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TYPES OF MOVABLE BRIDGES

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Presented January 12, 1914, before the Bridge and Structural Section.

Believing that there exists among engineers considerable interest in movable bridge design, the writer undertook the task of presenting a description of the various types of movable bridges which have been built. Any attempt to give a detailed description of these various bridges would result in a paper entirely too long to be presented at this meeting, and would be outside of the intended purpose of the paper, which is to give very briefly a description of the general principles involved in each type of bridge. Those desiring a detailed description are referred to articles in the technical journals (see Appendix), from which the information for this paper has for the most part been obtained.

With the rapid increase in transportation and the accompanying congestion of traffic and increase in transportation facilities, one of the problems which is forcing itself more and more upon the attention of the engineer is that of providing transportation over navigable streams without interfering with navigation. This transportation has been provided for by the use of ferries, high overhead bridges, tunnels beneath the channels, and by movable bridges which, when closed, provide for traffic over the streams, but which can be opened as occasion demands, so as to provide a clear channel for the passage of vessels. The ferry at best is a makeshift and can be used only where the land traffic is light or where a bridge would be impracticable. Tunnels are expensive to construct and necessitate the use of heavy grades which are very objectionable. High overhead bridges with underneath clearance sufficient for the passage of the largest vessels, are limited in use. to localities where the street or track level is very much higher than the water level. A large majority of the crossings are equipped with movable bridges.

In order to meet the widely varying conditions governing the

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design of movable bridges for the various crossings, the engineer has exercised considerable ingenuity, and a correspondingly large number of types of movable bridges are in use today. Mr. J. S. Langthorn in a paper on TYPES OF MOVABLE BRIDGES presented before the Brooklyn Engineers Club, April 14, 1904, gave the following classification:

"1. Swing Bridges, which revolve in a horizontal plane.

"2. Side folding bridges, which fold up in a horizontal plane.

"3. Bascule bridges, which revolve in a vertical plane and include the following:

(a) Trunnion bridges, which are revolved on horizontal shafts.

(b) Scherzer bridges, which open by rolling backwards and upwards on segmental girders.

(c) Miscellaneous types as the Harway Ave., Page, Schinke, Roll, Jack-Knife, or vertical folding, etc.

"4. Retractile bridges, or sliding draws which open in a horizontal plane and are mounted on wheeled trucks. The telescopic bridge at Queen's Ferry, England, is a modification of this type.

"5. Direct-lift bridges, which are simply large elevators.

"6. Pontoon or floating bridges, in which the channel pontoons may be moved for passing vessels. In some cases the pivot end is placed on the shore.

"7. Transporter bridges, in which a car hung from a high level truss travels back and forth between the banks of the waterway."

While there are many modifications of these various types, the only distinctly different type from those given above that the writer has seen described is one which rotates about a horizontal longitudinal axis.

The earliest moving bridges of which we have any record were used for defensive rather than transportation purposes. These in general were bridges hinged at one end and lifted vertically by means of chains or cables fastened to the other end, or horizontal draw bridges in which the movable leaf was drawn back into the fixed approach span.

Of the early movable bridges used to provide for navigation. the pontoon, or floating bridge, was very much in favor. These bridges were inexpensive and did not require for their construction the highly refined mechanical processes which are so essential to the successful manufacture of the newer types of movable bridges.

In the early days when land traffic was light and especially before the development of railroads which required that interruptions to traffic be reduced to a minimum, this type of bridge was very largely used. Its low initial cost and the ease with which it could be built without the use of elaborate equipment made it deservedly popular for pioneer road building in communities where funds were scarce and contractor's equipment crude. A comparativcly large number of the early movable bridges built were of this type. A number of them are still in use. In addition to the advantages claimed above for this type of movable bridges is the advantage common to all pontoon bridges—since they require no foundations they can be built over streams whose beds are so soft that the support of a bridge on a pier is impossible. This has led to the use of pontoon bridges with pontoon draw spans over various rivers of India. Probably the most notable of these is the one over the Hoogly which connects Calcutta with Howrah. A number of bridges of the same type have been built at this crossing only to be replaced when worn out by similar bridges. The last one was built in 1874. Designs are being considered for a new bridge at this point.

As the density of traffic increased, and especially with the adoption of fast railway schedules, the delays incident to the more or less cumbersome operation of the pontoon bridges became more serious. The new conditions were well met by the use of swing bridges, and for some time—in fact, up to and including the present time—a very large proportion of all the movable bridges built were of this type. Bridges with pivots at or near the center necessitating the use of but little, if any, counterweight and with supports to carry the live load at the center and both ends, are of economical design, of simple construction, quick of operation, rigid in service, and would seem to be of ideal design. The large number of these bridges in use indicates that they are so considered.

Horizontal rolling or retractile bridges were used in crossing moats around castles as a protective measure, but they have never been very popular among modern engineers. The rolling back and forth of the heavy structure consumes a large amount of energy. It is difficult to provide a motion of the moving leaf which will enable it to clear the fixed approaches, and the live load must be carried on the moving leaf acting as a centilever, which it is hard to do with a structure that can be moved horizontally. This type of bridge can be used for narrow channels and also for light temporary structures, but it has not been used much for large permanent bridges.

The last few years has brought about conditions which have made the swing bridge poorly adaptable to certain locations. Increase in water traffic, together with an increase in the size of boats, have made the center pier, usually associated with swing bridges, very objectionable in narrow channels, and increased value of land and dock frontage has made them expensive because of the property which they damage. Because the width of the center pier increases with the width of the bridge, it is not customary to have more than two tracks* on a single bridge, and as the bridges must be far enough apart to let the ends clear when the bridge is mov-

*The New York Central R. R. has a four track swing bridge over the Harlem River.

ing, the carrying of a large number of tracks over a channel at any point is impracticable, if not, in fact, impossible. These considerations have led to the development of the bascule bridge, which, while usually more expensive than the swing bridge, can be opened in a space no wider than its own width and which provides a clear channel with no obstruction at the center. There are a number of types of bascule bridges all of which have a motion in the vertical plane which causes the center of gravity of the moving parts to be stationary at the center of rotation or to move in a horizontal line. If either one or the other of these two conditions is satisfied, the only work which it is necessary to do in moving the bridge is that required to overcome inertia, friction, and wind pressure.

While the earliest draw bridges built, those used to cross moats at the entrance to castles, were bascule bridges, they did not come into general use until the new London Bridge was completed in 1894. Since that time their use has become very common. It is interesting to note that while some of the modern types of bridges are generally supposed to be new inventions and some of them are patented, a number of them are described, at least in principle, in the Handbuch der Ingenieur-Wissensch, which was published in 1888.

Vertical lift bridges which are opened by lifting the moving leaf in a horizontal position so as to allow clearance for the passage of vessels underneath have been built from time to time during the last century. The very recent development of a number of new types of vertical lift bridges has led to their acceptance in a number of instances during the last one or two years. Their extended use in the future is quite probable.

As the width of channel required has increased, the weight of the moving leaf of the bascule bridge whose weight is carried as a cantilever has increased very rapidly, and the weight of the counterweight has increased a corresponding amount. This has caused a large increase in the trunnion loads and in the weight of structural steel required to support the moving leaf as well as in the counterweight which balances it. In the case of the vertical lift bridge, the effective arm of the counterweight is much greater than for the bascule, so that the counterweight is much lighter. The bridge is supported on four trunnions, instead of two, making a corresponding reduction in the load on each trunnion. The dead load as well as the live load is carried as a simple span, which is much more efficient than the cantilever of the bascule bridge. The live load is carried directly into the masonry and not through the trunnions. It is sometimes possible to convert a fixed span into a vertical lift span by adding the necessary lifting mechanism. These facts would seem to indicate that for long spans where the underneath clearance is not too great the vertical lift bridge has some advantages over the bascule bridge.

At some crossings the water traffic is very heavy and the land traffic is comparatively light. This combination of conditions occurring at a point where a bridge would be expensive to construct has led to the use of what have been termed transporters or transfer bridges. They are similar to ferries and usually consist of a car or platform either suspended from a high overhead track or supported on a track in the bed of the channel. This platform travels back and forth across the channel as is required to accommodate the traffic, and offers no serious obstruction to navigation at any time. While this type of bridge cannot be said to be in common use, a number of them are in service at the present time.

It is interesting to note in connection with a study of the various types of movable bridges in use that, with the possible exception of very special types which have proven unsatisfactory in service, all the various types of bridges which have been designed are represented by bridges in use today. This indicates that the development of movable bridges has not been so much an improvement on the old types as it has been a development of new types to meet new conditions. In localities where early conditions exist today old types of bridges are still being built.

Most of the early bridges were operated by hand. For the most part they were comparatively small, labor was cheap, and the modern efficient methods of developing mechanical power unknown. Even the large double leaf swing bridge over Penfeld River at Brest, which provided a clear channel of 350 ft., for half a century the widest clear channel provided by any movable bridge in the world, was originally designed to be operated by hand. Later hydraulic power came into quite general use in Europe and steam power in America. It is only within the last few years that electrical power has been used. It is interesting to note in this connection that George Wilson, in an extended series of articles on movable bridges in the PRACTICAL ENGINEER for 1896, in discussing the difficulties encountered in the transmission of hydraulic power to the center pier of swing bridges states, "There is no doubt that electrical power would do away with this difficulty and possibly in the future may be used." At the present time electrical power is used almost exclusively for the operation of movable bridges. The ease with which it can be transmitted to any desired point and its property of being instantly available with no consumption of energy when no work is being done, makes it superior to other kinds of power for locations near a source of continuous supply. Most modern bridges are provided with an auxiliary driving mechanism which is usually operated either by hand or by oil engines.

As stated above, many of the early movable bridges were supported on pontoons and were opened by floating the draw span to one side. One of the more important bridges of this type still in use is the one which for a number of years has carried the C. M. & St. P. Ry. over the Mississippi River, between Prairie du Chien, Wisconsin, and North McGregor, Iowa.[1] The river at this point is about 7000 ft. wide, including an island which divides the stream into two channels each of which is navigable, and the bridge, except for the draw spans, was originally a pile trestle. Each of these draw spans was carried on a single float, 41 ft. wide, 6 ft. deep, and 408 ft. long. The level of the track was adjusted to the varying stages of the river by blocking confined by a frame and adjusted by means of hydraulic jacks. The range of variation between high and low water was 22 ft. The elevation of the deck of the bridge was adjusted by the bridge tenders at times when they were not occupied in operating the bridge. Girders projected beyond the ends of the draw span and when the bridge was closed, rested on seats on piles provided to receive them. These girders prevented any live load coming on the floats near the ends and eliminated any harmful effects that might result from a slight difference in level between the fixed and floating decks. The bridge was operated by a 20 h. p. steam engine and could be opened or closed in about three minutes. The bridge was designed by John Lawler and was built in 1874. It was rebuilt in 1882; the Wisconsin end was again rebuilt in 1898 and the Iowa end in 1900. It still carries the traffic of the C. M. & St. P. Ry. over the Mississippi River at this point.

A similar bridge was built over the outlet of Lake Champlain at Rouse Point in 1851. This bridge was 30 ft. wide and 303 ft. long, and was designed by Henry R. Campbell.

Swing bridges, which are the most familiar of all the various types of movable bridges, consist essentially of a truss or girder span which is balanced over a turntable on which it rotates about a vertical axis. The turntable consists of a pivot at the center of a circular track. The pivot serves to center the bridge and in some cases carries part of the load of the superstructure. Rollers on the circular track carry the remaining portion of the load. The bridge is balanced wherever possible by placing the turntable at the center of the span, in which case two channels are provided for navigation, one on each side of the pivot pier. In cases where it is undesirable to locate the pivot pier in the center of the channel, one end of the bridge is made longer than the other and the short end is counterweighted so as to bring the center of gravity of the whole moving structure at or near the center of support. Where such a bridge is used only one channel is provided. The pivot pier is set on one bank and the long arm of the bridge spans the channel leaving the full width open to navigation. Where two such bridges are used together, one on each side, a very wide channel can be obtained. Where this arrangement is used, the shore ends of the spans must be anchored, when closed, to prevent the moving leaf from tipping under the action of live load on the channel end.

The trusses acting as cantilevers will deflect under the action of the dead load while swinging so as to hit the end supports when the bridge is swung shut, unless some provision is made to lift the end of the bridge above its normal position when it is opened. This is done in a number of different ways. Bridges with a center circular track are lifted bodily by hydraulic pressure, or the ends are lifted by shortening an adjustable section of the top chord at the center or by means of a toggle mechanism at the ends.

When the adjustment of the end supports is such as to cause them to take only a portion of the dead load, leaving the balance to be carried by the trusses acting as cantilevers, the trusses are in reality continuous over the center support. Such a design is economical but a slight variation in the adjustment of the supports from what has been assumed causes such a variation in the resulting stresses that the scheme is not entirely satisfactory. For this reason engineers are inclined to sacrifice whatever gain may result from the continuous girder effect by providing an adjustable panel in the top chord at the center by which it may be relieved of all stress when the bridge is closed, thus causing the two ends of the bridge to act as separate single spans. The uncertainty of the continuous girder effect has also been eliminated by adjusting the end supports so that the ends of the trusses will just touch, but transfer no dead load to them when the bridge is closed. This causes the trusses to carry the dead load as cantilevers and the live load as continuous trusses.

