Cylinder-Pier Bridges, C. & N. W. Ry.

By W. H. Finley*

Bridge substructures of the cylinder-pier type, in which the pier consists of two or more cylinders instead of a single mass of masonry, have been used very extensively abroad but as yet only to a limited extent in this country. The article published below, however, describes some important American railway bridges of recent construction in which the piers are of the general type mentioned, but it is shown that the design differs essentially from that employed in foreign practice. The advantages of this type of substructure are explained, and both the design and the methods of construction are described.

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"It is a very curious fact that in America the cylinder caisson type of foundation is employed so rarely as to make it almost unknown." (ENGINEERING NEWS).

The above statement is an extract from an editorial in ENGINEERING NEWS of July 1, 1909, in which a comparison is drawn between the limited use of this type of bridge foundation in America and its extensive use in other countries. While the statement may describe the general situation with reasonable accuracy, there are important individual exceptions to the general rule, and the purpose of this paper is to show that the Chicago & Northwestern Ry. has used this type of foundation successfully for a number of years and for important structures. It may be noted, also, that in all probability the reputation of this type of construction (so far as its application to large bridges is concerned) has suffered from unsatisfactory experience with some of the small cylinder piers which have been used for highway bridges of the lighter class.

One special difference between the cylinder piers of the C. & N. W. Ry. and those of foreign railway bridges is that the former are of steel while the latter are mainly of cast iron, with flanged joints and stiffening ribs. The cast-iron cylinder pier has been used extensively by British engineers and there are many interesting examples of this type of construction in England, India and Australia. In this form the cast-iron shell is relied upon for carrying the loads and giving the necessary weight and stability, and the hearting in many cases is composed of concrete, brick or stone. In the cylinder piers described in this article, the steel shell is very thin and is used more as a form for the concrete, while the concrete filling becomes the pier proper and sustains the load. The deterioration of the steel shell would in no way affect the stability of the pier, while in the cast-iron shells it would do this, since the hearting is more in the nature of a filling than a monolithic construction.

The advantages of the cylinder-pier type of foundation may be stated as follows:

1. Where it is desired to provide for future second track, cylinder foundations will cost very little more for double track than for single track.

2. They can be constructed under traffic with less trouble than any other type. This will be particularly noticeable in the following description of the foundations for the bridge over Little Lake Butte des Morts.

3. They permit of rapid sinking by open dredging where the material is favorable and sunken logs are not likely to be encountered. Air pressure can be applied readily and cheaply if it becomes necessary.

BOONE VIADUCT

This is a double-track steel viaduct, built in 1900 and crossing the Des Moines River near Boone, Ia. (ENGINEERING NEWS, June 27 and Aug. 22, 1901). It is 2685 ft. long out to out of steel work, consisting of plate girder spans and a 300-ft. deck-truss span. The 300-ft. span (over the river) is supported by steel towers resting on cylinder piers 10 ft. diameter. Various types of foundations were considered for the support of this span, and after making a number of comparative estimates it was decided to adopt the cylinder piers, which have proved very satisfactory.

The cylinders are 10 ft. diameter and built of ⅝-in. plates. Four cylinders 70 ft. deep were required for the west tower, and four cylinders 64 ft. deep for the east tower. The pneumatic process was used in sinking these piers and no difficulty was experienced in founding them on the underlying sandstone. The high- and low-water lines are 8 ft. and 28 ft., respectively, below the tops of the cylinders, and the river bed is 31 ft. below the tops. The depth and character of the materials passed through by the 70-ft. cylinders are as follows:

	Thickness ft.	Depth below bed ft.
Sand and gravel..	24	24
Coal	1½	25½
Fireclay	2	27½
Black shale.......	2½	30
Sandstone	3	33
Fireclay	1½	34½
Coal	1	35½
Black shale	1½	37
Sandstone (in which cylinders penetrate 2 ft.).....	..	39

BRIDGE OVER LITTLE LAKE BUTTE DES MORTS

This bridge is on the Northern Wisconsin Division and crosses the lake formed by the junction of the north and south branches of the Fox River, south of Menasha, Wis. The work here consisted of replacing 1548 ft. of pile trestle with a single-track steel bridge composed of 33 plate-girder deck spans 46 ft. long, resting on cylinder piers designed to carry a double-track structure. The general design of this bridge is shown in Fig. 1. After a careful study of the situation

