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"Movable Bridge Type Selection"

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HMS 2000 MOVABLE BRIDGE TYPE SELECTION

by

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Many types of movable bridges were developed in the 19^{th} century. Most movable bridges of the early industrial era were of the swing type, because they were simpler to design and generally considered to be more economical than other types. Power was expensive at that time, and swing bridges used less power because they did not have to be lifted and lowered. In spite of this, one of the first railroad draw bridges in the country was the Paterson & Hudson River Rail Road's bascule bridge over the Hackensack River, built about 1833.

Swing bridges continued through the 19th century to be the most common type of movable bridge. O. E. Hovey, writing in the 1920's, continued to prefer swing bridges because they do not require "expensive counterweights". The rapid development of other types of movable bridges occurred around the end of the 19th century, with bascule variations, vertical lift bridges, retractile bridges, and other types coming into general use. A great many of these bridge variations were impractical, and either did not last long or were not repeated. It was also an age of complicated mechanisms, and even swing bridge were equipped with elaborate roller bearing center pivots, and complicated wedging and locking mechanisms. Most of this equipment proved to be not very durable, and prone to failure without constant attention, so that these variations largely disappeared from the scene.

For the typical movable bridge types, all things being equal, without external forces such as wind applied to the bridge, the swing span will require the least power to operate and the vertical lift will require the most. This is due to the amount of friction retarding movement of the bridge. The vertical lift bridge drive must overcome the resistance of the counterweight sheave bearings and the counterweight ropes operating over the sheaves. The swing bridge has a point bearing or a set of rollers supporting its moving weight, both low friction devices. The swing bridge has no gravitational forces to overcome during opening and closing, except some minor vertical movement at the end lifts. The bascule bridge, its weight supported on shaft type bearings as are the sheaves of vertical lift spans, has an intermediate friction value. Including all resistances to motion, per the standard power requirements calculations, the bascule bridge requires the greatest amount of power due to its higher wind resistances, while the vertical lift bridge has the least, due to its minimal wind resistance.

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Of the more unusual movable bridge types, the pontoon has a higher power requirement during ordinary operating conditions, due to having to move through water, while the roller supported retractile has a low, perhaps the lowest, power requirement due to slight wind resistances and no gravitational forces to overcome. In present times of cheap energy, the actual power required to operate the bridge is not a major factor in the cost of a bridge, and is of no concern in selecting the bridge type. This was not the case prior to the mid-20th century. The type selection of many if not most movable bridges at that time was heavily weighted by power considerations. This is not to say that the amount of power required to operate a movable bridge is a trivial item. Provision for power supply may be expensive, particularly if the nearest source of three-phase electric power may be miles away. Larger power requirements also require larger emergency generators, if such are installed on the bridge.

ADVANTAGES OF BASCULE BRIDGES

The bascule bridge provides the greatest rapidity of operation of any commonly used movable bridge. It also has the ability to pass smaller vessels navigating the channel without opening fully, as it is easier and safer for a vessel to pass a partially opened bascule draw than a swing or vertical lift type. This advantage is even greater with double leaf bascules than with single leaf. The bascule bridge is less likely to sustain severe damage in the event of a collision with a vessel than either a swing bridge or a vertical lift bridge. Ship captains are more likely to approach closer to a bascule bridge than a swing or vertical lift prior to the full opening, and as a result the bascule bridge must stay open a shorter time for the vessel to pass through than do the other types.

The bascule bridge leaf can provide an automatic barrier to vehicular traffic, preventing an automobile from driving into the waterway as the bridge opens. Double leaf bascules can provide this barrier on both sides of the navigation channel. By selective location of the rear break in the roadway joint of the leaf, the barrier function of the open leaf can be realized. Injury to vehicle occupants may occur when the partially opened leaf is struck, but occupants of vehicles that pass off the approaches of movable bridges into the waterway usually end up drowning.

The bascule bridge, particularly the double leaf bascule bridge, is the most readily accepted architecturally of any type of movable bridge. The typical double leaf bascule span, being a symmetrically opposed cantilever, can be readily and relatively honestly configured to resemble an arch bridge in configuration. Single leaf bascules have also been treated in this manner, with a generally positive effect but with less structural truth in an architectural sense. Vertical lift bridges can be tidied up and frills can be added to them, but the fact that they are large machines is difficult to disguise. Swing bridges can be aesthetically pleasing, unless they are of the through truss type, which most are.

The double leaf bascule bridge, by virtue of the fact that it has no need for structural integrity at the center of the navigation channel, provides the greatest clearance under the span at the midpoint of the navigation channel of any commonly used type of movable bridge. The bascule girders, even in a deck type structure, can be tapered down in depth until they are no deeper at the end of the leaf than the end floorbeam is required to be.

