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MECHANICAL FEATURES OF THE VERTICAL-LIFT BRIDGE

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This paper covers the important developments in the operating mechanisms of the vertical-lift bridge, beginning with the Halsted Street bridge built for the city of Chicago in 1892, *and ending with the* 1600-*ton lift span of Bridge* 458, *Pennsylvania Lines West, completed in the same city in* 1914. *It is shown that the improvements in design made in the* 22 *years intervening between the erection of these bridges were due not only to the observation and correction of faults, but to the fact that great progress was made during the same period in certain manufactured articles, principally the electric motor.*

The writer mentions points of special interest in the design of eight lift bridges, describing supporting, guiding, and locking details, and methods of erection, operation, and control. On a certain type of tower sheave it developed, after one of the bridges had been put in operation, that the disk plates forming the webs of the sheaves were loose and moving on the steel hubs to which they had been riveted, and a satisfactory method is illustrated of overcoming the difficulty between operations of the span.

The erection of the lift span of Bridge 458, *Pennsylvania Lines West, presented some unusual problems, and this work, with the unique method of solving one of these problems, is covered in considerable detail.*

PRIOR to the year 1892, movable bridges of the elevator or vertical-lift type were practically unheard of. A few very short and unimportant spans of low lift had been built, but in that year a bridge, much more pretentious than anything so far attempted, was built in Chicago from the designs of Mr. J. A. L. Waddell, Consulting Engineer, of Kansas City, Mo. This bridge, illustrated in Fig. 1, crosses the south branch of the Chicago River at Halsted Street. Its span is 130 ft., it provides for city highway and electric railway traffic, and lifts 140 ft., affording vertical clearance for boats of 155 ft.

2 In common with many later vertical-lift bridges, the Halsted Street bridge consists of a simple span between two towers. The live loads are transmitted to the piers in the ordinary manner, but the dead load is counterbalanced by a set of weights, equal in weight to

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the lift span, and connected to it by wire ropes which pass over grooved sheaves on the tops of the towers. The dead load of the span and counterweights is therefore carried to the piers entirely by the towers.

3 Unlike any bridge of this type which has succeeded it, this bridge is operated by machinery which is located under the roadway, at the base of one of the towers. Its power-transmission equipment consists of a system of wire-rope drives running from the grooved

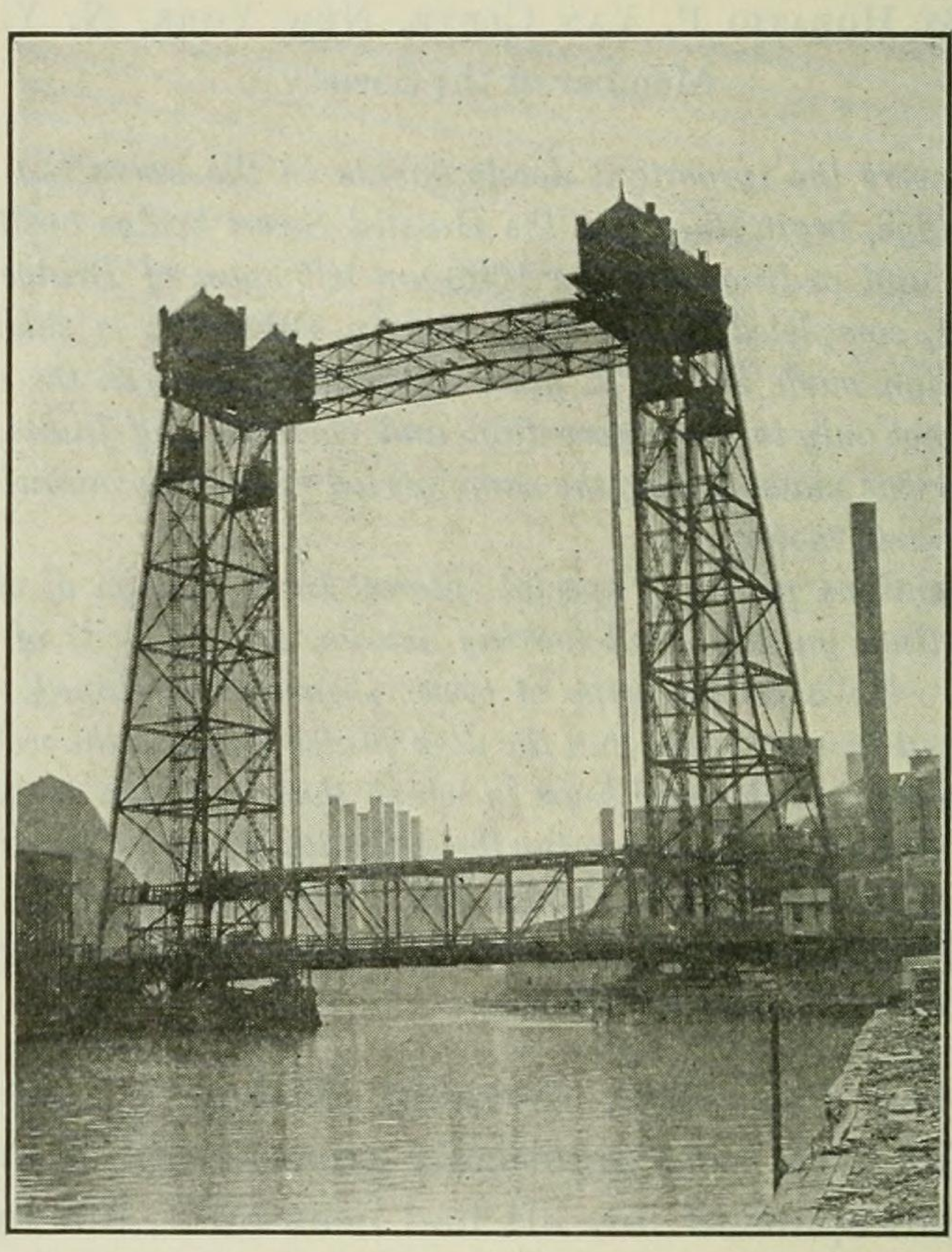

Fig. 1 Halsted Street Bridge Over South Branch of Chicago River, Chicago, Ill.

130-ft. span, 140-ft. lift. Design of J. A. L. Waddell, Kansas City, Mo.

drums in the machinery house to each end of the lift span, and to each counterweight. There are 16 ropes in all. Eight up-haul ropes, passing around a set of idlers at the bottom of the near tower, are carried to its top where they divide into two groups. Four turn downward over another set of sheaves and attach to the near end of the lift span, and four, running horizontally to the top of the far tower, are there deflected downward, and attach to the far end of the lift span. The eight down-haul ropes, in similar manner, are connected to the tops of the counterweights.

4 On account of the extreme height of these towers, some 217 ft. from the water to their tops, it was considered advisable to steady them by well-braced lattice girders, running from top to top, and these latter serve as a support for the idler sheaves placed midway between towers to guide and steady the horizontal reaches of the operating ropes.

5 This bridge is still in service and is giving satisfaction. The only material change in its operating machinery from that at first installed, was the substitution some years later of electric motors for the original steam engines. It is of interest to note that Dr. Waddell had recommended electric motors in the original design but the city had not accepted them on the ground that they were "untried toys."

6 It was not until 1909 that another vertical-lift bridge was built. The firm of Waddell & Harrington had meantime been formed and a new impetus was given to this type of structure. Late in 1908 designs were begun for a bridge across the Mississippi on the line of the Iowa Central Railroad near Keithsburg, Ill. It was decided to make one of the spans a lift span, and in the design several improvements were made on the operating mechanism of the Halsted Street bridge. Chief among these was the change in the location of the machinery from the pit below the tower to the top of the lift span. The advantages in this were several; the most important being that it shortened materially the length of operating ropes and reduced to a minimum the complications in their connection and arrangement; and it put the operator at once in reach of his machinery and in view of the river and approaching trains.

7 The scheme of operation — that used on nearly all succeeding lift spans — is as follows: The motor, in this case a gas engine, is connected by a train of gears to four spirally grooved operating drums, two over each top chord. Two operating ropes are fastened by rope clips to each of these drums, one for the upward movement of the span and the other for the downward, and are so wound on the grooves of the drum that the up-haul rope is wound on while the down-haul rope is paid off, and vice versa. An up-haul rope runs from each drum to the corresponding corner of the lift span, there over a double-grooved deflector sheave, and thence to the top of the tower, to which it is connected. The down-haul rope parallels the up-haul as far as the deflector sheave, and there, passing downward over the other groove in the latter, connects to the tower at a point in convenient reach of the deck. At each point of connection

to the tower, suitable means of adjusting the tautness of the rope is provided; in this case an ordinary eyebolt threaded its full length.

8 Rotation of the drums in one direction winds on the up-haul ropes, causing an upward force at the deflector sheaves and thus, overcoming the friction of the tower-sheave journals in their bearings, the unbalanced weight of suspended ropes and the inertia of the moving parts, lifts the span. Similarly, rotation in the opposite direction lowers the span. All four of the operating drums are locked together by the connecting gearing, thus insuring the synchronous rotation of the tower sheaves and keeping the span at all

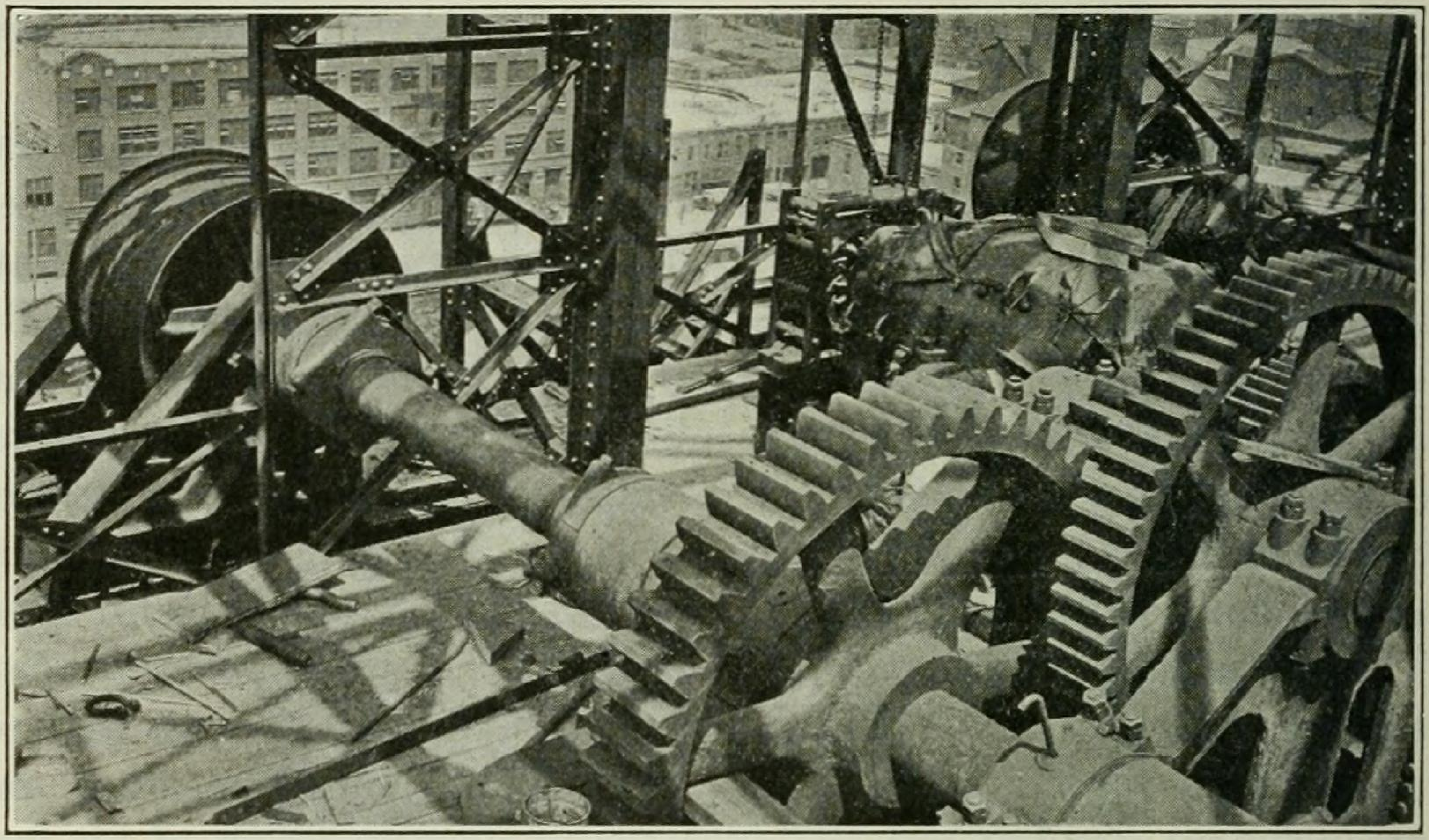

Fig. 2 Portion of the Operating Machinery, Bridge No. 458, Pennsylvania Lines

300-hp. railway-type motor; steel driving gears with 20-deg. involute-cut teeth, and operating drums. The large gear in the foreground has teeth of 4½ in. circular pitch; the shaft is 10 in. in diameter.

times parallel to its original position. The general scheme of operation is illustrated by Fig. 2.

