Yours faithfully,
J. A. L. Waddell.

BRIDGE ENGINEERING

BY

J. A. L. WADDELL

C.E. (Rens. Poly. Inst.); B. A.Sc., Ma.E., D.Sc. (McGill Univ.); D.E. (Univ. of Neb.); LL.D. (Univ. of Mo.); Kogakuhakushi (Doctor of Eng., Imp. Univ. of Japan)

Correspondant de l'Institut de France dans l'Académie des Sciences; Correspondiente de la Real Academia de Ciencias y Artes de Barcelona; Corresponsal de la Sociedad de Ingenieros del Perú; Knight Commander of the Japanese Order of the Rising Sun; Ordre de Bienfaisance de la Grande Duchesse Olga de Russie, Première Classe; Second Class Order of the Sacred Treasure of Japan; Second Class Order of the Sacred Grain of China; Cavaliere del Ordine della Corona d'Italia; Consulting Engineer New York City; Member of the American Society of Civil Engineers; of the American Institute of Consulting Engineers; of the Franklin Institute; of La Société des Ingénieurs Civils, Paris; of the Engineering Institute of Canada; of the Western Society of Engineers; of the Society for the Promotion of Engineering Education; of the American Association for the Advancement of Science; of the American Society for Testing Materials; of the International Society for Testing Materials; of the American Railway Engineering Association; of the China Society of America; of La Société de Géographie de France; of the National Conservation Association; of the National Economic League; of the Liberal League; of the Authors' Club, London; and Honorary Member of the Chinese Institute of Engineers; of the Association of Chinese and American Engineers; of the Chinese Railway Association; of the Asociacion Nacional de Ingenieros Industriales de Espagña; of the Kogaku Kyokai (Engineering Society of Japan); of the Engineers' Club of Kansas City; of the Société Internationale d'Études de Correspondance et d'Échanges Concordia, Paris; of the Phi Beta Kappa Society; of the Sigma Xi Society; and of the Tau Beta Pi Society

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CHAPTER XXVIII

MOVABLE BRIDGES IN GENERAL

Movable spans are required in bridges crossing navigable streams when they are not high enough to provide proper clearance for passing vessels. Before taking up the subject of movable structures, it will be well to consider the relative advantages and disadvantages of high and low bridges for the crossing of great rivers. As a rule, there is very little difference in the first cost of a high and of a low bridge for any such crossing, what little there is generally being in favor of the latter and seldom amounting to more than ten per cent. Each pier of a low bridge is cheaper than the corresponding pier of a high bridge; but this saving is offset by the cost of the pivot pier, which is extra. The superstructure of a low bridge may be a trifle lighter than that of the corresponding high bridge, but the more expensive metalwork of the draw span generally overbalances this. It is in the low, short trestle-approaches that the low bridge costs less than the high one. As these approaches are generally built of untreated timber, they have to be renewed about once in every eight years, and the cost of their renewal is a regular fixed charge, which lessens the annual net income from the bridge. Herein lies the superiority of the low bridge for such crossings. Nor is this its only advantage; for, by its adoption, there is avoided considerable climb at each end of the structure. On the other hand, the low bridge involves some expense for operation in excess of that for the high bridge, which is quite an important matter when there is much river traffic, but which is of slight importance when the draw has to be opened only a few times per season, as is the case with bridges over most western navigable streams. Everything considered, whenever there is any choice between a high and a low bridge, especially when the stream does not carry much traffic, the author favors the low bridge, not so much because of its smaller first cost, but mainly on account of the less expense required for maintenance.

The history of movable bridges goes back into the dim and distant past, for bascules were used over the moats that surrounded castles during the Dark Ages, and the pontoon bridges of the Romans undoubtedly had portions that could be removed in order to permit the passage of vessels. It was not until the advent of timber trusses that it became possible to build structures across navigable streams of some size, and then arose the problem of providing a passageway for both vessels and bridge traffic. Bascules operated by hand power were first employed for this purpose, but as they were necessarily limited to very small openings, the next step was the evolution of the swing with either a pivot or a turntable; and when iron and steel took the place of timber, it was natural that the wooden rotating draw should be copied in metal. For many years the swing bridge served its purpose excellently, and even to-day it is still the most common kind of movable span; but with the advent of great business on the waterways its defects became apparent. In narrow channels the obstruction of the stream by the pivot-pier and the draw protection is a serious matter as far as navigation is concerned, and in many cases it affects materially the hydraulic regimen. Again, the time required for opening and closing a swing in a crowded city is far greater than the populace is willing to submit to without protest. Besides, the dock front adjacent to a rotating draw is not available for business. On these accounts the various kinds of lift bridges were evolved.

In this and the three following chapters, all of which deal with movable bridges, the treatment has been made general and descriptive; for, as explained in the Preface, it has been arranged that the author's former partner, Mr. Harrington, is soon to write in detail a complete and exhaustive work on the subject of "Movable Bridges." It is mainly for this reason that these four chapters on the subject do not illustrate any details.

Movable bridges may be divided into the following classes:

1. Ordinary rotating draws.
2. Bob-tailed swing spans.
3. Horizontal-folding draws.
4. Shear-pole draws.
5. Double, rotating, cantilever draws.
6. Pull-back draws.
7. Trunnion bascule-bridges.
8. Rolling bascule-bridges.
9. Jack-knife or folding bridges.
10. Vertical lift-bridges.
11. Gyratory lift-bridges.
12. Aerial ferries, transporter bridges, or *transbordeurs*.
13. Floating or pontoon bridges.

The ordinary rotating draws will be discussed at length in the next chapter.

The bob-tailed swing span is a variation of the ordinary rotating draw formed by shortening one of the arms and counterweighting it so as to balance the structure about the two principal vertical planes containing the axis of rotation. It is not a common type of construction because of the objectionable feature of unbalanced wind loads, to which it is generally subjected. It is needed in those localities where the pivot pier is at or near one bank and where the shore arm, if of the usual length, would interfere with buildings or prevent the use of valuable property. As far as the cost of construction is concerned, there can be but little, if any, economy in its employment; for the extra cost of the machinery necessitated by the unbalanced wind load added to the cost of the counterweights must offset the net saving in cost of superstructure due to the shortening of a moving arm and the corresponding lengthening of the adjacent approach.

The horizontal-folding draw is such an objectionable style of railway bridge construction as hardly to merit even a passing notice. It is, of necessity, applicable to only very short spans. It consists of a pair of girders spaced about five feet centres, with the rails attached directly to the top flanges, stayed at intervals by hinged struts like a parallel ruler, each girder being hinged at one end to the abutment upon which it rests, with the other end tied back to a short tower. Such an arrangement permits the girders to revolve laterally nearly ninety degrees, one bearing being located in advance of the other so as to make such a large rotation possible. Blocks are used under the outer ends of the girders to receive the live load reaction and thus prevent any moving load effect upon the tower. It would be difficult to design a structure more crude or unsatisfactory than this; and yet it is said that there are still many such bridges scattered throughout the New England States. In addition to its general loose-jointedness this type of movable span has the exceedingly dangerous feature of being wholly without track ties or real lateral bracing of any kind. What would happen to both it and the train in case of derailment of passing wheels would not be at all difficult to prognosticate! The unstiffened condition of the top flanges of the girders is a violation of an important requirement in scientific bridge designing. In case of a wreck involving either the loss of human life or personal injury, caused by a structure of this type, the jury should certainly find the railroad officials guilty of criminal carelessness for permitting such a glaring breach of safe construction to remain on their road.

The shear-pole draw is somewhat similar to the horizontal-folding draw, but is not quite so objectionable, as it permits of the use of a floor. It has a single leaf turning around a pivot at one end, the other end, while swinging, being suspended from the top of a two-legged shear-pole by rods which are connected to a pivot that lies directly over the pivot below. The shear-pole is stayed by guy rods. When the bridge is closed it forms a simple span supported at both ends. The employment of this type of opening span is not to be recommended.

Very few double, rotating, cantilever draws have yet been constructed. There is one, built many years ago, across the canal at Cleveland, Ohio; and a number of them at various times have been suggested and figured upon, including once a large one by the author. The advantages claimed for this type of structure are a wide waterway and the retreating of either span without serious injury when struck by a vessel before it is fully opened; while its disadvantages are excessive first cost, ambiguity of live load stress distribution, and the double cost of operating two independent spans. It is recognized, of course, that when electricity is used as the motive power, both spans can be operated by one man by means of a submerged cable; but in no case is it advisable, on account of prudential reasons, to handle a moving span without a man upon it to manipulate the machinery and to act quickly in emergencies. This question of single and double operation arises also in the case of double-leaf-bascule bridges. The double, rotating, cantilever draw consists of two swing spans, differing but little from those of the ordinary type, each resting upon a pivot pier and meeting at mid-channel, where they are (or should be) locked together so as to make the adjoining ends deflect equally and simultaneously. The other end of each swing span is locked to the masonry of the outer rest-pier, which has to act as an anchorage for the cantilevered live load.

Fig. 28*a* shows a layout of the Cleveland bridge referred to above. It is described quite fully in *Engineering News*, Vol. XXXIV, page 83.

It is not absolutely necessary to make the shore arms of the same length as the channel arms, because each or either swing may be a bob-

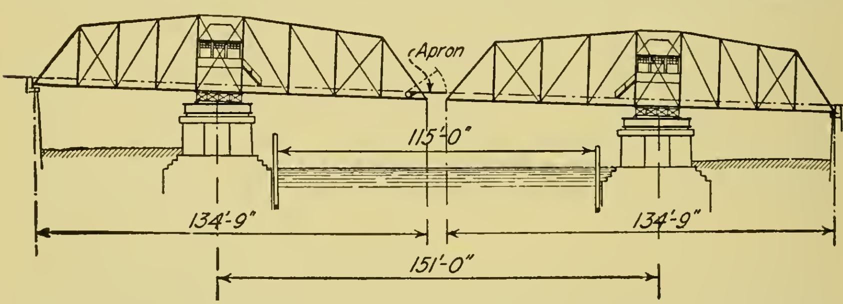

FIG. 28*a*. Double, Rotating, Cantilever Draw Bridge over the Cuyahoga River at Cleveland, Ohio.

tailed draw. In that case not only should the short end be counterweighted but also there should be added near its extremity a vertical surface of sufficient area to equalize the moments of the wind pressures on the two arms about the axis of rotation. The locking gear at the meeting ends of the two swings is an awkward and unsatisfactory detail to design. The most perfect device for this connection must, of necessity, be more or less loose and clumsy; and it is likely to give trouble in operation. While this type of bridge cannot be as rigid as the ordinary swing span type, nevertheless it is possible to make it fairly satisfactory and effective. It is not probable that many such structures will ever be built, because there are other and better types of movable spans, some one or more of which will meet any special conditions better and more economically than the double, rotating, cantilever draw.

The pull-back draw is also a very unusual type, and will always be so, for the reason that the first cost is great and its operation is expensive. This type may be divided into two classes: first, structures with one span over the entire opening, and, second, structures with two spans over the entire opening meeting at midchannel, as in the case of the double, rotating, cantilever draw. The first class requires a truss-bridge nearly, if not quite, twice as long as the width of channel between pier centres, the bottom chords thereof running on two groups of rollers that travel just half as fast as the bridge when the span is moved longitudinally. Although the shore arm may be made shorter than the channel arm, still its weight must be such that its moment will be somewhat greater than the tipping moment of the weight of the channel arm just as it leaves the farther pier. A disappearing platform will be required so as to leave space on the approach for the shore arm to move back, or else the whole bridge will have to be rotated slightly about a horizontal axis so that it can roll up onto the approach. Either method is very clumsy, and the operation of the bridge consequently must be slow. The double pull-back draw is similar to the single pull-back draw just described, except that the far end of each span has to be anchored down to a mass of masonry when the bridge is closed and ready for traffic, and the ends meeting at mid-channel must be locked together as in the case of the double, rotating, cantilever draw.

In the competition for designs for a movable structure to cross the entrance channel to the harbor of safety at Duluth, Minn., held about a quarter of a century ago, the author prepared and submitted a plan for a double, pull-back draw-bridge; and although he evolved a structure that would have worked, he was far from satisfied with the design, and in consequence, submitted another for a vertical lift—the first bridge of that type ever proposed in America for the passing of high-masted vessels.

In connection with this competition there was an amusing occurrence that illustrates the general futility of having engineers compete on plans. Designs had been called for on the basis of using the pull-back draw, the prize being one thousand dollars in cash and the engineering of the structure. The author's design for a vertical-lift bridge was selected by a Committee of five of Duluth's leading citizens as the best and most satisfactory of all the plans submitted, and it was decided to build upon it, provided the consent of the War Department could be secured. The chairman of the committee was a Norwegian, and a Norwegian engineer had submitted a design for a single-leaf, pull-back draw of mammoth proportions and a monstrosity in more ways than one—for instance, the railroad trains had to enter the structure on a twenty-five degree curve through one of the panels of one truss! Just think of steam railroad trains on such a sharp curve and what an invitation for derailment and disaster such an arrangement would be! A derailment there, even if it did not destroy the bridge entirely, would block the channel completely against navigation until the wreck could be removed and the structure repaired. The committee was firmly in favor of the vertical-lift design, but the president was insistent that his countryman receive the one thousand dollar prize, which he did by a compromise—the author being retained for a two thousand dollar fee to prepare preliminary plans for a vertical lift to submit to the War Department, with a promise of the engineering on the usual percentage basis for compensation if the application proved successful. The excuse given for not awarding the cash prize to the designer of the vertical lift was that "it pulled up and not back." In *Engineering News*, Vol. 27, page 168, and Vol. 28, page 390, will be found descriptions and estimates of cost for the various designs submitted in this competition. The outcome of the whole affair was that a special committee of U. S. Army engineers decided against permitting any bridge to be built across the entrance to the harbor of safety, toning down their adverse decision by terms of eulogy for the vertical-lift design. Years afterwards, however, the War Department permitted the building at the crossing of an aerial ferry, as being less dangerous for navigation than any other type of bridge.

There is described in the *Engineering Record* of July 31, 1897, a double pull-back draw over the River Dee at Queensferry, Scotland. It provides a clear opening of one hundred and twenty feet, and cost about $70,000. It is of the telescopic type, *i. e.*, each half of the opening span pulls back and telescopes into the approach span. This bridge must certainly be lacking in rigidity, and the transferrence of the wind loads to the piers can only be done by transverse bending of the truss posts of the approach spans, as the passage of the movable arm through its interior effectively precludes any attempt to provide vertical sway bracing except at the far end. If the vertical posts are properly figured to carry transversely the excessive wind load required by the British standard regulations, their sections must be enormous. Because of its inferiority to several other types of movable bridges, it is more than likely that no more structures of the pull-back type will ever be constructed.

Trunnion-bascule and rolling-lift bridges are treated at length in Chapter XXX, which deals with "Bascule Bridges."

Jack-knife or folding bridges were a freak design that passed out of existence more than a decade ago. Two of them were built in Chicago, but they proved to be so light and vibratory and were so continually out of order that they were soon removed. Each half of a jack-knife bridge consists of two steel towers, from the top of which are suspended by tie-rods the two leaves of the floor. These are hinged together at their point of junction, and when the draw is to be opened this point rises, the other ends of the leaves move downward, and each half of the floor assumes the position of an inverted V. In this position a portion of the space between the piers is left free for the passage of vessels; and it was claimed that "the raised floors form effective guard gates." Unfortunately, though, the said guards are badly placed, as there is left in front of each of them a big opening in the floor for animals and vehicles to fall into.

Concerning this type of structure in 1897 the author wrote thus in his *De Pontibus:*

"The jack-knife or folding bridge is a type of structure which is not at all likely to become common. There have been only two or three of them built thus far, and they have been often out of order; moreover, considering the size and weight of bridge, the machinery used is powerful and expensive. The load on the machinery while either opening or closing the bridge is far from uniform, and the structure at times almost seems to groan from the hard labor. The characteristic feature of the jack-knife bridge is the folding of the two bascule leaves at mid-length of same when the bridge is opened. The loose-jointedness involved by this detail is by no means conducive to rigidity, nevertheless these structures are stiffer than one would suppose from an examination of the drawings. The Canal Street Bridge, Chicago, is of this type; and its design is illustrated in *Engineering News* of December 14, 1893."

Anyone desirous of learning more concerning this defunct type of movable bridge is referred to *Engineering News*, Vol. 25, page 486, and Vol. 30, page 480.

Vertical lift bridges are treated at length in Chapter XXXI.

The gyratory lift bridge is another freak structure—impracticable, uneconomic, but exceedingly ingenious. The design was evolved and patented by Eric Swensson, Esq., C. E., of Minneapolis, for a crossing of "The Narrows" on Lake Minnetonka near that city. As far as the author knows, the proposed structure was never built. It was described in *Engineering News*, Vol. 59, page 367. It consists of a pony-truss or plate-girder span suspended by trussed hangers from trunnions bearing on a tower at each abutment. The draw is opened by revolving the main roadway trusses in an arc around the horizontal longitudinal axis marked by the trunnions. The upper portions of the trussed hangers carry counterweights equal in weight to the suspended span so that friction and wind are the only forces for the machinery to act against. Motors and gears are placed in the towers, the said gears engaging with circular racks attached to the hangers and extending over arcs of 180 degrees, so as to control directly the turning of the span. When the bridge is in its normal position, wedges are to be placed under the extreme ends so that the live load will be carried directly to the abutments and not through the hangers to the trunnions. Solely on account of its novelty and the ingenuity employed in its evolution, the illustration given in *Engineering News* is reproduced in Fig. 28*b*. This type of movable bridge is uneconomic in the extreme, the two most expensive features being the excessive length of the moving span, as compared with the horizontal clearance, and the two sets of operating machinery. If one will compare this structure with the vertical lift adopted as standard by the Southern Pacific Railway Company and illustrated in Figs. 31*h* and 31*i*, he cannot help being struck by the great difference in the economics of the two types. Another objectionable feature of the "gyratory lift" is the turning of the floor bottom upwards. This would preclude the employment of any kind of pavement, and would necessitate, for a highway bridge, the adoption of a plank floor—a detail that is incompatible with first-class bridge construction.

The aerial ferry, transporter bridge, or *transbordeur*, is a type of construction which may very properly be termed a cross between a bridge and a ferryboat. From the point of view of efficiency in transportation it is decidedly inferior to the former but somewhat superior to the latter.

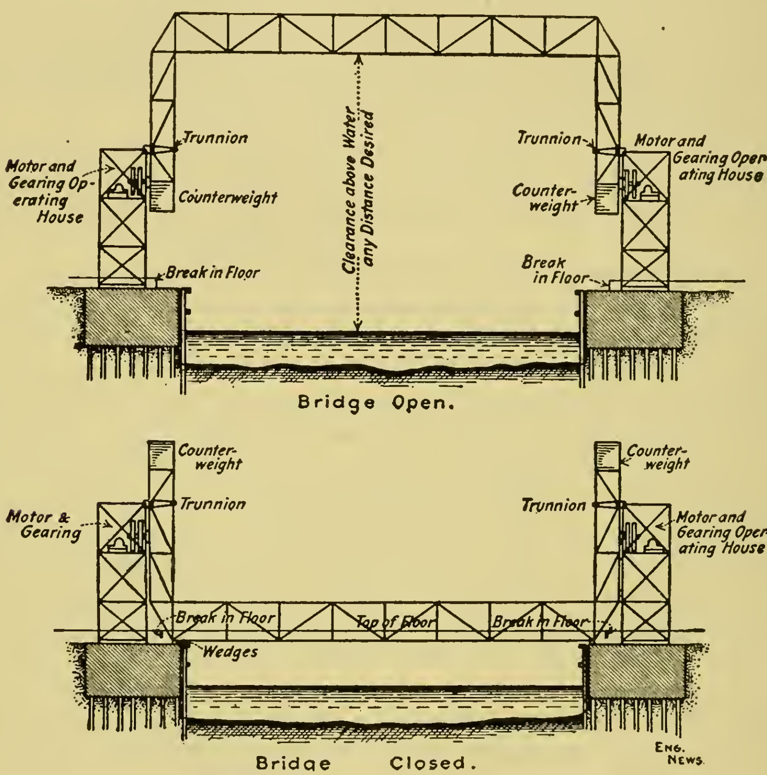

Fig. 28*b*. The Gyratory Lift Bridge.

Its excuse for existence is solely that the navigation interests will consent to its being built in certain localities where a real bridge of any kind, except one of long span and great vertical clearance, would not be permitted. It consists of two towers, an overhead span high enough to clear the masts of the tallest vessels, a track on the span, a car running upon the track, and a travelling platform suspended from the car. There is but one structure of this type in America, but a number of them have been built in Europe. The American one, as already mentioned in this chapter, crosses the entrance channel to the harbor of safety at Duluth, Minn. A description of it is given in *Engineering News*, Vol. 47, page 227. It consists of a riveted truss span of 394 feet supported on steel towers resting on pile and concrete foundations, and having the bottom chord of the span 135 feet in the clear above high water. The ferry-car is suspended by stiff riveted hangers from trucks running on tracks placed within the bottom chords of the trusses. It is proportioned to carry a loaded street car weighing 21 tons and a live load of 100 pounds per square foot on all the floor space not occupied by the car. In Fig. 28*c* is given a sketch of this bridge. It will be noticed that the ferry-car has to cross not only the canal but also a driveway on each side thereof. At each end of its travel it passes inside of the tower out of the way of everything and connects to a short ramp leading to the street. The ferry-car is operated by electricity at an ordinary speed of four miles per hour with capacity for moving much more rapidly should the necessity arise.

The first *transbordeur* built in Europe is the one at Rouen, illustrated in Fig. 28*d*. It was designed by a French engineer, Monsieur F. Arnodin, and a Spanish architect, Señor A. de Palacio. As the illustration indicates, the overhead structure is of the suspension type, which, owing to the long span and light live load that generally are ruling factors in aerial ferry structures, is eminently fitted for the purpose.

Other bridges of this type are as follows:

Transbordeur across the harbor at Marseilles, France, with a span of 541 feet and a car 33 feet by 39 feet. (See the *Proceedings of the Institution of Civil Engineers*, Vol. 167, p. 404.)

Transporter Bridge at Newport, England, with a span of 645 feet and a vertical clearance of 177 feet. (See same publication, page 405.)

The Widner and Runcorn Transporter Bridge over the Mersey, England, with a span of 1,000 feet (see *Proceedings of the Institution of Civil Engineers*, Vol. 165, p. 87).

Cableway at Brighton, England, with a suspension span of 650 feet and a car capable of carrying only eight persons. (See *Engineering News*, Vol. 33, p. 67.)

Transbordeur near Bilboa, Spain, with a span of 500 feet and a car capable of carrying 150 passengers, the time for transit being one minute. (See *Engineering News*, Vol. 30, p. 260.)