DISADVANTAGES OF BASCULE BRIDGES

Bascule bridges must resist wind loading to a greater extent than other common movable bridge types. The severe wind loading occurs only with the bridge in the open position, so that it is not combined with live load, and can be sustained at higher allowable stresses. The wind loading requires bascule bridge machinery to be much more robust than it otherwise would have to be, and is a bigger part of the machinery design than for vertical lift or swing bridges.

Most double leaf bascule bridges, particularly those in which each leaf acts as a cantilever in supporting live load, have a severe weakness in their need for a shear lock to connect the opposing ends of the main girders of the two leaves where they meet at the center of the navigation channel. These locks are prone to wear as they accumulate dirt, which contaminates the lubricant, and are subject to severe shocks when heavy traffic passes over the bridge. As wear increases, the shocks increase, increasing the rate of wear, until the center locks reach a state of almost complete uselessness.

Cantilevered double leaf bascule bridges are very dependent for stability on excellent alignment of the leaves, proper seating on their live load shoes, engagement of their live load anchors, if present, and depend on the two leaves being mated by their center locks. Differential distortion of the leaves, such as due to temperature differences, or wear on these components, results in poor engagement of these components and poor seating of the bridge. If left uncorrected, the condition develops to the extent that the bridge leaves bounce noticeably when heavier traffic, such as buses, pass over the movable span.

Simple trunnion and some rolling lift bascule bridges, when built at low elevations above the water, must have watertight counterweight pits, which are expensive to build and difficult to maintain.

ADVANTAGES OF VERTICAL LIFT BRIDGES

Vertical lift bridges have the advantage of being made to almost any length required. They are limited only to the maximum length of a simple span bridge. Several examples of vertical lift bridges exist in lengths in excess of 500 feet. For very long movable spans that do not have to lift very high to clear marine traffic, the vertical lift bridge is likely to be less expensive than the bascule or swing bridge.

The vertical lift bridge acts as a simple span for both live load and dead load. Thus as long as it is reasonably well balanced it will seat stably on its bearings and not move vertically under live load. Because of this the vertical lift is simpler to design and construct than bascule and swing bridges.

The vertical lift span can be built at any desired width, with as many trusses or main girders as needed, without difficulty, as the counterweights can be connected as required to balance the bridge, and the resulting sheaves and ropes can be connected as required. This is in contrast to multiple main girder bascule bridges, which require very careful alignment to avoid interference when operating; this is difficult to achieve. Vertical lifts compare even more favorably to wide swing bridges which require wide center piers in the navigation channel, and become impossible to fit in when they become too wide.

Double deck vertical lift bridges can be provided with a lower deck that lifts independently of the upper one, so that land traffic need only be partially disrupted to clear smaller vessels, as the upper deck can be left in place, open to roadway traffic, while the lower deck is lifted a few feet to allow smaller vessels to pass under it. The entire bridge, including the upper deck, is lifted only to allow very large vessels to pass through the navigation channel.

DISADVANTAGES OF VERTICAL LIFT BRIDGES

The key disadvantage of a vertical lift is that the overhead clearance, when open, is limited, but this has very seldom resulted in an accident. Most accidents involving collisions between vertical lift bridges and navigation vessels have occurred as a result of the vessel striking a partially opened bridge. This may occur due to a vessel having entered the navigation channel prematurely, before the bridge was fully raised, or due to a bridge beginning to lower in front of an approaching vessel. Rarely has a vertical lift bridge been lowered on top of a vessel in the channel, but this has been known to happen. The vertical lift bridge is the only common type of movable bridge that always obstructs the center of the navigation channel, even when fully opened. Serious accidents have occurred due to the bridge being struck by a vessel when nearly or partially opened. This occurred at Portsmouth, VA when the ship departed the scene with the vertical lift span resting on it. On the Chesapeake and Delaware Canal, a vertical lift span began lowering in the fog in front of a ship, causing damage that tied up the waterway and closed the bridge to traffic for a considerable period of time.

The vertical lift bridge requires expensive towers to support the bridge in the open position. Due to machinery restraints and the counterweight rope connections, these towers must be as much as 60 feet taller than the navigation clearance required. As the maximum navigation clearance required increases, the height of the towers and their resultant cost also increases, at a non-linear rate due to the rapid increase in wind moments, with the span in the fully opened position, that must be resisted as the height increases.