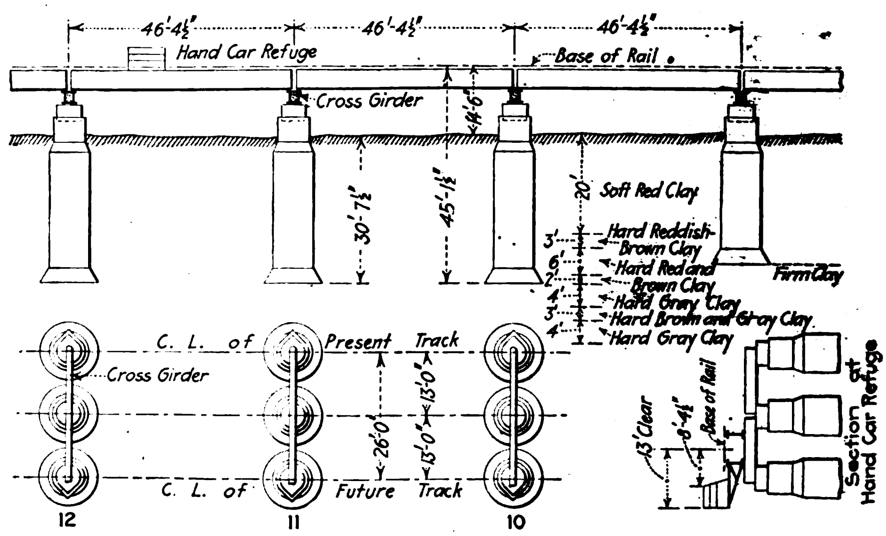


FIG. 1. PLATE GIRDER BRIDGE WITH CYLINDER-CAISSON PIERS OVER LITTLE LAKE BUTTE DES MORTS, WISCONSIN; CHICAGO & NORTHWESTERN RY.

it was decided to use cylinder piers for the reason that they could be put in place without interfering with traffic. Any form of concrete pier on piles would have required the building of coffer-dams and the removal of the stringers and deck of the trestle while driving the sheeting and piles. This would have interfered seriously with traffic. The relation of the piers to the trestle bents and deck is shown in Fig. 2.

Two hand-car refuges are placed about one-third of the length of the bridge from each end, and the deck is of the C. & N. W. Ry. standard construction. The alignment is a tangent, and a grade of 0.13% extends over the bridge. The abutments (Nos. 1 and 34) are of concrete and rest on piles.

Borings taken at several points along the structure indicated a soft red clay to a depth of 12 to 19 ft. from the bottom

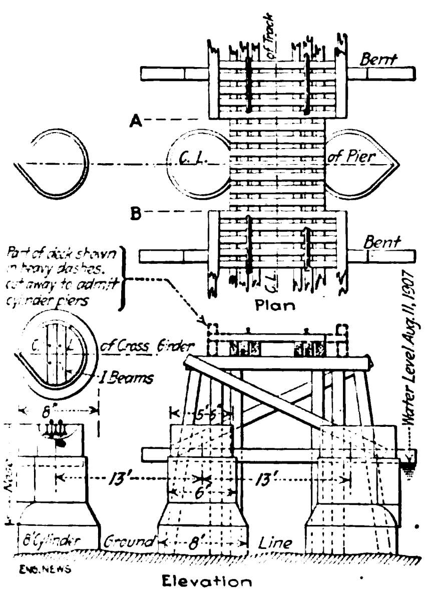


FIG. 2. ARRANGEMENT OF CYLINDER PIERS TO PERMIT OF PLACING THE NEW FOUNDATIONS WITHOUT INTERFERING WITH TRAFFIC ON THE OLD TRESTLE

[At A-B (over the cylinder piers) the guard rails and jack stringers are removed and the ties cut off flush with the ends of the track stringers]

of the river, then 2 ft. of blue sandy muck overlying generally hard red clay. It was planned to found the cylinders in the hard red clay and undercut them as shown in Fig. 1, which shows also the character of the material penetrated. As a matter of fact the line of hard red clay did not run very evenly and was interrupted at points with sand pockets that made it necessary to drive piles in some of the cylinders. It will be seen that each pier consists of three cylinders. These are capped by a cross-girder consisting of a double-web plate girder with concrete filling between the webs. Upon these rest the plate-girder spans. Embedded in the concrete at the top of each cylinder are I-beams placed longitudinally and riveted to angle brackets on the shell of the cylinder. Beneath these is an anchor plate for the anchor bolts which serve to hold the cross girders in position (Fig. 2).