9 To keep the span in proper alignment between the towers, vertical tracks are provided on the four tower legs adjacent to it, and on these tracks bear the rollers which hold the span both in transverse and longitudinal alignment. On account of temperature changes in the span·length it was considered necessary to provide heavy springs to act upon the longitudinal rollers, thus holding them at all times in contact with their tracks. This design was later found to be somewhat objectionable, and was improved upon

in some later bridges. It was considered impracticable to guide the span so closely during its entire lift that when brought to seat the rails would be in proper alignment for the operation of trains, and wedge-shaped steel castings were therefore located at the foot of each tower, and arranged to engage close-fitting mating castings on the span when the latter was still 2 ft. above its seat. At one end of the span these centering castings were arranged to provide longitudinal centering also and were made heavy enough to resist, in addition, the force of a train suddenly braked on the span. At the other end transverse centering only was afforded, thus allowing for temperature changes in the length of the lift span.

10 The Keithsburg bridge has a low lift, only 40 ft., but is 229 ft. long, or 100 ft. longer than the Halsted Street span, and is half again as heavy. On account of the comparative shortness of the towers, the overhead truss was considered unnecessary. Since 1892 considerable advance has been made in attachments for wire ropes, and the new designs were used in this structure. Rope sockets of steel could now be bought which would develop the ultimate strength of the rope, and these were employed instead of the rather clumsy sets of rope clamps of the Halsted Street design.

11 One feature of the design of this bridge, continued on a number of others, although usually in modified form, is the locks. These lock automatically and not only hold the bridge down when once seated, but also hold it in case one or both ends should not be entirely seated by the down-haul ropes, a condition considered quite possible either from a lack of adjustment or unequal stretching of the latter. The lock adopted is automatic in action. It consists of two cams locked together by two segmental gears and counter-weighted to swing toward each other and grip a link hanging from the lift-span floor beam. The cams are supported by a steel-casting anchor bolted to the piers, and the link in descending separates them and is in turn held by them when the end of the span is 1 in. above its final down position. Should a load come on with the end thus, the latter would be carried on down and the cams would swing further toward each other, locking it firmly in place. Unlocking is accomplished by a foot-shaped bar sliding vertically on the floor beam and connected by a wire rope to the lock lever in the operating house.

12 To save metal in the trusses of the lift span the machinery house was located on one end of the span. No difficulty was anticipated in such an arrangement, but after operation was started it was

found that the set of ropes leading to the far tower, about 100 ft. longer than those attaching to the near tower, stretched much more than the latter; and this condition caused the near end of the span to rise before the far end, and produced a halting, uneven movement throughout the lift.

13 Another lift span was almost complete when this condition was discovered, and the plans were immediately changed by moving machinery and house to the center of the span.

14 The counterweights of the Halsted Street bridge had been made of cast iron, but considerable money has been saved on the Keithsburg bridge and on all later bridges by making them of concrete. The construction usually adopted for each weight consists of two vertical steel members, one at each end of the weight, connected at the bottom by one or more laced struts and ending at the top in the equalizing devices to which the suspending ropes are attached. In this steel framework is usually cast a solid block of concrete, although several sets of weights have been built of previously cast blocks laid up in tiers on a big concrete beam at the bottom.

15 The equalizing devices referred to above consist of sets of balance bars, each set attached at its upper end to the rope sockets and terminating at the bottom in a single pin for each counterweight. The accepted form of equalizer in Fig. 3 was designed to meet a condition at the time unprecedented, i.e., 16 $2\frac{1}{4}$-in. ropes receiving their load from a single pin. On the Keithsburg bridge and on several succeeding it, the equalizers had been of straight horizontal bars and vertical links, each of the former having three pins on line. This device effects a very material saving in space over the preceding form and also has the advantage of being much less seriously affected should one of the ropes break. In fact, if a side of one of the top bars should drop, the load would shift laterally and readjust itself to such an extent that the remaining 15 ropes would each get an approximately equal share of the load originally supported by the broken one. This advantage over the former type is readily seen when it is realized that to break one rope of a pair in the earlier design would cause the other to receive double its original load.

16 The third important bridge to be built was across the Willamette River at Hawthorne Avenue, Portland, Ore. The lift span is 244 ft. long and lifts 116 ft. The main points of improvement in this design over that of the Keithsburg bridge are that the machinery is on the center of the span, as above noted, and is much more com

pact, all gears being mounted in the same frame instead of being supported on isolated bearings bolted to different parts of the steelwork. Operation is by two electric motors instead of by gas engine as on the former bridge.

17 Although the choice of power for operation is rarely within the control of the designer, but is dependent rather on local conditions, it is well to note that wherever possible to obtain it, electric power is far superior to any other, as it makes possible niceties in control, and interlocking mechanisms and safeguards not possible

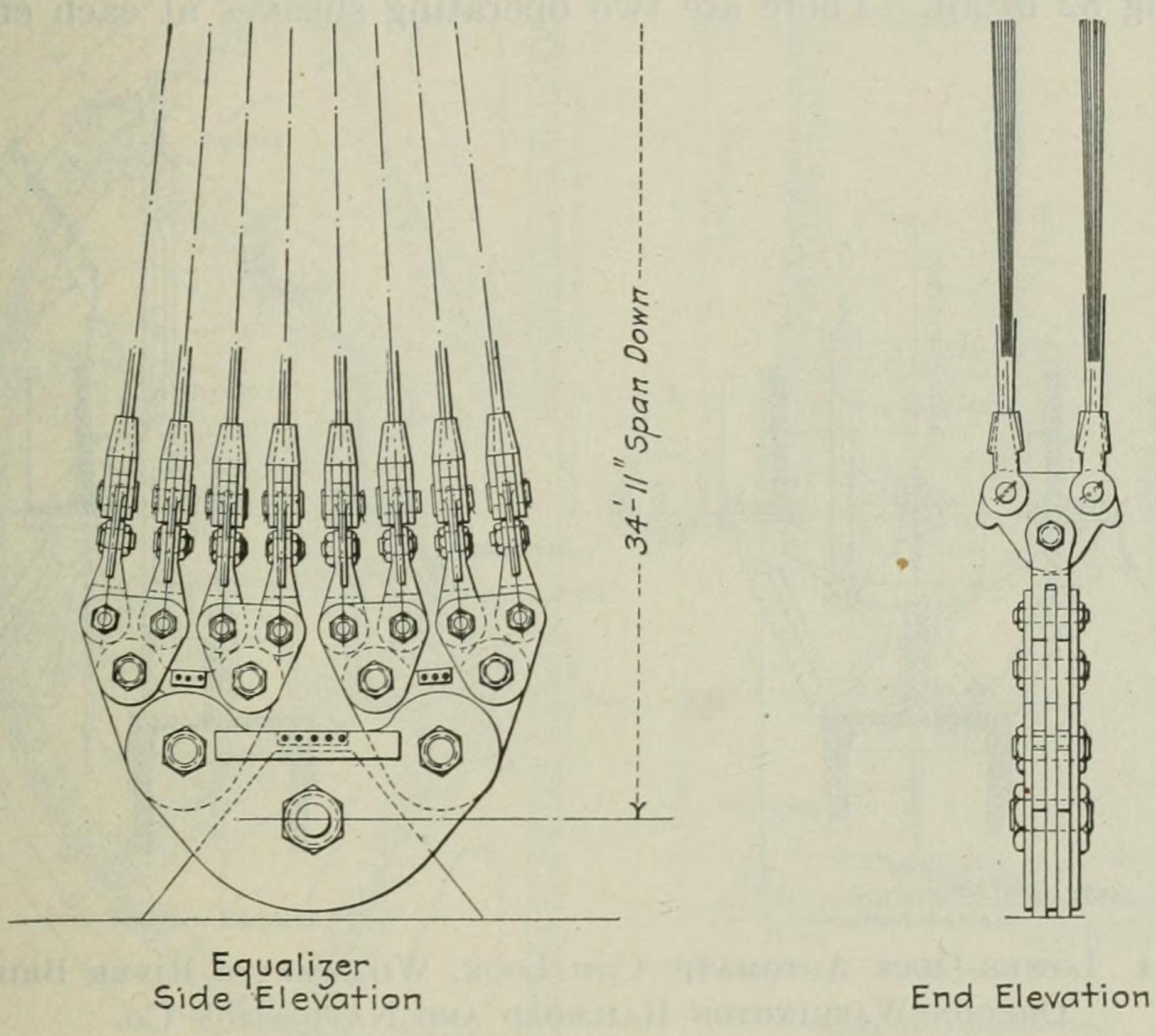

Fig. 3 Equalizer, Willamette River Bridge, Oregon-Washington Railroad and Navigation Co.

with any other kind of power. For lift-bridge operation direct-current motors are more economical than any other because of their high starting torque in proportion to their size.

18 While the Hawthorne Avenue bridge was under construction another lift bridge of entirely different character was being designed. This was the 425-ft. span of the combined highway and railway bridge across the Missouri River at Kansas City. It consists of two decks, a fixed upper deck for highway and electric railway, and a lower deck for railway traffic, the hanger posts of the

latter telescoping into the truss posts of the former as the lifting deck rises.