Aesthetically, the vertical lift bridge has about the worst overall record of any type of movable bridge, although there have been some relatively attractive vertical lift bridges built, such as the span over the Hudson River between Troy and Green Island, NY, the pedestrian bridge across the East River in New York City, and several Milwaukee River bridges. The chief advantage of the vertical lift span, its capability of long spans, forces it to usually take the truss form, which is a visual handicap. Several attempts have been made to rectify this aesthetic deficiency while retaining the truss form for longer spans, such as the Marine Parkway Bridge in New York City, the Schuyler Heim Bridge in Los Angeles, and others.

More recently, the Danziger Bridge in New Orleans used the deck girder for a longer vertical lift span, which was artistically pleasing but not particularly efficient structurally. Most aesthetes, however, when they think of vertical lift bridges, think of the lower Newark Bay bridge of the Central Railroad of New Jersey between Bayonne and Elizabeth, NJ (since demolished), or the "trio over the Hackensack River, Jersey City", which are referred to as just plain "ugly". When the producers of the movie "The Blues Brothers" wanted to capture the depressing squalor of South Chicago, they used the four vertical lift spans over the Calumet River as a backdrop. True, there was a heel trunnion bascule in the picture, but it was grossly overshadowed by the vertical lift bridges.

Vertical lift bridges require more maintenance than other common types of movable bridges, due to the presence of wire counterweight ropes, and for some bridges, wire operating ropes. These ropes must be periodically treated with preservative material to avoid rapid deterioration due to corrosion.

ADVANTAGES OF SWING BRIDGES

Symmetrical swing bridges can provide two movable spans in one moving structure. On some waterways, two separate channels can be an advantage in keeping the waterway traffic orderly. This was marked advantage at many locations in prior times, with a multitude of small commercial craft so that a bridge had to be opened often. Upstream bound traffic could pass on one side of the center pier, and downstream traffic could pass on the other.

At locations where long approach spans are required, the second balanced arm of the symmetrical swing may substitute for a fixed approach span. The second arm can reach across navigable water or non-navigable water. In some cases the second arm reaches across dry land, such as at the Canso Causeway bridge in Nova Scotia, eliminating the need for an approach span or fill. The question of whether the second arm is more economical than building a counterweight and finding another means to bridge the approach span gap is a matter of labor and material costs. The correct solution depends on time and place.

Swing bridges do not lift to open, so that they are less noticeable in operation. They also can be and usually are, symmetrical, so that providing a pleasing appearance is not as difficult as it is with some other common types of movable bridges. Thus swing bridges are often selected at locations where a movable bridge is necessary but where aesthetics play an important part in design.

The swing bridge does not lift up in the air to open, and the symmetrical swing bridge normally has no massive counterweight placing a large concentrated load on the piers. The swing bridge can thus be built with less massive piers than a bascule or vertical lift bridge.

The low profile of a swing bridge can allow it to fit under a high level bridge at the same location, whether the swing bridge is open or closed. The Center Street asymmetrical swing bridge in Cleveland, OH is in this situation. This was also, at least in part, the reason for building the concrete double swing bridge in Seattle a few years ago.

DISADVANTAGES OF SWING BRIDGES

Swing bridges are assumed by some designers to be least affected in operation by winds of any movable bridge. Unfortunately, this is something of a myth, as substantial rotational wind moments can be developed on a swing span. Swing bridges are sometimes constructed at locations that experience high winds, under the assumption that the swing bridge will be less susceptible to damage due to its low profile and typically symmetrical construction. The leading edge of a swing span, opening into the wind, produces a greater resistance to wind than the trailing edge. Apparent symmetry does not translate to zero wind resistance for opening and closing the bridge.

As a result, the wind resists rotation of the swing bridge as long as the leading edge is moving upwind, but if the bridge swings far enough to bring the longitudinal axis of the swing span parallel to the flow of wind, and then continues to rotate, the net wind moment shifts from resisting operation of the bridge to assisting it. If the wind is strong enough to produce a rotational moment greater than the sum of the other bridge resistances, the rotating span will overhaul and a shock load will be experienced by the drive machinery, as the backlash is transferred from one side of the gear teeth to the other. If the difference in moments is great enough, the shock can cause a machinery failure. This type of failure could cause a break in the drive train, resulting in a freely rotating bridge with no effective drive or control system. The swing bridge, in practice, usually has a lower allowable wind speed for operation than bascule or vertical lift spans.

The swing bridge requires much more machinery than a bascule or vertical lift bridge. The swing bridge does not automatically align itself when closing, and requires an active centering device to quickly align it in the closed position, something not required for bascule bridges or vertical lift bridges. The typical swing bridge also requires end lifting devices to hold up the ends of the bridge when carrying traffic. The end lifts must develop a positive dead load reaction as required by AASHTO and AREMA, so that deflection of the opposite arm of the swing span, due to live load, will not cause the end of the span to lift off its supports.

