HEAVY MOVABLE STRUCTURES, INC.

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WOODROW WILSON BRIDGE BASCULE SPAN

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OWNERSHIP/PUBLIC USE and MANAGEMENT

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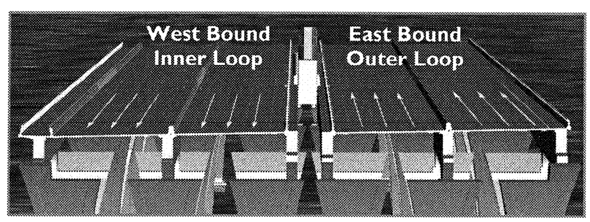
ABSTRACT: A signature crossing over the Potomac River has been designed to replace the existing Woodrow Wilson Bridge on the Capitol Beltway. Consisting of 8 bascule leaves, carrying 12 lanes of traffic, and weighing 34 million pounds, the bascule span of the replacement structure will be the largest movable bridge in the country and possibly the world once its construction has been completed. The new bascule span has been designed to meet unique criteria. Interdisciplinary features of this design are discussed in this paper.

Introduction

Upon completion of construction, the new Woodrow Wilson Bridge will be one of the signature crossings on the East Coast. The new structure will replace the existing 6000-foot long bridge as part of the $2.44 billion, 7 ½ mile long Capitol Beltway Interchange Project.

Replacement of the existing crossing was determined to be the only practical solution to the problems directly and indirectly related to the ever-growing volume of traffic. In addition to the heavy commuter traffic that uses the bridge to travel to and from the downtown Washington area daily, the interstate system funnels almost all freight through this corridor. In total, the bridge carries nearly 200,000 vehicles per day, including a high percentage of truck traffic. When it was built in 1961, the bridge was designed for a volume of 75,000 vehicles per day. The result of this excess volume has been intolerable congestion, and significant structural deficiencies and operational problems that have been in constant need of address over the last 20 years.

Hardesty & Hanover's 1994 report on the condition of the existing bridge eventually led to the 1998 design competition for a signature replacement structure. The competition was won by the Parson's Transportation Group (PTG), whose design utilized an ingenious pier and span model and satisfied the reviewers' desire for an arch shape without detrimental arch forces on the foundations.



RENDERING: General Roadway Configuration of New Bridge

Similar to the existing structure, the new Woodrow Wilson Bridge is configured as two separate roadways, the "Inner Loop" that goes south and west to Virginia and the "Outer Loop" that goes north and east to Maryland. Each loop is an independent structure. The movable portion of the bridge will be a double leaf bascule, with channel dimensions established as 175-foot horizontal clearance, 70-foot minimum vertical clearance in the span-down position, and 135-foot vertical clearance when the span is raised. As a result of the 20 foot increase in vertical clearance over the existing bridge with the span in the down position, the number of required bridge openings per year will be reduced from 240 to 65 once the new structure is built.

The new bridge will be significantly larger and more aesthetic than the existing structure. The existing bridge carries three lanes of traffic in each direction, is 85 feet wide, and is comprised of two double leaf bascule spans, for a total of four leaves. The new bridge is to carry six lanes of traffic in each direction and will consist of four side-by-side double leaf bascule spans, for a total of 8 leaves. The total width of the bridge will be 249 feet, including a 15-foot gap between the two adjacent loop structures. At these dimensions, 34 million pounds of structure will move to clear a vessel through the channel during each opening, possibly making this bascule bridge the world's largest movable span.

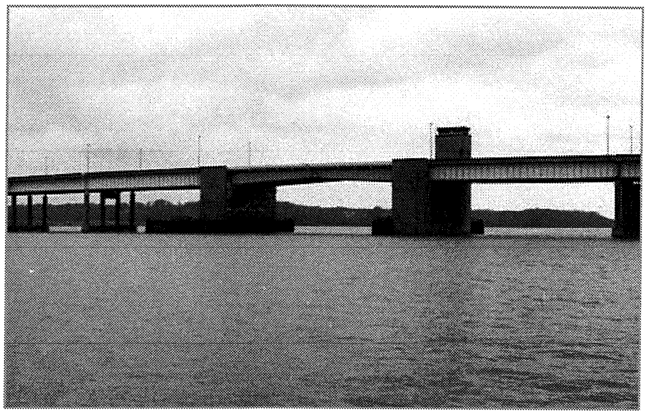
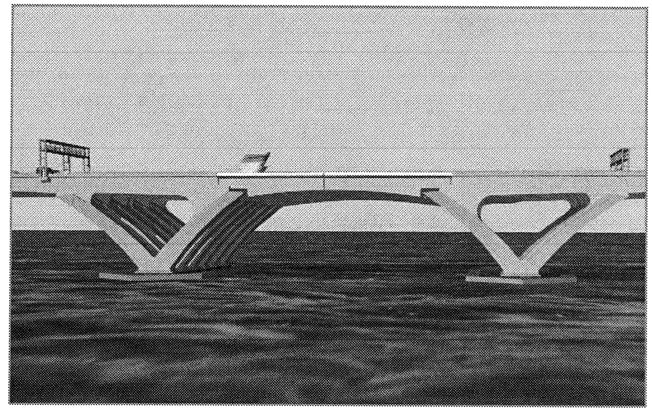


