HEAVY MOVABLE STRUCTURES, INC.

EIGHTH BIENNIAL SYMPOSIUM

NOVEMBER 8 – 10, 2000

Grosvenor Resort
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"The New Woodrow Wilson Memorial Bridge Design"

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A Winning Design for the New Woodrow Wilson Memorial Bridge

Introduction - The Woodrow Wilson Memorial Bridge is the only Potomac River crossing in the southern half of the Washington Metropolitan area. It carries the Capital Beltway (I-495), which is a part of I-95, the main north-south interstate route on the East Coast. The current bridge is a six-lane structure with a bascule span that accommodates shipping to Alexandria, Virginia and the District of Columbia. Built in the early 1950's for a daily volume of 75,000 vehicles, it is rapidly deteriorating under the present daily traffic volume of 175,000 vehicles. Replacement of the structure is estimated to be necessary by 2004, or weight restrictions may have to be imposed.

The new structure will be a part of the monumental core of the Washington Metropolitan area. Approximately 6,000 feet long, the new bridge will be substantially wider than the existing bridge to accommodate the traffic growth. This project has raised many concerns on the part of community groups and agencies regarding visual and urban design effects on the historical, architectural and community resources.

In 1987, FHWA, Maryland, Virginia, and the District of Columbia began a series of studies to determine the best alternative to enhance mobility in the corridor while addressing community and environmental concerns. The work culminated with the selection of six comprehensive crossings, which included a twelve-lane bridge with a movable span along with significant highway improvements to the interchanges at both ends of the bridge. The selected alternative also included considerable urban design, park, and environmental improvements along the bridge.

The Design Competition - The present design of the river crossing was selected via a competition. A general invitation was issued for interested groups to submit their credentials. Seven teams submitted their qualifications, and four were short-listed for presentation of design proposals. The entrants were allowed, within ten weeks, to submit as many as two proposals each, of which at least one had to exhibit an arch appearance. The design had to adhere to specified design criteria and include sufficient detail and calculations to confirm the size of major members and permit an initial cost estimate. All entries were submitted anonymously to prevent identifying them with specific teams and thus allow the selection of the best solution.

The Winning Concept - The 234 feet wide bridge is comprised of 34 fixed spans and an eight-leaf bascule span, and is divided in two independent structures separated by 15 feet to allow sunlight to pass through them. The deck widens by 12 to 24 feet at the Virginia and Maryland shores to accommodate acceleration/deceleration lanes at the adjacent interchanges. Although it appears to be a series of arches, the bridge actually is composed of continuous steel box girder spans with a composite concrete deck supported on independent concrete piers. This design concept was developed through an iterative process. Considerable effort was expended to address two major issues:

- What is the best structural system for the arches of the fixed spans that is responsive to the existing soft soil conditions at the site while providing superior aesthetic qualities?

- What type of movable span will integrate with the fixed spans in a structurally efficient and aesthetically pleasing manner?

The initial design concept consisted of a series of conventional arches with a bascule span cantilevered from the arch ribs. This concept integrated the movable span with the fixed spans in an aesthetically pleasing manner, but it did not fare well with respect to the following:

- The foundations, which were subjected to large longitudinal forces (thrust) under vertical loads such as dead and live. These forces were particularly high at the bascule piers, located in 25 feet of water and 65 feet of mud, requiring massive foundations.
- The sizes of the spans near the ends of the bridge, which were dictated by the aesthetics of a conventional arch system. To maintain a certain ratio between the height and span length of the arches, the spans became progressively smaller resulting in a "cluttered" look.

These shortcomings were resolved by introducing the v-shaped piers with curved legs, which support haunched girders. The curved legs together with the haunched girders display the desired arch appearance (Figure 1). This structural system consists of independent structural units (v-piers), and produces zero horizontal thrust forces under dead and live loads. Proper arrangement of the girder spans balances the dead loads and produces minimal bending moments at the piers. This system results in significant savings in the foundations, especially at the bascule piers. Furthermore, the v-pier system allows longer spans than the traditional arch system and thus provides greater openness underneath the bridge.

