HEAVY MOVABLE STRUCTURES, INC.
FOURTEENTH BIENNIAL SYMPOSIUM

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Willis Avenue Swing Bridge Construction

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INTRODUCTION

The Willis Avenue Bridge is a principal northbound route between the Boroughs of Manhattan and The Bronx, in New York City. In addition to carrying four lanes of traffic across the Harlem River, the bridge also provides a pedestrian and bicycle route, and is on the route of the NYC Marathon. Like the six other swing spans and four lift spans over the Harlem River, the Willis Avenue Bridge Swing Span allows most vessels to pass without opening but opens periodically to permit the passage of tall vessels.

FIGURE 1: Original Willis Avenue Bridge

The bridge connects from the local Manhattan street network, via First Avenue and East 125th Street, as well as from the FDR Drive, a limited access highway. Bridge traffic from these two approaches is given the choice of one of three destination routes in The Bronx. Vehicles can exit to Bruckner Boulevard, or head north toward Willis Avenue or to the Northbound Major Deegan Expressway. The overall length of the bridge is over three quarters of a mile, with 3185 feet of structure and 1170 feet of approach roadways. The original Willis Avenue Bridge was completed in 1901 to supplement the nearby Third Avenue Bridge which by that time was reaching its capacity to carry traffic. The most distinct part of the original Willis Avenue Bridge was the curved lattice truss swing span and adjoining through truss span over the Harlem River (**Figure 1**).

FIGURE 2: New Willis Avenue Bridge

Hardesty & Hanover Consulting Engineers (H&H) was retained by the New York City Department of Transportation (NYCDOT) to assess the condition of the existing bridge, prepare alternate reconstruction schemes, make recommendations and ultimately prepare plans for complete replacement of the bridge including design of both a new 346 foot long swing span and the substantial approach viaducts.

The hundred year old Willis Avenue Bridge had numerous non-standard geometric features which were associated with a high accident rate on the bridge and had one of the worst condition ratings in the City. The non-standard features could not be corrected on the existing roadway alignment. Further, due to the 70,000 vehicles per day crossing, all lanes of traffic needed to maintained on the Willis Avenue bridge throughout construction. An off-line replacement to the south of the existing bridge was recommended as it allowed for correction of the non-standard geometry, thereby mitigating the high accident rate and allowed construction to proceed on a parallel alignment with minimal impact on traffic. A new swing span was found to be the most suitable movable bridge type for this site (**Figure 2**).

The State Historic Preservation Officer (SHPO) found the Willis Avenue Bridge and the adjacent Willis Avenue Station eligible for listing on the National Register of Historic Places. The stipulations of SHPO in combination with the needs of vehicular and rail traffic and navigation all influenced the design parameters for this project.

Notice to proceed for the five year, $612m, project was given to Kiewit Constructors/ Weeks Marine, JV in late August 2007. Hardesty & Hanover continued to provide Construction Support Services for the project as it remained on track for substantial completion by the end of 2012. This paper discusses design as well as construction of this major project.

HISTORY OF THE WILLIS AVENUE BRIDGE

Authorized in 1894 and opened to traffic on August 22, 1901, the original Willis Avenue Bridge carried two-way traffic from First Avenue and E. 125th Street in Manhattan to Willis Avenue and E. 134th Street in The Bronx. The Willis Avenue bridge was constructed shortly after the adjacent Third Avenue Bridge. Both of these bridges were designed by Thomas C. Clarke. The original structure included four Manhattan Approach spans, the Swing and Through Truss spans, and 15 Bronx Approach spans. The original operating machinery was steam driven, with the steam plant located in the operator's house above center span on the swing span. The connection to Bruckner Boulevard was added in 1905. The bridge was converted to one-way Bronx bound traffic at the time of a major reconstruction in the 1950's which added the FDR Drive northbound connection and totally replaced the Manhattan Approach spans.

For many years, swing spans were the preferred method for accommodating marine traffic on heavily used waterways connecting low lying areas. This type of movable span became the predominant type on the industrial Harlem River. Over the past two hundred years, more than twenty swing bridges have been built over the Harlem River including the seven current swing spans as well as twelve predecessor swing spans.