PHOTO: North Elevation of the Existing Bascule Span



RENDERING: South Elevation of the New Bascule Span

The design of the new Woodrow Wilson Bridge required an extensive team effort, involving many organizations. The Sponsoring Agencies of the project are the Federal Highway Administration, the Maryland Department of Transportation State Highway Administration, the Virginia Department of Transportation, and the District of Columbia Department of Public Works. The General Engineering Consultant (GEC) for the project is a joint effort of Parsons Brinkerhoff, URS Greiner, and Rummel, Klepper, & Kahl, and the Prime Design Consultant is PTG.

Hardesty & Hanover was added to the design team to provide movable bridge expertise. Our responsibilities include designing the bascule span superstructure, certain mechanical systems, and the movable bridge electrical control system, as well as assisting in the overall coordination of movable bridge aspects of the project. Other members of the bascule span design team include PTG (design of bascule piers, operating machinery, and power distribution, and development of general span parameters); Cox, Graae, and Spack (architects for the operator's tower); Athavale, Lystad & Associates (structural design of the operator's tower and bridge drainage system); and Sidhu Associates (HVAC design for the operator's tower and span access lighting).

At present, the design of the new bascule span and bascule piers is complete. The contract for the construction of the bascule portion of the project has been advertised, with a bid date set for November of this year. The start of construction is scheduled for 2003. Construction of the foundations for the entire new bridge began in 2001 as a separate contract. Completion of construction for the new bridge in its entirety is scheduled for 2008.

After a brief discussion of the site and bridge history, this paper describes details of design for structural, mechanical, and electrical aspects of the new Woodrow Wilson Bridge bascule span; unique features required to accommodate future rail transit and roadway configuration; the bridge's significant operational and power source redundancy; and various other accommodations to meet the unique aspects of the signature aesthetics.

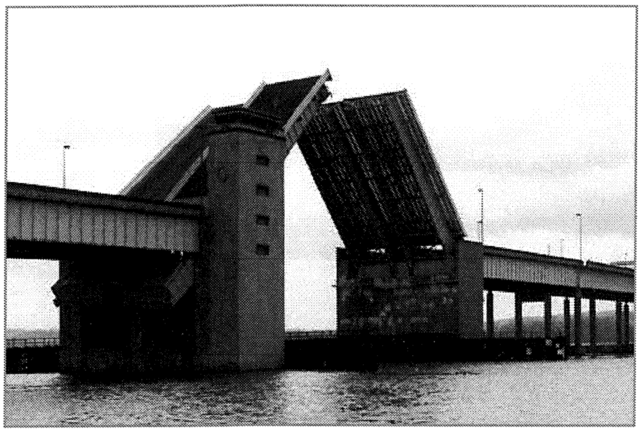
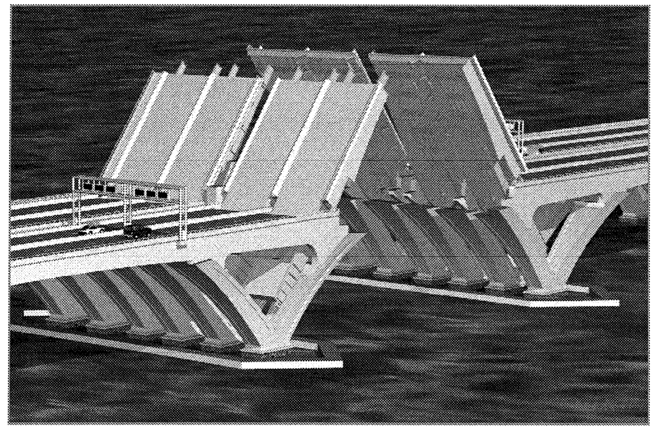


PHOTO: South Elevation of Existing Bascule Span at Opening



RENDERING: South Elevation of New Bascule Span at Opening

Site and Bridge History

As noted, the project site is the Capitol Beltway over the Potomac River in Alexandria, Virginia. The Potomac spreads to almost one mile wide at this point, about three miles south of the Capitol. The east side, along the Maryland shore, is very shallow. For roughly two-thirds of the crossing distance the river is barely deep enough for even shallow draft vessels to navigate. The movable span is located above the natural channel, just off the west shore on the Virginia side of the river. This places the bascule in the District of Columbia, making it the only Federally-owned bridge on the interstate system. It has been operated and maintained by the DCDPW since it's construction.