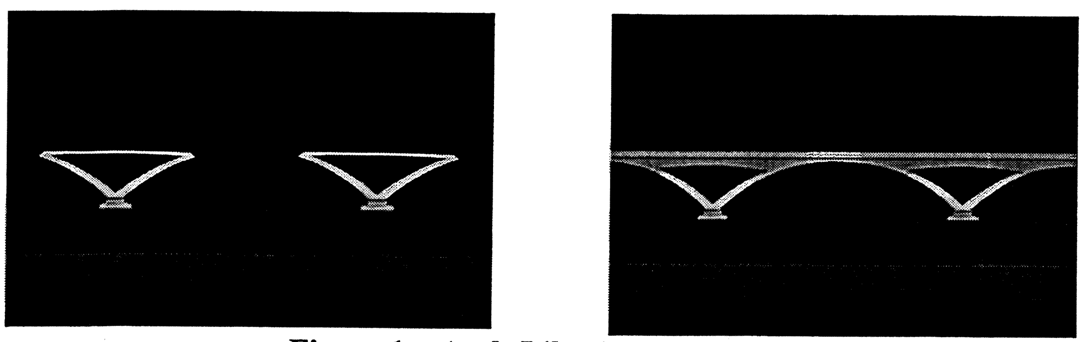

Figure 1 – Arch-Like Appearance

Bridge Description - The Fixed Spans - The bridge consists of eight steel box girders supporting a 10 inches thick cast-in-place composite concrete roadway deck, post-tensioned transversely. The depth of the girders at the center of the spans is kept to a minimum (7 feet) to maintain a slender profile and enhance the openness and light appearance of the structure. The girders are 12 feet deep at the supports. The v-piers provide dual support points for the girders, resulting in short spans and light sections that help reduce the overall loads to the foundations, including seismic loads. The small overall weight of the girders facilitates their erection, which can be achieved quickly and economically.

Steel box-shaped crossbeams provide transverse stiffness, and along with the longitudinal girders provide smooth surfaces along the entire bridge. To reduce maintenance, the roadway deck and girders have only four expansion joints. Provisions for future replacement of the deck are included in the design. The bridge is designed for HS25 loads consisting of six lanes for local traffic, four lanes for express traffic, and two HOV lanes. Provisions are made for future replacement of the HOV lanes with light rail or WMATA trains, Figure 2.

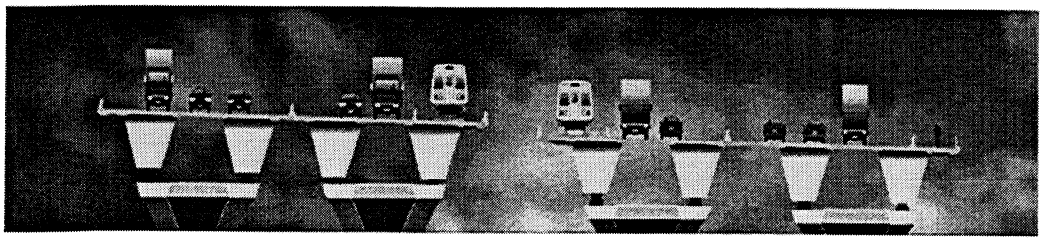

Figure 2 – Typical Section

A set of four v-piers is used to support the girders transversely at each support line. Each pier is composed of arch segments that change proportionally to reflect the varying height of the bridge. To accomplish this look and provide an economical design that can be constructed efficiently, the v-pier legs consist of precast, match-cast hollow concrete box sections that will be post-tensioned in place. To provide uniformity in the box section dimensions, the piers are grouped into two types based on the height of the pier and geometry of the pier legs. As the pier becomes shorter within the group, box sections at the base are eliminated to provide the proper height of each pier. The v-pier legs are tied together at the top with a precast hollow section beam that is post-tensioned to remain in compression under all loading conditions (Figure 3). The tie beams are hidden underneath the concrete bridge deck between the box girders.

The soils vary along the length of the bridge, and can generally be divided in three zones. In the navigation channel zone, 70 feet of mud overlies a 10-to-20 feet zone of sand and gravel, and a thick zone of hard clay. Beyond the river channel, the river bottom is composed of a 15-to-25 feet layer of mud, overlying a thick hard clay layer. The soil stratigraphy at the Virginia shore is composed of a 10-to-30 feet fill layer, overlying a 10 feet layer of sand and gravel, and a 20-to-50 feet layer of hard clay. Extensive soil investigation has helped to determine that the foundation depth is at approximately Elevation –145 at or near the channel, at approximately Elevation –100 beyond the river channel, and at approximately Elevation –70 at the Virginia shore. Pile load tests are being conducted to confirm the pile load capacities, the expected settlements, and other design parameters. Hydraulic studies have determined that the scour depth in a 500-year flood may reach approximately 60 feet in the soft layer of mud.

