Replacement of the Woodrow Wilson Memorial Bridge Bascule Span

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Summary

A mile-long signature replacement structure has been designed to replace the Woodrow Wilson Memorial Bridge on the I-95 Interstate System. With eight independent bascule leaves and a movable mass of 19000 metric tons, the bascule span is the largest movable bridge in the U.S. and possibly the world. To meet extraordinary public demands, the new bascule bridge has been constructed with many unique features including aesthetic V-shaped concrete piers, fully-composite concrete decks, moment-transferring span locking system, details to accommodate a future transit system, and a fully-redundant electrical control system. These components are amongst the innovative, interdisciplinary features described in this paper.

Keywords: Bascule bridge; movable bridge; v-shaped piers; post-tensioning; segmental concrete; trunnion; moment locks; tail locks; bridge control system.

1. Introduction

The Woodrow Wilson Memorial Bridge is the only Potomac River crossing in the southern half of the Washington, D.C. metropolitan area, USA. It connects the states of Virginia and Maryland, and carries the Capital Beltway (I-495) and I-95, the main north-south interstate route on the East Coast. The existing bridge was an aging steel structure with numerous short spans and a moveable span built in the early 1950's. This bridge was rapidly deteriorating under the daily traffic volume of 175,000 vehicles. Thus, in 1987 it was decided to replace the bridge with a new 1840 m long low level structure that can accommodate the anticipated traffic growth to 300,000 vehicles and reduce the frequent bascule span openings to approximately one per week.

2. The new bridge

2.1 Description

The culmination of the review process was a bridge of twelve-lanes, wide shoulders and a sidewalk including a movable span and increased navigational clearance (22,86 m). The new bridge has incorporated the following basic design requirements: 1) Be an arch structure in the tradition of other Potomac River bridges; 2) Integrate the moveable span with the fixed spans; 3) Provide open lines of vision between the shores of the river.

Fig. 1 *Photo of the new bridge construction*

The crossing is comprised of 34 fixed spans and a double-leaf bascule span. Each direction of traffic is carried by an individual structure. The two structures are separated by 4,6 m and have a 35 MPa reinforced concrete deck with combined width of 71,3 m, including a 2,45 m wide sidewalk that provides views to the Nation's Capital. The bridge consists of continuous variable depth steel girders, up to 530,3 m long between expansion joints, supported on lead-core elastomeric bearings at the ends of concrete v-shaped piers. The curved legs of the v-piers along with the variable depth steel girders form the arch shape which was a design requirement. The v-piers of the bascule span provide a platform for supporting the bascule leaves and integrate seamlessly the moveable with the fixed spans thus satisfying the second design requirement. Finally, with span lengths of 90 to 125 m, the new bridge dramatically reduces the number of bridge foundations compared to the existing bridge, and provides large open areas that maintain the views between the shores of the river (3rd design requirement).

3. Bridge piers

3.1 New type of pier

Conventional arches develop high thrust forces that need to be supported by firm foundations, preferably on rock. In multiple arch spans, the thrust forces are greatest at the end piers. Interior piers support horizontal loads as well due to span length variations and patterned live loads.

The main technical challenge of the Woodrow Wilson Bridge has been to support an arch bridge on poor quality soil, which is incompatible with the requirements of a classical arch structure. The subsurface soil profile along the length of the bridge consists of 15 to 25 m of soft silty clay underlain with deep deposits of hard sandy clay. The soft clay can be subjected to significant scour in the 500-year return period flood, especially at the main navigation channel where the entire soft layer was estimated to undergo scour. The challenge was particularly critical at the bascule span whose piers are founded in the deepest soft soil deposits. In a traditional multiple arch structure, the bascule piers would constitute end piers transferring huge thrust forces to the foundations, making them prohibitively expensive.

