

# Fabrication of Orthotropic Deck Sections for Port Mann Bridge

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Though in use in many parts of Europe for some years, orthotropic bridge decking is comparatively new on this continent. High labor cost as compared to European wage scales has inhibited its use in North America. Production line methods and equipment have been able to achieve efficiency and economy in this field, bringing orthotropic deck construction into competition in long-span bridge design and construction.

•THE MAIN span of the Port Mann Bridge was fabricated in the Vancouver branch of the Dominion Bridge Company. The Vancouver plant is situated on a 50-acre site with 7 acres under roof. About 600 people are employed in this branch at present and the services that they supply are fully integrated from engineering to erection. The fabricating plant is divided into three main areas of operation—structural shop, plate shop and machine shop. The shops are well supplied with the machines and handling equipment needed to produce heavy steel structures and vessels. A 92-ton bridge member and a 135-ton vessel are the two largest single pieces produced in the shop to date.

The main span of the Port Mann Bridge was constructed with six basic structural members: pier members, arch ribs, stiffening girders, deck sections, verticals and lateral bracing members. Fabrication problems were encountered with all members. Devices and techniques, new to the Dominion Bridge Company and to this continent, had to be developed to produce the orthotropic deck. This task might appear formidable, but the work was accomplished with standard machines and equipment. The design of the jigs and fixtures required to semimass-produce 83 deck sections was the main contribution to the fabricating techniques. Since all members other than the deck sections went through relatively familiar steel fabricating practices, this paper describes deck fabrication only.

The orthotropic deck was wholly fabricated and spliced in the plate shop. Some vessel work was done in the shop while the deck was being processed; however, most of the shop was devoted exclusively to deck fabrication. The plate shop is 80 ft wide and 620 ft long; 160 ft at the input end has a low roof and the rest of the shop has a high roof. The low roof area is serviced by four 6-ton overhead hoists on a Cleveland interlocking bridge system. The high roof area is serviced by two 60-ton cranes fabricated at the plant. These cranes have 10-ton auxiliaries with a 40-ft clearance under the main hook. Tracks are installed through the shop for rail shipments and road access is available for trucks to enter the shop.

## GENERAL DESCRIPTION OF A DECK SECTION

The bridge deck consists of a series of deck sections spliced end to end across the length of the bridge. The width of the deck sections is constant at 65 ft, and the length of each deck section varies according to geometry requirements; however, most of the sections were approximately 25 ft long.

An average deck section (Fig. 1) consisted of four floor beams, 31 stringers and a 65- by 25-ft deck plate. These components were continuously welded into a complete unit to form a deck section. The deck plate forms the top flange for the floor beams

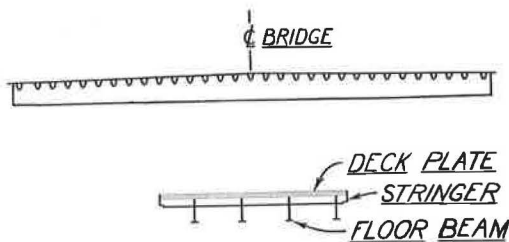


Figure 1. Deck section.

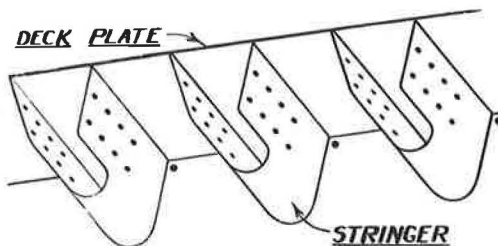


Figure 2. Floor beam web.

and for the bent plate stringers. The top of the floor beam web was cut to a profile to receive the bent plate stringers as shown in Figure 2. The top edges of each stringer were welded to the deck plate with a single outside pass of automatic welding and the top of the floor beam web was hand welded on both sides to the deck plate and the stringers. The bottom flange of the floor beam was welded on both sides to the web. The deck plates were fully butt-welded from both sides.

The deck was  $\frac{7}{16}$ - or  $\frac{1}{2}$ -in. plate, the stringers were  $\frac{5}{16}$  in. thick, the floor beam web was  $\frac{5}{16}$  in. thick and the floor beam flange was  $\frac{5}{8}$  in. thick. The heaviest deck section produced weighed 36 tons.

