Transactions of the American Society of Civil Engineers

American Society of Civil Engineers

TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. XXXIII.

JANUARY TO JUNE, 1895.

NEW YORK:
PUBLISHED BY THE SOCIETY.

1895.

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THE HALSTED STREET LIFT-BRIDGE.

By J. A. L. WADDELL, M. Am. Soc. C. E.

READ NOVEMBER 7TH, 1894.

WITH DISCUSSION.

History.—For a number of years there was a rotating combination draw bridge over the South Branch of the Chicago River at Halsted Street, but on June 30th, 1892, a vessel ran into it and knocked it down. When the city attempted to rebuild it, the lake navigation interests objected to having another rotating draw span at this crossing, on the plea that the pivot pier of the old bridge was always a serious obstruction to navigation; and they used such influence with the War Department that the city was restrained from building the structure as contemplated. The Commissioner of Public Works of Chicago at that time was the Hon. J. Frank Aldrich, who a few months later was elected to Congress. Mr. Aldrich was placed in a rather awkward predicament, for, on the one hand, the people of the district in the neighborhood of the Halsted Street crossing—which, by the way, is one of the greatest thoroughfares of the city—were clamoring for a bridge; and, on the other hand, the United States Engineer Corps would not permit him to build any structure which would narrow the water-way to any such extent as would a rotating draw span.

The folding bridge or "jack-knife draw" design, one of which pattern was then under construction at another crossing of the Chicago River, was advocated by certain parties; but Mr. Aldrich, who is himself, or, perhaps, more strictly speaking, was, a civil engineer, did not consider this type of bridge sufficiently rigid for the long span and for the heavy traffic.

After making a thorough study of the problem, Mr. Aldrich decided upon building a lift-bridge similar to the one designed previously by the writer for the proposed crossing of the ship canal at Duluth; and after considerable delay, permission was obtained from the War Department to build the structure, with the proviso, however, that the clear headway be increased from 140 to 155 ft. above mean low water.

Before the demand for extra clear height was made, bids had been asked for, and the contract had been awarded provisionally, on schedule prices for materials in place, to the Pittsburgh Bridge Company (W. W. Curtis, M. Am. Soc. C. E., Engineer), with the Hale Elevator Company of Chicago as subcontractors for the machinery, which latter company afterwards transferred its contract to the Crane Elevator Company of the same city. But it was not until the beginning of 1893 that the contract for building the bridge was finally signed, sealed and delivered. Even then the tribulations of those interested in the enterprise were not at an end, for the letting of the contract was irregular, in that there was no money in the City Treasury to pay for the bridge; so, according to the usual custom for such conditions, reliance was placed on the Finance Committee and Board of Aldermen voting, later on, the necessary funds. Under ordinary circumstances this irregularity would have done no harm; but in this case it was otherwise, because it gave each Alderman and each city official an opportunity to tie up the work if he so desired, by alleging that the scheme was impracticable and that the bridge could not possibly work successfully. Continual worry was experienced on this account, and it is fair to say that to this circumstance is mainly due the great delay in completing the contract, which required fifteen months, instead of the six months allowed. In fact, it was at one time doubtful whether the subcontractors for the machinery would ever finish their work because they debated seriously whether it would not be better to lose about $15 000, which they had already put in, rather than risk completing the contract and never receiving a dollar in pay-

PLATE I.
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WADDELL ON HALSTED STREET LIFT-BRIDGE.

ment. This difficulty, however, was tided over by Mr. Curtis, who gave to his subcontractors such satisfactory assurances that they would be paid eventually that they decided to proceed with their work.

Another main cause of difficulty and delay was the continual changing of city officials, for in the two years during which this bridge subject was on the *tapis* there were three changes of administration, involving the election or appointment of three Mayors, three Commissioners of Public Works, and three City Engineers, to say nothing of minor officials.

General Description.—The location of this bridge is a very awkward one, for not only does Halsted Street cross the river on a skew of 10½°, but there is an offset in it of 41½ ft. just at the crossing. This combination involves a skew of 22½° for the structure in respect to the channel. By setting the main and rear piers on lines at right angles to the central plane of structure, the effect of the skew was taken out of the bridge and carried to the machinery house and the street retaining walls.

As shown on Plates I, II, the bridge consists of a single Pratt truss, through span of 130 ft., in seven equal panels, and having a truss depth of 23 ft. between centers of chord pins, so supported and constructed as to permit of being lifted vertically to a height of 155 ft. clear above mean low water. At its lowest position the clearance is about 15 ft., which is sufficient for the passage of tugs when their smokestacks are lowered. The span differs from ordinary bridges only in having provisions for attaching the sustaining and hoisting cables, guide rollers, etc., and in the inclination of the end posts, which are battered slightly, so as to bring their upper ends at the proper distance from the tower columns, and their lower ends in the required positions on the piers.

At each side of the river is a strong, thoroughly braced, steel tower, about 217 ft. high from the water to the top of the housing, exclusive of the flag poles, carrying at its top four built-up steel and cast-iron sheaves, 12 ft. in diameter, which turn on 12-in. axles. Over these sheaves pass the 1½-in. steel wire ropes (32 in all) which sustain the span. These ropes are double, *i. e.*, two of them are brought together where the span is suspended, and the ends are fastened by clamps, as shown in Fig. 1; while, where they attach to the counterweights, castings and attaching oil cups thereto. This matter was overlooked in making the design. In case the main piers had not gone down to rock, the omission might have given trouble; but, as it is, it could not have done so.

Each tower consists of two vertical legs against which the roller guides on the trusses bear, and two inclined rear legs. These legs are thoroughly braced together on all four faces of the tower; and at each tier thereof there is a system of horizontal sway bracing, which will prevent most effectively every tendency to distort the tower by torsion.

At the tops of the towers there are four hydraulic buffers that are capable of bringing the span to rest without jar from its greatest velocity, which was assumed to be 4 ft. per second; and there are four more of these buffers attached beneath the span, one at each corner, to serve the same purpose.

The span, with all that it carries, weighs about 290 tons, and the counterweights weigh, as nearly as may be, the same. As the cables and their counterbalancing chains weigh fully 20 tons, the total weight of the moving mass is almost exactly 600 tons.

Should the span and counterweights become out of balance on account of a greater or less amount of moisture, snow, dirt, etc., in and on the pavement and sidewalks, it can be adjusted by letting water into and out of ballast tanks located beneath the floor; and should this adjustment be insufficient, provision is made for adding small weights to the counterweights, or for placing such weights on the span.

As the counterweights thus balance the weight of the span, all the work which the machinery has to do is to overcome the friction, bend the wire ropes, and raise or lower any small unbalanced load that there may be. It has been designed, however, to lift a considerable load of passengers in case of necessity, although the structure is not intended for this purpose, and should never be so used to any great extent.

The span is steadied while in motion by rollers at the tops and bottoms of the trusses, as shown on Plate II. There are both transverse and longitudinal rollers, the former not touching the columns, unless there is sufficient wind pressure to bring them to a bearing. The longitudinal rollers, though, are attached to springs, which press them against the columns at all times, and take up the expansion and contraction of the trusses. With the rollers removed, the bridge swings

PLATE II.
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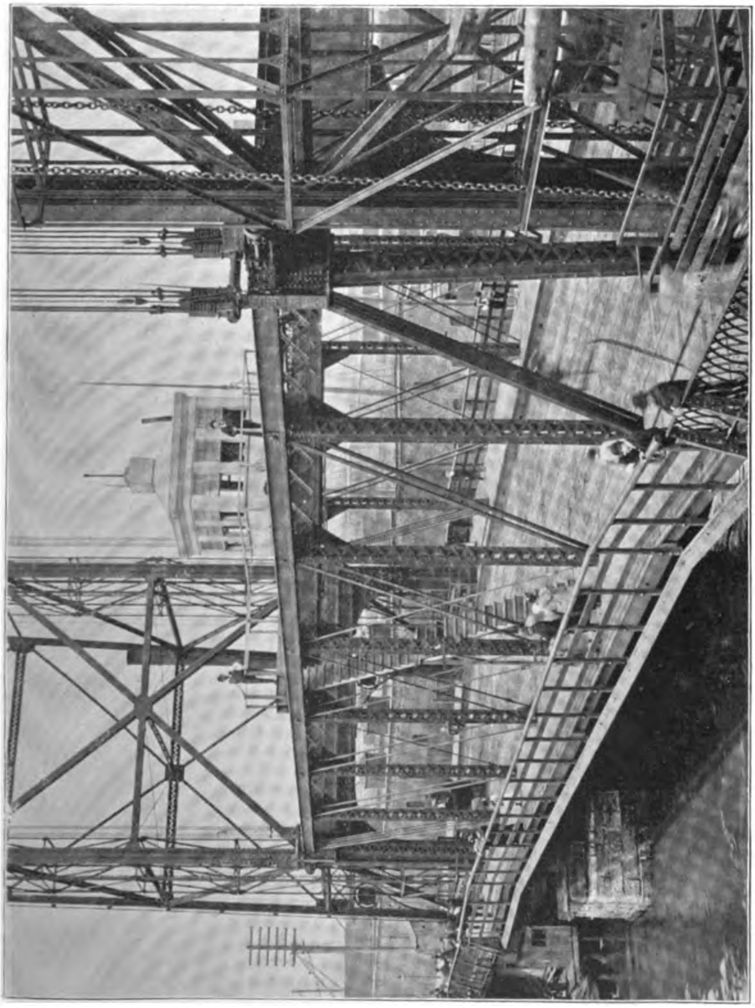


free of the columns; and, since the attachments are purposely made weak, the result of a vessel's striking the bridge with its hull will be to tear them away and swing the span to one side. Should the rigging of the vessel, however, strike the span, the effect will be simply to break off the masts without injury to the bridge. This latter accident has happened once already, the result being exactly what the writer had predicted. There is a special apparatus, consisting of a heavy square timber set on edge, trimmed on the rear to fit into a steel channel which rivets to the cantilever brackets of the sidewalk, and faced with a 6 x 6-in. heavy angle iron, to act as a cutting edge. This detail, which is a very effective one for destroying the masts and rigging of colliding vessels, is shown in the photograph of the structure reproduced on Plate II. The adoption of a wooden handrail on the span, while a steel one is used on the rest of the bridge, is a wise precaution against expense caused by collisions. The wooden rail is easily replaced by any carpenter, and is quite cheap; while the steel rail, if broken or bent, as it is liable to be, would be not only costly, but also difficult to match in replacing, and comparatively expensive to repair. Of course, the wooden rail is not quite so sightly as the metal one. The writer had contemplated using the latter over the entire structure, and conceded the change to a wooden rail with some reluctance, but is now convinced that it is the proper thing for the place. This wooden rail and the exterior guard are standard devices of the City Engineer's office of Chicago.

The bridge is designed to carry a double-track street railway, vehicles and foot passengers, as can be seen by the photographic view shown on Plate II. It has a clear roadway of 34 ft. between the counterweight guides in the towers, the narrowest part of the structure, and two cantilevered sidewalks, each 7 ft. in the clear, the distance between central planes of trusses being 40 ft., and the extreme width of suspended span 57 ft., except at the end panels, where it is increased gradually to 63 ft. The roadway, as shown in Fig. 2, is covered with a wooden block pavement 34 ft. wide between guard rails resting on a 4-in. pine floor that in turn is supported by wooden shims, which are bolted to 15-in. I-beam stringers spaced about 3 ft. 3 ins. from center to center. These stringers rivet up to the webs of the floor beams; and beneath them run diagonal angles, which rivet to the bottom flange of each stringer, and thus form a very efficient lower lateral system. The sidewalks are covered with 2-in. pine planks, resting on 3 x 12-in. pine joists spaced about 2 ft. from center to center.

The span is suspended at each of the four upper corners of the

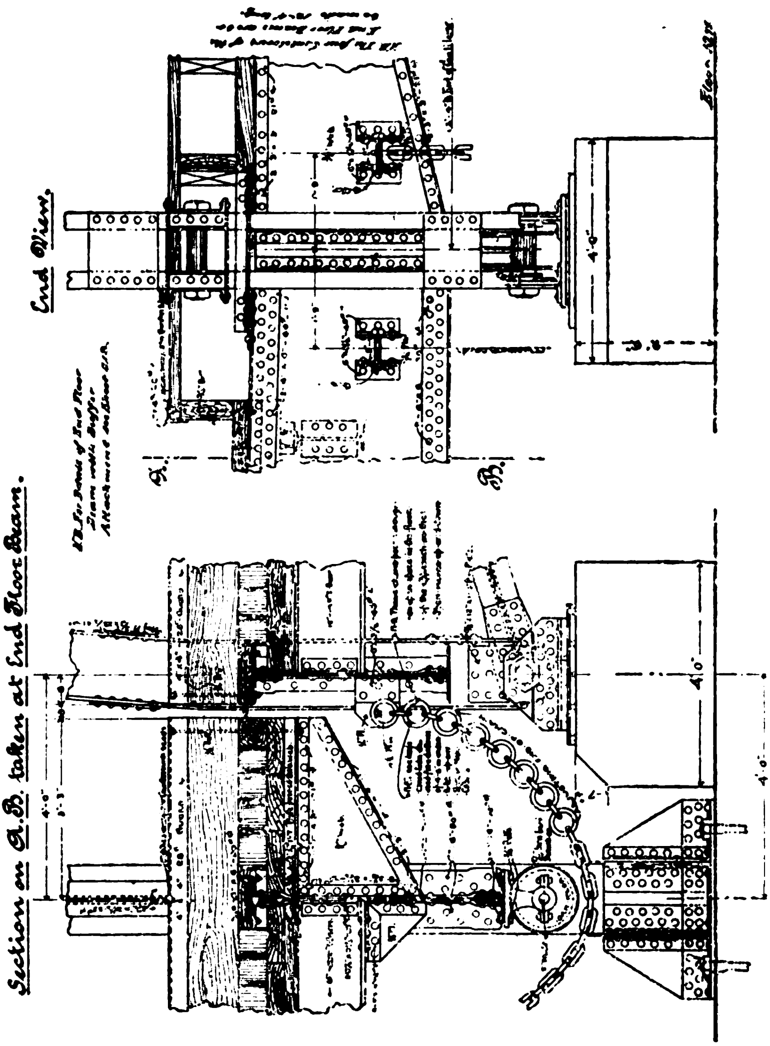


FIG 2.

trusses by eight steel cables, which take hold of a pin by means of cast-steel clamps. This pin passes through two hanger plates, which project above the truss, and are riveted very effectively to the end

SECTION AND PART ELEVATION OF BUFFER.