Transbordeur at Bizerte over the Canal (Tunis) with a span of 358 feet and a car 30 feet by 25 feet. (See *Le Génie Civil* of Nov. 21, 1903.)

Transbordeur over the Loire at Nantes, France, with a cantilever suspension span of 490 feet and a car 40 feet by 33 feet. (See the *Railroad Gazette* of August 26, 1904.)

Transporter Bridge across the Manchester Ship Canal, having a clear span of 1,000 feet. (See the *Scientific American*, of May 28, 1904, p. 420.)

Transbordeur at Martron, France, having a span of 460 feet and a car 46 feet by 38 feet. (See *Le Génie Civil* of Nov. 21, 1903, p. 35.)

The advantages usually claimed for the transporter bridge are as follows:

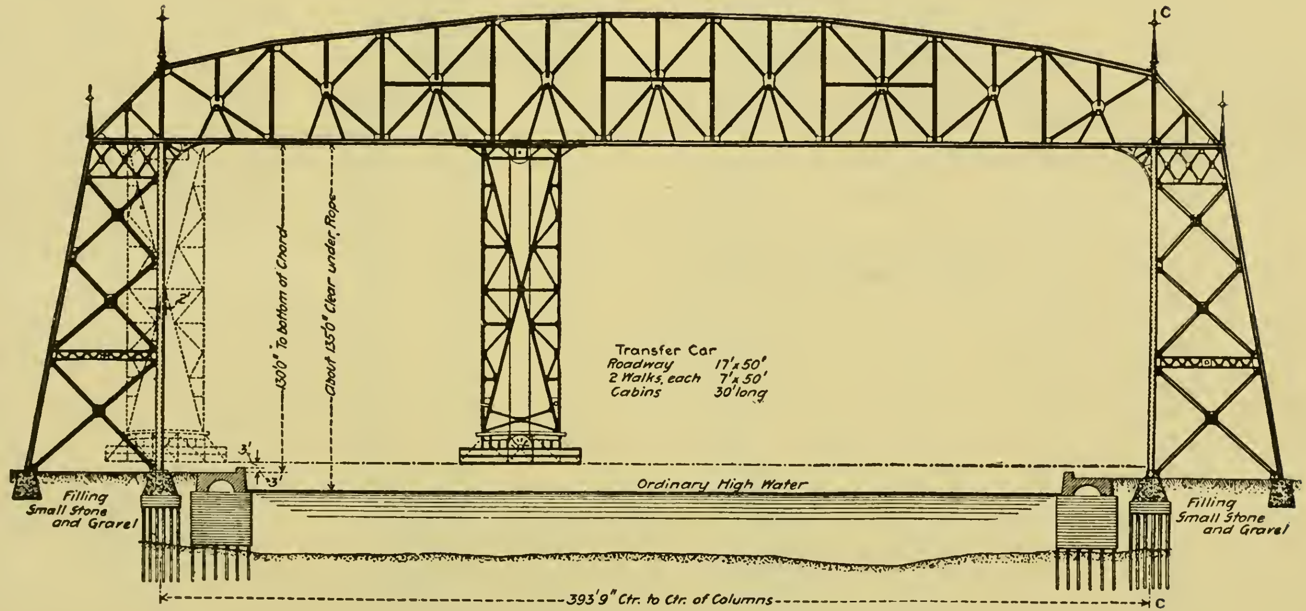

Fig. 28c. Transporter Bridge at Duluth, Minn.

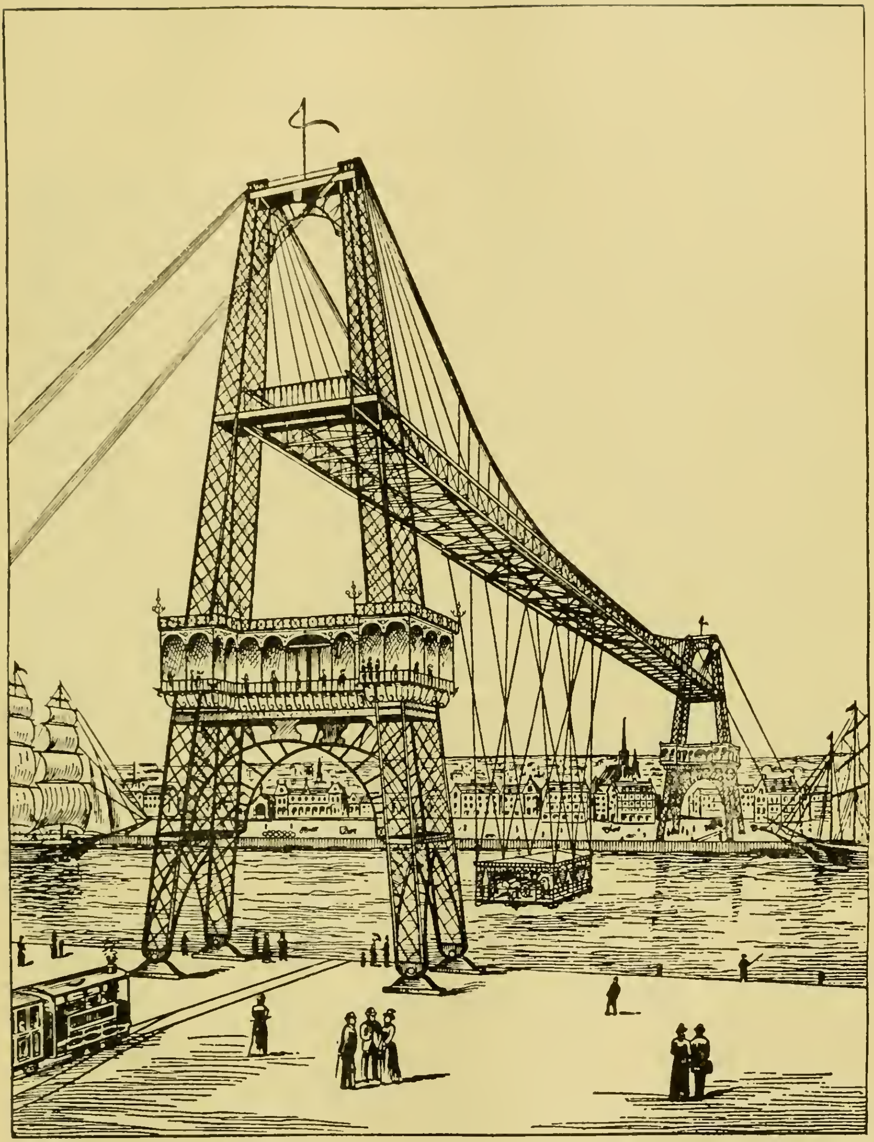

Fig. 28*d*. Transporter Bridge at Rouen, France.

1. The channel to be crossed is left entirely clear at all hours, without requiring vessels to make any special signals or modify their rate of speed any more than they would in case of a cross-channel ferry.
2. No increase of distance or ascent or descent is forced on the traffic in order to cross from one shore to the other.

The disadvantages are these:

1. The limited carrying capacity of the structure.
2. The long time usually required to cross.

If the author were ever called upon to design a transporter bridge, he would effect a great improvement by widening the structure so as to provide for a double track and would carry on it four or more cars. These cars would always travel upon the right hand track, and would run onto a single track at each end of span where they would discharge and take on passengers. Again, he would use powerful electric motors so as to travel at high speed. By these means, the carrying capacity of the bridge would be multiplied many fold and the time required for transit would be reduced to a minimum, because the intervals between cars could readily be made as small as one minute, requiring only sufficient time to unload and reload the foot passengers and vehicles. The car should be made double deck, the pedestrians being carried above; and the roadway should have a double track, the right one being for the use of a single street-car and the left for two, or possibly three, wagons. At the end of the trip the car would leave first, and the wagons would follow immediately, edging over to the right so as to permit of the ingress of the oncoming car, which in its turn would be followed by wagons to occupy the left hand side. While the vehicles would be going off and others getting on, the upper deck could easily be emptied of its pedestrians and refilled.

There is prevalent an idea that floating or pontoon bridges are employed only in communities where the inhabitants are absolutely too impecunious to build a permanent structure, and that they are a makeshift in every sense of the word, are expensive to operate, and require much time to open and close for the passage of vessels. This popular notion is not altogether correct, for there are some locations in which floating bridges with movable spans are not only legitimate construction but are truly economic. For instance, up to 1908 (and possibly to the present time) the Chicago, Milwaukee & St. Paul Railway Company was operating four pontoon draw spans, two of them having been in use since 1875 and one since 1883. They appear to have given satisfactory service and to have proved economical. Their life has been about twelve years and their first cost about twenty or twenty-five per cent of that of a permanent structure. Concerning these C., M. & St. P. R'y bridges, the reader is referred to *Engineering News*, Vol. 59, p. 474. It is quite true that floating draws are usually expensive both to operate and to maintain, notwithstanding the experience of the C., M. & St. P. R'y Co. to the contrary. The governing conditions must have been more favorable than those often encountered; for the author knows of a number of pontoon bridges that had to be abandoned soon after their completion because of excessive difficulty and expense in maintenance. Pontoon bridges have been built from time immemorial and are still much used for military purposes. It is practicable to employ a floating draw with fixed approaches of either spans or trestle; but, on account of the variation in water level, this expedient is resorted to generally only for temporary purposes. Pontoon bridges are often short lived, as the boats are occasionally carried far down stream during freshets, or are broken up by floating trees, logs, or vessels. Under adverse conditions they are very perishable and are easily put out of commission. There is one type of pontoon, though, that is a necessity in certain places, viz., those located at the ends of ferries where there are large variations in the water level. Such structures, strictly speaking, may not really come within the scope of this chapter. In *Engineering News*, Vol. 21, page 308, there is given a description with working drawings of a passenger ferry bridge for the New York, Lake Erie & Western Railroad; and in *The Engineering Record*, Vol. 48, p. 489, there will be found a very complete article treating of the New Orleans Railway Incline Bridge.

In *The Engineer* of June 28, 1912, there is described a novel and unique design for a floating bridge across the Hoogly River between Calcutta and Howrah, India—in fact, there are two designs, quite similar in character, as illustrated in Figs. 28*e* and 28*f*. The banks of the river are of mud, and the bed is silt so loose as to be incapable of supporting with safety any load whatsoever. On this account a floating bridge is a necessity. Messrs. Head, Wrightson & Co., the designers, have solved the problem in a masterly and clever manner. Each of their layouts consists of two approach spans of about 480 feet each and two bob-tailed swing spans having the longer arms 150 feet in length and the shorter ones about 70 feet. At the shore ends the approach spans rest on masonry abutments, and at the river ends both they and the swing spans are supported by immense pontoons, each composed of eight water-tight steel cylinders 15.5 feet in diameter and 220 feet long. In one design this platform of cylinders floats on the surface of the river, but in the other it is submerged, being firmly anchored into the mud by vertical rods attached to steel cylinders filled with concrete and buried therein. In both cases the pontoons are anchored up and down stream by chains attached to similar buried cylinders situated some 400 feet above and below the bridge tangent. If the pontoons float upon the surface of the river, the outer ends of the shore spans rise and fall with the changes in water level, thus putting heavy grades in the track; but if they are submerged, the rising and falling of the water will have no appreciable effect on the superstructure. Provision was made for repairing or removing, one at a time, the various cylinders without interfering with either the traffic over the

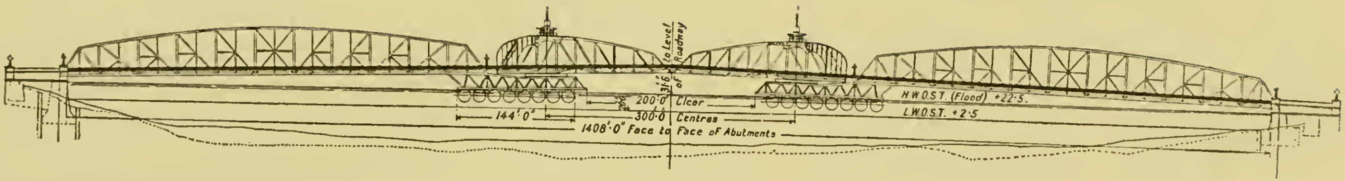

FIG. 28*e*. Proposed Pontoon Bridge over the Hoogly River between Howrah and Calcutta, India. Design No. 1.

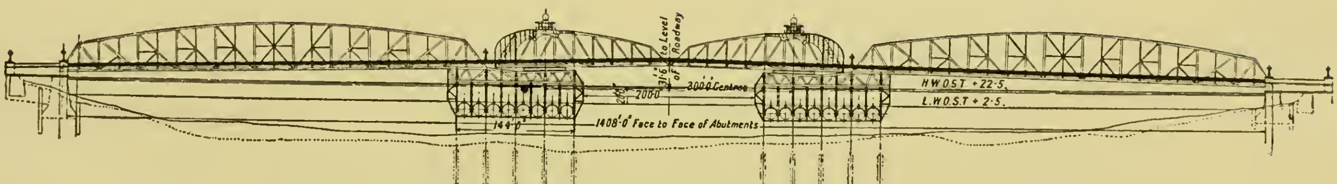

FIG. 28*f*. Proposed Pontoon Bridge over the Hoogly River between Howrah and Calcutta, India. Design No. 2.

bridge or the operation of the swing spans. For further details of these two designs the reader is referred to the columns of *The Engineer.*

In *Engineering News,* Vol. 70, p. 1,018, there is given a most interesting description of the new pontoon bridge over the Golden Horn at Constantinople. It has a clear roadway of 46 feet and two 18-foot sidewalks, the total length between abutments being 1,530 feet. The swing span, which is hinged at one end, can turn through 180 degrees. It is moved by propellers fore and aft, operated electrically. In the flanking portions of the bridge the pontoons are placed longitudinally, one on either side of the structure; and they carry trusses spanning transversely of the bridge, on which trusses the floor rests. The movable or draw section of the structure has transverse pontoons which leave, when it is closed, two boatways, each 39 feet wide with 17.5 feet of vertical clearance. The draw has a length of 205 feet.

To protect the structure-traffic when the span is open, gates should be provided at the ends of all movable spans of highway bridges. They should be arranged so as not to interfere with the traffic when the span is closed and so as completely to block all passage before it begins to open. Where the traffic in both directions uses the same roadway, the gates are best arranged in pairs at each end so that one of each pair can be closed to oncoming vehicles and pedestrians and the others shut just as soon as the traffic is off of the movable span. Where separate roadways are employed for the travel in the two directions, a single gate at each end of each roadway is generally used. These are arranged so that the gates obstructing the oncoming traffic are shut first: and the other gates are closed against pedestrians as soon as the movable span is cleared. This same construction is adopted also for single roadways with light traffic in both directions that can be easily handled. In such cases it is not infrequent to omit the gates altogether, the bridge tender merely stretching a heavy rope across the roadway at each end. Various types of gates are employed, those swinging in a horizontal plane being the most common. The pivots are placed near the trusses; and when not in use, the gates are swung up against the latter out of the way of passing vehicles, latching into place automatically. Various types of folding gates that are operated vertically about horizontal axes have been used, the main objection to them being the danger of striking passing vehicles and pedestrians when they are being lowered. This, of course, is not very important where gatemen are employed; but when the gates are operated from the machinery house, it is a serious matter. The same is true also of lifting gates which are dropped across the roadway from above or raised from beneath the floor.

The character of the construction of the gates will depend on the use to which they are to be put. If they are merely to serve the purpose of a tell-tale, a very heavy gate is not needed; but where provision is to be made for collision with a horse, wagon, or automobile, a substantially designed construction is necessary. Stops should be provided at the ends of swinging gates to hold them when shut. These may consist of pointed rods pivoted above the bottom of the gate and stuck into the pavement when the said gate is closed. The gates are usually made of structural shapes, although wood is sometimes employed. The horizontally-swinging and the direct-lifting gates are generally of latticed construction, while the folding gate is made up of angle flanges at top and bottom connected by hinged parallel bars. The operation may be effected by hand or by machinery controlled by the bridge operator. As a rule, gatemen are employed to handle the traffic and to operate the gates as well. This is the surest method of preventing accidents. With very heavy traffic the operation of the movable span and that of the gates should be done by different men, working with an efficient system of signals.

The question of what is the best kind of power for operating movable bridges is not difficult to answer, for where electricity is available it is the best and usually the cheapest energy to employ. But there are movable bridge locations where electricity is not available, and in such cases the best power to adopt is that produced by a gasoline engine. The latter is superior to the steam engine, because with steam the fires must always be kept going at great expense for both fuel and attendance, but with a gasoline engine, except when the river traffic is very dense, causing constantly-recurring calls for an open draw, there is no burning of fuel except during operation. Steam machinery used to be employed quite generally for operating swing spans, but no one nowadays ever thinks of adopting it. Hydraulic power has also been used in the past for operating bridges, especially in Europe; but it unavoidably involved the employment of such excessively expensive machinery that it never became popular. Compressed air has been adopted a few times in both America and Europe for operating swing spans, not, however, as a primary but as a secondary power. It is not likely ever to be used in the former manner, because the existence of an independent source of supply of compressed air in the vicinity of a movable bridge involves a most improbable combination of conditions; hence it would be necessary to compress and store the air by an electric motor, gas engine, or, possibly hydraulic machinery in case there was an available water power in the neighborhood. Electricity is certainly the ideal power for handling movable spans, especially when there is available more than one source of supply. If there be but one, and if the stream carry much traffic, as a matter of precaution the designer should install either a storage battery or an auxiliary gasoline engine capable of operating the structure at moderate speed.

Where natural gas is available and cheap, it is sometimes economic to adopt a gas engine; but even under these conditions it is difficult to compete successfully with electricity, especially when the items of interest, depreciation, and repairs are duly considered, for these are much greater when either gas or gasoline is used than when electricity is the motive power. The much greater weight and heavier vibration of the gas engine or the gasoline engine as compared with the electric motor militates materially against its employment for operating bridges, because it costs money to support weight even in the tower of a swing span, and excessive vibration is certainly a disadvantage that should not be ignored.

In *Engineering News* of Oct. 13, 1910, there is a paper by S. F. Nichols, Esq., E. E., who is an acknowledged authority on electrical engineering, entitled "The Electrical Operation of Drawbridges." His statements concerning the superiority of electricity as the motive power are so clear and conclusive that the author takes the liberty of quoting from the said paper as follows:

"The electric motor has many points to recommend it, with few disadvantages. It is very light and compact, and it is very conveniently reversed. It is capable of sustaining a very heavy overload for short periods, which enables it to take care of the very difficult problem of accelerating a heavy mass and also of operating the bridge against high wind pressures that may occasionally be experienced. It is almost noiseless in operation. It requires comparatively little attention, and when periodically inspected the possibility of its getting out of order and refusing to work is very remote.

"Being compact, it can be located very close to the point where the power must be used. This makes it possible to locate the operator at the most convenient position from the standpoint of accessibility or where the best view can be obtained of the river or railroad or highway traffic. The motors can be located on a moving portion of the structure while the operator's house is located on the fixed part."

Mr. Nichols' statement regarding the overload capacity of a motor applies, of course, to direct-current motors only; but the other points are true for alternating-current motors as well.

For bridges of importance it is certainly good practice to have as many sources of power as possible available for use in an emergency, and if both electric current and an independent source of energy can be furnished, the duplication is well worth the extra cost that it involves; for reliability is the prime *desideratum* to be attained.

In respect to the amount of power required for mechanically operated bridges, there is a good rule given by Albert Henry Smith, Esq., C. E., in his discussion of Schneider's paper on "Movable Bridges," viz., to allow one horse-power for each fifteen tons of weight to be swung. This provides ample margin for taking care of excessive wind pressures, and gives plenty of power to open and close the bridge rapidly. The rule was established for swing spans; and it applies very well on the average for vertical-lift bridges, *provided that the figured tonnage includes the counterweights and all moving parts.*

No matter what kind of power may be employed, every movable span should be provided with a means for operating it slowly by hand in order to meet the possible emergency of the failure of all other powers.

It is often necessary for an engineer to make a rough or hurried estimate of cost of power installation for a movable span. Of course, this will vary greatly with the numerous ruling conditions, especially the time of operation; but assuming them all to be averages of those usually encountered, the author has prepared the diagrams recorded in Fig. 28*g*, which show for swings, vertical lifts, and bascules the first costs per weight unit of 100,000 pounds for power installation. These curves, which are applicable to direct-current and gasoline engine but not to alternating-current operation, are recommended for use in preliminary estimates only, as each individual case should sooner or later be worked out accurately after all the conditions have been thoroughly and finally determined. With alternating current the cost of power installation will be about twenty-five per cent greater than that for direct current.

The best kind of movable bridge to adopt for any crossing will depend greatly upon the conditions that exist there. Generally the vertical lift or the bascule is superior to the swing for the following reasons:

First. Either of the lifts provides one comparatively large clear opening instead of the two smaller ones involved by the swing.

Second. It offers less obstruction to the flow of water, owing to the absence of the draw rest and (generally) also to the smaller number of piers.

Third. The cost of maintenance is less because of the necessity of maintaining a perishable draw rest for a swing span.

Fourth. The danger of the span's being struck by passing vessels is much greater in the case of a swing than in that of either kind of lift.

Fifth. The time of operation is two or three times as long for a swing as for either style of lift.

Sixth. The lifts generally afford better automatic adjustment of the railroad tracks than do swing spans, although with proper precautions there should be no danger of accident on account of derailment caused by improper track adjustment. A serious accident from this cause occurred at Atlantic City on October 21, 1906, in which a number of people were killed.

Seventh. The swing bridge often interferes with adjacent valuable property, which neither type of lift does, because the location of lifts is always confined to the city street or the company's right-of-way.

Eighth. In case of future enlargement of bridge to accommodate an increase of traffic, the swing bridge has to be torn down and rebuilt, while a vertical lift or a bascule can simply be duplicated alongside.

Ninth. The wider the roadway of a swing bridge the more obstructive does it become to navigation, while the widening of a lift does no harm thereto whatsoever.

Tenth. In passing vessels with low masts a swing has to open just as fully as for a high-masted craft, which is not the case with a vertical lift or a bascule. In this regard the vertical lift has a decided advantage over the latter in that the deck remains horizontal.