The solution to the above problems was found in the concept of the v-shaped piers, Figure 2. Two lines of 45 MPa concrete v-piers support the structure for each direction of traffic. The

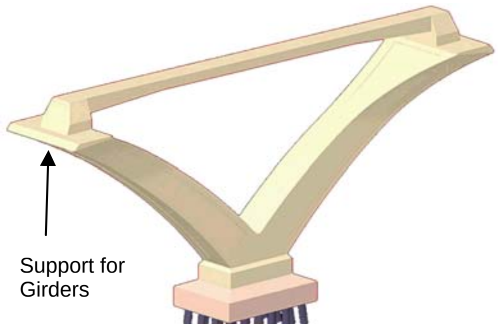

Fig. 2 *Typical V-pier*

v-piers consist of traditional arch segments connected at the top by a horizontal tie element. They have been praised for their graceful shape resulting from their varying size cross-section forming a corbel at the top for support of the superstructure girders. This type of piers is marvelously suited to the poor soil conditions at the site, since they eliminate the thrust at the foundations. The elimination of the thrust forces allows supporting of the piers on vertical pile foundations, which avoid the high cost and technical challenges of driving large diameter battered piles in deep soft deposits. Additionally, the vertical pile foundations limit the seismic loads transmitted to the superstructure.

The tie is a non-redundant concrete element designed to receive additional prestressing from provisional tendons if the need arises during the life of the structure. It remains in compression at all times under service load conditions. Proper control of grouting of the prestressing tendons and good protection from the elements, provided under the roadway deck, alleviates the concern of tendon corrosion.

3.2 Bascule piers

For each structure serving one direction of traffic, two 45MPa cast-in-place concrete bascule piers are used, founded 113 m apart, forming an 82,3 m long bascule span with four leaves, Figure 3. Each pier consists of three v-piers connected together with large transverse partially hollow beams at the intersection of the tension ties with the front and rear pier legs. The front transverse beam is 3,65 m deep and supports heavy loads from the bascule leaves.

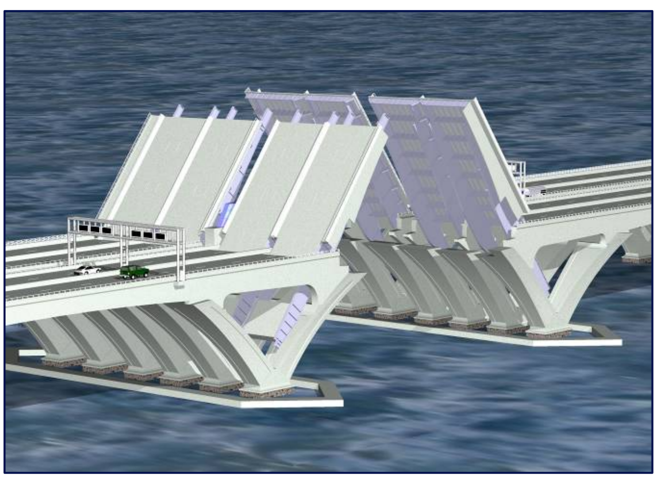

Fig. 3 *Rendering of bascule piers looking north*

Its trapezoidal cross section forms a 9,15 m wide platform that accommodates the machinery room. The rear transverse beam is 3,05 m deep with a nearly rectangular cross section, and provides room for the electrical equipment necessary to operate the bascule span and future rail transit. The pier legs are hollow, similar to the legs of the v-piers of the fixed spans but with larger cross section. The three ties of the v-piers serve also as girders supporting a lightweight concrete slab forming the roadway deck over the length of the pier. They are 44 m long with rectangular cross section of 1,5 m constant width and a minimum depth of 4,6 m. An extension of the front transverse beam at one of the four piers provides support for an architecturally one-of-a-kind, elegant operator's house located adjacent to the navigation channel. Each pier foundation consists of a 4,9 m deep and 26,5 m wide pile cap supported on 39 cylindrical concrete-filled steel piles, 1,87 m in diameter, driven 69 m below water level.