Swing bridges normally are placed so that their pivot pier is in the center of the navigation channel. This may be convenient for providing separate directional channels for two-way marine traffic, but it puts the bridge in a vulnerable position for ship impact. It is not unusual for a swing bridge to be struck many times over its life by vessels having difficulty navigating the channel. The swing bridge in such a position is normally protected by an expensive fender system, to reduce the damage from such impacts. The swing bridge with its additional piers and fendering becomes a greater obstruction to water flow as well as navigational flow, so that undesirable scouring can occur in one part of the river bed, while undesirable silting may occur in another.

Swing bridges require a lateral clearance equal to the length of the swing span leaf for operation. A great deal of space is wasted where parallel railroads or highways would be crossing a waterway in a congested area, in allowing each swing bridge space to open. In the event that expansion of the width of the roadway or railroad is required, a swing bridge must be replaced with another bridge, while a vertical lift or bascule bridge could simply have another similar bridge built alongside it in close proximity.

Swing railroad bridges are the only type of movable bridge in common use that require expensive and fragile mechanical rail disconnect devices to allow the bridge to swing open and closed, and provide a properly aligned surface for carrying traffic. Serious accidents have occurred because this mechanism has failed in service, and the failure was not detected by the safety devices in place on the bridge. This area has been a source of considerable inventive activity since railroad trains began operating at higher speeds a century or so ago, and completely satisfactory solutions have not yet been developed. Many types of "miter rails", as they are called, have been developed to separate the railway rails so that the bridge can swing open, and are in use, but none have been proven fully foolproof, maintenance free, and durable.

As the swing bridge has many more moving parts than the typical bascule or vertical lift span, it requires more maintenance than those types. In times of tight labor markets, this is a serious drawback to selection of a swing bridge. The swing bridge, because of the fact that it has three or more major mechanical functions to go through in opening or closing, takes longer to operate than a vertical lift or bascule span. The swing bridge also generally takes longer to move from closed to open and back than a bascule or vertical lift span of the same size. For these reasons, swing bridges have been considered to be functionally obsolete for some time, many decades, in fact. There are still occasional applications where these disadvantages are outweighed by the particular applicability of the swing bridge for certain situations. There is also some preference for the swing bridge for aesthetic reasons, so that the occasional swing span will continue to be built. In the past 20 years, new highway swing spans have been built at Yorktown, VA and Seattle WA, and new railroad swing bridges have been built at Atlantic City NJ, and at Mystic and New London, CT.

ADVANTAGES/DISADVANTAGES OF ODD TYPES OF MOVABLE BRIDGES

The following types of bridges are generally considered obsolete, although there have been some new examples built in recent times, due to special circumstances.

Retractile

The retractile bridge is usually supported on some kind of roller system, and rides on a set of horizontal tracks. The retractile bridge usually is constructed so that the deck of the movable span is at the same elevation as the deck on the approaches. The tracks supporting the retracting span are at some angle, close to 45 degrees, from the longitudinal bridge axis. The bridge opens by riding back on its tracks until the channel is clear. Some retractile bridges were built or proposed back in the late 19th or early 20th century, which retracted straight back along the bridge axis, but these required an auxiliary device to shift the roadway deck, usually upwards, before retracting. This type is only known to exist on pontoon type retractile bridges today. The pontoon retractile bridge is a floating span that retracts parallel to an approach span when opened to clear the navigation channel for a vessel. This type was proposed and used for some railroad bridges across the Mississippi River in the 19th century. The patent drawing for a pontoon railroad draw bridge built between Prairie Du Chien, WI and McGregor, IA indicated optional swing and retractile channel span openings for navigation. The pontoon bridge built there in 1874 was rebuilt in the early 20th century and lasted until 1961. There were at one time 3 railroad draw pontoon spans on the Mississippi River, and at least one on the Missouri River. They were all of wooden construction, the longest had a 365 foot span.

The Hood Canal Bridge, completed in 1961 on Puget Sound, is a larger example of this type, with a 600-foot draw opening. This bridge has reinforced concrete retractile spans, a deviation in the roadway for the east approach, and a hydraulically operated lift deck on the west approach span that raises to clear the retracting pontoon. The newest example of the type is the Ford Island Bridge at Pearl Harbor, Hawaii. This type of bridge is advantageous at locations where piers would be very expensive due to deep water, but vulnerability to storm damage is a serious problem. One of the Hood Canal draw pontoons sank in a storm, and had to be replaced; this has also occurred at other pontoon bridges of similar construction. The draw pontoons are high maintenance structures, and complicated and time consuming to operate.

