The New Woodrow Wilson Bridge

Span Drive Machinery and Traffic Gates

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The New Woodrow Wilson Bridge carries six lanes of highway traffic in each direction on I-95 and I-495 over the Potomac River, between Maryland and Virginia. It consists of two parallel bridge structures, each with 17 fixed spans and one 270 foot twin double leaf bascule span. There are a total of eight bascule leaves. This paper presents some of the general features of the bridge, machinery, and traffic control devices installed on the New Woodrow Wilson Bridge.

Bridge Features

The inner loop and outer loop are located on separate bridge structures. Each bridge carriers 6 lanes divided into two 3 lane roadways with shoulders. A 12 foot wide bikeway is located on the inboard side of the inner loop bridge which is 14 feet wider than the outer loop bridge. Eastbound traffic is carried on the outer loop bridge and westbound traffic and the bikeway are carried on the inner loop bridge. The two 3-lane roadways on each bridge are divided from each other with large safety shape barriers. The bikeway has a steel railing on the north side called the bicycle barrier and a concrete barrier with a short steel railing on top called the combination barrier to separate the bikeway traffic from the highway traffic. All other bridge fascias have a safety shape barrier with a steel railing on top called the fascia barrier. The inboard most travel lanes on each bridge (south inner loop and north outer loop) were designed with the provision to be converted to carry a two track commuter railway.

A 175-foot wide by 70-foot tall navigation channel is provided with the bascule leaves in the closed position. With all leaves fully open the height of the channel becomes 135 feet for the same width. The height of the roadway above mean high water is over 90 feet. The maximum navigation channel height was achieved by utilizing a relatively long bascule span of 270 feet with a relatively small normal opening angle of 52 degrees.

The specification referenced for the design was the 1988 AASHTO Standard Specification for Movable Highway Bridges. The 2000 AASHTO Standard Specification for Movable Highway Bridges was selectively used for additional guidance on shaft fatigue, gear tooth surface durability, incorporation of tail locks, span balance and prime mover sizing.

Each leaf is equipped with tail locks to stabilize the span as recommended by the 2000 AASHTO Standard Specification for Movable Highway Bridges. The tail lock bars are driven transversely from the bascule piers into receiving sockets in the tail ends of the bascule girders. The tail locks raise the counterweights transferring counterweight dead load to the tail lock bar. This upward reaction at the tail creates a moment that increases the dead load reaction on the live load bearings located on the leaf side of the trunnion axis. This increased live load bearing reaction reduces the possibility of uplift at the live load bearings during a transient live or rail load condition.

A cast steel hub, a rotating forged steel shaft and bronze bearings were selected for the simply supported trunnion configuration. The trunnion design uses a cast steel hub to connect the trunnion shaft to the web of each girder. The trunnion journals rotate in bronze sleeve bearings that rest on top of steel towers.

Span Drive Machinery Description

The eight leaves are driven by dedicated span drive machineries located on the bascule piers below the roadway deck and between the girders. Each leaf is equipped with a separate electromechanical machinery system. The components used on each leaf are identical to the other leaves with the exception of the heights of the rack weldments, the lengths of the intermediate shafts and the heights of the reducer supports. The design leaf speed is 0.13 RPM which requires a total reduction from the shaft of the electric motor to the leaf of 13512 to 1. This is accomplished using a rack and pinion with a ratio of 12.714 to 1 and quadruple reduction enclosed gearing. There are two double reduction secondary reducers acting in parallel and one double reduction differential primary reducer. The primary and secondary reducers are in series. All reducers feature through hardened gearing, splash lubrication, anti-friction bearings and a ratio of 32.6 to 1.

Each leaf is equipped with two motors rated for 150 HP at 1750 RPM. Both motors are connected to opposite ends of the continuous input shaft of the primary reducer. Only one motor is energized at one time to power the leaf. The non-energized motor rotates under no load. The motor to be energized is manually selectable by the operator. There is no provision to operate the motors simultaneously. The 150 hp motors are 480 volt, three phase, vector duty squirrel cage motors. Redundant Flux Vector drives provide automatic speed control of the motors.

All machinery components were designed to resist their proportional share of 150% of the Full Load Motor Torque (FLMT) produced by the 150 hp motor. The design HP for the primary reducer and each input shaft was 225 hp with the motor operating at its normal rated speed. The primary reducer output shafts, intermediate floating shafts, secondary reducers, pinions and racks are designed for 112.5 hp at their respective normal rotational speeds.