All foundations are supported on plumb and batter piles of various diameters. The largest foundations are near the navigation channel, where the water depth is approximately 25 feet. These foundations are supported on 54-inch cylindrical piles filled with concrete to the level of hard soil. Design requirements for the maximum scour event and to some extent stiffness-related issues have been decisive factors in the design of these foundations. The rest of the river foundations consist of 42-inch diameter cylindrical piles. The Virginia shore footings are supported on 36-inch diameter piles. The design of the piles indicates that about half of the capacity of the piles will be in end bearing with the other half developed in side friction. Due to the excessive depth to rock, a true end bearing pile system is not cost-effective. Reinforcing cages will extend into the pile caps to permit connections that can transfer moments. Batter pile locations will be carefully coordinated to avoid interference with each other and the existing bridge piles.

Elastomeric bearings with a lead core are used throughout. These bearings provide rigidity for longitudinal and transverse service loads, while allowing thermal expansion. They also uniformly distribute the horizontal loads to all piers. Their isolation properties including high damping which help reduce the seismic loads.

A single cross slope has been established for both bridges. This slope is consistent with the required superelevation at the curved portions of the alignment and reduces the transition lengths that would otherwise be required if a crowned cross slope section in the straight segments were adopted.

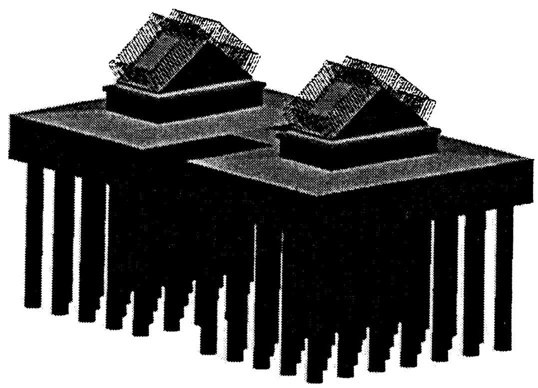

Figure 3 – Typical Foundation Arrangement

Bridge Description - The Bascule Span - A 260-foot long eight-leaf steel bascule bridge, supported on cast-in-place post-tensioned v-shaped piers, spans the 175-foot-wide navigational channel (Figure 4). The bascule span is fully compatible with and integrated into the overall arch spans resulting in a seamless overall appearance of the bridge. The eight-leaf bascule bridge was chosen due to the great width of the roadway in each direction of traffic (110 and 124 feet respectively). This system prevailed over an earlier four-leaf bascule configuration, due to its superior stiffness and because it can allow maintenance of a leaf in the open position without interruption of traffic. Due to live load configuration requirements (HOV lanes vs. rail loading), the bascule leaves are not symmetric. Steel I-sections are used for the bascule girders and the floorbeams, which are rigidly framed into the girders, to obtain a framing system with superior stiffness. The deck of the bascule bridge is composed of 7.5-inch-thick, cast-in-place, lightweight microsilica concrete. This type of deck has a proven performance history in bascule spans.

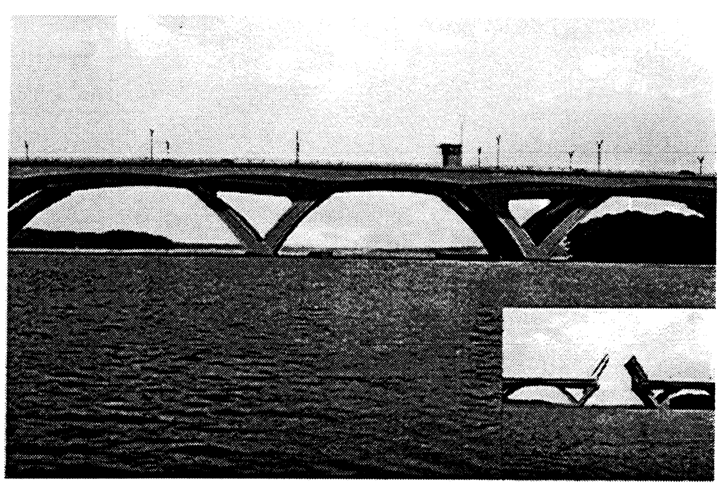

Figure 4 – Bascule Span

The live load support of the bascule girders is in front of the trunnion, a location that reduces the loads applied to the trunnion and the bending moments in the bascule girders. The trunnion design uses a cast steel hub to connect the trunnion shaft to the two webs of the bascule box girder. The trunnions rotate in bearings that rest on top of steel trunnion towers. A fixed trunnion shaft was considered but a rotating shaft was selected for ease of access for inspection and maintenance of the bearings. The trunnions do not go through stress reversal under live load or during bridge openings. They are designed for a long fatigue life, providing reliability and longevity.