Built in 1961, the bridge originally had 4 lanes of traffic plus shoulders. In response to rapidly increasing traffic and significant structural deficiencies brought on by the traffic volume, the bridge was modified in the early 1980's. An additional lane of traffic was squeezed onto the bridge, resulting in three lanes of traffic for each direction of travel. In addition, new approach roadway decks and a new grating was installed on the bascule. The bridge presently remains configured this way.

Maintaining the existing bridge has been a responsibility of Hardesty & Hanover for more than a decade. Our involvement with the project started in late 1989, as continued operational problems with the bridge were becoming extremely troublesome to traffic flow. The span was frequently experiencing lock system and general electrical failures that typically caused miles of traffic backup and delays. To address these issues, we designed four sequenced rehabilitations to keep the bridge in service at a reduced level of maintenance. Along with the Sponsoring Agencies, we conducted a 4-year long process of evaluation, testing, analysis, and study, and determined that bridge replacement was the only practical solution to the traffic and operational problems plaguing the bridge. As previously mentioned, our report led to the design competition for the replacement structure.

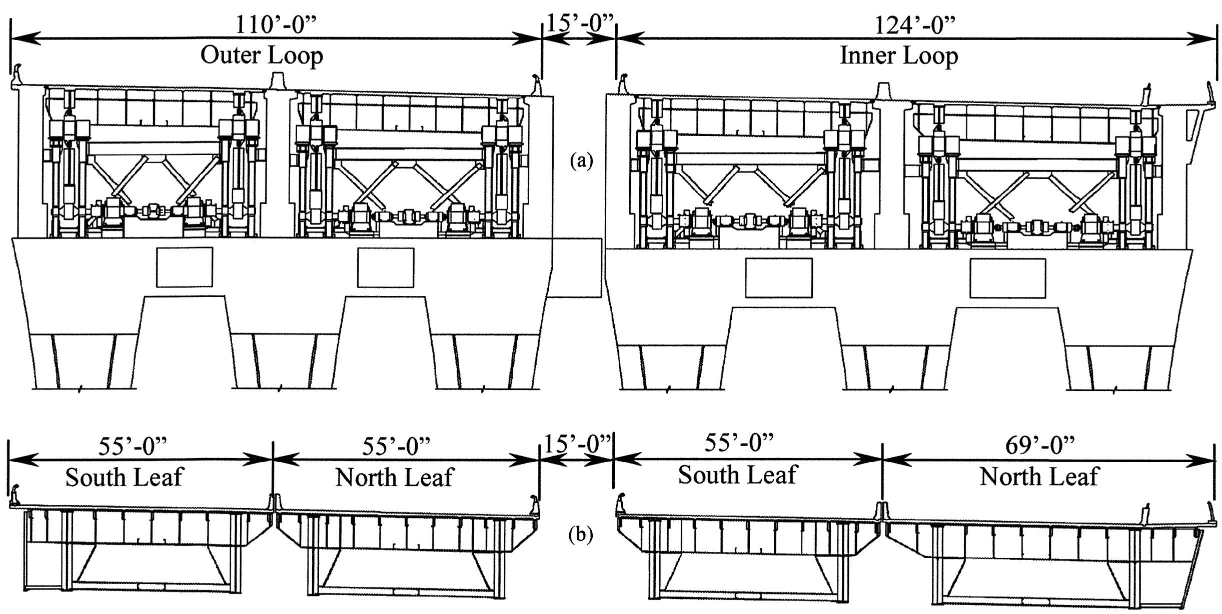
Bascule Span General Configuration

At 270 feet between trunnions and 249 feet wide, the new Woodrow Wilson Bascule Span will certainly be a very large bascule span. This substantial width drove many of the decisions made in developing the transverse section of the span. If a four-leaf configuration similar to the existing structure were to be maintained, each span would require floorbeams of nearly 100 feet across. In addition, considerable mechanical and electrical equipment would be required to provide the power to move that much structure while meeting the AASHTO design criteria. It was decided that each loop of the bridge is to consist of two parallel double-leaf bascule spans. This is illustrated in Figure 1. With this configuration, the bridge will have 4 leaves across or 8 leaves total, and the floorsystem and mechanical and electrical system designs are kept economical.