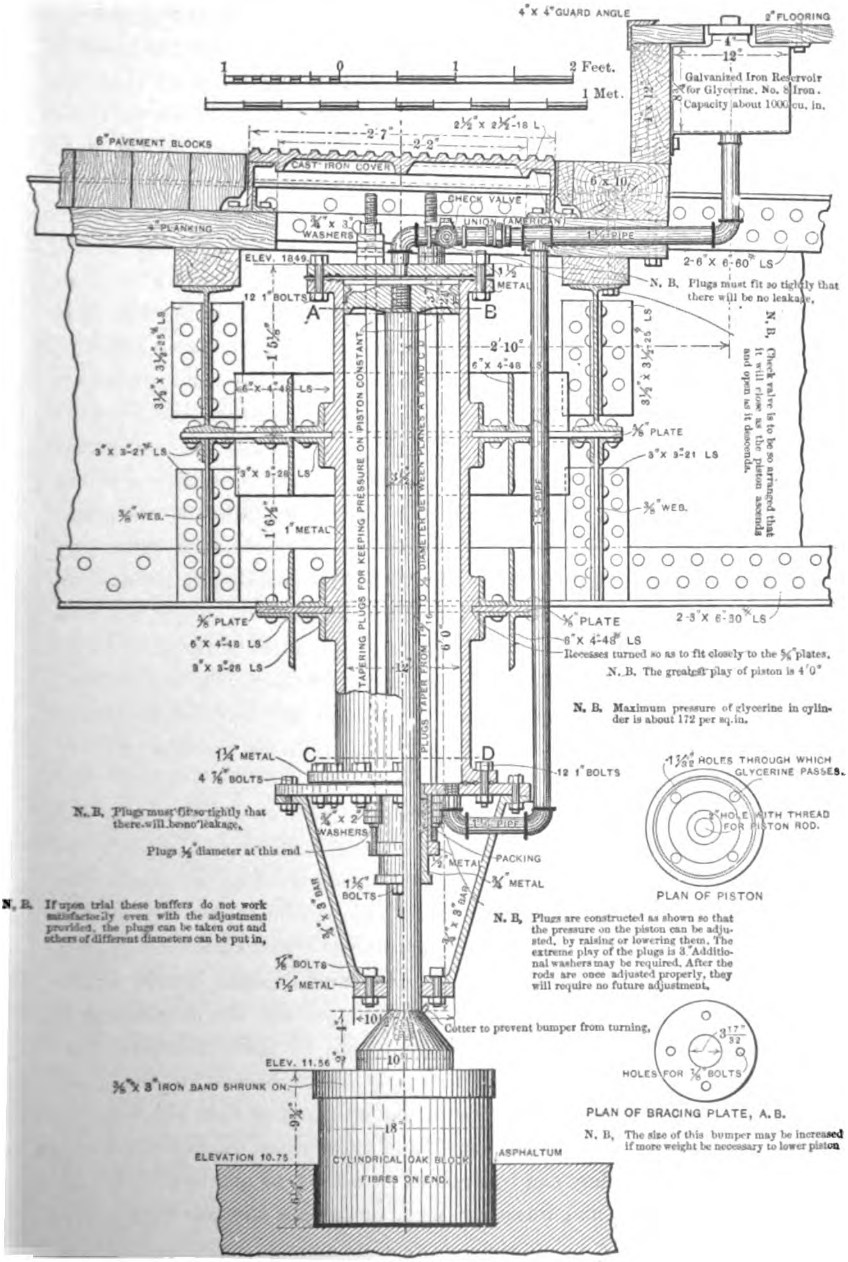


FIG. 3.

post by means of the portal plate girder strut on the inside and a special short cantilever girder on the outside, as shown in Fig. 1.

Each portal girder carries near each end an iron-bound oak block to take up the blow from the hydraulic buffer, which hangs from the overhead girder between towers. Similar oak blocks are let into and project from the copings of the main piers, as shown in Fig. 3, to take up the blow from the hydraulic buffers that are attached to the span.

The ballast tanks before alluded to, of which there are four in all, are built of steel plates properly stiffened, and have a capacity of about 19 000 lbs., which is probably more than enough to set the bridge in motion if it were all an unbalanced load. These tanks serve a double purpose, the first being simply to balance the bridge when it gets out of adjustment because of the varying load of moisture, etc., on the span, and the second being to provide a quick and efficient means of raising and lowering the span in case of a total breakdown of the machinery. If, for instance, which is highly improbable, the operating ropes were broken and had to be detached from their drums, by emptying all of the water out of the tanks, the span could be made to rise. It could be lowered again by filling them from a reservoir which is placed on top of one of the towers and kept filled with water at all times by means of a pump in the machinery house. The water in all of these tanks can be kept from freezing, or the ice therein can be thawed at any time by turning on steam from the machinery room into the coils of pipe which they contain.

Although the necessity for using the tanks for operating the bridge will probably never arise, nevertheless some experiments ought to be made, to ascertain what weight of water is required to unbalance the bridge sufficiently to put it in motion. In operating the bridge by the water ballast it would be necessary to take the precaution to place a simple, temporary friction brake of some kind at each corner of the span to press against the column, and thus prevent the attainment of too great a velocity. A stick of timber could be made to answer this purpose. It would do as well to apply these brakes to the main sheaves. All four tanks are connected by pipes so that the water in them can be kept at the same level; and these pipes are provided with stop cocks so that they can be drained in winter, to prevent their contents from freezing and bursting them, or so that any one tank can be emptied without discharging the others. Should the water in the tanks freeze, it would do no harm, because the sides thereof are battered. Access is had to the tanks by means of manholes through the paved floor, which holes are covered with cast-iron plates, properly ribbed, to give good foothold for horses.

On the floor at the entrances to the towers and at the corners of the counterweight guides are placed curved cast-iron bumpers, to protect the rear columns and the said guides from being injured by passing vehicles.

The lower ends of the counterweight frames are fenced in with wire netting, to prevent persons from injury by the descending counterweights.

It would be well to adopt automatic gates at each end of the bridge to shut off traffic from both roadway and footwalks when the bridge is being operated or just about to be. As such devices are not employed on the other Chicago bridges, at least not to any great extent, the writer did not provide for them in his design, preferring to leave the matter to the City Engineer's office. At present, traffic is stopped by a policeman, who stretches a rope across the roadway in the north tower; but there is nothing to prevent foot passengers from crowding out to the open ends of the footwalks, where there exists the double danger of falling into the river and being struck by the descending span, in case one lets his head project over the open end of the walk.

As shown on Plate I, the main sheaves at tops of towers are covered by small houses built in a somewhat decorative style, and finished with flag poles. The operating house on top of the span, shown on Plate II, is also slightly decorated. It is 10 ft. square on the inside, and is surrounded by a footwalk and a suitable hand-railing. When the span rises to its full height, this house passes through an opening in the bracing of the overhead struts that extend from tower to tower. The operating house contains only the signaling apparatus and the peeper, so affords plenty of room for the operator or watchman. It has windows all around so as to permit him to see in every direction.

The peeper referred to is an apparatus to enable the operator to determine when the span has risen sufficiently high to clear the masts of an approaching vessel. As the device is covered by a patent, the contract for designing and building it was let for a fixed sum to the patentee, who has failed thus far to provide lenses of sufficient power, consequently his work has not been accepted, and will not be, probably, until he makes the apparatus work satisfactorily. Meanwhile the operator, as a matter of precaution, has to raise the span at every passage somewhat higher than he would raise it, were the peeper in operation. This is no hardship though, because the span is raised and lowered so quickly. The best time made thus far for raising through the entire height is 34 seconds, which gives a velocity a little in excess of 4 ft. per second, or the speed for which the buffers were designed.

The operating machinery is located in a room 37 x 53 ft., the opposite sides being parallel, but the adjacent sides being oblique to each other, the obliquity amounting to about 12°. The placing of this machinery beneath the street was really forced upon the writer, who had originally contemplated using electrical machinery and putting it in a house in one of the towers. As the engineer for the machinery contractor insisted upon using steam machinery, the writer deemed it unsafe to place it in the tower, owing to the injurious vibrations which might be set up; hence the expensive and rather unsatisfactory construction adopted for the house, which rests upon a timber grillage supported on piles and carrying 4 ft. of concrete as a floor. As the level of this floor is about midway between high and low water, the reason for using so much concrete becomes apparent when one considers the buoyant effort which the water is capable of exerting. Although the writer insisted that the side walls of the room should be caulked and made water-tight, this has not yet been done, so if in the future the machinery house be flooded, the writer must not be blamed. The timber grillage is drift-bolted to the piles by bolts, which were put down through gas pipes driven into the top timbers to serve as small coffer-dams, and thus prevent the water from rising into the concrete. These pipes do not extend up to the surface of the floor, so when the latter was finished off, they were filled with grouting.

The retaining walls are built of monolithic concrete, resting on a timber grillage supported on piles, as in the case of the machinery house. These walls are tied back by heavy adjustable wrought-iron rods passing through dead-men placed some 40 ft. in the rear of the face of the wall. This construction was rendered necessary by the tendency of all retaining walls along the Chicago River to pitch forward and crack. There is a clear space of 1 ft. between the rear outer face of the machinery house and the front face of the retaining wall, so that in case of the wall slipping forward a trifle in spite of all precautions, the machinery house will not be disturbed.

At the north end of the bridge the rear columns of the towers rest on the floor of the machinery house, but at the south end they rest on solitary masonry piers, 8 ft. square under coping, and battered on all four faces. The masonry of each of these piers rests upon a timber grillage, supported by 16 piles driven to bedrock.

As for the main piers, as originally designed, there were to be two of them of masonry, resting on timber grillages supported on piles driven to the bedrock, which was supposed to be 38 ft. below the city datum, and to be overlaid with a stiff clay, capable of holding the piles in position. Although the writer asked on several occasions that borings be made to determine the exact depth of bedrock and the character of the overlying material, his request was refused. Afterwards, under a new administration, when borings were made, they showed the rock to be some 9 or 10 ft. nearer the surface, and that the overlying material consists principally of a semi-liquid clay incapable of retaining piles in place laterally. It is undoubtedly this condition of affairs which causes many of the river retaining walls to pitch forward and crack.

After considerable discussion, the writer gained his point and changed the style of the main piers fundamentally by substituting for each of them two solitary masonry piers, 12½ x 13 ft., under coping with battered sides, resting on a timber and concrete caisson sunk by the pneumatic process to bedrock. Naturally, these pneumatic piers were somewhat more expensive than they would have been had they been let with the rest of the work in competition. However, when everything is duly considered, the contractor was not greatly overpaid for this portion of the work.

The stone used for the piers is Cleveland sandstone, which, although not quite as good as the Kettle River sandstone called for in the specifications, is a very satisfactory material, as has been proven by its actual use in Chicago during many years.

The arrangement of the operating machinery is shown on Plate III and Fig. 4.

Two 70 H. P. steam engines communicate power to an 8-in. horizontal shaft, carrying two 6-ft. spiral-grooved cast-iron drums, around which the ⅞-in. steel wire operating cables pass. As one of the lifting ropes passes off the drum, the corresponding lowering rope takes its place, and *vice versa*, the extreme horizontal travel being a little less than 12 ins. Thus by turning the drums in one direction the span is raised, and by turning them in the other direction the counterweights are raised, and the span consequently is lowered. When the span is at its lowest position, the full power of one engine can be turned on to

PLAN OF ENGINE ROOM.

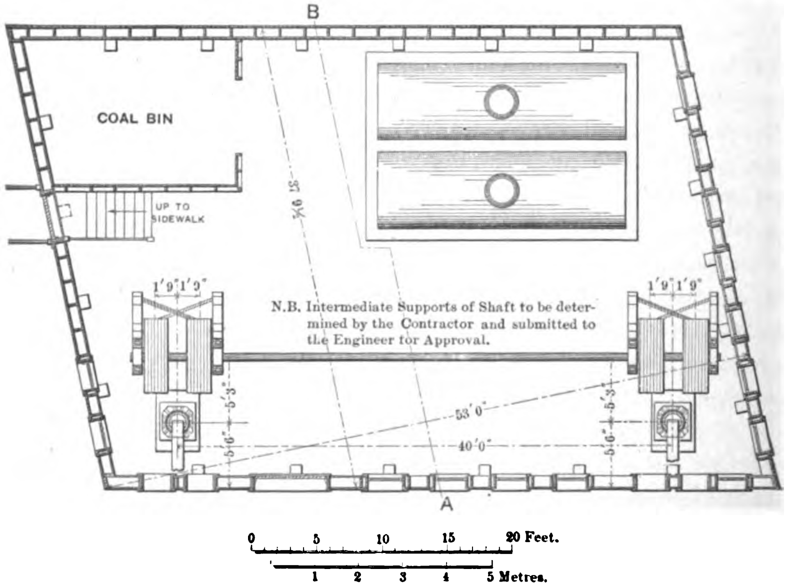


FIG. 4.

pull up on the counterweights, thus throwing some dead load on the pedestals of the span, after which the drums can be locked. Before the bridge was completed, the writer considered that this would be necessary, in order to check vibration from rapidly passing vehicles; but such has not proved to be the case, for the span is very rigid, and the amount of the vibration is not worth mentioning. It is possible, though, that in some other lift-bridges, where the ratio of live load to dead load is greater, this feature of operation cannot be ignored.

The engines are provided with friction brakes that are always in action, except when the throttle is opened to move the span; consequently no unexpected movement of the span is possible.

The stretch of the operating cables is taken up, as shown in Fig. 1, by turn-buckles near the points of attachment of rope to span and counterweights; and when the adjustment is exhausted, the rope can be shortened by loosening the turn-buckle to its greatest limit and either cutting off the outer end of the rope and making a new splice, or by overhauling it on the drum and pulling the end through a hole in the periphery, placed there to afford a fastening for said end. Each of the operating ropes stretched about 2 ft. soon after the bridge was first operated, but since then the further stretch has been very slight.

As shown on Plate III, the raising ropes, after leaving the drums, pass out of the machinery house to and beneath some 5-ft. idlers under the towers, thence up to the top of the north tower, where they pass over some 4-ft. idlers and the main 12-ft. sheaves. Four of them here pass down to the north end of the span and the other four run across to the other tower over more idlers, then down to the south end of the span.

The lowering ropes, after leaving the drums in the machinery room, pass under some idlers below the north tower, and thence up to more idlers at the top of the tower. Four of them here pass down to the counterweights in the north tower, and the other four run across, over intermediate idlers in the overhead bracing, to the main 12-ft. sheaves of the south tower, then downward to the counterweights.

In addition to the previously mentioned method of moving the span by the water ballast, there is a man-power operating apparatus of simple design in the machinery house which when used alone can raise and lower the span slowly in case the steam-power gives out, or more rapidly when combined with the water-ballast method.

The original design contemplated operating the engines directly from the operating house on the span by ropes and pulleys, as in the case of ordinary elevators; but, at a conference with the engineers for the contractors, the writer and the city's Inspector of Machinery, Mr. F. Sargent, upon their advice, decided to operate them by signals given in the operating house, transmitted to the machinery room, and, as a matter of precaution, repeated to the operating house. The writer has thus far seen no reason to regret the decision in respect to this change of design.

As the span nears its highest and lowest positions, an automatic cut-off apparatus in the machinery room shuts off the steam from the cylinders and thus prevents the hydraulic buffers from being overtaxed.

The writer expects that Mr. T. W. Heermans will discuss this paper and will give a full description of the steam machinery and signal apparatus, and will present to the Society some indicator diagrams from which can be computed the actual power required to raise and lower the span under various conditions.

Specifications that Governed the Designing.

The following is a concise statement of the leading features of the specifications, which the writer adopted when making the design.

Live load for stringers, 11 tons on a single roller 6 ft. wide.

Live load for remainder of floor system, 100 lbs. per square foot.

Live load for trusses, 4 500 lbs. per lineal foot.

Dead load for trusses, 4 100 lbs. per lineal foot.

Wind pressure for span and towers, 30 lbs. per square foot of exposed surface, including both sides of the bridge.

Intensities of working tensile stresses.

Chord bars, 15 000 lbs.

Main diagonals, from 12 500 to 15 000 lbs.

Counters (adjustable, iron), 10 000 lbs.

Lateral rods (adjustable, iron), 15 000 lbs.

Sway bracing (steel sections), 15 000 lbs.

Flanges of rolled beams (extreme fiber), 12 500 lbs.

Flanges of built beams (web resistance ignored) 15 000 lbs.

Intensities for compression members by the following formulas :

For Truss Members.

Flat ends .... $p = 15\,000 - 56 \frac{l}{r}$

One flat and one pin end .... $p = 15\,000 - 66 \frac{l}{r}$

Pin ends .... $p = 15\,000 - 75 \frac{l}{r}$

For Sway Bracing.