The normal angle of opening is 52 degrees. A maximum leaf speed of 0.13 RPM or 0.78 degrees per second will yield an opening time of 85 seconds with 10-

second acceleration periods. Increasing the operating time (decreasing the speed) would require less horsepower and increase the required total speed reduction ratio, but would not reduce the size of the rack, pinion or speed reducers because the required leaf torque would be the same.

An electric power supply and distribution system was provided to supply the bascule span with power from two different electric substations, both on the Virginia side. The cable run to the Virginia shore is much closer than the Maryland shore.

Many bridges are equipped with either a smaller auxiliary drive motor and a suitable generator or an internal combustion engine drive either directly driving the machinery, or using a hydraulic pump and motor. The leaf operation is generally slower to minimize the size of the auxiliary drive components. Auxiliary operation on the Woodrow Wilson Bridge is provided by redundant motors and generators in the event both sources of electrical power are unavailable. The alternate drive motors provide a redundant motor of the same size. The flux vector drives are also redundant. One generator is provided for the Maryland bascule pier and one generator is provided for the Virginia bascule pier. The starting of leaf motion on each pier can be staggered to minimize the maximum current draw and yet minimize the increase in the total time to open all leaves.

All four thrustor brakes on any one leaf are energized and de-energized together regardless of which motor is selected for operation. The thrustors are self contained electro-hydraulic actuators and are equipped with needle valves to provide a time delay from the time electric power is removed to the time the shoes are fully set around the wheel. A time delay setting of approximately 2 seconds was set for the machinery brakes and 0.6 seconds for the motor brakes. This delays the setting of the machinery brakes so all brakes do not begin to apply torque simultaneously. The location of the machinery brakes on the secondary reducer input shaft is between the differential and the pinion providing a positive holding torque on the nearest pinion only. The braking torques is the highest torques to be resisted by the machinery under normal circumstances and is approximately 180% FLMT when all brakes are operating simultaneously.

The span drive closes the leaf and motor torque holds the leaf in the seated position until the brakes are set. The span drive motor is de-energized and the locks are driven. Once the span locks and tail locks are driven the brakes release and allow the machinery to spin to the zero torque state. The brakes are then set and the machinery remains in the zero torque state until the next opening.

Span Drive Machinery
The primary reducer and floating shafts in the foreground, motors and motor brakes in the back ground.

Rack and Pinion

The pinions were forged integral with their pinion shafts using steel conforming to ASTM A291 Class 7. The pinions have 21 teeth and a circular pitch of 5.25 inches. The pinions are simply supported by spherical roller bearing pillow blocks. Shims were provided under the pillow blocks for adjustment. The rack and pinion has full depth straight spur teeth with a twenty degree pressure angle.

The pinion pillow blocks are fastened to structural steel supports that have machined mounting surfaces. These supports were fastened to the lower horizontal structural member of the trunnion tower with high strength bolts. AGMA quality 7 was specified for the rack and quality 8 was specified for the pinion. Shims allow adjustments in the directions that require the most precise alignment requirements.

The racks for each girder are one piece weldments connected to the bottom of the bascule girders with two discrete bolted and shimmed connections. The rack weldments were fabricated from material conforming to ASTM A291 Class 6 for the gear rim segment and to ASTM A709 GR 36 for the webs and top bolting flanges. The mounting surfaces on the top flanges of the rack were machined to provide flat surfaces with a finish of 125 micro inches. The gear rim including the teeth were machined with reference to these surfaces.

The bridge has a nearly constant 2% transverse slope that allows motorists in all lanes and roadways to have a better view northward to Washington DC. More importantly the bridge deck and superstructure appear thinnest to an observer standing on the shoreline approximately 1 mile to the North. At this distance only the North fascia girders are visible. The remaining girders are in line behind the fascia girder. The transverse slope as well a longitudinal slope are present on the bascule span.

The transverse slope causes the southernmost bascule leaf structures to be located at higher elevations than the northernmost ones. The trunnions on any one leaf are at the same elevation but the North girder is always lower. This results in the racks being different from each other. The elevation of the trunnions from leaf to leaf rises from North to South. The spacing between the girders varies from leaf to leaf with the greatest distance between girders on the northernmost roadway. The southernmost roadway has the narrowest girder spacing and the girder spacing of the center two leaves are equal to each other. This variation of the girder spacing between leaves caused the intermediate shaft length to vary, as well as the location of the trunnion bore in the bascule girder web. There are six different racks, each with their own shop drawing, and eight different bascule girders. One rack is used in six different locations and the rest in two locations each.