The leaf arrangement chosen also increases options for future rehabilitations. By not connecting adjacent (side-by-side) leaves together, and providing separate machinery and the ability to operate each leaf independently, any one of the leaves can be taken out of service if required for maintenance or repairs while maintaining a minimum of three lanes of traffic in each direction.

Given the critical nature of the bridge and having knowledge of the deficiencies of the existing structure, the goal of the designers was to develop a bascule span that would be durable under the extremely heavy traffic volumes, operationally reliable, maintainable, and constructable knowing the importance of initial structural and mechanical alignments to long-term performance of the bridge. To accomplish this, the design utilizes historically proven structural, mechanical, and electrical configurations where possible, while incorporating several unique features and maintaining the signature aesthetics of the bridge.

The bascule span will be supported on bascule piers that are to be cast-in-place post-tensioned structures comprised of compression rib elements tied together with tension tie struts. Portions of the bascule piers are shown in Figures 1 and 2. The shape and aesthetic nature of these piers is evident in renderings appearing earlier in this paper. Three ribs will make up each bascule pier, and between each rib will be a large transverse concrete beam at both the front and rear. On the rear transverse beam, the pier will house the electrical equipment including the transformers, generators for back-up power, electrical span control equipment, and other miscellaneous electrical equipment. The rear transverse beam will also support the approach span girders. On the front transverse beam, the bascule span trunnion towers will be supported, as will the mechanical operating equipment. This beam is shown in Figures 1 and 2.



The designed bascule span is a simple trunnion Chicago-type bascule. The front transverse beams of the piers described above will support the forward live load bearings at each bascule girder. A fixed deck beam of the bascule pier will serve as the rear live load anchor. Other design features of the bascule include a composite lightweight deck, fully counterweighted leaves, shear and moment-resisting span locks, and tail locks. The average weight of each leaf will be roughly four and a half million pounds. Subsequent text of this paper describes several of these noted features in further detail.

Other features of the new bridge added complexity to the design and details of the bascule. The span, in fact the entire bridge, is to be superelevated across its width, with the lower side at the Inner Loop north gutter line and the high side at the Outer Loop south gutter line. This is apparent in Figure 1. Also, the bascule span was designed for dual load requirements. In addition to each leaf being designed for three lanes of HS25 vehicular traffic, the inboard leaves of both the Inner and Outer Loop were designed to carry the light rail system that serves the Washington DC area simultaneously with vehicular traffic. These issues are among those discussed later.

Structural System

Steel Floorsystem

All bascule leaves of the new span are designed similarly in terms of configuration, with variations dependent upon lane geometry, shoulder widths, future rail locations, and the bikeway that is located on the Inner Loop, North Leaves only. To meet the goal defined above, it was decided that the floorsystem framing and detailing should be kept as simple as possible. The designed floorsystem has a conventional arrangement, with each leaf consisting of two bascule girders that support floorbeams and stringers. In