A trunnion bascule bridge that rotates about a fixed point lends itself very well to rotating machinery. A system of electric motors and enclosed speed reducers powers the bascule span. This system has a long history of proven reliability and low maintenance. The operating load of the bascule is equalized between the two pinions using a differential in the high-speed reducer. Failure of any component would be sensed by tachometers and would result in immediate operator warning. The design specifications will include shop and field testing procedures that will ensure high quality mechanical installation that will be reliable and trouble free.

The operator's tower will be placed adjacent to the bascule span, as shown in Figure 4. At this location, the tower will afford a direct and clear view of the ships as they approach and cross the bridge. The tower will be supported on the south bascule pier and will lie in the 15-feet space between the eastbound and westbound bridges. There will be direct access from this tower into the machinery rooms of the bascule piers.

Analysis and Design - At this time, the bridge is undergoing extensive analysis and sizing of the fundamental structural elements. A three dimensional model of the structure has been developed to determine the global static and dynamic performance of the bridge (Figure 5). This model includes testing of several bearing support configurations, preliminary sizing of the structural members and tabulation of various important groups of loads, e.g. foundation and bearing loads. It also includes verification of the permissible rotations and deflections in critical portions of the bridge such as the bascule span.

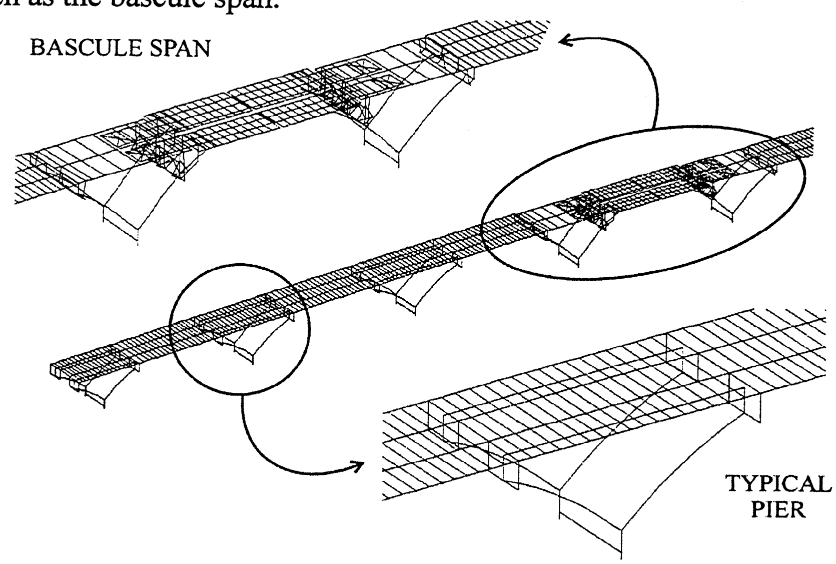

Figure 5 – 3D Model

Two aspects of the global analysis and design are of particular interest. First is the extensive use of spreadsheets for the design of the steel box girders and the global stresses of the concrete deck. The spreadsheets are being used for processing the global model results and to verify the AASHTO requirements for box girder design. Second is the iterative nature of the design process, which includes the establishment of initial sizes for members and verification of their performance. Two cases in point are the design of the elastomeric bearings and the design of a small number of foundations, whose design is affected by the underlying deep soft soils.

The design of critical areas of the bridge requires the development of special detailed models. A portion of such a model is shown in Figure 6.

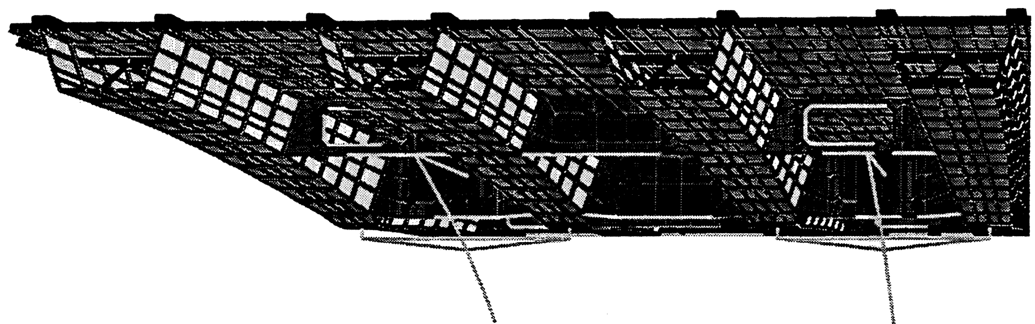

Figure 6 – Detailed Plate Element Model

The model is a detailed plate element model of the steel box girders and concrete deck. It has been used to study the shear lag problem of the deck and determine an effective deck width for use with the global three-dimensional analysis model. It is also being used to conduct special studies on the behavior of the box crossbeams. These studies examined the local stresses of the boxes around the openings (Figure 7) compared the behavior of composite versus non-composite crossbeams, and finally confirmed the ability of the global model to correctly represent the behavior of the box crossbeams.