In each cylinder the lower part is 8 ft. diameter; this is the main portion of the cylinder and extends below the bed of the lake. Above this is a 2-ft. conical course, reducing the diameter from 8 ft. to 6 ft., and on top of this is a section 6 ft. diameter and 5 ft. high. Into this telescopes a section 5 ft. 6 in. diameter and 4 ft. high, forming the top of the pier. The cylinders increase in length from 27 ft. at pier No. 2 to 34.25 ft. at piers Nos. 10 to 13 inclusive, when they gradually decrease in length to the last pier (No. 33), which is 19 ft. deep. Between piers Nos. 2 and 20, the 8-ft. sections are circular, with a pointed nose on both the up-and-down stream cylinders from the bottom of the reducing section to the top of the cylinders. From piers Nos. 21 to 33, where the water is deeper, the up-stream and down-stream cylinders are pointed all the way down. The shells for the pointed cylinders are shown in Fig. 3.

The reason for reducing the size of the cylinders above the bottom of the river was to give as much waterway as possible through the bridge, and this was done to meet the requirements of the Federal Government. The reason for the arrangement of the sharp-ended cylinders lies in the peculiar conditions as to the ice. The current does not exceed one mile an hour and owing to the fact that the lake freezes more below the bridge than above it, the ice pressure is upstream, so that the pointed ice-breaking nose is required at both ends of the piers. During the life of the old pile structure it was necessary to maintain a crew at the bridge during the winter in order to keep the ice cut below the bridge, and so prevent it from moving the bridge out of line.

The cylinders are of 5/16-in. steel plate, with butt joints and inside splice plates. The circumferential joints are strengthened by an angle-iron ring inside the splice plate. The conical reducing course is 2 ft. high, and has a special splicing ring made of a bent plate 6½x5/16 in. at the top and bottom joint; the bottom ring is inside, while the top ring is outside of the cylinders. Each ring is shop riveted to the conical course, and field riveted to the upper and lower cylindrical courses. All rivets are ¾ in. diameter in 13/16-in. holes. Plates and rivets are of open-hearth steel, and the cylinders are given two coats of paint on the outside only. The construction is shown in Fig. 3.

FOUNDATION CONDITIONS — Considerably more difficulty was found in sinking the cylinders than had been anticipated. From pier No. 2 to No. 25 there is a bed of soft red clay varying from 12 to 16 ft. in thickness and overlying a bed of hard red clay in which the cylinders are founded. Between the soft and hard clay is a stratum of blue sandy muck (with shells) from 1 to 2 ft. thick; this is not found beyond pier No. 20. The hard red underlying clay extends to pier No. 28. Starting at pier No. 26, the bed of the lake is sand, which extends over the remainder of the length of the bridge and reaches a maximum depth of 8 ft. at pier No. 33. Starting at pier No. 28, a hard red sandy clay occurs, with a maximum depth of 5 ft. at piers Nos. 29 and 30; this runs out at pier No. 32. Underlying this, from piers Nos. 29 to 33, is a hard red clay, mixed with stones, which increases in hardness as it approaches the north end of the bridge. It is this last stratum in which the cylinders are founded.

To get an idea of the character of the material through which these cylinders were sunk it may be stated that test bore holes put in a year previous to the beginning of the work had not closed up when the cylinders were sunk, and in some cases (where these holes came close to the location of a cylinder) they caused blowing in at the bottom. It was found that after a cylinder was partially

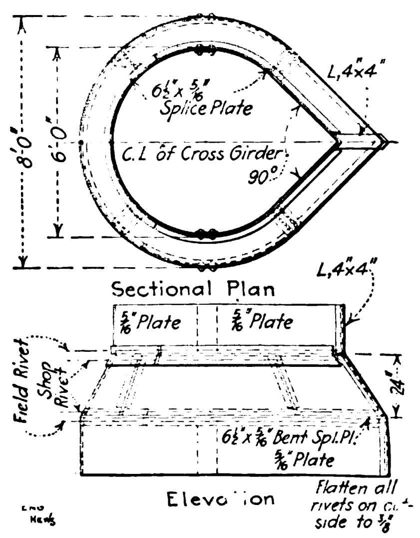


FIG. 3. STEEL SHELLS FOR OUTER CYLINDERS; FORMED AS ICE BREAKERS

excavated and loaded, pumping out the water from the interior of the cylinder caused the cylinder to sink. This was due to the fact that the hydrostatic pressure on the outside forced the water through the clay and destroyed the skin friction.