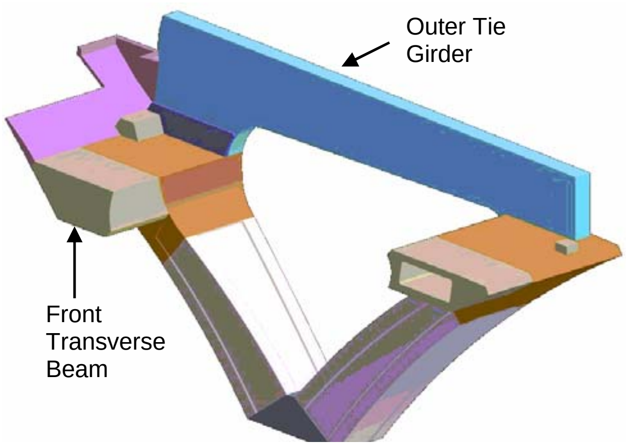

Fig. 4 *Longitudinal section of the bascule pier*

The bascule piers are rigid structures, and they support the adjacent span girders in addition to the bascule leaves. The roadway slab is reinforced with stainless steel bars and has been designed to be replaceable with limited interruption of traffic. The piers are highly redundant structures, externally structurally determinate however, since they are independent units with no rigid connection to other parts of the structure. The dead loads are the predominant loading and they are nearly balanced to minimize the bending moments on the foundations. However, this balancing does not eliminate the large bending moments acting on the pier legs, which are heavily prestressed. Due to the size of the transverse beams, there is considerable interaction and load sharing between the three v-piers. This is important for the design and construction of the piers because of the influence of the erection sequence on the development of secondary bending moments. The outer two ties are eccentric with respect to the centerline of the corresponding pier legs, Figure 4. This eccentricity along with the location of application of the design controlling heavy dead loads of the bascule leaves, produce a true three dimensional flow of stresses in the solid concrete connections of the transverse beams (especially the front beam) with the exterior legs and ties.

Due to the importance of this bridge, the piers were designed so that the bascule span will remain operational after a ship collision event. For this purpose, a fender ring protection system was designed to resist the main impact from collision of stray ships, Figure 4. The ring with a 4 by 4 m cross-section either from cast-in-place or precast reinforced concrete is supported on 1,37 m diameter 7,2 m on centers cylindrical concrete-filled steel piles.

The global analysis of the piers was performed using the computer program RM 7 Spaceframe. SAP2000 models were used to study the flow of stresses in critical locations. Strut and tie models were developed to study the ultimate state condition of forces at the transverse beam/exterior leg/tie connection. Extensive three-dimensional CADD work was used to verify the complex geometry of the piers and position of the prestressing tendons to avoid interference.

3. Bascule span general configuration

The movable portion of the bridge is a double leaf bascule, with channel dimensions established as 53,34 m horizontal clearance, 22,86 m minimum vertical clearance in the spandown position, and 41,15 m vertical clearance when the span is raised. Because of the increase in vertical channel clearance of the new bridge, the projected number of annual span openings is reduced from roughly 260 to 60. The new bridge carries six lanes of traffic in each direction and consists of four side-by-side double leaf bascule spans, for a total of 8 leaves. The total width of the bridge is 76,2 m. At these dimensions, 19000 metric tons of structure will move to clear a ship through the channel, representing the largest moving mass of any bridge in the U.S., possibly the world.

Fig. 5 *Photo of bascule span construction*

In addition to allowing for economical floorsystem components and economical mechanical and electrical systems, the aforementioned 8-leaf arrangement allows for increased options for future maintenance and 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 while still maintaining a minimum of three lanes of traffic in each direction.