### MATERIAL PREPARATION

The orthotropic deck for the Port Mann Bridge was fabricated entirely from plate. The shapes necessary were made by forming in the case of the stringers, and welding and profile burning in the case of the floor beams. All material was steel shotblasted before entering the shop for fabrication. All mill scale, without exception, had to be removed from this structure before painting.

After blasting, all material was ripped to width and trimmed to length on an automatic burning machine locally referred to as the Straightograph. The machine, designed and manufactured in the Vancouver shop several years ago, consists of a bridge mounted on two parallel rails. Burning torches are mounted on the bridge. As the bridge travels down the rails it passes over plates lying between the rails and parallel edges are burned on the plate. By adjusting the angle of the torches, bevel cuts may be burned on the plate edges for weld preparations. The machine is strictly a ripping device; the same results could easily be obtained using any modern shape-cutting machine.

Some buckling was encountered when the floor beam webs were burned to width. This was minimized by mounting two heating torches on the bridge at about the third points across the plate and heating two stripes along the plate as the edges were being cut.

### STRINGER PREPARATION AND SUBASSEMBLY

Thirty-one stringer plates were used in each deck section. The ripped plates from the Straightograph were moved to pit drills and were stack drilled with ordinary pit-type bogie drills. During the early stages of fabrication, full-sized splice holes were drilled at one end of the stringer plates and  $\frac{1}{4}$ -in. undersized splice holes at the other end of the stringer. The intention was to ream the small holes to size during the deck-to-deck splicing operation. However, it soon became apparent that it was a real problem to get "good" holes consistently. Many refinements were made in the bending techniques and welding controls in an attempt to improve the hole alignment. Eventually, it was decided to drill full-sized splice holes in one end of the stringer plate and "blow" and template ream the holes at the other end of the stringer during the deck-to-deck splicing operation. Since one set of holes had to be reamed anyway, little expense was added by the extra operation of "blowing" or "burning" the pilot holes. However, substantial savings were realized by avoiding the welding and grinding of "bad" holes before reaming.

After drilling, the stringer plate was bent into its final shape in a 750-ton hydraulic press brake. This was accomplished with one stroke of the brake. Since the stringers were to be spliced between deck sections, the profile of the stringer had to be uniform, particularly at the ends. It was also most desirable to have the two longitudinal edges of the stringer straight and parallel to facilitate subsequent welding operations. A nearly perfect stringer was consistently produced after minor die adjustments were made. Diaphragms were welded into the stringers which were then ready for the final deck assembly.

The 750-ton Dominion press had to be modified to press the stringers with one stroke. Five-foot extensions were bolted to either end of the bed and the blade, extending the capacity from 16 to 26 ft. This extension proved to be very successful.

The top or male die had two locating pins projecting vertically down on the die centerline. These pins entered two drilled holes in the stringer plate before the plate started to bend. They restrained any tendency toward differential slippage of the plate in the die and also insured that the pre-drilled splice holes would be equally spaced from the centerline on either side of the finished stringer.

The top male die consisted of a solid round bar 25 ft long welded to plates and stiffeners so that it could be mounted on the press blade. The female die was a square trough stiffened to resist the side thrust. Hardened round rods were set in the top inside edges of the trough to form the contact and wearing surfaces. The final profile of the stringer was controlled by shimming the bottom of the trough so that the blade descended to exactly the right depth (Fig. 3).

#### FLOOR BEAM PREPARATION AND SUBASSEMBLY

The bridge deck was crowned  $7\frac{1}{2}$  in. To save material and facilitate fabrication, the floor beams were fabricated from a plate girder one half the length of the finished floor beam and twice the mean height of the floor beam. The web was then split diagonally, as shown in Figure 4, and the two wide ends of the beams were spliced to form the crowned floor beam.

The basic girder was assembled from two flange plates and one web plate in a plate girder fitting and welding jig. The plates were clamped in position by air jacks at intervals along the girder. The flanges were tack-welded and then automatically welded to the web. The assembly was turned over in the jig and the other side of the joints were welded.

The web of the resulting plate girder was then laid out and stress relief holes were template drilled in the web. A burning machine mounted on a bridge that spanned the flanges of the girder was then used to cut the profile of the deck and stringers on the web of the floor beam. It is important to note that this profile was the theoretical profile with regard to stringer spacing. The

machine used to burn the profile was mounted on a frame with an "overhead" steel template the same as the profile. Once the equipment was properly located on the plate girder, a following device made the profile burning automatic. After profile burning, the two half girders were then ready for the final assembly.