Pontoon Swing

The pontoon swing bridge is a floating span which rotates in a horizontal plane to provide an opening in the bridge for navigation. These are usually rather small bridges, and most examples remaining in use today are located in the bayou country of Louisiana.

Removable Spans

There are several "movable" bridges around the country that are simple spans which are fitted for temporary removal. These may be as small as 20 foot span length or less, but some of these are quite large, and would require a rather heavy crane or some other substantial equipment to move out of the way. Due to the difficulty in opening these bridges, they are only practical for spans which seldom open for navigation, or for which the regulations allow for substantial advance notice, weeks or months, to the bridge owner prior to requiring an opening. Some of these installations may have been intended to satisfy the letter of the navigation regulations, without having to go to the expense of building a movable bridge.

Many of these removable spans are quite small, but the average length is probably in the 30 to 50 foot range. One particular example of a larger removable span installation is the 103-foot long single-track railroad span with 21 feet vertical clearance above the level of the Wisconsin River just upstream from the Mississippi. The bridge was built in 1908 by the Chicago, Burlington & Quincy Railroad as part of their Chicago to St Paul extension. It would require a great deal of effort and expense to open this bridge for navigation, as it is in a remote and relatively inaccessible location, and it probably has never been opened. It was apparently originally intended to have a swing bridge at this location, as the center pier is configured for a swing bridge, but the removable span seems to have been used as a temporary expedient that became permanent.

APPLICATION OF TYPES HIGHWAY

AASHTO, in their Standard Specifications for Movable Highway Bridges, states:

> "Movable bridges shall be of the following types:
> Swing Bridges
> Bascule Bridges
> Vertical Lift Bridges"

No preference is indicated by AASHTO between these types. AASHTO makes no comment about the specific desirability or undesirability of double leaf bascules.

Quick Acting - Double Leaf Bascule, Particularly Scherzer Type Rolling Lift

Many movable bridges must open for small vessels hundreds of times a day during certain seasons, while keeping the roadway open to highway traffic as much as possible. This situation usually arises where a small island in a resort area is popular for visitors coming by both boat and automobile, and the island is connected to the mainland by a movable bridge. The double leaf bascule bridge has the advantage of being the quickest type of movable bridge to clear the center of the navigation channel when opening for a vessel. This is due to the fact that the toes of the two leaves move apart as the bridge is raised, so that vertical clearance at the center of the navigation channel becomes unlimited almost as soon as the bridge begins to open. Smaller vessels frequently take advantage of this, and start to move through the draw opening as soon as the leaves begin to separate. The Scherzer type of rolling lift bridge is especially advantageous in this regard, as the entire bridge moves back away from the navigation channel as the bridge rotates open. The Scherzer firm made great use of this facet of their bridge type's operation in their advertising in the early 20th century. The amount that the Scherzer bridge leaves move back is a function of the diameter of the rolling lift treads, the larger the diameter, the farther the bridge moves back as it opens. The State of Wisconsin has made advantageous use of this fact at several locations in the northern part of the state. Both bridges connecting the part of Door County with the rest of the state, across the Sturgeon Bay Ship Canal, are double leaf Scherzer type bascules. This type is also used for one of the newest bridges in the area, the Main Street Bridge in Green Bay.

The Rall type rolling lift bridge also moves away from the navigation channel as it opens, but usually to a lesser degree, dependent on the dimensions of the linkage connecting the lift span to the pier. This type of bascule was used for the Stone Harbor Bridge over Great Channel, on the southern Atlantic coast of New Jersey. To some extent the advantage of a rolling lift bridge can be negated by the application of safety appliances, such as barrier gates, on a highway bridge, so that the bridge opening takes a long time anyway. It is also of little advantage when the bridge must open for a long period of time for a larger vessel.

Stability - Single Leaf Bascule and Vertical Lift

The vertical lift bridge and the single leaf bascule bridge require the fewest mechanical components to support live load. The center shear locks of double leaf bascule bridges are very difficult to maintain with the desired snug fit. They tend to loosen up over time, with the result that the leaves bounce when heavier live loads traverse the structure. The swing bridge has many components which must be kept in proper order for the bridge to safely carry traffic. The end lifts usually end up out of order, as it is difficult to maintain them so that they hold the ends at the proper elevation. Center wedges for center pivot swing bridges also tend to be poorly adjusted. These defects usually result in damage to main bridge supports, particularly when a center pivot type bearing is used.