Flat ends .... $p = 17\,000 - 65 \frac{l}{r}$

For Pins and Rivets:

Shearing	10 000 lbs.	per square	inch.
Bearing	16 000 "	"	"
Bending	20 000 "	"	"

Bearing on Masonry:

Sandstone (extra strong quality),	300 lbs.	per square	inch.
Concrete (Portland cement)....	150 "	"	"

N. B.—These intensities are for a combination of all loads, including wind pressure.

Pressure on Journals:

Upon projection of semi-intrados, 600 lbs. per square inch.

Pressure in Buffers:

Approximately .... 200 lbs. per square inch.

Tension on Wire Ropes:

Total load for $1\frac{1}{2}$-in. cable........ 18 750 lbs.

N. B.—This corresponds (by experiment) to an initial factor of safety of about nine and one-third.

Pressure for Screw Threads of Rear Column Pedestals:

Approximately .... 600 lbs. per square inch.

Shafting:

Intensity on extreme fiber for combined twisting and bending .... 10 000 lbs. per square inch.

Minimum Thickness of Metal:

Below roadway	$\frac{3}{8}$ in.
Above roadway	$\frac{5}{16}$ "

Velocity:

Greatest velocity of span...... 4 ft. per second.

It will be noticed that the assumed dead load makes the span weigh only 533 000 lbs., while the actual weight is about 580 000 lbs. Of the latter amount, however, some 50 000 lbs. are concentrated either at or very near the ends of span (for instance, the weight of the hydraulic buffers, water tanks and their ballast, end floor beams, portal girders, rollers, etc.), and do not affect materially the stresses in the trusses; consequently the assumed dead load is about right.

Extracts from the General Specifications.

The following extracts from the general specifications, upon which the contract for building was let, will give a correct impression as to the quality of the materials in the structure, and the manner in which it was built. The extracts will be taken in the regular order in which the various items mentioned appear in the original specifications, and will be condensed to the greatest extent that is compatible with a clear understanding thereof. In fact, in some places, instead of making extracts, the writer will simply describe tersely certain portions of the specifications, especially those which are standard.

Piles.—Straight, live, white oak timber, free from cracks, shakes, rotten knots and all defects; not less than 10 ins. in diameter at tip, nor less than 16 ins. at butt.

Timber in Foundations.—Yellow pine, 12 x 12 ins., drift-bolted by ⅞-in. round bolts 22 ins. long, spaced not to exceed 3 ft., and driven into ¾-in. holes.

Masonry.—Regular coursed ashlar of the best description. Stone to be of the best quality of Kettle River sandstone, quarried near Sandstone, Pine County, Minn., or other stone equally good.

Backing.—Backing of piers to be of Portland cement concrete. Mortar for same to be mixed in the proportion by volume of 1 part cement to 2½ parts sand. To this is to be added as much broken stone as the mortar will thoroughly cover without leaving any voids in the mass.

Cement.—Best quality of English or German Portland, 90% fine, with 2 500-mesh sieve. Tensile strength of neat cement 100 to 140 lbs. at one day, and 250 to 500 lbs. at seven days.

Metal Work.—All metal in span and towers to be medium steel, excepting adjustable members, which are to be of wrought iron; rivets, which are to be of soft steel, and portions of the moving parts, which are to be of cast iron. All wrought iron to comply with the Manufacturers' Standard Specifications. Cast iron to be of tough, gray iron, free from injurious cold shuts, or blow holes, true to pattern and of a workmanlike finish. Sample pieces, 1 in. square and 4 ft. 6 ins. long between bearings to carry a central load of 500 lbs. All steel to be manufactured by the open hearth or Bessemer process. Ultimate strength of medium steel from 60 000 to 68 000 lbs. per square inch. That of rivet steel from 53 000 to 61 000 lbs.

Tests to be made according to the usual practice.

Workmanship first class in every particular.

One coat of lead paint in shop, and two coats in the field.

Workmanship on the large wheels, their axles and bearings, to be of the very best that is given in machine shops to that class of work.

Timber in superstructure to be of the best quality of white or yellow pine. Floor planks to be sized to a uniform thickness. Pavement to be cedar block and built in strict accordance with the standard specifications of the city of Chicago.

Machinery.—The entire machinery is to be bid upon in a lump sum, and is to include the following:

1. All of the machinery (of whatever kind that may be adopted) located in the machinery house beneath the street.

2. Apparatus for operating bridge by man-power, in case of breakdown of machinery.

3. All operating ropes from machinery to bridge, with their adjusting details.

4. All apparatus in operating house and that leading from same to machinery in machinery house.

6. Ropes sustaining span, together with all details attached thereto and pertaining to same.

7. Rockers between ropes and counterweights.

8. Counterweights.

9. Counterweight rods with their details.

10. Straps for keeping the component parts of the counterweights in position and letting the adjacent tiers of castings slide by each other.

11. Cast-iron weights to either rest on ends of span or be attached to counterweights, so as to adjust the balancing of weight of bridge.

12. Counterbalancing chains, with their attachments to bridge and to counterweights.

13. All guide wheels on span, together with their bearings and the details by which they attach to the chords.

14. Four hydraulic buffers at top of tower and four at bottom of span.

15. Glycerine tanks and their connections to the hydraulic buffers.

16. Glycerine for filling buffers.

17. The peeper, complete, with all its attachments to structure.

18. All signals and electric alarm bells.

19. All apparatus or machinery not herein specified that may hereafter prove necessary to operate the bridge properly and satisfactorily.

Machinery in Machinery House.—Each bidder will be required to furnish with his bid an outline plan and complete typewritten description of the machinery which he proposes using. There will be no restriction as to the kind of machinery to be used, whether steam, hydraulic or electrical, but in any case it is to be first class in every particular and acceptable to the engineer. Its capacity must be such that under the most unfavorable conditions of wind pressure, unbalanced weight, etc., it will be capable of lifting the bridge to a clear height of 100 ft. above the water in 50 seconds by using one engine only, the other engine acting as a reserve in case of breakdown. The second engine must, however, be capable of being thrown into action instantly, so that the bridge can be moved rapidly out of the way in case of the too close approach of a vessel.

All parts of this machinery must have ample strength, so as to avoid all possibility of a breakdown, more especially in those parts which are not duplicated, such as winding drums, with their shafts and gearing.

Man-Power Hoisting Apparatus.—Each bidder will be required to furnish an outline plan and complete typewritten description of this apparatus. It must be so designed as to be capable of hoisting the bridge slowly out of the way of vessels in case of any serious breakdown in the machinery, and must have sufficient strength and be of simple and easy application.

Operating Ropes.—There are to be eight of these for raising, and eight for lowering, the bridge. They are to be of $\frac{7}{8}$-in. "Hercules" rope as manufactured by the A. Leschen & Sons Rope Company, of St. Louis, Mo., or other rope of the same diameter, and equal strength, quality and pliability.

The adjustments of these ropes are to be made by means of long-threaded rods of sufficient strength, and the connecting details are to be of the most approved design.

Sheaves or Idlers.—These are to be about 5 ft. in diameter, of cast iron, each cast in one piece. The workmanship thereon is to be first class.

Operating Apparatus.—Each bidder will be required to furnish with his bid an outline plan and complete typewritten description of this apparatus, which must be made perfectly effective in every particular, amply strong, quick in action, and to the approval of the engineer.

Sustaining Ropes.—These are to be 1¼ ins. in diameter, and of the same kind and quality as specified for the operating ropes. There are to be 32 of these ropes, eight at each corner of the bridge. All connecting details for these ropes are to be of the best standards in use.

Rockers.—Rockers between ropes and counterweights are to be built of steel in strict accordance with the requirements of the specifications for metal work.

Counterweights.—These are to be cast as smooth and true as practicable for ordinary castings, so that they will work smoothly up and down in the guides, and so that the adjacent tiers of castings can pass each other vertically without undue friction.

Counterweight Rods.—These are to be of wrought iron, of the quality specified for the metal work, upset, and furnished with nuts and washers of standard type.

Sliding Straps.—These straps, which serve to keep the counterweights in position, are to be of wrought iron, and are to be made as shown on the drawings.

Counter-Balancing Chains.—These are to be of wrought iron, the weight per vertical foot of all chains being just equal to the weight per foot of the 32 supporting ropes. They are to be attached to the counterweights so as to distribute their weight equally over the supporting ropes.

Guide Wheels.—All guide wheels between span and tower are to be made of the pattern shown. They are to be of the best workmanship, so as to reduce the rolling friction to a minimum. The springs employed are to be manufactured according to the directions of the engineer.

Hydraulic Buffers.—These shall have sufficient capacity to bring the bridge to rest without shock from a velocity of 4 ft. per second, which is to be the greatest velocity allowed by the governors that are to be attached to the machinery in the machinery house. These buffers are to be of the most approved type, and of ample strength.

Glycerine Tanks.—These, with their connections to buffers, are to be of the best quality and ample strength.

Glycerine.—Glycerine for filling buffers is to be of the best quality used for such purpose; and as much of it shall be used as the engineer may deem necessary.

Peeper.—The peeper and all its connections shall be built to the satisfaction of the engineer; and the contractor shall pay any royalty that may be required by the holder of the patent for this apparatus.

Signals, etc.—Signals for warning passengers and for communicating with vessels, such as used on other bridges over the Chicago River, shall be furnished and put in place by the contractor, including two electric alarm bells of size and capacity to be determined by the engineer.

The span shall be erected on pontoons and shall be floated into position, but not until the machinery is all ready to connect to the bridge; and the obstruction to navigation, caused by putting the span into position, shall be reduced to a minimum.

Description of Details.

Span Details.—As can be seen on Plate II the style of span does not differ essentially from the ordinary, although it has several rather uncommon features, such, for instance, as the slight inclination to the vertical of the end post, as previously mentioned, the carrying of the posts below the bottom chord pins so as to have the floor beams below the chords, and the division of the upper lateral system by a continuous longitudinal strut lying in the central plane of structure. This last detail was rendered necessary by the great distance between central planes of trusses. The dropping of the floor below the bottom chords is required by the condition of making the distance from its surface to lowest part of span a minimum. An inspection of Fig. 2 shows that the floor beams are altogether too shallow for economy of metal therein. The same plate shows that the paved roadway is pitched from the middle to the sides so as to draw off water rapidly.

The heavy portal girders are required for two reasons; first, rigidity; and second, to take up the shock of the blow given to them by the buffers at the tops of the towers.

The pedestals hang from the feet of the end posts, and are pin-connected. There is a strut passing from each of the feet to the first panel point from the end. One case in which this strut would prove useful, is, if in winter, when there is no navigation, the suspending cables were removed in order to repair them, and the span thus made to act like any ordinary span, changes of temperature would cause a bending on the extended portions of the end posts. The struts referred to prevent this, and would in such a case cause the span to slide sufficiently to accommodate the expansion and contraction. The end posts are figured to carry both the entire dead and live loads, although, under ordinary conditions, the former never travels thereby, but is taken up by the suspending cables.

The top and bottom chords (the latter being stiff in the end panels) project beyond the end panel points so as to afford connection for the rollers. Behind each longitudinal roller is a spring which keeps the roller pressed at all times against the column. Should the span tend to lurch forward, there is a stopper in each spring, which prevents such lurching from exceeding a certain limit. The connections of all rollers to the span are strong enough to withstand the wind pressure and any blow from the masts or rigging of a vessel; but should the hull of the latter strike the span, these connections would fail and allow it to swing sideways, which it would do until the vessel would be brought to rest.

The connections of cantilever brackets to floor beams around the posts, as shown in Fig. 2, have been objected to as being too elaborate for the size of the cantilevers; but the writer holds that such a detail is necessary in any case, in order to avoid direct tension on rivets. The tightly fitting straining angles at the post feet are also just as necessary as the upper connection, unless some equally efficient detail, such as an underneath plate extending from cantilever to beam, be adopted.

The detail for attaching the span to the cables is shown on Plate II and Fig. 1. Some difficulty was found in designing a satisfactory and efficient connection for the ends of the sustaining ropes. The Crane Elevator Company objected to the detail first proposed by the writer on account of expense, so at his request they submitted a design of their own. Upon examining it, the writer pronounced it inefficient, and proceeded to submit it to test, with the result that his judgment was verified. The company then submitted another similar, but improved, design, shown in Fig. 1, which the writer judged would be strong enough to develop the full strength of the rope. Some tests to destruction proved the correctness of this surmise; and it is the writer's opinion that this design for the clips is the best and most efficient that can be made, although it must be confessed that its appearance is somewhat clumsy. Hitherto no one appears to have used clips that would even begin to develop the full strength of

DETAILS OF FOOT OF MAIN COLUMN.

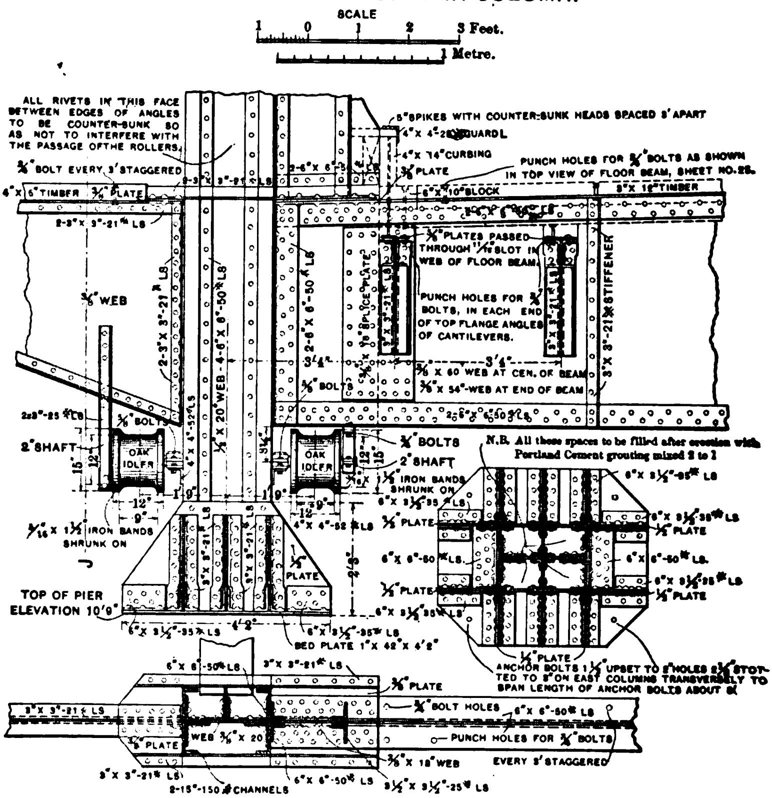
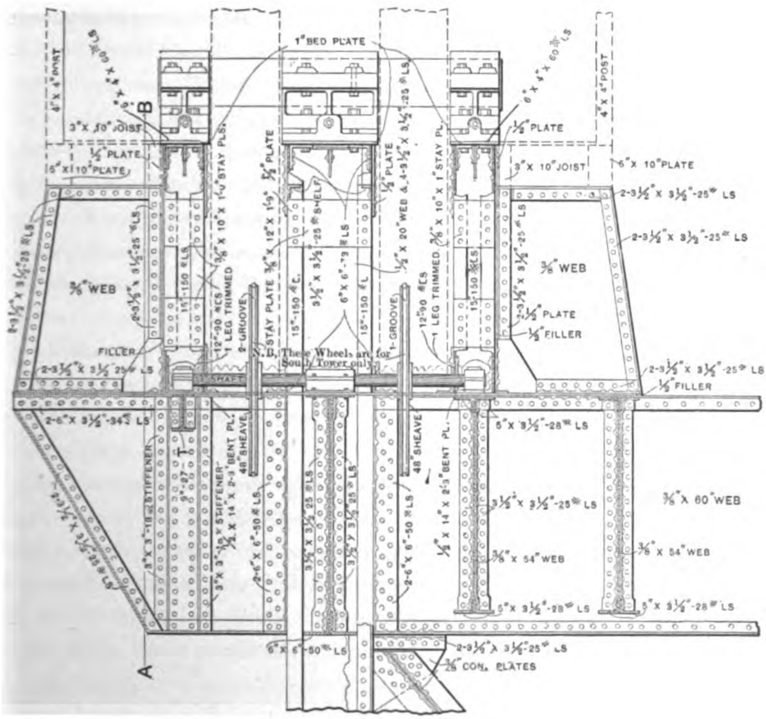


FIG. 5.

wire rope; but in this case it is essential, notwithstanding the fact that it is contemplated to use these cables until they have lost as much as 40% of their strength.