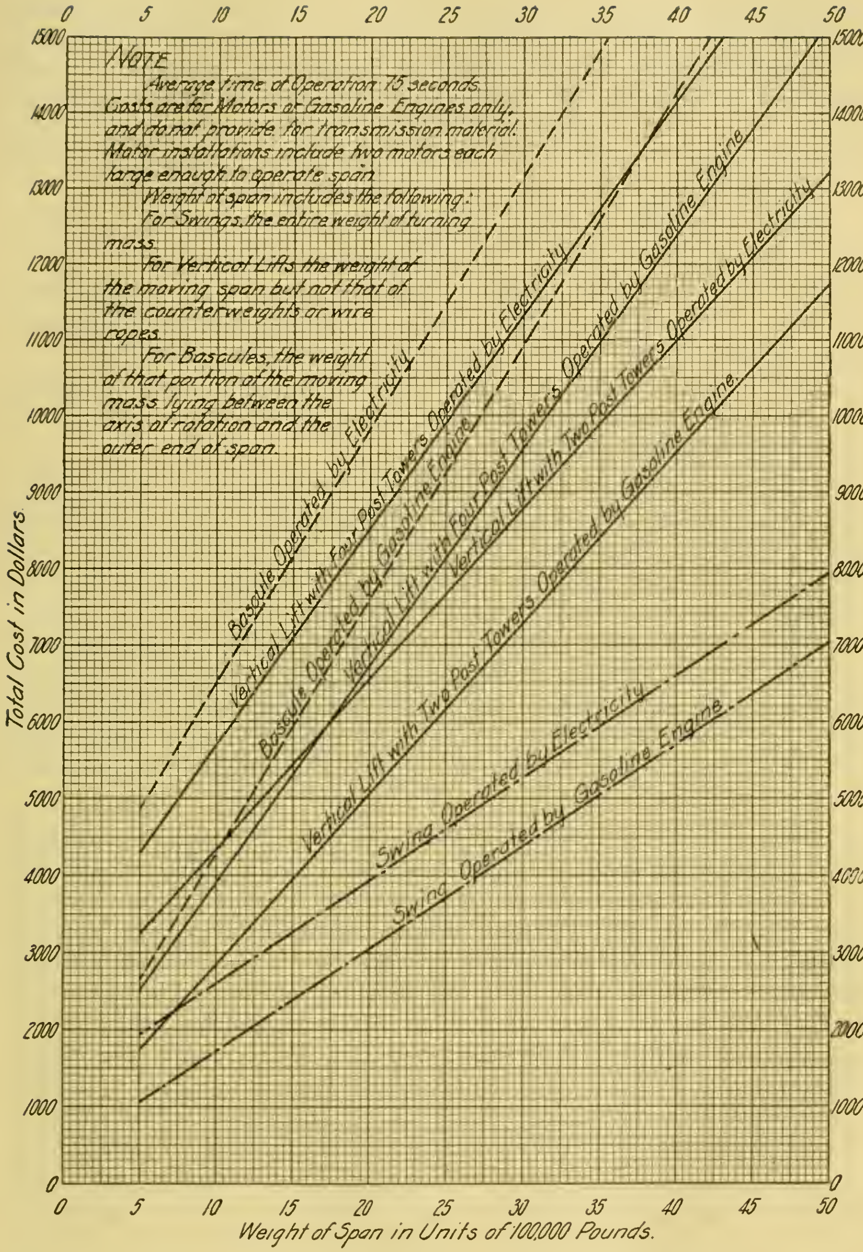

FIG. 28*g*. Cost of Power Equipment for Movable Spans.

Eleventh. In sand-bearing streams the protection works at the pivot pier cause a deposit of sediment and thus often tend to obstruct navigation.

Twelfth. Generally speaking, the first cost of a swing bridge is more than that of either the vertical lift or the bascule, although there are occasional exceptions. This question is discussed at length in Chapter LIII.

Comparing the vertical lift with the bascule, the former has a few advantages, among which may be mentioned the following:

First. The floor is always horizontal, permitting the use of a block pavement, which cannot well be employed on a bascule.

Second. Great wind pressure during operation has no appreciable effect on a vertical lift, while it may cause serious delay to a bascule, or even, under extreme conditions, prevent its operation altogether.

Third. As previously indicated, the vertical lift does not have to rise so high for low-masted passing craft as does the bascule, and thus it saves a small amount of time.

Fourth. In railroad bridges when the moving span is down it acts just like any fixed span as far as operation under traffic is concerned, which cannot be said for either the bascule or the swing; or in other words, for railroad traffic the vertical lift is the most rigid of the three types.

Fifth. In case of a shifting channel, it is feasible at very moderate expense to make a number of the spans alike and to arrange, for any time in the future, to have the towers and machinery taken down, transferred, and re-erected so as to lift any one of the said equal spans. This could not by any possibility be done in the case of any other type of movable structure.

Sixth. The vertical lift, when its towers do not rest on flanking spans, lends itself readily to a future raising or lowering of the grade line in a way that no other type of movable span can possibly do; for all that is necessary is to change the elevation of its bearings at the four corners and to modify slightly the transverse bracing of the towers. If a change of grade be anticipated when the plans are being prepared, provision should be made therefor by increasing adequately the heights of the towers; but if at any time the grade on a vertical-lift bridge of the type mentioned, for which no such preparation had been made, has to be raised to such an extent that the required clear headway will be interfered with because of the counterweights reaching the new decks of the approaches in the towers, the result desired can be accomplished by arranging for a small portion of the said approaches to move either laterally or vertically out of the way of the counterweights whenever a very-tall-masted vessel has to pass. For any other vessel, however, these moving approaches would not have to be utilized; consequently, they would very seldom need to be operated.

Seventh. As explained in detail in Chapter LIII, for large bridges, long opening spans, and expensive substructures the vertical-lift bridge costs less than the bascule.

In the 1908 *Transactions of the American Society of Civil Engineers* there is a masterly paper upon the subject of "Movable Bridges," by Past-President C. C. Schneider; and no one who aims to be a bridge engineer can afford to neglect studying it thoroughly.

CHAPTER XXIX

SWING BRIDGES

THERE are three general classes of revolving draw bridges, viz., the rim-bearing, the centre-bearing, and the combined rim-bearing and centre-bearing. In each of these classes a bridge may be either equal armed or bob-tailed. Again, rim-bearing draws may have either one or two supporting points per truss at the pivot pier. Centre-bearing draws are generally arranged so as to carry the dead load on the pivot and the live load on either a drum or four carriages formed of groups of rollers. Combined rim- and centre-bearing draws carry a portion of the dead load on the pivot and the remainder on a drum, with the live load supported as in the last described case. Swing bridges may be classified also as to the character of their main girders thus—plate girder swings; open-webbed, riveted-girder or riveted-truss swings; and pin-connected-truss swings. Another general division of swing bridges is in relation to their continuity or the reverse for the travel of live load shear across the pivot pier. Most structures are more or less continuous in this regard; but a few have been designed and built in such a manner that, when the ends of the arms are raised to their normal position for the span closed, the two halves of the structure are entirely independent of each other in respect to all kinds of loading and all conditions thereof. Many years ago the author designed a small swing span of this kind. It was operated by man power, and required so much time and energy to lift the ends adequately that he has never repeated the experiment. Other engineers have tried similar designs, and, undoubtedly, with equally unsatisfactory results, because the type has not persisted. Once more, swing spans may be divided into through, half-through, and deck.

In addition to these various classes of swing spans one will occasionally run across some freak design that, if perpetuated, would form a class of its own; but such abnormal variations from general practice are either still-born or very short lived. One of the most glaring cases of this kind is described in *Engineering News*, Vol. 29, p. 141. Its characteristic feature is the floating of the movable span by means of a water-tight steel tank working loosely in a similar shell encased by the concrete of the pivot pier, the space between the two shells being filled with water. Setting aside the abnormally high cost of such a contrivance, just think of what would happen should the inner shell spring a leak or should the water freeze! It was suggested by someone to use mercury instead of water, but that would prove a costly expedient, for mercury is expensive, and it has a bad habit of evaporating when exposed to the air. This freak design won the first prize in a competition on plans at Sydney, N. S. W., in 1892, but the author has never heard that the bridge was constructed according to the said design. It is but fair to state that at Sydney there would be no danger of the water freezing. It is stupid awards of this kind that discourage expert bridge engineers from competing on plans.

With all the preceding groupings it is evident that there are many possible kinds of swing spans differing from each other quite materially. The most common kinds are the rim-bearings ones, and of these the deck-plate-girder and the riveted-through-truss types are the most numerous. Half-through, plate-girder swings occur occasionally, and in times past pin-connected rotating draws were very common; but of late, as explained at length in Chapter XXXII, riveted trusses have supplanted pin-connected ones in spans of ordinary length, and, indeed, often in quite long spans; and this statement holds good for movable as well as for fixed bridges.

The choice between rim-bearing and centre-bearing swings is almost entirely a matter of taste; for there is no great difference between them in the cost, what little there is being in favor of the latter. In general it may be stated that while the rim-bearing draws are often more rigid and stable, the centre-bearing draws move with less friction. In respect to the minimum dimensions for pivot piers, the centre-bearing structure has somewhat the advantage; but with the type of rim-bearing draw that the author has for many years been building, in which the diameter of the drum is equal to the perpendicular distance between central planes of trusses and in which there are provided at least eight points of bearing for the span upon the drum, the saving in substructure cost by adopting the centre-bearing type is not great. Since writing *De Pontibus*, the author has had occasion to modify his opinion concerning the comparative merits of rim-bearing and centre-bearing swings, because the latter type has been so materially improved in the last two decades that it has today a slight advantage in both initial cost and ease of operation over the former; but he still adheres to the adverse opinion expressed in that treatise concerning swings that divide the load between rim and pivot. While it is not impossible to build satisfactory bridges of that type, there is always a certain amount of ambiguity in regard to the division of the load between those places. The choice between rim-bearing and centre-bearing swings will often depend upon the character of the pivot pier. In a late alternative design for the moving span of the Pacific Highway Bridge over the Columbia River near Portland, Oregon, which is being engineered by the author's firm, the swing span was made rim-bearing, and the pivot pier was a six-foot-thick shell of concrete covered by a reinforced concrete cap four feet thick, the foundation for the pier being very long piles. This construction was estimated to cost somewhat less than a pivot-bearing swing supported by a solid pier. That there are still conflicting opinions among high authorities concerning the relative merits of the rim-bearing and the centre-bearing swing can be ascertained by comparing the opinions of C. C. Schneider, Esq., Consulting Bridge Engineer, as expressed in his paper on "Movable Bridges" presented at the April 3, 1907, meeting of the American Society of Civil Engineers, and of C. H. Cartlidge, Esq., Bridge Engineer of the Chicago, Burlington, and Quincy Railway, as stated in his paper, "The Design of Swing Bridges from a Maintenance Standpoint" presented at the April 18, 1906, meeting of the Western Society of Engineers.

Mr. Schneider says: "The centre-bearing type, designed in accordance with good modern practice, offers more advantages than the rim-bearing type, and should always receive the first consideration in determining upon a design. It requires less power to turn, has a smaller number of moving parts, is less expensive to construct and maintain, requires less accurate construction than the rim-bearing bridge, and does not as easily get out of order. The structural and the operating or machinery parts are entirely separate, and when the bridge is closed it forms either two independent fixed spans, or a fixed span, continuous over two openings, resting on firm, substantial supports. There are no ambiguities in the calculations in reference to the distribution of the load, and the distance required from base of rail to masonry is generally less than that required for a rim-bearing bridge with proper distribution of the load over the drum. Any irregular settlement of the masonry does not materially affect its operation.

"On the other hand, the rim-bearing bridge requires a circular girder or drum of difficult and expensive construction, a ring of accurately-turned rollers, and circular tracks, which require great care in their construction and delicate adjustment in their erection in order to make the bridge operate satisfactorily. Repairs are troublesome and expensive, and any irregular settlement of the masonry will throw the whole turning apparatus out of order."

On the other hand, Mr. Cartlidge says: "The writer's experience with centre-bearing draw-spans has been such as to prejudice him against them for spans of any magnitude. It seems difficult at any reasonable cost to proportion the pivot-bearing so that it will not wear; and any wear on a pivot-bearing is expensive to repair. On one draw the wearing away of the bronze bearing in the pivot allowed the upper and lower castings to rub, making the turning of the draw a very noisy operation, while the few wheels provided to steady the span while turning were overloaded and cut the circular track badly."

It is a difficult matter to choose between the opposing dicta of two such eminent authorities. Mr. Schneider's experience, extending over an unusually long professional career, has been mainly in designing and manufacture, and Mr. Cartlidge's in erection and operation. Mr. Schneider is of the opinion that centre-bearing bridges are adapted for single-track structures of any span, but for four-track bridges and heavy highway bridges carrying wide city streets they are not suitable; while Mr. Cartlidge would use centre-bearing swings for short, light spans, and either rim-bearing or combined rim-and-centre bearing swings for long, heavy ones.

Mr. Cartlidge's explanation of how he divides the dead load between rim and centre shows how uncertain must be the true distribution. Referring to one of his bridges he says: "The beams bearing on the centre casting are designed to carry half the dead load to the casting. The adjustment of the load is by means of shim plates between the beams and the top of the pivot. The adjustment is made during erection, the beams first being allowed to rest on the rollers with the centre casting clear. The centre is then jacked up until the drum just clears the wheels. After noting the amount of the lift, shims to half its amount are put in and the beams lowered to permanent bearing. This is, of course, only an approximate method." It certainly is only approximate; and when the adjusting is finished, the ratios of load division will be somewhat uncertain, but nothing like as much so as later after the pivot-bearing has begun to wear, for the more it wears the greater will be the share of the load carried by the rim. The author certainly prefers either the centre-bearing or the rim-bearing swing to the hybrid design. As before stated, his practice has been mainly (and especially in the early portion of his professional career) confined to rim-bearing swings, nevertheless he has become convinced that centre-bearing ones, everything considered, are the best; for he has had troubles of his own with rollers getting out of adjustment. Mr. Cartlidge says: "One great advantage which accrues to a centre bearing is that of ease of turning; and while everything is new and in adjustment this advantage is realized. Should there be any excessive wear, however, this is soon lost, and it is necessary to make bearing areas as large as practicable, in order to prevent such wear.

"The complications involved by the use of a rim-bearing centre are more theoretical than actual, as experience with spans of widely varying length has demonstrated."

It is quite evident that both rim-bearing and centre-bearing swings have given considerable trouble in operation in times past; but the author is of the opinion that those of either type, designed and built today in strict accordance with specifications that are based upon the accumulated knowledge concerning the weak points of old structures of the said type and how to avoid them in the future, would give equally satisfactory service—but, as before indicated, this conclusion does not apply to the hybrid type.

The weak points in the rim-bearing swings were too shallow and inadequately stiffened drums; adjustable radial spider rods held to spacing by light bars or light channels; centre castings insufficiently anchored to the masonry; track segments too thin or of cast iron, or both; inadequate connections of track segments to drum or masonry or to each other; faulty contact between track segments and drum; spider rods of too small diameter; unscientific connections of brackets to drum; and improperly designed operating machinery.

The weak points in the pivot-bearing swings were centre bearings of cone-shaped rollers or balls, failure to provide proper sliding surfaces, and excessive bearing pressures.

The necessity for deep drums has already been dwelt upon, shallow ones never having been a weakness of the author's. Schneider states that the depth of the drum should be not much less than one-half, in no case less than four-tenths, of the distance between the centres of support. There should be eight supports for single-track and twelve for double-track swings. The trouble that came from adjustable spider rods does not exist in modern rim-bearing swings; for the detailing has been fundamentally changed by using a stiff ring of two channels held to gauge by batten plates passing between the wheels, with rigid radial arms riveted to it and to the pivot ring. The wheels run on short axles, adjustable radially, and have tool steel or bronze washers to prevent their being turned by friction and, consequently, put out of adjustment. Centre castings are now being made more substantial than they were formerly, and are being buried for most of their length in the concrete that forms the top of the pivot pier. Track segments, too, are being made thicker and are much better connected to each other and to the metalwork and the pier than they used to be years ago, consequently there is now more perfect contact between rollers and drum. One of the greatest improvements, though, consists in providing adequately and scientifically designed operating machinery and connecting it firmly and rigidly to the structural metalwork. In centre-bearing swings the cone-shaped rollers and the ball-bearings have been abandoned, and bearing disks of ample size and satisfactory material are being employed.

There is a feature of construction of old type drums that is deserving of passing notice on account of its glaring inefficiency and crudeness of manufacture, viz., the insertion of a so-called "rust joint," composed of iron turnings or filings and acid, between the flange of the drum and the upper track segments. It used to be made from a quarter to a half inch in thickness, and it invariably sooner or later was squeezed out when the intensity of pressure upon it was large. The manufacturers who employed it did so because they claimed that it was impossible to produce a close bearing in any other manner. Fortunately, the detail is now a thing of the past.

Truss swing spans are almost invariably of the through type, primarily because the deck is usually kept as close to the high water elevation as it is safe to go, and secondarily because even when the fixed spans of the bridge are deck, it pays to make the swing span through so as to let small craft pass beneath without the necessity for opening the draw to let them go by. A good example of this is the author's railway bridge over the Maumee River near Toledo, Ohio. It is so high above the ordinary stage of water that most of the passing craft go beneath it, thus saving the constant breaking of the railroad track which would have been necessitated had the swing span been made deck.

In respect to the power required to operate rim-bearing draw-spans, the author for many years has used an average of the Boller formulæ, viz.,

$$\text{H. P.} = \frac{0.0125\, Wv}{550}$$

where W = total load on rollers in pounds, and v = velocity on pitch circle of rack in feet per second; but in the specifications of Chapter LXXVIII (Clause 87) there is given a more detailed method for making the computation.

The author obtained a fine check on the correctness of the Boller formula when testing the draw-span of his Jefferson City highway bridge. This span of 440 feet weighs 660,000 pounds, and was opened by four men in four minutes and fifty seconds. The power applied by the men was measured by dynamometers, and from the length of their path and from their pull the horse-power was computed. It proved to be just a little less than unity; so near, in fact, that it was called unity. The velocity v was, on the average, 0.066 feet per second. Substituting in the formula gives

$$\text{H.P.} = 0.0125 \times 660{,}000 \times 0.066 \div 550 = 0.99.$$

It is possible that, if the experiments were to be made again, a greater divergence from the formula would be found, for the reason that the bridge is liable to work more easily after it has been operated a while.

Concerning the methods of computing live load stresses in swing-spans, the author, in 1897, wrote thus in *De Pontibus:*

"Candidly, the author has very little faith in even the approximate correctness of the ordinary methods of computing live-load stresses in draw-spans; nor has he much more in the superrefined methods involving the principle of least work, or stretching of the different truss members, or the principle of the Three Moments with varying moments of inertia. In his opinion, there is but one satisfactory method of ascertaining the reactions for both balanced and unbalanced loads, viz., by making large models of a number of spans of various lengths, and weighing therewith the reactions for all kinds of loading. From a series of experiments of this kind there could be prepared a diagram or diagrams, similar to that shown on Plate IX, which would give approximately correct reactions for all spans and all loadings. Such an investigation would require considerable time and money; but if some professor of civil engineering would undertake to make the experiments, he could undoubtedly get the models built free of charge by dividing up the work among several of the leading bridge manufacturing companies. The results of such experiments would be of great value to both the engineering profession and the railroads of America."

Later the author persuaded his friend, Prof. Malverd A. Howe, the well-known engineering writer, to make the suggested series of experiments on end reactions from balanced live loads upon a rather-large-scale wooden model of a swing span having four points of support. Prof. Howe reported that all his experiments gave a phenomenally close agreement with the reactions as computed by formula and as indicated on the diagram just mentioned, which gives the proportions of end re-

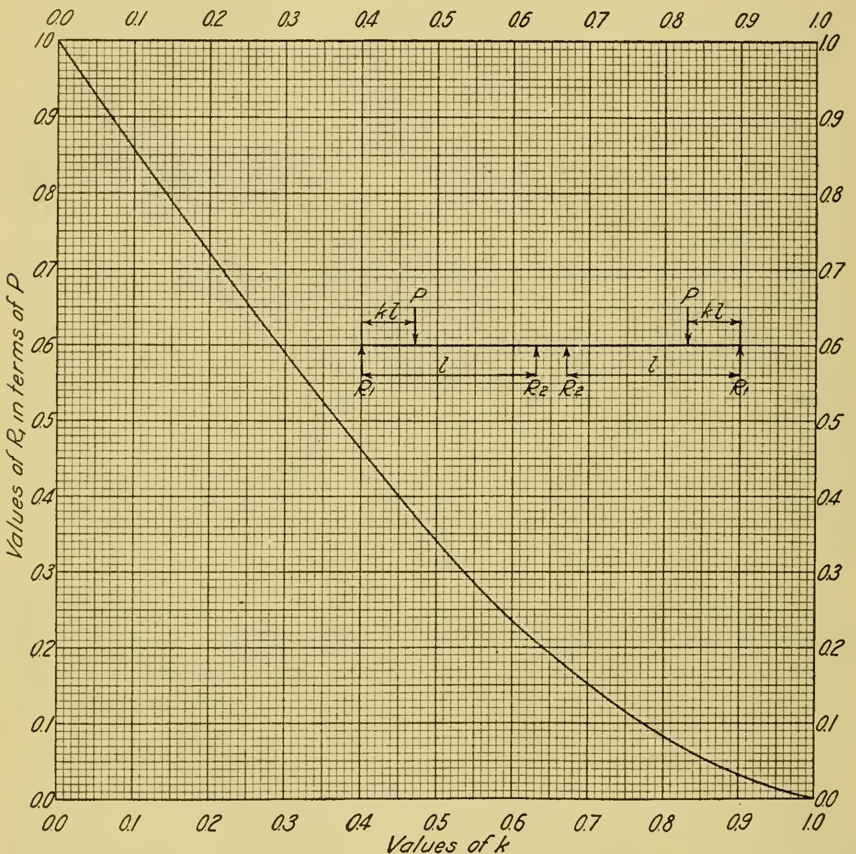

FIG. 29*a*. Reactions for Balanced Loads on Rim-bearing Draw-spans.

actions for balanced live loads when the swing has four points of support. It is reproduced in Fig. 29*a*. That diagram was prepared in the late eighties by the author, in opposition to the advice of his then-associated engineers, who claimed that it would not be accurate enough for all cases, as it was based upon average relations of span and mid-panel lengths; but after they had tried it for use in computing swing-span stresses, they reported that it gave so close an agreement to the results of the formula that they were perfectly satisfied. Fig. 29*b* gives the proportions of reaction for single loads in swing spans having only three points of support. The employment of these two diagrams will save the computer much labor in figuring live load stresses in rotating draws.