The single leaf bascule bridge and the vertical lift span act as simple bridge spans in support of the live load, and have no need for span locks for stability in support of live loads. There is no machinery of any type for these bridges upon which the live load is dependent for its support, except for trunnions or rolling lift tracks for the single leaf bascule. Any live load instability of these bridge types is usually found to result from improper balancing, so that the bridge does not seat firmly, or deterioration of the live load supports. Large single leaf bascule spans for highway use have been constructed recently, such as the Erasmus Bridge in Rotterdam, Netherlands, with a 59 meter span and 33 meter width.

Very Long Span - Vertical Lift

The vertical lift bridge can be built to any span length for which a simple truss span can be built. The longest vertical lift spans known to date are in excess of 500 feet, but less than 600 feet. Most of these longest spans are railroad bridges, such as the Buzzards Bay Canal bridge on Cape Cod, MA, and the Arthur Kill bridge between New Jersey and New York. There are a few highway vertical lift bridges of length in excess of 500 feet. Some of these bridges are tower drive spans, such as the 540 foot long Marine Parkway Bridge in New York, but the Burlington Bristol Bridge is a Waddell type span drive bridge. All of the long span vertical lift bridges, whether built for railroad or for highway use, are truss type.

A single leaf bascule span could be built to a length nearly equal to that of a vertical lift bridge, but severe operating difficulties develop, as the bridge is lifted and balanced from only one end, magnifying the forces involved tremendously, as the entire leaf is cantilevered for dead load. The vertical lift bridge, being lifted by essentially equal forces at each corner, is lifted and balanced by forces in a 1:1 ratio, which are not multiplied by the leverage ratio inherent in a bascule span. As the bascule bridge is lifted, its machinery is subject to increasing wind moments as it reaches the fully opened position. The vertical lift bridge machinery experiences no such moments, but must simply withstand the direct wind forces. The vertical lift towers and the bascule span when open must withstand the wind forces, which tend to be higher at higher elevations.

Very High Wind, i.e., Hurricane Locations - Vertical Lift

The vertical lift bridge and the swing bridge do not project angularly into the air as they open, so the effect of high winds upon them is reduced as compared to bascule bridges. The swing bridge does experience variable wind moments as it opens, however, so that operation can be difficult in a wind storm. Swing bridges located in high wind areas must be adequately powered, with strong drive trains, to avoid breakdown when operated in such winds. The vertical lift bridge machinery does not experience wind moments in operation, as the wind resistance translates directly to operating force. There is no change in the wind force on the bridge, nor is there a change in the resultant wind load on the machinery, as long as the wind stays constant. The towers of vertical lift bridges are subject to wind moments in proportion to their height, and the vertical lift span as it opens produces increasingly large moments in the towers during high winds, which must be resisted by the towers and foundations. The towers and foundations must be designed for such loads when the bridge is built in an area subject to high winds, particularly if the bridge is normally left open, or opened in emergency situations such as hurricanes. Many railroad vertical lift bridges could be in one of these situations.

Safety of Highway Traffic - Double Leaf Bascule

Safety is here considered only with respect to exposure of the public to danger because of the fact that the bridge is a movable one, which is displaced to accommodate marine vessels. The double leaf bascule bridge can be designed to provide automatic barrier protection for highway traffic, to prevent automobiles from plunging into the water. By careful location of the pivot axes of the leaves, combined with a particular layout of the heel joints, each leaf of the partly opened bascule becomes an upward projecting ramp from its approach. The ramp becomes steeper as the bridge opens, so that it is impossible to climb when the bridge is fully raised. This is not an impact attenuating type barrier, however, and damage can result to a vehicle hitting a fully raised bridge. Survivability is generally conceded to be much higher in an impact with such an object than in plunging off a bridge into a waterway. Conversely, when the bridge just begins to open an automobile can pass onto the bridge and run off the toe of the partly lifted leaf. Many old television "cops and robbers" programs have scenes of just such an event occurring, staged on an actual bridge. An automobile piloted by a stunt driver leaps across the partially opened span from one side of the bridge to the other, and continues on its way. Some double leaf bascule bridges have not been designed with consideration for the safety of motorists approaching or impacting the open or partially opened bridge, with tragic consequences.

Unlimited Vertical Clearance – Bascule or Swing

At some locations it is a great advantage to have no concern about a too tall vessel striking the open bridge. In these cases a bridge that completely clears the waterway is necessary. The bascule bridge, single or double leaf, would usually be the most practical choice, but in some applications a swing bridge may be advantageous.