The double leaf swing bridge at Tarante, Italy[2], has pivot piers clear of the channel. The shore or short arms of the trusses are counterweighted so as to balance the long arms when the bridge is swinging, and are anchored to the masonry when the bridge is closed so as to prevent the bridge from tipping under the action of the live load on the channel arm. The curved bottom chord gives an arch effect which is very pleasing in appearance.

A similar bridge over Penfeld River at Brest built in 1861 provides a clear channel of 350 ft., which was the record width for a clear channel provided by a movable bridge until the new vertical lift span over the Missouri River at Kansas City was completed in 1912. A swing bridge at Havre has two leaves with unequal arms. When closed the short end is anchored to the masonry, after which the center support is lower so as to transfer the load to the masonry at the front edge of the abutment where proper support is provided. This method of supporting the bridge when closed reduces the length of the cantilever subjected to live load, throws the point of support a considerable distance in front of the center of gravity of the superstructure thereby reducing the live load moment to be balanced by the anchor, and increases the effective lever arm of the anchor so as to greatly reduce the stress to which it is subjected.

Figure 1[3] shows two swing bridges over the Missouri River at Omaha, which carry the double track of the Omaha Bridge and Terminal Railway Co. Each swing span is 520 ft. long, longer than any other movable bridge in the world. The bridge was completed in 1903. Waddell & Harrington were the consulting engi-

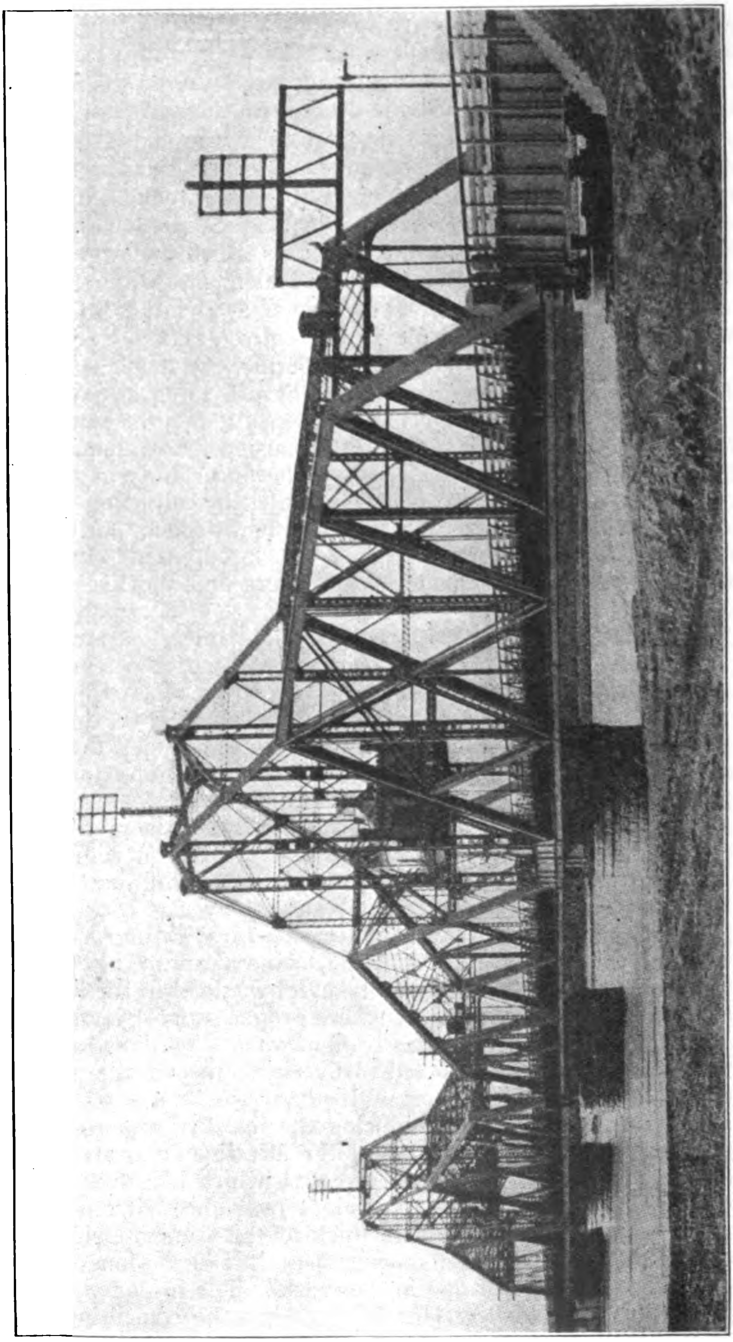


Fig. 1.—Two Swing Bridges Over Missouri River at Omaha, Neb.

neers. Most American swing bridges with center piers are of this general type.

The Joliette Bridge[4] in the port of Marseilles has a moving leaf which turns about a pivot supported on a hydraulic ram. The shore end of the truss, which is shorter than the channel end, carries wheels which run on a track on the shore. The bridge is very close to the water and most of the traffic on the canal consists of low barges. To permit of the passage of these barges without swinging the bridge, the hydraulic ram which carries the pivot is raised, thereby raising the front or channel end. This gives ample head room for the passage of the barges. The bridge was built in 1878.

The main road from Chester to Manchester crosses the River Weaver at a point where the surface of the ground is gradually subsiding due to the mining of salt in the district. For many years a plate girder swing bridge was in operation, but its gradual subsidence, averaging 4½ in. per year for 16 years, had reduced the clear head room until it became necessary to replace the old bridge with a new one, giving greater head room. One of the main points which had to be considered in designing the new bridge was the impossibility of preventing a concentrated load from settling under the action of its own weight.[5]

In order to prevent settling, the bridge was supported on a floating pontoon whose buoyancy, which could be varied at will, was somewhat less than the weight of the superstructure. This pontoon had an air-tight deck 1 ft. below normal water so that neither its buoyancy nor elevation was affected by the level of the water. The pontoon, which turned with the bridge to which it was rigidly attached, floated in a chamber provided for the purpose and was surrounded by cast-iron piles which carried a gridiron girder. This gridiron girder supported a track and the portion of the weight of the superstructure not carried by the pontoons was carried on a series of rollers running on this track. The track served the further purpose of keeping the bridge properly centered. By keeping the buoyancy properly adjusted the portion of the stream bed under the point of support of the bridge was subjected to but little greater load than at other points. The load on the rollers was also comparatively light and the friction to be overcome in operating the bridge correspondingly small.

In 1893, in anticipation of the building of this bridge, the engineer in charge, Mr. John Arthur Saner, converted a cattle bridge in the same neighborhood into the type just described, and upon its proving satisfactory the larger bridge was built and put in operation in 1899.

Conditions similar to those governing the design of the bridge over the River Weaver near Manchester were found at the crossing over the Hoogly, that connects Calcutta with Howrah. The present pontoon bridge which was built in 1874 is to be replaced by a modern bridge. The river bed is soft mud and the swift current scours so badly that it is practically impossible to put a pier in the channel. The old pontoon bridge has been satisfactory, but there are drawbacks to this type of bridge for so important a point which make it undesirable to repeat the design. A substitute has been proposed in the form of a double leaf swinging bridge on floating piers.[6] Two such designs have been submitted. For one design, the shore ends of the two approach spans rest on fixed abutments, and the stream ends of the approach spans and the swinging spans rest on a floating pontoon which rises or falls as the water level in the river changes. For the other design, the bridge is supported in a similar manner except that the pontoons which have a buoyancy greater than the maximum dead load plus live load are anchored into the river bed so as to be slightly submerged when the water is at low level. These anchors prevent the pontoons from rising and falling with the water level in the river and the bridge is at a fixed level at all times. This system is the invention of Mr. F. Forssell and the patent rights are held by Head, Wrightson & Co., Limited.

In addition to what are usually known as swing bridges, there have been a number of other types of movable bridges built which open by rotating about a vertical axis.

One of these is known as a bobtail swing bridge. The pivot is at the extreme end and the weight of the moving leaf is balanced by an overhead counterweight attached to the rear end. A bridge of this type carries the C. M. & St. P. Ry. over Ogden Canal just off the North Branch of the Chicago River at Cherry St.[7] It was built in 1902. This road has other bridges of the same type.

A type of temporary wooden bridge which has been used by the New York, New Haven & Hartford R. R.[8], consists of four wooden deck trusses each of which is pivoted to swing in a horizontal plane. These trusses are all pivoted to a swing beam near their front end. Rods fastened to this swing beam pass up to the top of a tower and support the outer ends of the trusses as the bridge is moved. When the bridge opens, the trusses swing together and in the open position are just far enough apart to clear. The tower is prevented from tipping forward when the bridge is in the nearly closed position, by tension rods which run from the top of the tower to the top of a group of piles. It is prevented from tipping sideways when the bridge is open, by a stiff-leg frame on the compression side and a tension rod on the tension side. Provision is made for lifting the front end of the trusses a few inches before opening the bridge so as to clear the support. The bridge is operated by hand. When it is closed the front end rests upon pile bents and the live load is carried the same as for a simple span.

The Miami and Erie Canal Transportation Co., of Cincinnati, Ohio, has a charter for operating the canal by electric towage using trolley locomotives on a track along the towing path. At several points the track crosses the canal, and in order to make the curves as easy as possible the crossing is made on a skew bridge, of a type designed by Mr. Ward Baldwin.[9] It was desired to build these bridges as cheaply as possible. The bridge consists of two parallel plate girders pivoted at one end and supported on vertical posts at the other. The heels of the girders are connected by a semi-circular drum which rests on rollers. Two I-beams framed between the two girders carry the center bearing. The posts under the outer end of the girders are carried on rollers which run on a circular steel track supported on piles at the bottom of the channel. The operating pinion is carried on the lower end of the post and meshes with a rack concentric with and just outside of the steel track. A recess is cut in the side of the canal to allow the end post to swing back and leave the channel clear when the bridge is open. The bridge can be operated by electric motors or by hand.

A temporary bridge which was built over the Chicago River[10] to accommodate pedestrians while the new permanent bridge at State Street was being erected, swings about a pivot supported on timber piles at one end and is carried on a pontoon at the other. This design was submitted by Roemheld & Gallery.

A horizontal automatic swing bridge, which is used on a canal near Bordentown, N. J.[11] consists of a single leaf horizontal swing bridge with a counterbalanced short arm. The track is slightly inclined toward the canal, and the center of gravity of the moving parts is between the center of rotation and the channel so that when the bridge is opened the center of gravity is raised. The weight of the bridge makes it swing shut. There is no one to tend the bridge, it being opened by the canal boat pushing against it, and is closed by its own weight. A number of similar bridges are in use on the Ohio State canals.

What is known as the Victoria Bridge[12] is one of the largest horizontal rolling bridges which have been built. The moving leaf is carried by lattice girders which are supported by the approach span. The channel ends of the girders are balanced by counterweights on the shore end. To close the bridge the moving leaf telescopes so as to allow it to pass beneath the floor of the approach span. It is then rolled back on wheels which run on a track supported by the approach girders. The design was made by Mr. T. W. Barber and was selected from among eighteen designs submitted. The bridge was formally opened to traffic by Mr. Gladstone June 2, 1897.

A wooden horizontal draw bridge designed by Mr. C. E. Burroughs of Norfolk, Va. [13], is applicable to short spans. It consists of a stringer span mounted on a carriage which travels on an inclined steel track. The carriage is inclined so that the floor of the moving leaf is always horizontal. When the bridge is closed the front end of the moving leaf rests on a pile bent and the live load is carried the same as on a simple span. When the bridge is to be opened, the hinged door in the floor is lifted and fastened to a hook provided for the purpose and the carriage is drawn back on the inclined track. The combination of the inclined track and hinged door in the floor allows the moving leaf to clear the approach span as the bridge is opened. The front end of the bridge is supported in the open position by means of tie rods passing over a gallows frame. The moving leaf is counterbalanced by a second carriage loaded with ballast and running over a track inclined in the opposite direction from the one which carries the moving leaf. These two carriages are connected by a steel cable. The bridge is operated by hand.

A horizontal rolling bridge has just been constructed over the Milwaukee River at Oneida St., Milwaukee[14], to take care of the foot traffic at this crossing while the new permanent bascule bridge is being erected. It consists of two through trusses carried on a counterweighted carriage which runs on a track supported on piles. The bridge is opened and closed by running this carriage back and forth on the track. In the closed position the front end of the bridge rests on the dock and the live load is carried the same as in the case of a simple span. The approach span on the same side of the channel as the track is a platform parallel to the track. The pedestrians go from the platform to the deck of the bridge by passing through the next to the end panel of the truss, from which the diagonal bracing has been omitted. The shear on this panel has been taken care of by a plate-girder in the top chord. The passage to the dock at the opposite end of the bridge is the same as for an ordinary span. This bridge was designed and constructed under the supervision of Mr. L. J. King, as Superintendent of Bridges and Public Buildings.