SINKING THE CYLINDERS—The cylinders were sunk by weighting them with pig iron and steel plates and excavating within them by an orange-peel bucket. A total load of about 35 tons was used in sinking. In the hard material the cylinders were pumped out, and the excavation for the undercutting was done by hand.

Since the original pile trestle was built, several sets of piles have been driven and the old piles cut off at the bed of the lake. It was found necessary to pull about 250 of these old piles, as they interfered with sinking the cylinders. Throughout the length of the bridge the clay was stiff enough to stand without closing in when the piles were pulled, and this caused a very serious delay in completing the bridge. In order to sink the cylinders to their final elevation and to undercut them, it was necessary to pump out and excavate by hand when the hard clay was reached, and these pile holes (like the bore holes mentioned above) left weak places which could not withstand the pressure of the clay and water outside the cylinder. Over 150 times the clay and water was forced under the bottom of the cylinders. This blowing in was greatly reduced by plugging the pile holes with bags of clay and banking up around the cylinders with clay. In 31 of the cylinders this continual blowing in made it impossible to keep the clay and water out of the cylinders long enough to undercut them, and piles were driven in them. Of the remaining cylinders, 59 were undercut an average of 15 in. below the bottom of the cylinders and 12 in. outside, while the six cylinders of piers Nos. 31 and 32 were founded in material so hard that undercutting was considered unnecessary.

The work of sinking was made more difficult, in a number of the cylinders, by the partial collapse of the bottom section of the cylinder. This was caused in some cases by hidden piles forcing in the edge of the cylinder; but in the piers between Nos. 21 and 33 it was caused by the flat sides of the nose not being able to withstand the pressure of the material outside the cylinder. In the down-stream cylinders of pier No. 11, the bottom was bent in so badly (before it could be settled to place) that the 5-ft. section above the reducing section was taken off and the cylinder filled with piles, driven to 15 or 20 ft. below the bottom of the cylinder. This work was completed in 1909 and no trouble of any kind has developed up to the present time. These cylinders withstood the heavy ice pressures of the past winter very satisfactorily.

Buffalo Lake Bridge

The Chicago & Northwestern Ry. has built a new line from Milwaukee to Sparta, Wis., known as the Milwaukee, Sparta & Northwestern Ry., and this was put in operation during the latter part of 1911. On this line there is another crossing of the Fox River, at what is known as Buffalo Lake, near Packwaukee, Wis. Here there is a bridge 1014 ft. long, consisting of a steel trestle supported on cylinder piers; it has also a double-track drawspan 209 ft. 9 in. long, resting on a concrete center pier and concrete rest piers, the piers being founded on hard gravel. The main spans are 60-ft. and 40-ft. deck girders, alternating with 30-ft. tower spans. Each tower has four cylinder piers and two steel bents, the bents being connected by struts and diagonal bracing to form a tower. Fig. 4 shows the type of construction of this bridge and shows also the material through which the cylinders were sunk.