Tower Details.—Each of the main columns of the towers is built of a single ½ x 20-in. plate and four 6 x 6-in. 50-lb. angles, forming a built **I** beam, which is riveted between two 15-in. 150-lb. channels turned face to face, the web of the built I beam lying in a plane transverse to the length of span. The front face of this column is left open so as to permit of the travel of the vertical roller, but the back face is stay-plated occasionally. Wherever the rollers touch the column, the rivet heads are countersunk so as to be perfectly flush with the web. The column is expanded at the foot, as shown in



DETAILS AT TOP OF MAIN COLUMNS.

SCALE

1 0 1 2 3 Feet

1 Metre.

FIG. 6.

Fig. 5, so as to give a sufficiently low bearing pressure on the masonry, and so as to distribute it uniformly without overstraining any of the metal. The boxed spaces in the foot are filled with bituminous concrete.

At the top of the tower each column is expanded, as shown in Fig. 6, so as to afford proper support for the journal boxes of the main sheaves. These boxes are lined with bronze, which is grooved spirally so as to carry the lubricant to the bottom of the bearing and distribute it uniformly.

Attention is called to the rigid character of the sway bracing in numerous planes in the vicinity of the main sheaves. No metal was spared in the endeavor to obtain the greatest practicable rigidity.

The bracing in the plane of the main columns consists of a heavy plate-girder portal near the bottom carried down the sides of the columns to the large floor beam and connected therewith, and a similar, but lighter, plate girder at the top to aid in carrying the main sheaves, and to take up the uplift from the buffers, with sway bracing of a double system of cancellation between, each diagonal and transverse member of which consists of four angles in the form of an I beam with a laced web. This system of sway bracing has a much greater strength than the computed wind stresses call for. It was put in thus for the sake of rigidity.

The sway bracing between main and rear columns consists of a single system of cancellation, all the members of same being struts, each built of two angles in the form of a star, and stayed to each other by short pieces of angle iron, spaced about 3 ft. centers, excepting two members, one of which is in the first tier below the main sheaves, and is a built I beam, designed to carry the counterweights before the span is attached to them by the sustaining cables. The other is the diagonal in the bottom panel, which is composed of four angles in the form of a star. Although these star struts make a good and rigid bracing, nevertheless, in a new design the writer would use more metal and adopt four Z bars.

The sway bracing between the rear columns is put in for rigidity only, because the figured stresses therein are insignificant. The main sheaves are built up of steel plates and angles with a cast-iron periphery grooved to fit the wire ropes. This design is a modification of one made especially for the writer over two years ago by Thomas E. Brown, Jr., M. Am. Soc. C. E., who had been called in consultation when the plans for the proposed lift-bridge at Duluth were being prepared.

Overhead Bracing Details.

As shown on Plate I, the overhead bracing between towers consists of two lattice girders built of angles and having a double system of cancellation for the web, which changes, however, at the ends into plates. Between these girders is a system of sway bracing similar to that between the top chords of the span, and containing the same peculiar feature of an intermediate longitudinal strut. In this case, though, this strut, instead of being continuous from end to end, is made in two parts, and does not extend across the middle bay, which is left unbraced so as to permit the operating house to pass through. The detail for connecting this system to the towers is very simple and effective. It was suggested by Mr. Curtis and accepted with a slight modification by the writer. Its essential feature consists in cutting the girders (as originally designed) through the plate-girder portions near the ends by planes inclined to the vertical, so as to make the length of the top chord of the intermediate portion shorter than that of the bottom chord, facing all the cut ends with stiffening angles, riveting the short pieces on to the towers, and hoisting at one operation the two intermediate pieces with all their sway-bracing, which had previously been assembled and riveted together on the false work, so that the oblique ends met, after which these ends were riveted together, and the flanges of the girder were spliced above and below by cover plates.

Machinery Details.—As shown in Fig. 3, each hydraulic buffer consists of a cast-iron cylinder 12 ins. internal diameter and 4 ft. stroke, with a tightly fitting piston, that has through it four symmetrically disposed holes. Through each of these holes passes a tapered rod. When not in use, the head, owing to the weight of the piston, lies at the bottom of the cylinder, but, when struck, rises and forces the fluid (a light petroleum product) through the four annular spaces around the rods. As will be shown later on, the taper of the rods is so figured that the total pressure on the piston remains constant at all positions of the piston-head for any one stroke. Should the calculations have been slightly at fault, the resistance of the buffer can be increased or decreased by lowering or raising slightly the rods by means of the screw adjustment provided in the design; and should this be insufficient, it would be a simple matter to take out the rods and put in new ones with a different taper. Fortunately, though, the buffers, as nearly as can be determined by a casual examination, appear to work exactly as they were designed to do. The writer had some doubt about the ability of the piston to descend of its own weight unless it were made to fit so loosely in the cylinder as to permit of the passage of some of the fluid around the periphery during the stroke, but his fears were groundless, for only one of the eight pistons showed any tendency to stick, and that one got to working all right in a day or two. The idea of running rods through the piston came from Edward Flad, M. Am. Soc. C. E., who very kindly placed his invention at the disposal of the writer, who personally made the original design, computations and drawings for the buffers of this bridge. This design was not varied from essentially in making the working drawings.

As the piston ascends, the total amount of metal within the cylinder is constantly increased, consequently the amount of fluid therein is correspondingly diminished, the excess passing out of a pipe at the bottom and into a small reservoir situated only a few feet above. As the pressure of the escaping fluid is quite small, the reservoir is left open to the air, and there is no loss of fluid caused thereby.

The attachment of the balancing chains to the counterweights provides for an equal distribution of the weight of the chains over all the sustaining cables, even should the latter stretch unequally.

The design for the drum, shown on Fig. 4 is very simple, and requires no further explanation.

The driving wheels for the drum shaft are placed symmetrically near the middle of the length of the latter. They are cast-iron spur wheels, 10 ft. in diameter. These and all the rest of the machinery from them towards the engines were designed by the Crane Elevator Company under the inspection of and to the approval of Mr. F. Sargent.

The attachment of the operating ropes to the span and counterweights, as shown in Fig. 1, is by means of ordinary clips, such as are used in elevators. The detail for lining up and clamping the suspending ropes was manufactured and delivered on the ground, but the bridge was found to work so nicely without it that it was decided not to put it in.

Testing.—All testing was done by Messrs. G. W. G. Ferris & Co., of Pittsburgh, who are the regularly employed inspectors of bridge materials for the city of Chicago. The usual tests of the steel were made, and the results were fairly good, considering that the use of Bessemer steel was permitted. Some very interesting tests of wire rope were made by these gentlemen under the direction of the writer, who hopes that some of the engineers of the firm will see fit to contribute to the discussion of this paper by giving a full description of these tests, and the conclusions to be drawn therefrom in respect to the ultimate strength and other properties of steel wire ropes.

Calculations.

Buffers:

Moving weight................ = 1 200 000 lbs.
Moving mass.................. = $1\ 200\ 000 \div 32.2 = 37\ 267$.
Maximum velocity............. = 4 ft. per second.
Energy due to same............ = $37\ 267 \times (4)^2 \div 2 = 298\ 136$.
say—300 000 ft.-lbs.
Number of buffers............. = 4.
Energy per buffer due to moving mass...................... = $300\ 000 \div 4 = 75\ 000$ ft.-lbs.
Stroke of buffer................ = 4 ft.
Constant pressure on piston.... = $75\ 000 \div 4 = 18\ 750$ lbs.
Diameter of cylinder........... = 12 ins.
Area of cylinder............... = 113 sq. ins.
Area of four holes............. = 4 sq. ins. (approximately).
Net area of piston............. = $113 - 4 = 109$ sq. ins. $= A$.
Intensity of pressure on piston. = $18\ 750 \div 109 = 172$ lbs.
Hydraulic head due to 172 lbs. pressure.................. = 396 ft., say, 400 ft.
Formula for velocity through holes.................. $v' = 0.7\sqrt{2\,gh}$.
$= 0.7 \times 8\sqrt{400} = 112$ ft. per second (nearly).

Let v = velocity of piston at any part of the stroke. Its value will diminish uniformly from 4 ft. per second to zero.

Let A' = net area of the four orifices for the position of piston corresponding to the varying velocity v.

Then by the law of continuity—

$$A\,v = A'\,v', \text{ and } A' = \frac{Av}{v'} = \frac{109}{112}\,v = 0.973\,v.$$

For $v = 4$, $A' = 3.892$ sq. ins., and $\frac{A'}{4} = 0.973$ sq. in.

For $v = 3$, $A' = 2.919$ sq. ins., and $\frac{A'}{4} = 0.730$ sq. in.

For $v = 2$, $A' = 1.946$ sq. ins., and $\frac{A'}{4} = 0.486$ sq. in.

For $v = 1$, $A' = 0.973$ sq. in., and $\frac{A'}{4} = 0.243$ sq. in.

For $v = 0$, $A' = 0.000$ sq. in., and $\frac{A'}{4} = 0.000$ sq. in.

Let us assume diameter of plug at bottom = ½ in.

Then area of plug at bottom = 0.196 sq. in.

Therefore area of hole in piston = 0.973 + 0.196 = 1.169 sq. ins.

Diameter corresponding to 1.169 sq. ins. = $1\frac{7}{32}$ ins. (nearly),

Diameter of plug at top must be almost exactly $1\frac{7}{32}$ ins., so as to fit the hole tightly, but without binding.

For $v = 3$, area of plug = 1.169 — 0.730 = 0.439 sq. in., corresponding to a diameter of 0.748 in.

For $v = 2$, area of plug = 1.169 — 0.486 = 0.683 sq. in., corresponding to a diameter of 0.936 in.

For $v = 1$, area of plug = 1.169 — 0.243 = 0.926 sq. in., corresponding to a diameter of 1.086 ins.

If the plug were conical, the diameters at the several quarter points would be respectively 0.68 in., 0.86 in., and 1.04 ins.; consequently it will have to be swelled a little beyond the conical surface in order to make the total pressure on the piston constant at all parts of the stroke.

These calculations were furnished by the writer to the subcontractors for the machinery. How closely they adhered to them in manufacturing the buffers he cannot say; but, at any rate, the latter work satisfactorily, which is all that is really necessary. It is seldom that the span will strike the buffers with a velocity of 4 ft. per second, for two reasons, viz., first, it is not necessary to operate the bridge at such a velocity; and, second, the automatic cut-offs in the engine-room reduce the speed near the ends of the travel. On the other hand, though, if the span be out of balance, the buffers will have to overcome an extra amount of energy equal to the unbalanced load multiplied by the buffer stroke.

If the unbalanced load for an extreme case be assumed equal to 5 000 lbs., the total extra energy to be overcome will be 20 000 ft.-lbs., or 5 000 ft.-lbs. per buffer. This is, however, less than 7% of the capacity of the buffer.

Power.—The amount of power required is dependent mainly upon the coefficient of friction in the journals of the main sheaves. Unfortunately, but little is known concerning its probable value for such a case as this. A study of the various authorities shows a very wide range of opinion. It is well, perhaps, to assume with Morin that its value is 0.05 for ordinary working pressures and ordinary conditions.

Let us investigate three cases, viz.:

1st. No wind acting, balanced loads, and a maximum velocity of 3 ft. per second.

2d. No wind acting, balanced loads, and a maximum velocity of 4 ft. per second.

3d. Greatest assumed wind pressure acting, an unbalanced load of 2 000 lbs., and a maximum velocity of 2 ft. per second, which velocity will probably just suffice to raise the span, according to contract, 85 ft. in 50 seconds.

CASE No. 1.

Load on journals.............. = 1 320 000 lbs.

Frictional resistance of journals. = 1 320 000 x 0.05 = 66 000 lbs.

Velocity of axle in journal..... = 0.25 ft. per second.

Work of friction............... = 66 000 x 0.25 = 16 500 ft.-lbs.

Corresponding horse-power.... $= \frac{16\ 500}{550} = 30.$

Inertia.—Let us assume that in 15 ft. the full velocity of 3 ft. per second will be developed.

Mass.... $= \frac{1\ 200\ 000}{32.2} = 37\ 267.$

Kinetic energy...... $= \frac{37\ 267}{2} \times (3)^2 = 167\ 700$ ft.-lbs.

The average velocity during development = 1.5 ft. per second.

Time required for development = 10 seconds.

Energy expended per second $= \frac{167\ 700}{10} = 16\ 770.$

Corresponding horse-power $= \frac{16\ 770}{550} = 30.5.$

Bending Cables.—For a velocity of 3 ft. per second, it will take approximately 6 H. P.

Summation.—The sum of these three values is equal to 66¼ H. P., nearly. This seems high, and it is more than likely that the experiments about to be made will show, first, that the coefficient of friction is less than 0.05; and, second, that it takes ordinarily a greater travel than 15 ft. to develop a velocity of 3 ft. per second.

CASE No. 2.

Friction.—The work of friction is directly proportional to the velocity, consequently in this case the horse-power will be $30.0 \times \frac{4}{3} = 40.0$.

Inertia.—Energy developed $= \frac{37\ 267 \times (4)^2}{2} = 298\ 136$ ft.-lbs.

The average velocity during development = 2.0 ft. per second; therefore, the time, as before, will be 10 seconds.

Energy per second........ $= \frac{298\ 136}{10} = 29\ 814$ ft.-lbs.

Corresponding horse-power $= \frac{29\ 814}{550} = 54.3$.

Bending Cables.—For a velocity of 4 ft. per second, it will take approximately 8 H. P.

Summation.—The sum of these three values is equal to 102 H. P., nearly. With this arrangement of speed, the time required would be as follows:

To attain maximum velocity...............	10	seconds.
Duration of same = 116 ÷ 4................	29	"
To overcome same in 4 ft...................	2	"
Total..................................	41	"

If these figures are correct the bridge must have been considerably unbalanced when it was moved the full height in 34 seconds. That it was somewhat unbalanced was known, because the span went up more quickly than it went down, although the difference of time for raising and lowering was ordinarily not very much.

CASE No. 3.

Friction.—For a velocity of 2 ft. per second, the horse-power required will (from Case No. 2) $= 40.0 \div 2 = 20.0$.

Inertia.—The energy developed will be $\frac{298\ 136}{4} = 74\ 534$ ft.-lbs., and the time, as before, 10 seconds; therefore, the energy per second will be $\frac{74\ 534}{10} = 7\ 453$ ft.-lbs., corresponding to a horse-power of $\frac{7\ 453}{550} = 13.6$.

Bending Cables.—For a velocity of 2 ft. per second, it will take approximately 4 H. P.

Unbalanced Load.—

Energy = 2 000 x 2 = 4 000 ft.-lbs., corresponding to a horse-power of 7.3.

Wind Pressure on Span:

Total wind pressure on span = 50 000 lbs., nearly.

Diameter of roller = 15 ins.

Diameter of axle = 5 ins.

Velocity of axle = $\frac{5}{15}$ x 2 = 0.67 ft. per second.

Coefficient of friction = 0.05.

Frictional resistance = 50 000 x 0.05 = 2 500 lbs.

Work of friction = 2 500 x 0.67 = 1 675 ft.-lbs.