In cases where the street traffic is light and the water traffic is heavy so that the latter should be given more consideration than the former, use is made of what has been called transporter bridges. One of the more important examples of this type of bridge is the one over the Ship Canal at Duluth, Minn.[15] This bridge consists of two structural steel towers about 400 ft. apart between which is a track carried by steel trusses. This track supports carriages which run back and forth across the channel. Platforms with decks level with the roadway on either side of the channel are suspended from these carriages by means of a steel frame. When pedestrians or teams wish to cross the channel, they walk onto this platform and the platform is carried across the channel by the carriage to which it is attached. The clear headroom over the water is 135 ft. The bridge was built in 1904 and 1905. Other bridges of the same type have been in successful operation at other points.

Another type of transporter bridge crosses a narrow arm of the sea between St. Malo and St. Servan[16], on the north coast of France. At low tide the bed of the sea is bare. A track was laid on the bed from dock to dock and a carriage conveying a platform on the top of a steel tower, traveled back and forth across the channel. The bridge was operated during high tide and in currents due to a tide of 5 or 6 nautical knots. This bridge was devised and built by Mr. Leroyer, a local architect, about 1871 and was successfully operated for a number of years

As has been previously stated, bascule bridges were used in the early days as a means of defense. They have been used to a limited extent to provide crossings over navigable streams since early in the 19th century, but their use was not common until the adoption of the bascule type for the new London Bridge. The general scheme of this bridge is shown in Fig. 2[17]. The draw span is a double leaf bascule bridge supported on fixed trunnions and counterbalanced by counterweights attached to the shore end at such a point as to make the center of gravity of the whole moving structure fall at the center of the trunnions. Each leaf is supported on four lattice girders. Instead of each girder being supported on a separate shaft the four girders of each leaf are supported on a single shaft 21 in. in diameter and 48 ft. long. This shaft is supported on eight journal boxes with steel roller bearings. These journal boxes are carried on curved girders, one on each side of the bascule girders, which rest upon the front and rear walls of the trunnion piers. By curving these girders up at the shore end the counterweight falls below the bascule girders and does not interfere with them when the bridge is opened. When the bridge is closed, a resting block in front of the trunnion comes in contact with a live load support and the tail end is anchored to the masonry so that the moving leaf acts as a cantilever. The effect of the front support is to relieve the trunnion of the live load and to reduce the stress on the anchors The bridge is operated by a pair of pinions which mesh with a rack quadrant fastened to the tail end of the girders. The clear channel is 200 ft. and the distance center to center of trunnions is 226 ft. 6 in. The counterweight is composed of lead and cast iron

Mr. William Scherzer invented a rolling lift or bascule bridge but died before any of his bridges were constructed. After his death the design was taken up and a large number of his bridges, usually known as the Scherzer Rolling Lift Bridge, have been constructed and are now in use. The first one of these bridges was built in 1895. It is shown in Fig. 3[18]. The bridge consists of two leaves, each of which is supported on two trusses. The tail ends of these trusses are in the form of a circular arc and rest on tracks carried by the foundation, counterweighted so as to bring the center of gravity of the moving leaf at the center of the circular arc. The bridge is opened by rolling the circular arc on the track on which it rests. Since the center of gravity is at the center of the arc it is not raised or lowered as the bridge is moved, and all the work which has to be done is that required to overcome the wind, friction, and the inertia of the moving parts. Since the moving leaf rolls back as it is opened, the front end does not overhang the channel, and the angle of opening and the length of span can be reduced to a minimum. When the bridge is closed the tail end is anchored to the foundation and the live load on the front end is carried by the bascule trusses acting as cantilevers. Where there is sufficient headroom over the channel to permit of the use of a deck bridge

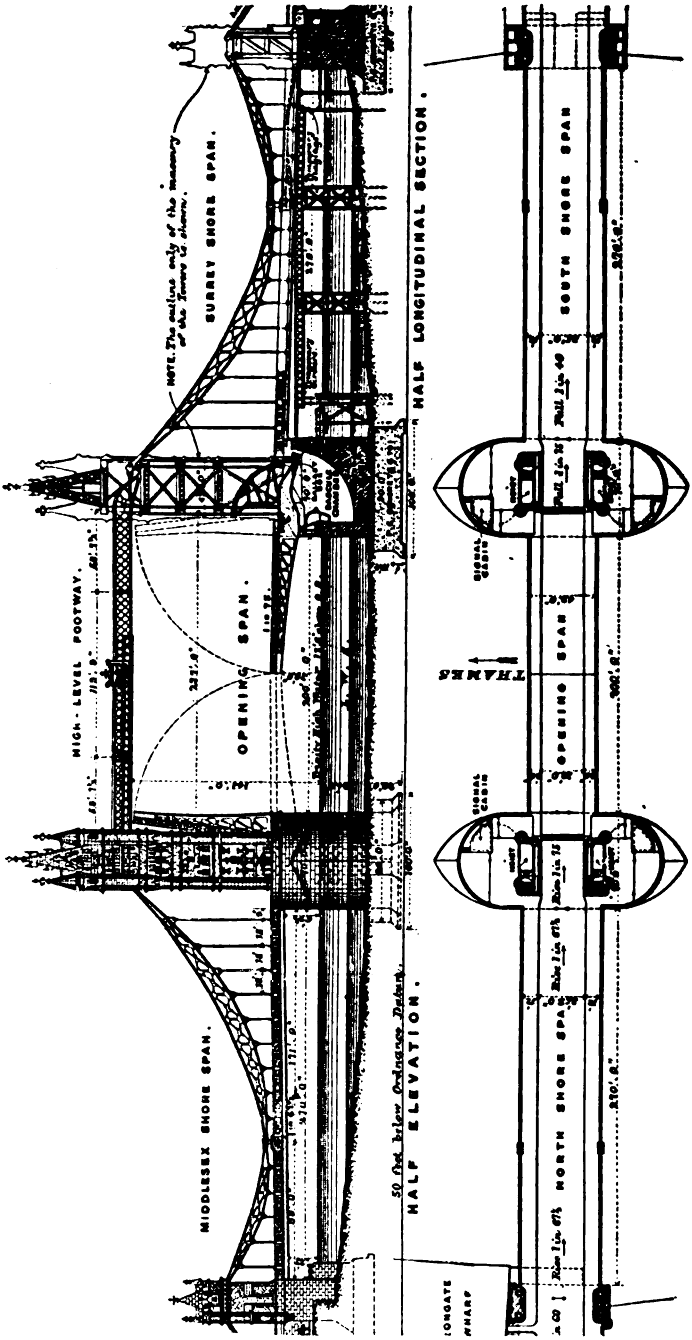


Fig. 2.—The Tower Bridge, London.

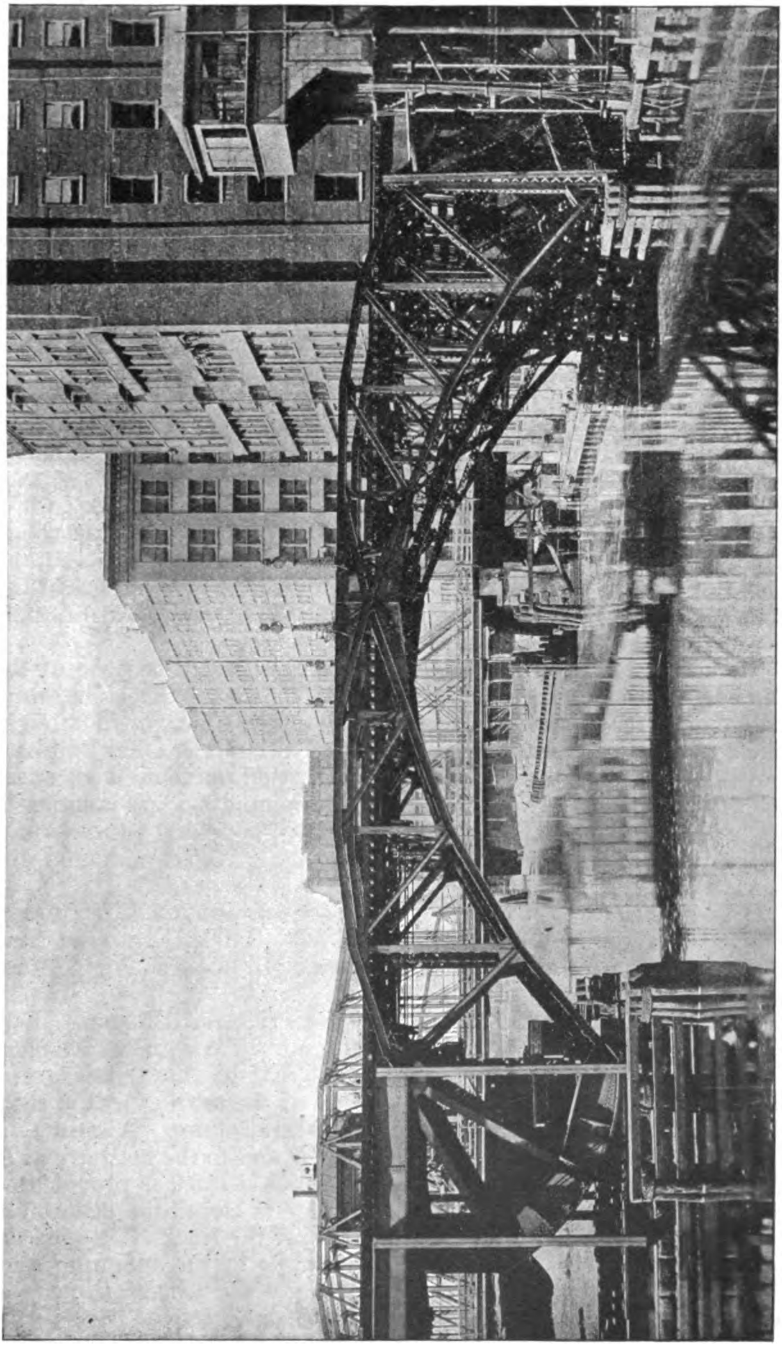


Fig. 3.—Metropolitan West Side Elevated Railway Crossing the South Branch of the Chicago River.

quite pleasing effects may be obtained with this type. Figure 4[19] shows the 212 ft. double leaf highway and electric railway bridge over the Connecticut River at Saybrook, Conn. The outline of this bridge gives an arch effect but the load is carried as a cantilever.

A Scherzer bridge carries the double track of the Tehauntepec National Railways of Mexico[20] across the harbor at Salina Cruz, Mexico. When the bridge is closed a pin at the end of the top chord of one leaf engages a pin bearing at the end of the top chord of the other leaf. Pin bearings are also provided where the moving leaves rest upon their supports when in the closed position so that the bridge is supported at the three points and the two leaves act together as a three-hinged arch to carry the live load. A number of double leaf bascule bridges, not only of the Scherzer but of other types, act as a three-hinged arch to carry the live load.

There are a number of Scherzer Rolling Lift Bridges worthy of note. The double track, double leaf railroad bridge over the Chicago River at Taylor St., Chicago, built in 1901, is the longest double leaf cantilever bascule railroad bridge ever built. It has been subject to very heavy railroad traffic and to frequent operations for a period of thirteen years and is still in use. A similar bridge which has just been completed forms the only connection between the island of Ceylon and the main land of India. It is described in the RAILWAY AGE GAZETTE of March 28, 1914, and the LONDON GRAPHIC of February 28, 1914.

Another Scherzer Rolling Lift Bridge, notable because of the number of bridges together, is the one known as the eight track bridge over the Drainage Canal near 31st St., Chicago. The eight tracks of the Pennsylvania Railroad, the Baltimore & Ohio Railroad, and the Chicago Junction Railway are carried on four independent bridges placed side by side. By having adjoining bridges pointing in opposite directions, the tail of one on the same side of the channel as the front end of the other, the tracks are spaced a minimum distance apart.

There are three multiple bridge Scherzer Rolling Lift Bridges on the main line of the N. Y., N. H. & H. Railroad between New York and Boston. Each crossing is composed of three double track bridges placed side by side.