Two Rack supports are welded to the bottom of the bottom flange of each girder. The rack support near the counterweight is a weldment consisting of a bottom flange welded to a web and stiffeners which are welded to the bottom flange of the bascule girder. The rack support near the live load bearing consists of a plate welded around its perimeter to the bottom flange of the bascule girder. The bottom surfaces of both rack supports were machined to provide two flat and parallel surfaces with a finish of 125 micro inches. These details provide two discrete connections that can be adjusted with shims.

The rack mounting surfaces on the girders were machined with portable milling machines in the shop while the leaf was assembled. The milled surfaces were parallel to each other and perpendicular to the milled areas of the bascule girder webs.

The pinion shaft locations are adjustable by varying the shim thickness under the pillow blocks or adjusting the locations of the pillow blocks. Any adjustments to the pinion shaft location would affect the rack and pinion alignment at all locations along the rack equally. The following alignment adjustments are possible with the rack and pinion. All directions referenced assume the leaf is in the closed position.

Installing shims that are beveled transversely (in the direction of the trunnion axis) would enable adjustments that could correct a condition where the rack and the trunnion axes were not parallel in a vertical plane.

Removing the bolts that secure the rack to the girder, pivoting the bolted connections about one point and installing new fasteners in reamed holes would enable adjustments that could correct a condition where the rack and trunnion axes were not parallel in a horizontal plane.

Adding or removing shims in equal amounts in both connections would enable adjustments that would correct a condition where the rack axis was not co-located with the trunnion axis in the vertical direction. Adding shims to both connections can correct a backlash anomaly where the backlash at the mid point of travel is greater or less that the backlash at both ends.

Varying the shim thickness between the connections and installing shims that are beveled longitudinally (in the direction of the girder axis) in a complementary manner would enable moving the axis of the rack longitudinally in relation to the trunnion axis. This could also be accomplished by removing the fasteners, moving the rack longitudinally, drilling or reaming the holes to a larger size and installing new oversize fasteners.

Backlash between the rack and pinion was measured with feeler gauges at eight positions along each rack. The axial and radial runout of the rack was measured along the rack with dial indicators as the leaf was operated.

The racks were fastened to the girders in the shop. On the outer loop, four of the eight racks were adjusted in relation to the girder in the field, after more convenient attempts to correct the alignments were not entirely successful. In one case, all the bolts were loosened and all were removed except for one. Some smaller temporary bolts were installed and tightened after the rack was adjusted. The rack position was monitored with dial indicators while it was moved horizontally with jacks.

Rack and Pinion

The pinion is engaged with the rack here with the leaf in the closed position. The weld connecting the rack webs to the rack rim is visible.

Gate Design Requirements

During the bridge design phase of this project it became apparent that the gate requirements for this bridge would be very demanding. The demands included heavy traffic, high travel speeds, a wide bikeway, infrequent openings usually at night and bridge aesthetics. The longest gates would be required to span three travel lanes, two shoulders, a bikeway, the combination barrier and the bicycle barrier.

Three types of gates were used. Warning gates provide a warning to motorists and pedestrians with a visual barrier that warns of unsafe conditions ahead. The hazards to a vehicle passing the warning gates include colliding with the leaf, traveling off the end of a leaf or falling between the deck sections near the counterweight. Warning gates or dedicated pedestrian gates also warn pedestrians of the unsafe conditions of an open or moving leaf. A pedestrian could travel off the open end of a walkway and fall or be exposed to injurious contact with the moving leaf. The projected amount of pedestrian traffic was uncertain but separate pedestrian gates would reduce design and operating constraints on the warning gates. Resistance gates (Barrier gates) provide physical barrier across the roadway to prevent a vehicle from colliding with the leaf or falling between the decks. Some barrier gates are designed to be impact attenuating in order to reduce forces applied to the gate and structure and more importantly for the safety of the vehicle occupants.

Based upon AASHTO, MUTCD, traffic safety principles and common sense, the following traffic control and gate design goals were established:

- Warn the traffic miles in advance using variable message boards.
- Provide flashing red signal lights to command the traffic to stop on the bridge approach at least one span away from the bascule pier.
- Provide warning gates across all on-going and off-going roadways.
- Provide impact attenuating barrier across the on-going roadways to stop vehicles traveling in the normal travel direction that did not stop fro the warning gates. The stopping force of the barrier gate should not cause an excessively violent impact to the vehicle.
- Provide separately controlled pedestrian gates on the bikeway.
- Minimize the effect of the gates to the appearance of the bridge.

