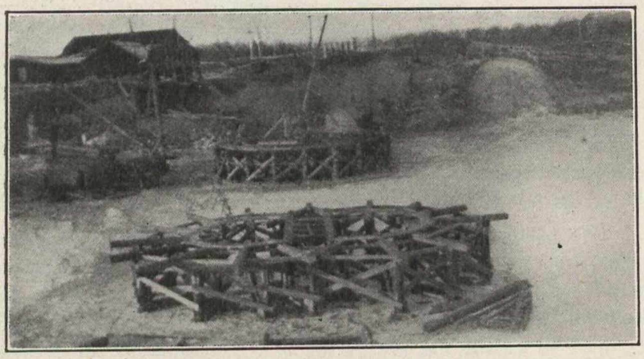
upward, thus forming a steel-protected pipe or drum, having an outside diameter of 31 feet, the inner opening being octagonal.

When the shell finally reached rock, the surface of the rock was cleaned, and a layer of concrete about seven feet in thickness was deposited under water, which sealed the flow from the water-bearing gravel and allowed the removal of the bracing. When the timber was removed, the interior



Falsework and Derrick Car, Pivot Pier.

opening was filled with concrete, forms were built at the water level, and the pier was carried up to its final elevation.

The concrete used was a 1:3:5 mixture, the gravel and sand being brought in by train from a point thirty miles distant on the line of the Grand Trunk Pacific. This material was clean, and in its natural state closely approximated the required proportions. Tests were made from time to time to determine its condition, and enough sand was added to make it comply with the specifications. Screening was considered unnecessary. To prevent the concrete from freezing, the sand and gravel were heated. Three heaters, made from sections of 36-inch cost-iron pipe, were placed near the stock piles. Wood for heating purposes was plentiful, and the cost of heating all material averaged about $1 per cubic yard of concrete. The materials were conveyed to the mixer by cars, and the concrete was swung to the derrick on the fender crib by using a second derrick located on the river bank. After the ice formed, the derricks exchanged boxes on the ice, and the mixer, running constantly, kept one batch of concrete moving at all times. The batches averaged 22 cubic feet, the average output being 11 cubic yards per hour.

In the concrete, pieces of stone, containing from 2 to 15 cubic feet, were placed by the derrick on the fender crib. These stones were heated by immersing them in a tank of hot water for a few minutes, the volume being indicated by a displacement scale marked off inside the tank. In this way a check on the total volume of material was obtained, the combined volumes of stone and concrete equaling the quantity indicated from measurements made inside the shell. The total quantity of stone and concrete in this pier is 2,200 cubic yards.

Conditions at the smaller pier on the south side of the river were somewhat different, the water being only 17 feet deep, and bed-rock 57 feet from the water surface.

This pier consists of two concrete-filled steel shells, 15 feet in diameter, set side by side at right angles to the centre line of the bridge, with a space of three feet between them. Falsework, similar to that at the pivot pier, was erected. To handle the steel plates, a derrick was placed on the centre line of the bridge, resting on three small cribs sunk for the purpose.

The shells were lined with concrete as they sank, and, owing to the fact that they could be pumped out, about two-thirds of the total excavation was completed in the dry, the derrick disposing of the material as it was excavated. The shells were in no way connected, but were carried down with as nearly the same amount of progress as possible. The general progress was in jumps of from 2 to 5 feet. The steel was carried high enough at all times to prevent any chance of the shell disappearing beneath the surface. The progress could be closely controlled by the amount of excavation. The shells were brought to place finally with a difference in elevation of less than ½ inch. Along the centre line of the bridge they were about four inches out of position. This was corrected when the forms were built at the water line, where a slight offset had been provided for such a contingency.

There were 1,055 cubic yards of concrete in this pier, the same mixture, 1:3:5, being used as in the pivot pier. The two shells were joined at the top by a reinforced concrete beam. The sand and gravel for this pier had been placed on the south bank of the river before the close of navigation. This material was dredged from the bed of Lake Superior during the summer, and was used without screening. The mixing plant for this pier was located on the south bank, and the concrete was conveyed to the derrick by cars running on a track laid on the ice.

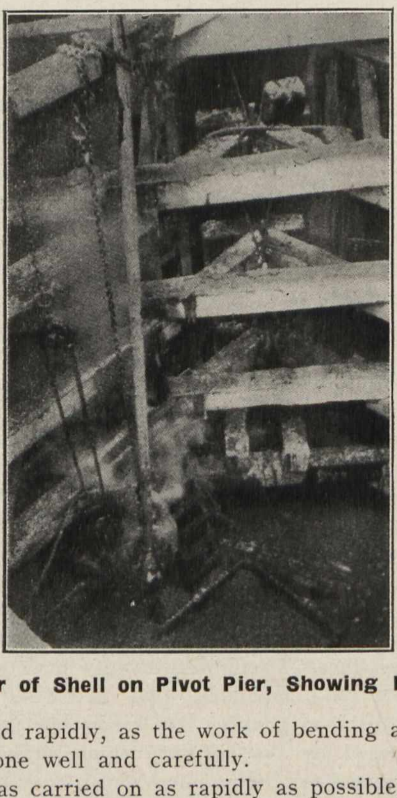
It was thought that difficulty might arise from the shrinkage of the concrete inside the shell, with a consequent destruction of the bond between it and the steel, and, to prevent this, the first course of concrete was allowed to set under water, where some expansion would occur. The concrete in the piers was kept warm, where exposed to the air, by covering the piers and turning live steam into the enclosed space. The concrete below the ice line, and under water, was, of course, in no danger from freezing.

The steel shells were rendered watertight by caulking them at the laps, and by driving a small triangular wedge at the scarfs. The resistance of the material through which the shells were sunk was found to vary from 275 to 320 pounds per square foot. This is the net skin friction, after deducting the resistance caused by the cutting edge, the laps in the plates and the rivet heads.

The cutting edges were reinforced by riveting to the lower course of steel an additional ½-inch plate, three feet wide. This was considered sufficient, as the test borings had shown the material to be clear, and free from sunken trees or boulders.

The riveting and caulking were done with air, the compressor being of the locomotive type. Owing to the atmospheric moisture, the air line and hammers at times gave some trouble, due to the intense cold.

The plates for the shells were punched and bent at Chicago, and shipped ready for erection. They were fitted



Interior of Shell on Pivot Pier, Showing Bracing.

up easily and rapidly, as the work of bending and punching had been done well and carefully.

Work was carried on as rapidly as possible, three shifts being employed on the concrete at times. The total time consumed in this work, disregarding lapses and minor delays, was about five months. The cost of the two piers was about $60,000.

The work came under the supervision of Mr. George A. Knowlton, Division Engineer in charge of the Lake Superior branch of the Grand Trunk Pacific Railway. The writer designed the lay-out of the plant and the method of construction, and was in charge of the work.