Figure 5 shows the bridge which carries the Pittsburg, Fort Wayne & Chicago Ry.[21] over the Miami and Erie Canal at Delphos, Ohio. This bridge, which is of the single leaf bascule type, is counterweighted so that the center of gravity of the moving leaf is at *A*, the center of the shaft about which the leaf rotates. A strut *C* is pivoted to the lower side of the girder at *D* and to the masonry at *E*. The shaft *A* carries the wheels *B*, for which a track is provided on the top of the masonry. When the bridge is closed the pedestal *K* rests on the pin *E* and lifts the wheels *B* off the track. To open the bridge the shaft *A* is pulled back horizontally by the operating strut *J*. The moving leaf revolves about *E* until the wheels *B* come in contact with the track, after which the shaft *A* moves horizontally and the leaf moves about *A*. This horizontal motion has the effect of pulling the upper part of the moving leaf back away from over the channel, thus reducing the length of span required for a given channel and also keeping the counterweight away from the front wall of the counterweight pit. This bridge, which is the first one

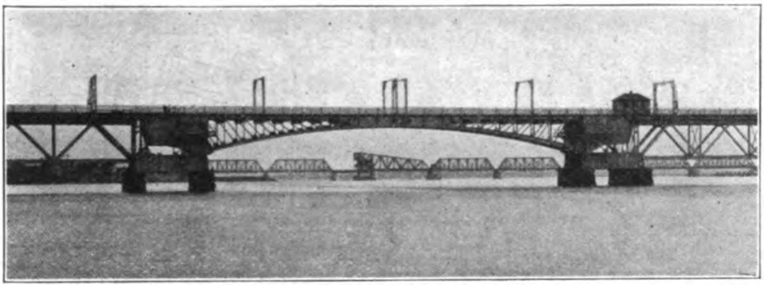
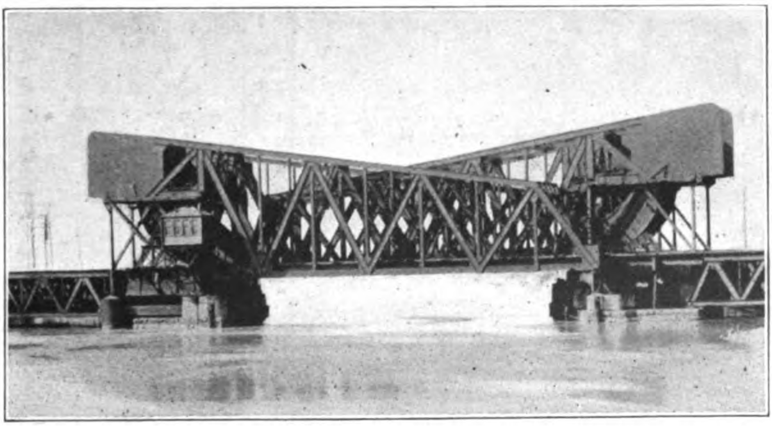


Fig. 4—Rolling Lift Bridge Over the Connecticut River at Saybrook, Conn.

of its type, was designed and erected by the Strobel Steel Construction Co. of Chicago in 1901. It was invented by Theodor Rall. Through bridges of this type have also been built.

The largest bridge of this type is the one known as the Broadway Bridge, Portland, Oregon. It is 70 ft. wide and 278 ft. long



Pig. 4a.—Eight-Track Bridge, Chicago.

center to center of rollers. At the time it was built it was the largest bascule bridge in the world.

Another Rall Bridge crosses the Neva. It is described in the Deutsche Bauzeitung of November 18, 1911.

Figure 6 shows what is known as the Page Bascule Bridge invented by John W. Page, of Chicago. The bridge shown, the first

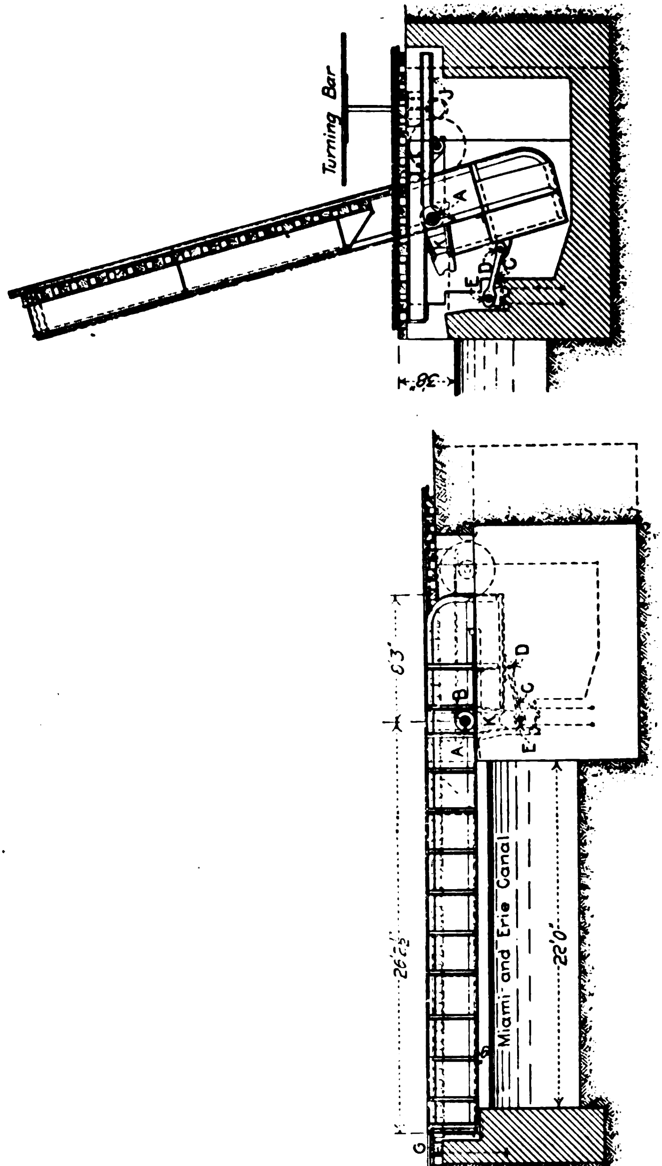


Fig. 5.—Single-Span Bascule Bridge at Delphos, Ohio.

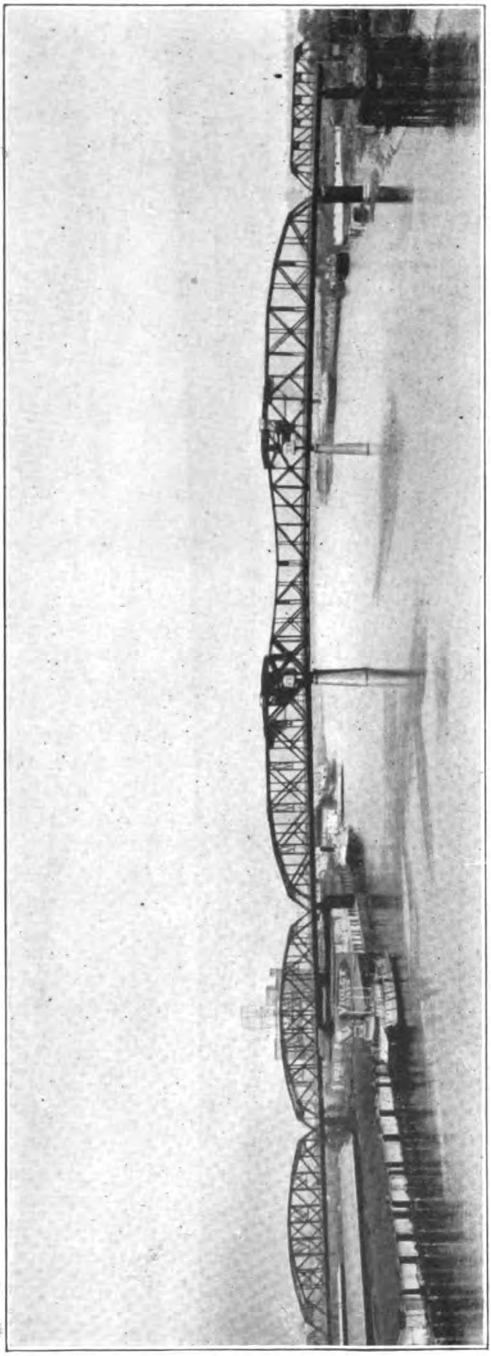


Fig. 5a.—Broadway Bridge, Portland, Ore.

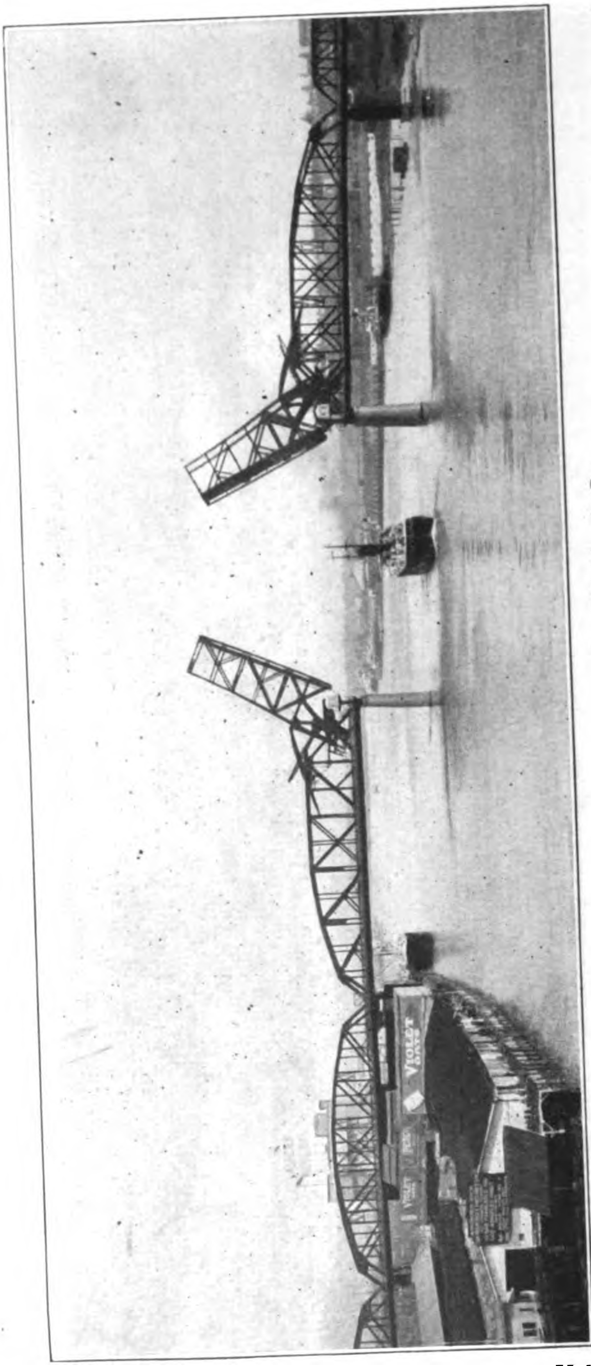


Fig. 5b.—Broadway Bridge, Portland, Ore.

one built of this design, is over the Chicago River at Ashland Ave., Chicago.[22] It consists of two pairs of through cantilever bascule trusses and two pairs of deck approach trusses. The bascule trusses are pivoted on the trunnions supported on the end posts of the approach spans. The shore ends of the bascule trusses extend back of the trunnions and are connected to the approach trusses by means of hinged anchor struts. These struts are hinged to the approach girders at the lower end, and the near and far struts are connected at the upper end by means of a heavy box girder to which they are pivoted. This box girder is supported on a pair of rollers at each end which run on the curved top chord of the bascule trusses. This box girder carries the operating machinery which transmits the power to operating pinions, one for each truss of each leaf. These pinions mesh with the racks which are fastened to the top chord of the trusses. The counterweights which balance the bridge are of two parts,—one part is rigidly attached to the tail end of the bascule truss, and the other is carried on the box girder. The first part has a fixed position and the second has a changing position relative to the trunnion and the center of gravity of the moving leaf. By properly proportioning the different dimensions and properly shaping the curved track on the top chord of the bascule truss the bridge can be balanced in all positions.

A late adaptation of the Page patent[23] is low and has semi-through trusses which greatly reduce the objectionable appearance of the Ashland Avenue bridge. The moving leaf is balanced by the approach span which is pivoted at the shore end and is carried by a segmental rocker at the trunnion end. This rocker rolls on a curved surface on the heel of the bascule trusses of such shape as to cause the bridge to be balanced in all positions.