Poor Foundations, Poor or Unknown Soil Conditions - Swing

For a given size of movable bridge span, the swing bridge exerts much less force on the foundations than a bascule or vertical lift bridge. The swing bridge weighs less, because, at least in the symmetrical configuration, which is more common, it has no counterweight. It exerts less overturning moment on the foundations than a bascule or vertical lift span, because it does not project into the air, open or closed.

APPLICATION OF TYPES - RAILROAD

Durability

Railroad bridges are usually designed and built under the assumption that they will never be replaced. The rolling lift bridge is sure to wear out after a finite number of operations, and will eventually require either replacement or expensive major rehabilitation. A rolling lift bridge operating often in a harsh environment may require tread replacements every 20 years or less, and can develop fatal disintegration of its segmental and support girders if tread wear is allowed to continue too far. Many heel trunnion bridges have developed defects at their hinges, and while these bridges may operate satisfactorily with these defects for many decades, many owners have felt it was necessary to repair the defects to avoid a bridge failure. Some heel trunnion bascules have experienced structural steel fatigue cracking due to the fact that they open to a very large angle, resulting in high degrees of stress reversal in operation. The articulated counterweight bascule presents a threat of catastrophic failure, but there is no reason why a movable bridge of this type, if properly designed, conscientiously built, and scrupulously maintained, won't last indefinitely.

The vertical lift bridge almost always requires counterweight rope replacement after a period of time. There are examples of these ropes lasting as long as 70 years, but these are exceptional cases. Fifty years seems to be an optimistic expectation on the life of vertical lift bridge counterweight ropes. The operating ropes of a Waddell type vertical lift bridge do not last nearly as long, and replacement of these ropes should be considered a part of regular maintenance expense.

AREMA, in their Manual for Railway Engineering, Chapter 15, Part 6, Movable Bridges states:

> "Movable bridges preferably shall be of the following types:
> Swing
> Single leaf bascule
> Vertical lift"

No preference is indicated by AREMA, other than in their commentary, between these types.

Double leaf bascule bridges were once used fairly often as railroad bridges, but serious accidents have occurred due to failure of the center locks. One notable example was on the Soo Line bridge over one of the Soo Canals at Sault Ste Marie, MI. The center locks failed, causing a train to fall into the canal as the two bridge leaves separated.

When the design engineer selects a movable bridge type for a particular installation, he must be aware of the advantages and limitations of the different types movable bridges. At the same time, the designer must not ignore the shortcomings of the traditional types: The simple trunnion bascule requires a large vertical clearance under its counterweight to allow it to open. Many railroads cross waterways at low elevations, so that this type of bascule bridge may require a waterproof counterweight pit, expensive to build and difficult to maintain. Counterweight pits should always be avoided where possible, as they are a large capital and maintenance expense. If the bridge can be built at a sufficient elevation to allow the simple trunnion counterweight to clear the high water line with the bridge open, then this is a very satisfactory form of movable bridge.

In the old days when long, heavy freight trains were pulled by steam locomotives with limited tractive effort, uphill grades when crossing a navigable waterway were a serious operating handicap. These were avoided whenever possible, so that many railroad bridges cross waterways at very low elevations, sometimes with the lower parts of the superstructure lapped by the waves, or even submerged at high tide. With modern diesel-electric locomotives, much greater tractive effort is available, so that raising the elevation of a waterway crossing to the extent that a simple trunnion bascule bridge can be installed without a pit is frequently feasible.

The swing bridge, once the most common type of railroad movable bridge, after having been ignored as "obsolete" for several decades, has made a comeback as the shortcomings of other types have been revealed over the years. The utility of the swing bridge has also improved as fewer multiple track railroad bridges and more single-track bridges are built so that the swing bridge provides less of an obstacle to the navigation channel when opened. Increases in traffic can be handled by sophisticated signal systems so that the number of tracks on a line can be reduced at the bridge with little or no obstruction to traffic flow. The swing bridge has mechanical limitations, however, including the necessity of mechanically actuated miter rails at the track joints at the ends of the swing span, and very complicated machinery for end lifting and locking. This all requires competent maintenance attention for reliable operation. These limitations apply generally to all swing bridges except for very small bobtail types, including shear pole swings, and other special cases such as the concrete swing bridge.

The simple span load carrying capability and simplicity of design of the vertical lift bridge outweighs, for most designers, the limitations of rope life and the possibility of counterweight sheave shaft fatigue failure. It has become by far the preferred type of movable bridge for railroad applications in recent decades. The U.S. Coast Guard, when mandating movable bridge replacement over inland waterways under the Truman-Hobbs act, invariably specifies the vertical lift type for new movable bridges.