In determining the dead load stresses in swing spans, it is customary to assume that the draw is open; but the author also assumes, as previously mentioned in Chapter V, that there is an upward reaction from

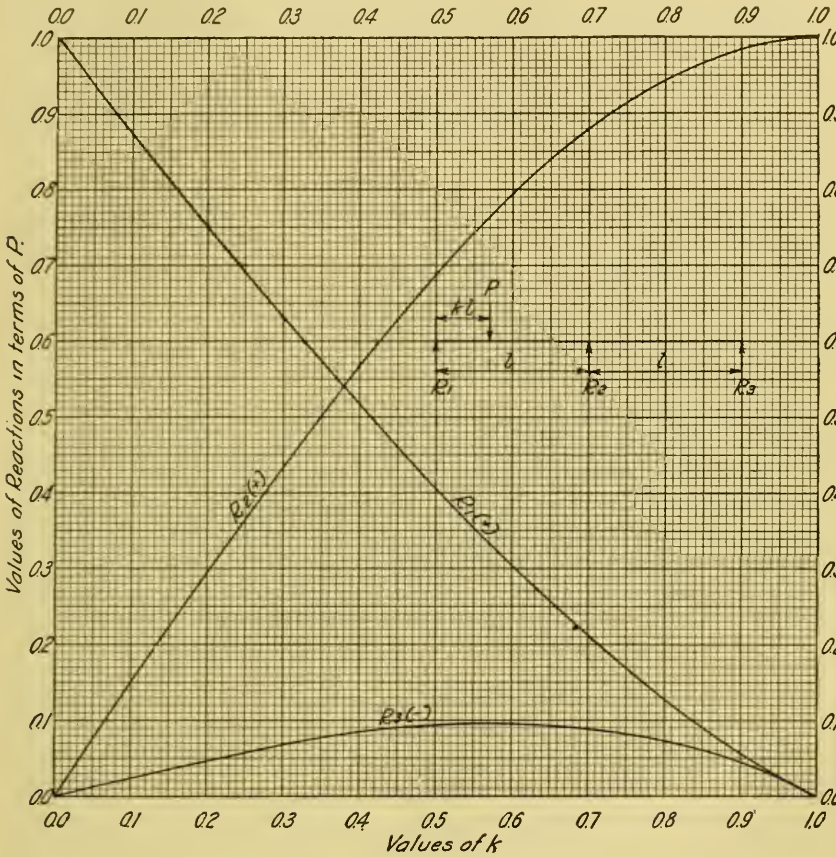

FIG. 29b. Reactions for Centre-bearing Draw-spans.

the lifting machinery at the ends, and finds the stresses therefrom; then, when any such stress tends to increase the section of any member, it is considered; but when it tends to decrease the section, it is ignored. This method may involve some errors on the side of safety, but they are of minor importance.

The designing of a drum for a turntable is a matter requiring much care. The load coming upon it should be distributed as much as possible, and all concentrated loads should be taken care of by a sufficient number of stiffeners of ample size and thoroughly attached. The girders over the drum should have not only ample strength and stiffening but also the proper comparative rigidities. The greater the number of points of support, the more evenly will the load be distributed to the drum and rollers; and the deeper the drum, the better the distribution. As an extra foot of depth of drum costs much less than one foot of height of pivot pier it stands to reason that it is better, whenever practicable, to make the drum much deeper than the calculations for strength and stiffness demand. The only good reason for not adopting in every case an excessive depth is that so doing might place the rollers below the level of high water, and thus render the structure liable to injury from drift, and the machinery to being blocked by an accumulation of mud under and between the wheels.

When the vertical distance between high water and the lowest part of the bottom chords is small, the longitudinal and cross girders can be placed with their bottom flanges flush with the lower surface of the said bottom chords, and the drum can be built inside of the box thus formed, so that its lower flange angles will be flush with the bottoms of the said girders. But if the vertical clearance be great enough to permit it, the box should rest on the drum at either four or, preferably, eight points.

Many designers rest the tower posts directly over the drum, thus making the diameter of the latter about forty per cent greater than the side of the square upon which are located the axes of the tower columns. Other designers let the sides of the square intersect the circle of the drum so as to divide the latter into eight equal parts, thus making the diameter of the drum about eight per cent greater than the side of the square. The author's practice for more than two decades has been to let the diameter of the drum equal the side of the square, obtaining eight points of support by inserting four small girders in the corners of the square, at angles of forty-five degrees with its sides. As the cost of a pier varies very nearly as the square of its diameter, it follows that this method of designing drums for rim-bearing swings effects a great saving in the cost of the pier as well as in that of the drum. Occasionally it will give a pier of very small diameter in comparison with the length of the draw-span. The remedy for this, provided the pier have the requisite stability against overturning, is not to increase the pier diameter but to anchor the draw-span to the pier in such a manner as not to interfere with the turning, but so as to offer an effective resistance to any tendency to lift the span off its support. In the case of the Jefferson City highway bridge, the length of the draw-span is four hundred and forty feet, while the diameter of the drum is twenty-two feet—the same as the perpendicular distance between central planes of trusses. Such a ratio of span length to drum diameter is too great for safety in case of a strong lifting wind acting on one arm only, for such an uplift would have to amount to only twelve and a half pounds per square foot of floor in order to throw the span off the pier.

It was, therefore, necessary to anchor the span to the pier by means of a long four-inch bolt passing through a wide heavy casting which is embedded in the concrete, and projecting at the upper end between two beams and through a saddle and a heavy washer-plate. The nut on the anchor-bolt is turned down so as nearly but not quite to touch the said washer-plate, thus causing no obstruction to turning the draw, but making the anchorage always ready to resist the slightest tendency to lift the span.

The limiting ratio of length of span to diameter of drum that can be employed without using a central anchorage cannot well be determined by rule, but must always be left to the judgment of the designer. It might suffice, perhaps, to specify that, whenever the uplift on one arm only necessary to upset the draw is less than fifteen pounds per square foot of floor in situations exposed to high wind-pressure, or less than ten pounds in other situations, an anchorage shall be adopted. In the case of three of the author's swing bridges on the Kansas City Southern Railway, the span length is two hundred and twenty-five feet, and the diameter of the drum is only seventeen feet; nevertheless no central anchorage was used. In these bridges the open floor reduces the uplift, and the situations are not such that the spans will be exposed to abnormally high wind-pressures.

Heavy draw-spans should be operated by two or more pinions; and when these are placed, as they should be, diametrically opposite each other, some kind of apparatus ought to be used to equalize the pressure on the pinions, otherwise both the latter and the rack are liable to have their teeth broken. The reason for this is that it is impossible to make the toothing of the rack so perfect in the distance of the semi-circumference that opposite pinions operated by a single shaft shall at all times act equally. When electrical machinery is used, the equalizing can be done by adopting independent motors; but with other machinery, some kind of mechanical equalizer should be employed. The author many years ago designed one for the first-built swing-span of the East Omaha Bridge, which worked to perfection. It was made by cutting the engine-shaft and attaching to each end a bevel-gear wheel. These bevel-gear wheels engage with two small pinions which are inserted between the spokes of a large spur-wheel that turns loosely on the engine-shaft. If we assume the pressures on the main rack-pinions on each side of the drum to be constantly equal to each other, the two halves of the engine-shaft will always have the same angular velocity; but in case the pressure on the teeth of the two rack-pinions on one side of the drum should fall below that on those of the two rack-pinions on the other side, the spur-wheel will move slightly on the shaft until the rack-pinions receive equal pressure again. By this apparatus equal pressure on the teeth of rack and pinions is at all times insured. The author was convinced of the necessity for such a device by watching it when the span was being turned; for several times during each quarter rotation the little pinions on the spur-wheel would make a sudden movement of such magnitude as to indicate a considerable variation in the spacing of the rack-teeth.

In designing draw-spans with high towers, especially long, double-track ones, there is an important matter that is sometimes overlooked, viz., the tendency of the end of the unloaded arm to rise when a moving load is on the other arm. For single-track bridges the only harm that this would do would be to pound the end bearings; but for a double-track bridge it would certainly some time cause a serious disaster by the derailment of an oncoming train when the other track on the other arm is covered by another train. Before designing the 520-ft. draw-span for the East Omaha Bridge (see Fig. 52*k*), the author looked up this matter as well as he could, having heard of trouble being experienced from rising ends on a double-track draw-span but little shorter than the one then contemplated. The results of the investigation were rather contradictory, consequently the design was made with three features that were conducive to resisting the raising of the ends, viz., extra-deep trusses at both inner and outer hips; stiff, continuously riveted top chords between these points; and an end-lifting apparatus capable of raising the ends one and a half inches. This was the best at that time which the author could do to avoid the difficulty; but at the same time he figured upon using later a holding-down apparatus in case the necessity therefor should ever arise. This span has at present only a single track at the middle, and the highway cantilevered floors are not yet put on. Observation has proved that, with one arm loaded by a train and the other arm empty, there was no rising of the ends when the latter were properly supported. Some years after the completion of the bridge as first built, an inspection showed that the timber cribs, which were then used as a temporary support for the swing span, had so shrunk vertically, on account of the seasoning of the wood, that the end rollers barely touched their bearings, necessitating some shimming thereunder. This condition of the ends afforded an excellent opportunity to note the rise with one arm only loaded by an engine and enough cars to cover the said arm. The amount observed was three-eighths of an inch. From this it may be concluded that with masonry piers and the completed superstructure, and with a hoist of one and a half inches by the lifting gear, there is no chance for the ends to rise from their bearings; for, to cause such a rise, it would take a live load just four times as large as the test load, which is more than could be placed on the double-track railway, wagonways, and footwalks. Had the bridge been built with shallow trusses and with eye-bars in a portion of the top chords between outer and inner hips, as was the similar bridge which was reported as giving trouble from rising ends, it is probable that similar difficulty would have been found in this structure.

Some engineers may think that, because each span of a draw is figured as an independent span for unbalanced live loads, on the assumption that the longitudinal tower rods are so small as to carry no vertical shear past the drum, there should be no tendency for the end of one arm to rise when the other arm is loaded; but such is not the case, as the tendency would exist if there were no longitudinal tower rods at all. The rising, for instance, of the right-hand end, induced by a live load on the left-hand arm, is evidently due to the fact that the inner hip of the left-hand arm moves to the left and downward a small amount. This movement causes the inner hip of the right-hand arm to move to the left and upward a similar amount, and, as a result, the end of the right-hand arm tends to lift.

In erecting draw spans, some method of adjustment must be provided so as to bring the ends to the correct elevation. This is accomplished by placing a group of thin plates under each bearing on the rest-piers. Two decades ago the metal manufacturers deemed it to be absolutely necessary in spans of more than 200 or 250 feet to provide also an adjustment for each bottom chord of each arm near the drum by inserting vertical transverse plates at the splice of the chord to the longitudinal girder over the drum. The sole reason for this detail was the crude shopwork of those days; but some twelve years or more ago when designing the second swing span of the East Omaha Bridge (then the longest draw span in the world, and exceeded today by only one span of a lighter structure that is one foot longer), the author, deeming that the shop work of the American Bridge Company had improved sufficiently to warrant the change, omitted the chord adjusting plates and relied entirely upon those under the bearings on the rest-piers. This required very careful calculations for deflection, because any material error might have put a break in the grade over the rest pier too great to work out by dapping the track ties. Fortunately, the experiment was a success, and ever since that time the author has followed in his practice the precedent thus established.

In all swing spans there must be some kind of arrangement for lifting the ends when closed. Numerous mechanical contrivances have been employed for this purpose, including rollers, wedges, screws, eccentrics, cams, hydraulic rams, and toggle joints. The requirements for a satisfactory lifting apparatus are as follows:

First: It should provide sufficient power to raise the ends to the required height within a reasonable time.

Second: The energy lost through friction should be a minimum.

Third: The resistance to the mechanical effort should be fairly uniform.

Fourth: The bearing afforded finally after the ends are raised should be solid and substantial, similar to the pedestals in a fixed span.

Fifth: When the span is closed it should be free to move longitudinally under changes of temperature.

The most common details for lifting the ends are the transverse roller, the longitudinal roller, and the wedge. The first mentioned was the one in general use until about twenty-five years ago, then the third gradually replaced it. The second mentioned device is not at all common, but has been employed for a number of years. Its advantage over the first type is that the actuating toggles are more conveniently placed, lying close to the bottom chords instead of beneath the end floor-beams. The wedge requires more power to operate than the roller but affords a somewhat better bearing. Bevels for wedges vary from one in ten to one in five, Schneider preferring the steeper pitch. The mechanism for moving the wedges should be designed so as to make the resistance to motion nearly uniform during all stages of the lifting, and so as to lock them in order to prevent their sliding backward. In small centre-bearing swings, especially in highway structures, it will suffice to have the lifting apparatus at one end only, thus producing a slight tipping of the span; but it is evident that such an arrangement would not suffice for a long span, because it would produce an unequal distribution of load on the rollers.

In the old forms of end lifts the nut traveling on the horizontal screw was of steel without bushing, and at times of heavy duty, especially when the weather was warm and the span deflected abnormally in consequence, this nut sometimes became welded to the screw; but bushing with phosphor-bronze has been found to stop this trouble entirely. In all swing-spans exceeding two hundred and fifty feet (or better still, two hundred feet) in total length there should be a nest of longitudinal rollers over each bearing on the rest piers so as to permit of the unimpeded expansion and contraction of the span. The roller nests, preferably, should be attached to the moving span instead of lying permanently on the piers.

In centre-bearing swings there are two methods of carrying the weight to the pivot, viz., by suspension and by superposition, the former being preferable. Its advantages are that it brings the point of support nearer to the centre of gravity of the bridge, that the disks can easily be removed, examined, or replaced without interfering with traffic, and that it provides an easy method of adjusting the height of the span. It is best to use phosphor-bronze disks between two hardened-steel disks; for the surfaces of the latter in contact with the phosphor-bronze cannot wear out, consequently the wearing is confined to the alloy disk, making it the only part outside of the operating machinery which will ever require replacement.

All railroad swing-spans must be provided with some kind of device for lifting the rails, in order to permit them to swing clear of the approaches when the span is rotated. That designed by the late Geo. S. Morison, Past President of the American Society of Civil Engineers, has been used very generally.

As indicated in the preceding chapter, just beyond each end of every swing-span (or of any other movable span) for highway traffic there should be provided a substantial and quickly operated gate or portcullis for the prevention of accidents due to animals or vehicles running off the open end of the approach. Failure to supply such a device has already been the cause of the loss of many lives and much valuable property.

The tops of all pivot piers should be so designed as to drain thoroughly by pitching the upper surface from the centre toward the periphery, and by providing an adequate number of weeping pipes that pass below the lower-track segments.

In designing all parts of the turntable, the operating machinery, and the girders over the drum, great care is necessary to ensure that every piece and every connection are made sufficiently strong and stiff; for there are involved certain bending moments, torsions, and secondary stresses that used often to be overlooked, the result being loosened connections, broken rivets or bolts, and machinery out of order. The truly scientific designer nowadays will give due consideration to all these unusual conditions and will meet them by using ample sections for all parts and a liberal supply of rivets in the connections. The attachment of gear-brackets to the drum used to be the detail that gave most trouble, because of the great bending moment induced by the turning of the down-shaft when the span was operated against a strong, unbalanced wind pressure.

All man-power machinery should be made very strong, because if anything prevents the apparatus from operating properly, the men are likely to crowd upon the levers wherever they can find room and surge thereon to their utmost capacity. Once when operating by hand the first-built swing-span of the East Omaha Bridge, using two sets of six or seven men on each of the two four-armed levers, it failed to move. Immediately upon finding the unexpected resistance, they all stepped back a few feet and threw themselves with full force upon the levers. the result being the same as before. The author stopped this instantly, and upon investigating found that the two sets of men were working against each other. By starting one set in the opposite direction the span was readily put in motion. This example is given to show how ignorant workmen will abuse machinery, and the consequent necessity for making all man-power apparatus extra strong, notwithstanding any opposition that may be offered thereto by bridge manufacturers or other interested parties. If the specifications given in Chapter LXXVIII be strictly adhered to, and if due consideration be given to all the existing conditions when designing operating machinery, ample strength, rigidity, and endurance will be attained without any great unnecessary expenditure of metal or shop work.

As a drawbridge is a piece of machinery, it will require a certain amount of care, for otherwise it will get out of order and give trouble just at the wrong time. It should be opened at least once a month, and all parts which move on other parts, especially the wheels and tracks, should be kept clean and well lubricated. The lower rolling surface for the wheels should be kept free from all obstructions, and the wheels should be maintained in proper adjustment. The operating machinery also should receive due care and attention. In respect to those details of design of swing spans which affect materially the question of maintenance, Mr. Cartlidge has expressed his opinion in his before-mentioned paper, and as the author concurs in it without exception, it is herewith reproduced as follows:

"It may be laid down as a general rule that there should be absolutely no adjustable members in the trusses. All parts subject to complete reversal of stress should be stiff members and have, as far as possible, riveted connections. No pin-connections should be employed save for eye-bar members. This is particularly true of the connection between the end of the lower chord and the foot of the end post. The constant reversal of stress at this point, due to lifting and lowering the ends of the draw, very soon develops serious wear on the pins and pin-holes. With a properly designed riveted connection, no play being possible, there will be no difficulty.

"In draw-span design, perhaps to a greater degree than in any other, simplicity and rigidity are the prime requisites to economical operation and maintenance."

In making preliminary estimates for the cost of bridges on a railroad the question sometimes arises as to how the total weight of metal in a swing span, including that of the operating machinery, compares with that in a simple span of the same total length. This question cannot be answered with accuracy, mainly on account of the personal equation of the designer; but, in general, it may be stated that for spans of one hundred feet the weights are about equal, and for spans of five hundred feet the swing with its machinery requires seventy-five or eighty per cent of the amount of metal in the fixed span, as can be seen by referring to Fig. 55*ee*.

But if the question be one of comparative costs of the superstructures of swings and fixed spans, that is quite a different matter; because the machinery metal of the former in place is about two and a half times as expensive per pound as the ordinary structural steel, making the average pound price for the erected metal of a draw from one and a half cents to two cents higher than that of the corresponding fixed span. Again, the preceding figures do not allow for the cost of electric motors or gasoline engines; hence it is evident that the total cost of a swing span is always greater than that of a simple span of the same length. If the operation is to be done by man-power, the ratios of total costs will vary from 1.4 for spans of 200 feet to 1.13 for spans of 500 feet. If the cost of mechanical power be included, these figures would be about 1.5 and 1.2.

The economics of swings as compared with other kinds of movable spans are treated in Chapter LIII, and the specifications for designing them are given in Chapter LXXVIII.

In Chapter LV there are given directions for finding the weights of metal per lineal foot of span for the various portions of swing bridges and for the spans as a whole.

In Chapter LXXVIII there is given, in the portion of the specifications relating to draw-bridges, much information concerning styles of bridges for various span lengths, heights of towers, depths of trusses, panel lengths, loadings of all kinds, combinations of stresses, details of design for various styles of swings and their turn-tables, operating machinery, power determination, machinery houses, etc.; and the reader who has a swing span to design is advised to read the same with care before starting his computations.

CHAPTER XXX

BASCULE BRIDGES

The modern bascule span has for its prototype the drawbridge of the mediæval castle. In ancient times it served a double purpose—bridging the moat when lowered and barricading the doorway when raised. It was hinged at one end and raised by hand power; and, consequently, only short light spans could be utilized. Although these early bascules were counterweighted to some extent, the simple arrangement of weights attached to chains running over pulleys and connected to the free end of the span did not provide a balanced system and, therefore, it was hard to start the bridge and hard to check its motion when nearly raised. In this regard these early types did not measure up to the significance of their name—"bascule" coming from the French and meaning a balance.

Owing to the crude arrangements of counterweights and the lack of ample and convenient power for operating, the bascule remained in its primitive state until comparatively recent years. Most of the early types rotated about a fixed axis. Two exceptions were the 40-foot track girder bridge built at Havre, France, before 1824, and another, rotating on a wheel, built at Bregère. These were the forerunners of the modern rolling lift bascule. An early span of the trunnion type which gave practical service was the railroad bridge on the line of the North Eastern Railway at Selby, England. This bridge was built in 1839, and consisted of two fixed spans and two moving leaves which gave a 45-foot clear channel when opened. When closed the bascules formed an arch. For operating them a rack wheel and hand power gearing were employed. Another trunnion bascule was the Knippel bridge built at Copenhagen in 1867. Hydraulic power was used for operating this span, and cast iron pockets were provided for the counterweights, which were attached directly to the short arm of the rotating span and thus maintained a uniform balance. In 1878 the Fijeenord trunnion bascule was built at Rotterdam, Holland. It has a clear span of 75 feet. Each leaf is in two sections with four trusses to a section. The two outside trusses act as arches when the bridge is closed, while the two inner trusses carry counterweights on their short arms. The gearing can be operated by gas, hydraulic power, or man power. Another trunnion bascule is the highway bridge built at Koenigsberg in 1880. This bascule acts as a cantilever when closed, anchors being provided at the piers to take care of the uplift on the tail ends of the leaves.

The first important bascule bridge built in the United States is the

Michigan Avenue Bridge at Buffalo. This is of the trunnion type with cables attached near the free end and running diagonally to pulleys at the top of the tower, over which they pass to large, cast-iron wheel-counterweights. The latter roll on a specially curved track so constructed that the component tension in the cables decreases as the lever arm of the centre of gravity of the leaf diminishes. Several bridges of this character were built; but, other types proving more efficient, their construction was discontinued.

The modern era of bascule building may properly be said to have commenced with the construction of the Tower Bridge of London in 1894. At the same time the Scherzer rolling lift bascule was completed for the Metropolitan Elevated Railroad over the Chicago River near Van Buren Street. Since that time the bascule bridge has developed rapidly, and many different types, or rather sub-types, have been brought out. Wherever heavy bridge traffic has to be frequently interrupted by boat service the swing bridge is no longer adequate, and the bascule bridge becomes one of the alternatives for the engineer to consider. The advantages of the bascule over the swing span are:

1. Wide centre channel free from piers and pier protection.
2. Increased space for dockage.
3. Rapidity of opening to permit passage of vessels and subsequent closing again for bridge traffic.

For a general discussion of the comparative advantages and disadvantages of the bascule with other forms of movable bridges the reader is referred to Chapter XXVIII.

Modern bascules are comprised in three classes, viz., the trunnion type, the rolling lift type, and the roller bearing type. Any of these bridges may have either a single leaf or two leaves meeting at the centre of the span. For railroad traffic the single leaf is preferable, for it can be made to act as a simple span when closed; and greater rigidity is thereby secured.

In the trunnion type the centre of rotation remains fixed or nearly so, and is at or close to the centre of gravity of the rotating part. This is a highly desirable feature where yielding foundations are unavoidable. In the rolling lift type the centre of rotation continually changes and the centre of gravity of the rotating part moves in a horizontal line, thereby shifting the point of application of the load on the pier, which is a faulty feature, unless the pier be founded on rock. The rolling lift in opening recedes from the channel, thereby leaving a greater clear waterway for the same span length than does the trunnion type. However, it also encroaches on the land side, which is objectionable in congested quarters. In the roller bearing type the centre of rotation remains fixed and coincides with the centre of gravity of the moving mass. The trunnion is eliminated and the load is carried by a segmental circular bearing on rollers arranged in a circular track. In this way the load can be distributed over greater area, thereby reducing the unit bearing stress; and at the same time the frictional resistance to rotation is decreased.