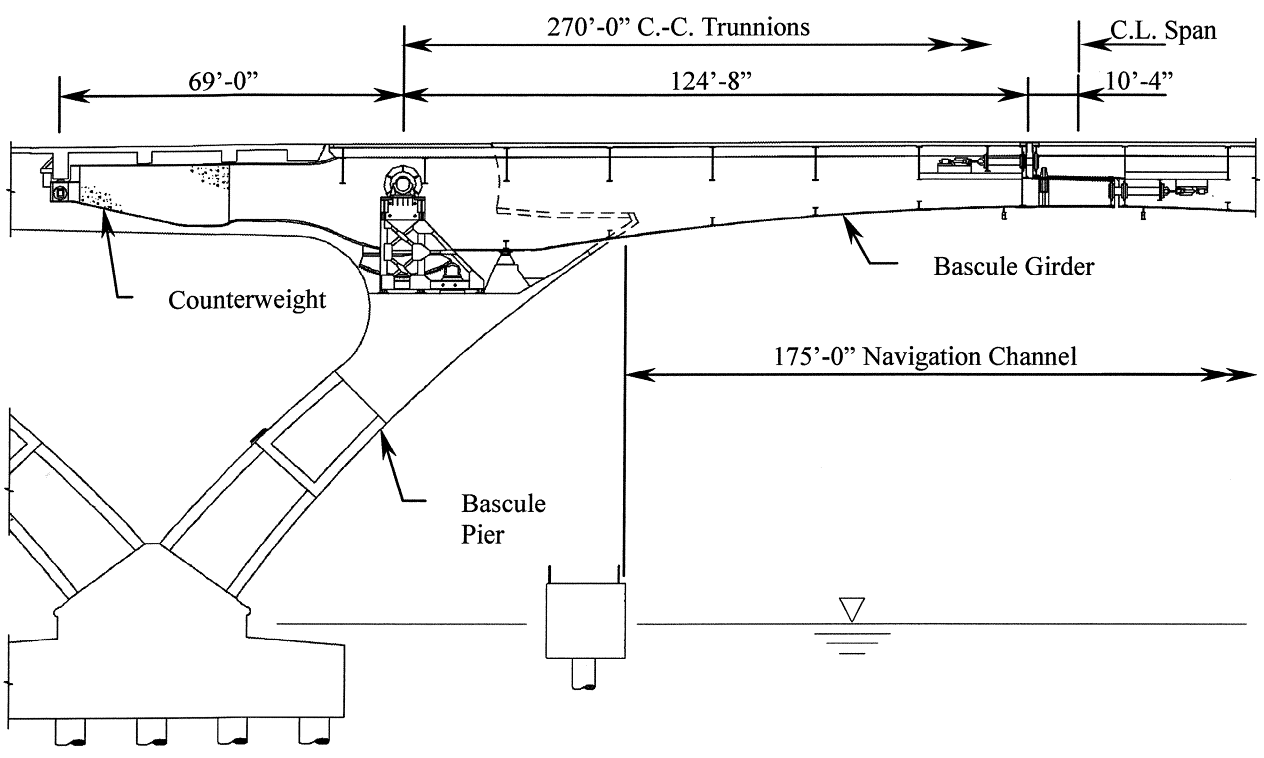


FIGURE 2: Longitudinal Section through the New Bascule Span and Bascule Pier.

the design, girder-to-girder distances vary for different leaves, ranging from 35'-0" to 40'-6". The typical floorbeam spacing is 20'-9" and stringer spacing is kept under 6 feet. Girders and floorbeams are welded I-shaped members, and the stringers are rolled sections. Bolted connections are used throughout the span.

To minimize out of plane stresses with the span in the open and closed positions and throughout travel, main members are detailed such that their tops will be approximately at the same elevation relative to the deck. The project requirement that the floorsytem be fully composite with the concrete deck is satisfied in the design by including shear studs on the girders, floorbeams, and stringers. In consideration of the superelevation and the requirement for a composite deck, it was decided that the floorsystem should be placed along the cross slope of the span.

Bracing systems of the bascule span design include upper and lower lateral bracing, as well as a vertical longitudinal bracing system.

Bascule Girders

In all, 16 bascule girders are required. These girders will be very large, with webs varying in depth from nearly 12 feet at the toes to 20 feet in the vicinity of the trunnions and 28 inch wide flanges that range between 1½ and 4 inches in thickness. The overall length of each girder will be 215 feet. To keep girder segments within sizes and weights that can be fabricated and to provide shipping and erection options, the girder design includes two field splices. Each bascule girder will weigh between 350 and 400 tons.

The girder web geometry detailed is identical for all girders for the portion forward of the trunnion, except at the toes where girders for the east and west leaves of a given span are lapped. This lap is required to accommodate the moment-resisting span locks. These span locks and their effects are discussed in much detail in the Mechanical Systems section of this paper. The shape of the rear portion of the girders is controlled by the confines of the bascule pier. With the span in the closed position, the top of the girder will fit beneath the fixed deck beams of the bascule pier while the girder remains completely hidden behind the pier. In the open position, the girder will remain clear of the pier rib and front transverse beam throughout travel. The shape of the bascule girders is shown in Figure 2. As a result of these geometric constraints that limit the web depth, the critical section in the girder design is the portion between the trunnion and the counterweight.

Another critical portion of the bascule girder is at the toes where span lock reactions are ultimately to be supported. Here, fatigue issues associated with lock bar reactions that produce full stress reversals during each live load cycle controlled the design and required careful detailing.

Concrete Deck

The deck system designed is one of the unusual features of the bascule span, as the decision reached by the Sponsoring Agencies was to use a lightweight concrete deck, fully composite with the supporting steel superstructure. The difficulty in enacting this decision, borne as a result of repeated grating failures on the existing bridge, was designing a concrete deck wholly in a tension field and accommodating the weight of a solid concrete deck on a movable span.