Corresponding horse-power = $\frac{1\ 675}{550} = 3.0$, nearly.

To this should be added about 1 H. P. for the rolling friction, making the total horse-power for rollers = 4.0.

Wind Pressure on Counterweights:

Area exposed = 4 x 8 x 10 = 320 sq. ft.

Pressure on same = 320 x 30 = 9 600 lbs., say, 10 000 lbs.

Assume coefficient of friction = 0.15.

Frictional resistance = 10 000 x 0.15 = 1 500 lbs.

Work of friction = 1 500 x 2 = 3 000 ft.-lbs. per second.

Corresponding horse-power = $\frac{3\ 000}{550} = 5.5$, nearly.

Summation.—The sum of all these values is 54.4 H. P. From this it is evident that, if the various assumptions are correct, one 70-H.-P. engine will easily raise the span 100 ft. clear above the water in 50 seconds, under a wind pressure of 30 lbs. per square foot, and with 1 ton of unbalanced load on the span; consequently the contractor has complied generously with the specifications.

Erection.—The treatment of this subject will be left to Mr. W. W. Curtis, the engineer who represented the contractors, and under whose personal supervision it was so ably done. There is but one adverse criticism to make thereon, viz., the great length of time it took; but for this there are many extenuating circumstances. Under like conditions many a contractor would have thrown up the contract in despair; and, in the writer's opinion, if Mr. Curtis had the work to do over again, with everything favorable, instead of unfavorable, he would finish it all in the contract time. It was contemplated, when the specifications were written, to erect the span on pontoons, float it into place, and raise it clear of everything in a single day; but the erection being delayed until after the close of navigation, the contractor was permitted to drive false-work piles all the way across the river. The passage of the latter for tugs was blocked in consequence only three or four days.

Estimates.—Owing to unavoidable changes in both substructure and superstructure, it is not practicable to check the total cost of bridge with the preliminary estimate, which was based upon the quantities given at the end of the "General Specifications." There is only one item of all these that it is convenient to check, viz., the total weight of metal, 1 250 000 lbs. To this must be added the writer's preliminary estimate of 100 000 pounds for raising the towers 15 ft., making the total estimated weight 1 350 000 lbs., which agrees within 5 000 lbs. with an estimate made in the writer's office from the complete detail drawings.

The reasons why the total cost of the bridge is higher than was anticipated are as follows:

1st. Increased cost of superstructure (nearly $5 000) because of the increased height of towers.

2d. Greater expense involved by the necessary change from pile piers to pneumatic piers.

3d. Adding to the legitimate cost of the structure that of removing the old pivot pier and doing considerable dredging for the purpose of deepening the channel.

4th. Extra expense for engineering and inspection due to the delay in completing the structure.

If the contract for building a duplicate of the Halsted Street lift-bridge were to be let to-day, at present prices, with close competition, and if the engineer were allowed full sway in making plans and specifications for substructure, superstructure, approaches and machinery, based upon correct data, it is not too much to say that the entire cost would be reduced to, at most, $150 000, instead of $200 000, which is about what the structure itself really cost, exclusive of outside extras.

Advantages of Lift-Bridges.

The advantages of lift-bridges, in comparison with rotating draw-bridges, are as follows:

1st. A lift-bridge gives one wide channel for vessels instead of the two narrow ones afforded by a center-pivoted swing-bridge.

2d. There are no land damages in the case of a lift-bridge, as the whole structure is confined to the width of the street. These land damages in the case of some swing-bridges amount to a large percentage of the total cost of structure.

3d. Vessels can lie at the docks close to a lift-bridge, which they cannot do in the case of a swing-bridge; consequently with the former the dock front can be made available for a much greater length between streets than it can with the latter.

4th. The time of operation for a lift-bridge is about 30% less than that for a corresponding swing-bridge.

The advantages of a lift-bridge in comparison with a bascule or a jack-knife draw, both of these being supposed to be without a center pier, are as follows:

1st. The lift-bridge can be made of any desired span, while, in the case of the others, the span is necessarily quite limited in length.

2d. A lift-bridge can be paved, while the others cannot.

3d. The lift-bridge is very much more rigid than any structure composed of two or more partially or wholly independent parts, a feature characteristic of the jack-knife bridge or the bascule without a center pier.

4th. In a lift-bridge, the operating machinery is much more simple; and, in case that it should ever get out of order, the span can be raised or lowered either by unbalancing, or by simple hand mechanism, or by both combined.

Conclusion.—In concluding this paper the writer desires to give full credit to the following gentlemen:

Primarily, as before stated, to the Hon. J. Frank Aldrich is due the fact that the bridge is in existence.

To W. W. Curtis, M. Am. Soc. C. E., is due great credit, not only for the careful and conscientious manner in which all of his work was done, but also for his unfailing courage in dealing with continual occurrences of the most disheartening character.

To Mr. T. W. Heermans, engineer for the machinery contractor, is due the credit of the fact that every portion of the machinery went together as it was designed.

To S. M. Rowe, M. Am. Soc. C. E., the resident engineer, is due the credit of the correct location of all parts of substructure and superstructure.

To Mr. Ira G. Hedrick, the writer's engineer and chief draftsman, and to Mr. Rudolf Markgraf, his architect, are due the credit of preparing the complete detail drawings for the entire structure, excepting the steam machinery and signal apparatus, which were designed, as well as built, by the Crane Elevator Company.

It would be unfair to omit to mention Lee Treadwell, Assoc. M. Am. Soc. C. E., the writer's principal assistant engineer, who, although but slightly connected with the designing of the Halsted Street bridge, was, nevertheless, instrumental in evolving many of the special details employed therein, when studying with the writer on the design for the proposed lift-bridge for Duluth. Moreover, he assisted in making the drawings for the span of the Halsted Street bridge.

As before mentioned, the writer is indebted to Thomas E. Brown, Jr., M. Am. Soc. C. E., for many valuable suggestions concerning general details, and to Edward Flad, M. Am. Soc. C. E., for his kind permission to use his idea for hydraulic buffers.

The Halsted Street lift-bridge has now been in operation long enough to show that all that was claimed for it by its projectors was true, and that it works even more easily than was anticipated; and as the writer is now engaged on the preliminary designs for several similar structures, in which he is so arranging the manner of their operation as to reduce the cost of same below that for corresponding swing-bridges; and as the first cost of other lift-bridges can be made very much less than that of the pioneer structure, it is not improbable that in the next few years many structures of this type will be built over navigable waters in American cities adjacent to the sea-coast and the Great Lakes.

DISCUSSION.

GUSTAV LINDENTHAL, M. Am. Soc. C. E., remarked that while the paper was very interesting, there were some points which were omitted, for instance, the testing of the wire ropes. This question had recently come up in discussion in connection with the use of sockets for fastenings, and it was shown by tests that that method was unreliable, because it was very difficult in practice to pin every wire fast in the socket, and hence the full strength of the wire rope was never developed in testing to destruction. Mr. Lindenthal.

The reason for the use of this type of bridge is given in full by the author, namely, that at the site of the bridge the U. S. War Department objected to the use of an ordinary draw-bridge as an obstruction to navigation, and that the type adopted was thought to be one which would meet those objections. He did not think, however, that this type of bridge would be used generally as a substitute for draw-bridges, because it was more expensive in first cost and more expensive to maintain.

L. L. BUCK, M. Am. Soc. C. E., stated that he had not been able to give the paper the attention which he would like to do before entering into a detailed discussion of it, but that he could not at the present moment see any good reason for raising the whole span to such a height as to permit the passage of masted vessels under it. His feeling was that, had the problem been presented to him, he would have exhausted all other resources before adopting the plan of the author. He had heard that objection to a draw-bridge was made by the War Department, but on the Erie Canal the State of New York also objects to draw-bridges. It occurred to him that raising the floor of the bridge alone might be a more desirable method. The supporting structure could then be placed above and made stationary and permanent. An examination of a draw-bridge across the Chicago River had satisfied him that a satisfactory solution of the problem might be worked out in this way. Mr. Buck.

G. H. THOMSON, M. Am. Soc. C. E., called attention to the fact that on page 35 some of the advantages of lift-bridges are noted. One other advantage can be mentioned, viz., lift-bridges can be manipulated with ease while a stiff gale is blowing, and this has been tested with the type known as the end lift-bridge. The difficulty of manipulating circumrotary draws during gales has been experienced in both hand and power swing bridges of equal arms; while the bob-tail draw (unequal arms) presents much greater difficulties in the way of rotation. Mr. Thomson.

Mr. Thomson. Another advantage in some types of lift-bridges is that the amount of coal required is less than the amount required for rotary draws of equal single span.

The statement that a lift-bridge of the bascule type cannot be paved (*sic*) will not find acceptance with those who think that there is no difficulty in laying wooden block pavement on bridges with inclined surface roadways.

He further remarked that the cost of this structure seems excessive; that how much of this cost is chargeable to substructure does not appear, and that it would be interesting to know the weight of the towers. The paper, with its accompanying plan, does not disclose this, and an economy analysis is not easily made off hand. The magnitude of the counter-weighting (given at 290 tons) is something more than an "end" lift-bridge requires. An "end" lift-bridge needs but one tower of about one-half the height, with presumably less material than the Halsted Street bridge towers.

He called attention to an end lift-bridge designed for W. Katté, M. Am. Soc. C. E. (see Plate V), a view of which shows a double-track end lift-bridge on temporary line over the Harlem River, of a total length of 106 ft., center of end pin to extreme end. It has been lifted about 50 times a day for about six months, and one and one-half minutes is the usual time of a full lift, and it is responsive in action.

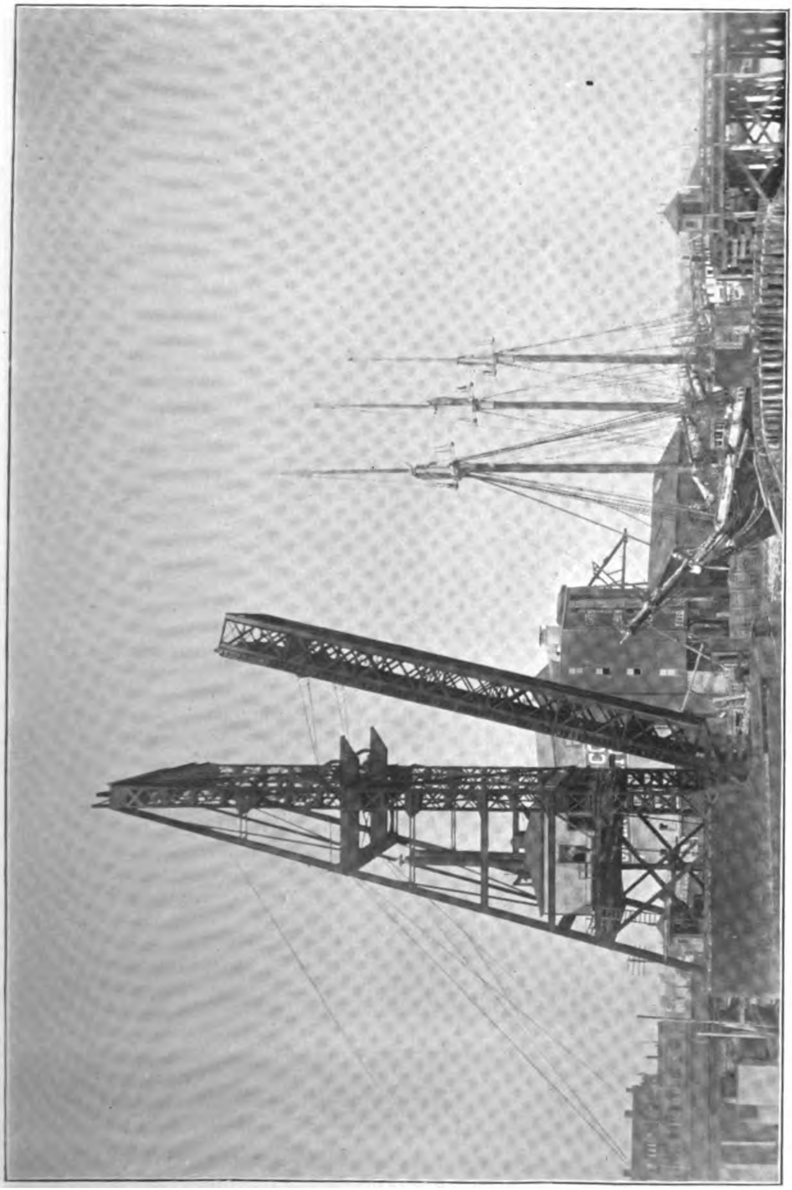
The Halsted Street bridge is rapid in movement. One double-track through plate (of 60-ft. span) end lift-bridge has been lifted to the full height in nine seconds.

He thought the selection of any type of lift-bridge should be the result of mature deliberation after weighing all the conditions presented in each particular case; that some situations point to the selection of a lift-bridge as justifiable, whether viewed in the light of first cost or cost of maintenance, while others admit of no other type of draw, but that the usual conditions presented by most situations permit the use of the rotary draw, and economy and other matters indicate soundness of judgment in its adoption.

Mr. Skinner. F. W. Skinner, M. Am. Soc. C. E., complimented the author on the excellent manner in which he had presented the paper, and called attention to the elaborate and unusual screw adjustment at the base of the towers, which he presumed had been very fully studied, but which at first glance seemed to be somewhat remarkable. As adjustments would require to be made very infrequently at most, it seemed to a casual observer as if it would have been better to simply arrange for differential loose packing plates and the temporary insertion of hydraulic jacks, than to use costly steel screw bearings.

He said further that the design of bridges that should cause the least interruption of traffic on the numerous highways and waterways of large cities is a subject that had lately received special

PLATE V.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXIII, No. 742.
THOMSON ON HARLEM RIVER END LIFT-BRIDGE.



attention by a large number of the most prominent bridge-builders. Notably interesting and original designs were prepared by the late Mr. Scherzer, and the engineers associated with the elevated road in Chicago, while the author had carefully developed a fundamentally distinct line of construction. He called attention to a type of bridge differing from that described by the author, consisting essentially of a bascule bridge, the leaves of which are made to slide back, with their centers of gravity moving always in a horizontal line and revolving about them until they reached the wide open position, of which type there is a bridge in Milwaukee already completed, and another for which George H. Benzenberg, M. Am. Soc. C. E., has prepared plans of a structure without any towers. By this arrangement the distortion by necessity for absolute adjustment and danger from settlement is considerably relieved. Mr. Skinner.

Charles E. Emery, M. Am. Soc. C. E., desired to add his testimony to the very thorough way in which this subject had been presented. In regard to the type of bridge, he thought that those engaged in actual construction were best fitted to criticise, but as there seemed to be a difference of opinion among them, he might be permitted to remark that apparently something more in the way of land damages might have been allowed, and a simpler bridge placed at that site. The raising of a span of only 130 ft. to such a great height would seem to be unnecessary, for had the whole span been lifted in one direction, the tower spanning the river would not have been required and the load to be lifted have been reduced one-half. It might be, however, that the conditions were much worse than appear in the paper. Mr. Emery.

T. J. Long, M. Am. Soc. C. E., said that the only point which occurred to him was the statement of the author that one of the advantages of this type of bridge over the bascule and jack-knife lift-bridges is that it can be paved, while the latter cannot. His impression was that the Tower Bridge, of London, which is a bascule bridge, is paved, and that the two bridges of the jack-knife lift type in Chicago are also paved. Mr. Long.

J. Sterling Deans, M. Am. Soc. C. E., said that he was not prepared to discuss the details of construction, but would state that he had heard objection made to this special design of draw, by one of the assistant engineers of Chicago, on account of the great cost for operation. He had since heard, however, that a large proportion of this cost was due to some defect or inefficiency in the machinery and not due to any defect in the design of the structure proper. Mr. Deans.