19 The live load coming on each lifting-deck hanger is carried by a pin into two saddle diaphragms in the upper deck truss. The dead load is carried into a pair of suspending ropes which, passing up through the upper deck posts, over a deflector on the top chord, along the chord to the operating sheaves, and then downward over another deflector, terminate in a counterweight. There are 15 panel points for each truss, and each point, except the two in the center, has one counterweight; the center points have two each, making 32 in all. There are two operating sheaves at each end of

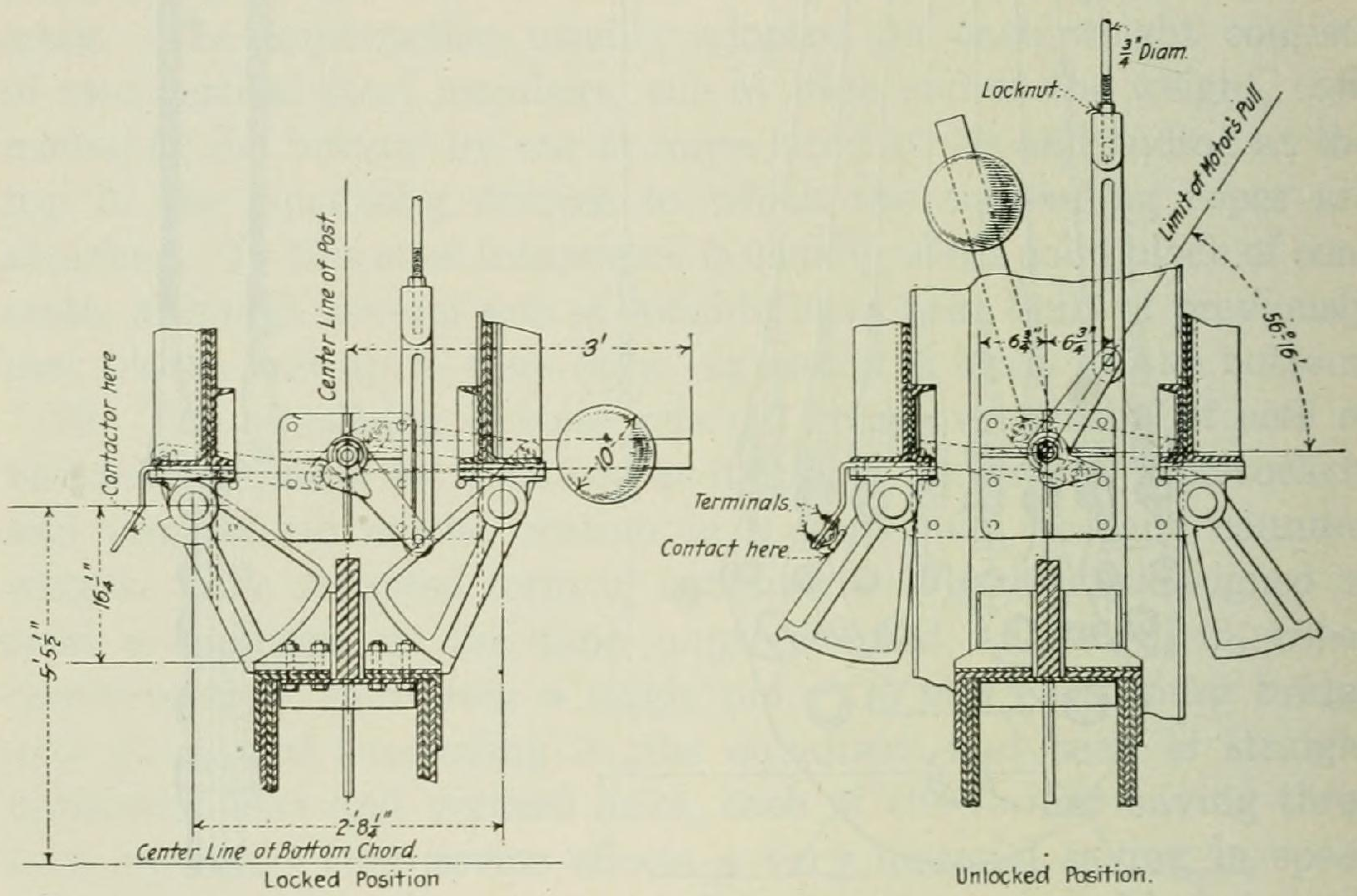

Fig. 4 Lower-Deck Automatic Cam Lock, Willamette River Bridge, Oregon-Washington Railroad and Navigation Co.

the bridge, and each pair is controlled by a motor and gear train near it. All suspending ropes pass over the four operating sheaves and motion is transmitted to the lifting deck by virtue of the friction between the former and the latter. The two sets of machinery, one at each end, are made to act together by means of two rope drives, one acting when the span is lifting, the other when it is lowered.

20 Each intermediate panel point of the lower deck is locked down by a cam lock similar to the one later installed on the bridge of the Oregon-Washington Railroad and Navigation Co. over the Willamette River at Portland and shown in Fig. 4. This is a further

development of the lock for the Keithsburg bridge above described, and is fully automatic for locking.

21 Each end of the span is latched down by a lock operated by a wire rope pulled by a segmental sheave in one of the machinery houses. All the hanger locks, 26 in number, and the two end locks, are operated by the same motor and gear train.

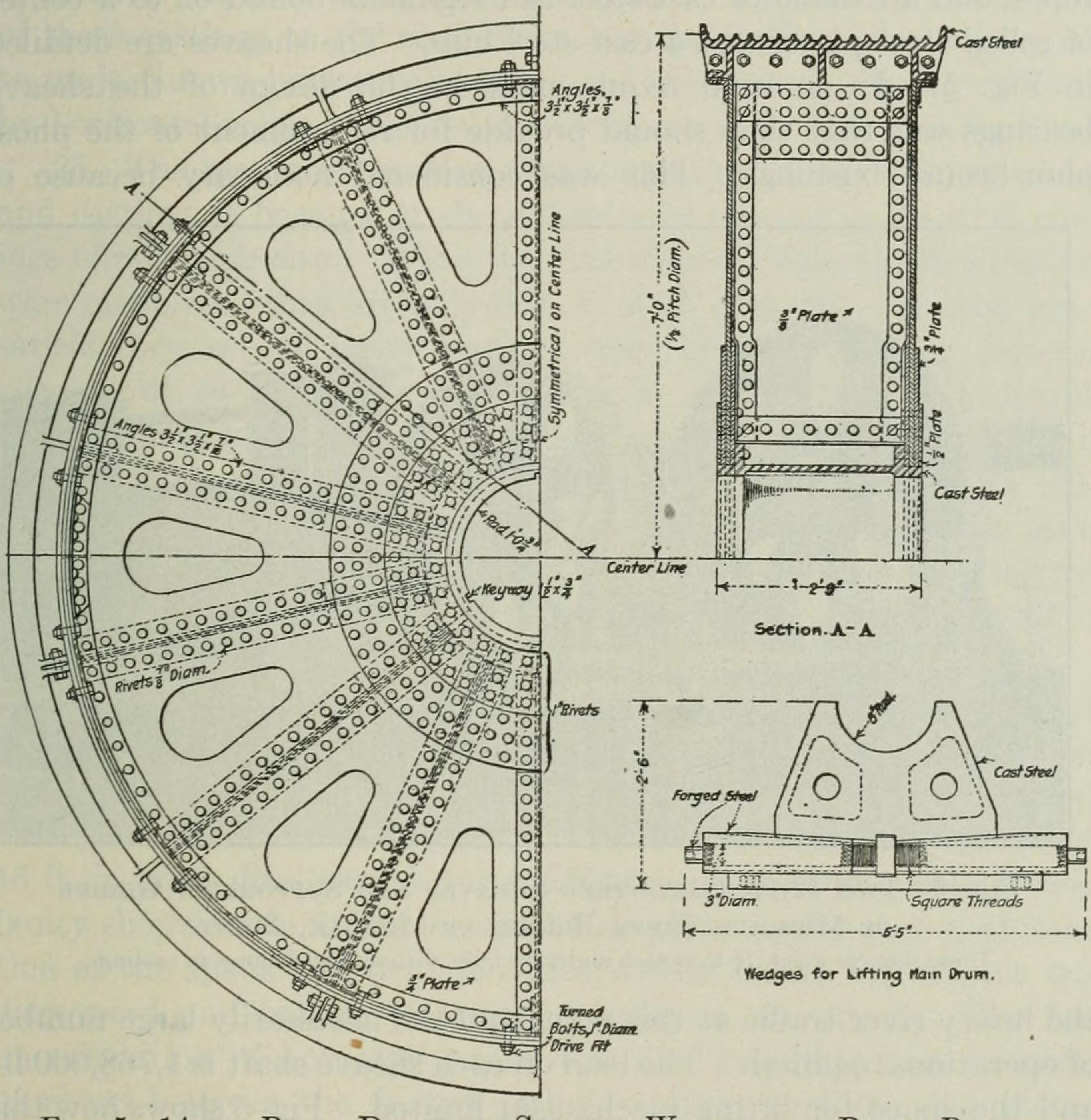

FIG. 5 14-FT. PITCH DIAMETER SHEAVE, WILLAMETTE RIVER BRIDGE, OREGON-WASHINGTON RAILROAD AND NAVIGATION CO.

22 The bridge designed for Oregon-Washington Railroad and Navigation Co. across the Willamette River at Portland, Ore., has some points of interest. It is a combination of a simple lift span and the lifting deck just described. This lift span is 211 ft. long, weighs 3,420,000 lb. and lifts 89 ft., while the lifting deck below it can lift independently for 46 ft., and will then lift with the span for 89 ft. The advantage of this arrangement is evident when it

is realized that the highway traffic on the upper deck is not interrupted for ordinary river traffic, as the upper deck must lift for high-masted vessels only. There are five or six full operations daily and ten times that number of lower-deck lifts.

23 The large tower sheaves of this bridge are the first of this size and type. They are 14 ft. in pitch diameter, carry sixteen 2¼-in. ropes, and are made of cast-steel rim segments bolted on to a center of rolled-steel plates and a cast-steel hub. The sheaves are detailed in Fig. 5. An unusual requirement in the design of the sheave bearings was that they should provide for replacement of the phosphor-bronze bushings. This was considered necessary because of

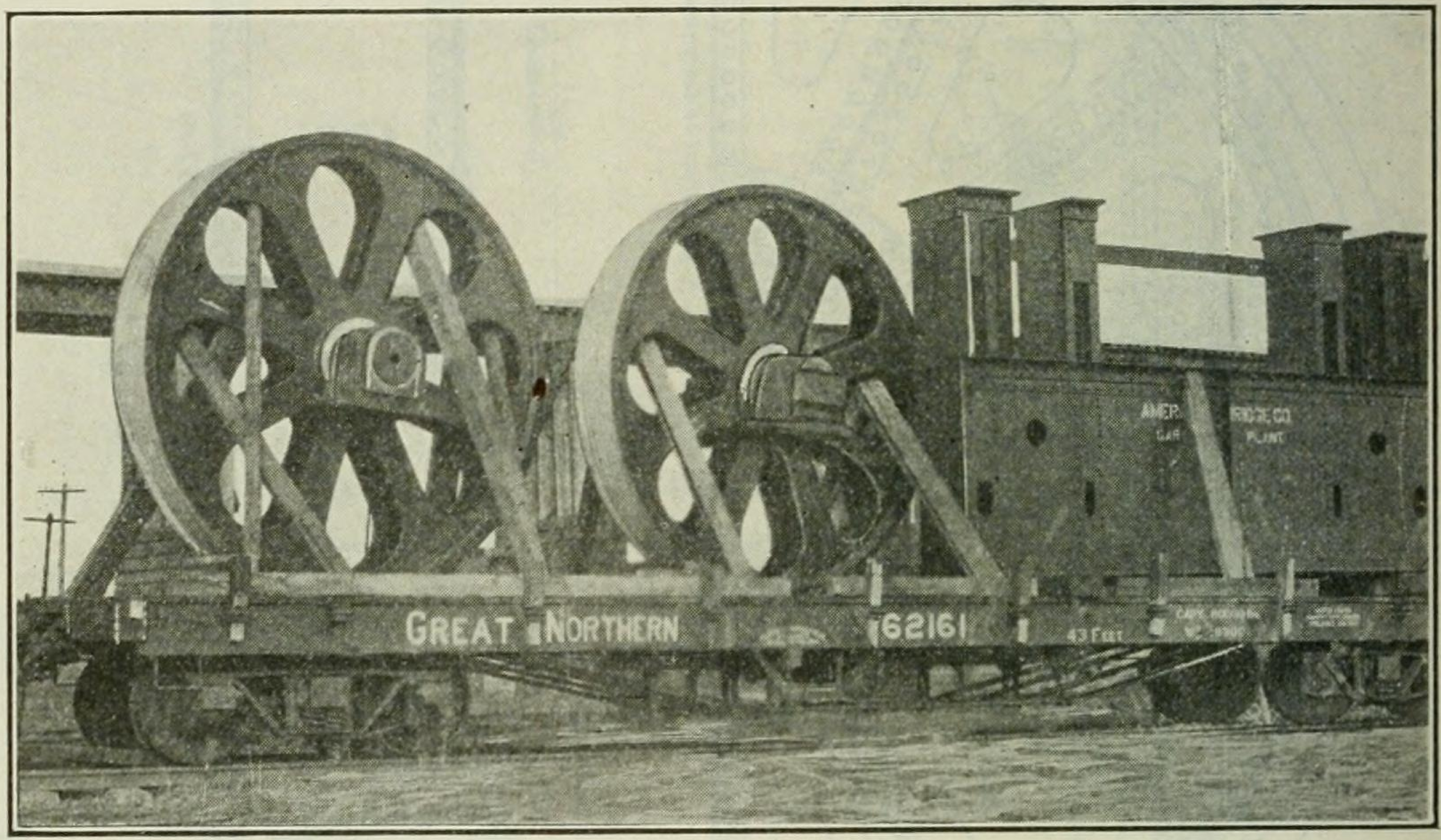

Fig. 6 Two 12-ft. Cast-Steel Sheaves and Supporting Girder of Missouri River Bridge at Mondak, Mont.