Pedestrian Gates

The pedestrian gates were located inboard of the bicycle barrier in a dedicated space that did not reduce the width of the bikeway. Two gates were installed on each approach to the bascule to provided redundancy and the ability to stop pedestrians from moving towards the bascule span while allowing pedestrians already on the span to continue moving and exit the span. The moving panel was detailed to complement the pattern of the pedestrian railing.

Pedestrian Gate
The pedestrian gate panel details complement the bicycle railing. The pivot axis is to the right.

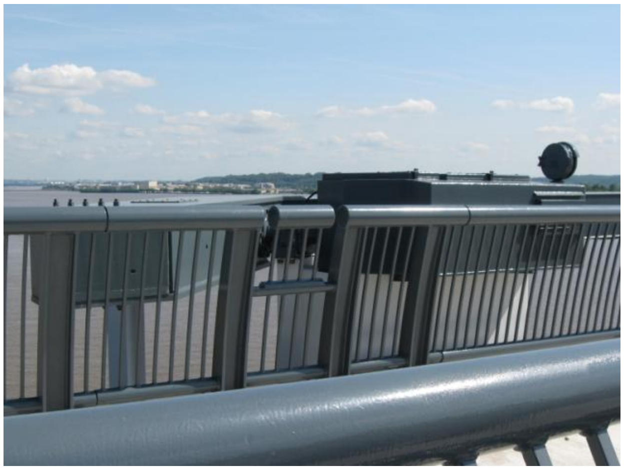
Warning Gates

Gate catalogs at the time did not depict standard products for arms long enough for this application but referred the purchaser to the gate company for a custom designed gate. The warning gate should have High visibility while operating in order to effectively warn the traffic to stop. The gate options available for warning gates included a semaphore type gate and a horizontal swing gate. The semaphore type had the most visibility while in motion before entering the travel lane envelope. That was desirable due to the multiple high speed lanes.

All roadways were to be protected by an on-going and off-going gate. The long arm length of at least 65 feet required a custom gate. If gates with a semaphore type motion were used with the arm stored in the vertical position, the tip of the arm would be the highest point on the bridge. A horizontal swing gate could be stored above the railings for a much smaller visual impact than the semaphore gate stored in the vertical position. There were concerns that a horizontal swing gate would have limited visibility to traffic until it has moved into the travel lane. A gate having the semaphore type motion that could be stored next to and or above the railings would satisfy both the safety and aesthetic concerns. A solution to the aesthetic and safety goals was discovered moving the axis of rotation of the gate. If the gate arm shaft axis is aligned to be midway between the stowed and deployed positions, 45 degrees from the direction of travel and still in a level plane, the arm will rise and move from the stowed position to the deployed position in one motion. From the stowed position, the gate arms move upward, over and across the roadway and downward to span the roadway in the horizontal position.

Warning Gate Arm
The warning gate in the stowed position behind the fascia barrier. The reflectorized striping faces inboard only. Sign structures are visible in the background.

The warning gates were located outboard the parapet barriers and outboard of the bikeway railing. There are eight warning gates installed on the bridge. Two different sizes of warning gates were designed. There were two gates with a 86 foot arm installed on the north side of the inner loop spanning the roadway and the bikeway. The remaining six gates are some 10 feet shorter and only cross the roadways.



Warning Gate Housing and Counterweight
The warning gate counterweight in the stowed position behind the bicycle barrier. The counterweight is to the left and the machinery housing and gong are to the right. The narrow slots in the bicycle barrier are visible.

Gates usually require gaps in railings or occupy space on sidewalks. The gates were detailed to minimize the discontinuities in bridge parapet railing, bicycle barrier railing pedestrian railing. A steel box connected the gate arm with the gate trunnion and counterweight. The box had an opening in the bottom surface to allow a short section of railing to fit inside the box when the gate was in the deployed position. Only two 4 inch wide slots were required in the bicycle barrier and the pedestrian railing for the warning gate in the deployed position.