Unlike the other Harlem River bridges, the original Willis Avenue Swing Span was not centered on the River. Its Manhattan Rest Pier was located at the edge of the relieving platform which defines the Manhattan shoreline. The Swing Span was flanked on The Bronx side by the Through Truss Span which provided an additional navigation channel for vessels of low height. This arrangement of river spans was justified since it minimized impacts on carfloat operations and other activities associated with the Harlem River Yard. The original Willis Avenue Bridge, with its unsymmetrical span arrangement has been regarded by many as one of the least attractive bridges on the Harlem River. As the river uses associated with the Harlem River Yard declined, so did the need for this unsymmetrical span arrangement. Navigation was further complicated at Willis Avenue bridge when the Triborugh Lift Span was built in the 1930's just downriver in a position favoring navigation on the opposite side of the river. A new span arrangement was proposed for the replacement bridge to correct this concern (**Figures 3 and 4**).

The historical high in the number of recorded annual bridge openings was 5,132 in 1917, and openings have declined steadily since then. More recently there are approximately 30 openings per year with the majority of the openings being for maintenance purposes. The decline in openings of the bridge reflects the historical decline of marine traffic on the Harlem River yet the US Coast Guard still mandates that a span of this height be able to open to allow occasional tall vessels to pass.

Eccentric rotation and transverse movement of the old Swing Span, the lack of active bridge power from the Bronx and the poor condition of the submarine cables made the continued reliable operation of the old span uncertain. In addition, the last major mechanical and electrical rehabilitation occurred fifty years prior. Maintenance crews kept the span working but upgrades were definitely necessary.