Lee Treadwell, Assoc. M. Am. Soc. C. E., remarked that in regard to the question of wire rope the tests made were very interesting, and he was sorry that they were not embodied in the paper. The author expected, however, that their results would be given in the form of a discussion by G. W. G. Ferris & Co., who made the tests. When Mr. Treadwell.

Mr. Treadwell. tested the rope parted at a point between and removed from the fastenings, showing thereby that its full strength was developed, and that the efficiency of the fastenings was all that could be desired. According to his recollection the maximum strength of a $1\frac{1}{2}$-in. steel cable was found to be 175 000 lbs., or about 15% less than its estimated strength. The breaking strength of wire rope, as given in manufacturers' catalogues, is generally arrived at by multiplying the strength of one wire by the number of wires in the cable.

He desired to say, that about six weeks ago he went up on the Halsted Street bridge, and that the buffers worked in a perfect manner, there being absolutely no reaction such as is felt when an ordinary passenger elevator is brought to a stop.

Answering Mr. Buck, he said, that in working up the design for a proposed lift-bridge at Duluth, which finally led to the Halsted Street bridge, a number of different designs were carefully considered by the author, one of which was with a fixed span at the top of the towers, but, that when the cost of the span, together with the cost of the suspended floor and all the necessary cables, drums, counterweights, pulleys and attachments were considered, it was believed that there would be little or no saving in cost over the movable span. He thought a more serious objection, however, to the fixed span and suspended floor was that the long chains or cables going down to support the floor could not be protected from the weather and the swaying action of the wind. Moreover, a floor 130 ft. long and suspended by cables 155 ft. in length would be seriously lacking in rigidity, especially under the passage of heavy coal wagons and similar loads. The design was therefore abandoned as being entirely inadequate to meet the requirements of the case.

The unusual conditions that affected the Halsted Street crossing he considered to be eminently favorable to the lift-bridge type of construction. A rotating draw, with its pier and protection piles occupying a space 60 ft. wide by 200 or more feet long in the middle of the river, would interfere seriously with navigation interests, for the river is both narrow and crooked at Halsted Street. A counterbalanced swing span, with one short arm and the pier on the shore, could probably have been constructed for a little less than the cost of the lift-bridge, but the damage to private property and the occupation of about 300 ft. of wharfage would have more than offset the saving. Moreover, such a span, not permitting of a complete rotation through 360 degrees, would require more time to open and close. There being continuously heavy traffic on Halsted Street, the item of time in opening and closing any bridge for the passage of boats was therefore a most important consideration. The lift-bridge was built entirely within the street limits, there being no damage to private property and no interference with boats receiving or discharging cargoes at the adjoining wharves. He stated, also, that so far as he was able to learn when in Chicago, the lift-bridge is giving better satisfaction to both navigation interests and to the general public than is any other bridge over the Chicago River. The average time that street traffic is interrupted for the passage of a vessel at the lift-bridge is said to be less than the corresponding time at the swing bridges. Mr. Treadwell.

As to the cost of the bridge, he said that no bridge-builders in this country had previously had experience with a structure of this kind, and consequently they bid with a large margin for contingencies. In addition to this, the contractor was required to give a bond for the successful operation of the bridge, according to the requirements of the plans and specifications, namely, that it should be raised 100 ft. in 50 seconds. The approaches and machinery house were included in the cost of $200 000. He believed that the bridge could now be built for something like $50 000 less than that amount.

In regard to the operation of the bridge, he was told recently by the day signalman on the span, that, excepting with the engines, not the least difficulty had ever been experienced in operating the bridge. Some weeks ago the main driving pinions on the crank shaft of the engines were broken, through rough usage by an inexperienced engineer, and, as a consequence, the span remained at the top of the tower for a period of 36 hours, at the end of which time the repairs were completed and the bridge again put in operation. He said another reason that the engines have not given perfect satisfaction is, that they are run at a much higher rate of speed than their designers ever intended that they should run. Instead of raising or lowering the span at the rate of 2 ft. per second, as required by the specifications, it is generally moved at the rate of 3 or more feet per second; hence there is a tendency to shake the engines to pieces and to loosen the connections.

He further remarked that the force required to operate the bridge is a large item in the expense account, three engineers, two signalmen, four policemen, and one man to shovel coal, clean the machinery, oil bearings, etc., being required to make up the shifts for 24 hours. The cost of operation is said to be about $1 000 per month during the navigation season. He understood, however, that the author would in future designs use electrical power and make such other modifications as to reduce the operating expenses to about one-half of the amount given, depending on the weight of the bridge and the local requirements.

Foster Crowell, M. Am. Soc. C. E., thought that the author in speaking of the jack-knife construction refers to a structure of two parallel folding girders, and that those spoken of by Mr. Long were modifications of the bascule type. The old-fashioned jack-knife bridge evidently could not be paved unless the supports were made entirely Mr. Crowell.

Mr. Crowell. free from the floor, which is impracticable. The pavement on the Halsted Street bridge he believed was wooden blocks, which would not be a great weight on a bridge of this length. While a permanent pavement would be a desirable thing, it does not seem to be a very serious matter.

He understood there was a report that the annual expenses of maintaining the Halsted Street bridge would be about $150 000, and that when a bridge of the same type as this was recently in contemplation not far from New York City, the authorities abandoned the idea on account of this expense.

CORRESPONDENCE.

Mr. Heermans. T. W. HEERMANS, Esq., said that in describing the construction, erection and operation of the machinery designed and erected by the Crane Elevator Company for the operation of the Halsted Street lift-bridge, it would, perhaps, be well to consider the subject under the following heads :

1st. The general plan and arrangement of power-house.
2d. The determination of power required.
3d. Type of engines to be used.
4th. Methods of connecting gearing to drum shaft.
5th. Mounting of the drum shaft and gearing.
6th. Friction clutch used in connection with gearing.
7th. Method of piping and running engines.
8th. Counterweights.
9th. Method of setting counterweights.
10th. Cable fastenings.
11th. Method of connecting cables to span.
12th. Water counterbalance.
13th. Hand-power operating device.
14th. Signaling device.
15th. Peeper.
16th. Suggestion for ascertaining power required for operation.

First.—In the general plan and arrangement for the machinery in the power-house, ample space had been set aside by the engineer for the machinery, and consequently the only requirements were that the best use possible be made of this room, so that the machinery be readily accessible for maintenance or repairs. This was accomplished by placing the boilers on one side of the engine-room, with their fire doors towards each other, and sufficient space between them for fire irons or for renewing the flues in the boiler when necessary.

Mr. Heermans.

This arrangement of boilers allowed the engines to be placed centrally in the engine-room, with their working end readily accessible and near the firing space. It was so arranged that the man in charge of the machinery, in caring for his boilers, would also be near the engines and operating levers when any signal is given from the operating house on the span. The engines were connected with the drum shaft by spur gearing, and are clearly shown on the plans submitted with the paper, which show, also, what other arrangements have been made with respect to the machinery.

Second.—The determination of power required for operating the span has been very thoroughly gone into by the author in his paper. The figures made by him, or rather the results arrived at, were similar to those obtained by the writer. The proportioning of the gearing is such that the piston travel of the engine is to the motion of the bridge or span as 500 is to 158, making the pressure available on one piston equivalent to a disturbance of the balance between the bridge and the counterweights (with 100-lb. boiler pressure and the span uniformly balanced) about 20 000 lbs. This appears, from all experiments made, to be ample for overcoming the inertia and friction. No absolute data has yet been ascertained as to the amount of power required to start, accelerate and keep the bridge in motion, but this matter is now being considered by the city engineer, and experiments will doubtless soon be made that will give reliable data.

Third.—The type of engine used for operating the machinery is one built by the Crane Elevator Company, and used largely in the steel plants for operating the transferring cables, cranes, etc., and is of the steam reverse type. While this engine is not as economical in the use of steam perhaps as some link motion engines, its construction is so much more simple that, like the valve motion used with steam pumps, it has come largely into general use where such engines are employed, and receive a maximum amount of use and minimum amount of care.

Moreover, as the engines are standing for a large portion of the time, it is easy to make steam for them, as the fires under the boiler may be kept in more uniform condition.

Fourth and Fifth.—The method of connecting the gearing to the drum shaft was such as to admit of the removal of any of the gears without disturbing the machinery. In other words, should any one of the gears forming the two trains of gearing connecting the engines with the drum shaft be broken, it might be removed in a short time without disabling the operation of the span.

Sixth.—The friction clutch used in connecting or disconnecting the engines from the drum shaft was of special design, and made necessary by the position in which it was placed. These clutches are of the Weston type, and are set up by a wedge and toggles operated by a screw passing through a stationary nut.

Mr. Heermans. *Seventh.*—The plan or method of running the piping was arranged so that both engines are fed from a main header or drum supplied by independent pipes from the two boilers, thus making it possible to use either or both the boilers, as well as either or both the engines. In addition to the ordinary throttle valve, which is operated by a lever easily reached from the operator's position, a small by-pass valve was supplied, having an area of a ½-in. pipe. This valve is kept continuously open on both engines, so that the chests of these engines are kept supplied with steam at boiler pressure. The chests are also provided with steam traps for removing the water of condensation. It will be readily understood that with this connection, either engine can be placed in commission instantly by opening the throttle valve. In practical running it is customary to keep both engines in gear, allowing the one not used to be driven by the other. The small quantity of steam passing through the ½-in. by-pass valve, being of so small importance, is immaterial, and the advantage gained of being able to throw in the engine not in use instantly by opening the throttle valve is of much more importance.

Eighth.—The arrangement of counterweights was very clearly explained by the author. These counterweights, it will be remembered, are in 16 groups, each group being carried by a double cable, having its bight at the counterweight, and the two ends at the suspension pin on the span.

Ninth.—The method of setting these weights was as follows: Wrought-iron stirrups were placed over a girder built in the construction of the tower near their highest point of travel, and to these suspension bolts I beams were fastened that would bring the bottom of the counterweights to a point 1 ft. below their highest position. The weights were then raised to the platform thus constructed, and placed in their cage or guides by a small contractor's engine. The counterweights when thus set form four groups, each group containing 44 weights, and each weight weighing about 3 200 lbs., and were then ready for the suspension cable fastenings.

Tenth and Eleventh.—The cable fastenings for these suspension cables have been referred to by the author, and consist of an equalizing sheave on each of the four sections of each group, and clamps through which the suspension pin passes at the opposite or span end. These clamps were rendered necessary by the distance between the cables where they passed over the sheaves, this distance being only 2½ ins. It was necessary to get some fastening that would securely hold the ends of the cables, and not occupy more room than the 2½ ins. mentioned above. These clamps are made of cast steel, and are clamped together with reamed bolts. The cables were measured to length, and fastened in them before they were delivered at the bridge, the only work required at that point being the lifting of the cables in position and the driving of the pin through the clamp on the span. When this was done, the span which was then in position was lowered by jack screws until the suspension cables were taut. It will be remembered that the counterweights were within 1 ft. of their highest position, consequently the span, when lowered on the cables, had yet 1 ft. to move before it reached its lowest position. This was easily accomplished, allowing the sustaining platform under the weights to be removed, and the operating cables from the power-house to be attached to both the span and the counterweights. Mr. Heermans.

Twelfth.—The water counterbalance and its connections, mentioned by the author, consist merely of balance tanks on the span and a 2 000-gall. tank in one of the towers of the bridge, with supply pipes that can be used at the lowest position of the span or at its highest position. The tank on the tower is kept supplied by the boiler pumps in the engine-room, either of which can be used. It is also arranged so that steam can be admitted for the purpose of keeping the tanks thawed out in winter.

Thirteenth.—The hand-power device is simply a series of pawls arranged in much the same manner as on a ship windlass and for the same purpose. The proportion of lever arms is such that the power of two men applied to the end of the brake handle will operate the bridge.

Fourteenth.—The signaling device is operated in much the same manner as similar devices used on shipboard, with the exception that its connection to the moving span must be in some manner that will admit of transmitting signals while the span is in motion.

Fifteenth.—The peeper, which is referred to in the paper, has been set in position on the bridge, but, owing to the use of soft coal by the tugs and steam barges, it is not entirely satisfactory, as it is difficult to keep the lenses clean, and without being clean they are not satisfactory. It is not difficult, however, without the use of the peeper to so gauge the height of approaching vessels as to raise the bridge to the necessary height to an absolute certainty, and in actual practice the operator acquires the necessary skill without the use of the peeper.

Sixteenth.—In regard to ascertaining the power required for operating the bridge, many plans have been suggested as to the most feasible test. The writer has suggested that a hydraulic cylinder be placed in the position of the friction clutch and used as a driver in actuating the drum shaft. A pipe leading from this hydraulic cylinder to a recording gauge could be made to draw a card of the pressure delivered at that point. This card could be divided, the spaces corresponding with the seconds during which the bridge was in operation, and points made on it with every revolution of the driving shaft to which the hydraulic cylinder is attached. With this it would be extremely easy to ascertain

Mr. Heermans. exactly the amount of power required at any given second, as well as the power required in starting and accelerating the motion. Such information would be extremely interesting, and it is to be hoped that at some future time such data will be obtained.

Mr. Rowe. SAMUEL M. ROWE, M. Am. Soc. C. E., said that as his connection with the erection of the Halsted Street lift-bridge was in a certain measure vicarious in this, that he represented the designer, so far as minor matters, in connection with the work that did not especially require his personal attention, and as the author had treated the matter of mechanical construction and operation of the bridge quite exhaustively, it would seem most proper and profitable that he should confine himself in discussion to those side matters of which he had especial knowledge and which might possess some interest in practical engineering.

A cursory examination of the river-bed by means of a long iron rod showed a mean depth of water over the whole breadth of channel of about 18 ft., but below this the earth was very soft, allowing the rod to penetrate some 6 ft. further almost without pressing it.

It was first understood that rock existed here at a depth of 35 to 40 ft., and on this basis the plan contemplating pile and grillage foundation for the main pier was based; but, after pressing the matter, permission was obtained to make two borings, one at each dock, to definitely determine its level.

One hole was put down about midway between where the two main caissons were since sunk at the south tower, driving 4-in. casings to depth of about 20 ft. An earth auger was used to clean the pipe and to extend the boring below.

Progress of the boring was slow and tedious on account of the yielding nature of the clay, and it was only by repeated returns of the auger that it was penetrated, the walls closing in immediately on withdrawal of the auger. At about 26 ft. a firmer clay was found and rock was supposed to be struck, but which proved, on sinking the caissons, to be fragments of limestone embedded in the hard clay overlying the rock.

The boring at the north bank showed much the same formation, the harder stratum overlying the rock being slightly thicker. On reaching the rock with the pneumatic caissons its true elevation was found to be at about 30 ft. below Chicago datum at the south piers and about 1½ ft. deeper at the north piers.

He said that in relation to a foundation they reasoned thus. Using Chicago datum, which was here only a little below ordinary water level, and placing the elevation of the bottom of the grillage, which would be the elevation of the cut-off of the piles, at minus 15 ft. there would be a length of pile of only from 14 to 16 ft., four-fifths of which would be in a very unstable material. The remaining one-fifth, should the pile reach the surface of the solid rock, would hardly afford that degree of stability that would seem to be required to insure against lateral movement of the pier. Mr. Rowe.

He thought that when it is considered that the bridge is a piece of mechanism, in which any distortion from this source would be exceedingly mischievous, if not fatal, it would be seen that safety requires that the masonry should go to the rock. The fact that these piers may be subject to violent shocks from collisions from lake vessels of 4 000 tonnage, and over, either on the pier or on the span, gives force to the objections to the plans originally made.