Considerable effort was spent performing finite element studies of the deck and options to mitigate potential cracking. We found that tension stresses in the deck due to live load and shrinkage will exceed the rupture modulus of the concrete and can not be brought below this level unless a pre-stressing and/or post-tensioning system is utilized. However, a crack analysis revealed that theoretical crack widths are expected to remain below ACI and AASHTO recommendations.

The decision was made to not use a pre-stressing or a post-tensioning system, but to detail the reinforcing steel such that predicted crack widths will remain within acceptable values. As an added precaution, stainless steel reinforcement will be used to resist corrosion of the bars should cracks occur in the deck.

The deck concrete is to have a minimum compressive strength of 4500 pounds per square inch and an average weight of 118 pounds per cubic foot.

Counterweight and Span Balance

Each leaf of the bascule span will be balanced about the trunnion through the use of counterweights. The counterweights are to be 30-foot long steel boxes filled with normal-weight concrete that span between bascule girders and are full depth of the girders. Pockets for balance blocks are provided in the counterweights for making balance adjustments.

Several factors contributed to making the task of designing the balance and counterweight for each leaf especially challenging. For one, each leaf is very heavy due to the use of a concrete deck instead of a more conventional open or filled grating. Since the mass of this heavy deck is positioned at the highest point relative to the trunnion, the counterweight material required to counterbalance the deck must be placed even further below the trunnion. Adding to the complexity of balancing is the superelevation of span. This creates a vertical imbalance transversely across the span that had to be accounted for in the counterweight design.

Several design features were developed to address these problems. First, the height of the span above the channel and the open nature of the bascule pier were utilized in positioning the counterweight further behind the trunnion than usual, with the center of gravity of the counterweights roughly 50 feet from the trunnions. The location of the counterweight is shown in Figure 2. At this increased moment arm, the required counterweight mass, and thus the overall weight of each leaf, is reduced significantly. The ratio of the mass of counterweight to forward span is roughly 1.3:1. For a typical bascule span, this ratio is between 2:1 and 3:1.

To lower the center of gravity of the counterweights to counterbalance the deck, the design calls for a well at the bottom of each counterweight to be filled with lead plates. Additional lead plates are to be placed asymmetrically inside the counterweight box to counterbalance the effects of the superelevation previously described.

Required by code, the counterweight pockets must be of sufficient size to account for over-runs and under-runs in the final span weight. For this project, several additional unusual factors that may result in variations in the span weight had to be accounted for in designing the size and locations of the counterweight pockets and the amount of initial balance block material to be placed in these pockets. These factors include potential variations in the unit weight of the deck, potential variations in the deck thickness, and the future addition of the light rail system. The counterweight design takes all these factors into consideration.

As designed, the weight of the counterweights varies for each leaf, ranging between 950 and 1300 tons. Overall, the counterweights will total nearly 9000 tons.

Mechanical System

Each leaf of the new bascule span will have the following mechanical systems: trunnion assemblies, operating machinery, span locks, and tail locks. Features of these systems are discussed in detail in the following text.

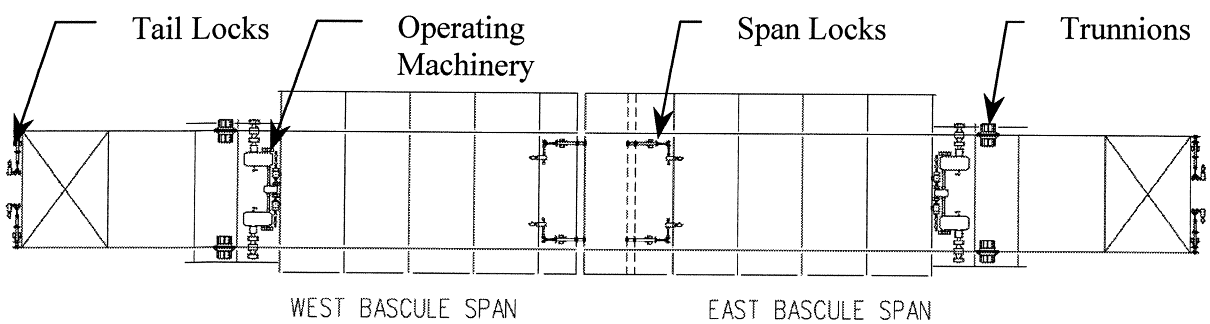


FIGURE 3: Machinery Location Plan

Trunnion Assemblies

The trunnion arrangement utilized for the design is known as a simple trunnion type. For this type, a trunnion shaft passes through and is rigidly fixed to the bascule girder. This shaft supports the entire weight of the bascule span. On either side of the trunnion shaft is a trunnion journal bearing. For this bridge, the bearings will transfer the entire weight of the bascule span to the steel trunnion towers that are supported directly on the front transverse beam of the bascule piers.