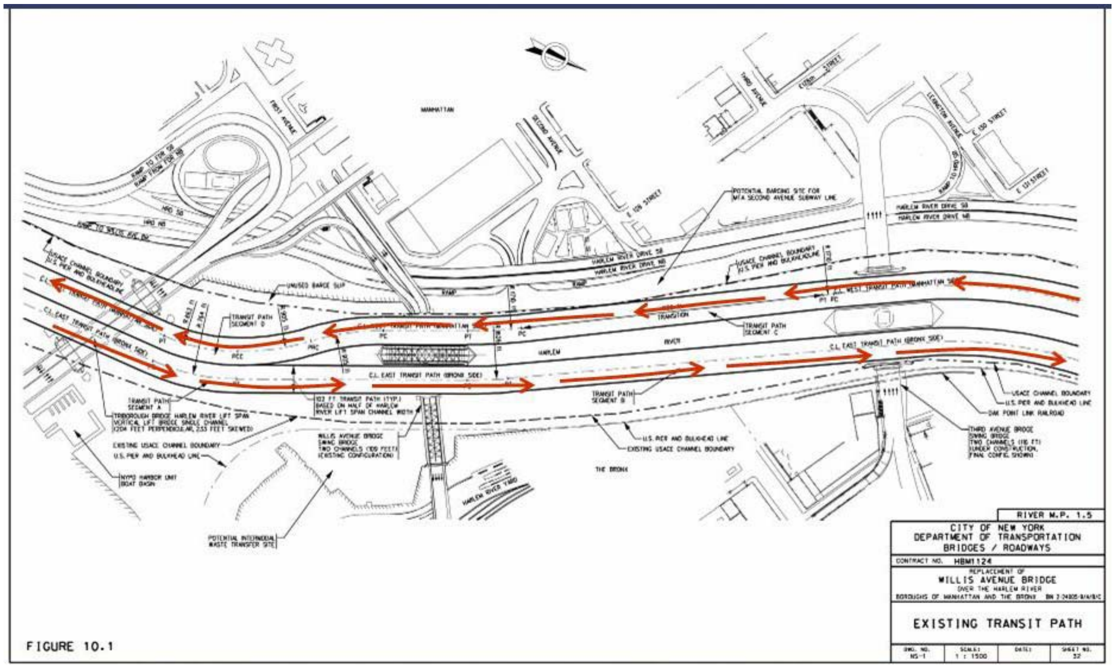

FIGURE 3: Prior Navigation Path

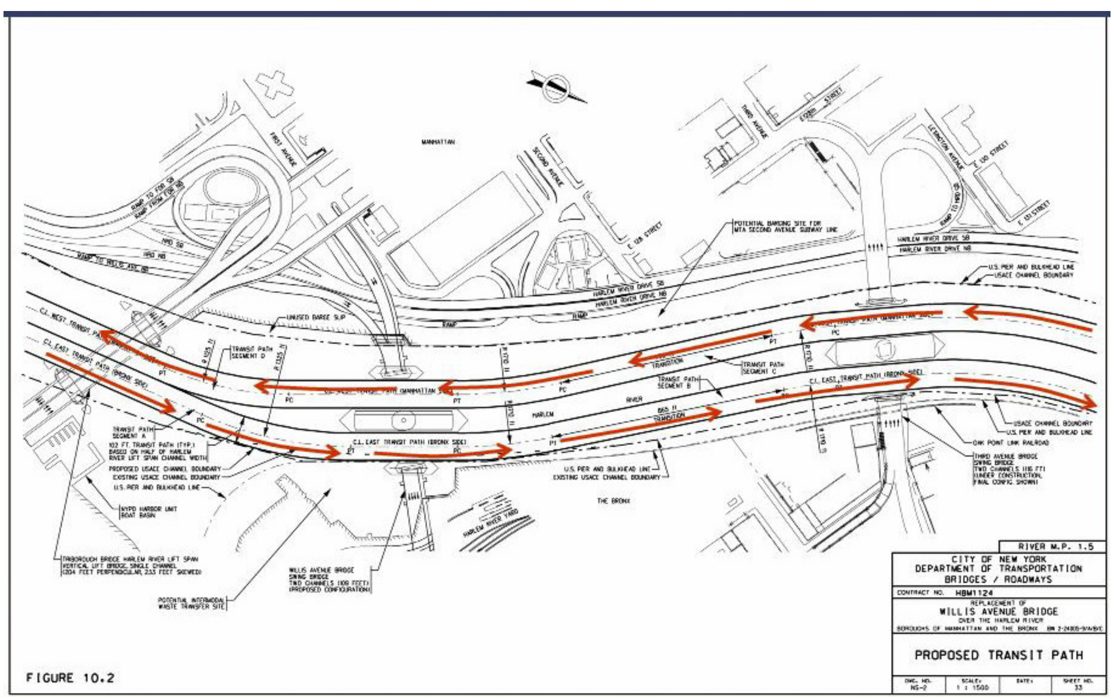

FIGURE 4: New Navigation Path

RECONSTRUCTION ALTERNATIVE EVALUATION

The Bridge Reconstruction Project Report included development of viable reconstruction schemes for the Willis Avenue Bridge. Many factors in addition to the structure condition played a key roles in selection of an appropriate reconstruction scheme. Based on the evaluation of the bridge, the reconstruction of the bridge should meet the following objectives:

- Ensure a minimum 30 year service life (100 years desirable).
- Minimize future maintenance needs.
- Eliminate the non standard geometric features.
- Provide adequate structural capacity (MS18 minimum; MS23 desirable) and adequate fatigue life.
- Meet applicable seismic criteria.
- Minimize and manage potential conflicts with adjacent projects.
- Minimize traffic impacts during reconstruction.
- Address environmental issues, including hazardous materials, historical significance and potential impacts on parkland.

The Bridge Reconstruction Project Report provided the rationale for replacement type selection. Further assessment in the Design Report/Environmental Impact Statement (DR/EIS) prepared for FHWA eliminated all but the one preferred alternative, off line replacement with a new swing span.

Due to Coast Guard requirements, any new river span would need to be movable. Various movable bridge types were considered including bascules and vertical lifts. In the end, a new swing span similar to to others in the area was preferred. This alternative was endorsed by the State Historic Preservation Office. The swing span offers the advantage of similarity to other NYCDOT owned bridges on the Harlem River. This is a significant advantage from a maintenance standpoint. Further, swing spans provide a low and visually unobtrusive profile, continuation of historic use of swing bridges in the area and cost savings over a vertical lift span. Therefore, a swing span was recommended for the Willis Avenue Bridge and this scheme was advanced into final design.