Consequently four pedestal piers 12 ft. square were substituted for the two long ones and timber caissons were built on shore, launched into the river and floated into position. These caissons were built 18 ft. square, of hemlock timber, the walls consisting of a double wall of 12-in. square timber chamfered off at the lower 2½ ft., forming a cutting edge and roofed at about 8 ft., with three courses of 12 x 12 in. timber. The crib was built above the roof of the working chamber, a single wall of 12 x 12 in. timber with ties of the same crossing alternately in the center, to such height as was necessary to receive the base of the masonry. Of course this could only be approximated, and when the caisson reached the rock, some of the masonry courses had to be recut.

After anchoring the caisson in place, concreting was commenced and continued until the crib was filled, after which the masonry was commenced, laying courses slightly larger than the neat dimensions of the pier, to meet any tilting movement of the caisson in sinking.

When the caisson cutting edge was resting on the rock and all excavation cleaned except such fragments of rock or boulders as could be utilized in filling, all interstices under the cutting edge were chinked with concrete deposited dry and rammed into place, after which the working chamber was filled with concrete in the same manner, except that water was increased as leakage diminished. As soon as the caisson was fully sealed and such portions of the working shaft removed as was practicable by means of a wooden curb built around it, the masonry was brought in to its neat dimensions and finished.

The anchor bolts were set with a template and built into the pier.

The masonry was built of Cleveland (Berea) stone of best quality in courses from 2 ft. to 18 ins. in thickness, the stone being laid to form the face and angles, the backing consisting entirely of concrete well rammed.

The cement used was a German Portland—the Sphinx—used in the proportion of 1 part of cement to 2½ parts of good, medium sand, tempered before adding as much broken stone as it would take, the result being a very excellent quality of concrete.

The question of guarding against the movement of the abutments

Mr. Rowe. by reason of the tendency of the river banks to press toward the river channel, thus bringing into play another possible disturbing element, was early raised.

He said that most engineers are aware the Chicago River was originally a shallow slough or creek, and in making the harbor and docks as they are now found, the channel has been deepened, and large quantities of earth have been removed from the channel and deposited on the bank adjacent, and although supported by a row of piles driven close together, timbered, and in most cases anchored to piles some distance back, yet there is a tendency to slide toward the stream.

Not only does the material removed become soft and unstable, absorbing water readily, but the formation of which the river banks consist being mostly a soft, stiff, tenacious clay, shows this same tendency, only in a less degree, to move toward the unsupported side.

Many instances could be cited where the wing wall of the abutments of the Chicago bridges have been broken and the face wall tilted toward the channel, and it is presumed that the same will hold true as to any heavy building erected on the dock, only perhaps in a less degree.

To guard the bridge pier and the machinery room against displacement from this cause, he stated that a clear space had been preserved between the machinery room and the abutment, and an elaborate anchorage was planned for the abutment.

Five sets of four piles each were driven deep into the ground about 40 ft. back of the face of the abutment, and two iron rods from each set of piles connect to cast-iron washers bedded in the concrete abutment and drawn tight by nuts at the anchorage.

Notwithstanding these precautions, the wing walls have cracked through the entire depth, showing a slight tilting forward. It seems as if the anchorage should be heavier and should also be placed deeper and be reinforced by a mass of masonry concrete, to render it entirely effective.

The measurements for the location of the bridge were made with a steel tape, which was carefully compared with standard measuring rods furnished by the Pittsburg Bridge Company and found to agree exactly with 25 lbs. pull upon the tape, the tape being supported; and the rods and the tape were found to agree with a standard 200-ft. measure in the corridors of the City Hall at a temperature of 70° Fahr.

The base line for the location of the bridge was an arbitrary line parallel to the center line of the street, both north and south, but, owing to the jog in the street at the river crossing, this base line corresponded with the curb line on the west line of the street northward, and on the east curb line southward. Using a point on this base line near the middle of the river as the middle of the bridge, the center line of the bridge was fixed by calculation at an angle of $12^\circ\ 16\frac{2}{10}'$ to the right, and reference points on the street were set, from which all work was located. A practicable point was chosen on each dock by which two auxiliary base lines were turned from this center line of the bridge and intersecting the first base line, which enabled the engineer to fix convenient points for location of the main piers, etc. The true centers of the main posts of the two towers corresponding to the centers of the caissons were the main points located, and when erection commenced, these main posts were very carefully set. Mr. Rowe.

The angles were carefully turned with the transit and calculated, and, when practicable, distances were checked with the steel tape.

From this basis every part of the foundation was laid off, even to the anchor piles back of the abutments.

The main posts over the piers were first set, the inclined posts following, and when the first section of the tower was complete, the inclined posts were adjusted by means of the large screw at the base until the main posts were plumb, after which the erection was completed, the towers reared nearly 200 ft. high, and the truss joining the towers raised as a whole and bolted into its place without the least delay, showing that the columns were accurately located, that they were truly plumb and that the shop work of the Pittsburg Bridge Company was accurate. This result was creditable to the bridge company's engineer and to Mr. Kellog, Assistant City Engineer, who did all the instrumental work on the location.

During the planning and erection of this bridge there was a feeling of doubt as to the result, a feeling of wonder at the audacity of the design, and incredulity as to its success. This was owing largely to the great mass that it was proposed to handle and the very considerable height to which it was to be raised, and, more than all other considerations, its controllability—in short, whether it could be handled promptly, moved quickly, and brought to rest safely.

W. W. Curtis, M. Am. Soc. C. E., remarked that the problem of the erection of the Halsted Street bridge, so far as the towers were concerned, was by no means an easy one. At the base about 40 ft. square, at the top 180 ft. above, the tower was less than 11 x 40 ft. in the clear. The members to be handled were in some cases over 58 ft. long, the main post sections being 48 ft. long, and weighing over 5 tons. The best method of handling this work seemed to be by means of a traveler to pass up inside the tower; and such a traveler was designed 12 ft. x 30 ft., in plan 40 ft. high to the foot of two derricks, placed on the top. The width of 12 ft. was too great to clear the top, but it was intended to erect all but the cross girders between the tops of the rear columns with it, and then handle these and the large sheaves by derricks erected on the top of the work, then up. The traveler was erected on the ground, one section of tower put up, and Mr. Curtis.

Mr. Curtis. then, by means of blocks attached to the top of the four columns in place, the traveler was hoisted bodily through two panels, and supported on beams running from front to rear face of tower. This was repeated to the top, three hoists in each tower being required. This traveler weighed 20 tons, and as the drift between blocks when raised into its new position was only about 12 ft., with the blocks attached to the bottom of the traveler, which extended above some 60 ft., and during the lower lifts with a large side pull, due to the tower being much wider than the traveler, the operation was one requiring great care. To add to the difficulties, the first lift made, after being completely successful so far as the raising was concerned, through carelessness in placing on the beams on the second level, resulted in a complete wreck of the traveler, with loss of life. Being satisfied that the plan adopted was the correct one, a new traveler was built, and an attempt made to devise some attachment which would make a repetition of the previous disaster impossible. After consideration of various schemes, automatic stops, etc., such as are in use on elevators, a system of counterweights was adopted. A snatch block was attached to the same chains to which the blocks for hoisting the traveler were fastened, and through these was passed a steel cable, one end attached to one of the corners of the bottom of the traveler, the other to several yards of stone threaded on an eye-bolt. These four counterweights weighed slightly less than the traveler, leaving a very small amount to be handled by the four lines carried to the engine. Other lines attached to the counterweights and carried to the ground and passed around snubs gave absolute control of the machine, regardless of the engine. It was soon found the time to attach the counterweights was a small item, and the added security fully compensated for the lost time.

He thought that the expense of erection of such a bridge as this is very heavy, that possibly there might be some more economic method than that described, but he was not prepared to say that he would follow it in another bridge. There are various slight changes in design, which would much simplify the erection if the same method were followed.

The main sheaves, built up of plates and angles, are worthy of illustration, as being something new, at least as far as his knowledge extends, and well adapted for special uses. Such a sheave would be desirable only where the load to be carried by it was excessive; or possibly where a high velocity was necessary. It seemed at first that a cast sheave could be made to answer the purpose, costing less, but on asking prices on such a construction, it was discovered that the steel wheel could be built cheaper than the cast one. As an illustration of a bridge shop's method of doing machine work, he offers the following description: By referring to the drawing of the

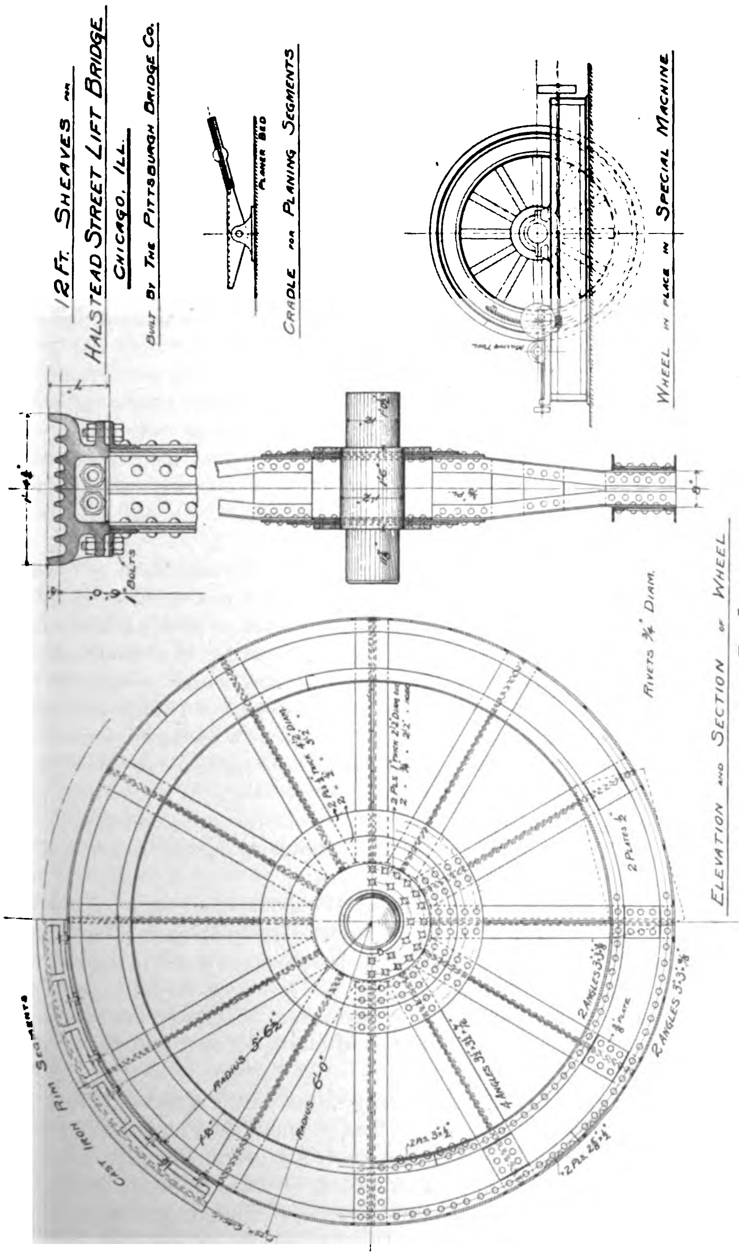

12 Ft. Sheaves for
Halstead Street Lift Bridge
Chicago, Ill.
Built by The Pittsburgh Bridge Co.
Planer Bed
Cradle for Planing Segments
Wheel in place in Special Machine
Rivets ¾" Diam.
Elevation and Section of Wheel
Cast Iron Rim Segments
Radius 5'-6½"
Radius 6'-0"
2 Plates ½"
2 Angles 3·3·⅜
2 Angles 3·3·⅜
4 Angles 3½·3½·⅜

FIG. 7

Mr. Curtis. sheave, Fig. 7, it will be seen to consist of a cast-iron rim resting on and attached to a steel rim of plates and angles. This again is supported by steel spokes of four angles running to a steel hub. The steel shaft and hub plates having been carefully finished, the sheave was built up in a special machine, as shown. The hub piece being keyed on the shaft, this was placed in the trunions of the machine, the spokes and rim added, bolted on, the wheel revolved and trued up. The hub plates were turned on both inside and outside edges, and the spokes were milled off on inner ends, and close contact with hub plates secured. After being made perfectly true, the holes were all reamed by machine, the rivets driven by hand, and the rim milled off. The interior surface of the cast rim having been previously planed by use of the cradle attachment to an ordinary bed planer, shown in Fig. 7, the sections were attached to the wheel, the holes reamed for turned bolts, and the wheel again revolved, with the milling tool replaced with one which turned out the eight grooves at one operation. When completed, the rim sections were all match marked and numbered, removed and shipped loose. The result when the sheaves were in place on the towers was very satisfactory and creditable to the carefulness of the shop superintendent, Mr. A. T. Nichols.

He remarked that one of the many points of skepticism as to this bridge on the part of the general public related to the effect of wind on it. And while to an engineer such evidence is neither necessary nor conclusive, it was worthy of notice that during the construction, the span, with the floor and all other surfaces which would be exposed to the wind when the work was complete, was hoisted to the highest position and left up at night for about a week, during which time occurred one of the most severe wind storms ever experienced in Chicago.

In such a structure the dead loads in the towers are so great and the necessary bracing to support the main section so large, that the wind does not enter into the question of design.

He called attention to the fact that the author had very clearly indicated the points of merit in lift-bridges. They are not adapted for general use, and cannot pretend to compete with a draw-bridge where this is admissible. For special locations, however, he believed their advantages are great, and for the condition of a railroad crossing, where a center pier is inadmissible, and the span over 100 ft., such a design is far superior to any other.

He further remarked that the only unfavorable criticism that has been passed on the Halsted Street bridge since its practicability and efficiency were demonstrated mechanically has reference to its first cost and operating expense; but that for both of these there is ample excuse in this particular instance, and the improvements provided for in future designs will modify greatly these objections.

E. SHERMAN GOULD, M. Am. Soc. C. E., thought this paper and its discussion was very interesting. In commenting upon it, he wished to do so under great reserve, since the structure belongs to a class of work somewhat out of the line of his own specialties. Mr. Gould.

The oral discussion, at the time of reading the paper, turned mainly upon the design of the draw, that is, as to whether the principle of the direct, vertical lift, the tipping up on end, the horizontal swing, or the doubling up, or "jack-knife," idea, is the true one. It is evident, *a priori*, that in this, as in all other engineering problems, local circumstances enter as important factors—frequently controlling ones. He would be willing to take it for granted that an important engineering problem so carefully studied on the ground by an acknowledged expert, as this was, had received the best possible solution for that particular case.

But passing to the general thesis, it would seem that the direct lift has much to recommend it on its own merits. The author claims that the time consumed in operating such a bridge is about 30% less than for a corresponding swing-bridge. This, no doubt, applies to the particular case, but if the proposition can be generalized, and made to apply to the class, it constitutes an advantage that it would require many drawbacks to offset. A draw-bridge is at best a make-shift, and in a busy city an almost intolerable nuisance, and whatever system shortens the duration of the interruption to traffic which its operation occasions must be, on the face of it, the best. One point struck him at once: There must be many craft which only lack a few feet of going under the draw when in place. For these a very short hoist suffices; whereas, in other systems, so far as known to him, the draw must be either shut or open to its full extent. Indeed on an emergency the draw could be lifted when loaded, which would be impossible with any bascule system.

It seems clear that the strains in the lift draw must be more uniform than in any other system. There is no change in their character, whether it is open or shut. As a mechanical principle, the direct vertical lifting of an object seems the simplest and smoothest way of removing it, when it is desirable to disturb the object as little as possible.

The comparative cost cannot, he believed, be determined upon general principles; each case must be a special one. He would be inclined to think that the operation of a lift draw would be nearly always more satisfactory than that of any other system, but that its cost might frequently be the greatest.