These sheaves weigh 7½ tons each and were built without any failures in casting.

the heavy river traffic at this point and the necessarily large number of operations required. The load on each sheave shaft is 1,768,000 lb. and the space for lifting mechanism limited. Fig. 5 shows how this requirement was met by a system of wedges; the projections on the ends of each sheave shaft are for the purpose of resting in a steel saddle casting of the wedging devices.

24 After the span had been placed in operation a rather serious difficulty was observed with these sheaves. It was noticed that when they turned, nuts and broken bolt ends began to fall, and it was found that they were coming from the flange connections of the steel rims to the angle of the supporting steel centers. Careful investigation developed that the inner circumference of the assembled

rim castings was slightly longer than the outer circumference of the steel disks on which they were designed to bear. Because of this fact the ropes forced the error to accumulate at the bottom of each sheave, separating appreciably the rims from the disks and breaking the connecting bolts. This discrepancy had not been detected until the sheaves received their load. On later designs in which this type of sheaves has been used, no reliance has been placed on the bearing of these castings on the steel disks, but the former have been made to project down between the latter and are securely riveted to them by horizontal rivets sufficient in number to carry the loads in shear.

25 The reason for making these large sheaves of built-up plates and castings is because of the difficulty of getting single steel castings of adequate size. When the Hawthorne Avenue bridge sheaves were made, and they are only 9 ft. in pitch diameter, the shop got a satisfactory set of eight castings only after having six rejected because of serious flaws. This was in 1910. That considerable improvement had been made in three years in the processes used in making large steel castings is attested to by the fact that in 1913 four sheaves 12 ft. in pitch diameter, and weighing $7\frac{1}{2}$ tons each, were built without any failures in casting. These are the sheaves of the Missouri River bridge at Mondak, Montana, illustrated in Fig. 6.

26 Another trouble with some built-up tower sheaves occurred in connection with those for the three bridges of the Pennsylvania lines in Chicago. These bridges were all put into service in the winter of 1913 and the summer of 1914. The sheaves on all of them are 15 ft. in pitch diameter, and the difficulty referred to resulted from faulty shopwork in fitting the steel disk plates to the cast-steel hubs. One of the spans had been put into service before the trouble was discovered and had to be repaired between operations. The first manifestation of anything wrong was the loosening and breaking of rivets between the flanges of hub castings and the disk plates. Examination showed that the holes for the hub castings were too large and that there was a creeping going on between the disks and the hub. This was corrected by drilling holes into hubs and disks where they come together and driving in slightly tapered tool-steel pins. The scheme will be evident upon examination of Figs. 7 and 8.

27 A bridge illustrating the most recent arrangement of operating machinery is that designed for the Vladicaucase Railway for a crossing of the Don River near Rostoff, Russia. By reference to Fig. 9 it will be noted that the drums are close together instead of

being at the opposite ends of the main drive as is the case with the Pennsylvania bridge illustrated in Fig. 2. The advantage in this arrangement is one of economy. It will be noted that a large gear reduction is made at the drums and that there is only one line of shafting across the bridge instead of two. With the reduction used,

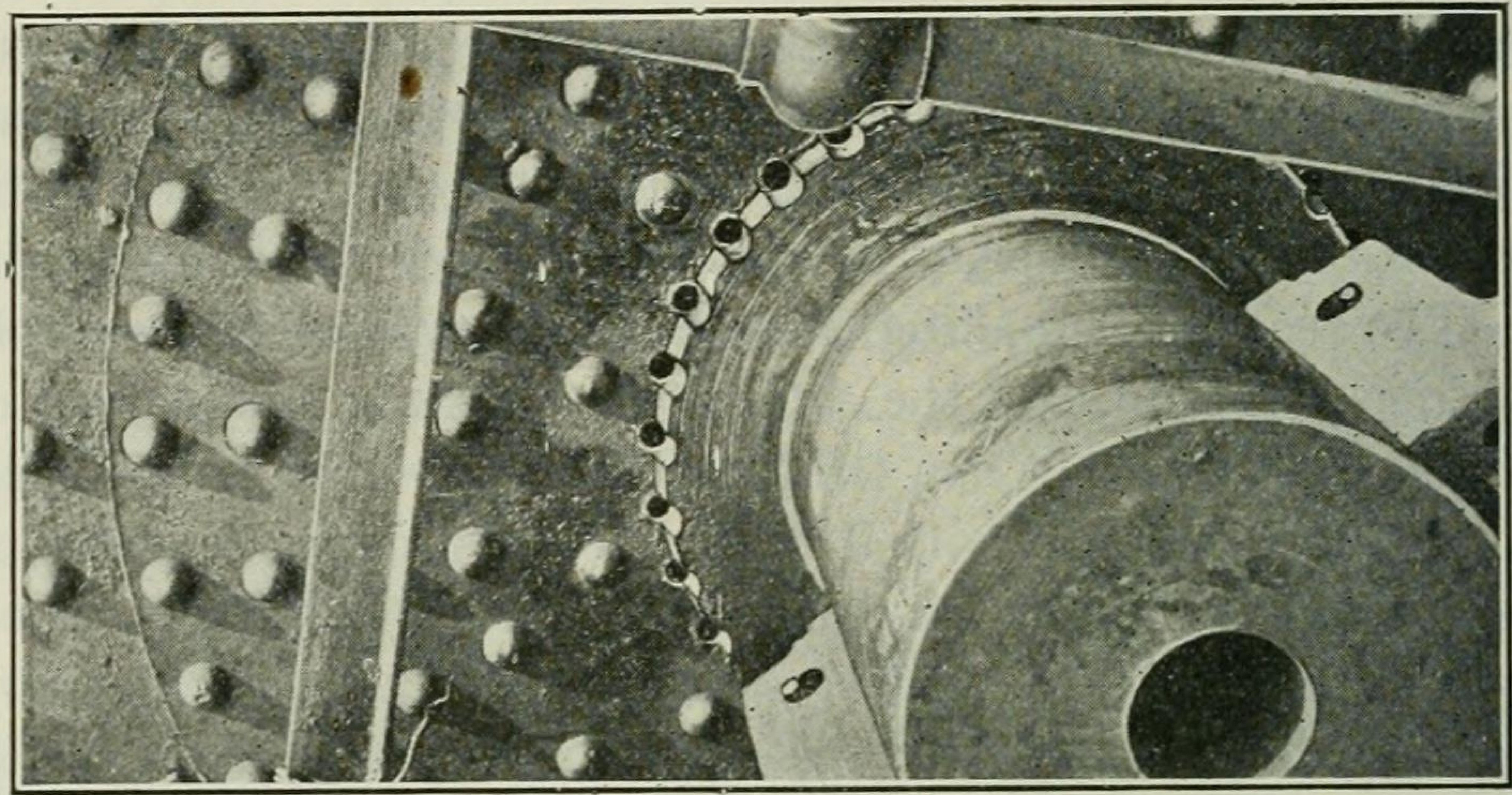

Fig. 7 Repairs to Hubs of Built-up Sheaves for Pennsylvania Lines Bridges in Chicago

It will be noted that the hub casting projects outward from the face of the disk plate, making necessary the guiding arrangements in Fig. 8.

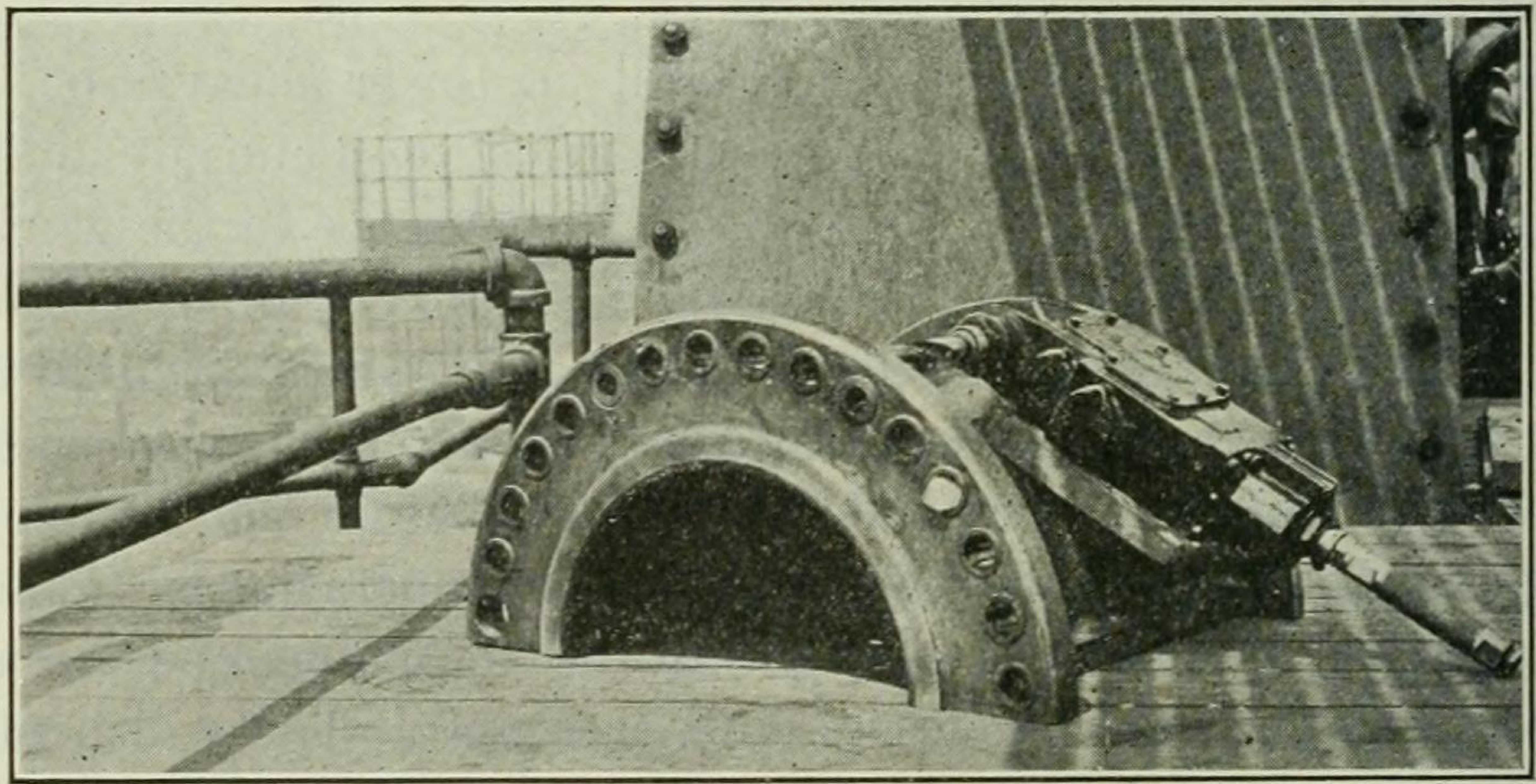

Fig. 8 Cast Templet and Air Drill, Pennsylvania Lines Bridges, Chicago

The holes for the hub casting were found to be too large. This defect was corrected by drilling holes into hubs and disks where they come together and driving in tapered steel pins.

this shaft is considerably smaller than one of the two required in former layouts. The gear frame is also much smaller. It will be noted that auxiliary power is furnished by a small gas engine operating through a gear reducer.