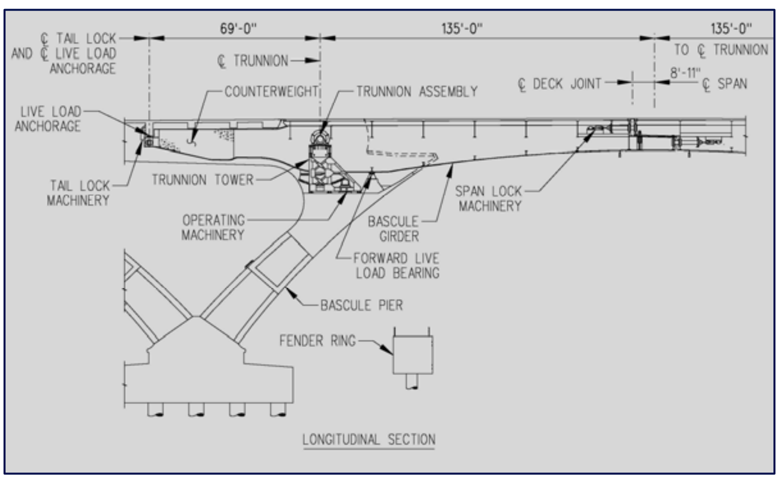

Fig. 6 *Longitudinal section through bascule span*

The new bascule span is a simple trunnion Chicago-type bascule. The front transverse beams of the piers serve as supports for the forward live load bearings at each bascule girder, and fixed deck beams of the bascule piers serve as rear live load anchors. Other design features include a fully-composite lightweight concrete deck, fully counterweighted leaves, shear and moment-transferring span locks, and tail locks. See Figure 6.

In addition to each leaf being designed for three lanes of vehicular traffic, the inboard leaves of both the Inner and Outer Loop were designed to potentially carry either a light rail system or the current heavy rail system that serves the greater Washington DC area.

4. Bascule span superstructure

4.1 Steel floorsystem

To meet project goals, 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 the design, girder-to-girder distances vary for different leaves, ranging from 10,67 m to 12,34 m. The typical floorbeam spacing is 6,32 m and stringer spacing is kept under 1,80 m. Girders and floorbeams are welded I-shaped members, and the stringers are rolled sections. Bolted connections are used throughout the span.

4.2 Bascule girders

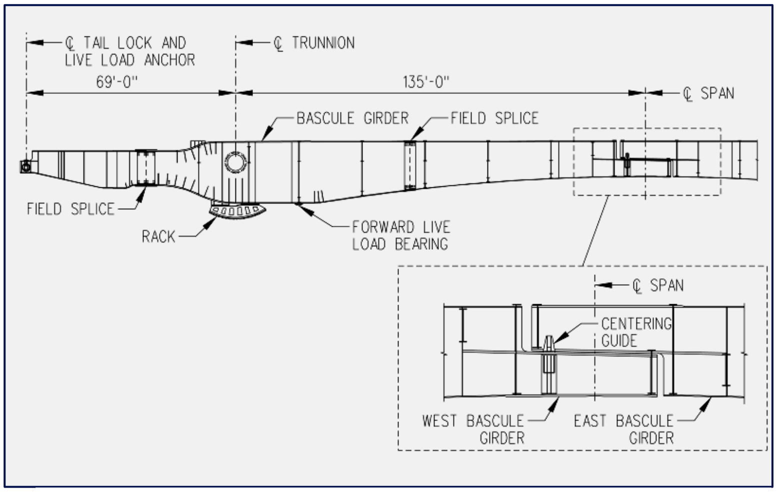

Fig. 7. *Elevation of bascule girder*

The 16 bascule girders are massive, with webs varying in depth from 3,66 m at the toes to 6,10 m at the trunnions, and with 700 mm wide flanges that range between 40 mm and 100 mm in thickness. The overall length of each girder is 65,53 m. 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 girder weighs between 400 and 480 metric 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-transferring span locks. These span locks and their effects are discussed 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 girders 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 transverse beam throughout travel.

4.3 Concrete Deck

The deck system is one of the unique features of the bascule span. To achieve durability and overall system stiffness, the bascule span has a lightweight concrete deck, fully composite with the supporting steel superstructure. The use of a solid concrete deck located wholly in the tension field of the span meant that not only did the deck weight have to be counterweighted, but also that concerns of cracking needed address. Rather than specify a prestressed or post-tensioning system, designers chose a simpler option by detailing the reinforcing steel such that predicted crack widths remain within acceptable values. As an added precaution, stainless steel reinforcement is used throughout the bascule decks to resist corrosion of the bars should cracks occur in the deck.

