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Canadian Society of Civil Engineers.
INCORPORATED 1887

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DESIGN AND CONSTRUCTION OF THE AVON BRIDGE.

By R. F. Uniacke, M. Can. Soc. C.E.

To be read 24th October.

The problem of renewing the old toll bridge at Windsor, known as the Avon Bridge, has for years been looked upon as a perplexing and costly undertaking, and it was not until the early part of 1886 that actual steps were taken by the Government of Nova Scotia to take over the old bridge, open it free to the public, and make provision for its renewal, when in the interests of the public safety this should become necessary.

The old bridge was built in the year 1836, and consisted of five spans, varying in length from 147 to 162 feet in clear, supported by piers and abutments of close faced cribwork with cribwork approaches. The height of piers was from 45 to 50 feet. Ordinary tides rise 27 feet, spring tides 34 feet. The trusses were Towns wooden lattice, double, with double chords top and bottom. The whole of the trusses were built of 3" planking, and housed in. They had been supplemented by wooden arches springing from about 6 feet below the floor; an additional pier had also been built under the centre of one of the spans. The structure had settled and warped considerably, in some places as much as four feet, and all indications pointed to the fact that it would soon become necessary to take steps for its renewal.

The structure had been purchased by the Provincial Government from the stock Company who had hitherto owned it, and it was at once declared free of toll to the public for ordinary traffic. Some repairs were put upon it, extra vigilance being exercised to prevent heavy and continuous traffic, and with those precautions the public were allowed the use of it, until such a time as the progress of the new work would render it necessary to close it altogether.

The question of renewing the bridge having been decided on, it was next to be determined what style of structure should be erected.

Besides the plan selected, two designs were submitted. One was for four spans of iron 200 feet each between end pins, supported by piers and abutments of close faced cribwork filled with concrete; roadway 18 feet in clear with two footways 5 feet each; estimated cost $56,000. The second design was for four spans of Howe Truss of wood 160 feet each, and two smaller spans of wood 120 feet and 50 feet respectively, piers to be of close faced cribwork filled with stone, estimated cost $36,000.

The first would have made a strong and handsome structure, but the cost was considered excessive. The plan for a structure altogether of wood was strongly advocated by adherents of the old system, who argued that since the old wooden bridge had stood so long, a similar structure would answer all requirements. This view at first sight seemed reasonable enough, but when we consider the fact that the bridge had in its lifetime undergone a series of repairs and additions, and that such costly repairs together with the first cost of the bridge would go for naught in considering its reconstruction, it was not thought desirable in view of the experience of the past to project a similar experience into the future.

Before taking up and describing the supplementary and adopted plan, it may be as well to state some of the reasons why a masonry substructure did not enter into our calculations. The experience gained in this Province, from bridges built across tidal estuaries of the Bay of Fundy, goes to show that masonry structures built in these places have invariably proved failures, whereas old bridges that have been built of cribwork, as far as the piers are concerned, have stood firm and sound, without appearance of decay below high water mark for half a century. A most striking example of the failure of masonry is close to this bridge in the Windsor and Annapolis Railway Bridge, crossing the Avon River, a few hundred feet up stream. This is a rivetted iron lattice bridge of the English type, with river spans 166 feet centre to centre of piers. The piers were completed in the year 1869, and are of regular coursed ashlar masonry. Since that time several thousand dollars have been expended on them in repairs. The face stones had been connected by iron dogs or clamps, which has not prevented the destructive process which was threatening the stability of the structure; the effect of tides and frost became each year more apparent, the piers became cracked, these cracks seeming to extend completely through them so much that they were considered unsafe, and condemned by the Provincial Government. The Railway Company have surrounded these piers with close-faced cribwork, leaving a clear space of about 3 feet all around, which space was filled with concrete, and iron rods passed through the piers outside to outside, making a permanent and substantial job, though somewhat detracting from the dignity of the structure.

Precisely the same course was adopted on the Intercolonial Railway Bridge at Sackville, N.B., and extensive repairs and renewals have been made to the piers of the Railway bridge across the Shubenacadie, both tidal rivers of the Bay of Fundy.