28 One of the heaviest bridges so far designed is that over

the South Branch of the Chicago River at Chicago, known as Bridge No. 458, Pennsylvania Lines. This bridge presents many interesting features and will be described at some length. It carries the double track of the Pennsylvania Lines across the South Branch near 19th Street and will be used by the Pennsylvania, the Chicago & Alton

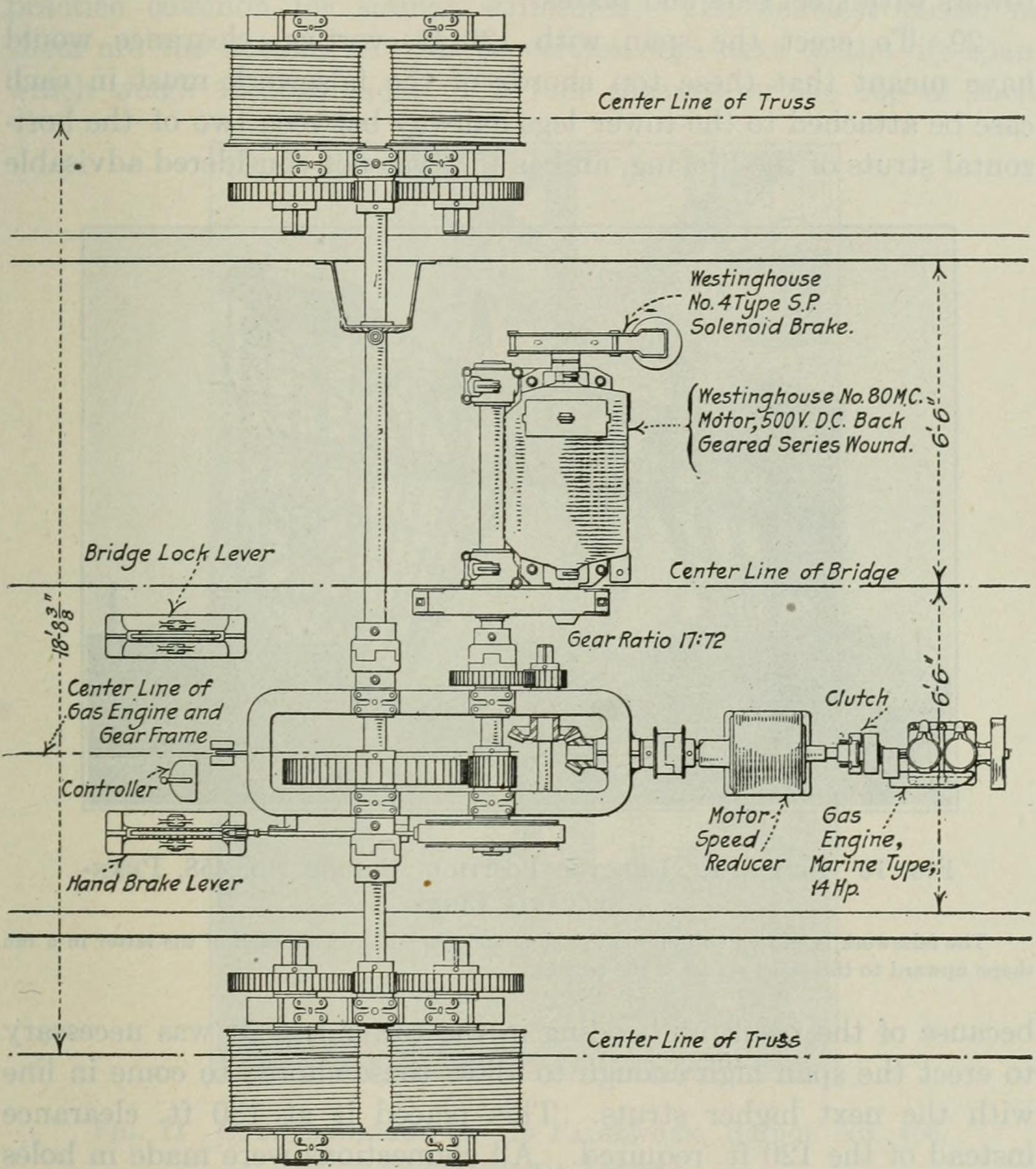

FIG. 9 ARRANGEMENT OF OPERATING MACHINERY, DON RIVER BRIDGE, VLADICAUCASE RAILWAY, ROSTOFF, RUSSIA

and the Pere Marquette. There is no *closed season* on the river at this point and the Government required that the lift span should be erected 120 ft. above the river, the normal clearance for the span when lifted. As it was not possible to drive any piling into the river bed because of the resulting obstruction to river traffic, the falsework had to be carried entirely on the piers and spread out from each of the latter in a fan shape upward to the panel points of the trusses, as represented in Fig. 10. There were no connecting struts between the two sets of falsework and the upper end of the leaning members of each set had therefore to be tied back to the towers with steel bars and plates.

29 To erect the span with 120 ft. vertical clearance would have meant that these top chords of the falsework must in each case be attached to the tower legs halfway between two of the horizontal struts of the bracing, and as this was not considered advisable

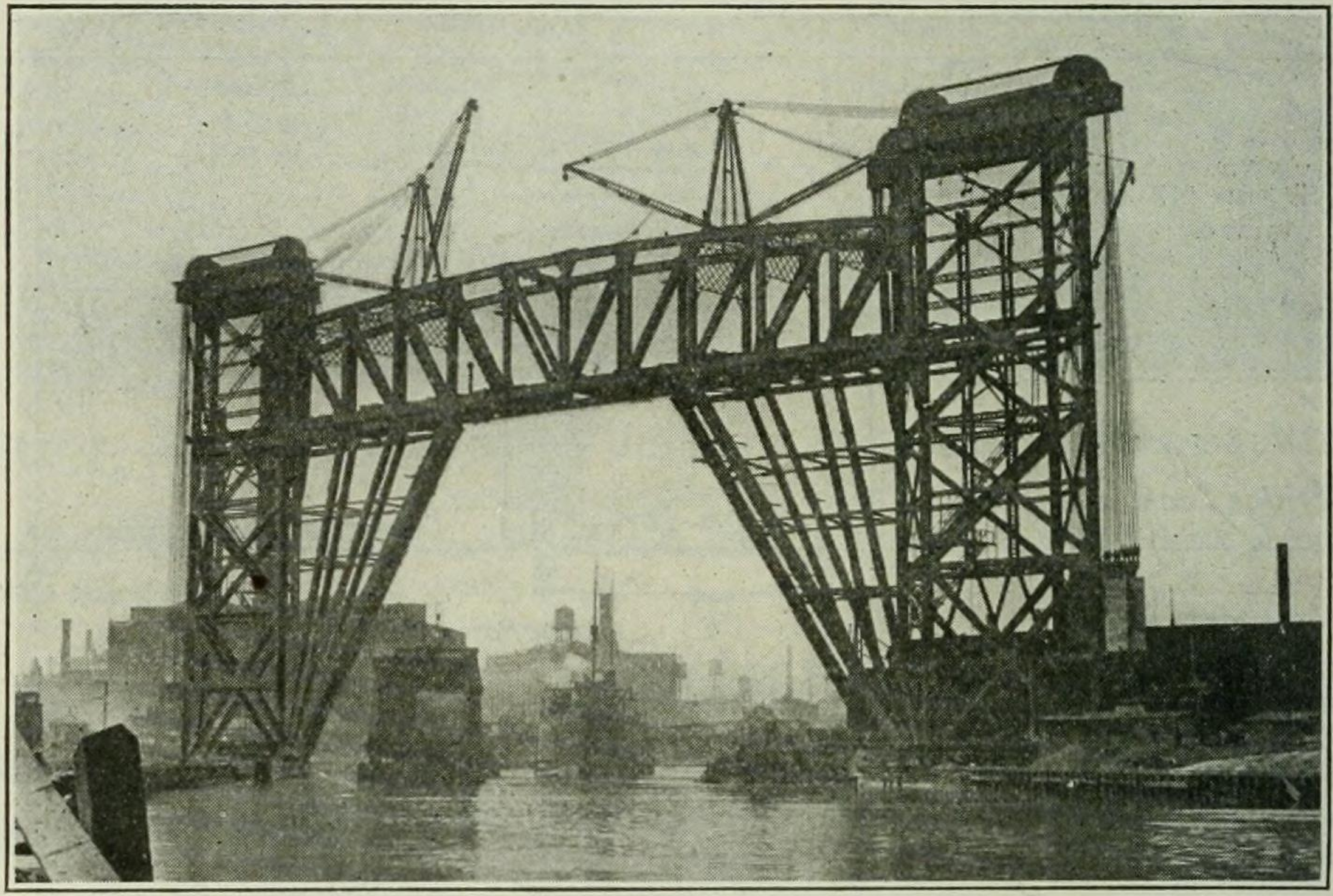

Fig. 10 Lift Span, Erected Position, Bridge No. 458, Pennsylvania Lines

The falsework is carried entirely on the piers and spread out from each of the latter in a fan shape upward to the panel points of the trusses.

because of the resulting bending in the tower legs, it was necessary to erect the span high enough to allow these chords to come in line with the next higher struts. This placed it at 130 ft. clearance instead of the 120 ft. required. All connections were made in holes from which the rivets had for the time being been omitted.

30 On account of the shape of the falsework the erection of this span upon it would have developed an uplift in the shoes of the far tower legs too great to be safely carried by the anchor bolts, and it was therefore decided to build the concrete counterweights in such a way that their weight would be carried into these shoes. This was done (see Fig. 11) by supporting the 800 tons of concrete

at each tower on girders which delivered the load to two inclined struts bearing on 6-in. pins carried in saddle castings riveted into the columns just above the bases.