Much ingenuity has been exercised in devising various mechanisms and operating machinery in the attempt to overcome the several unsatisfactory features of the original bascules. This has led to different subtypes or varieties. To the rolling lift class belong the Scherzer and the Rall varieties. To the trunnion class belong the Strauss, Brown, Page, Chicago City, and Waddell & Harrington varieties; and to the roller bearing class belong the Montgomery Waddell and the Cowing varieties.

In the Scherzer bascule (see Fig. 30*a*), the leaf, L, rotates on the quadrant Q, which rolls along the horizontal track girders, T. The centre of gravity, G, of the leaf is at the centre of this quadrant and, therefore, moves in a horizontal line as the bridge opens. A counterweight, W, is attached to the short arm projecting shoreward, so that the leaf is main-

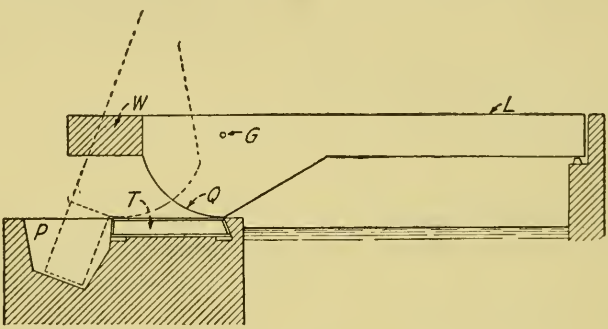

FIG. 30*a*. Scherzer Bascule.

tained in balance at all positions; and, consequently, the operating machinery has only to overcome inertia and the friction of the moving parts. A pit, P, is provided in the main pier so that the counterweight can sink into it as the leaf opens and rolls backward. This pier is of large size, as it carries the track girders; and it requires a good, solid foundation, since the shifting of the point of application of the load disturbs the base pressures. Two other smaller piers are required for a single leaf structure—a rest pier at the front end and a shore pier or abutment at the rear end to carry the approach span. In the case of a double leaf bascule a second main pier will be required and also an abutment. A locking device at the centre of the span connecting the two leaves when the bridge is closed renders unnecessary a rest pier. The span is operated by a pinion working in a rack pivoted to the upper part of the quadrant. Fig. 30*b* shows one of the Scherzer rolling lift bridges.

The Rall type, shown in skeleton form in Fig. 30*c*, rotates about the centre of gravity, G, of the leaf where a pivot or trunnion is provided, which rests in a roller, R, carried by a horizontal track girder, T. When the leaf is closed the main girder or truss bears on the pin A, which is fixed to the pier; and the roller, R, is slightly raised off the track girder, so that the load on the bridge is carried directly by pin A to the pier. The swing strut, S, is connected at one end to the movable girder by pin B, and at the other end to pin A. When the leaf rises, it first revolves

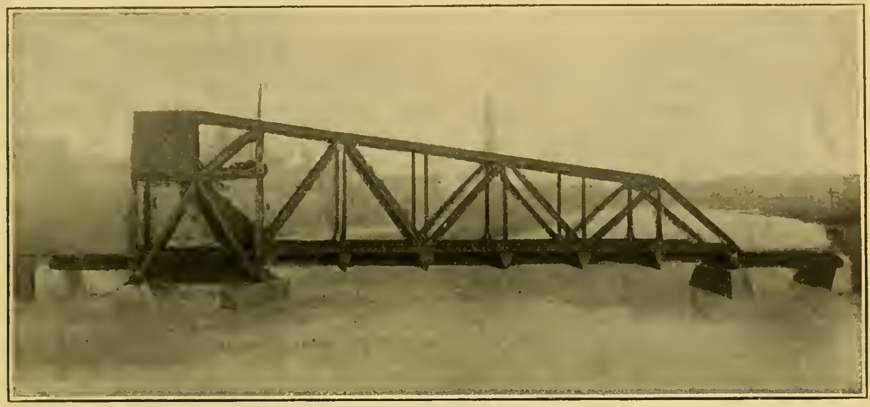

Fig. 30*b*. Scherzer Bascule Bridge.

around pin A, until the roller is in full bearing with the track girder; then as the operation is continued, the roller moves horizontally on the track girder, while pin B of the main girder describes an arc with A as the centre. The leaf is operated by the main pinion, P, engaging a rack fixed to the strut, E, which is pivoted to the girder at C. When the leaf is closed the

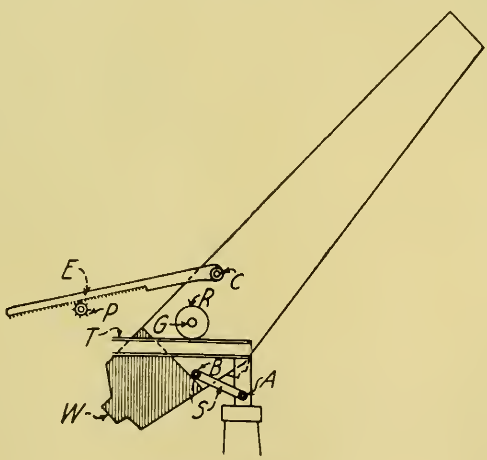

Fig. 30*c*. Rall Bascule.

pivoted roller, R, is free and can be removed and replaced without difficulty. The centre of rotation is so far above the pier that no pit is required to receive the tail or the counterweight, W. The horizontal motion of the pivot is sufficient to allow the tail to clear the masonry when the span is raised. This retreating motion of the leaf permits of using the minimum span length to obtain a given clear waterway. However, the shifting of the centre of gravity disturbs the foundation pressures. Fig. 30*d* shows the Rall bascule erected at Peoria, Ill. The Rall bascule patents are now controlled by the Strobel Steel Construction Company of Chicago.

The distinctive feature of the Strauss trunnion bascule is the pivoting of the counterweight at the end of the short arm. This enables the said counterweight to move parallel to itself at all times; and it can, therefore, be made in such shape that no pit is required to receive it when the leaf is in an upright position. In one variety of this type the counterweight is placed beneath the approach floor. In the other variety it is

FIG. 30*d*. Rall Bascule Bridge over the Illinois River at Peoria, Ill.

located in a frame above the floor (see the skeleton diagram in Fig. 30*e*). The frame, F, carrying the counterweight, W, is attached by means of a strut to the short arm of the bascule at the pivot, A, and at the top by the pivot, B, to a link, K, which is pin-connected to the tower at C. This system of connections provides for a parallel movement of the counterweight at all times, and thus does not alter the ratio of lever arms nor displace the centre of gravity of the system, which is at the main trunnion, G, of the bascule. The leaf is operated by the pinion, P, engaging the rack, R, on the short arm. Fig. 30*f* illustrates the Strauss bascule at Polk Street, Chicago. Since the construction of this bridge, the Strauss Bascule Bridge Company has developed a modification known as the "heel trunnion" bascule, which is shown in skeleton form in Fig. 30*g*. This modified type has a fixed pivot point, E, at the end pin of the bottom chord of the truss. The counterweight trunnion, T, is also a

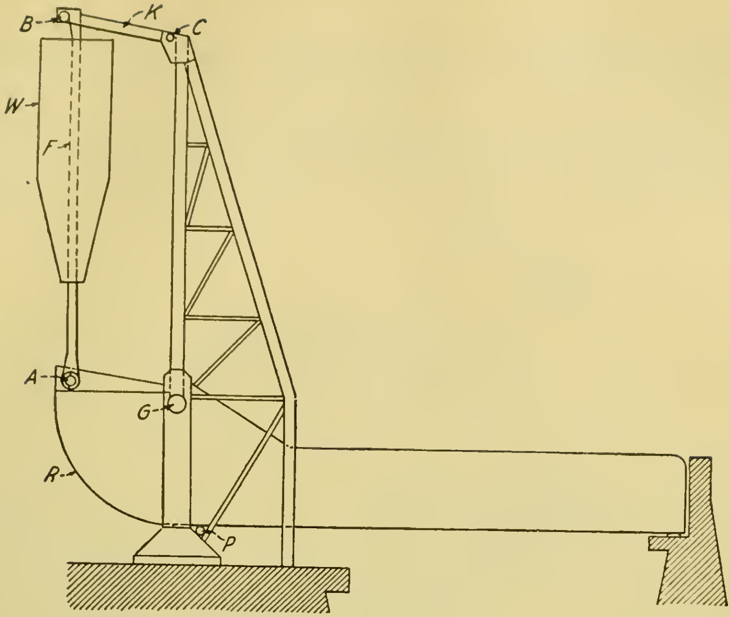

FIG. 30e. Strauss Bascule.

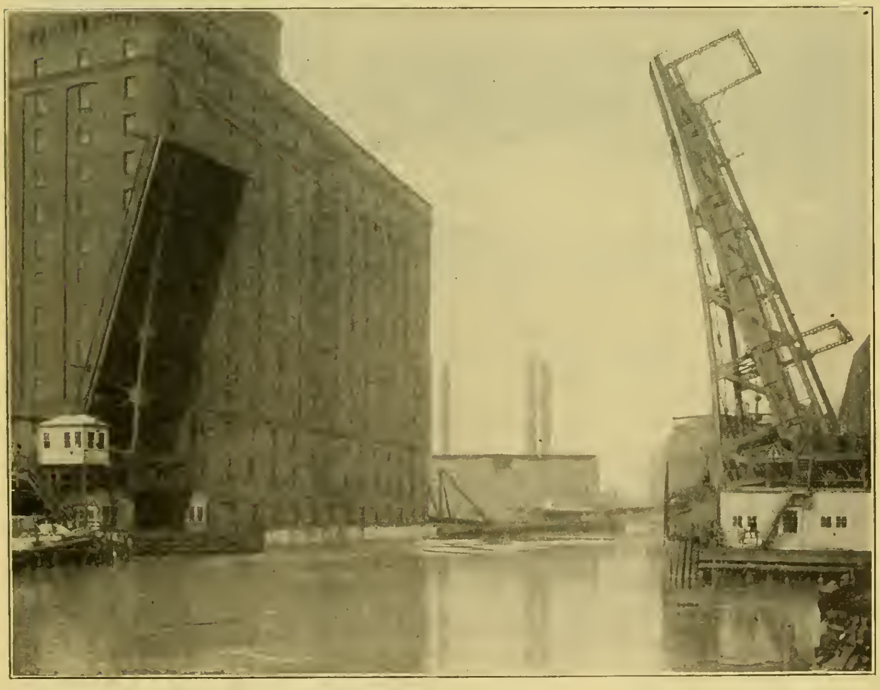

FIG. 30f. Strauss Bascule Bridge at Polk Street, Chicago, Ill.

fixed pivotal point, and is located at the top of a stationary tower supported by the main pier and an auxiliary pier. The counterweight, W, is carried by one end of a trussed frame rocking on the trunnion, T. The other end of this frame is connected by a pivot, F, to a link, K, which in turn attaches to the hip of the main truss by the pin, H. This provides a parallelogram of linkages, with the side formed by the triangular

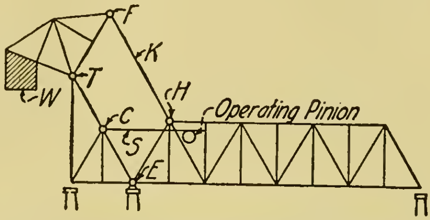

FIG. 30*g*. Strauss Heel-trunnion Bascule.

tower before mentioned as a fixed link. Near the centre of the latter the operating strut is pivoted by the pin, C. A pull on the strut, S, causes the parallelogram to close up, thereby raising the leaf. A detailed description of the heel trunnion type will be found in *Engineering News*, Vol. 67, page 830.

The Brown type of trunnion bascule differs from the others chiefly in its method of operation and in the application of its counterweights. (See Fig. 30*h*.) The usual truss form rotates about a pivot, E, in the end post.

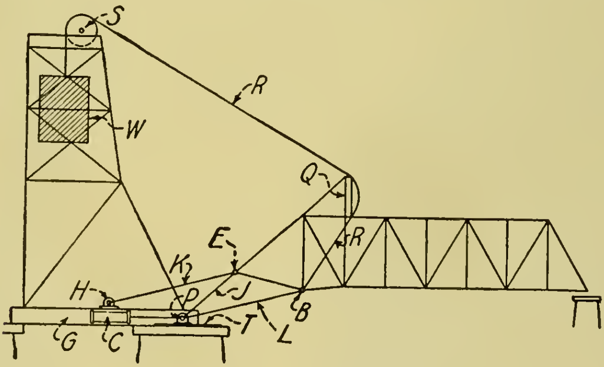

FIG. 30*h*. Brown Bascule.

Two connecting links, K and J, control the movement of this point. The link, K, is hinged at H, a fixed point on the approach girder, G, while the other link, J, is really a continuation of the end post and is connected by a pin, P, to the cross-head at the end of the piston rod of a hydraulic cylinder, C. This cross-head slides along a horizontal guide, T, and transmits through a strut, L, which is really a continuation of the lower chord, its motion to the span. As this cross-head moves forward, the leaf is forced to rotate about the pivot, E, as that point is fixed horizontally by the link, K, the said link being the only member that can provide the reaction to the force on the pin, P. However, this system of linkages provides for a slight, nearly vertical motion of E as the span rises, the link, K, turning about the hinge, H. The fixed length of the link, J, and its attachment to the cross-head held to the guide, T, limit the movement of E to a small arc only. The counterweight, W, is of the overhead type, and moves vertically in a tower built over the approach span. It is attached to a cable, R, which runs over a sheave, S, at the top of the tower and then on an inclination to a specially curved and grooved

Fig. 30*i*. Brown Bascule Bridge at Buffalo, N. Y.

track, Q, fixed in an upright position to the top chord, around which track the cable bends to a reverse inclination and then fastens to a pin, B, at the panel point in the lower chord next to the end. The curvature of the track, Q, is such that, as the span rotates from the horizontal position through an angle of about 81 degrees, the horizontal reaction on the cross-head remains very small (thus ensuring that the mechanism will have to overcome merely the friction of moving parts and the wind pressure), while the vertical reaction thereon gradually increases from zero to an uplift of nearly one-third of the weight of the span. After a rotation of 81 degrees has occurred, the centre of gravity of the span is almost directly over the point P, and the line of action of the cables passes through the same point. If the movement progresses still further, the cables leave the guide, Q, and come into contact with other guides (not shown in the sketch) located near the top chord; and the bending of the cables around these guides sets up a horizontal force which prevents the span from tipping over toward the tower. During this last stage, the horizontal reaction on the cross-head increases very rapidly, while

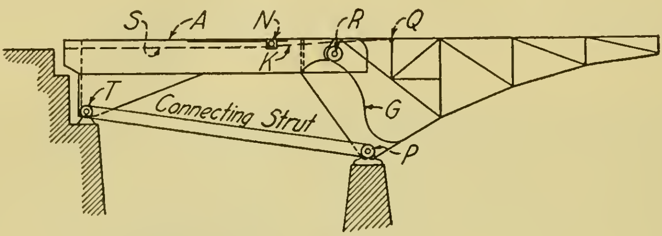

FIG. 30*j*. Page Bascule.

the vertical reaction thereon remains nearly constant. Fig. 30*i* illustrates the Brown bascule at Buffalo, N. Y.

The Page bascule has the unique feature of a tilting approach span for highway bridges. This approach span is utilized as a counterweight. In through railroad bridges the approach span is fixed and a tilting counterweight is placed overhead. As the principle of operation is the same in each case, one description will suffice for both kinds. See Fig. 30*j*. The approach span, A, pivots on trunnions, T, at the shore end; while the free end is carried by rollers, R, resting on specially curved track

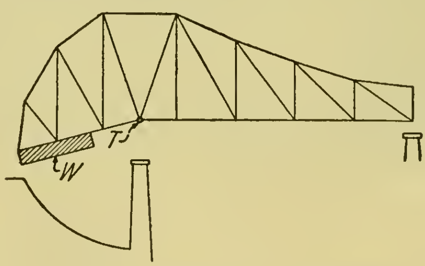

FIG. 30*k*. Chicago City Type Bascule.

girders, G, that are fixed to the main trusses of the bascule. As the leaf rises the track girders rotate with it about the pin, P, and cause the free end of the approach span to drop also. This approach span is loaded so that it balances the weight of the leaf in all positions. To produce this condition of constant equilibrium, the contour of the track girders, G, is curved in such a way that the point of application of the counterweight load gives a decreasing lever arm as the leaf rises and its centre of gravity approaches the vertical line passing through the centre of rotation. The operating mechanism consists of long screws, S, provided with nuts, N, moving in guides on the girders. The motion of the nuts is transmitted by the operating struts, K, to the truss through the pin connection, Q. Owing to the inherent inefficiency of the screw mechanism, more power is required to operate this type than is needed for any of the other bascules. The effectiveness of the counterweight is reduced by the support given the counterweight girders at the pivot, T. No pits are required to receive the counterweights.

The Chicago City Type of bascule was developed by the Engineering Department of Chicago. See Fig. 30*k*. The trusses are supported on trunnions, T, in line with the lower chord, placed a short distance back from the centre of gravity of the span. Counterweights, W, are rigidly

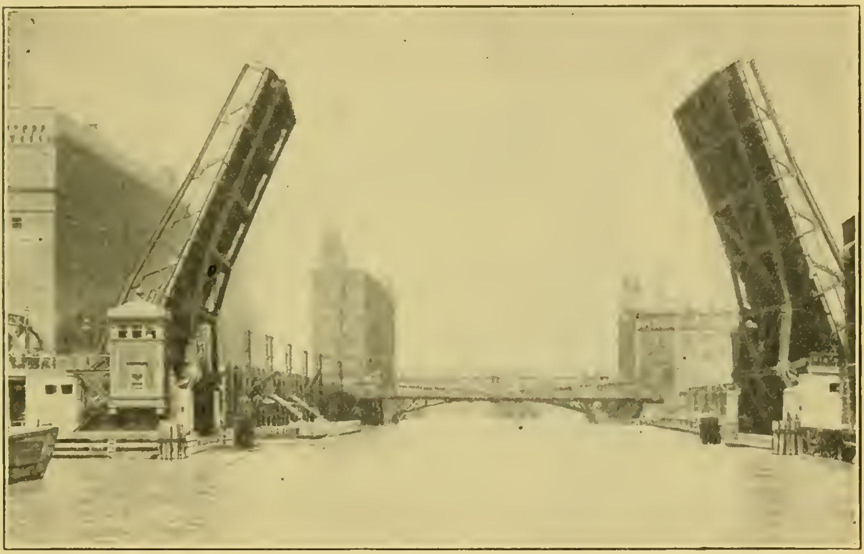

Fig. 30*l*. Chicago City Type Bascule Bridge.

attached to the end of the shore arm, and a pit is provided in the pier for their reception when the bridge is opened. The leaf is operated by a pinion and segmental rack attached at the end of the short arm. Elastic bumpers are provided to absorb the shock in opening and closing the span. A worm gear brake is also supplied to check any downward motion of the leaf, should occasion require. For a double leaf bridge centre locks are employed, but no rear locks are needed, as the centre of gravity is ahead of the pivot.

Fig. 30*l* shows a Chicago City Type bascule bridge opened for river traffic. Just beyond can be seen a Scherzer Rolling Lift Bridge.

The Waddell & Harrington bascule has a number of distinctive features. See Fig. 30*m*. The trunnions, T, which are in line with the top chords of the trusses, are made of special steel castings which are rigidly attached to a box-girder, B, spanning the distance between the trusses. The free end of each trunnion has a cylindrical bearing, C, with its axis parallel to the plane of the truss. This bearing fits into a cup, D, mounted on a standard or tower anchored to the pier. The object of this cylindrical bearing is to permit a slight rotation due to the deflection of the box-girder connecting the trunnions. Between this cylindrical bearing and the end of the box-girder is an enlargement of the trunnion, or a segmental ring, R, having a spherical surface. A hub casting, H, bored to fit this spherical surface, turns on the segmental ring and supports

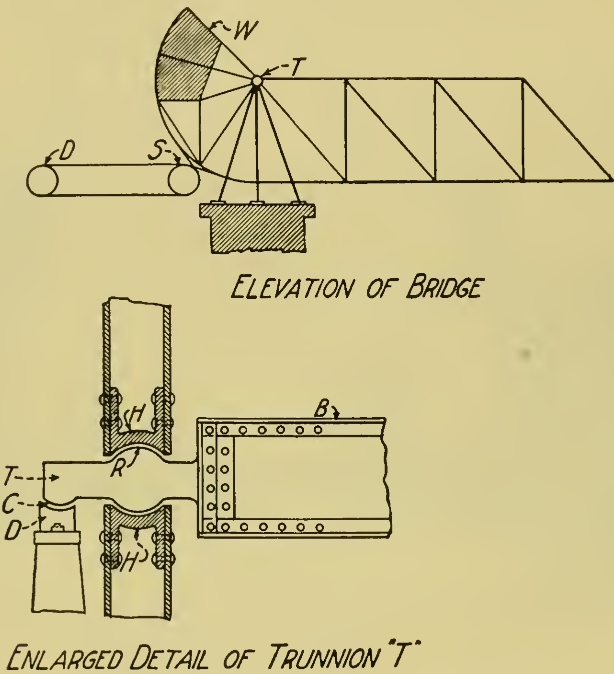

FIG. 30*m*. Waddell & Harrington Bascule.

the truss. This gives a bearing of large area and permits of using a lower unit pressure. This spherical surface also provides for the slight bending of the trunnion in a plane perpendicular to the truss as the deflection of the box girder varies with the change in loads, thereby preventing any binding or any unequal distribution of loading on the two sides of the truss that would involve high secondary stresses. The span is operated by a system of cables connected by equalizer bars to each truss at the ends of the segment of the short arm of the bascule. These cables follow the curve of the segment and pass around a nearby idler sheave, S, under the floor and then to the winding drum, D, from which they return to the idler and then to the other attachment at the segment. Provision is made for reversing the rotation of the winding drum. As the span is balanced about the centre of rotation by a concrete counterweight, W, at the upper end of the segment, extending from truss to truss, only sufficient power to overcome the friction and inertia of the moving parts is needed to operate the span. Fig. 30*n* depicts a bascule of this type erected over False Creek at Westminster Ave., Vancouver, B. C.

The first roller bearing bascule was developed by Montgomery Waddell, Esq., C. E., to whom patents were issued in 1899. See Fig. 30*o*.