Short and Medium Spans - Single Leaf Bascules

This is generally the most desirable form of movable bridge. It has least cost, highest reliability, and greatest longevity. The span length limitation is not that great - spans of over 250 feet have been built, with 80 year old technology. There is no reason spans crossing 300 foot or wider navigation channels could not be built. The chief drawback is wind loading, which increases machinery loads and foundation forces as the square of the span length. For movable bridges of from 10 foot to 200 foot length, the single leaf bascule is most often the best choice. This type of bridge is uncomplicated and durable. This length of span does not result in excessive wind related stresses in the open position, and a truss type span can easily be designed with sufficient rigidity to support the heaviest traffic on a longer span. If the base of rail is at a sufficient elevation above high water, the simple trunnion type can be used, but if the bridge is at a low elevation, the heel trunnion type has can be employed. The majority of larger railroad bascules in this situation have been heel trunnion type, and many are in successful operation today, with not a few in excess of 50 years of age. There are also many rolling lift type bascule bridges in railroad service in the 200-foot size range, although this type has been most frequently used for shorter spans of 100 feet or less.

Very Long Spans - Vertical Lifts

For movable spans of extreme length, the vertical lift span is about the only practical choice. Several spans of over 250 foot clear span have been installed to replace swing bridges, replacing two short width navigation spans separated by a pivot pier in the middle by one long span without obstruction. This has been mostly to the advantage of navigation interests, easing waterway congestion and making navigation easier through the draw. The U S Coast Guard usually mandates a 300 foot clear channel for movable bridge alterations under the Truman Hobbs Act, and has preferred vertical lift spans. Several vertical lift spans have been built of 500-foot length or slightly over. A vertical lift span could presumably be built in length equal to the longest simple truss non movable spans, up to such as the CB&Q –L&N - IC RR bridge over the Ohio River at Metropolis, IL, a 700 foot eyebar truss type built in 1917.

Short and Medium Spans with Truss Approach spans - Swings are Acceptable

When navigation channel span length is not great, say up to 150 feet, and one or more sizeable approach spans are required to clear the edges of the waterway or to cross a valley alongside the waterway, swing spans are not impractical. Both sides of the center pivot pier can be used as navigation channels if desirable. In many cases, only one navigation channel is necessary or possible. Many asymmetrical or bobtail swing spans have been built in such situations, with the short arm of the swing sometimes extending over dry land.

Unlimited Vertical Clearance – Bascule or Swing

At some locations it is a great advantage to have no concern about a vessel striking the open bridge. In these cases a bridge that completely clears the waterway is necessary. The bascule bridge would usually be the most practical choice, but in some applications a swing bridge may be advantageous.

In Egypt, the railroad bridge across the Suez Canal was destroyed in one of the Arab-Israeli wars. Ships from all around the world, to the limit of the size capacity of the canal, pass through the canal, so it was necessary to provide a bridge that would minimize the likelihood of a collision. The structure was a double swing bridge, with a very wide clearance. It was decided to replace the bridge with a new structure that was virtually identical to the previous one, which will be the third double swing span on the site. Double leaf railroad bridges have a difficulty in providing moment continuity at the juncture of the two movable leaves, but this problem was surmounted in a satisfactory fashion. The movable bridge was a much less expensive option than a tunnel or high level fixed bridge. The relative infrequency of train operations prevents the bridge from being an obstacle to navigation.

High Wind, i.e., Hurricane Locations - Vertical Lift

The bascule bridge is highly sensitive to wind loading, and resistance to high winds when operating adds proportionately more to the power requirements for a bascule bridge than for a swing or vertical lift bridge. It may be just as well to go ahead and build a bascule bridge so that its many advantages can be employed, and provide sufficient driving and braking power to withstand the wind loads expected. In many cases, however, a vertical lift or swing bridge is selected to reduce the effect of wind loading on the design. The Louisville & Nashville Railroad constructed new swing bridges along the coast of the Gulf of Mexico in the 1960's and 1970's, ostensibly to lower the hurricane hazard. A new span was installed near Gulfport MS in 1967 and at Biloxi MS in 1978. This has sometimes failed of the desired result, as the new swing bridge at Biloxi was blown off its bearings by Hurricane Bob.

A properly designed swing or vertical lift bridge, taking into consideration the wind loads expected at the site, will likely be less expensive over the long term than a bascule bridge. This is especially likely to be the case for a railroad bridge, on a lightly traveled line, which is normally left in the open position and only lowered for oncoming train traffic. Some bascule bridges in this situation are equipped with special locking devices that transfer the wind moments directly from the open bascule leaf to the fixed superstructure or pier, bypassing the bridge drive machinery.