A bridge built at Huron St. Milwaukee, Wisconsin, is shown in Fig. 7.[24] It is a double leaf bascule bridge but the motion of the moving leaf instead of being a motion of rotation about a fixed axis is a combined motion of rotation and translation produced by a pivoted link and a curved guide. A large triangular supporting girder is rigidly anchored to the masonry. A strut or link is pivoted to this supporting girder at its lower left hand corner. At the upper left hand corner is a pair of rollers mounted on pins. The upper end of the strut is pivoted to the lower side of the main bascule girder. The tail end of the bascule girder shaped to a smooth curved surface is rigidly supported by web plates and rests upon the rollers carried by the supporting girder. The moving leaf is counterweighted so as to bring the center of gravity between the supporting rollers and the strut pivot in the bottom of the bascule girder. This causes the curved surface to be pressed firmly down on the rollers. As the bridge opens the center of the upper strut pin, a point in the bascule girder moves in a circle about the lower strut pin as a center. The curved surface moves along over the top of the supporting rollers. The motion of the center of gravity of the moving leaf is a combination of the two motions just described

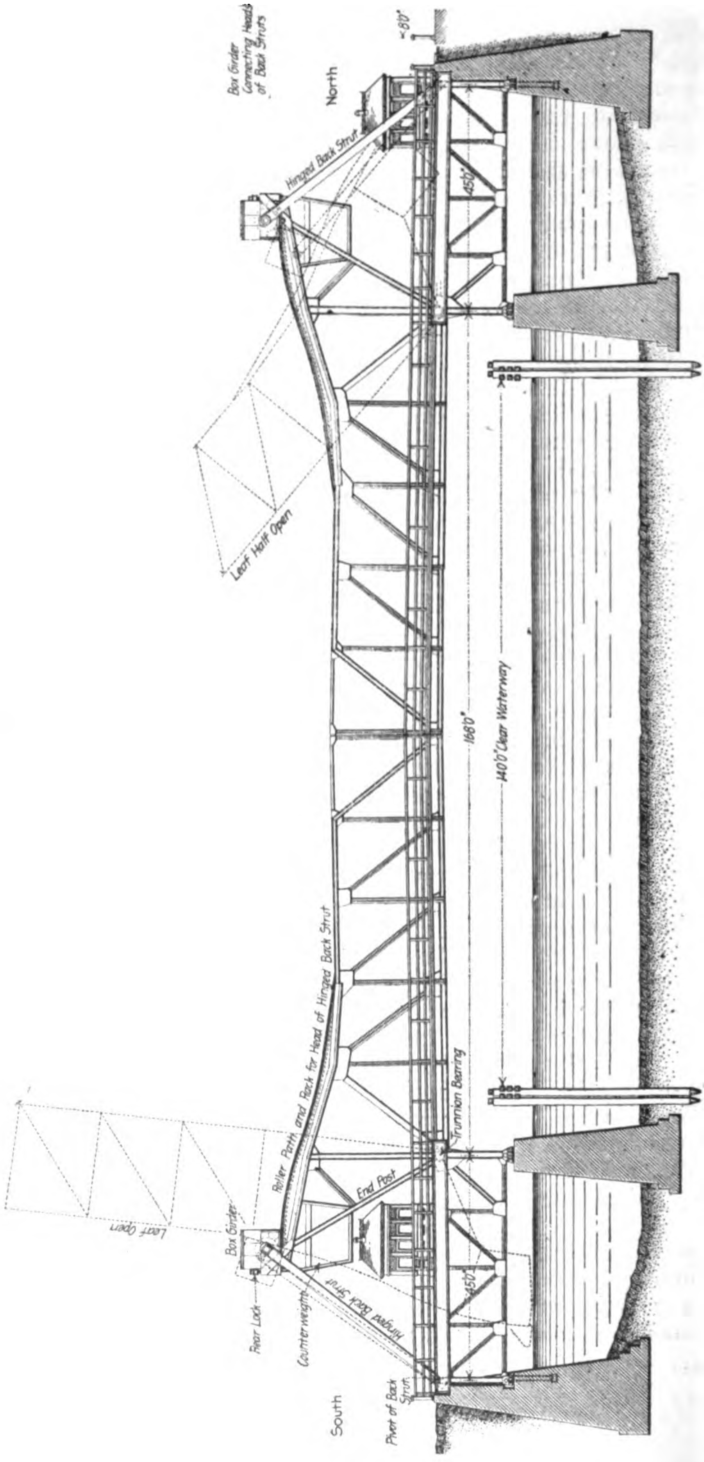


Fig. 6.—Bascule Bridge at Ashland Avenue, Chicago.

and by properly laying out the curved surface it can be made to move in a straight horizontal line. With such a motion the bridge is balanced in all positions. The moving leaf is acted upon by three forces, axial compression in the strut, normal pressure of the roller against the curved surface, and the weight of the moving leaf

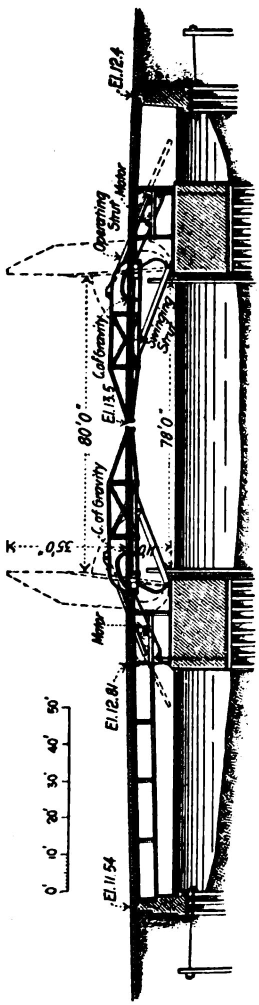


Fig. 7.—Huron Street Bridge, Milwaukee, Wis.

acting vertically through its center of gravity. For the bridge to be balanced these three forces must intersect at a common point. As the bridge was built, the tail end of the bascule girder was allowed to strike against a support when in the nearly open position and relieve the pressure on the roller. When the bridge is closed the moving leaf acts as a cantilever and the strut and roller hold the bridge in position against the action of the live load. This design was made under the supervision of Mr. Geo. H. Benzenberg, then City Engineer for the city of Milwaukee. The bridge was opened for traffic January 1, 1897.

The various bascule bridges described support the channel end of the moving leaf on the bascule trusses acting as cantilevers. This produces large dead load stresses in the bascule trusses, necessitates the use of comparatively short counterweight arms, and makes it necessary to carry the weight of the counterweight as well as the weight of the moving leaf upon the trunnions. By supporting the channel end of the moving leaf on a cable passing over a pulley at the top of a tower and fastened to a counterweight the counterweight arm is increased, the weight of the counterweight and part of the weight of the moving leaf is removed from the trunnion and the dead load, and in some cases the live load is carried on the bascule girders acting as simple beams. There is the disadvantage, however, that this type of bridge requires the use of a tower which is expensive and usually unsightly. A further difficulty lies in the fact that the moment of the weight of the moving leaf about the trunnion varies through a considerable range as the bridge moves, whereas the moment of the counterweight is more nearly constant. This necessitates the use of some special means to keep the bridge balanced in all positions. The taking care of this one feature has led to the development of various designs

One bridge of this style built over the Buffalo River at Ohio St., Buffalo, New York, in 1907, was designed by Mr. Brown. A diagrammatic sketch is shown in Fig. 8.[25] The bridge is a single leaf bascule hinged at the point *C* and balanced by means of a counterweight supported on a cable attached to the moving leaf and passing over a large pulley at the top of a tower. The cable is attached to the moving leaf at the point *D* and passes over the curved guide *F E*. The pivot *C* instead of being fixed is connected by hinged struts to the fixed point *A* and the point *B* which is free to move between horizontal girders. A hydraulic piston moves the point *B* horizontally. This raises the point *C* and causes the moving leaf to revolve about *C*. As the leaf is raised the moment of its weight decreases. The curve of the guide *E F* is laid out so that the counterweight acting through the cables produces a moment which varies as the moment of the moving leaf so that the bridge remains balanced in all positions. When the bridge is fully open, forked guides at *G* straddle the cable and prevent the leaf from falling onto the tower. When the bridge is closed it carries the live load as a simple span. A similar bridge was built over a slip by the Buffalo Creek R. R. and another highway bridge of similar type is being designed by the city of Buffalo.

The bridge at Harway Ave., Brooklyn, N. Y., is shown in Fig. 9.[26] It is a single leaf bascule bridge with fixed trunnions. To balance the bridge a steel cable attached to the bascule girder passes over a large pulley at the top of a tower and is attached to a counterweight which rolls on a curved girder. This girder is so formed as to cause the counterweight to balance the moving leaf in all posi-

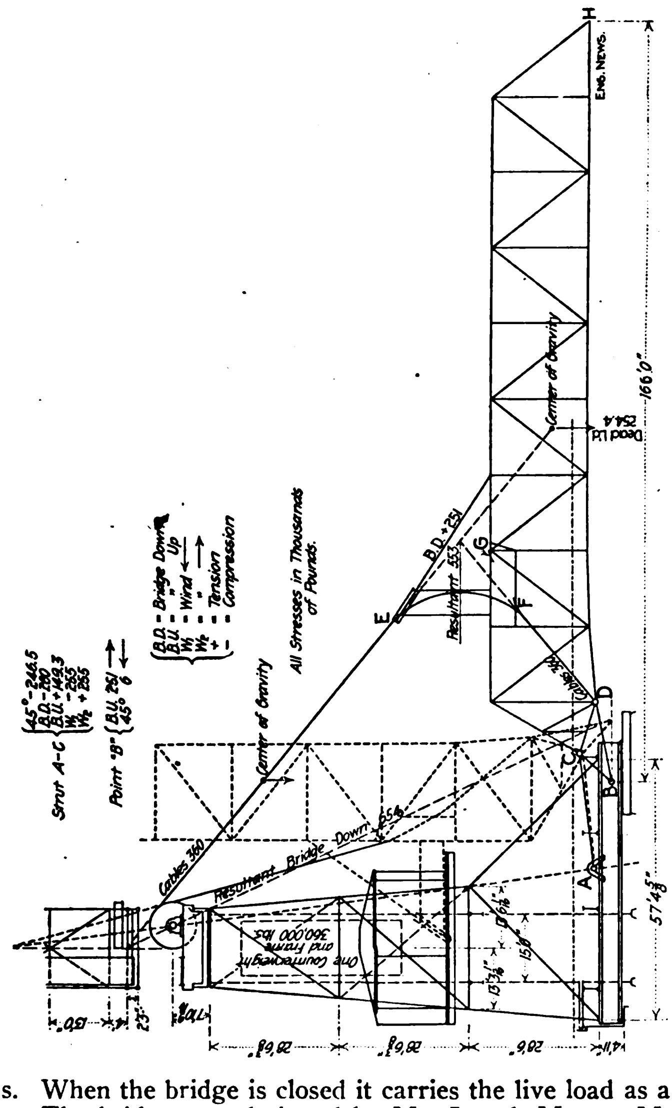


Fig. 8.—Bascule Bridge at Ohio Street, Buffalo, N. Y.

tions. When the bridge is closed it carries the live load as a simple span. The bridge was designed by Mr. Joseph Mayer; Mr. E. S. White was the engineer in charge, and Mr. J. S. Langthorn was Resident Engineer of Construction. It was completed in 1898. A bridge of this type was built at Michigan Ave., Buffalo, N. Y., in 1897 and is still in use. A number of other bridges of the same type have since been built.

The double leaf bascule span of the Rhode Island stone bridge over the Sakonet River between Portsmouth and Tiverton[27], R. I., is of a very similar type. Instead of making use of cables the front end of the moving leaf is supported by means of struts, which are pivoted to a carriage running on a curved track supported on a tower over the approach span. The carriage carries the counterweight and the track is so curved as to cause the bridge to be balanced in all positions. When the bridge is closed the carriage is brought up against a bumper so as to enable the pivoted strut to support the front end of the moving leaf under the action of the live load. The design was made by Mr. Augustus Smith of New York. The bridge was completed in 1908.

One of the competitive designs submitted for the bridge over the Calumet River at 95th St., Chicago[28], is a double leaf bascule bridge, for which the moving leaves are supported by cables which pass over pulleys on the top of towers. Attached to each pulley is a large spiral over which passes a cable that supports the counterweight. The counterweight slides between vertical guides and the spiral is so formed that the moving leaf is balanced in all positions. This design was submitted by the Milwaukee Bridge & Iron Works in 1900.

A steamboat striking the pivot pier of the swing bridge which carried the New York Central and Hudson River R. R. over the Harlem River at 135th St., New York, a point where the traffic is congested, while not putting the bridge out of commission impressed upon the officials of the road the desirability of having an emergency draw span to be used in case the regular span should be out of commission. A bridge[29] was put in place of the fixed span adjoining the swing span. It consists of a double track plate girder span hinged at one end and resting upon a pier at the other. Cables fastened to the outer end of the moving leaf pass over a wheel supported on a tower, down to and around the drum of a hoisting engine and thence up and over wheels at the top of the tower. Weights hung on the end of this cable balance the bridge. There are two sets of these weights and each set is made up of 23 parts placed one upon another. The cable passes through holes in the centers of the top 22 weights and is fastened to the 23rd weight. Brackets project from the weights and engage projecting angle supports on the tower provided for the purpose. These supports are so arranged that one after another of the weights are removed as the counterweight is lowered so that just enough remain on the cable at each position to balance the bridge. The bridge was designed by Mr. G. H. Thompson, then Engineer of Bridges for the N. Y. C. & H. R. R. R. It was built about 1892, and was afterwards used as a temporary bridge during the reconstruction at Spuyten Duyvil Creek.