Fig. 30*n*. Westminster Avenue Bridge over False Creek at Vancouver, B. C.

There are two distinct designs for this type of bascule. In one the circular end of each truss of the moving span rests on a nest of solid rollers, R, that are effectively connected to each other by spacers and which are supported in a cylindrical, cup-shaped bearing. These rollers have trunnions which rest on the curved track, T, and which have a diameter one half of that of the rollers, consequently the translation of the rollers is only one-fourth as rapid as that of the cylindrical surface which bears on them. In the other design the last mentioned surface rests on two stationary compound rollers per truss, of the type shown in the lower portion of Fig. 30*o*. In both types, and more especially in the second, the frictional resistance to motion is reduced to a very small quantity. As shown in the drawing, the compound roller consists of a single large solid cylinder, R_3, surrounded by a nest of small, solid rollers, R_2, that are encased by a large, hollow cylinder, R_1. Such a combination approximates closely in efficiency to a ball-bearing. To operate the bascule, a pinion engages a rack on the outside of the segment in the planes of the trusses. An overhead counterweight, W, is provided at the upper end of the segment. No pit is required in the pier to receive either the tail end of the span or the counterweight. The centre of gravity corresponds to the centre of rotation so that only friction and inertia have to be overcome.) Fig. 30*p* shows a general plan for a 750 foot, double-leaf, bascule bridge for a proposed crossing of the Mississippi River just below New Orleans, designed jointly by the author and his brother, Montgomery, for the noted railroad builder, the late Collis P. Huntington, Esq., and his

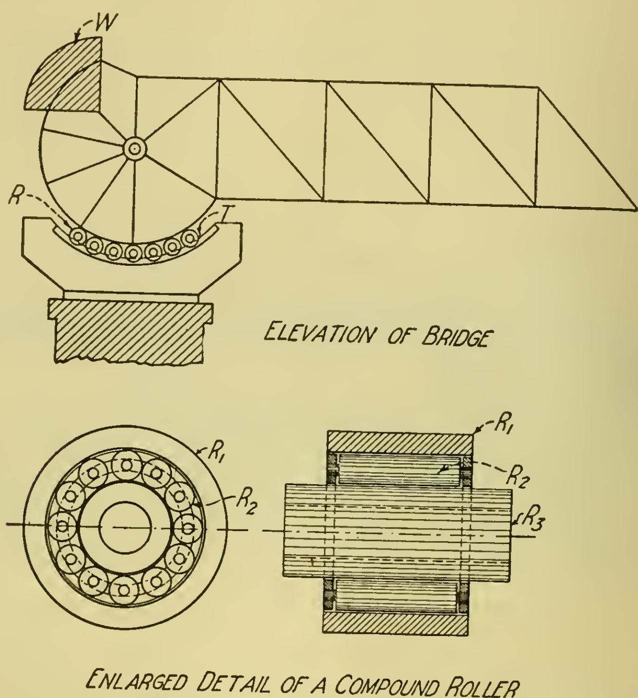

FIG. 30*o*. Montgomery Waddell's Roller-bearing Bascule.

consulting engineer, Dr. Elmer L. Corthell. The death of Mr. Huntington was the sole reason for the failure of this bridge project to materialize. In this case the rollers were to be stationary, and the counterweights were to be attached to long arms extending beyond the rolling segment and outside thereof. Fig. 30*q* shows a plan for a double-leaf bascule bridge over the Chicago Drainage Canal. For this bridge the moving rollers were selected. Attention is called to the relatively small amount of concrete needed for substructure.

The Cowing bascule, based on patents issued to John P. Cowing, Esq., in 1900, is very similar to the Montgomery Waddell type. The semicircular segment, forming the tail end of the lifting span, moves on a nest of solid rollers, which in turn move on a track girder curved to correspond with the said rolling segment. The counterweight is partly above the floor and partly below. The leaf is balanced in all positions,

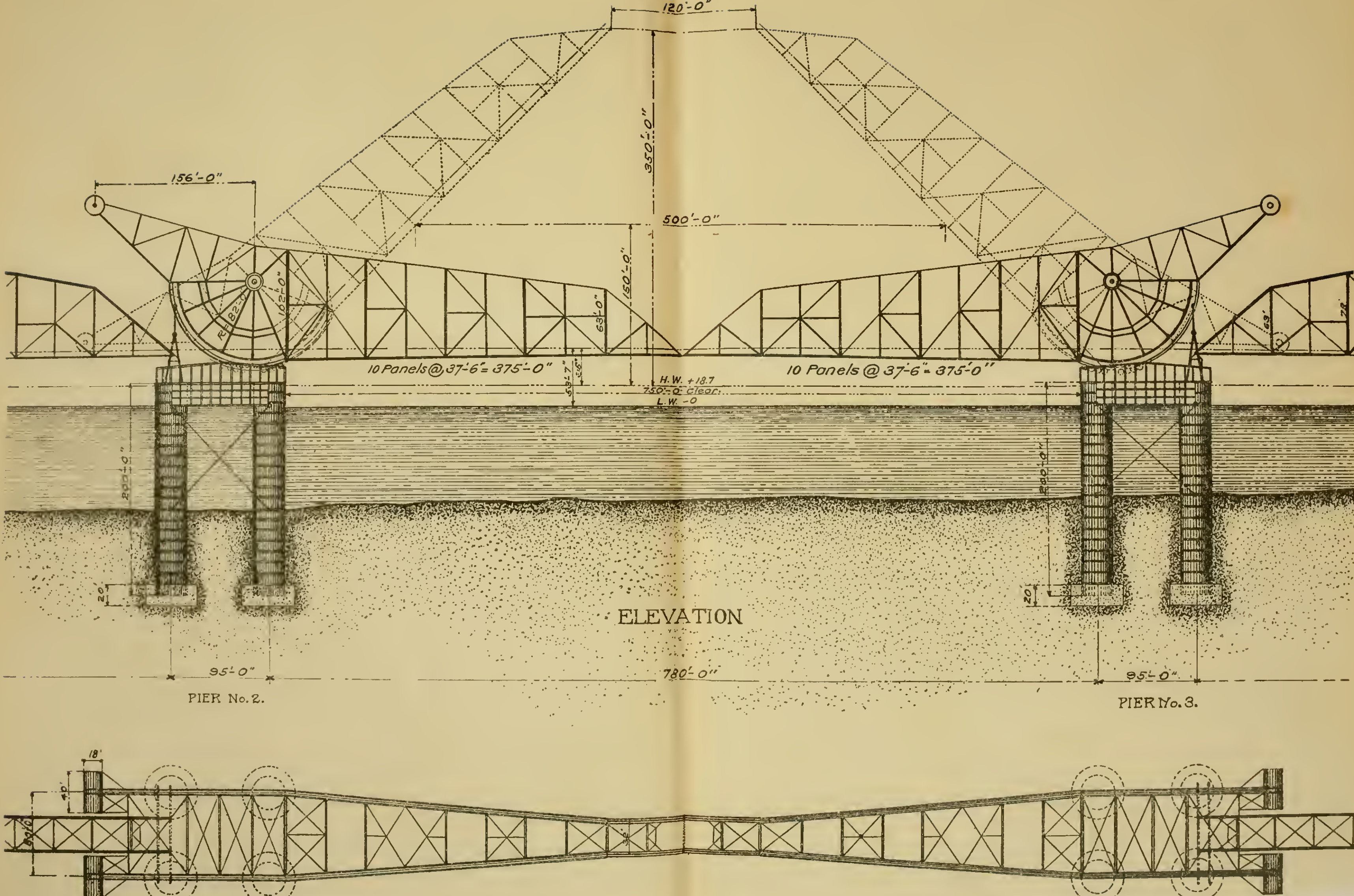

FIG. 30*p*. Proposed Roller-bearing-bascule Bridge over the Mississippi River at New Orleans, La.

as the centre of rotation is at the centre of gravity of the mass. When the bridge is closed, the live load reaction comes on a bearing placed upon the pier in front of the curved track or cradle. It is claimed that the Cowing type is a direct infringement on the Montgomery Waddell patents.

The question is often asked: "Which is the best of the various types of bascule?" It is a difficult one to answer. Truth to tell, there is not today much difference in efficiency between any of them. Each has its advantages and its disadvantages. All of them are inherently ugly, and for all but comparatively short spans are uneconomic in comparison to the vertical lift; but they are scientific, and they represent, probably, the best and most profound thought that has ever been devoted to bridge engineering. They certainly are complicated structures, and as such they require good care and constant attention. They are more satisfactory than the swing span in several important particulars; and wherever they can be built more cheaply than the vertical lift, they should be adopted.

The retreating type, in which the axis of rotation has a motion of translation longitudinally with the struc-

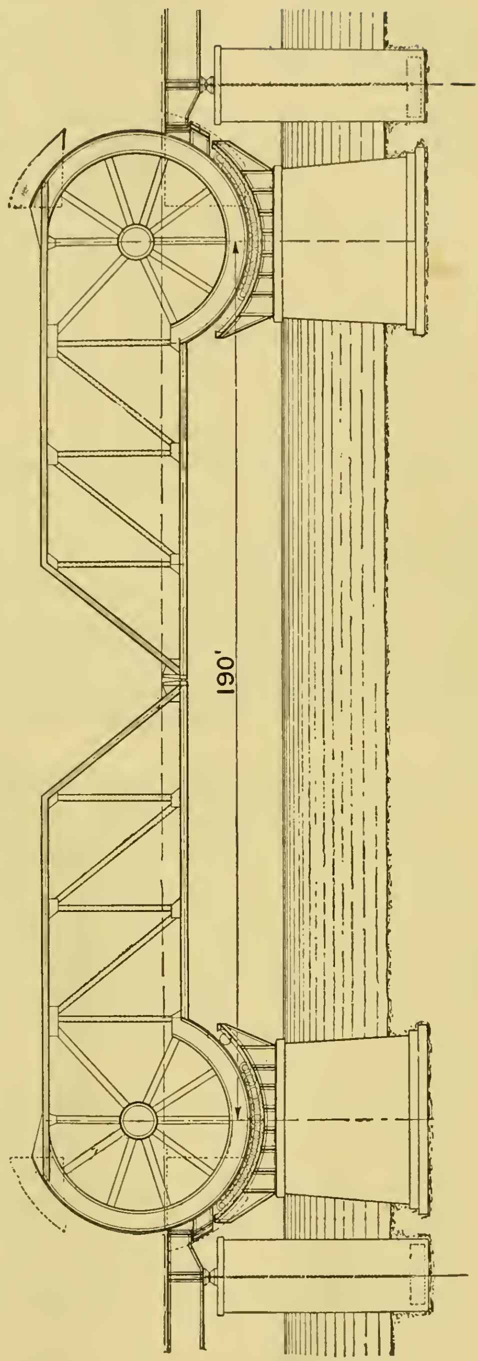

Fig. 30*q*. Proposed Roller-bearing Bascule Bridge over the Chicago Drainage Canal.

ture, has the advantage of giving generally a greater clear opening for any total length of span than does the type with the fixed trunnion, and on that account it ought to be somewhat cheaper; but, on the other hand, it usually involves greater expense for the machinery and the structural details directly connected therewith. The principal disadvantage of the retreating type, as before stated, is that it is really suitable only when the pier foundations are either rock or some other very solid material; because the variation of the loading on a pile foundation, by constantly changing the location of the centre of pressure of the load, tends to rack the pier or abutment. In general, the author's choice would be for the type with the fixed position of axis of rotation, but he is not at all prejudiced either pro or con; hence, if a case were to occur in which the piers were designed to rest on a solid bearing and in which the retreating type showed by careful estimates a material saving in first cost, he would not hesitate to adopt it.

The Scherzer type of bascule apparently has been the most popular of all types up to the present time, notwithstanding the fact that many of the earlier bridges of this make wrenched themselves to pieces, the principal points of failure being the teeth of the rack, the peripheral segment connecting thereto, and the attachment of the said segment to the span; for the teeth broke and the rivets sheared constantly after a few years of service. It is claimed, though, that these defects have been remedied in the later designs of the Scherzer Bridge and that the structures of that type built during the last few vears are giving good satisfaction.

Not enough bridges of the Rall patent have been built to warrant one in passing judgment upon its merits and demerits; but, from all that can be learned, it appears to be a satisfactory type of structure.

A good many bridges of the Strauss type have been built, and from all that can be learned they are operating well; but they are specially deficient from the æsthetic point of view. However, that cuts very little figure, as no bascule bridge ever designed can be claimed to be a thing of beauty. If it will open quickly and keep in good order, that is about all that can be expected of it.

As yet there is only one of the Brown bascules in operation. It is giving good service and is of as scientific construction as any of the types. Some engineers may claim that the employment of wire rope in its design is a defect; but the author does not agree with that opinion, because that material is the most reliable of all the kinds of metal with which an engineer has to deal. For comparatively short span bridges (and those are the only ones for which the bascule is truly suitable) this type ought to give satisfactory service.

The Page bascule has not yet been thoroughly tested by age, nor have many of them been built. The screw mechanism employed in its operation is certainly not a feature of design that can be considered in its favor; for it must increase greatly the amount of power required.

The Chicago City type of bascule has given good satisfaction for a number of years, although it is said to be somewhat expensive in construction. The fact that it involves the use of a pit below water level may account for a large portion of the excess cost; and, moreover, that feature is not, to say the least, a desirable one, owing to the necessity for keeping the pit clean and free from water, However, the city authorities in Chicago seem to prefer it to all other types, possibly because it is not patented; and the existence of such a preference is certainly a strong point in its favor.

There has been but one bridge of the Waddell and Harrington type of bascule built, and that one does not often have to be operated—in fact, it is needed so seldom that the bridge has to be opened occasionally in order to keep all the moving parts properly lubricated. On that account it is impracticable to pass judgment upon its efficiency. This, however, may be stated—that, because of its two adjustment-provisions for axle deflection, it is the most perfect of all bascules yet built with overhead axle. The secondary stresses that are induced in any bridge of that type in which the axle deflections are not properly cared for would startle by their magnitude any computer who might take the trouble to analyze them thoroughly. The type is not specially economical. It was adopted by the City of Vancouver because of the fact that no royalty was asked for its use, the patents on it being controlled by the City's consulting engineers.

Of all the kinds of bascule with which the author has ever had anything to do, that one of his brother's numerous patented types which is described herein appeals to him the most, notwithstanding the fact that in years long gone by he made a number of unsuccessful attempts to introduce it in competition. His failures cannot be attributable to any inferiority in the plans or in the type of structure; for his estimates, as compared with those for the competing structures, always showed a decided economy in first cost. The true reason was that he was unwilling to resort to the means of introduction of the type that were indicated to him as necessary to ensure success. There is but little to choose from between the two styles of rollers, although Mr. Cowing evidently preferred the nest of solid ones, as that is the type which he adopted in taking out his patent.

More bascules of the trunnion type have been built than of the other types. The longest bascule bridge yet constructed is one of the Strauss trunnion variety at the Canadian Pacific Railway crossing of the Sault Ste. Marie ship canal. This bridge is of two leaves and has a length of 336 feet between trunnions. It is of the through truss type, and is provided at the ends of the leaves with locking devices for the top and bottom chords, so that when closed and locked it acts as a simple span. For a detailed description of the structure with illustrations, the reader is referred to *Engineering News*, Vol. 73, page 108.

The number of bascules constructed in America has become so large that a complete list of them would be beyond the scope of this chapter. The cities of Chicago and Milwaukee have been their largest users in this country, and the Sanitary District of Chicago has built a great number of them over the Drainage Canal. Bascules have also been adopted at Cleveland, Buffalo, Toledo, Peoria, Portland, Ore., Providence, Philadelphia, and other cities. In general, the modern bascule has given good service. For spans requiring leaves not much longer than one hundred feet it is eminently satisfactory; but beyond that limit the first cost of the structure begins to become too high as compared with the vertical lift type of movable bridge, which type is treated at length in the next chapter.

In concluding this chapter the author desires to express his hearty thanks to the following gentlemen and companies for their courtesy in furnishing him with the data concerning their types of bascule bridges:

The Scherzer Rolling Lift-Bridge Company.

The Strobel Steel Construction Company.

J. B. Strauss, Esq., C. E.

Thos. E. Brown, Esq., C. E.

Messrs. Page and Shnable.

The engineers of the Bridge Department of the City of Chicago, and especially John Ericson, Esq., C. E., the City Engineer.

CHAPTER XXXI

VERTICAL LIFT BRIDGES

The history of vertical lift bridges has been thoroughly worked up by Henry Grattan Tyrrell, Esq., C. E., in a paper presented to The University of Toronto Engineering Society, published in *Applied Science* in 1912, and reprinted in pamphlet form by Mr. Tyrrell. It is well worth perusal by anyone who is interested in the evolution of bridge building. Briefly stated, the development of the vertical lift bridge is as follows:

The first one of which there is any record was a thirty-foot span having a lift of six and a half feet, being a portion of a wooden trestle over the Danube River at Vienna. Subsequent to this a number of very short spans with low lifts were constructed in Europe. The first design for a lift of any importance in respect to both span and rise was one submitted in 1850 by Captain W. Moorson of London in a prize competition on plans for a bridge to cross the Rhine at Cologne. It had a lifting span one hundred feet long and about fifty feet wide with a rise of fifty-four feet. The prize was awarded to another competitor. In 1867 a design was made by Oscar Roper of Hamburg for a three-hundred-foot lift span, which could be raised high enough to permit ocean-going vessels to pass beneath, but nothing ever came of it. In 1872 T. E. Laing proposed a lift span in a bridge over the River Tees at Newport near Middlesbrough, England; but it did not materialize. The movable span was to be two hundred feet long, the lift forty feet, and the maximum vertical clearance ninety feet. It was to be operated by adding and withdrawing water, the tank therefor being a part of the counterweight. In 1878 there was an elaborate design for a lift bridge made by M. H. Matthyssens for a crossing of the Scheldt at Antwerp, involving a span of one hundred and thirty-one feet and about the same clear height. About this time a few small spans with low lifts, generally over canals, were built in various parts of Europe, but until quite lately no vertical lift bridge of any importance has been constructed in Europe.

In 1872 Squire Whipple, one of the pioneers in American bridge building, began to design and build short lift spans with small rises to cross the canals of New York State, including one at Syracuse in which only the deck moves. During the next two decades a number of small vertical lifts were built across canals in the Eastern States, and a few were constructed abroad. In 1892 the author proposed for a crossing of the ship canal at Duluth a vertical lift span of two hundred and fifty feet with a vertical clearance of one hundred and forty feet. As explained in Chapter XXVIII, his design was accepted in competition; but the War Department prevented the building of the structure. A similar bridge of one hundred and thirty feet span and one hundred and fifty-five feet vertical clearance was proposed a few months later by him for a crossing of the South Chicago River at South Halsted Street, Chicago. His proposition was accepted and the bridge was built. A full description of the structure is given in a paper by the author published in the *Transactions* of the American Society of Civil Engineers for January, 1895, and from it the following condensation was made and published in *De Pontibus:*

"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 centres 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 position 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 $1\frac{1}{2}$ 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, while, where they attach to the counterweights, they form a loop, which passes around a 15-in. wheel or pulley that acts as an equalizer in case the two adjacent ropes tend to stretch unequally.

"The counterweights, which are intended just to balance the weight of the span, consist of a number of horizontal cast-iron blocks about 10 x 12 inches in section, and 8 feet 7 inches long, strung on adjustable wrought-iron rods that are attached to the ends of rockers, at the middle of each of which is inserted the 15-inch equalizing wheel or pulley previously mentioned.

"The counterweights run up and down in guide-frames built of 3-inch angles.

"The weight of the cables is counterbalanced by that of wrought-iron chains, one end of each chain being attached to the span and the other end to the counterweights, so that, whatever may be the elevation of the span, there will always be the same combined weight of sustaining cables and chain on one side of each main sheave as there is upon its other side.

"Between the tops of the opposite towers pass two shallow girders thoroughly sway-braced to each other, and riveted rigidly to the said towers. The main function of these girders is to hold the tops of the towers in correct position; but incidentally they serve to support the idlers of the operating ropes and to afford a footwalk from tower to tower for the use of the bridge-tender. Adjustable pedestals under the rear legs of each tower provide for unequal settlement of the piers which support the tower columns. Each of these pedestals has an octagonal forged steel shaft, expanding into a sphere at one end, and into a cylinder with screw-threads at the other. The ball end works in a spherical socket on a pedestal, and the screw end works in a female screw in a casting which is very firmly attached to the bottom of the tower-leg. It is evident that by turning the octagonal shaft the rear column will be lengthened or shortened. The turning is accomplished by means of a special bar of great strength, which fits closely to the octagon at one end, and to the other end of which can be connected a block and tackle if necessary.

These screw adjustments were useful in erecting the structure, but it is quite likely that they will never again be needed. But in case there is ever any tower adjustment required, it will be found that the extra money spent on them will have been well expended.

"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 feet 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 the 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. 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 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 author 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-inch heavy angle-iron, to act as a cutting edge. This detail is a very effective one for destroying the masts and rigging of colliding vessels.

"The bridge is designed to carry a double-track street railway, vehicles, and foot-passengers. It has a clear roadway of 34 feet between the counterweight guides in the towers, the narrowest part of the structure, and two cantilevered sidewalks, each 7 feet in the clear, the distance between central planes of trusses being 40 feet, and the extreme width of suspended span 57 feet, except at the end panels, where it is increased gradually to 63 feet. The roadway is covered with a wooden block pavement 34 feet wide between guard-rails resting on a 4-inch pine floor, that in turn is supported by wooden shims which are bolted to 15-inch I-beam stringers, spaced about 3 feet 3 inches from centre to centre. 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-inch pine planks, resting on 3 x 12-inch pine joints spaced about 2 feet from centre to centre.

"The span is suspended at each of the four upper corners of the 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 post by means of the portal plate-girder strut on the inside and a special, short, cantilever girder on the outside.

"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 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 pounds, 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.

"The operating machinery is located in a room 37 x 53 feet, the opposite sides being parallel, but the adjacent sides being oblique to each other, the obliquity amounting to about 12 degrees. The placing of this machinery beneath the street was really forced upon the author, who had originally contemplated using electrical machinery and putting it in a house in one of the towers.

"The arrangement of the operating machinery is as follows: Two 70-H.P. steam-engines communicate power to an 8-inch horizontal shaft carrying two 6-foot spiral-grooved, cast-iron drums, around which the ⅞-inch 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-inches. 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 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 could not 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 raising-ropes, after leaving the drums, pass out of the machinery-house to and beneath some 5-foot idlers under the towers, thence up to the top of the north tower, where they pass over some 4-foot idlers and the main 12-foot 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-foot 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.

"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."