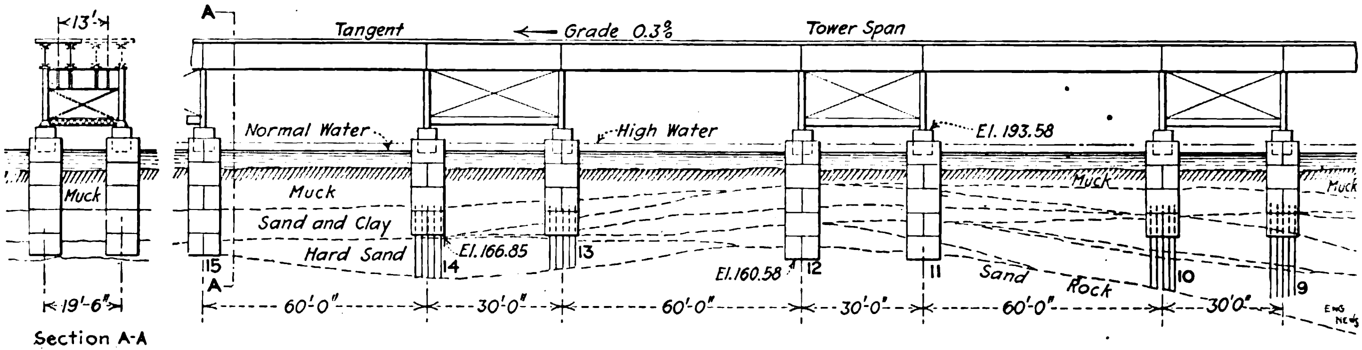


FIG. 4. PLATE GIRDER BRIDGE WITH STEEL TOWERS ON CYLINDER PIERS AT BUFFALO LAKE, WISCONSIN; CHICAGO & NORTHWESTERN RY.

FIG. 5. BUFFALO LAKE BRIDGE, SHOWING STEEL SUPERSTRUCTURE ON CYLINDER PIERS (JANUARY, 1912); CHICAGO & NORTHWESTERN RY.

The flow in this lake is very sluggish and the bottom of the river consists of muck followed by sand and clay, as shown.

The cylinders are 8 ft. diameter, reduced to 5 ft. for the top section. This top section is 6 ft. high, and projects about 3 ft. above the larger cylinder, being embedded in the concrete filling. The 8-ft. cylinders are of ⅜-in. plate courses 6 ft. high, with four plates to each ring; the plates and rings have butt joints with inside splices, as already described. The 5-ft. cylinders for the top courses are also of ⅜-in. plate, and each cylinder is formed of two semicircular plates. The anchor bolts for the tower bents are set in 6-in. gas-pipe sleeves about 2 ft. long, with a ¼-in. bottom anchor plate 8x8 in. The concrete filling was a 1:3:6 mixture.

The cylinders were sunk by excavating with an orange-peel dredge and loading the shell with rails. It required about 25 tons weight to sink each cylinder to position. The sand rock shown on the drawing is very soft and its elevation varied so much that in some cases it was necessary to drive piles in the cylinders. These piles were 24 ft. long, with 16 piles to each cylinder. No great difficulty was encountered in sinking these cylinders. After they were sunk, con-

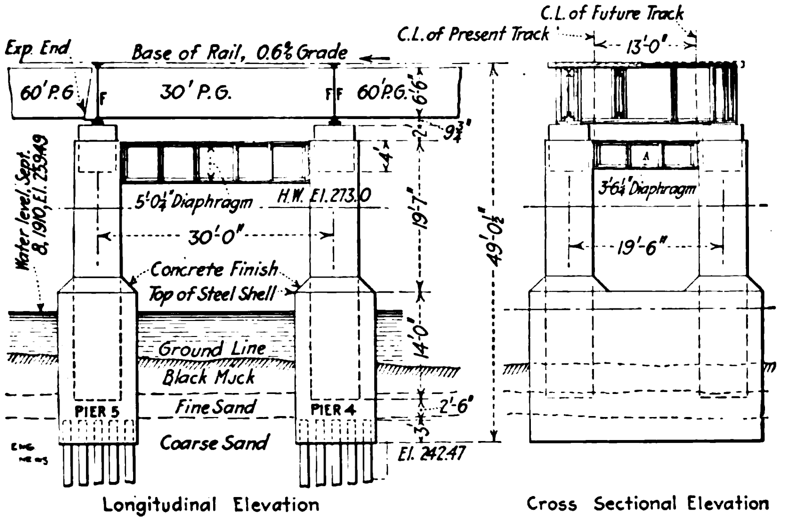


FIG. 6. CYLINDER PIER CONSTRUCTION FOR THE OXFORD MILL POND BRIDGE (WISCONSIN); CHICAGO & NORTHWESTERN RY.

crete was placed under water to a depth of 3 to 4 ft.; this was allowed to set and then the cylinder was pumped out. In one instance the cylinder, after being pumped out, was forced upward by the hydrostatic pressure of the water. Computations showed that the weight of the cylinder and concrete was not sufficient to withstand this pressure if no allowance was made for skin friction, and it was very evident that the pressure of water had completely destroyed the skin friction on the cylinder. Fig. 5 is a view of this bridge, showing the cylinders and trestle towers. The river was frozen at the time the photograph was taken.