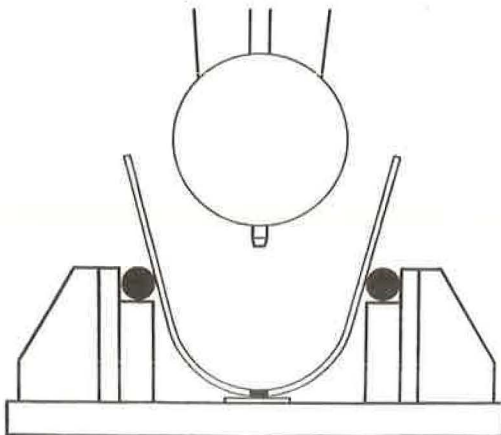


Figure 3. Stringer forming.

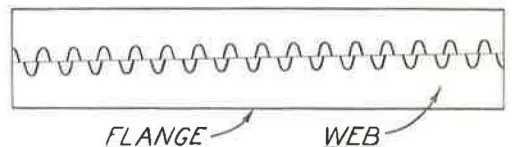


Figure 4. Floor beam preparation.



## DECK PLATE AND STRINGER ASSEMBLY

A rather large fixture was constructed to facilitate butt-welding the individual plates into a whole deck plate and welding the stringers to the deck plate. The fixture was stationary and the plate and stringers passed through the fixture. This first stage of assembly was done with the deck plate on the bottom and the stringers on top.

The fixture consisted of a grillage of beams over which the deck plate could be progressively hauled as each new plate was butt-welded to the preceding deck plates. Two very rigid bridges spanned the fixture and the deck plate. On the first bridge was mounted an automatic submerged arc welding machine which welded one side of the butt joint between the individual deck plates. About 15 ft farther down the fixture, another bridge spanned the deck plate. This bridge served a dual purpose. It carried an automatic submerged arc welding machine on either side and located and clamped the stringer to the deck plate during welding.

The deck plate welding machine was mounted directly over a large water-cooled copper backing bar. An air hose ran full length under the bar. When the air was put into it, the bar lifted the deck plates against the bridge and clamped them in position until they were welded.

The same type of air hose clamping device was used on the second bridge to clamp the stringers to the deck plate during welding. In this case, the stringer was forced, as shown in Figure 5, into a series of profile plates in line. These plates were hinge mounted to the underside of the bridge so that they could be flipped up out of the way to permit the assembly to be hauled through the fixture.

In the initial planning it was anticipated that some reverse camber in the stringer would be necessary at this point of fabrication to compensate for the eccentricity of the weld relative to the neutral axis of the stringer. However, in practice, the distortion due to welding was negligible and no attempt was made to camber at this point.

The weld applied between the stringer and the deck plate was a single fillet weld. Farther down the assembly line, the fillet weld was returned inside the end of the stringer to the first diaphragm and across the first diaphragm, making the fillet continuous around the exposed side of the joint.

This stage of fabrication of the deck was by far the most critical. If the stringers were located perfectly on the deck plate after welding, the subsequent operations became much easier.

The stringer-to-deck plate welding reduced the narrow dimension of 25 ft by approximately  $\frac{1}{4}$  in. and the spacing between each stringer by about  $\frac{3}{64}$  in. It was necessary to experiment for some time to establish the shrinkages and great care had to be taken in locating the stringer on the plate before welding.

As the assembly was passing through the fixture, it was essential to keep the centerline of the assembly tracking the centerline of the fixture. The plate was guided by stops on one side of the fixture. Since the overall shrinkage was  $\frac{1}{4}$  in., to keep the centerline tracking properly, it was necessary to move the stops past the welding station  $\frac{1}{8}$  in. closer to the fixture centerline than the stops ahead of the welding station.

The fixture originally was designed with end stops to locate each stringer automatically. It was found to be almost impossible to locate the stringers accurately with the equipment as fabricated. Some time was lost attempting to get better results mechanically. Eventually the location of each stringer was laid out on the deck plate before assembly and welding. This proved quite satisfactory but did not give perfect results. Misalignment of stringers between deck sections continued to occur throughout the job. Filler plates were added where necessary when the splicing operation was being done. However, in

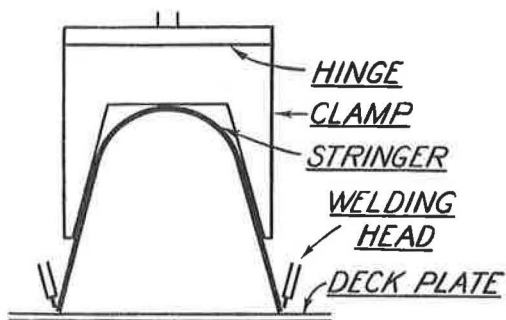


Figure 5. Stringer welding.

considering the size of the weldments and a condition where 31 bent plate stringers on one deck section were being lined up with 31 stringers on another deck section, the results after the initial run-in period were excellent.