These and other examples, together with the excessive cost, precluded the adoption of masonry.

The form of the structure as adopted and built may be described as follows: Beginning at the Windsor side was a small span of iron 50 feet centre to centre of end pins, then four spans of 159 feet each, and a shore span on the Falmouth side of 110 feet. There were five piers placed 162 feet apart centres, each pier consisting of two cylindrical columns each 5 feet inside diameter 19' 4" apart centre to centre, built of steel plates 3/8" in thickness, the joints both vertical and horizontal butted together and connected by steel bands 4½" x 3/8" rivetted on the outside. The bottom of each column was provided with a flange, turning outwards, formed by bending a 3" x 4" angle iron and riveting it on. This bottom flange in each instance rested upon the bed rock. The distance from a little above low water to the underside of the cap was divided into three spaces by four horizontal struts, each strut consisting of two laced channels abutting against the columns, and secured by connecting plates, pins were placed in the ends of each strut, and all connected with 1¾" round iron rods with turnbuckle adjustment. Each pair of columns was enclosed up to 2 feet above low water with a cribwork of square timber 20' x 40' outside measurement. Spaces 8' x 8' were left in the cribwork, where the columns would come, and these spaces together with the cylinders themselves were filled to the top with concrete; the remaining voids in the cribs were filled with stone. Each column was capped by a circular plate and an ornamental casting *cyma recta*. Two 12" rolled beams, 60 lbs. per foot each, extended across the columns secured to the caps, and upon these beams rested the bed plates of the trusses.

To protect the sway bracing against the heavy ice floes, a system of sheathing was built between the columns, enclosing the rods and struts on each side from high water down with 4" plank, placed vertically, and bolted through and through, wooden struts being placed at intervals between them to keep the planking the right distance apart. As a further precaution, extra cribwork with stone filling was built up the same section as before to the second horizontal strut, or 26 feet below the floor of the bridge.

The height of each pair of columns from finished floor of bridge to surface of rock foundation as built was —

Pier No.	1	47.36
"	2	59.84
"	3	49.65
"	4	53.94
"	5	55.63

The columns varied slightly in height, that given is the average height of each pair.

The cribs were built on shore, and sufficient ballast placed in them to partially submerge them. They were then towed to their place, and all the voids except those reserved for the columns were filled with stone at time of low water.

The bed rock extends across the stream; in some places it is bare, at others it is covered with from two to six feet of mud and silt. Means had been provided for removing this deposit from within the cribs, but this was not found necessary, for when the cribs were once placed in position, the increased tidal current caused by contracting the waterway completely scoured this loose material out, leaving the rock bare, and any loose stones or detached boulders were removed by grapnels.

As an additional precaution against any tendency of the cylinders to slide on the rock, it was determined to secure them by iron dowels. Nine of these were used in each column. A rough floor was placed across the crib, and the exact position of each cylinder marked upon it; auger holes were bored as guides, and the rods of two inch round iron tempered at the end, and fashioned to a rock drill point, were jumped into place. No difficulty was found in thus drilling three feet into the rock, leaving about five feet projecting.

At this stage preparations were made for lowering the bottom sections into place. The lengths of these sections as shipped vary from 9½ to 23½ feet. The roof and side covering had by this time been removed from the old bridge, and overhead braces were secured strong enough to take the weight of sections, which were lowered into place through the floor by block and tackle. A wooden cross head was fixed to the top of each section, the centre marked on it, and the cylinder accurately centred by means of a suspended plumb bob. The section was secured by wooden shores against the inside of the crib, and everything was now ready for the concrete filling. The materials for this were brought alongside in a scow. The mode of laying the concrete as practised here, in from five to twelve feet of running water, is a somewhat novel experiment, and the success which attended it in this case will lead to its adoption in other instances in this province.