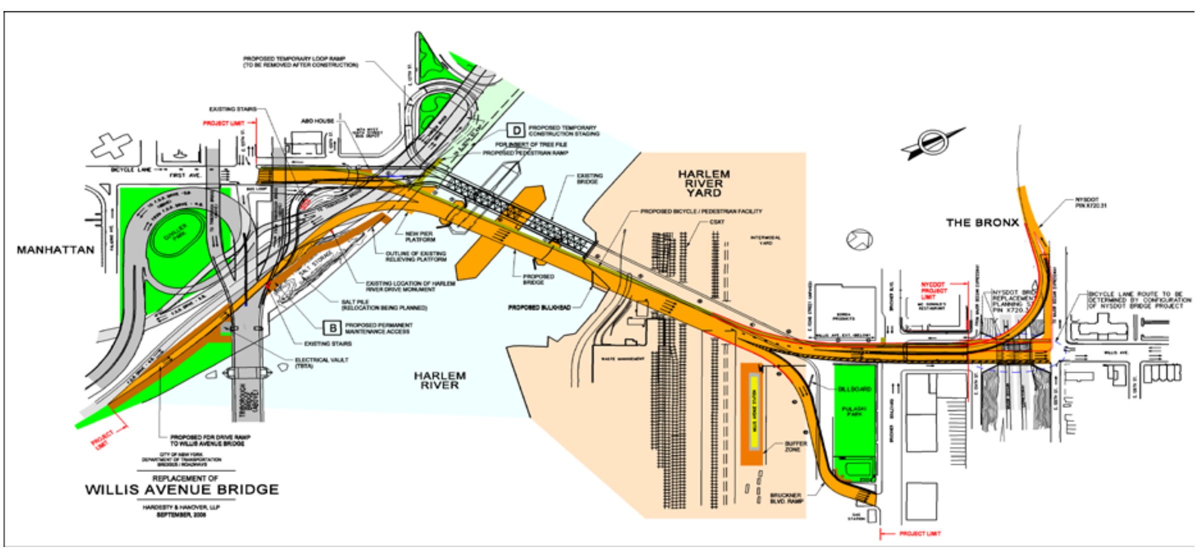

FIGURE 5: Off-line Replacement Bridge

SWING SPAN DESIGN

Once the decision was made to replace the existing bridge, the alignment drove many of the design decisions. There was ample room to the south of the existing bridge for a new bridge provided that its alignment could tie in at each of the four existing ramp termini (**Figure 5**). At the Manhattan end of the bridge, the tight s-curve on the FDR Drive ramp connection was particularly problematic as was the sharp curve to the right at the shoreline marking the beginning of the swing span. This ramp also had to be aligned between the columns of the RFK Triborough Bridge. The optimum alignment addressing both of these geometric deficiencies placed the bridge close to the existing bridge on an alignment that was slightly skewed to the existing one. The convergence of the two curved ramps pushed the movable span away from the shoreline to a point further out into the river. This swing span position would be consistent with the preferred channel alignment and navigation path.