In Fig. 31*a* is presented a view of the Halsted Street Lift Bridge partially raised. The original design called for the use of two sixty-five horse-power electric motors, but the city of Chicago required a steam engine plant of one hundred and fifteen horse-power instead. The cost of this plant for both operation and maintenance was found to be excessive; and in 1907 electric motors were substituted for the steam engines. Operation by steam had required the services of three engine men, two signal men, four policemen, and one coal shoveler, ten men in all, their combined wages amounting to one thousand dollars per month; and in addition there were one hundred and seventy dollars per month expended for coal, as it was necessary to keep the boilers going at all times during the season of navigation. The cost of the electric power for intermittent service proved to be only one hundred and fifty dollars per month; and the services of only one tender were required, while two had been formerly needed with steam. The change resulted in a saving of over three thousand dollars per annum in the operating expenses.

In the before-mentioned paper published by the American Society of Civil Engineers there appeared the following:

"If the author were to design another lift-bridge similar to the Halsted Street structure, and if he were given *carte blanche* in the designing, he would make the following improvements:

"1. Curve the rear columns and arch the overhead girders at tops of towers, so as to improve the general appearance.

"2. Operate by electricity instead of by steam.

"3. Place the machinery-house in one of the towers and dispense with the operating-house on the span, letting the operator stand in a bow-window of the machinery house so as to command a view of the river in both directions.

"4. Omit the water-tanks as an unnecessary precaution, and rely on the great capacity of the electric motors to overcome any temporary unbalanced load.

"5. A simpler and less expensive adjustment at feet of rear columns.

"6. Cast steel instead of cast iron for all machinery.

"7. Catch the balancing chains in buckets placed on top of the span instead of hanging them to the counterweights."

In the later designs for vertical lift bridges prepared by his firm, the author was persuaded, rather against his will, to omit the hydraulic buffers and the balancing chains, on the plea that with electric power these are not necessary; but after an experience of several years with lifts in which these two features of his first design were omitted, he has decided to adopt them again in some of his future vertical lift bridges.

In large and heavy lift-spans the unbalanced load of the cables augments materially the starting torque and adds considerably to the amount of power used per annum, besides increasing somewhat the first cost of the

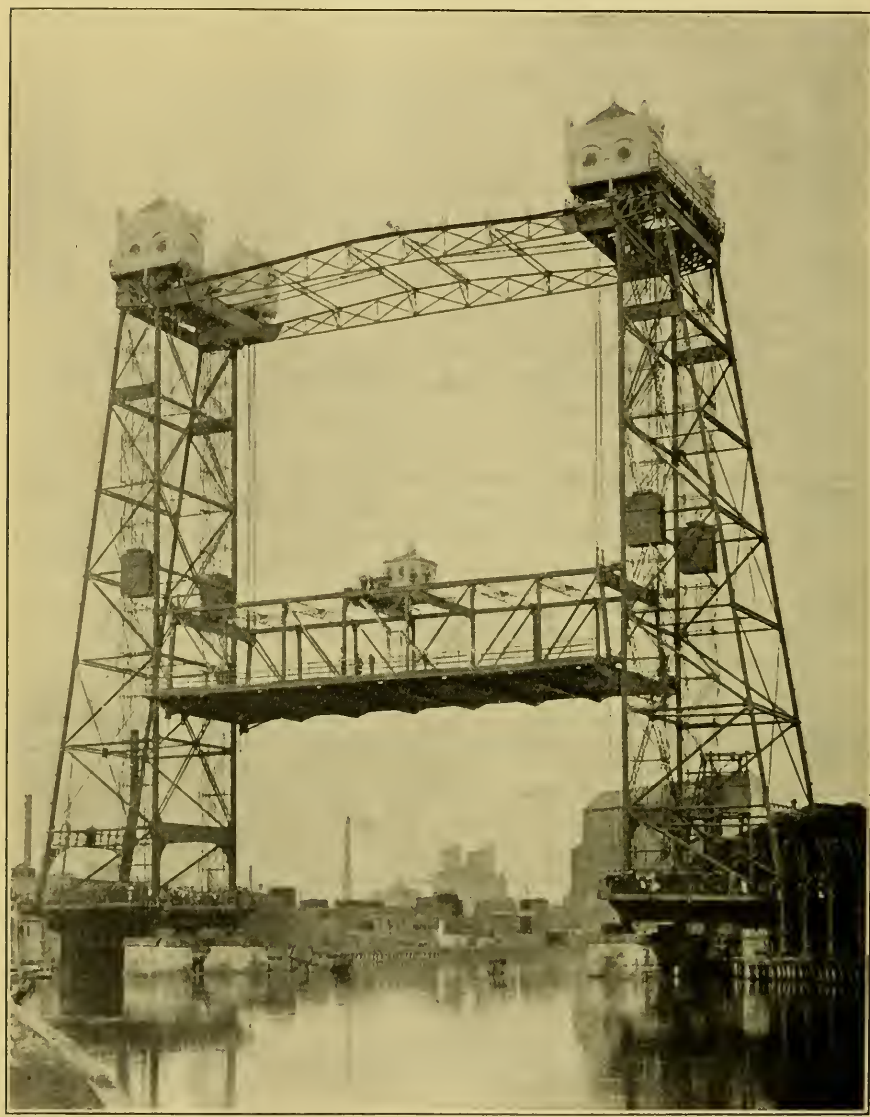

FIG. 31*a*. Halsted Street Lift Bridge over the Chicago River at Chicago, Ill.

machinery. Whether it is good policy in any particular case to adopt the counter-balancing chains is to be determined by an economic study. If the annual interest on the difference between the first cost of the said chains and the saving in cost of machinery is greater than the value of the annual saving of power which they effect, they should be omitted, but otherwise they should be used. All depends upon the question of how often the bridge is to be operated. If it is to be opened only a few times per day, the additional expense would be unwarranted; but if it is to be used very often, the saving of cost of power may be great. In the Pacific Highway Bridge, designed by the author's firm and now under construction, the economic study indicated a stand-off, hence the chains were omitted, as it was desirable to keep down the initial cost of structure to a minimum; but all the Chicago vertical lift-spans should have been provided with the chains, as the number of openings often runs as high as seventy-five per day. Moreover, in some cases a flat rate based upon the peak load is charged for the electric power—and in such cases it is evident that the adoption of the detail for balancing the weight of the cables would be in the line of true economy.

Good and effective hydraulic buffers that are properly maintained in commission are a wise precaution against accident; and they certainly relieve most effectively all jar in bringing the span to rest.

For many years after the completion of the Halsted Street structure the author endeavored unsuccessfully to build similar bridges at other places, the main reason for his failures being that he often ran into political and financial conditions of such a nature that his engineer's conscience prevented his dealing with the parties interested.

In 1894 he made plans for a bridge over the Missouri River at Kansas City, known at first as the Winner Bridge, in which there was a span of four hundred and twenty-five feet carrying a lifting deck; but the construction thereof was delayed for many years. The original design was described in *De Pontibus;* but it was changed materially when the bridge was built some eight years ago, mainly because of the developments that had taken place in bridge designing in the preceding decade. A description of how the structure was actually built will follow presently.

From 1894 until 1907 no progress worth mentioning was made in the building of vertical lift bridges, mainly for the reason that the author's patents prevented other engineers from entering the field, and because of his personal discouragement previously mentioned. But soon after the formation of the firm of Waddell and Harrington in 1907, the author heard from good authority that the changes made in the machinery of the Halsted Street Bridge had converted it into the most satisfactorily operating movable bridge in Chicago; hence he and his partner made a joint study of how to improve on the design of the Chicago bridge; and soon there came to them a request from F. W. Fratt, Esq., C. E., the new president of the Union Depot, Bridge, and Terminal Railway Company, to make a study and estimate of cost for finishing the partially constructed Winner Bridge, which his company had bought in, upon the general lines described in *De Pontibus*. They did so, making a number of changes in the old design, the principal of which were the following:

First. Adopting riveted construction instead of pin-connected.

Second. Telescoping the hangers inside of the vertical posts of the supporting trusses instead of letting them pass outside.

Third. Using concrete instead of cast-iron counterweights and placing them at the ends of the span instead of at the panel points.

Fourth. Operating from a machinery house at each end of the span instead of from a single house at mid-span, and using wire ropes instead of shafting for the transmission of power.

Mr. Harrington's extended experience in various lines of mechanical engineering, especially that obtained as engineer to the C. W. Hunt Company of New York, enabled the firm to effect many valuable improvements in operation, not only in this structure, but also in other vertical lift bridges built later.

While Mr. Fratt and his clients were debating about the advisability of undertaking the work of building the structure, the firm was retained to rebuild the Iowa Central Railway Company's bridge across the Mississippi River at Keithsburg, Ill. Bids were obtained upon both a swing and a vertical lift, showing a material economy for the latter, which was, consequently, adopted and built. The span is two hundred and thirty-four feet and the maximum vertical clearance fifty-five feet. It carries a single-track railway only. In its design there is an innovation which results prove was not a good one. The operating house is placed at one end of the movable span instead of at the middle. It was so located in order to reduce the dead load moment on the span, especially as the machinery is unusually heavy on account of the operation being by gasoline engines. Such a location was a violation of a principle of æsthetics, viz., that perfect symmetry in a layout is the acme of artistic designing; and the result showed that it was not good practice, because, on account of the inequality in length of the operating ropes, the stretches therein were unequal, necessitating frequent adjustments, the neglect of which caused a jerky motion of the span when being raised or lowered. The defect is of but little importance, nevertheless its cause should always be avoided in future construction.

During the building of the Keithsburg Bridge, a little highway lift at Sand Point, Idaho, was designed and constructed. It showed great economy as compared with a swing span.

Next came the Hawthorne Avenue Bridge over the Willamette River at Portland, Oregon, with a lift span of two hundred and forty-four feet and a vertical clearance of one hundred and thirty-five feet, carrying a double-track street railway, two wagonways, and two footwalks. Two views of this structure are shown in Figs. 31*b* and 31*c*. It is of the same general type as the Halsted Street Bridge, except that there is no overhead span between tops of towers.

While this structure was under way Mr. Fratt and his associates, after

Fig. 31*b*. Hawthorne Avenue Bridge over the Willamette River at Portland, Ore.—Lifting Span Down.

Fig. 31*c*. Hawthorne Avenue Bridge over the Willamette River at Portland, Ore.—Lifting Span Up.

long deliberation, decided to build their bridge; but before they would make up their minds to adopt the lifting deck, they had a large working model made of it to scale and operated by electric power; and although this worked to perfection, they still were not satisfied until they had an expert committee of civil and mechanical engineers examine the plans, specifications, and model and report upon the efficiency and practicability of the design. This committee was composed of the following well-known gentlemen: Thos. E. Brown, Esq., C.E., of New York City; S. B. Fisher, Esq., C.E., of St. Louis; Prof. W. V. M. Goss, of the University of Illinois; and Geo. W. Jackson, Esq., of Chicago. This committee gave its unanimous approval to the project, and the bridge was built. The following is a description of the structure, which is shown with the deck down in Fig. 31*d* and with the deck up in Fig. 31*e*.

The bridge proper, *i. e.*, the portion between the established harbor lines, and excluding the approaches, consists of three double-deck, riveted-truss spans, providing on the lower deck two standard railway tracks, and on the upper deck two street car tracks and separate roadways and sidewalks for vehicular traffic and pedestrians. To permit the passage of boats, one of the three spans contains a lifting deck, which consists of a double-track railway bridge floor, the metal thereof being nickel steel so as to reduce the weight to be lifted, with a lateral system that includes special wind chords, all supported by stiff hangers, also of nickel steel, from each panel of the upper trusses. When the deck is in its lowest position, a pin in the end of each hanger rests on a socket in diaphragms in the post above, transmitting the live load directly to the upper trusses. Each hanger is arranged to telescope into the truss post above, and is attached to two cables which pass up and over a sheave on the top of the truss, thence to the end of the span and over a common drum at one corner thereof, and thence downward to a counterweight. There is, thus, a separate counterweight for each hanger. Operation is effected by rotating the four drums at the upper corners of the span. The two drums at each end are on a single shaft which is geared down to a motor. In order to synchronize mechanically the movements of the machinery at opposite ends of the span, a double rope drive is provided connecting the two sets of machinery. A full-size model of this drive was made and tested by the engineers before the design was adopted, in order to satisfy the projectors of the enterprise that it would work satisfactorily. The counterweights for the rope drives are arranged so that one rope is taut for driving in each direction. Under ordinary operation both motors are in service; but, should one motor fail, the entire deck can be handled by the motor at the opposite end through this rope drive.

When the deck reaches its lowest position, locks automatically engage each hanger and the ends of the deck. All locks are withdrawn by one operation by means of a motor and gears in the south machinery house.

Fig. 31*d*. Fratt Bridge over the Missouri River at Kansas City, Mo.—Lifting Deck Down.

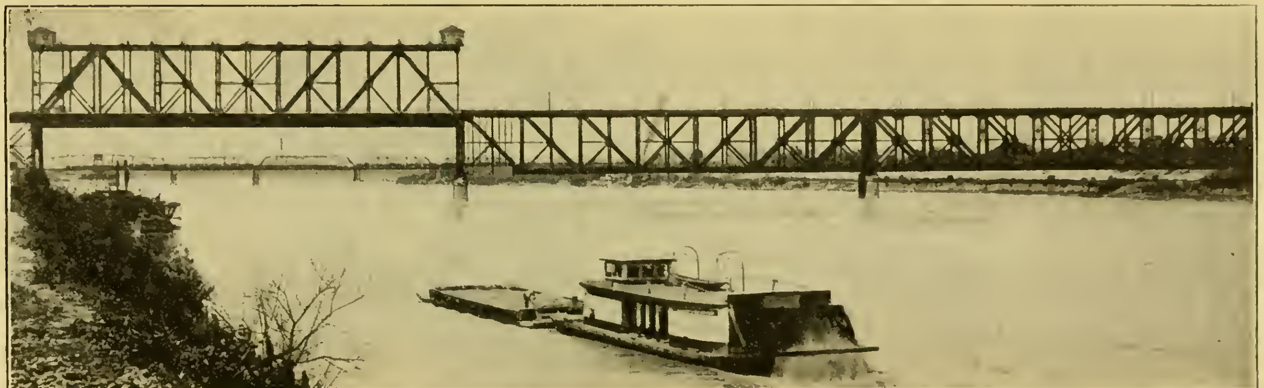

Fig. 31*e*. Fratt Bridge over the Missouri River at Kansas City, Mo.—Lifting Deck Up.

In addition to the manifest advantage of maintaining traffic on the upper deck at all times regardless of the movement of boats, this movable deck afforded large economies in construction, and it will afford also similar economies in operation.

The vertical clearance when the deck is raised to its full height is fifty-five feet above high water, and the horizontal clearance for vessels is four hundred and thirteen feet, the overhead through span and the two adjoining deck spans being each four hundred and twenty-five feet long. The reason for the excessively great horizontal clearance is that the superstructure is built on old piers that had been standing in the river for nearly two decades.

The lifting deck, which weighs one and a half million pounds, is fully balanced by the counterweights and is always locked down when in service. It is raised to its full height or is lowered in fifty seconds by electric power. The total cost of the bridge and its approaches was $2,200,000. The total weight of metal was over eighteen thousand tons, and a number of the pieces handled weighed over one hundred tons each. There were some twenty-five miles of rivet holes reamed in the field and about half a million field rivets were driven. The amount of paint used on the metalwork was fifty tons.

The next structure containing a lift span built by the author's firm was the Arkansas River Bridge between the cities of Fort Smith and Van Buren, Arkansas. As can be seen from Figs. 31*f* and 31*g*, it contains nine spans all alike, one of them being lifted so as to give the usual vertical clearance requirement of about fifty feet. It carries a railway, street railway, and vehicular and pedestrian traffic. The distinctive feature of this structure is that it is arranged so that should ever the channel shift permanently, the towers and machinery can be taken down, moved, and re-erected so as to lift any of the other spans.

Next came the highway bridge at Tehama, California, a comparatively small structure containing no special features; and this was followed by the little M. L. and T. bridge, Figs. 31*h* and 31*i*, which has been adopted as a standard for its small bayou crossings by the Southern Pacific Railway Company. It is operated by one man, as it is not opened often.

Next in order came the great Oregon-Washington Railroad & Navigation Company's bridge, at Portland, Oregon, carrying traffic just like that of the Fratt Bridge, but with the difference that the overhead span, instead of being fixed, was made movable so as to permit the passage beneath of the largest ocean-going vessels. Like the Fratt Bridge, the main portion of the structure consists of three spans, but the total length of them is only seven hundred and ninety-six feet, that of the movable one being two hundred and twenty feet.

In Figs. 31*j*, 31*k*, and 31*l* is shown the structure in its three principal positions, viz.: first, with both the movable span and the movable deck

Fig. 31*f*. Arkansas River Bridge between Fort Smith and Van Buren, Ark.—Lifting Span Down.

Fig. 31*g*. Arkansas River Bridge between Fort Smith and Van Buren, Ark.—Lifting Span Up.

down and taking care of the traffic above and below; second, with the movable span in commission for highway traffic, but with the deck beneath raised to its full height so as to permit the passage of small steamers; and third, with both the movable span and the movable deck raised to their greatest height so as to provide for the passage of the tallest-masted ocean-going vessels that enter the port. Fig. 31*m* has been added, as it gives an excellent view of almost the entire structure, approaches included. Attention is called to the height of the water, the photograph having been taken at its maximum stage.

The distinguishing features of the structure are its unusually heavy construction and the method of lifting the two decks of the movable span either together or separately. The upper deck was designed to carry the heaviest possible city traffic, including pedestrians, electric railway cars, road-rollers, and lorries; and the lower deck to care for the heaviest locomotives and cars used on the Harriman system. The movable span is a through one for highway traffic, while the two flanking spans are through for railway traffic and deck for highway traffic. The lift span rests on columns placed on the piers. The lower deck has a clearance of twenty-six feet above low water and one of only five feet above high water, the base of rail being six feet higher. The upper deck is fifty-two and a half feet above the lower deck. The latter has a separate lift of forty-six feet, making a clear height of seventy-two feet above low water, or fifty-one feet above high water, without moving the upper deck. The latter has a lift of ninety-three feet, so that when hoisted with the lower deck also in raised position, the total lift of the lower deck is one hundred and thirty-nine feet, and the total clearance is one hundred and sixty-five feet above low water and one hundred and forty-four feet above high water. This clears the highest-masted vessels entering Portland. When the lower deck alone is lifted, all but the largest steamboats plying the river can pass at ordinary stages of water. The vertical lift span is much the heaviest of that type thus far built, the total load lifted, including counterweights, amounting to nearly nine million pounds. The towers are about two hundred and seventy feet high above low water.

The main or upper deck is lifted at each corner by sixteen steel cables, two and a quarter inches in diameter, passing over a sheave fourteen feet in diameter. Each sheave weighs twenty-four tons; but as the boxes were attached before hoisting, the weight to be lifted was thirty-five tons. These main sheaves rest on heavy sheave girders between the tower posts.

In each tower there is a single main counterweight made of concrete weighing over one million seven hundred thousand pounds, the over-all dimensions being forty feet height, thirty feet width, and ten feet thickness. These counterweights were constructed in place around a steel framework. At the corners are projecting guides that engage the fixed guides on the tower. The lower deck has separate counterweights that were cast in sections on the main deck and after hardening were trans-

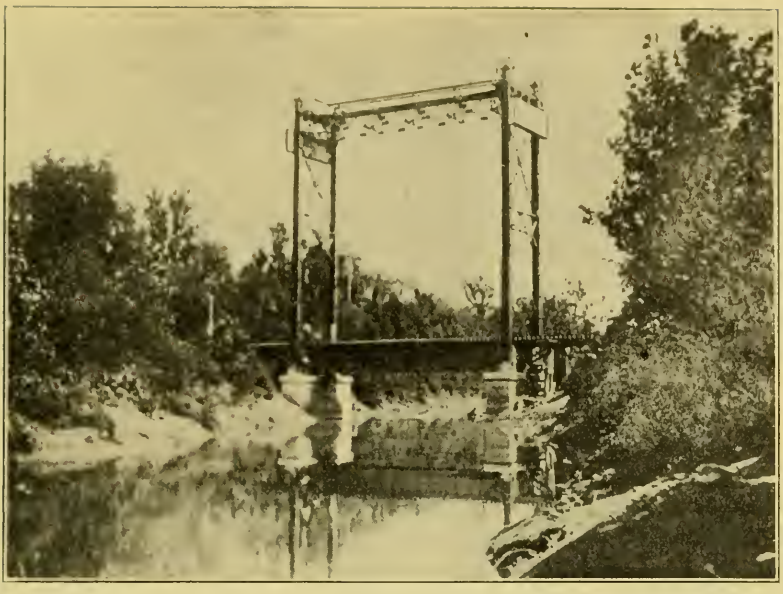

Fig. 31*h*. Vertical Lift Bridge over the Big Choctaw Bayou, Louisiana, on the Line of the M. L. and T. R. R. & S. S. Co.—Span Down

Fig. 31*i*. Vertical Lift Bridge over the Big Choctaw Bayou, Louisiana, on the Line of the M. L. and T. R. R. & S. S. Co.—Span Up.

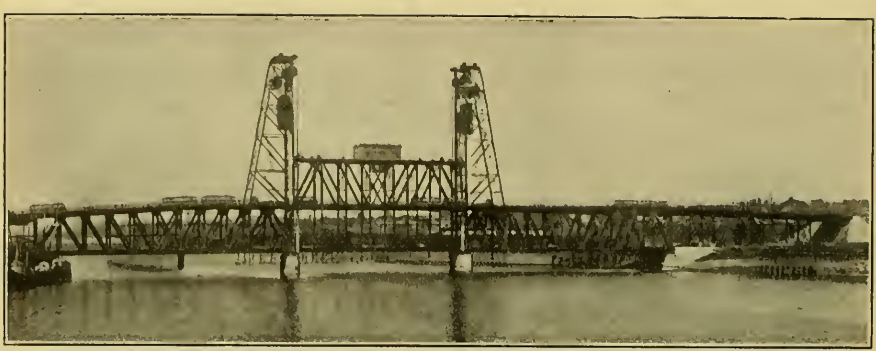

Fig. 31*j*. O.-W. R. R. and N. Co.'s Bridge over the Willamette River at Portland, Ore.—Lifting Deck and Lifting Span Down.