31 There was nothing unusual in the erection of the towers, the derricks being stepped up from story to story according to practice common for similar structures. The heaviest pieces in them are the bottom sections or vertical legs next to the lift span which weigh 42 tons each. The four sheaves on the top of each

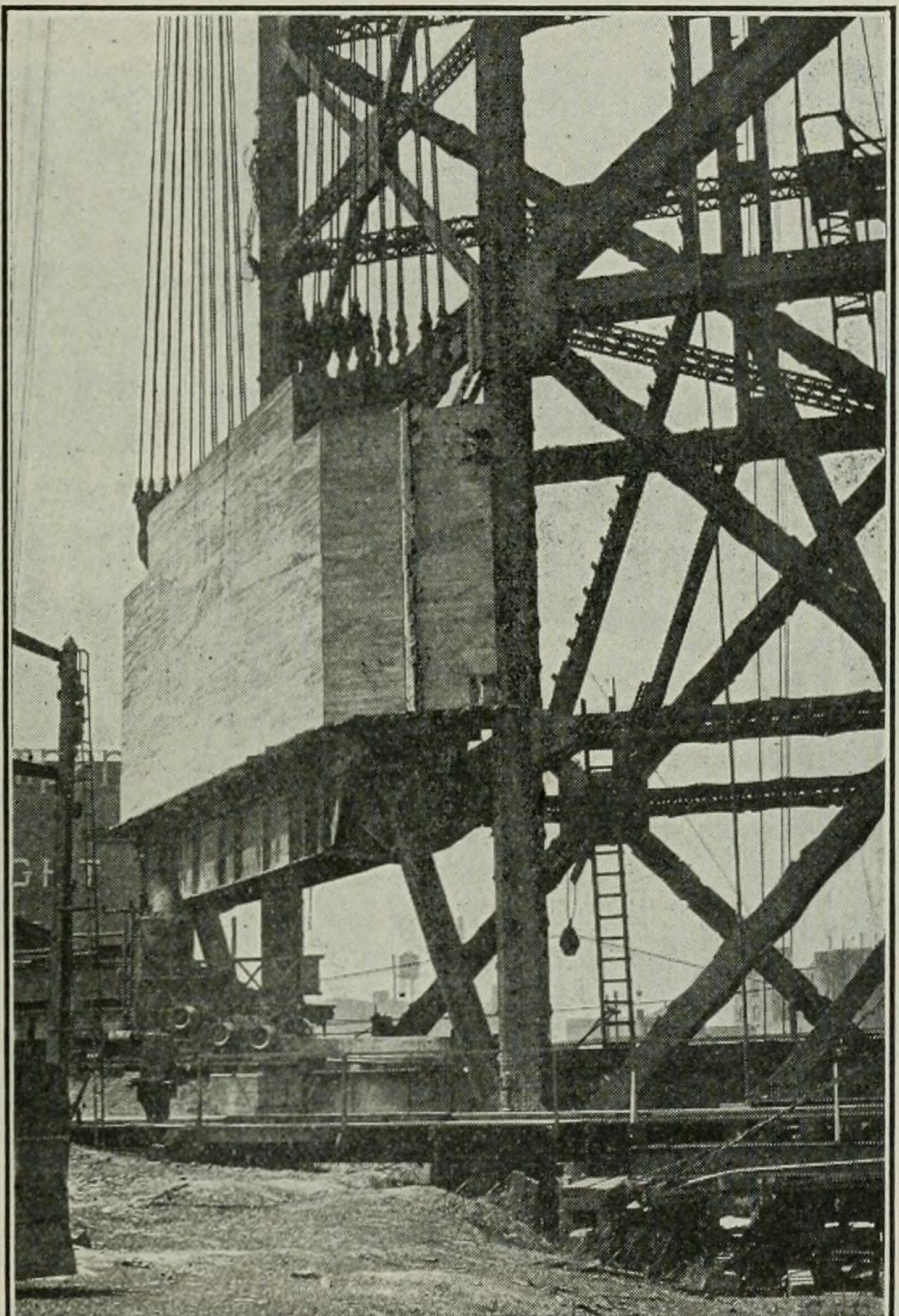

Fig. 11 Counterweight on Its Falsework, Bridge No. 458, Pennsylvania Lines

Eight hundred tons of concrete are supported on girders which deliver the load to two inclined struts bearing on 6-in. pins carried in saddle castings.

tower weigh 31 tons each and are the largest of their kind so far built. They are 15 ft. in pitch diameter and each pair carries sixteen $2\frac{1}{4}$-in. plow-steel ropes, each weighing with its sockets about 2000 lb.

32 The span erection was carried on with two A-frame derricks shown in Fig. 10, the work progressing on the two sides simultane-

ously. Only enough falsework to carry the end panel of the span was first set from the towers, and after the erection of these panels the derricks were moved from the towers to their first positions on the span, directly above the two sway frames nearest the ends. From here more falsework and more steel was erected and the derricks were again moved out. In Fig. 10 they are shown in their third and last positions as they stood to place the steel of the four center panels.

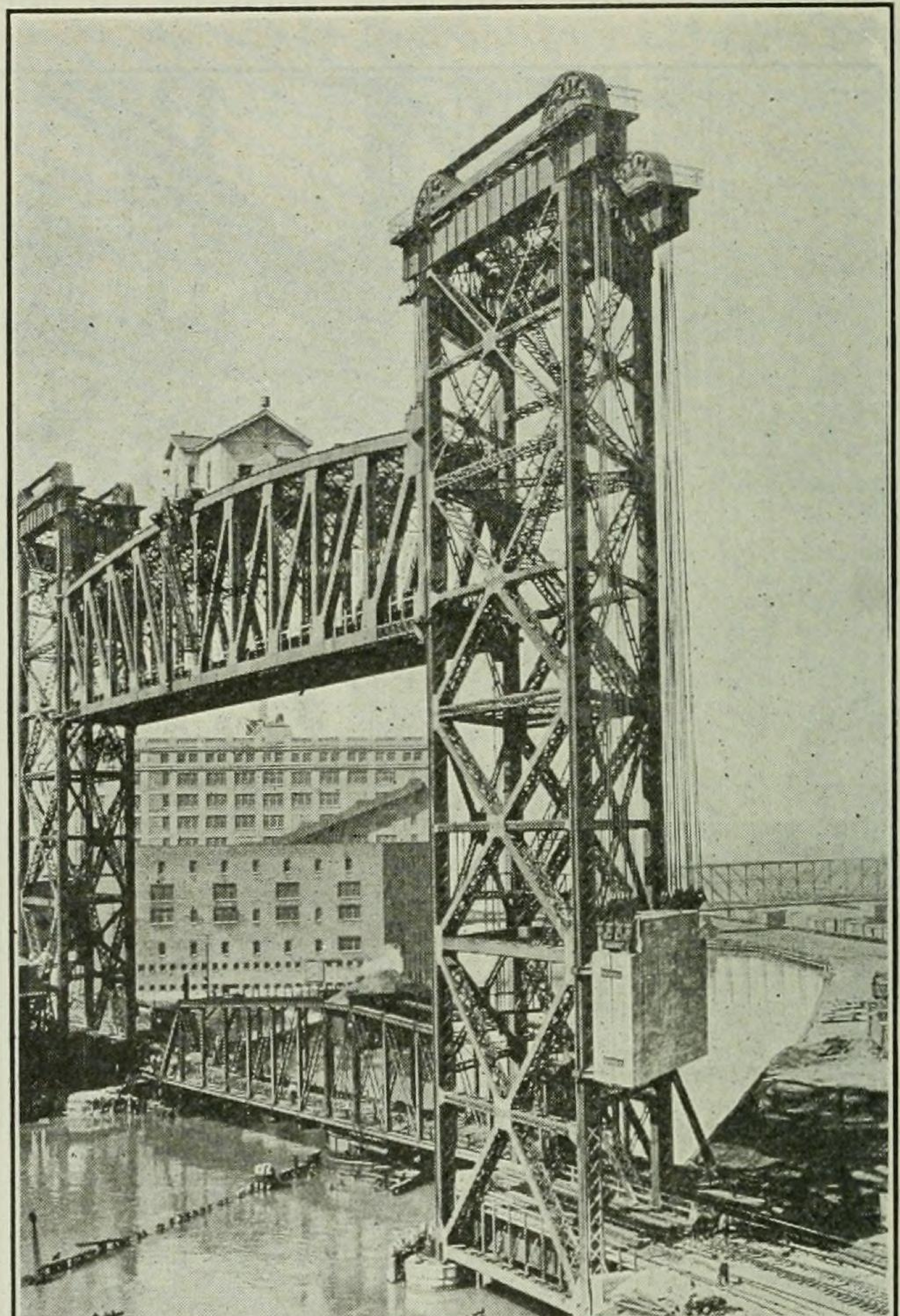

FIG. 12 BRIDGE NO. 458, PENNSYLVANIA LINES, AFTER REMOVAL OF FALSEWORK

The old swing span was kept in service until the upper structure was completed.

To regulate the temporary camber to suit the erection of the last pieces of top chord, four hydraulic jacks were set beneath the bottom chord, immediately above the ends of the last four members of the falsework. Because of the eccentric loading on the towers there was bound to be some deflection of each tower toward the river, but calculations and measurements had been so carefully made that the two center pieces of bottom chord, 73 ft. 6 in. in length and weighing 36 tons each, when lowered into place fitted so exactly that the erection bolts could be entered without the use of drift pins. To get the last pieces of top chord in it was necessary to use the jacks.

33 Fig. 12 shows the bridge after the removal of the falsework and while the old swing span was still in service. This latter was partly under the new bridge, both open and closed, and as more than 300 trains use this crossing every day it was very important to take great care that nothing should be dropped from the span 100 ft.

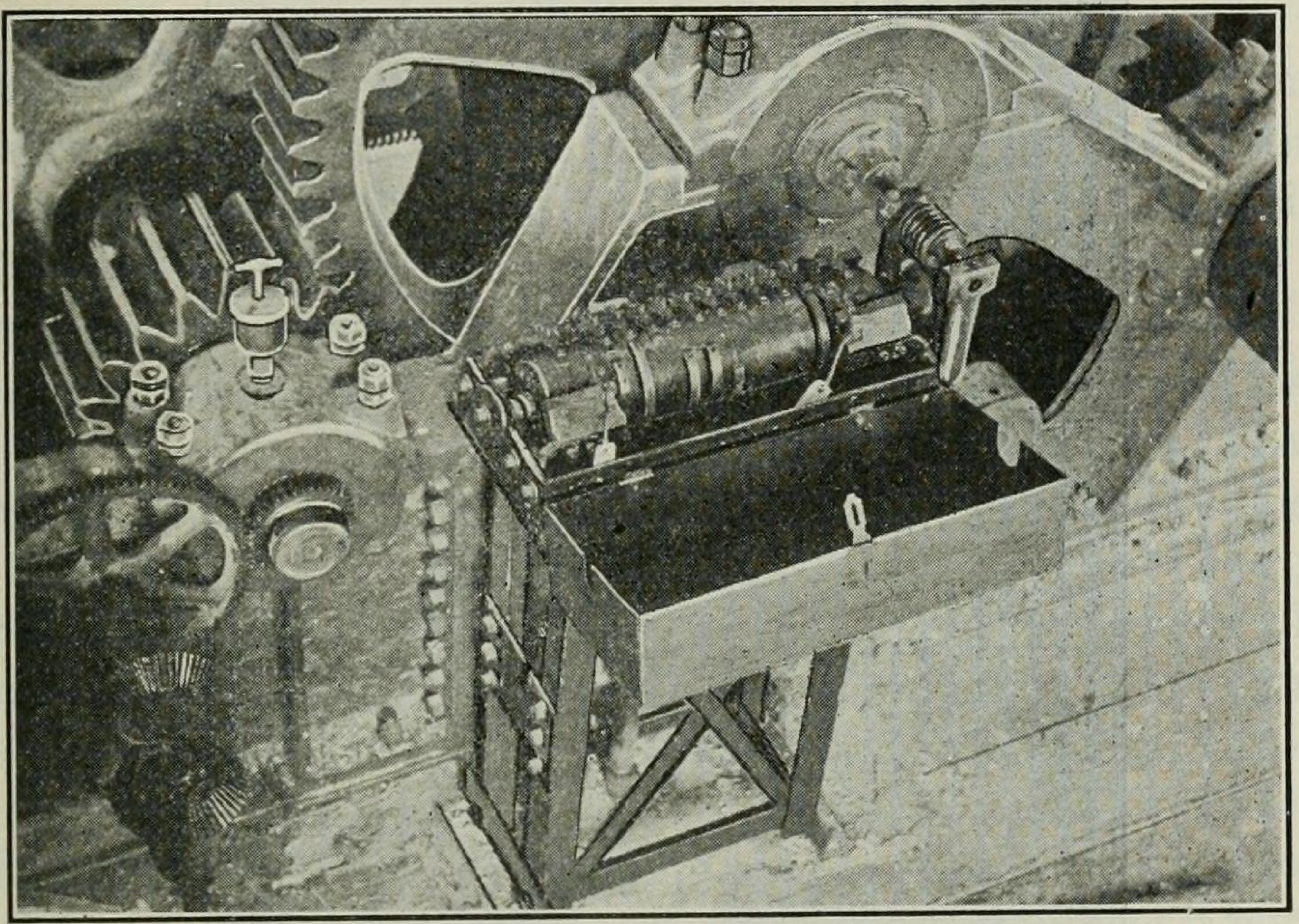

Fig. 13 Electrical Indicator and Limit Switch, Bridge No. 458, Pennsylvania Lines

This apparatus indicates by lights in the operator's house several points in the height traveled by the span, and cuts the controller circuit near each limit of travel.

above. It is a matter for which the erecting contractor deserves congratulation that no accidents from this source occurred.