### FLOOR BEAM ASSEMBLY TO DECK AND STRINGERS

The deck plate was then moved to another large fixture where the floor beams were added to the assembly. The deck of this fixture was shaped to the crown of the bridge. Vertical posts were mounted at each end of the fixture to receive the webs of the floor beams. The posts positively located the floor beams relative to each other. This, of course, was important so that the beams would match the floor beam brackets on the stiffening girders.

As was previously mentioned, the contoured profile of the floor beam web was cut to the theoretical profile. At this point in the assembly, the deck plate and stringers were fitted to the floor beam. Fitting was assisted by jacking the floor beam against the deck plate which was in turn being pushed against the fixture shaped to the crown of the bridge. Very consistent deck splices resulted from forcing the deck plate to assume the theoretical profile of the crown.

When the floor beams were first applied to the stringers and deck plates, the latter always appeared to be short. The floor beams were fitted progressively from the center of the deck to the outside; each stringer was fitted and tacked to the floor beam. This operation had the effect of "tightening" the deck plate. Since the stringers were being fitted to the theoretical profile, this operation was the test of the accuracy with which the stringers were located on the previous operation.

A beam or bridge was set above the floor beams running parallel to the stringers, as shown in Figure 6. By jacking between the beam and the flange of the floor beam the floor beam web was forced tightly against the stringers and deck plate. It was then tacked in that position and the jacking beam was moved on to the next fitting position. If a stringer were so far out of position, over  $\frac{1}{8}$  in., that it was binding on the floor beam web profile, some of the web was burned away to permit entry of the stringer. Where the joint was open too much, a small backing plate was added to assist the welding at the next operation. The two halves of the floor beams were spliced in the center at this station and were welded at the next operation.

### FLOOR BEAM WELDING TO DECK ASSEMBLY

At this stage the complete deck panel was assembled; however, the floor beams had to be welded to the deck plate and stringers, the floor beam halves had to be welded together and the deck butt welds had to be welded on the top side.

The assembly was then moved to another station where it was clamped, on the deck side of the section, to two beams, as shown in Figure 7. The ends of the beams were curved through 90 deg and projected about 3 ft beyond this curve. A series of holes was drilled in the curved portion of the beams. Two other beams directly below the curved beams had pintles projecting upward from the top flange. The position of the pintles matched the holes in the curved beam. The whole arrangement

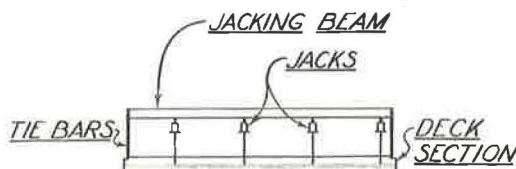


Figure 6. Floor beam fitting.

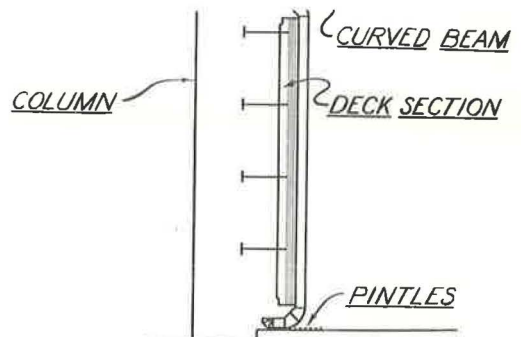


Figure 7. Floor beam welding.

was used as a device to support the deck section on edge for position welding of the floor beams to the deck and stringers.

The crane was connected to one end of both curved beams through an "evenner" beam. The crane hook lifted the evenner beam which in turn lifted the one end of the curved beams. The pintles below entered the holes in the curved beam and prevented any slippage of the assembly during raising. When the deck section was vertically on edge the upper ends of the curved beams were connected to the side of the building to hold the assembly in position. When the welding was completed on the upper side of the floor beams, the whole assembly was turned over by the same process and the floor beam welding was completed. The deck section was then put into its normal position, with the deck plate on top, and it remained in this position in all subsequent work.