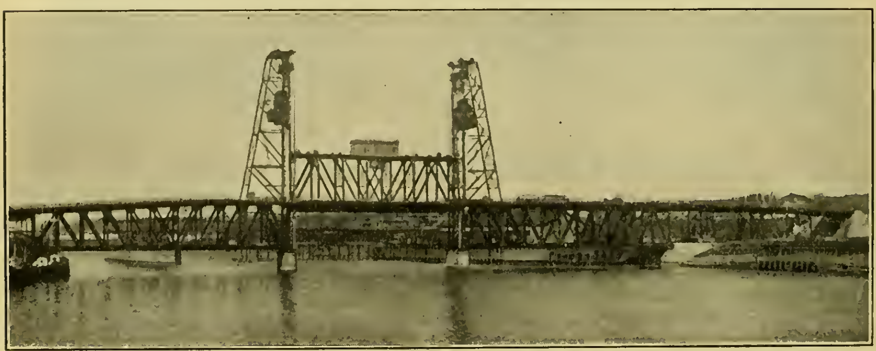

Fig. 31*k*. O.-W. R. R. and N. Co.'s Bridge over the Willamette River at Portland, Ore.—Lifting Deck Up.

Fig. 31*l*. O.-W. R. R. and N. Co.'s Bridge over the Willamette River at Portland, Ore.—Lifting Deck and Lifting Span Up.

FIG. 31*m*. O.-W. R. R. and N. Co.'s Bridge over the Willamette River at Portland, Ore., with the Approaches.

ported to the towers and raised into position. In order to keep the proper adjustment between span and counterweights there were provided a large number of concrete blocks one cubic foot in size. These can be added to the counterweights as required. The total weight of the lower deck and its attachments is over one million pounds, which, of course, is also that of the balancing counterweights.

The operating machinery is placed in a house on the top of the movable span and at its mid-length, covering the full width between trusses. The operator's room is suspended beneath this house, so that he can observe the main deck traffic as well as the river traffic. The machinery for operating the lower deck is driven by two electric motors of two hundred horse-power each, placed on the down-stream side of the house, and that for the upper deck by two similar motors located on the upstream side thereof. In the operator's room is placed the mechanism for locking and unlocking both the lifting span and the lifting deck. The cams for holding down the lower deck lock automatically; but they are unlocked by a special mechanism driven by a small motor. The main deck also locks automatically, but it is released by the operator's turning a wheel.

The erection of the superstructure was a most formidable task, because the channel had to be kept open at all times for the passage of boats, including high-masted sailing vessels. The immense weight of the movable span, the fact that it was to rest on columns high above the water, and the swiftness of the current made it seem to the contractor too difficult to build the span on scows and float it into place, as was done on the Hawthorne Avenue lift bridge over the same river some two miles distant where the conditions were less onerous. It was, therefore, necessary to erect the movable span at its full height, supporting it by four wooden Howe trusses. The total cost of the structure was $1,700,000.

Figs. 31*n* and 31*o* are photographic views of the City Waterway Bridge in the city of Tacoma, Wash. Its peculiar features are the unusually great height of the deck above the water and the overhead span for carrying water pipes. It will be noticed that the structure is on a grade. The Puyallup River Bridge located only a few blocks away is quite similar in type but of shorter span and narrower roadway.

Fig. 31*p* is a reproduction of a photograph of the Pennsylvania Railroad Bridge over the South Branch of the Chicago River in the city of Chicago. It is built on quite a skew, necessitating vertical rear legs in the towers. The length of span is two hundred and seventy-two feet. It is a double-track structure, and some three hundred trains cross it daily. It is opened on the average about seventy-five times per day during most of the navigation season. This structure is designed for a possible future 24-foot raising of the grade line.

Fig. 31*q* is a view of another Pennsylvania Railroad Bridge, crossing the Calumet River in South Chicago. Strictly speaking, there are two bridges, one being located close alongside the other, and each carrying

Fig. 31*n*. Bridge over the City Waterway at Tacoma, Wash.—Lifting Span Down.

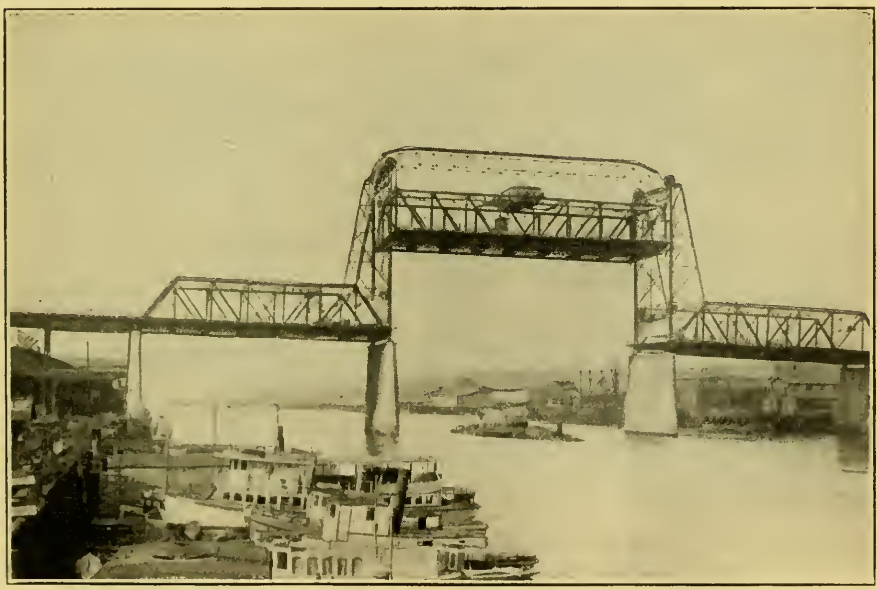

Fig. 31*o*. Bridge over the City Waterway at Tacoma, Wash.—Lifting Span Up.

a double track. The skew is about the same as in the bridge last described, but the span length is only two hundred and ten feet. In the rear of the left-hand tower will be seen a Strauss bascule bridge in open position.

FIG. 31*p*. Pennsylvania R. R. Co.'s Bridge over the South Branch of the Chicago River, Chicago, Ill.

FIG. 31*q*. Pennsylvania R. R. Co.'s Bridge over the Calumet River, South Chicago, Ill.

In *Engineering News*, Vol. 68, p. 1056, will be found a description of the Columbia River Bridge at Trail, British Columbia, together with the layout and a photographic view of the structure. Its peculiarity is that the towers and the machinery have been temporarily omitted, as at present there is no steamboat traffic on the river at that place; but the complete plans are drawn for the said towers and machinery, and the steelwork is all arranged even to the open rivet-holes for attaching the new construction at any time in the future so as to pick up either of the two intermediate spans.

The Lake Shore and Michigan Southern Railway Bridge over the Calumet River in South Chicago is very similar to the Pennsylvania Railroad Company's Bridge for the same crossing, described previously. At first the L. S. & M. S. Co. intended to build a four-track lift span, and the plans were prepared accordingly; but later they decided to follow the lead of the P. R. R. Co. and build two bridges close together, the object being to provide for a possible break-down. Their tracks at each end are so arranged that the traffic can be switched from either bridge to the other.

Figs. 31*r* and 31*s* illustrate the Yellowstone River Bridge on the line of the Great Northern Railway. It is located a short distance above the junction of that river with the Missouri in Montana, and there is a similar structure over the latter a few miles away. These lift spans have lengths, respectively, of two hundred and seventy-five and three hundred feet. The Missouri River lift-span is the longest yet built, and in fact the clear opening is the largest in the world for opening bridges, barring only the Fratt Bridge at Kansas City, where, as explained previously, the determination of opening was fixed in advance by the existing piers of an unfinished structure. It does not seem logical for the War Department to require such large openings in Missouri River bridges near the head of navigation thereon, while much smaller openings have been permitted everywhere else below; but such was the case, and the railroad company and their consulting engineers could do naught else but comply with the law.

Figs. 31*t* and 31*u* show the Black River Bridge on the line of the Louisiana and Arkansas Railway in Arkansas. Its lift span is one hundred and sixty-three feet long, and the vertical clearance is the usual fifty feet. Figs. 31*v* and 31*w* illustrate the bridge over the Little River on the same line of railway in the same state. Its movable span is one hundred and eighteen feet long. Attention is called to the symmetry of the layout for this structure and to the dolphins employed for protecting the piers.

Figs. 31*x* and 31*y* show a photograph of the Salem, Falls City, and Western Railway Bridge over the Willamette River at Salem, Oregon. The length of the movable span is one hundred and thirty-one feet. In one view the span is shown rising as a steamer is approaching; and the picture indicates how close to a vertical lift it is permissible to run a vessel before raising is begun. In some of the Chicago bridges which have to be opened often and over which pass daily many trains, the steamers are allowed to come very close, indeed, to the structure before hoisting is

FIG. 31*r*. Great Northern Railway Bridge over the Yellowstone River, Montana.—Lifting Span Down.

FIG. 31*s*. Great Northern Railway Bridge over the Yellowstone River, Montana.—Lifting Span Up.

FIG. 31*t*. Louisiana & Arkansas Railway Bridge over the Black River in Louisiana.—Lifting Span Down.

FIG. 31*u*. Louisiana & Arkansas Railway Bridge over the Black River in Louisiana.—Lifting Span Up.

started; and the lowering is begun before the vessel has actually passed the bridge tangent.

In Fig. 31*z* is given a profile of a bridge over the Don River at Rostoff, Russia, the movable span, towers, and machinery of which were

FIG. 31*v*. Louisiana & Arkansas Railway Bridge over Little River in Louisiana.—Lifting Span Down.

FIG. 31*w*. Louisiana & Arkansas Railway Bridge over the Little River in Louisiana.—Lifting Span Up.

designed by the author's firm, the flanking spans having been designed by the bridge engineers of the Russian Government. The length of the moving span is two hundred and ten feet and that of each flanking span three hundred and seventy-seven feet. Attention is called to the unusually great curvature of the rear legs of the towers, adopted so as to conform to the decided curvature that exists in the top chords of the flank-

FIG. 31x. Salem, Falls City, and Western Railway Bridge over the Willamette River at Salem, Oregon.—Lifting Span Down.

FIG. 31y. Salem, Falls City, and Western Railway Bridge over the Willamette River at Salem, Oregon.—Lifting Span Up.

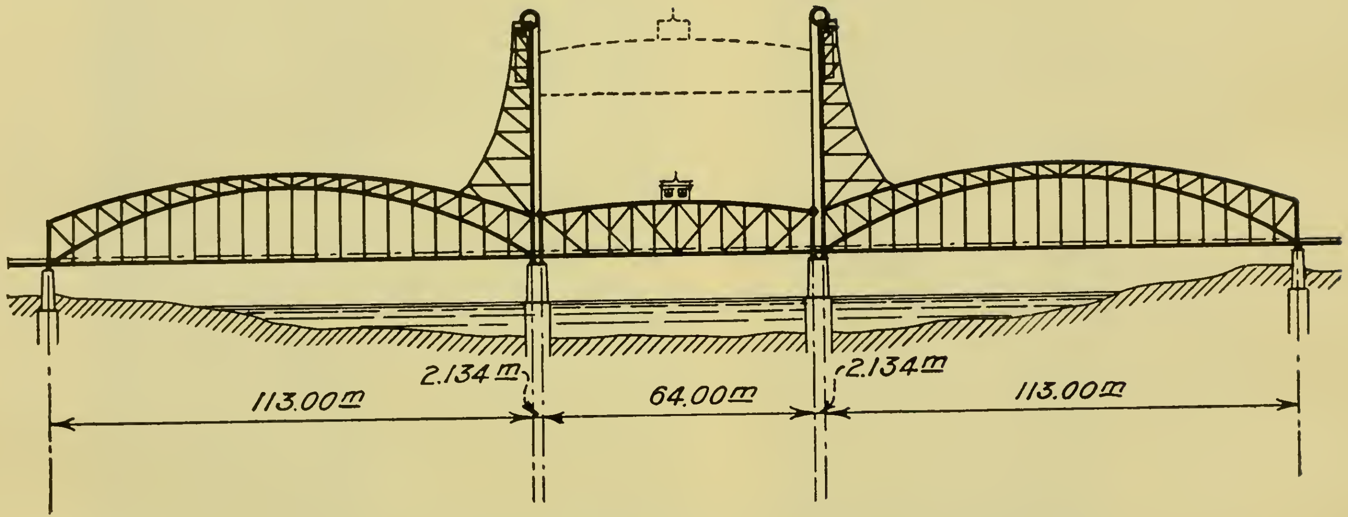

Fig. 31z.—Don River Bridge at Rostoff, Russia.

ing spans. This structure is now under construction. It is to be operated by electricity.

In Fig. 31*aa* there is shown a portion of the long, deck, plate-girder bridge over the North Thompson River near Kamloops, B. C., with its

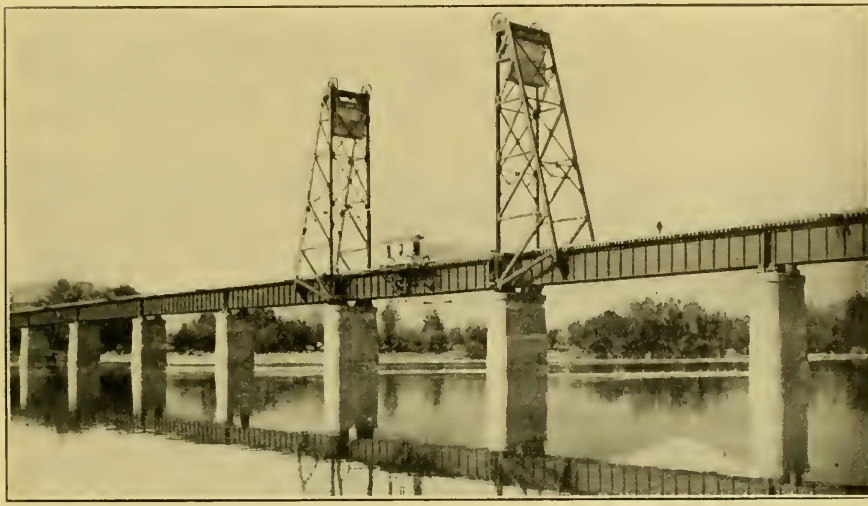

Fig. 31*aa*. Canadian Northern Pacific Railway Bridge over the North Thompson River in British Columbia.

lifting towers and machinery, all of which can be shifted at any time so as to pick up any one of the numerous spans that were made alike mainly for this purpose.

In Fig. 31*bb* is illustrated a half-through, plate-girder bridge over the Oromocto River on the line of the St. John and Quebec Railway in New Brunswick, with its lifting span and towers, which it will be noticed are of a different type from those shown in Fig. 31*aa*, because of there being no necessity for rear columns and bracing.

In addition to the types of vertical lift bridges covered by the patents of the author and those of his firm, both Mr. Strauss and Mr. Rall have lately patented vertical lifts operating like their patented bascules but lifting at both ends of the span instead of at one. These are certainly more expensive than the vertical lifts herein described, as was proved in one case in the author's practice by detailed comparative estimates made by his firm's computing force.

In the following table are given, as nearly as may be in chronological order, the various vertical lift spans, designed and engineered by the author and his firm, together with their general dimensions, load to raise and lower, and height raised, including four small ones designed by contractors and checked by the firm's computers.

Bridge	Distance c to c of Trusses in Feet	Length of Lift Span in Feet	Load to be Lifted in Pounds	Height to be Lifted in Feet	Remarks
1. Halsted St.	40	130	600,000	140	
2. Keithsburg	17.7	229	940,000	48	Spans Interchangeable for Lifting
3. Sand Point	18	83	60,000	50	Small Highway Bridge
4. Hawthorne Ave.	23.3	244	1,770,000	116	
5. Mo. River, K. C.	32	425	1,560,000	43	Lifting Deck Only
6. Arkansas River	24.5	192	1,500,000	50	Spans Interchangeable for Lifting
7. Tehama	21.8	167	266,000	63	
8. M. L. & T. Ry.	16.3	50	69,000	43	Plate-Girder Lift-Span
9. O.W.R.R.&N.—U.D.	34	211	3,420,000	89	Upper Deck
9. O.W.R.R.&N.—L.D.	34	211	1,060,000	46-89	Lower Deck
10. City Waterway at Tacoma	53.3	214	1,640,000	78	Carries Water Pipe Overhead
11. Puyallup River at Tacoma	43.3	161	943,000	115	Carries Water Pipe Overhead
12. Penn. No. 443	31.3	210	1,837,000	101	Two Bridges Like This Close Alongside
13. Trail	21	171	266,000	50	Towers and Machinery Omitted Temporarily
14. Little River	17.3	118	380,000	44	
15. Black River	17.3	165	620,000	56	
16. St. Francis River	17.3	162	620,000	73	
17. Ill. River	18.3	173	698,000	43	
18. Red River of North	19.2	140	120,000	25	Light Highway Span
19. Penn. No. 458	29.5	273	3,006,000	114	To be Duplicated in Future
20. Harrisburg	17	200	656,000	63	
21. Salem	17.5	131	462,000	54	
22. C.N.P.R.R.No.10	18.2*	90	236,000	56	Plate-Girder Lift-Span
23. St. Paul	21.8	189	850,000	56	
24. L.S.&M.S.R.R.No.6	31	210	1,410,000	101	Two Bridges Like This Close Alongside
25. International Falls	15	75	200,000	50	Light Highway Span
26. Mo.Riv.G.N.Ry.	17.7	296	1,560,000	43	Spans Interchangeable for Lifting
27. Grand Rapids	19	83	78,600	30	Light Highway Span
28. Yellowstone	17.7	271	1,370,000	43	Spans Interchangeable for Lifting
29. Oslo, Minn.	18	155	112,000	25	Light Highway Span
30. Oromocto	17.5	58	147,000	59	Plate-Girder Lift-Span
31. Don River	30.6	210	1,600,000	131	Under Construction
32. Caddo Lake	18.5	92	218,000	53	Small Highway Bridge
33. Pacific Highway	41	272	2,400,000	139	Under Construction

* Width of towers.

The vertical lift bridges thus far constructed as listed above may be divided into three general types, viz.:

A. Those in which the whole span is raised.

B. Those in which a deck only is raised up to an overhead fixed span.

C. Those in which a deck is raised to an overhead movable span, which also can be raised to clear high-masted vessels.

Class A may be subdivided into the following groups:

a. Those structures in which there is an overhead span.

b. Those structures in which there is no overhead span.

Those in Group "*a*" may be still further divided thus:

Alpha. Where the supports consist of four columns with trusses between their tops, and

Beta. Where the supports consist of towers braced on four faces.

Those in Group "*b*" also may be subdivided thus:

Gamma. Where the rear columns of the towers are inclined and where there is a main sheave at each of the four corners, and

Delta. Where the rear columns of the towers are vertical and where

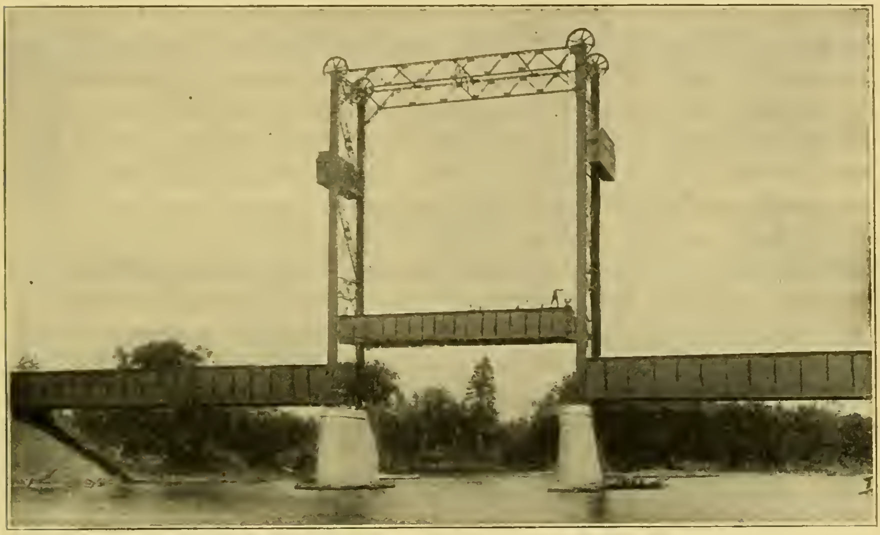

FIG. 31*bb*. St. John and Quebec Railway Bridge over the Oromocto River in New Brunswick.

there are eight sheaves in all, one over each of the four columns of each tower.

The Halsted Street Bridge (Fig. 31*a*) and the Hawthorne Avenue Bridge (Figs. 31*b* and 31*c*) represent Class A; the Fratt Bridge (Figs. 31*d* and 31*e*) illustrates Class B; and the Oregon-Washington Railway and Navigation Company's Bridge (Figs. 31*j*, 31*k*, 31*l*, and 31*m*) is an example of Class C.

Group "*a*" is represented by the Tacoma City Waterway Bridge (Figs. 31*n* and 31*o*) and by the M. L. & T. (Southern Pacific) Railway Bridge (Figs. 31*h* and 31*i*), and Group "*b*" by the Hawthorne Avenue Bridge (Figs. 31*b* and 31*c*), and the Fort Smith-Van Buren Bridge (Figs. 31*f* and 31*g*).

The Alpha subdivision is exemplified by the M. L. & T. Ry. Bridge (Figs. 31*h* and 31*i*), Beta by the Halsted Street Lift Bridge (Fig. 31*a*), Gamma by the Rostoff Bridge over the River Don in Russia (Fig. 31*z*), and Delta by the two Pennsylvania Railroad bridges in Chicago (Figs. 31*p* and 31*q*).

Before drawing this chapter to a close it is necessary to sound a note of warning to the computer who makes the calculations for a lift-span that has cantilever brackets, in relation to the effect of a live load on one cantilever only. In an ordinary span of this type the uplift at the corner due to the overturning moment of the live load on the bracketed portion is resisted by the dead load reaction there; but in the case of the lift-span there is no such reaction; consequently, there is nothing to resist the said overturning effect except the unbalanced load of the cables (if any), the starting friction of the sheave-journals, and the holding-down power of the operating ropes and bridge locks. For ordinary cases where only narrow sidewalks are cantilevered from a wide deck, this overturning moment may be ignored; but where either the street railway tracks or the wagonways are cantilevered, as in the case of the Hawthorne Avenue Bridge, some effective means of resisting this overturning moment must be provided. In that case cantilever brackets from the substructure were put on so as to furnish at their end bearings for receiving the extremities of the end cantilever brackets of the lifting span.

The true economy of the vertical lift bridge as compared with both the swing span and the bascule is proved beyond the peradventure of a doubt by the thirty or more structures listed and described above. The type has come to stay; and it will continue to be used more and more as time goes on; for not only is it inexpensive in first cost, comparatively speaking, but it is also simple, rigid, easy to operate, and economical of power. It has met with considerable opposition up to the present time, mainly from the owners of bascule patents; but it has overcome that opposition most satisfactorily and unequivocally, consequently the future of the type may be counted upon as assured.