34 The new span is 272 ft. 9½ in. long, lifts 112 ft., and weighs 1600 tons. At present it will be lifted at the rate of 15,000 times a year, for it lies near enough to the water to be in the way of every tug, but the great majority of these operations will require lifts of only a few feet. In a few years' time it is planned to raise the grade at this crossing, and the design of the bridge was carried out with this idea in view. Aside from raising the floor systems in the towers, lowering one story of tower bracings and raising the base castings of the lift-span shoes, no change in this bridge will be necessary to

accomplish this end. The span is operated by two 300-hp. series motors drawing their power from a 120-cell storage battery.

35 The electrical indicator and limit switch in Fig. 13 is connected to the drive by worm-gear reduction, indicates by lights in the operator's house several points in the height traveled by the span, and cuts the controller circuit near each limit of travel, thereby breaking the

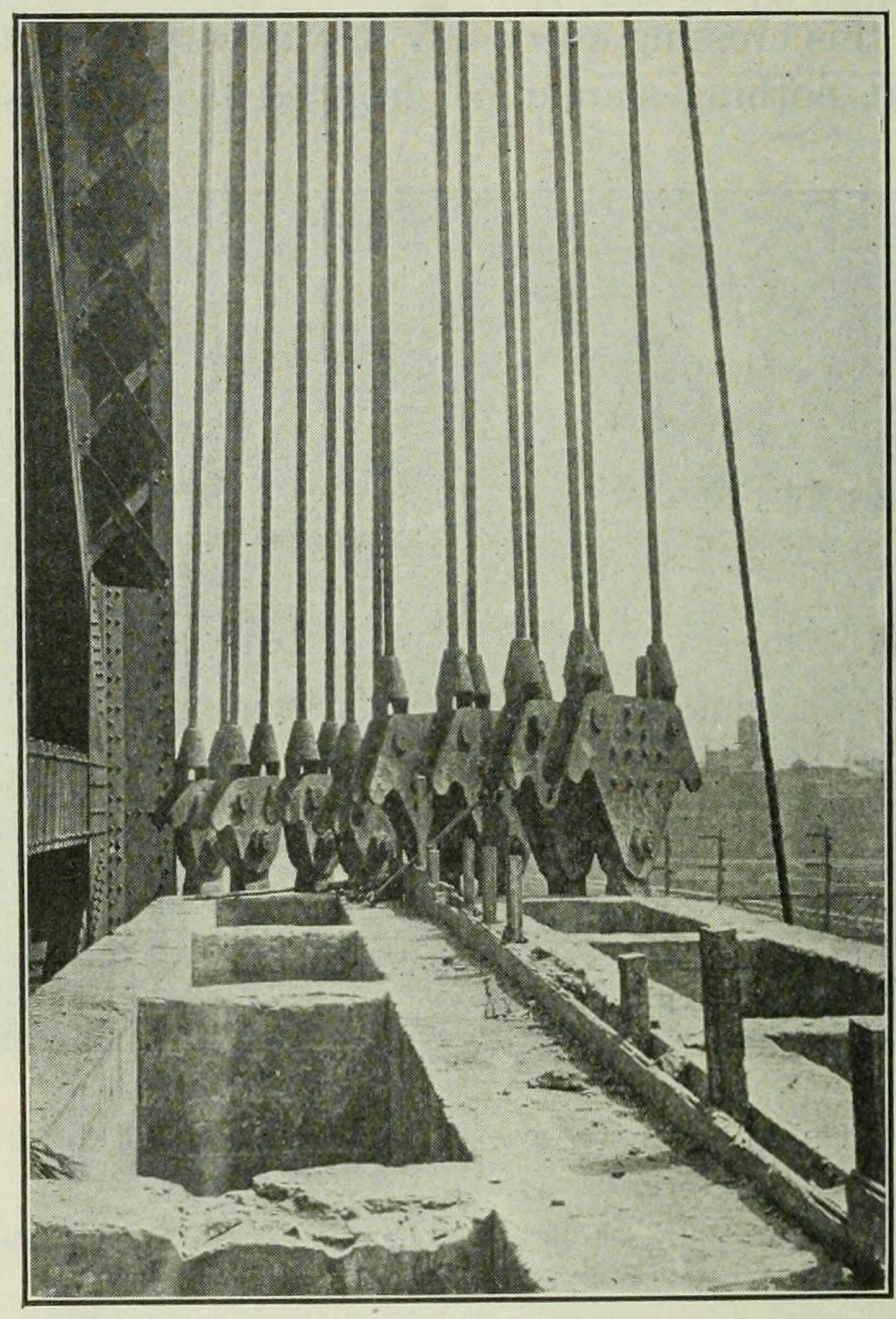

Fig. 14 Equalizer and Counterweight, Erected Position, Bridge No. 458, Pennsylvania Lines

When the span is lowered into place the parts of the equalizer become more closely packed together. An outer view of this equalizer is shown in Fig. 11.

main circuit, stopping the motors, and applying the solenoid brakes. Details of the equalizer and counterweight are shown in Fig. 14. Waddell & Harrington were the designers, represented in the field by the writer, and the Pennsylvania Steel Company were the contractors for fabrication and erection of superstructure.

DISCUSSION

J. A. L. Waddell [1] (written). Mr. Van Cleve's excellent paper has proved of special interest to the writer, who may justly claim to be the father of the modern vertical-lift bridge. His first design, made in 1892, was for a 250-ft. span at Duluth, Minn., to cross the canal which forms the entrance to the harbor of refuge for lake vessels in that vicinity. The War Department prevented the building of the structure, but in 1902 permitted at the same location the construction of a *transbordeur*.

Soon after the rejection of his plans for that proposed bridge, the writer was retained to design and supervise the construction of a similar but shorter-span bridge at South Halsted Street, Chicago, the first bridge mentioned in the paper. This structure was built under great difficulties and in spite of many discouragements. The Chicago engineers as a body were opposed to this type of bridge; and the then highest authority on bridges in America, the late George S. Morison, stated flatly that it could not possibly operate, and that it would be impracticable to raise the span off the piers. On the strength of this statement the City Engineer made all the arrangements for canceling the contract for the construction although some of the substructure had been completed and a large portion of the metal work had been manufactured. It took some very earnest pleading by the writer to persuade him to permit the work to proceed; and the said pleading would not have been successful had it not been for an important fact pointed out, viz., that the city of Chicago would have had to pay the full contract price for the structure whether it were built or not.

The specifications called for the lifting of the span to the full height (involving a raise of 140 ft.) in 60 sec.; and, much to the surprise of everybody, on the first trial the span went up in about half of that time. Afterward the writer timed the operation, both up and down, and found that the span could be moved over the full height in 28 sec. This was certainly a great triumph for a comparatively young engineer in a struggle with the local technical body, including the highest bridge authority in America.

Referring to the Keithsburg bridge which Mr. Van Cleve mentions, the heavy-duty, slow-speed gasoline engine used is clumsy,

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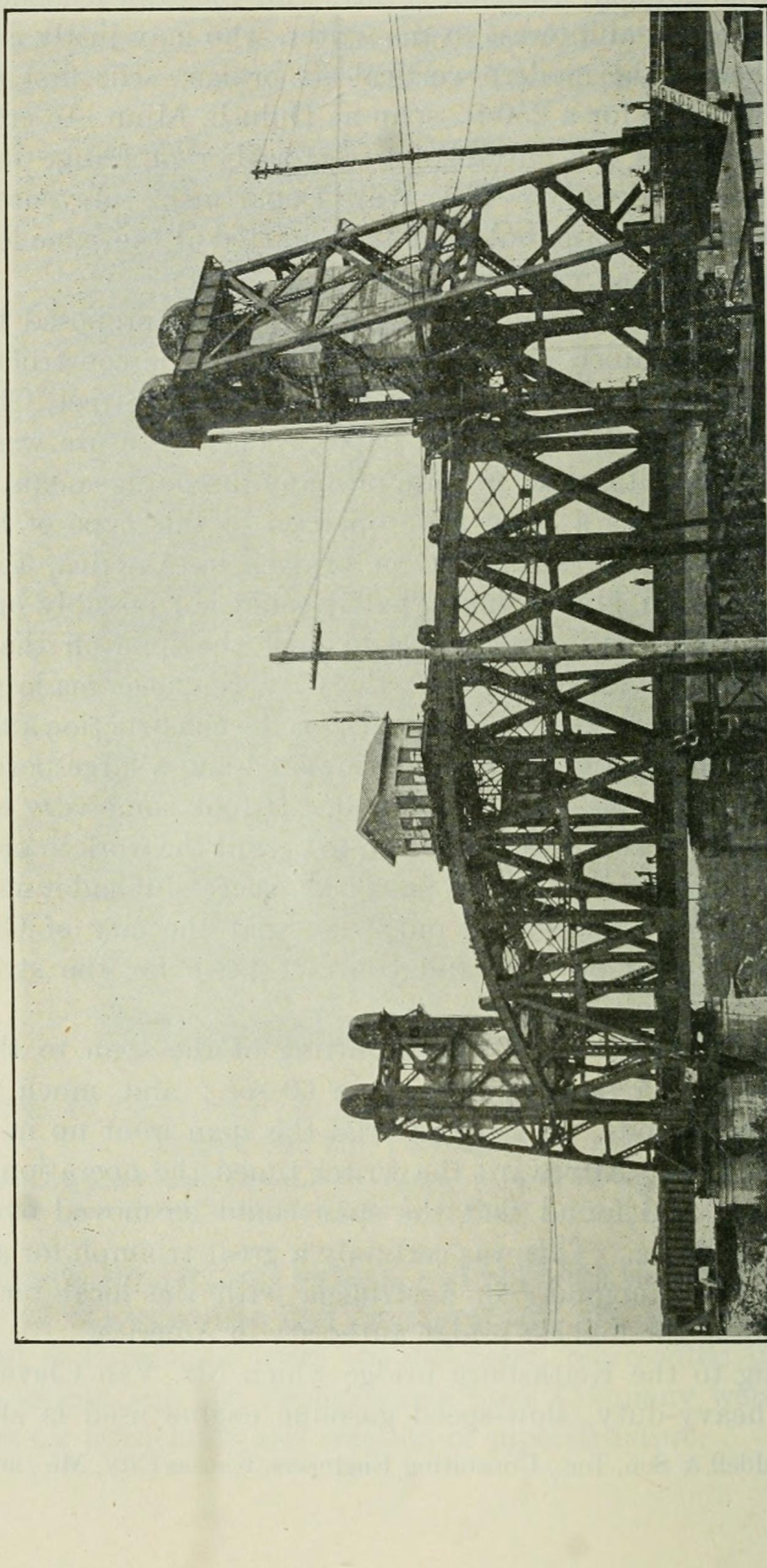

FIG. 15 DOUBLE-TRACK LIFT BRIDGE OF PENNSYLVANIA LINES AT LOUISVILLE, KY.

ponderous, and conducive to jar, although undoubtedly effective. It is quite certain that a light, high-speed type, such as the automobile or tractor engine, will prove more satisfactory for future lift bridges.