The trunnion assemblies designed are typical for most bascule bridges. The size of the trunnion shafts, however, is not. Due to the weight of the span, the trunnions will be massive, with shaft diameters of 34 inches. The sleeve-type bronze bushed bearings designed are typical for bascule bridges.

Operating Machinery

The 150-horsepower span operating machinery assemblies that will power each of the eight leaves are also of classical arrangement. They consist of enclosed gearings that will drive the main pinions and bascule girder mounted racks. Each drive is to be equipped with a differential reducer to equalize pinion torque. The machinery shafts will be supported by standard spherical roller bearings and connected with gear couplings. Machinery and motor brakes are included in the design to stop the span in case of drive failure, and to serve as holding brakes in any span position.

Span Locks

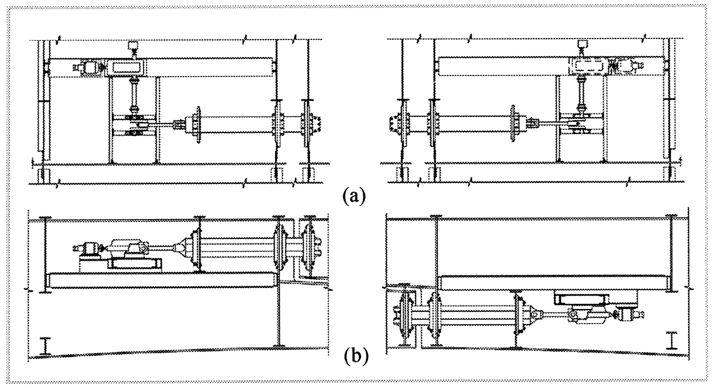


FIGURE 4: Span Locks. (a) Plan View (b) Elevation

The designed span lock arrangement for the new Woodrow Wilson Bridge is truly unique in that the locks will transfer moment as well as shear between the leaves of each double leaf span.

Before going into detail on the system designed, a brief discussion of span locks for any double leaf bascule is required. When designing a double leaf bascule bridge, a shear transfer device is always placed at the center between the two bascule leaves. The function of this device is to ensure that the live load on the span is shared between the two opposing leaves via several mechanically actuated devices that are withdrawn to permit the spans to open. The shear locks, as they are sometimes called, transfer shear between leaves, but do not transfer moment. The reason they do not transfer moment is that the loads become prohibitive given the physical limitations of the components. Moreover, it has been found that the bridge will function quite adequately transferring shear only if the locks are conservatively sized and the bridge leaf itself is sufficiently stiff. However, relatively large deflections occur since the locks are at the end of a cantilever beam.

The use of a span lock system with moment transfer capacity for the Woodrow Wilson Bridge was studied during the design phase because the bridge will potentially carry future light rail loads. AREMA does not recommend a double leaf bascule for a rail structure. It does not, however, specifically exclude a double leaf configuration. To address the AREMA concerns with placing rail loads on a double leaf span, the design team needed to implement a system that can control end deflections and improve deflected shapes from the typical.

It was decided that a moment lock system would be designed to reduce the span end deflections and allow the future mitre joints and limit switches a better operational environment. The moment lock concept selected is an adaptation of an old European moment lock that has two typical shear lock systems installed on lapped girders in an opposing fashion. These systems are in-line horizontally, but separated vertically.

Theoretically, the use of moment locks will reduce live load deflections at the centerline of the channel significantly. Analysis shows that the live load deflections will be reduced by nearly 60% if moment locks are used instead of shear locks. With the designed moment lock system, the maximum live load deflections of the bascule span are expected not to exceed 1½" at the centerline of the span.

Another unique feature inherent to the span lock arrangement designed is that either of the lock bars for a given moment lock system can be taken out of service for maintenance without interrupting traffic. The span and the single bar can accommodate traffic loads in this temporary condition. Details have been developed in the mechanical, structural, and access systems to allow maintenance work to be performed without having to raise the bridge.

Learning from the poor performance and durability of the original lock bar system under the heavy traffic on the existing bridge, the design calls much more substantial lock bars on the new bridge. They are sized at 20 inches deep and 16 inches wide, and weigh 6 tons each.

Tail Locks

Working in conjunction with the span locks will be the tail locks. The machinery for the tail locks is to be mounted on the same bascule pier deck beam that serves as rear live load anchor. Receiving sockets for the locks are located at the tail end of each bascule girder. Although tail locks are not commonly utilized on bascule bridges, the decision was made to use them on this bridge due to the need for high stability of the span under rail loading, and the potential for uplift at the forward live load bearings.