F. W. WILSON, Jun. Am. Soc. C. E., remarked that the author states that "should the rigging of the vessel, however, strike the span, the effect will be simply to break off the masts without injury to the bridge." It appeared to him that the effect of such a collision is possibly Mr. Wilson.

Mr. Wilson. underestimated, although the author states that it has occurred once with the results mentioned. The use of wire rope in the rigging of vessels is now so common that if the masts should be well stayed by wire guys, it would seem that the effect might even be serious, particularly if the wire ropes became entangled with the truss span, and in case the headway of vessels was such as to make a sudden stop impossible.

He would like to inquire how it occurred that when the engines broke down and the span was left suspended for some hours that the many devices described in the paper for meeting such emergencies were not called into play. For example, the water ballast, the additional counterweights, and the hand-operating arrangement.

He thought that a detailed statement of the total cost would be an interesting addition to the paper, and that it would at least be more satisfactory to know how much of the $200 000 was expended for substructure.

Mr. Wagner. SAMUEL TOBIAS WAGNER, M. Am. Soc. C. E., stated that in reading this valuable paper his attention had been attracted to the following general points which are of interest.

In all large cities where swing, draw, or lift bridges must be used there should be laws requiring the use of automatic gates across the open ends of both roadway and sidewalks when the bridge is open for the passage of vessels. Such places are specially dangerous to street traffic of all kinds, and some suitably designed automatic gates should be used wherever it is practicable. He thought it is rather surprising that in a city operating as many movable bridges as Chicago there are no existing laws bearing upon this subject. In a railroad grade crossing there is a chance of the trespasser not being struck by a train, but the result of stepping or driving off the open end of a movable bridge is a sure one.

The matter of the operator in the house on the bridge being sure that his signals to the engine-room have been understood is one of importance under the existing conditions, and repeating the signal is a good way of avoiding trouble. He remembered having seen on a lake steamer some years ago an automatic electrical device connecting the pilot-house with the engine-room, which enabled the pilot by means of different sounding bells by night, or by colored signals by day, to tell immediately whether the engineer had obeyed his signal. The use of this device was occasioned by a steamer running into a swing-bridge at Buffalo through a misunderstanding by the engineer of the pilot's signal. This was only another instance of the value of automatic machinery for safety appliances.

In specifying the steel to be used for a bridge of any kind, in view of the existing knowledge of the metallurgy of the metal, he would always specify: "All steel to be manufactured by the open-hearth process, and all eye-bars to be of acid open-hearth metal," and thus exclude the use of the Bessemer process. This is on account of the uniformity and homogeneity of the open-hearth product as compared with the Bessemer. The words of Mr. H. H. Campbell, in a paper on the "Open-Hearth Process," read before the International Engineering Congress in August, 1893, and published in the *Transactions* of the American Institute of Mining Engineers of that date, express his views. Mr. Wagner.

"Uniformity and homogeneity, therefore, are two of the most important factors in the comparison of the merits of the Bessemer and open-hearth product; but unfortunately no conclusive testimony can be given to the skeptical or even the careful mind, although *ex-parte* arguments are easily constructed. No one conversant with the facts doubts that Bessemer heats can be made which are as homogeneous throughout as any open-hearth charge as was ever melted. No one doubts that in good practice the proportion of Bessemer heats which are not homogeneous is a small percentage of the whole number. But the question is not as to the homogeneity of 99 heats; it is about the quality of the hundredth. And it is not one single test of this hundredth charge that is required, but a large number of tests taken from all parts of the cast. One piece of steel differing radically from the rest wipes away all favorable arguments drawn from any number of other tests indicating homogeneity. The foregoing comparison of the open hearth and converter may not be a convincing argument against Bessemer metal. It may justify engineers in using the cheaper article in many structures, but it will also sustain the more cautious members of the profession who refuse to incur a known or a probable risk."

He added that the author does not say whether he has specified any chemical analysis for the steel in this structure, and it would be interesting to know what was done in this direction. Probably it is not fair to the manufacturer to give both physical and chemical requirements, but in view of the history of the failures in steel, it does not seem safe to omit giving a reasonably low limit for phosphorus in the specifications.

Horace E. Horton, M. Am. Soc. C. E., remarked that the author gives portions of the specifications for the work. In the way of discussion it occurred to him that further extracts from the specifications under which this work was built might be interesting. Mr. Horton.

"Contractor" * * * "for the machinery" * * * "shall give the city of Chicago a bond for the sum of $50 000" * * * "as a guaranty for" * * * "successful operation of the bridge, and this sum shall be collected from the bondsmen and retained by the city of Chicago in case said contractor fail to make the bridge operate successfully."

"Substructure is to be paid for upon completion and acceptance thereof by the commissioner of public works, but the remainder of the work will not be paid for until the bridge is completed and accepted."

"Hydraulic buffers are to be designed by the engineer and contractor's expert jointly." * * * "All apparatus or machinery not

Mr. Horton. herein specified which may hereafter prove necessary to operate the bridge properly and satisfactorily."

"At any time before the bridge is accepted, should the commissioner of public works decide that any apparatus not covered by this specification is necessary to the successful operation of the structure, such apparatus shall be furnished and put in place by the contractor without extra charge."

Such, he wished to state, were the conditions presented to contractors. They were asked to give bonds in the sum of $50 000 forfeiture upon failure to make the structure a success, and no prudent man will undertake work under such stipulations at ordinary profits. There were no plans of machinery. Several tenders were, however, made for the work under the harsh conditions outlined.

The only detail of the fixed structure the author describes at any length is the ball and socket screw adjustment of the rear bent of the tower, which he implies cost extra money. The sketch Fig. 8 clearly shows adjustment to be impossible, except as the pedestals are moved upon the masonry. He ventured to suggest that the author in future designs for lift-bridges will eliminate the ball and socket screw adjustment for back bent of towers, because there are many ways to accomplish the adjustment, which will "adjust" beyond any question or argument.

He believed that the ability the Halsted Street bridge to withstand the shock of collision with moving vessels can best be shown by experience.

There can be no argument, he thought, as to the necessity of something other than the pivot draw-bridge under the conditions existing in Chicago. The Chicago River, which is the harbor, approximating 200 ft. wide between dock lines, with a demand for bridges at every street of 60 ft. in width, real estate adjacent, of such value as to preclude the purchase of property to allow a pivot bridge to be swung from one side of the river. In fact, there should have been developed folding or lift-bridges 20 years ago. The public were very slow to recognize the necessity for change in design, and up to this time only four structures of the folding or lift type have been built (two completed and two approaching completion). The next few years, he thought, will see considerable evolution in design for Chicago river lift or folding bridges. The first example is the folding bridge on Canal Street, 32 ft. wide by 80-ft. span, which cost the city $18 per square foot of the area of the movable parts. The second structure, the Halsted Street lift span (subject of this discussion), is 52 ft. wide by 118 ft. opening, and cost the city $35 per square foot of opening. The third structure, Van Buren Street (not fully completed), bascule type, designed by the late William Scherzer, M. Am. Soc. C. E., 58 ft. wide by 108 ft. opening, cost $24 per square foot of opening. The fourth is the Metropolitan Ele-

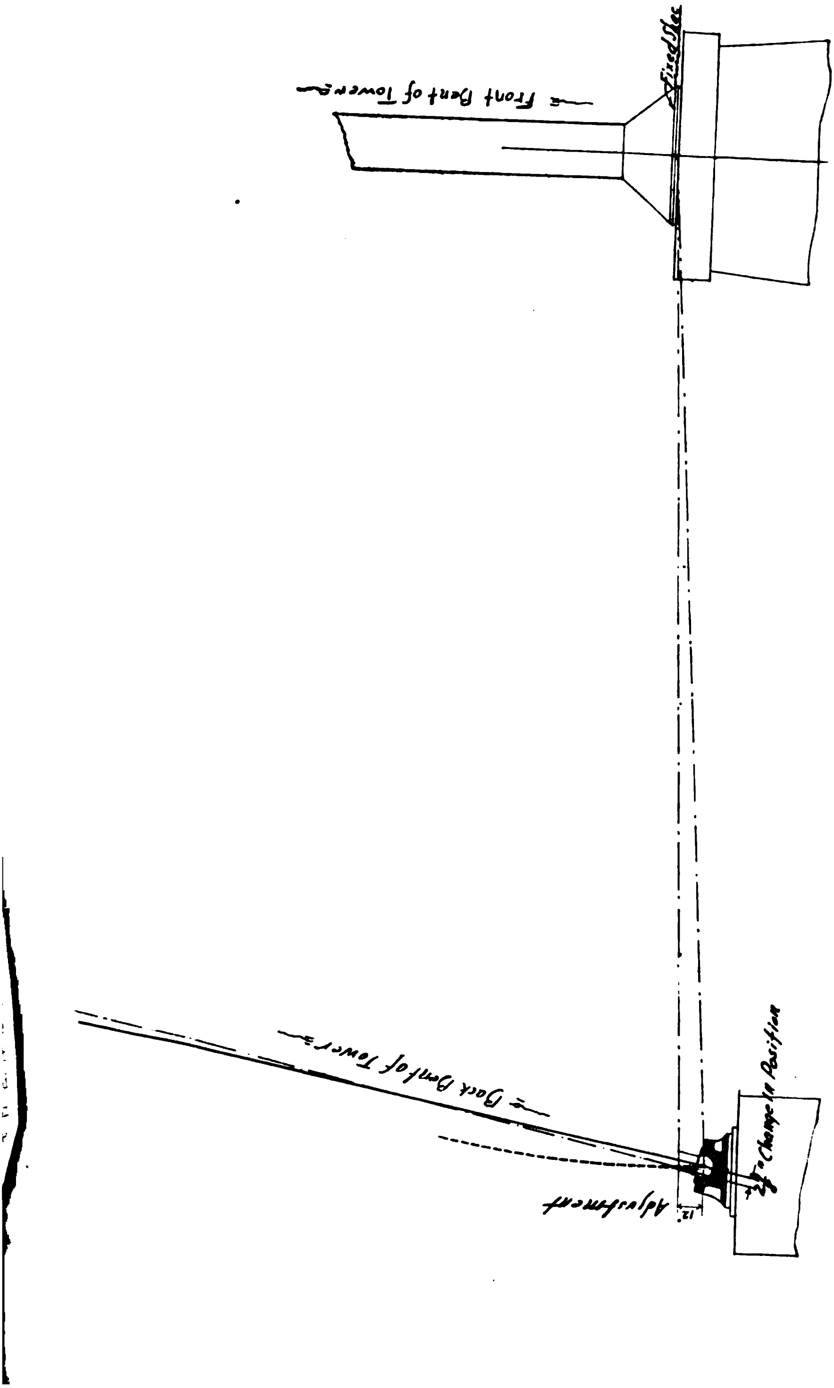


FIG. 8.

Mr. Horton. vated Railway span, a four-track structure of the same general design as the Van Buren Street bridge.

The Halsted Street structure has been in use for some time, and has given fairly satisfactory results, leaving much to be desired, however, in the way of economy of maintenance, as well as certainty of operation.

He regretted that the author did not give particulars of the failure to operate, whereby the lift remained at its extreme elevated position somewhat over 24 hours. His understanding was that it resulted from the breakage of a pinion in the power operating gear. This calls attention to the fact that the hand moving appliance spoken of can be made of use at such times as the power operating machinery is in order, and not under other conditions.

As to maintenance, he thought the 14 000 ft. of wire rope in use on the Halsted Street bridge, of necessity to be renewed at short intervals was somewhat appalling, and that it is more than likely the apprehension of failure, and the certainty of the wearing out of wire rope necessary to manipulate bridges of this type accounted for the seeming want of confidence of both the public and engineers in such structures.

The only example that had come to his attention, of a lift-bridge other than the Halsted Street one, is the bridge on the West Shore Railway across the Erie Canal, at Syracuse, N. Y., designed by Albert Lucius, M. Am. Soc. C. E., and built by the Hilton Bridge Works, of Albany, in 1882, this structure being a double-track railroad bridge on a skew, 104-ft. span, the lift being about 8 ft., the motive power being a water motor worked by pressure of Syracuse city water. There was an interval of fully 10 years as between the building of the West Shore railroad bridge at Syracuse and the Halsted Street bridge, which is reason for the conclusion that this class of design is not a favorite.

Mr. Waddell. J. A. L. WADDELL, M. Am. Soc. C. E., remarked that it was fortunate that Mr. Treadwell was present at the meeting at which the paper was read, for he was able to answer many of the questions raised in the discussion. On this account, in replying to the various discussions, he would omit all reference to those points dealt with by Mr. Treadwell.

Answering Mr. Skinner, he stated that his first design for rear column adjustment involved the use of "differential loose packing plates and hydraulic jacks"; but that he abandoned it for the reason that such an adjustment is troublesome to make, and would, in consequence, in all probability be neglected, while with the design adopted the trouble is reduced to a minimum.

Answering Mr. Long, he said that the folding bridges of Chicago are planked and not paved. It would be difficult to keep paving blocks in place when the entire floor is lifted continually from the horizontal to the vertical.

Answering Mr. Wilson, he understood that there had been two collisions of vessels with the Halsted Street bridge, and that the structure had not been injured to the slightest extent. A glance at the bridge is almost sufficient to assure one that no rigging, even with wire rope guys, can do it any harm. Mr. Waddell.

The failure to use the hand-power apparatus when the break-down of the engine occurred was not due to any inefficiency thereof, but because it was considered best to interrupt wagon and pedestrian traffic rather than to interfere with navigation. No one imagined at the outset that the operation of the bridge would be interfered with more than a few hours; and it was only because of a complication of peculiar circumstances (involving a strike of foundrymen) that any difficulty was experienced in getting a new gear wheel.

Answering Mr. Wagner, he stated that his original specifications stipulated the use of open-hearth steel only, but that he was forced to accept Bessemer. In the building of this bridge he was by no means a free agent, so had to make many concessions which he did not approve of, deeming himself fortunate in being allowed to build the bridge at all.

If he were to enumerate all the unnecessary difficulties encountered by both the contractors and himself from start to finish, far more space would be occupied than would be permissible. He thought it sufficient to say that until the span was hung neither they nor he could feel at all certain that they would ever be allowed to finish the bridge, such being the prejudice against it on account of a preconceived notion among engineers as well as laymen that it would be impossible to move such a great weight in any reasonable time.

Answering Mr. Horton, he acknowledged that the specifications were severe and "harsh," but would say that in preparing them he had no choice in the matter; as the city officials would not consider for a moment the building of such an innovation, unless the contractor would guarantee the successful operation of the bridge.

The papers for bidding upon were prepared under high pressure, and were made as complete as the limited time permitted; moreover, the only portions of the machinery left to the contractor to design were the steam machinery with its connections to the operating drums, and the hand-power apparatus. As the contractor was compelled to guarantee the operation of the bridge, it would have been manifestly unfair to handicap him by forcing him to use steam machinery of a design and power determined without reference to him.

As for maintenance and repairs of wire rope, he believed that, owing to the large factors of safety adopted, in all probability there will be no large expenditure necessary for many years to come.

The automatic gates suggested on page 11 have since been put in for the footwalks, but not for the main roadway. They operate very satisfactorily.

Mr. Waddell. In conclusion he desired to state that, while in making a design for another lift-bridge there are many improvements which he would introduce (principally in the line of economy of operation), he was well satisfied in every particular with all of the details of this structure; for everything worked just as it was designed to work, and there was no cutting or fitting necessary to ensure this result. Moreover, most of the important changes now contemplated would have been made in this case, had he been at liberty to design according to his own wishes. On this score, though, he desired to make no complaint, for he was well content in having had an opportunity to prove the practicability of his lift-bridge designs, even with the accompanying irksome restrictions.