OXFORD MILL POND BRIDGE

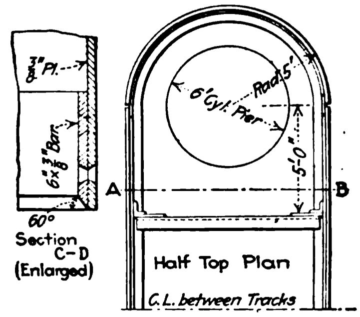
This bridge also is on the new line mentioned above (the Milwaukee, Sparta & Northwestern Ry.), and crosses a mill pond on Neenah Creek, 0.9 mile west of Oxford, Wis. It consists of 30- and 60-ft. plate girders resting on cylinder piers. It is 481 ft. long from face to face of back walls. The construction is different from that of the Buffalo Lake Bridge, described above, although as first planned this bridge was similar to the other; that is, it was proposed to use cylinder piers to support steel trestle towers. After the contracts had been let for the cylinders and superstructure it was found that the mill owners proposed to raise their dam and increase the height of water some 10 ft. This necessitated a change in the bridge, as the steel towers would have been submerged.

After consideration of the matter it was found that we could cancel the order for the trestle towers, but that the 6-ft. cylinders were so far advanced that they would be a loss if not used. It was then decided to use these cylinders, but extending to a higher elevation than originally designed and to use for the base of the piers steel shells 10 ft. wide and 29 ft. 6 in. long, with rounded ends. In these were placed the lower ends of the 6-ft. cylinders. When the cylinders were in position, the concrete filling was continued to the top. The tops of the four cylinders of each tower are connected in both directions by plate girders, just under the superstructure, making a rigid pier.

Fig. 6 is a general drawing of this bridge showing the arrangement of the piers and the materials encountered in the foundations. Fig. 7 gives the details of the shells and cylinders, with their connecting girders. Fig. 8 is a view of the completed bridge, with the present water level; when the dam is raised the water will be nearly up to the girders connecting the tops of the cylinders.

PEKIN BRIDGE

On the St. Louis, Peoria & Northwestern Ry., which is now under construction (and will form a part of the Chicago & Northwestern Ry. system), there is a crossing of the Illinois River near Pekin, Ill. This bridge will consist of a 175-ft. single-track through-truss vertical-lift draw span, four 150-ft. single-track through-truss spans and two 70-ft. deck-girder spans. Borings taken at the site of the proposed bridge developed sand with streaks of blue clay, then sand and gravel to the underlying shale at elevation 376 at the lift span. Comparative estimates and plans of various types of foundations were made, covering the following: 1, pile foundations with open coffer-dams and concrete piers; 2, pile foundations sawed off under water with open caissons floated into position, and, 3, cylinder piers sunk to the underlying shale.