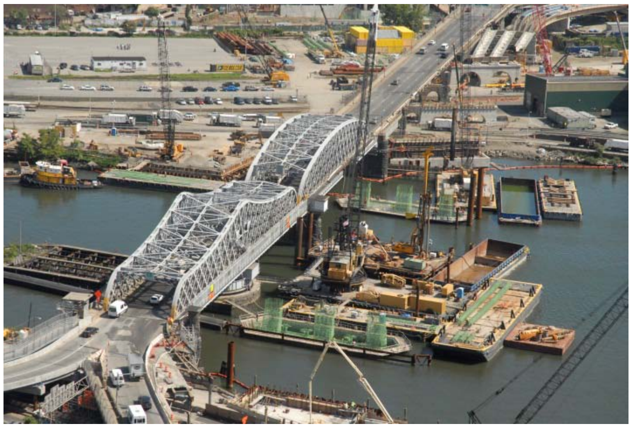

FIGURE 6: Off Line Pivot Pier Construction

With two swing spans built on close parallel alignments, simultaneous opening of the swing spans for passage of tall vessels would not be possible. The location of the new pivot pier was set staggered with the existing one so that foundation construction would not interfere with operation of the existing swing span (**Figure 6**). During construction, navigation was shifted to one or more of the available channels with at least one channel passing beneath the existing swing span. This arrangement was used up until the new swing span was floated into position. Once the new swing span was in position, the concrete deck was placed and machinery was aligned to make the swing span operational under backup operating systems. Until the new swing span was ready for traffic, the existing swing span remained open for traffic but could not open for navigation for several months. Immediately after shifting traffic to the new swing span, the old swing span and flanking span were removed to clear space for opening the new swing span. Initial swing span operation was under backup systems while the final primary operation system was hooked up and tested. Test operations occurred during overnight periods to minimize traffic disruptions. The float in operation was a key project milestone which occurred in August 2010 (**Figure 7**).

FIGURE 7: Swing Span Float in Operation

The new swing span is a through truss type with four lanes and a twelve foot wide bikeway /walkway. The span provides two 109 foot wide navigation channels. The overall swing span is 75 foot wide and 348.5 foot long (**Figure 8**). The floorsystem consists of floorbeams and stringers with a half depth filled steel grid deck. The truss is supported by two central floorbeams which transfer load to a longitudinal pivot girder and the center pivot bearing. These two floor-beams form the walls of a machinery room located below deck level (**Figure 9**).

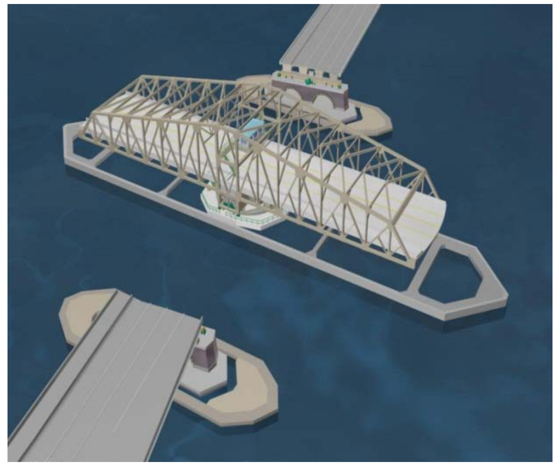

FIGURE 8: New Willis Avenue Swing Bridge

MECHANICAL SYSTEMS

The new swing span is a center pivot bearing type with a spherical roller thrust bearing capable of supporting the entire weight of the 2500 ton swing span and providing seismic restraint. This cutting edge bearing offers minimal friction during operation and is presumed to be the largest bearing of this type in the world in this application (**Figure 10**). There are eight balance wheels arranged on a 62.84 foot diameter track. Operating machinery includes a pier mounted rack, a pair of pinions and right angle reducers driven form a central differential reducer. There are pier mounted eccentric end lifts at the rest piers and span mounted centering lock machinery (**Figure 11**). A total of four center wedges are located at the pivot pier. An electrical room and storage room flank the machinery room.

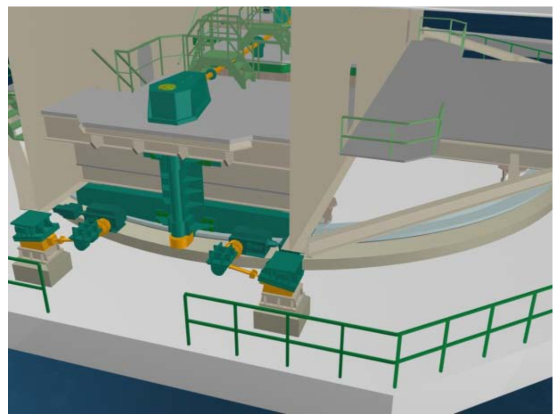

FIGURE 9: Below Deck Framing and Machinery

FIGURE 10: Spherical Roller Thrust Bearing

FIGURE 11: End Lifts and Center Locks

ELECTRICAL SYSTEMS

The bridge control house is located on the swing span above the roadway and houses the control console, CCTV and communication systems (**Figure 12**). The remaining major components of the bridge's electrical control system are located inside the swing span electrical room underneath the roadway. An auxiliary bridge operator's house is provided on the Manhattan approach which houses locker facilities for the bridge operators and an electric service vault (**Figure 13**). Electric Power for bridge operation is provided from two power grids for redundancy. An Automatic Transfer Switch (ATS) located in the swing span electrical room will switch power feeders in case of electrical service interruption. In addition there is a diesel operated hydraulic power unit in the event of a power outage. Routing power and controls to the swing span is via flexible cables passing through the center pivot bearing. Fully redundant electrical systems are provided for operation of the span and the associated auxiliary equipment in the event of failure of the primary systems.