In addition, using tail locks provides an advantage in that they will allow the operating machinery to be relieved of live load transferred through rack into the main pinions. This will reduce wear on the operating machinery, which is a significant problem on the existing bridge.

The tail locks designed are wedge-shaped, and will drive an upward holding force at the back of the bascule girder, deflecting the girder approximately ¼ inch under ideal ambient temperatures. The flexibility of the girder serves as a "spring" so that at all times tail lock engagement is assured, regardless of thermal expansion effects. The upward reaction from the tail locks will be reacted by the forward live load bearings, resulting in an extremely stable structure under live load conditions.

Electrical System

The design of the electrical system for operation of the Woodrow Wilson Bridge bascule span comprises a power distribution system to deliver power to the eight bascule leaves, a control system to govern the sequence of operation of the various devices, and a motor-drive system to raise and lower each bascule leaf.

Power Distribution System

The power distribution system, designed by PTG, will be fed from two independent utility sources; one source derived from one utility power grid on the Virginia side of the span, the other source from a second power grid on the Virginia side. The utility sources are sized such that all eight bascule leaves can be operated from either utility source.

Control System

The bridge control system, designed by H&H, governs the sequence and operation of the traffic control devices, tail locks, span locks and bascule leaves. The traffic control devices included in the design are:

- advance warning signs and traffic signals to signal motorists of an impending bridge operation
- warning gates similar to those used at a railway grade crossing for stopping motor vehicles
- barrier gates to stop an errant vehicle from impacting the bascule span during operation
- sidewalk gates to prevent pedestrian traffic from encroaching upon the bascule span during operation

Sequence interlocking to control operation of the traffic control devices, tail locks, span locks, and bascule leaves in the proper sequence will be achieved through the use of electro-mechanical, hard-wired relays. A relay logic control system was selected by the Sponsoring Agency for its reliability and durability. Given the significant adverse effects on traffic should a device fail to operate, two discrete, redundant relay logic control systems are provided in the design to ensure that each device is operable on command.

Operation of the traffic control devices, tail locks, span locks, and bascule leaves is to be controlled from a control console located in the top floor of the operator's house that will be integral with the Outer Loop bascule pier. The system has been designed to be operated by a single bridge tender.

Motor-Drive System

The prime mover of the operating machinery on each bascule leaf is to be an electrical motor-drive system consisting of an alternating current, induction motor under control of a flux vector variable frequency drive (VFD). A flux vector VFD was selected for its superb regulation of motor shaft speed and torque, especially at low speeds over a wide variety of shaft loads. Each bascule leaf is designed with two induction motors, each to be furnished with its own VFD. Either motor-drive combination will be capable of operating the leaf independently, thus, ensuring reliability of leaf operation. Electrically-released, spring-set drum brake are to be provided for stopping the leaf in an emergency and holding the leaf in any position.

System Redundancy

The span electrical system, including power and controls, is designed to be fully redundant, meaning that operation is ensured if the primary electrical system fails. This is a requirement of the project deemed necessary to minimize the potential for system failure to cause vehicular or vessel delays.

In order to provide electric power should both utility sources fail, two standby engine-generator sets are to be installed on the bascule piers with each generator capable of operating two bascule leaves simultaneously. During operation under generator power, four leaves are to be operated simultaneously, followed by the remaining four leaves.

Each bascule leaf will be fed by two redundant power feeders, either of which is used to supply power to the control system and motor-drive system. This redundancy in the power distribution system ensures electrical power will be available to the required devices necessary to operate the span and subsequently permit safe passage of vehicular traffic after bridge operation is complete.

Redundancy in the motor-drive and control systems will be achieved with fully rated auxiliary span drive motors, separate auxiliary motor controllers and drives, and a complete auxiliary system of wiring.

Conclusion

In conclusion, a new signature bridge has been designed to replace the existing Woodrow Wilson Memorial Bridge. An essential part of this bridge is the bascule span, which has been designed to accommodate demanding interdisciplinary criteria. Once constructed, this span and the entire bridge will be truly unique.

Acknowledgements

We would like to acknowledge the steadfast efforts of Mr. Robert Healy, Assistant Deputy Chief Bridge Administrator of the Maryland State Highway Administration, the Sponsoring Agencies, and the GEC working with the designers and the community to keep this project moving forward. They have encountered and solved as many problems as may be expected for a project of this magnitude and stature.