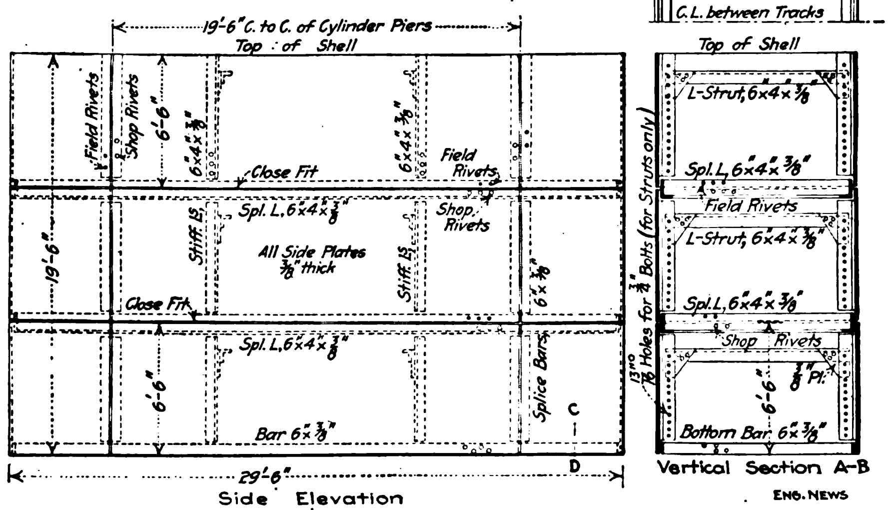


FIG. 7. SHELLS FOR BASE OF CYLINDER PIERS OF THE OXFORD MILL POND BRIDGE

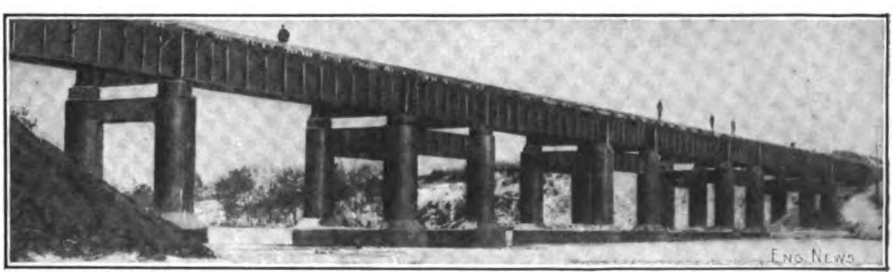


FIG. 8. OXFORD MILL POND BRIDGE; CHICAGO & NORTHWESTERN RY.

(When the dam is raised the water level will be just below the plate-girder struts connecting the tops of the piers)

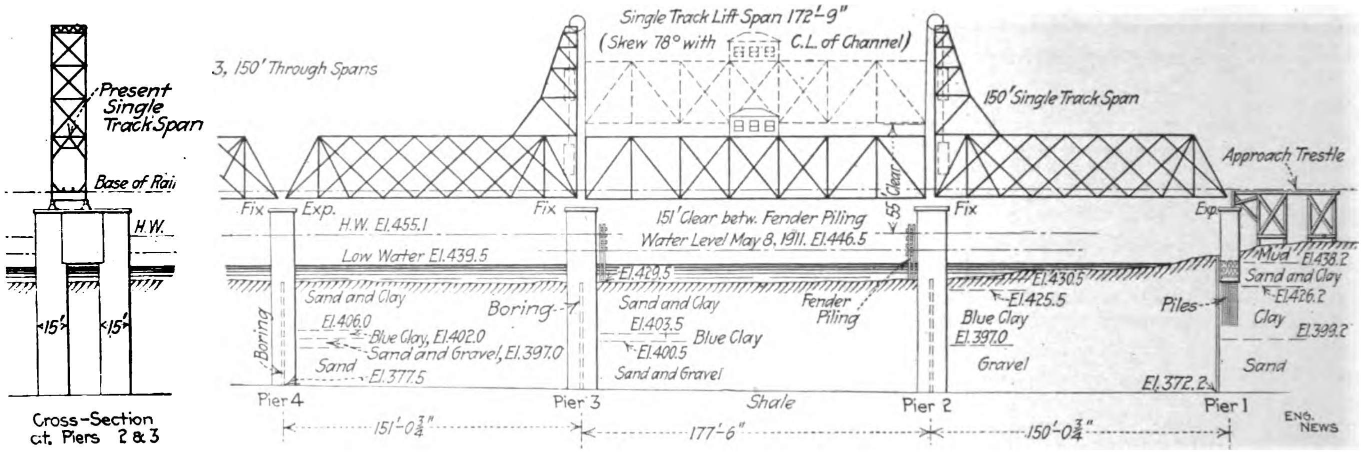


Fig. 9. Vertical Lift Bridge with Cylinder Piers Over the Illinois River at Pekin, Ill.; Chicago & Northwestern Ry.

The plan adopted was to use two 15-ft. cylinders for each of the piers of the lift span. For the other spans there will be two 12-ft. cylinders extending to rock, or two 10-ft. cylinders footed in the gravel and having piles driven below them. In each case, the two cylinders will be connected laterally above the low-water line by a pair of deep lattice-web trusses embedded in concrete. The general construction is shown in Fig. 9, while Fig. 10 shows the cross-girder connections or struts between the cylinders of the draw span. The plan as prepared contemplated sinking these cylinders by open dredging. The contractor, however, preferred to use the pneumatic process, and the cylinders for pier No. 5 have been sunk by this method very successfully.

It will be seen that these foundations will provide for the future second track. The towers and supporting machinery for the lift span will be designed for double track, so that when the second track is added the single-track lift span will be taken out and used elsewhere on the road and a new double-track bridge substituted.