The deck plate welds were completed with automatic submerged arc welding and spot X-rays were taken of the deck seams. The deck section was then ready for drilling and splicing.

### POSITIONING AND SPLICING OF DECK SECTIONS

The complete bridge deck was spliced in the shop before field erection. The fabrication of the orthotropic deck was started early so that the shop splicing started at one end of the bridge and progressed to the center section and then from the other end to the center without interruption.

Since the bridge construction started over the piers and worked both ways toward the approaches and the center of the bridge, it was essential that the first few deck sections erected be oriented correctly over the piers. To insure correct fit and alignment on these sections, four stiffening girders and five deck sections immediately over the north pier were completely assembled in the shop. All connections were pinned and partially bolted and the assembly was drilled and reamed in position. The assembly proved to be so satisfactory that two girders and three panels were assembled for the south pier.

All of the deck splicing was carried out at one position in the shop. The deck sections were supported on large beams below each end of the floor beams. The supporting beams were high enough to allow head room for the men making the stringer splices. The supporting beams were long enough to accommodate two deck sections.

In the splicing operation, two deck sections were positioned end to end as they would be on the completed structure. The centerline of the center stringer on each deck section was marked at each end of the stringer, and then the stringer centerline was transferred to the top of the deck. The centerlines of the two deck sections were then carefully aligned. The two sections were squared up until the diagonals of the assembly were less than  $\frac{1}{8}$  in. different in length.

Steel drilling templates with hardened steel bushings were then applied to the deck and carefully aligned to the layout. The holes for the deck to stiffening girder connections were drilled undersized for field reaming.

Most of the deck-to-deck holes, both in the stringers and the deck plate, were put in full size. However, control splices on the deck plate were positioned at about every 150 ft, and these holes were shop drilled undersized for field reaming.

After the deck plate holes had been located, the positions of the holes in the ends of the floor beams were established from them. These holes were also template drilled in this position. An attempt had been made at the beginning of the job to drill these holes in the fixture where the floor beam was fitted to the deck plate and stringers. It was found easier to control the relationships of the floor beam holes to the deck holes rather than the reverse process.

All 31 stringer splices were made at this station. Any misalignment of the stringers was adjusted with filler plates. The blank-ended stringers had holes blown into them and were then template reamed. The splice material was, as a consequence, identical.

The drills used on the deck were mounted on wheels. One was a radial arm type and the other was a universal type. The difference was not significant. However, to get good production speed, it was important to use fairly powerful, rugged drills.

## CLEANING AND PAINTING

In the early stages of the deck fabrication, all welds were neutralized before priming. This process was not only time consuming and costly, but satisfactory results were difficult to obtain. Eventually sandblasting was substituted for passivation with excellent results. This work required 6 man-hours per deck section instead of the 32 man-hours previously necessary, and the prime coat of paint was excellent on the blasted surfaces.

After blasting the welds, the deck sections were primed with one coat of red lead iron oxide alkyd oil type primer and were stored in the yard. Just before shipping to the field, the deck sections were brought back into the shop. The faying surfaces at the splices were cleaned or blasted and clean splice material was ship bolted to the deck. A final paint inspection and touch-up was also carried out at this time.

## CONCLUSIONS

A substantial number of man-hours were lost throughout the deck fabrication, mainly because of inaccuracies in the location of the stringers. Man-hours were also lost attempting to pre-drill the stringers completely before bending.

In retrospect, it is apparent that a large fixture should have been made to locate the stringers accurately at each end and where they passed through a floor beam. This could have been done based on a calculated or experimentally determined shrinkage. Regardless of the amount of final shrinkage, the location of each line of stringers would have been consistent between deck sections and between any two stringers. In such a fixture, the stringers would be tack-welded to the deck plate in a separate operation.

It would also seem to be desirable to drill the stringers at least after bending and preferably after the deck section is completely welded. All holes on any single panel that connected to the supporting steel and all holes that in any way influence the longitudinal bridge alignment should be drilled after all fabrication and welding has been completed.

Since welding makes up a large portion of the work involved in fabricating a deck section, fully automatic welding or at least semi-automatic welding should be used.

Apart from using good shop practice on normal operations, the single key to success in the fabrication of an orthotropic deck is accurate dimensional control at all stages of fabrication.