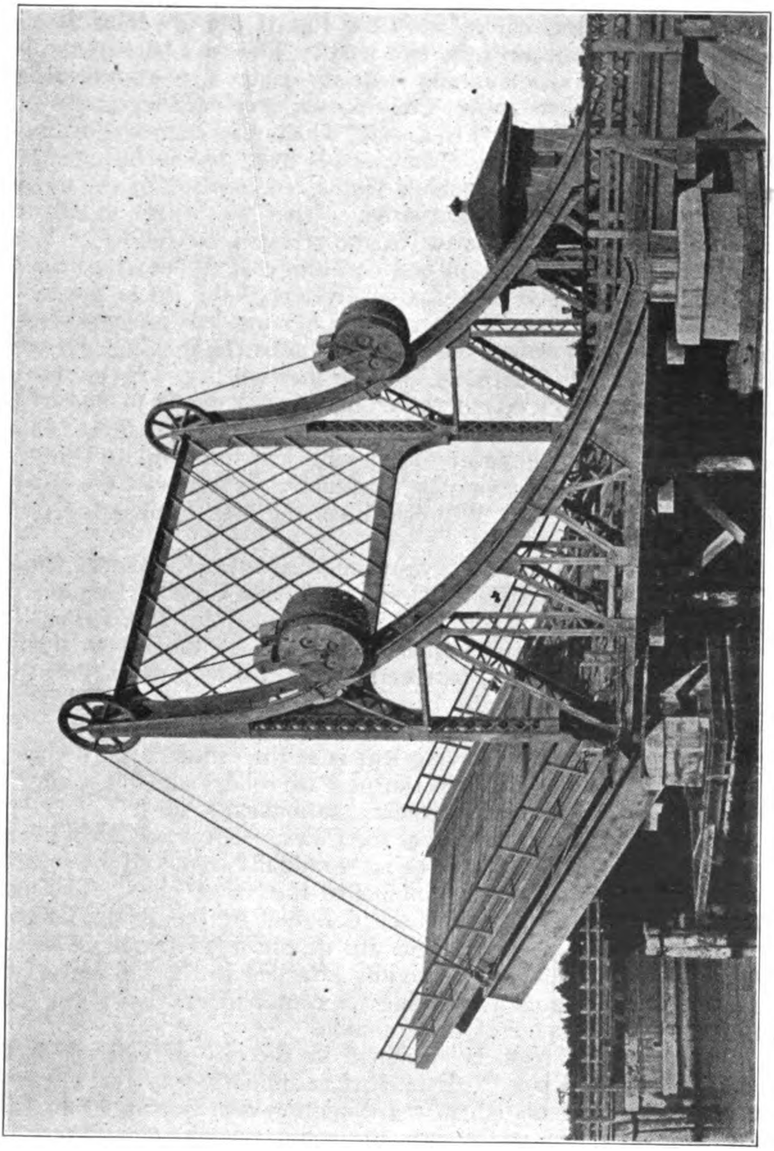


Fig. 9.—Harway Avenue Bridge, Brooklyn, N. Y.

The jack-knife type of drawbridge was used over the Chicago River at Weed St., Chicago.[30] The bridge is composed of two similar leaves. Each leaf is made up of two parts connected by a hinge. Steel rods extend from the top of a tower to the outer end of the leaf and steel cables from the top of the tower to a point near the hinge connecting the two parts. The rear part of the leaf is pivoted on a fixed trunnion near its center. A counterweight hung from the end of a steel cable passes over a pulley and over a cam. This cam is fastened to a shaft which also carries a drum. A steel cable fastened to this drum passes over and is fastened to a segment which is rigidly attached to the rear portion of the moving leaf. The radius of the cam varies so that the bridge is balanced in all positions. The operation of the bridge is as follows: When the bridge is closed the front end and hinge of the moving leaf are supported by rods and cables respectively passing up to the top of the tower, and the rear portion of the moving leaf is supported on the trunnion. In opening, the rear portion of the moving leaf turns upon its trunnion. The hinge joining the two parts of the moving leaf moves in a circle about the trunnion, and the front end of the moving leaf moves in a circle about the top of the tower. This motion causes the middle of the moving leaf to go up and the two ends to come down, leaving the channel clear between the towers. It was invented by Mr. Wm. Harman and was opened for traffic April 18, 1891.

A bascule bridge over the Cuyahoga River at Cleveland, Ohio[31], which was built in 1907, was designed by the Cowing Engineering Co. of Cleveland and is of a type invented by John P. Cowing. The bridge is a double leaf bascule, but instead of the leaves turning about fixed trunnions the rear ends of the girders are made in the form of a circular arc and set in and roll upon a nest of 29 ten-inch anti-friction rollers arranged in the form of a circular arc. The center of gravity of the moving leaf is at the center. As the bridge is opened the girder rolls on the nest of rollers and the center of gravity of the moving leaf remains stationary.

The original structures over the Chicago River at Chicago were swing bridges. These are being gradually replaced by bascule bridges in order to free the channel of the center piers. The more recent of these bridges have been designed by the Bridge Department of the City. All of them are of the fixed trunnion bascule type with the counterweight rigidly attached to the tail end of the trusses, and so located as to bring the center of gravity of the moving parts at the center of the trunnion.

The first bridge to be designed by the city of Chicago is the one at Clybourn Place.[32] Each leaf is supported by three trusses, each of which is carried on a trunnion whose bearings rest upon longitudinal girders which span the counterweight pit. There is a pair of these girders for each truss and they are spaced just far enough apart to allow the tail end of the truss to swing between them. The span being comparatively short and there being three trusses for each leaf, sufficient counterweight is obtained by bolting cast iron blocks to the tail ends of the trusses. These blocks are so narrow that they pass between the girders which support the trunnion bearings. This design was prepared by Mr. Edward Wilman, City Bridge Engineer, and Mr. John Ericson, City Engineer, with a view to its adoption for all bascule bridges over the Chicago River.

Some of the later bridges had the trunnions supported on inverted A-frames instead of girders. The back ends of these frames were high enough to allow the counterweight to extend from truss to truss, thus increasing the volume and decreasing the unit weight. The Kinzie St. bridge[33] is of this type. For both the Clybourn Place Bridge and the Kinzie St. Bridge the live load on the moving leaf is carried on the bascule trusses acting as cantilevers. The main trunnions act as the front supports, and anchors in the masonry hold down the tail end.

A further development is noted in the bridge at Washington St., which has just been completed. Instead of there being a longitudinal girder on each side of the trusses to support the trunnion bearings, a longitudinal girder outside of each truss supports a cross girder which carries the trunnion bearings. This is partly shown in Fig. 10.[34] The cross girder passes through the bascule truss, which is of such design that no web members interfere with the cross girders as the bridge is opened. The absence of the inside longitudinal girders permits of the use of a large counterweight volume and a low unit weight. There is a support in front of the main trunnion to take the live load when the bridge is closed.

The new bridge at Jackson St., for which plans have been made, is to be of the same general type as the one at Washington St., except that it will be a deck bridge.

The Bridge Department of the City of Chicago has prepared plans for the proposed bridges at West Lake St.[35] and at Michigan Blvd.[36]. Both of these bridges are to be double-deck structures and both are designed as double leaf bascule bridges. In the method of handling the bridges and supporting the trunnions they are similar to the one at Washington St.

Other fixed trunnion bascule bridges with counterweight rigidly attached to the bascule trusses differ from the bridges just described in having the trunnions above the roadway instead of underneath. The counterweight is over the roadway when the bridge is closed. The False Creek Bridge[37] at Westminster Ave., Vancouver, B. C., is of this type, and was designed by Waddell and Harrington.

The crossing over the Oswego Canal at North Salina St., Syracuse, N. Y., presented unusual conditions. The street crosses the channel at an acute angle so that if the bridge, which is a single leaf bascule, had been placed with the bascule girder parallel to the center line of the street the span would have been excessive for the required width of channel. In the design used the bascule girders were placed normal to the channel as shown in Fig. 11.[38] A cross

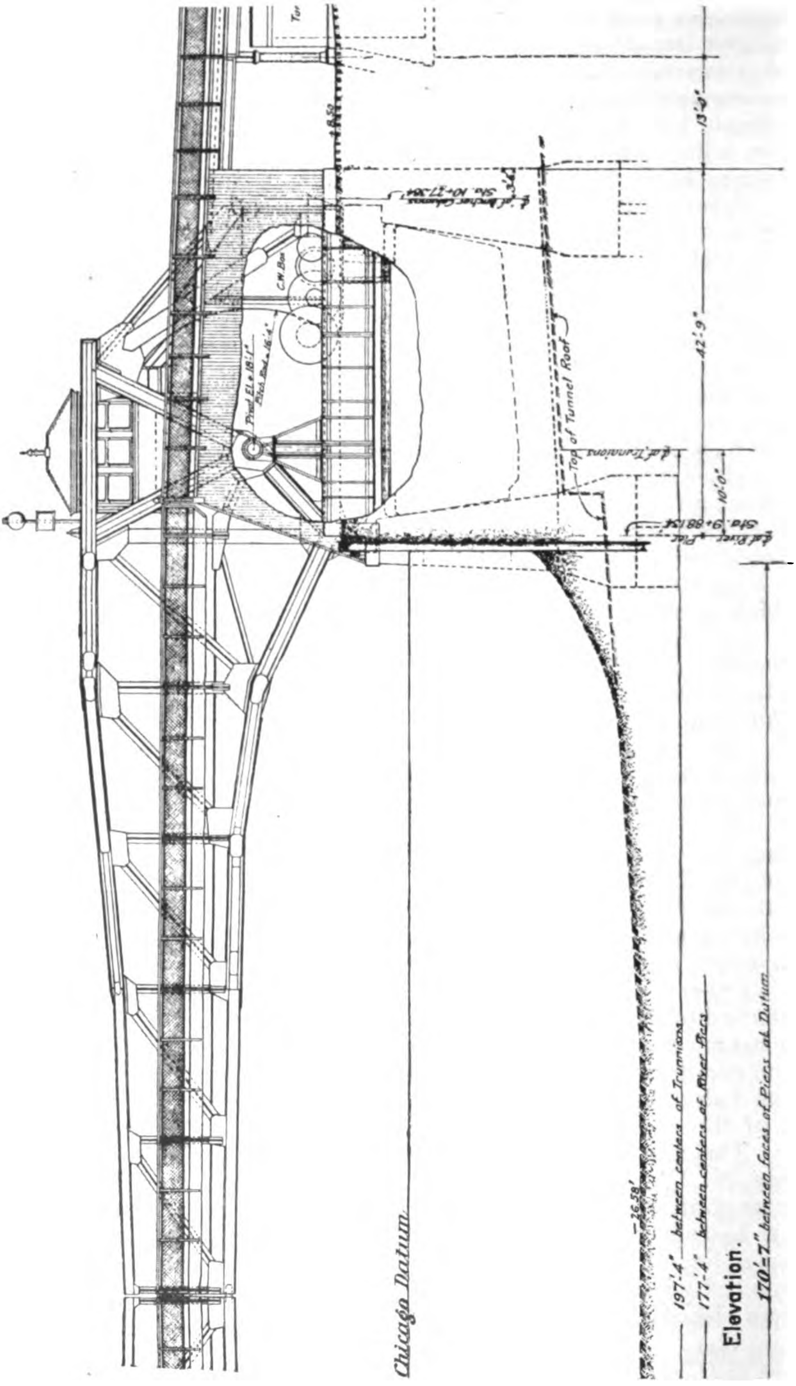


Fig. 10—Part of Washington Street Trunnion Bascule Bridge, Chicago.

girder is framed across the front end of the two bascule girders and cantilevered out to carry the triangular section of the floor to the left. A similar girder extends to the right near the trunnion to carry a similar section of the floor. These cantilevered girders,

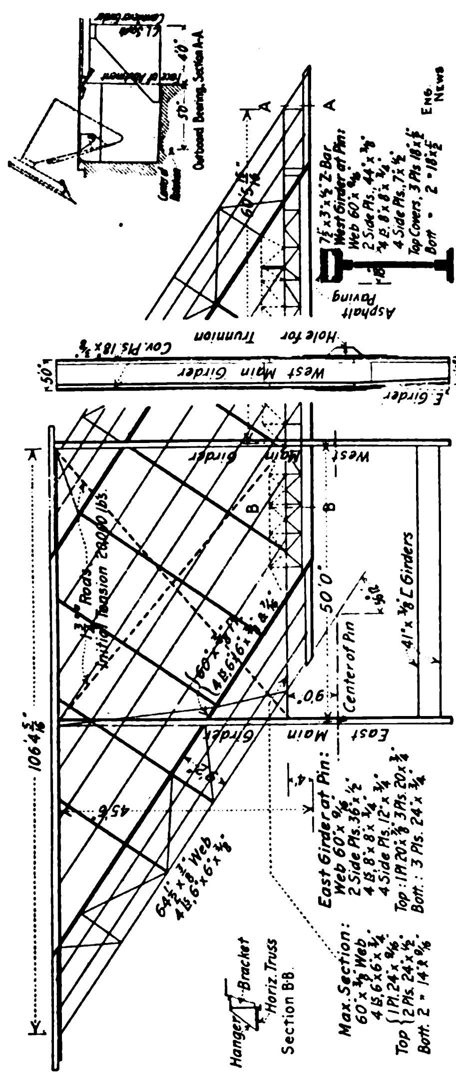


Fig. 11.—Skew Bascule Bridge at Salina Street, Syracuse, N. Y.

however, carry only the dead load, as pedestals are provided to support them at various points when the bridge is closed. The bridge was designed by the Bridge Department of the State Engineer's office under Mr. Wm. R. Davis, Chief Bridge Designer. It was opened to traffic in 1908.