Warning Gate
The warning gate in the stowed position behind the bicycle barrier. The narrow slots in the combination barrier railing are visible

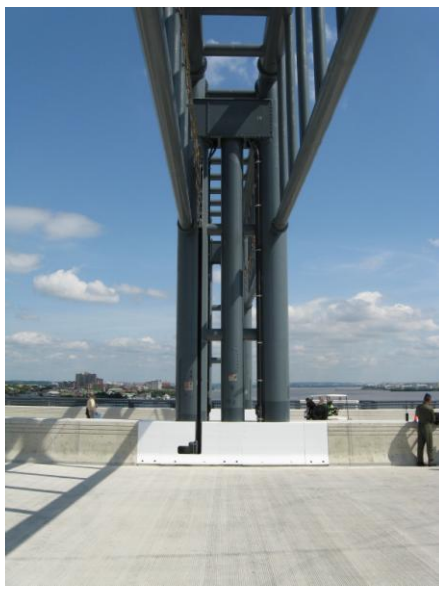
Barrier Gates

The roadways are divided with large safety shape barriers so discrete roadways and travel directions could be gated. It was decided to equip the bridge with barrier gates on all approach (ongoing) roadways and no barrier gates on the off going roadway. This provides maximum protection to motorists traveling in the standard travel direction from improper vehicle operation and malfunctioning or inoperative components. These components include bascule leaves, warning gates and traffic signals.

The barrier gates protect motorists failing to heed the warning of the traffic signals and the warning gates and traveling in the standard traffic flow direction from colliding with and open leaf or from leaving the end of the roadway. Some incidents and accidents have occurred when components are inoperative such as signals, gates, and even bascule leaves. A double leaf bascule span with one leaf inoperative becomes a single leaf with one approach open to the channel, similar to a swing bridge or vertical lift bridge.

A vertical lift type barrier gate was capable of placing an impact attenuating energy dissipating gate across the roadway. Gates fabricated by Lokran were studied and selected for this project based on the safe stopping performance and the history of prior installations. A vehicle is brought to a stop by the gate through a wire rope unwinding off of a reel. The rotation of the reel is resisted by a brake. If the energy of the vehicle being stopped is less than the design energy for the gate, the gate should not be damaged. To return the gate to service, the gate is raised and the wire ropes connecting the gate net to the towers retract into the reel boxes. Once the wire ropes are retracted and the gate net is raised, the gate is ready to be redeployed.

Vertical lift style barrier gates are typically supported by a structure that has the appearance of an overhead sign structure. The sign structures on the bridge were custom designed for the bridge. They were to be 12-inch diameter steel tubes rising vertically, curving horizontally and meeting above the roadway. The two tube structure was highly advantageous because it provided one tube in which the gate energy conversion mechanism could be stored and travel as well as another tube which could house the counterweight. The appearance of the custom sign structures was used but the diameter of the tubes and the total height of the structure was increased.



<u>Transverse View of Barrier Gate intersecting the median barrier</u>
The vertical slot in the left tube and barrier allows the gate for the foreground roadway to extend out of the tube as it travels vertically. Vehicle travel is from right to left. The right tube is detailed similarly for the background roadway. The center tube has two separate counterweights, one for each gate that travel vertically also.

There are 4 on-going barrier gates located between the on-going warning gates and the bascule span. One temporary gate was provided for the outer loop inner roadway which would have westbound traffic during the intermediate construction stage but eastbound traffic when the bridge is complete.

Outer Loop Barrier Gates
The outer loop barrier gate structure in the left foreground is similar style to the sign structures in the background.

Statistics

8 leaves, 4 million pounds each, 32 million pounds of moving mass

Fabricated Component Quantities

- Span Drive Machineries -8
  - 8 Primary Reducers
  - 16 Secondary Reducers
  - 16 Motors and Motor Couplings
  - 32 Brakes
  - 16 Racks and Pinions
  - 32 Large Spherical Bearing Pillow Blocks
  - 32 Trunnion Bearings
  - 48 Gear Couplings

- Lock machineries -32
  - 32 Lock Motors and Motor Couplings
  - 32 Lock Reducers
  - 32 Gear Couplings
  - 64 Spherical Roller Bearing Pillow Blocks

- Gate Machineries – 16
  - 8 Warning Gates
  - 4 Permanent Barrier Gates

    - 4 Pedestrian Gates

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Machinery Fabricator
- Steward Machine Company

Warning and Pedestrian Gates
- B&B Roadway

Barrier Gates
- Lockran

Electrical and Controls
- Wellington Power
- Panatrol