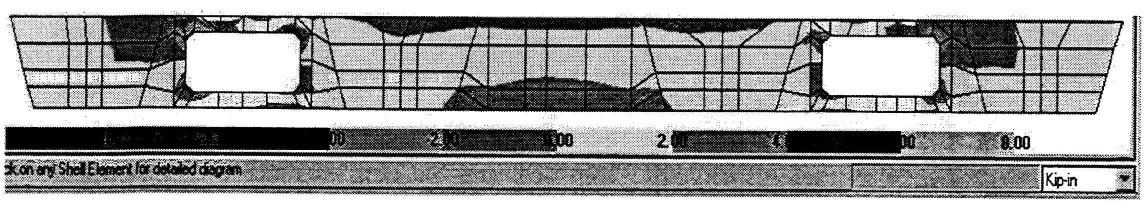

Figure 7 – Local stresses

The local model shown in Figure 8 has been prepared to examine the performance of the bascule pier critical connection between tie girder, cross beam and pier leg. In particular, this model examines whether the global model results for this area of the structure represent the true stress conditions. The model consists of an assemblage of solid elements.

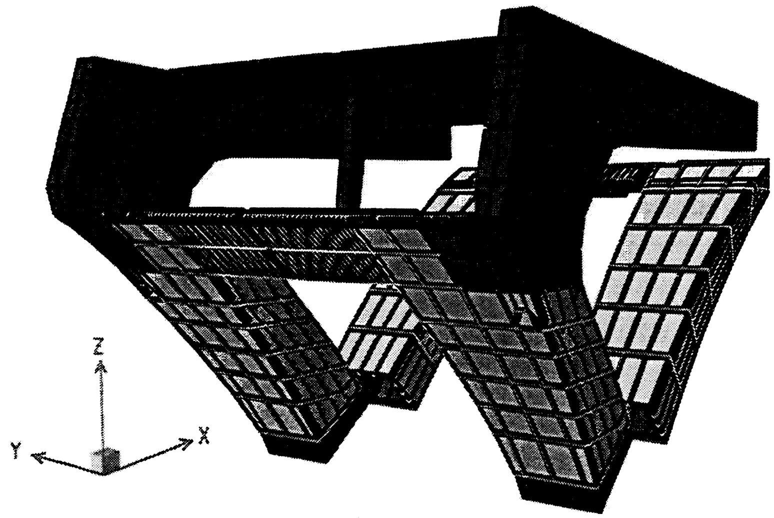

Figure 8 – Bascule Pier Model

A bascule pier deck model has been prepared to examine various configurations of the bascule pier roadway system of supporting beams. This model includes the tie girders, floorbeams, and the roadway deck. The stresses and deflections of all structural members are examined considering the erection sequence, the post-tensioning tendons, and the long-term creep and shrinkage effects.

Conclusion - The new Woodrow Wilson Bridge combines the aesthetics of a conventional arch bridge in the spirit of the other Potomac River bridges with the structural benefits of a continuous girder structure. The new bridge will have longer spans and fewer piers than the existing bridge, with independent piers that efficiently transfer loads through the soft mud to the underlying deep hard soil layers. Fewer piers open the views from the river, Jones Point Park, Rosalie Island, and Alexandria and result in a lighter structure. Moreover, the new bridge visually and functionally integrates the bascule span into the overall bridge.

Much attention has been taken in the details. The steel box girders under the bridge are painted in a shade lighter than the concrete itself, emulating the white marble of the Lincoln and Jefferson Memorials. The bridge piers over the river are lighted from below to emphasize the "v" shape. The railings, light poles, and sign structures all incorporate forms recalling the v-piers. All railings, poles, and sign structures will be painted pewter to give a light but formal appearance.

The pedestrian walkway has a light source mounted in the barrier railing between the walkway and the roadway shoulder. This provides an even light sources so both pedestrians and roadway users can enjoy the upstream nighttime vistas as well as views along the walkway toward Rosalie Island or Old Town Alexandria.

The new Woodrow Wilson Bridge will greatly increase traffic capacity over the Potomac River, minimize traffic disruptions on this major thoroughfare on the East Coast, while providing an aesthetic structure that enhances the beauty and historic integrity of the area.

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