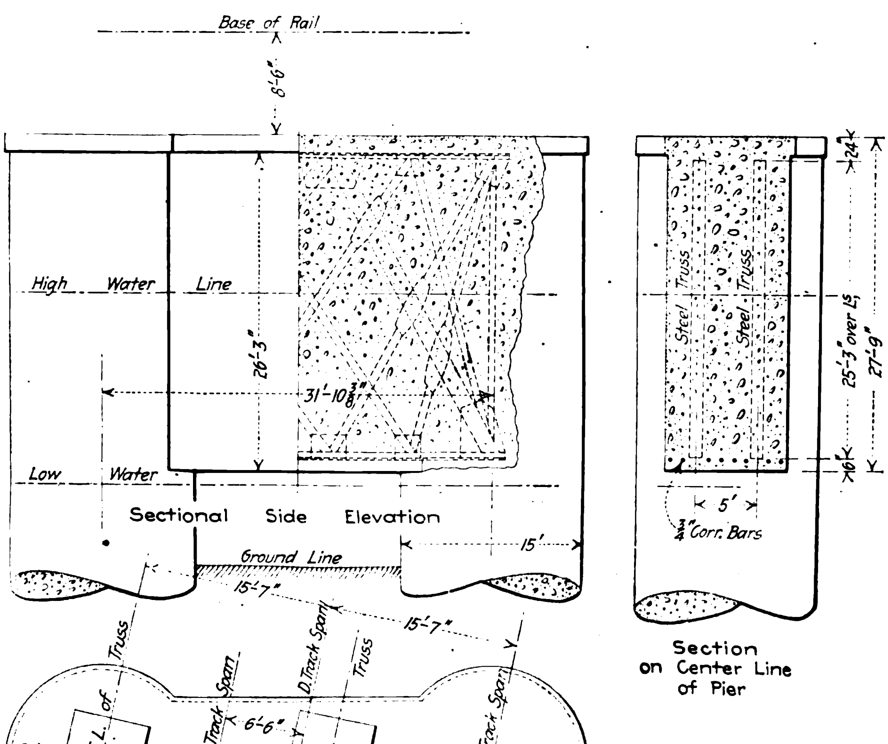


Fig. 10. Cylinder Piers for 173-ft. Lift Span of Illinois River Bridge; Chicago & Northwestern Ry.

The Aiken System of construction for concrete buildings, in which the walls are cast in a horizontal position and raised bodily into position, was described in our issue of June 27, and further particulars as to the operation of the telescopic screw jacks used in raising the finished walls have been received since then from the Monolithic Concrete Construction Co., 1414 Hartford Building, Chicago. This company undertakes contracts for building work, and operates under the process patents of the inventor, Robert H. Aiken, Winthrop Harbor, Ill., by whom the jacks are manufactured.

The jack (shown in Fig. 2 of the article mentioned above) consists of three parts: 1, the chair or support; 2, the walking beam (which supports the form); and 3, the telescopic screw, with a ball-bearing gear head attached. The jacks are made in three sizes for walls up to 20, 30 and 45 ft. high respectively. In use they are set in a row along the foundation spaced 5 to 6 ft. apart. The foot of the chair rests on the foundation of the wall, while the rear of the chair (supporting the screw) rests on a substantial blocking or temporary foundation. This end of the chair has bolt holes for the attachment of spacing bars (steel channels) which serve to give the proper alignment and to hold the jacks upright while being erected. In preparing to raise the wall, hexagonal steel tumbling bars are fitted to holes in the gear heads of the jack to operate the worm gear on the screw. These bars form a continuous driving shaft which connects all the jacks and insures their equal and uniform motion. The bar near the middle of the work is fitted with a driving gear head and pulley, a belt on the pulley being operated from a small steam or gasoline engine (3 to 6 hp.) It takes 96 revolutions of this shaft to raise the screw 1 in. When the wall is in its vertical position, its weight is carried by the axles of the walking beams until the narrow space (2 or 3 in.) between its foot and the top of the foundation has been filled with concrete, which is allowed to harden before the weight of the wall is imposed upon it. To take down the jacks, the screws can be operated simultaneously by reversing the engine or giving the belt a half twist; in each jack the top pin of the walking beam is uncoupled and an iron bar run through the hole in the end of the screw to prevent the screw from turning.