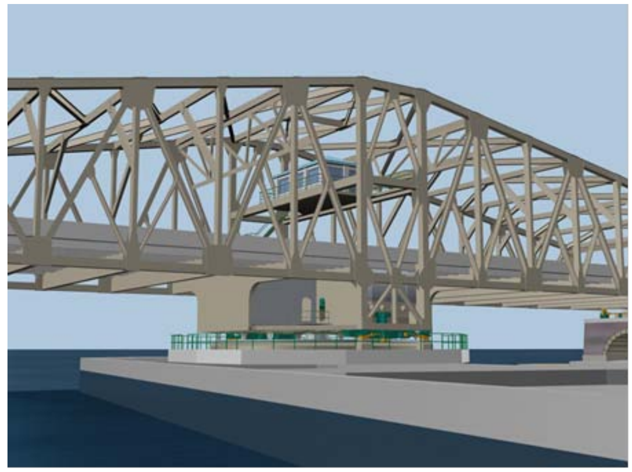

FIGURE 12: Control House

C gates, end lifts, center wedges, centering locks and s eration of the bridge will take place in the proper sequence. Key-operated bypass switches are provided at the control console to permit bypassing an interlock in an emergency. Two traffic warning gates and two barrier gates are provided on each approach. The gates and barriers are operated from either the Control Console or by the west and east gate control boxes located in the sidewalk area on the north side of the approaches adjacent to the barrier gates.

FIGURE 13: Auxiliary Bridge Operator's House

APPROACH SPAN STRUCTURES

The approach structures account for roughly 85 percent of the bridge deck area and 75 percent of the overall project cost. At the Manhattan end of the bridge, the FDR Ramp and the First Avenue approach merge just before the swing span. These spans include a combination of straight and curved girder spans some of which are supported on transverse steel cap beams straddling the Harlem River Drive. There are concrete cantilever retaining walls, abutments, wall type piers and multi-column piers as determined by project geometric and staging requirements. The FDR approach consists of eleven spans while the First Avenue Approach has five spans passing over a bus turnaround loop, the Harlem River Drive, the waterfront marginal street slated for a future park and the near shore area of the Harlem River. At the Bronx end of the swing span four steel trapezoidal box girder spans pass over the Harlem River Yard including spans over five active railroad tracks plus a planned future track, access roads to a waste transfer facility, and access roads for a future intermodal transfer facility (**Figure 14**). The mainline bridge continues towards Willis Avenue where it straddles an existing roadway known as the Willis Avenue Extension. New work in this area occurred concurrently with and very close to the construction of a new apartment building on an adjoining lot.

FIGURE 14: Trapezoidal Box Girder Spans

As the bridge approaches Willis Avenue, a NYSDOT designed connector ramp to the Northbound Major Deegan Expressway diverges and crosses above the Bikeway/Walkway eliminating the conflict between pedestrians and the flow of traffic to the Major Deegan Expressway. The NYSDOT and NYCDOT projects were carefully coordinated to result in the overall best profile and alignment. Just east of the Railyard, the Bruckner Blvd Ramp splits off to the right curving past the site of the former Willis Avenue Station to connect with the existing ramp terminus adjacent to Pulaski Park. The superstructure at the Bronx end past the railyard includes two transverse steel box girders straddling roadways and but mostly steel straight and curved girders seated directly on the piers. The Bronx mainline includes eight spans while the Bruckner Blvd Ramp has four spans with a tight radius. Piers at the Bronx end includes column type piers supporting the transverse box cap beams as well as a series of arched piers with solid granite masonry facing reminiscent of the existing historic piers at this end of the bridge (**Figure 15**). Abutments consist primarily of precast modular walls as well as some permanent soldier pile walls.