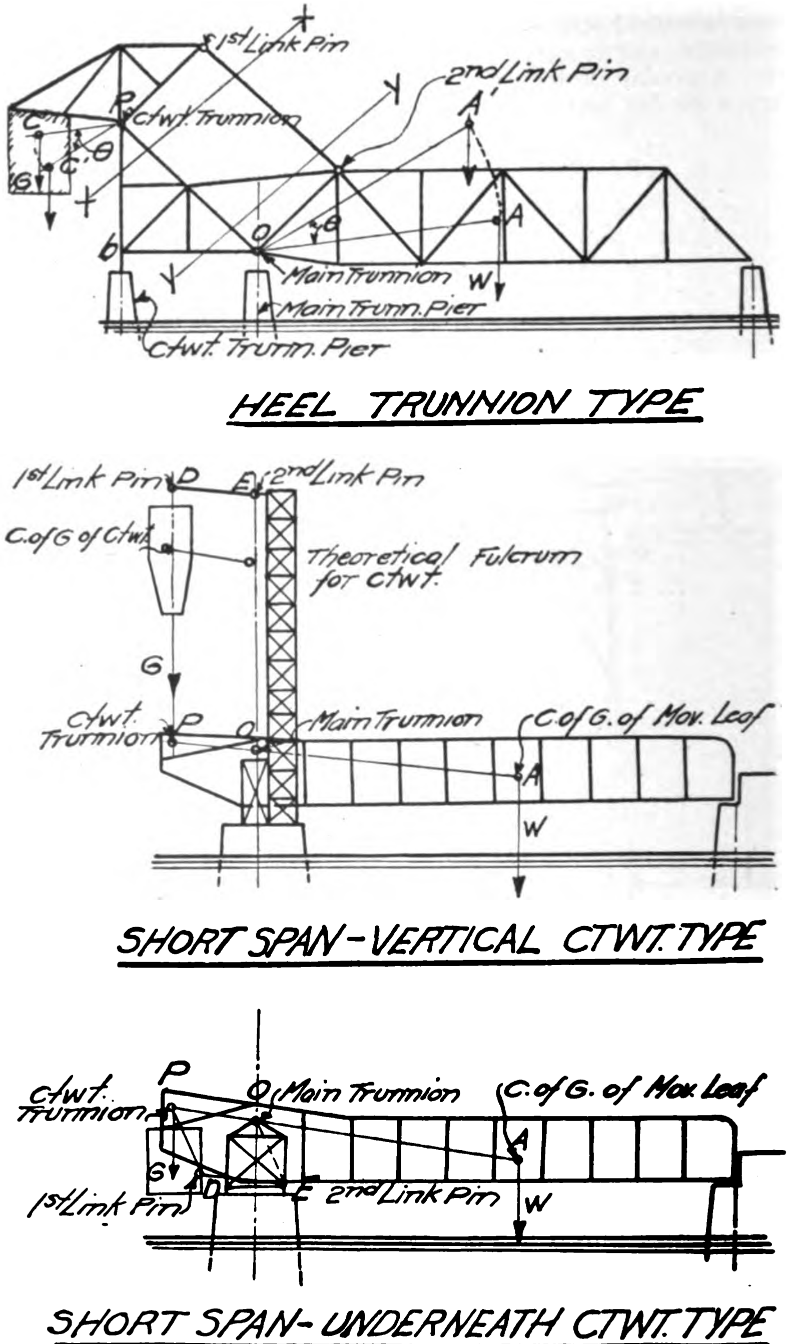


Fig. 12.—Types of Strauss Bascule Bridges.

Figure 12[39] is a schematic drawing showing the principles of the various types of what are known as Strauss Bascule Bridges. While there are many modifications of the Strauss Bascule Bridges, they all belong to some one of the three types shown and known as "Heel Trunnion," "Overhead Counterweight," and "Underneath Counterweight." For all three types the counterweight is connected to the moving leaf by means of a parallelogram whose sides are steel members hinged at the intersection point. The use of this parallelogram eliminates the necessity of having the center of gravity of the counterweight on a line through the center of gravity of the moving leaf and the center of the trunnion. This makes it possible to locate the counterweight where it will not interfere with traffic or other parts of the structure. All three of these types of bridges are balanced in all positions and, for all of them, the dead load pier reactions are always vertical and remain constant throughout the movement of the bridge. These bridges are designed by the Strauss Bascule Bridge Company of Chicago. The first Strauss bridge to be built is the one which carries the Wheeling and Lake Erie R. R. over the Cuyahoga River at Cleveland, Ohio.[40] It is of the overhead counterweight type. The moving leaf is hinged at the main trunnion at a point nearly in line with the bottom chord of the truss. The ccunterweight is supported on a steel frame pivoted to the tail end of the bascule truss at the lower end and pivoted to a link at the upper end. This link which is pivoted to the tower prevents the counterweight from tipping. The main trunnion and the counterweight trunnion are on a line passing through the center of gravity of the moving leaf and when combined with the two link pins form a parallelogram. The inside trunnion bearing is supported on a cross girder which passes through the bascule truss whose members are so placed that the cross girder does not interfere with the truss as the bridge is opened. This bridge was opened for traffic October 14, 1905. A later form of the overhead counterweight type is shown in Fig. 13.[41] This bridge was built for the Boston & Maine R. R. at Manchester. The counterweight frame is vertical and both the inside and outside trunnion bearings are carried on steel columns which rest directly upon the masonry. It was completed during the summer of 1911.

What is known as Knippel's Bridge, Copenhagen, Denmark[42], is of the overhead counterweight type. Large monumental towers which enclose the counterweights and provide operator's houses give the bridge a very pleasing appearance. The bridge has two leaves which when closed rest on pins so located as to enable them to act together as a three-hinge arch to carry the live load. This bridge was completed in 1909.

Figure 14[43] shows the new Strauss double leaf heel trunnion bridge which carries the track of the Canadian Pacific Ry. over the U. S. Ship Canal at Sault Ste. Marie, Mich. Each leaf is pivoted on a trunnion nearly in line with the lower chord. The counterweight is supported on a pair of trusses which are pivoted on the top of a tower. The front ends of the counterweight trusses are connected to the moving leaf by means of a pair of links pivoted at each end. The main trunnion, counterweight trunnion and the two link pins form a parallelogram. By having the center of gravity of the counterweight on a line through the center of the counterweight trunnion, parallel to a line through the center of the main trunnion and the center of gravity of the moving leaf, the bridge is balanced in all positions. This bridge is of special interest because of the fact that it is the only double leaf heel trunnion bridge which the Strauss Bascule Bridge Co. have designed and because of the fact that, as far as the writer is aware, it is the only double leaf bridge

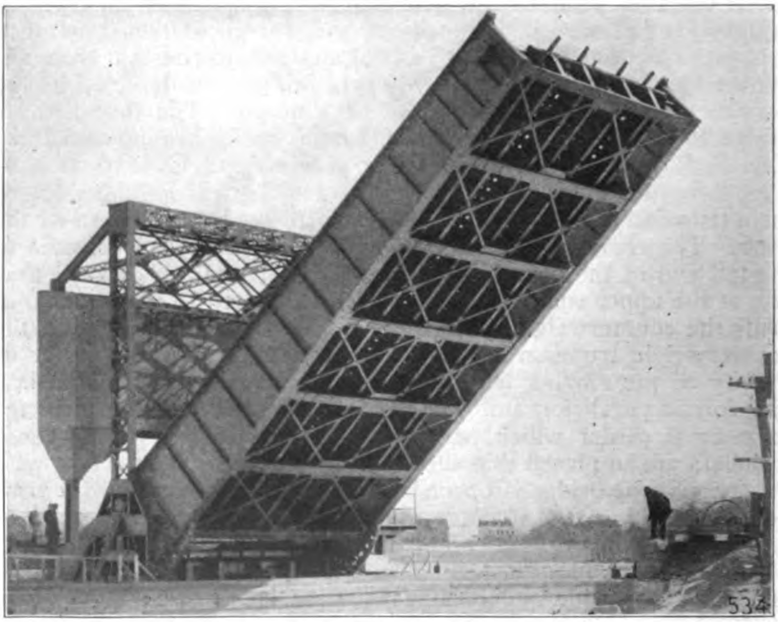


Fig. 13.—Bascule Bridge for B. & M. R. R., Manchester, N. H.

which has ever been built for which a moment lock is provided at the center. A compression and shear lock is provided at the center of the top chord and a tension lock is provided at the center of the bottom chord. These locks enable the section at the center of the bridge to act together as a simple span to support the live load. The distance center to center of trunnions is 336 ft.

Figure 15[44] shows the Strauss heel trunnion bridge which is to carry the B. & O. R. R. over the Calumet River at South Chicago. It is a double track bridge and is claimed to be the longest single leaf bascule bridge in the world. The length, center to center, of supports is 235 ft. The moving leaf is completed and was closed in the spring of 1913 but has not been put in service because other track changes are yet to be made.

Dr. J. A. L. Waddell has designed a number of the more recent vertical lift bridges. The first one built after his design is at South Halsted St., Chicago.[45] Steel cables fastened to the four corners of the lift span pass over large wheels supported on towers at the ends of the span. Counterweights supported on these cables balance the lift span. While the bridge is moving it is held in place by guides on the tower. The lift span is 130 ft. long and has a vertical motion of 142 ft. 6 in., giving a clear head room when open of 155 ft.

Figure 16[46] shows the vertical lift span of the bridge over the Missouri River at Kansas City. The structure, which is double deck, carries a railroad on the lower deck and a highway on the upper

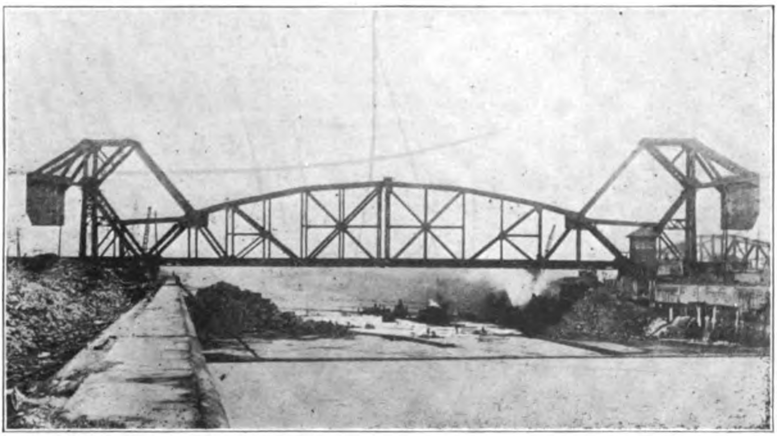


Fig. 14.—Bascule Bridge for C. P. R. R. at Sault Ste. Marie, Mich.

deck. The lower deck which is suspended from the upper deck by means of rods can be raised by telescoping the rods into the posts of the upper truss. The upper truss is fixed. The lower deck has a vertical movement of 50 ft., which gives a minimum clear head room of 65 ft. above standard high water. This bridge is of additional interest because of the length of span which is 428 ft., providing a clear channel of 413 ft., which is the widest provided by any movable bridge in the world. The double deck vertical lift bridge at Willamette River at Portland, Oregon[47] has a lower deck which can be raised by telescoping the suspension rods which support it, into the vertical posts of the upper deck so as to provide for the passage of ordinary boats. To provide for the passage of tall-masted vessels, after the lower deck has been raised until it comes nearly up to the upper deck, the two are lifted together so as to provide an underneath clearance of 140 ft. above high water. The

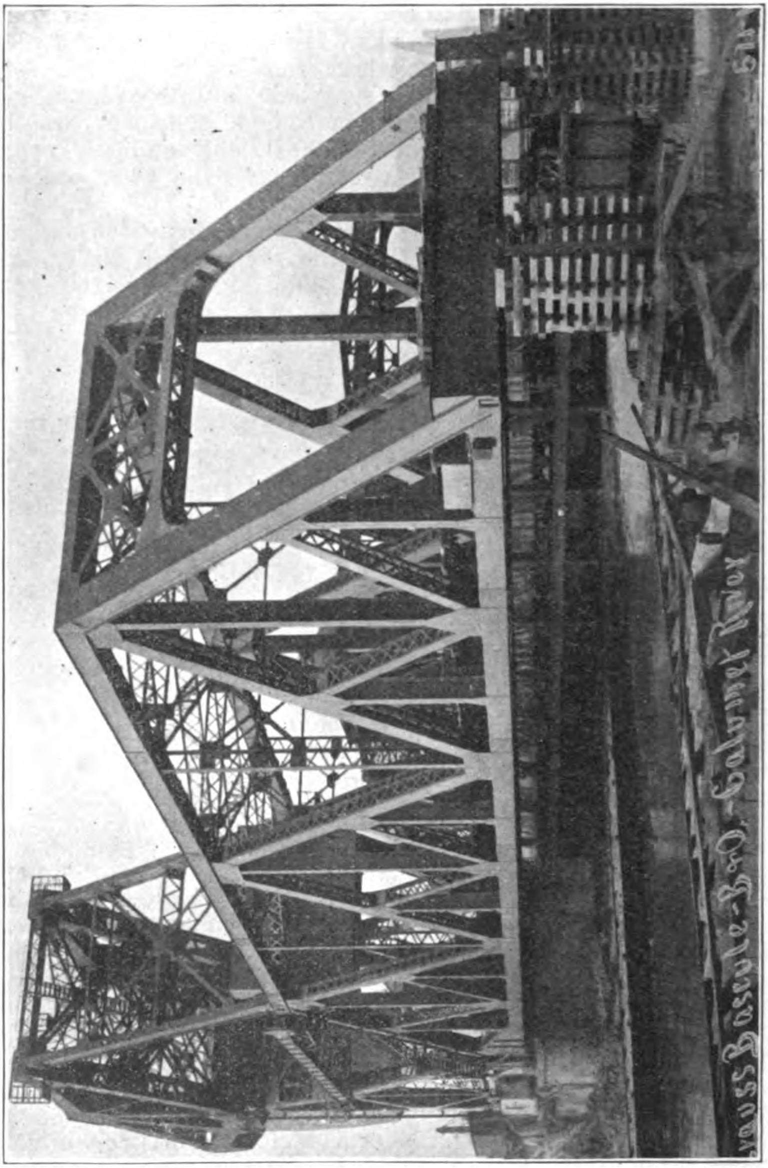


Fig. 15.—Bascule Bridge for B. & O. R. R. Over the Calumet River at South Chicago.