This point has been referred to by Mr. Murphy in his paper on Concrete Structures, read before this Society; * but a more detailed account of it will perhaps be in keeping with the subject of this paper. Coarse brown paper bags, well stiffened with glucose, of a capacity of two cubic feet, were employed. A small wooden tray, suspended on trunnions at the end of a pole, was used, and could be tipped at any position by the workman guiding the pole by a cord attached to the back of the tray. The bag was placed upon the tray, and about one cubic foot of concrete placed in it, the superfluous paper bring roughly folded down. The whole was raised from above by a rope attached to the handle, guided into place by a

* Concrete as a Substitute for Masonry in Bridge Work, by M. Murphy, Trans. Vol. II., Page 79, Feby., 1888.

man standing on a plank placed across the top of section, and tipped at the proper time. This operation was repeated very quickly, the paper dissolving and opening up almost as soon as the bottom was reached, allowing the concrete to flow into any cavities or irregularities in the rock under the cylinder, and forming a level bed of concrete. This operation was continued until the cylinders were filled to within a foot or two of the bottom of the crib, and the voids around them filled to the top of cribs.

As soon as a pair of bottom sections were secured in place, levels were taken on the top of them, and the exact height from the top of each to finished floor was at once sent to the Dominion Bridge Co., contractors for the iron work, thus enabling them to send the proper length of sections to complete the columns. The same operation was performed for each of the foundations, the concrete gang being on hand as soon as the iron men had placed the bottom sections in position.

Before the cribs were all set, the Falmouth span at the shore end caught fire and soon dropped into the river, the trusses breaking off at the pier, and the burning mass floating downstream with the tide. Up to this time the public had the use of the old bridge. Our located points for pier No. 5 were of course gone, and a quick and ready means had to be adopted for setting these cylinders in proper position. This was effectually done by means of steel wire placed in position over centre of each cylinder. Two plus points were procured as far as convenient on the old floor, the distance to the abutment was about 160 feet, and we had 54 feet to centre of draw pier. These distances were first carefully laid out on the old floor and the points fixed on the wire which was stretched clear off the floor with a plummet attached at this point, and giving the wire the same curve it would have in its proper position. The wires were next drawn across the opening, with plummet attached, brought to the same sag and made fast. This was done on a calm night, and proved an accurate means of setting these columns.

The cribs for piers Nos. 4 and 5 were both larger than the rest, being 51 x 30 feet outside measurement. Shears had been erected on the last crib for hoisting the sections. Through some accidental cause some of the ballast had fallen into the voids of this crib reserved for the columns, and it became necessary to employ a diving crew to remove them. With this exception the operation of setting the bottom sections as previously described was performed for each of the piers.

The time of setting these sections was as follows:

Pier No. 1 July 19th, 1887.
" 2 " 25th, "
" 3 " 28th, "
" 4 Aug. 9th, "
" 5 " 19th, "

Two periods of low tide were generally sufficient for setting these sections. The first tide was sufficient for a pair of them to be lowered, and they were grouted and centred at the next.

The foundations by this stage were all ready for the iron men to proceed with their work of completing the columns and connecting the sway bracing; but owing to unfortunate delays caused by unforeseen difficulties, the remainder of the iron did not arrive on the ground until late in the fall. The process of building on the sections proceeded with energy, the sway bracing was connected, and concrete filling followed on as fast as each section was rivetted. Cold weather suddenly came, and with it a run of ice in the river. Piers Nos. 1, 2 and 3 had been completed and filled with concrete up to high water, pier No. 4 partially finished, and pier No. 5 had to be abandoned without any bracing or concrete filling above low water. Urgent efforts were made to get these finished, but with the river now almost blocked with floating ice, the men's lives were in danger, and the work had to be left, not however till the 50 feet span had been swung, and two sets of false work for the next span had been carried away. Attempts to get the sheathing in place failed, but some additional protection of round timber had been built around the cylinders.

The columns were now left in a seemingly precarious condition, without the trusses to stiffen them longitudinally, the cross bracing exposed to heavy ice floes, which could strike them obliquely with the force of the rushing tide, and some of them only partially filled with concrete, or not at all.

