May, 1887.

THE SUPERSTRUCTURE FOR THE LACHINE BRIDGE.

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

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

In adopting the lengths for the different spans at this crossing of the Saint Lawrence River, there was no precedent to guide the designer, excepting the lengths which had been adopted for the Victoria Bridge, which are as follows: 24 spans each 240 ft. centre to centre of piers, with one channel span of 350 ft. centre to centre of piers. In the Lachine Bridge we have eight spans of 240 ft. centre to centre of piers, two spans of 269 ft. centre to centre of piers, and two channel spans of 408 ft. centre to centre of piers. (See Plate I.)

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

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

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

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

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

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

The two systems being entirely independent of each other throughout (see Plate III). Where the diagonals cross the vertical posts, there is a pin running through the post, making the ties in two lengths. It is a matter of regret that this practice has been used indiscriminately by the Engineers in the States, without any regard as to its pernicious effects. This has been the case, for example, to such large structures as the Platsmouth bridge, in which there are posts 50 ft. long on centres, divided into half lengths by the ties crossing at their middle, without any provision for the effects of distortion due to strain in the members; the effect of a load coming on a structure framed in this manner can be easily shown (see Fig 1., Plate III). Supposing the trusses to be cambered when there is no strain in any member, the intersection of the tie is at some point below the centre of the post. Now, when the load comes on the span, the chords tend to become horizontal, the posts tend to become vertical, bringing the intersection of the ties with the posts more and more towards the centre of the post, until finally, when the entire camber is taken out of the truss, the intersection must necessarily be at the centre of the post; the amount of this movement depends on the length of the panels and the depth of the truss. In the 240 feet spans of the Lachine bridge, this movement amounts to about ¼". and has been provided for by making the holes in the posts 1" larger than the pin, thus allowing ample movement for the pin when the load comes on the bridge. This movement can be noticed in a structure at any time where the pin is free to move, as in the Lachine Bridge. Where the pin is not free to move the distortions must necessarily take place in the members themselves; and, moreover, I question this practice where it has been done with a view to figure the posts for half their total length, and consider them as fixed ended where they are held by the diagonals at the centre.

The next portion of the bridge to be considered are the two 269 ft. spans and two 408 ft. spans, forming four continuous spans over five supports (see Plate IV). There were two designs proposed besides the one that was finally adopted (see Plate V). The design as adopted is known in Mr. Smith's office as the "Flying Cantilever," and was first proposed for the Storm King bridge over the Hudson River, in State of New York. As used in the Lachine Bridge it is, properly speaking, no cantilever bridge, as the spans are continuous. The cantilever principle is used here for erecting the bridge only, which is built out from the piers on each side, the ends being joined at the centre when the final coupling is made, and the spans become continuous over five supports. The advantages of the cantilever principle are only in saving in the erection, there being no saving in the weight, as we merely make a different distribution of the material than we would in ordinary disconnected spans. In a continuous girder there is necessarily a saving in the weight over the piers, as was the case in the Lachine Bridge; but the saving in the mode of the erection is the principal item to be considered here. The advantage of using two centre piers instead of one would have been a considerable saving in the cost of erection, but not sufficient to counterbalance the increased cost of the extra masonry; this was the principal reason why one centre pier was only used instead of two, as shown in Fig 1, Plate V.

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

THE CONTINUOUS GIRDER.

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

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

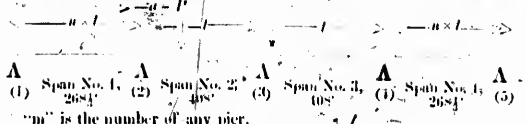
S. is the radius of curvature of the beam at that point.

E. is the modulus Elasticity of the material.

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

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

Formulæ for obtaining pier moments and reactions, as applied to the four continuous spans in the Lachine Bridge.



"m" is the number of any pier.

"r" is the number of any pier loaded span.

M is any pier moment.

S is the total number of spans = 4.

We have for Pier Moments when $m < r + 1$.

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

When $m > r$ we have,

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

in which

$$A = P\,l_r\,\{2k - 3k^2 + k^3\} \qquad k = \frac{a}{l_r}.$$
$$A^1 = P\,l_r\,\{k - k^3\}$$

P denoting the load in any span.

l, denoting the length of that span.

a = distance from nearest left hand support to the load "P," which is necessarily a concentrated load.

$$c_1 = 0 : c_2 = 1 : c_3 = -(2 + 2n) = -3{\cdot}3151.$$
$$c_4 = 1 + 3 + [n \times (1 + 1)] = +12{\cdot}2616.$$

SHEARING FORCES.

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

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

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

S^1_m (in unloaded spans) $= \frac{M_m - M_{m-1}}{l_{m-1}}$.

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

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

S_m and S'_m apply to the unloaded spans in the same manner.

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

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

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

1st.—The modulus of elasticity, as is well known, has wide margins of variation in the same material, but by rigid inspection of the material at the mill this variation may be reduced to a minimum. Mr. Bouscaren gives the margin for variation of the modulus of elasticity of iron at per cent. For mild steel, which is a far more homogeneous metal than iron, this margin may be very much reduced. Of course slight variations in the percentage of carbon in steel produces wide margins in its ductility, but a rigid inspection at the mill can guard against this. In the Lachine Bridge great care was taken in securing a mild uniform steel with an ultimate of about 60,000 lbs. with a ductility of 18 per cent. in 12 diameters. The tests subsequently made on some of the full sized members at Pittsburg, Penn., showed the material to be the same as when tested in small specimens. The material was found to be all that could be desired, and the Steel Company of Scotland deserve great praise in furnishing a uniform steel, something which is not easy to obtain. Their process is the Siemens Open Hearth process.

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

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

The three objections to the continuous girder are very serious, and would have undoubtedly been sufficiently strong to have prevented using a continuous girder for these spans, had it for the conditions under which this design was made, a consideration of these will at once show that the problem for closing the two channel spans was certainly solved in the most scientific manner, when it is borne in mind that the positions of the piers were all fixed, and it was impossible to use false-work in raising the two channel spans.

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

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

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

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

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

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

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

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