FIGURE 15: Arched Granite Faced Piers

Foundation types vary throughout the site to accommodate diverse subsurface conditions and loadings. The two most heavily loaded piers use 5-foot diameter drilled shaft foundations while twelve other piers and abutments plus the relieving platforms along the river use 4-foot diameter drilled shafts. There are a total of 271 drilled shafts on the job with lengths varing from 32 foot to 130 foot deep. There also are 9 5/8" diameter bored in piles, H-piles and spread footings each selected to best accommodate the wide range of subsurface conditions. Sections of bulkhead and relieving platforms were replaced at both the Manhattan and Bronx waterfront.

The four river piers, including the pivot pier, two rest piers and a pier at the Manhattan bulkhead area are built on precast pier boxes elevated above the river bottom. The rest pier boxes are 117 foot long by 35 foot wide and the pivot pier box is 66 foot in diameter. The original plan was to float the boxes into position as a single piece. The contractor has opted to frabricate segmental boxes and lift them into place over the drilled shafts. The boxes are temporarily supported and filled with concrete to form a base for the pier shaft (**Figure 16**).

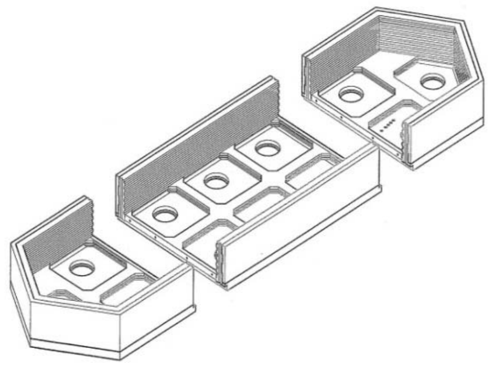

FIGURE 16: Segmental Precast Concrete Pier Box for Rest Pier

FIGURE 17: Temporary Loop Ramp

Temporary structures were required to facilitate staging and at maintenance of traffic crossovers. A temporary loop ramp structure was required to divert traffic from the FDR Drive Ramp so that two lanes of traffic could be maintained at all times while replacing that ramp (**Figure 17**). Other work included city street reconstruction and extensive associated utility work including municipal sewer and water as well as coordination of private utility work including electric, gas and telephone facilities. There is also landscaping, park restoration work, and historic preservation work.

The project required permits from the US Coast Guard, The Army Corps, New York State Department of Environmental Conservation, The NYC Parks Department, NYCDOT OCMC (Traffic), and CSXT Railroad, among others.

CONSTRUCTION HIGHLIGHTS

Some of the highlights of construction included the pier box lifting operations and the dramatic swing span float in.

The concrete pier boxes for the four river piers were precast in Virginia complete with granite cladding and stainless steel reinforcement for added durability. When the drilled shaft work was complete at a specific river pier, heavy floating equipment was used to hoist the boxes into place over the drilled shafts. The boxes were then temporarily supported and filled with concrete. This economical arrangement simplified construction in the river and allowed for elevated piers with a minimal environmental footprint and minimal hydraulic constriction of the river.

One of the more memorable events of this project was the dramatic swing span float in operation. The journey of the Willis Avenue Bridge swing span to its new home over the Harlem River was the subject of much press coverage, but the full story began well before the actual float in operation. The new swing span truss was fabricated and shop assembled in Wisconsin to assure proper fit-up prior to shipping the individual truss components to a riverfront facility just south of Albany, New York (**Figure 18**). Some of the larger components needed to be shipped via barges through the Great Lakes and the New York State Canal system. Final assembly of the swing span structural members as well as most architectural, electrical and mechanical

FIGURE 18: Truss Assembly near Albany, NY

work was completed in Albany. The assembled swing spa
modular transporters for its 160 mile journey down the H
The final seating operation occurred two weeks later and
barges to a pair of barges located towards the ends of the span, followed by moving and lowering the span onto the new center pivot bearing using a combination of tidal action and hydraulic jacking. Upon completion of some on site work, the new swing span opened to traffic on October 2, 2010 and the old river spans were removed over the next month.