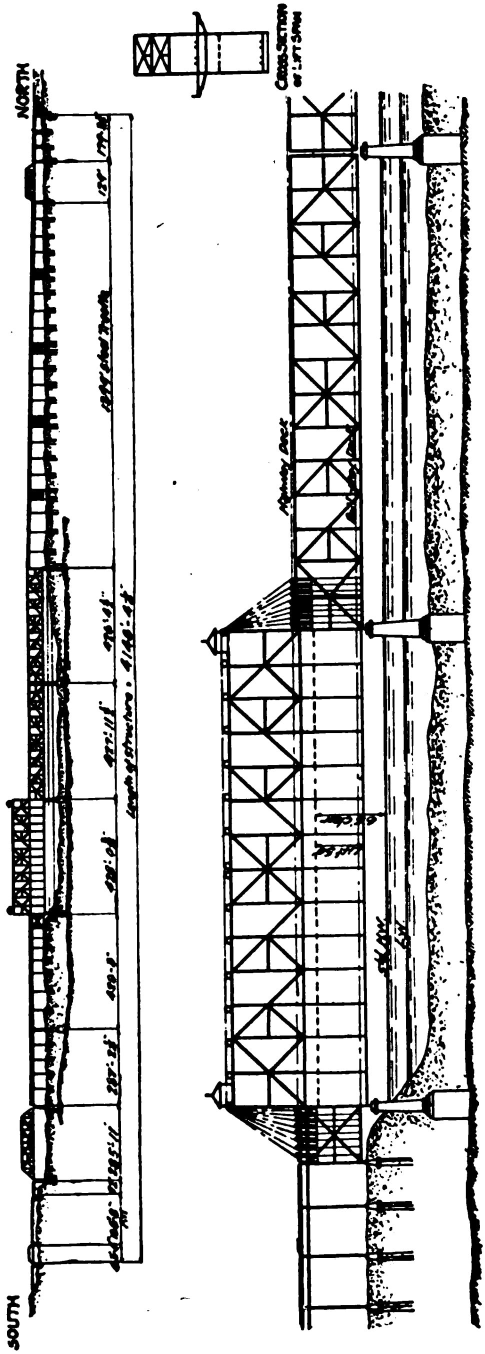


Fig. 16.—Vertical Lift Bridge Over Missouri River at Kansas City, Mo.

two decks are counterbalanced independent of each other. Both of these bridges were designed by Waddell and Harrington, Consulting Engineers of Kansas City.

Figure 17[48] shows a type of vertical lift bridge which is of recent invention. Near each end the top chord of the lift span is hinged to the lower end of a hanger. A pivot near the center of the hanger connects it to the end of a truss which is supported near the center of its bottom chord by means of a trunnion carried on the top of a tower. A counterweight is pivoted to the opposite end of the truss. A pivoted link connects the top of the hanger and the top of the counterweight. As the lift span is raised the lower hanger pin moves in a vertical line and the hanger trunnion moves

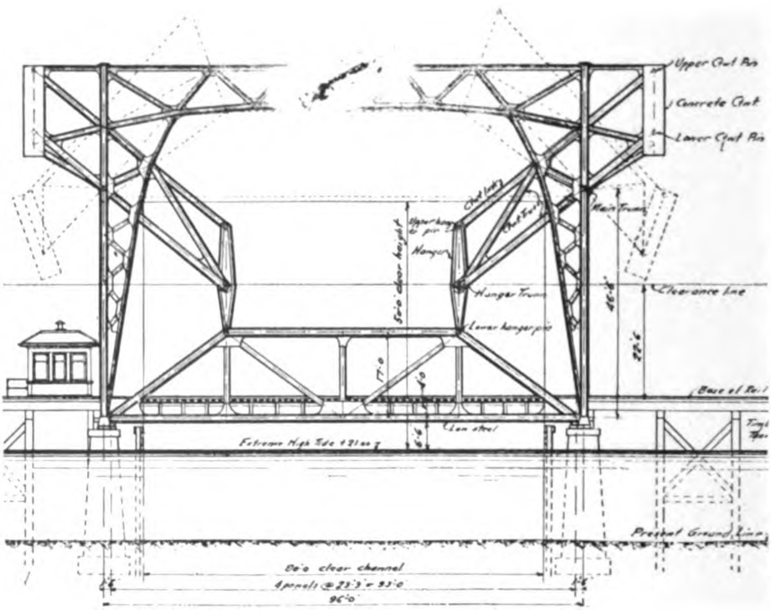


Fig. 17.—Vertical Lift Bridge at Tacoma, Wash.

in a circle about the main trunnion as a center. This inclines the hanger and since the hanger link, counterweight, and bottom chord of the counterweight truss form a parallelogram, the counterweight is inclined an equal amount. The weight of the lift span hanging from the lower end of the hanger tends to make it return to the vertical position. This tends to put compression in the link. At the same time, the counterweight being inclined it tends to fall toward the channel and also tends to put compression in the link. By properly proportioning the weights and dimensions the action of the counterweight can be made to exactly balance the action of the

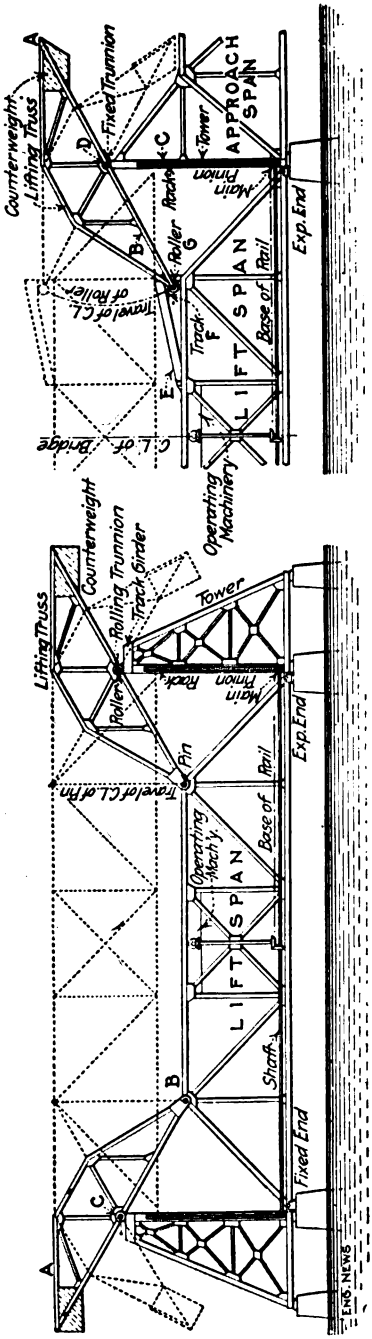


Fig. 18.—Lift Bridge at La Salle, Ill.

weight of the moving leaf. For the bridge to be properly balanced, not only must the moment of the counterweight about the lower counterweight pin be equal and opposite to the moment of the moving leaf about the hanger trunnion but their moments about the main trunnion must also balance. To effect this latter balancing a second or auxiliary counterweight is provided which is rigidly attached to the counterweight truss just below the pivoted counterweight. The bridge shown in the figure was designed by the Strauss Bascule Bridge Co. for the Northern Pacific R. R. over Steilacoom Creek at Tacoma, Washington.

No bridges of this type have been built, but a number of them have been contracted for during the last year and a half.

Figure 18[49] shows a type of vertical lift bridge developed by the Strobel Steel Construction Co. With this bridge the weight of the moving leaf is counterbalanced by a counterweight on the outer end of a truss which rocks over the top of a tower. For the bridge shown in the left of the figure, pivot *C* is supported on rollers which move back and forth as is necessary while the point *B* moves in a vertical line. For the bridge shown in the right of the figure the corresponding horizontal motion is provided by means of a roller at *G*.

APPENDIX.

Sources from which the information concerning the different bridges was obtained.

1. Trans. Am. Soc. C. E., Vol. 13. March, 1884, p. 67.
2. Scientific American Supplement, Jan. 14, 1888, p. 10023.
3. Cut furnished by Waddell & Harrington, Consult. Engrs., Kansas City, Mo.
4. Engineering, May 29, 1896, p. 699.
5. Engineering News, Sept. 20, 1900. Vol. XLIV, p. 190.
6. London Engineer, Jan. 28, 1912, p. 668.
7. Railway Age, March 7, 1902, p. 290.
8. Engineering Record, Jan. 4, 1908, p. 13.
9. Engineering News, Oct. 22, 1903, p. 372. Vol. L.
10. Engineering News, Aug. 21, 1902, p. 125. Vol. XLVIII.
11. Proceedings Engrs. Soc. of Western Penn. Vol. 25, p. 14.
12. Engineering, June 11, 1897.
13. Engineering Record, Aug. 10, 1895, p. 184.
14. Engineering News, Jan. 30, 1913, p. 210.
15. Dufour's Bridge Engineering, p. 206.
16. Sanitary Engr., April 23, 1887, p. 545.
17. Proceedings, Brooklyn Engrs. Club. Vol. 8, p. 108.
18. Scherzer Rolling Lift Bridge Co.'s Catalog, p. 61.
19. Photograph furnished by Scherzer Rolling Lift Bridge Co.
20. Photograph furnished by Scherzer Rolling Lift Bridge Co.
21. Engineering News, May 25, 1905, p. 546.
22. Engineering News, April 25, 1901.
23. Engineering News, April 25, 1901.

24. Engineering News, April 22, 1897, p. 255.
25. Engineering News, Jan. 16, 1908, p. 53.
26. Proceedings, Brooklyn Engrs. Club. Vol. 8, p. 142, 1904.
27. Engineering Record, Feb. 29, 1908, p. 237.
28. Engineering News, Jan. 10, 1901, p. 19.
29. Railroad Gazette, June 10, 1892, p. 424.
30. Engineering News, May 23, 1891, p. 487.
31. Iron Trade Review, Oct. 31, 1907, p. 699.
32. Engineering News, Jan. 31, 1901, p. 76.
33. Print furnished by the Bridge Dept., City of Chicago.
34. Print furnished by the Bridge Dept., City of Chicago.
35. Report of Dept. of Public Works, City of Chicago for 1912.
36. Engineering News, July 17, 1913, p. 116.
37. Cut furnished by Waddell & Harrington, Consult. Engrs., Kansas City, Mo.
38. Engineering News, Sept. 24, 1908, p. 327.
39. Cut furnished by the Strauss Bascule Bridge Co. of Chicago.
40. Cut furnished by the Strauss Bascule Bridge Co. of Chicago.
41. Cut furnished by the Strauss Bascule Bridge Co. of Chicago.
42. Cut furnished by the Strauss Bascule Bridge Co. of Chicago.
43. Cut furnished by the Strauss Bascule Bridge Co. of Chicago.
44. Cut furnished by the Strauss Bascule Bridge Co. of Chicago.
45. Cut furnished by Waddell & Harrington.
46. Cut furnished by Waddell & Harrington.
47. Cut furnished by Waddell & Harrington.
48. Cut furnished by Strauss Bascule Bridge Co.
49. Engineering News, June 5, 1913, p. 1171.