5. Mechanical systems

Each leaf of the new bascule span possesses the following mechanical systems: trunnion assemblies, operating machinery, span locks, and tail locks. Although the necessary mechanical equipment needed to move the span is noteworthy in terms of size and quantity alone (for example – 860 mm diameter trunnion shafts and 56 speed reducers), the most innovative of the mechanical systems are the span locks and the tail locks.

5.1 Span locks

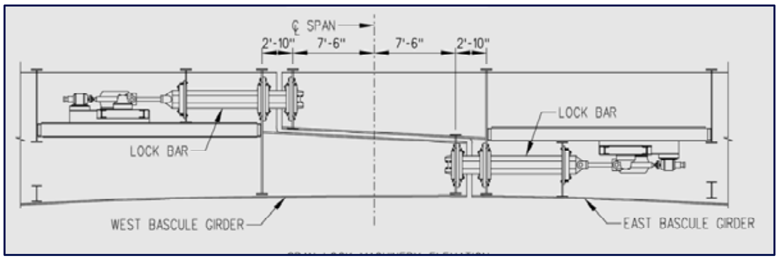

Fig. 8 *Elevation of typical span lock*

The span lock arrangement is truly unique in that the locks transfer moment as well as shear between the leaves of each double leaf span, representing the only such lock arrangement in the U.S. Concerned with span deflections under rail loads (in terms of deflection magnitude and deflected shape) at the open center joint between bascule leaves, designers selected the moment lock concept. The concept detailed 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 reduces live load deflections at the centerline of the channel significantly. Analysis shows that the live load deflections are reduced by nearly 60% if moment locks relative to conventional shear locks. With the designed moment lock system, the maximum live load deflections of the bascule span are expected not to exceed 40 mm at the centerline of the span. In addition and perhaps more importantly than deflection reduction, the lock system produces a smooth deflected shape across the span, thus creating a much more favorable condition as a train crosses mitre joints in the future.

5.3 Tail locks

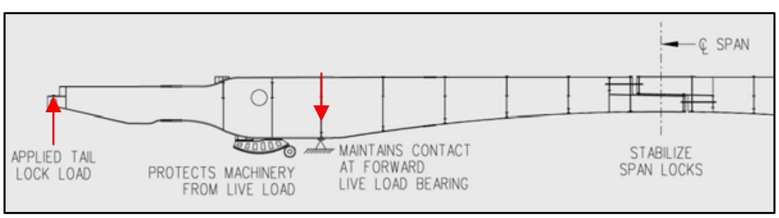

Fig. 9 *Function of tail locks*

Working in conjunction with the span locks are 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 allows the operating machinery to be relieved of live load transferred through rack into the main pinions, will reducing wear on the operating machinery.

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 6 mm 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.

6. Electrical system

Fig. 10 *Control desk*

The electrical system for operation of the 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. The span electrical system, including power and controls, is fully redundant to ensure operation if the primary electrical system fails. Redundancy in the power system is achieved through the use of two independent power feeders, either of which is used to supply power to the control system and motor-drive system. Redundancy in the motor-drive and control systems is achieved with fully rated auxiliary span drive motors, separate auxiliary motor controllers and drives, and a complete auxiliary system of wiring.

The control system governs the sequence and operation of the traffic control devices, tail and span locks, and bascule leaves. Sequence interlocking of these components is achieved through the use of electro-mechanical, hard-wired relays. 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.

7. Project status

Fig. 11 *Bascule span opening for ship passage*

At present, the project is on schedule for completion by the summer of 2008. The six lanes of the Outer Loop have been open to traffic since the summer of 2006. These four bascule leaves are fully operational. The four leaves of the Inner Loop structure are fully-constructed, with only mechanical and electrical work remaining. Figure X shows opening of the new Outer Loop structure to allow passage of a tall ship.