In truth, though, gasoline engines are to be used for lift bridges only as a last resort or as an auxiliary; because electric motors are far superior in every respect. Again, direct-current motors are much more satisfactory than alternating-current motors and, consequently, they should be used whenever an ample direct-current supply of power is obtainable.

Mr. Van Cleve mentions that the heaviest sheaves yet used for any vertical-lift bridge were those for Bridge No. 458 of the Pennsylvania Lines West of Pittsburgh, and that each sheave weighs 31 tons. Within the last few weeks there has been completed for the same railway company a vertical-lift bridge, designed by Waddell & Son, Inc., across the Louisville and Portland Canal that lies adjacent to the Ohio River at Louisville, Kentucky; and the sheaves for this structure weigh 38 tons each.

As this is the very latest thing in lift-bridge construction, the following description of the structure should prove of interest:

The double-track span, which is 260 ft. long between centers of end bearings, weighs about 3,000,000 lb., and is lifted 32.4 ft. in 45 sec. There are 64 counterweight ropes $2\frac{1}{8}$ in. in diameter, passing over the four 15-ft. sheaves. The motive power consists of two 150-hp., 220-volt, alternating current, 60-cycle, 580-r.p.m. motors equipped with solenoid brakes. Magnetic control is used. Speed reduction from the motors to the winding drums is made through a train of three sets of spur gears to a cross-shaft having a pinion at each end meshing with two drum gears.

The span is shown complete in Fig. 15. The operating drums which raise or lower the span are quite similar to those used in the Don River bridge in Russia. However, the detail of the cross-shaft has been improved by adding two bearings and two couplings, thus giving more rigid supports for the pinions and making the lengths of shaft between the center main frame and the drum frames truly flexible. This detail eliminates entirely any trouble from errors in the alignment of the three frames, which otherwise would cause considerable friction and loss of power. Hand operation is provided for by two 4-arm capstans.

There are 16 plow-steel operating ropes, each 1 in. in diameter, the drums and sheaves over which they run being 36 in. in diameter.

These ropes work in pairs, i.e., there are two up-haul and two down-haul ropes at each corner of the span. The take-up devices for the ropes are eyebolts threaded over the entire length, with anchorage attachments at top and bottom of towers.

The counterweight sheaves, the heaviest yet built, are constructed of steel plates, angles and castings. In their designing special care was taken to eliminate the troubles which had arisen in connection with the built-up sheaves described in Mr. Van Cleve's paper. Each rim segment is fastened to the side plates by a sufficient number of rivets to take the entire load coming upon it from the ropes; and $\frac{1}{2}$-in. spaces were left between the segments so that there might be no trouble if the lengths of the segments should overrun. It was originally intended to fill these spaces with hemp; but the cutting tools gave trouble when the machining of the grooves was begun; and it was found necessary to fill them with babbitt. The trouble previously experienced from bad fit of side plates on the hub casting was eliminated by making the said side plates bear directly on the shaft instead of on the hub casting. The hole for the shaft was bored out after the sheave was completely assembled and riveted. The journals are $22\frac{1}{2}$ in. in diameter and 24 in. long, the overall length of the shaft being 7 ft. 8 in. The hub is keyed to the shaft by three keys $1\frac{1}{2}$ in. wide and 1 in. deep, secured from longitudinal movement by set screws. The bearings are lined with phosphor-bronze bushings for high pressure and low speed. Oil grooves are cut into the bushings, the lubricant being supplied from marine-type, screw-feed, compression grease cups.

The rail locks are of sliding-tongue type, standard with the Pennsylvania Lines. The four tongues at each end of the span are driven by a 5-hp. motor. Limit switches are provided to cut off the current at each end of the travel. The controllers for the rail-lock motors are interlocked with the signal system so that the locks cannot be opened until the signals are set against train movements over the bridge, and so that clear signals for train operation cannot be given until the locks are closed. The controllers are also interlocked with those for the main operating motors so that current cannot be supplied to the latter until the locks have been opened, and so that the locks cannot be closed until the bridge has been seated.

The span is kept in correct position during motion by guide rollers, which roll on vertical guides on the outsides of the tower columns. There are eight rollers for transverse guiding, one at each L_0 point and one at each U_0 point. Longitudinal guiding is effected by two rollers at each L_0 point at the fixed end of the span. There is considerable play in the guides so as to eliminate any possibility of binding. On account of this play they do not center the span closely enough for the rail locks, which have very little play. For this reason there is placed a transverse centering casting, having very little play, at the middle of each end floor beam. In earlier designs a transverse centering casting was placed at each L_0 point; but considerable play had to be left in these castings to provide for expansion and contraction, and they did not center the span accurately enough for the rail locks.

The train thrust is cared for by two thrust castings, one at each L_0 point at the fixed end of the span.

In order to eliminate jar when the span seats, there are provided air buffers near each end of each of the end floor beams. Adjustable needle valves on the exhaust ports of the buffers enable the resistance of the said buffers to be varied at will.

Bridge locks were not used, but the counterweights were made about six tons lighter than the span, the excess weight of the latter overcoming any tendency for it to rise.

The span can be handled from the machinery house, which is located at the center thereof, or from an interlocking tower on shore about 100 ft. from the south end of the span. It is intended to operate the span from the machinery house until the operators become thoroughly familiar with the manipulation, after which it will be operated from the interlocking tower. Duplicate switchboards, with indicator lamps, meters, etc., are placed in each house. The main switchboards and the resistances are located in the machinery house.

As was stated previously, each motor is equipped with a solenoid brake. In addition there are two other brakes, one operated by hand and the other by motor. The lever of the hand brake is in the machinery house on the span, and gives the operator graduated braking power, so that he can stop the moving mass without jar. The controller of the motor-operated brake, which has three degrees of braking power, is located in the interlocking tower. These braking devices are not of great importance in a slow-moving bridge like this one; but for a high-speed bridge, which will coast for several feet after the current has been turned off, they are much more important.

The erection of the lift span was quite difficult, as traffic had to be maintained over the bridge and as navigation could not be interfered with. The old moving span was a swing. It was at first proposed to erect the new span in its fully lifted position. As the counterweights would then have to be built at the lowest point of their travel, it would have been necessary to leave large notches in them for the passage of trains. This scheme was abandoned for that and other reasons, and a new one was worked out. Permission was secured from the United States Government to leave only a 100-ft. channel near the north tower. This channel was spanned by a plate-girder lift span of the same type as the main span, worked by hand-operated crabs. After the main-lift-span towers were partly erected, navigation was stopped for a few hours while one end of the swing span was removed, the gallows frames for the plate-girder-span towers were erected, and the plate-girder span placed in position. The remainder of the swing span was then removed, the towers erected, the sheaves and ropes placed thereon, and the counterweights constructed on falsework resting on the piers and floor beams. The south portion of the lift span was then erected, also the north hangers; and the counterweight ropes were attached. The machinery was erected complete and thoroughly tested out. Navigation was then closed for a day, the plate-girder span removed, the remainder of the lift span erected and riveted, and the operating ropes connected up.

Special care was taken in the aligning of the main-sheave bearings. This was done by means of a steel straight-edge as long as the shaft. The bushings had been scraped to fit the shafts in the shop, the shafts and bushings being matchmarked. The aligning was so carefully done that when the sheaves were hoisted up they fitted perfectly in the bearings, and each 38-ton sheave could be rotated by one man. The machinery and motors were also aligned and tested out very carefully. The motors were run for several hours before the operating ropes were attached to the drums, in order to get the machinery into smooth-running condition and to determine if there were any poorly aligned bearings. Any hot bearings which developed were realigned. The machinery and the electrical equipment were in perfect operating condition before the operating ropes were attached to the drums and before the plate-girder swing span was removed.

Waddell & Son, Inc., have lately designed deflection bearings for main sheaves which insure a uniform pressure over the entire length of the journal. With the high bearing pressure used in the design of journals for lift-bridge sheaves and bascule trunnions this is extremely advisable. The use of this type of support greatly simplifies the problem of aligning the bearings.

One general fault of the electric equipment of movable bridges may be pointed out — that of using too small power lines. The overload capacity of the motors for vertical-lift bridges is called into play if a span becomes unbalanced, and, for bascules, when operating against a high wind; and this requires power lines of ample capacity. This point is not quite so serious in the case of direct-current motors, as the drop in voltage in the power line will merely cause the motors to run slower; but with alternating-current motors the drop in voltage reduces the torque materially, because the torque of such a motor varies as the square of the voltage. For instance, a 10 per cent drop in voltage means nearly a 20 per cent drop in torque. This point requires special attention when the power lines are long.

In spite of all the opposition which the vertical-lift type of movable bridge has encountered in the last quarter of a century (some of it being very bitter and most of it totally unfair), that type has come to stay; and it will be used more and more in the future, after railroad and city officials overcome their prejudice against the use of wire rope and learn that, for economy in first cost, simplicity of design, quickness of operation, rigidity under load, and economy in maintenance and repairs, it is unequaled by any other type yet evolved.

L. S. Randolph (written). A bridge of the type described in the paper comes in the category of a piece of machinery and the question which arises in the mind of the mechanical engineer is, What is the economic problem and how does this type of bridge compare with the rolling-lift bridge?

Of the three types of removable bridge, the ordinary drawbridge revolving about a central pier limits the horizontal element of the cross-section of the waterway so that a vessel which can pass along the river cannot necessarily go through the bridge. The rolling-lift bridge limits neither horizontal nor vertical dimensions of the fairway. The vertical-lift bridge limits the vertical dimension.

While it may be answered that it is inconceivable that ships should develop to such an extent as to be inconvenienced by a height of 120 ft., such reasoning has too often been found fallacious.

It would add the final perfecting touch to a most excellent paper if the author would demonstrate why this method of removing the bridge for passage of vessels is economically better than either of the other two mentioned.

THE AUTHOR. I have been much interested to read Dr. Waddell's comments on my paper, and also to learn something of the details of the Louisville lift bridge, the only one so far constructed with which I am unfamiliar.

The guiding, centering, and interlocking details described have all been used on previous bridges, but the operation of the span from a point on shore a distance as great as 100 ft. from one end of it, is new and deserves some comment.

To me this feature seems objectionable, mainly because it would put the operator somewhat out of touch with the requirements of passing boats, but also because it would prevent that vital contact with the movement of the span which goes a long way toward preventing careless operation. I have been present during operation on ten lift spans of this type, sometimes as operator, and sometimes as observer, and feel that the presence of the operator on the span is, while not absolutely necessary, at least very desirable; and that if it seemed best to have one man operate both the track signals and the lift span, it would be better to place the signal stand on the lift span than the span master controller in the signal tower. This alternative may have been considered in the case under discussion and found impossible, but it was done very satisfactorily in the case of the C. & N. W. Ry. bridge over the Illinois River at Pekin, Ill. In this installation all track switches and signals are thrown electrically, but this is not necessarily the case, as demonstrated by the fact that at least one of the lift spans now in operation carries on its deck some twenty lines of pipe of the signal system which automatically unjoint at both ends of the span when the latter is lifted.