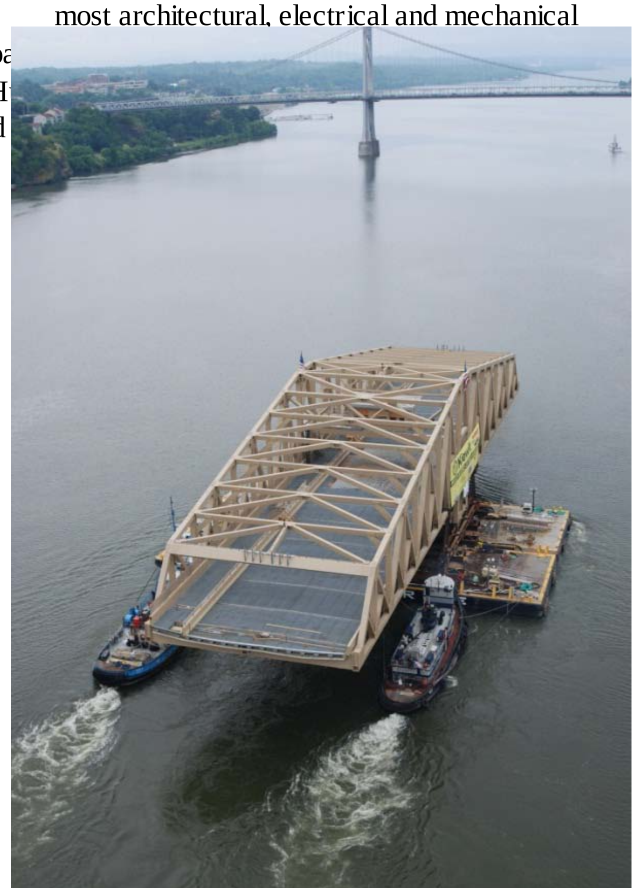

FIGURE 19: Swing Span en Route Down the Hudson River

The swing span is protected in both the open and closed position by an energy absorbing fender system. Similarly, the rest piers are protected by fenders. There are over 800 fiber reinforced plastic piles incorporated into the fenders as well as FRP wale beams and a concrete cap. The fender system is designed for a long service life in the saltwater environment yet needed to absorb ship impact energy and be open to minimize constriction of tidal exchange and hydraulic flow in the river (**Figure 20**).

FIGURE 20: Fiber Reinforced Plastic Fender System

Aesthetic details of the project were developed in coordination with the Public Design Commission and the State Historic Preservation Office. Piers along the mainline and at the Bronx end include a series of arched piers with granite facing reminiscent of the piers of the historic original bridge. The State Historic Preservation Office stipulated that one of the existing solid granite piers remain in place, that some of the existing granite be repurposed at several parks throughout the City. The granite was utilized in adjoining parks as benches and for major construction in Brooklyn Bridge Park. A new major ADA compliant pedestrian ramp provides access from the bridge to the area of a future riverfront park. Adjoining parks and green spaces were landscaped and restored as bridge construction work was completed. Even with the major work done, the final details of the project required considerable attention and make a significant difference in the final appearance of the site and its surroundings.

CONCLUSION

The hundred year old Willis Avenue Bridge needed to be replaced while continuously maintaining numerous modes of interfacing traffic. River navigation as well as numerous roadways and a rail yard could all have been affected. The solution was to build the new bridge alongside the old one. This was accomplished by assembling a new river span off site and floating it on barges to its final position. In this case a 160 mile journey down the Hudson River was required. After much fanfare, the new 2500 ton, 350 foot long swing span opened to traffic and the remaining viaduct connections were completed. The river span can swing open to allow tall vessels to pass but its regular duty is carrying over 70,000 vehicles per day. A continuous bikeway / walkway now connects Manhattan with the Bronx along the north side of the new bridge and the tight curves and rough riding surface of the old bridge are things of the past.

Due to the large scale of the project and the need to phase work at each of the ramp structure tie in areas, the project was planned for an inherently long construction schedule. However, the work has proceeded quickly and major milestones were completed ahead of schedule with virtually no impacts to the travelling public.

Construction of the project is currently in its final phase. All roadways are open to traffic and construction of ancilliary work, including the final testing of the movable span is planned for wrap up this year.