The winter months passed, and the proverbial oldest inhabitant failed to recollect larger or more continuous floes of heavy ice than the Avon river experienced during that time. When spring came, it was found that pier No. 4 had experienced some dents above the concrete filling, and one of the tie rods was broken. Pier No. 5 which had no bracing or concrete filling was partially demolished, the rest stood firm and perfectly true. This might fairly be considered a pretty severe test, and a sufficient answer to much adverse criticism on the adaptability of such a structure for the Avon River.

Operations were resumed in the month of May and prosecuted to completion. The injuries to the columns had been repaired, the missing plates replaced and filled to the top with concrete. The work proceeded with rapidity, and the last span was swung in the first week in July. Soon afterwards the bridge was opened for traffic.

The superstructure is the ordinary type of American pin connected Pratt truss with an ornamental iron lattice hand railing on each side. The specifications were the same as generally adopted under the Nova Scotia Bridge Act for iron bridges, with special clauses and modifications to suit this particular case, and as they would present nothing new it will not be necessary to reproduce them here, beyond a few of the principal requirements.

One span 50 feet between end pins.
Number of panels 5.
Depth of truss, 8 feet.
Four spans 159 feet each between end pins.
Number of panels, 10.
Depth of trusses, 22 feet.
One span 140 feet between end pins.
Number of panels, 7.
Depth of truss, 22 feet.
Roadway throughout 18 feet in clear.
No footways.

Rolling load 1,350 lbs. per lineal foot, or 75 lbs. per square foot of roadway.

Ultimate tensile strength of iron at least 50000 lbs. per square inch, an elastic limit not less than 26,000 lbs. per square inch, and a minimum elongation of 20 per cent. in 8 inches. Tensile strain produced in any member not to exceed 10,000 lbs. per square inch. Working strain reduced on counters, hip verticals and beam hangers. Working compressive strain not to exceed 8,000 lbs. per square inch reduced by formula.

The cylinders were to be put together in sections of not greater length than 8 feet of $\frac{3}{8}$ boiler plate hot rivetted, no screw bolts to be allowed in connecting the sections. On top of each pair of cylinders there were to be two rolled I beams, 12 inches in depth, 60 lbs. per foot each, with plates and stiffening T's to support trusses.

Considerable work was done on the approaches. The old abutment on the Windsor side was cut down to the foundation, and rebuilt. The floor in the approaches is supported by trestles resting on the old work at about high water level, and has a grade of 1 in 20.

The iron superstructure, complete together with the columns, was contract work, and built by the Dominion Bridge Co., Engineers and Contractors, Montreal. The preparation of the foundations, cribwork, concrete filling, together with the work on approaches, was all performed by day's work, under Government superintendence.

Supplying material, such as sand, gravel, stone and timber, was generally let by contract, the contractor delivering the material at bridge site as required.

A contract was also let for building additional cribwork around the cylinders up to within 26 feet of floor

COST OF WHOLE WORK.

Erection of iron superstructure and column.......	$32190
Substructure (days work).......................................	22395
Sheathing cribs and removing old piers (contract)	1760
	$56345

In looking at the cost of this work, it must be remembered that the circumstances here were anything but favorable to making a good showing with a crew of men in a short time. Men were at their post night and day, whenever the tide permitted, and could not work more than three hours at the most before having to make everything fast and get ashore when the flood tide came. High wages had to be paid, as otherwise men could not be induced to work broken time in the wet and mud. Experienced foremen were employed, who even kept a sharp lookout for the safety of the men, as well as to see that each performed his full share of the work in a skilful and workmanlike manner, and it is a happy feature that although the work was prosecuted at all hours of the day and night, in a dangerous locality, especially when the cold weather set in, not an accident or fatality occurred.

The bridge as now completed in general appearance is such as to satisfy the most sceptic, and is to the casual observer the most elegant structure of the kind in this province. To the eye of the engineer it is bold and strong, each detail being designed to add strength where it is most needed. The columns have a graceful and finished appearance, the workmanship is all that can be desired and standing side by side with the English lattice railway bridge the two bridges present striking examples of the European and American practice.