HEAVY MOVABLE STRUCTURES, INC.
12TH BIENNIAL SYMPOSIUM
November 3-6, 2008

REPLACEMENT OF THE HAMILTON AVENUE BRIDGE, A RARE HANOVER SKEWED BASCULE

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KEYWORDS: Bascule Span, Bascule Bridge, Movable Bridge, Knee-girder, Skew Bascule

Abstract

The rarely seen Hanover skew bascule, also known as a knee-girder bascule bridge is a unique and complex movable structure in terms of both design and construction. The replacement of a movable bridge during an accelerated construction period is also an incredibly difficult task to engineer and construct. Either one of these constraints would make a project difficult to execute. For the Hamilton Avenue Bridge project in New York City, however, these two levels of complexity combined to create a one-of-a-kind project that would challenge the owner, designers and constructor to achieve a near impossible goal: to replace a skewed bascule bridge with a new, fully operational span in sixty-four days.

This paper will address the design constraints of this project with respect to the complexity of a skewed bascule bridge as well the shop and field work performed for the structural and machinery interface. The impact of the highly constrained project site and schedule, 64 day construction window, will also be discussed. These aspects combined to make this $60M project unique and a highly challenging endeavor for all parties in the project team.

Introduction

At approximately 3am on August 31, 2007, four lanes of traffic heading northbound on Hamilton Avenue flowed freely across the Gowanus Canal. This may seem uneventful even though traffic is usually heavy at this early hour but it is especially notable since the traffic crossed the canal over the new East Span of the Hamilton Avenue Bridge. The new span was constructed during a traffic closure of only 64 days. During the closure the existing bridge was demolished and a new span constructed while traffic was maintained through a detailed maintenance and protection of traffic plan. The replacement of a relatively small urban arterial bridge in such a short time period may not be remarkable but this was not a typical bridge nor was this a typical, simple bridge project.

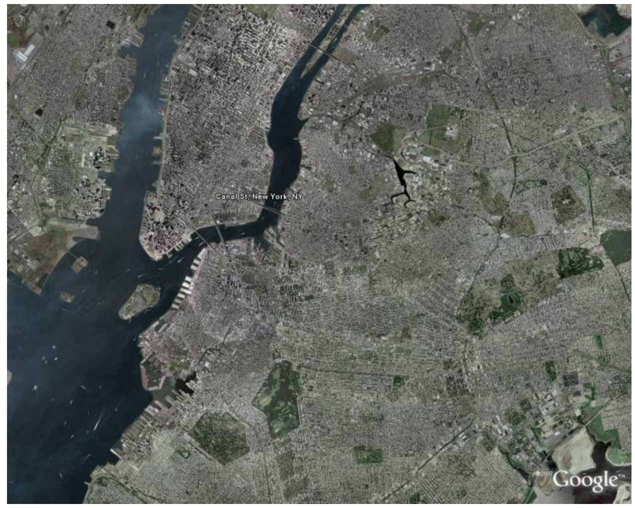

Figure 1-Project Location

The existing Hamilton Avenue Bridge was constructed in 1945 based on the novel knee-girder bascule design patented by Clinton D. Hanover of the NYC Department of Public Works and later namesake of the movable bridge engineering firm, Hardesty & Hanover. The bridge comprises two separate single leaf bascule bridges with each leaf carrying four lanes of Hamilton Avenue. The East Span carries traffic northbound to the Brooklyn Battery Tunnel and lower Manhattan and the West Span traffic southbound to lower Brooklyn. The bridge carries approximately 55,000 vehicles per day with a high percentage of truck traffic. The traffic includes both commuters from Brooklyn to the businesses of Manhattan as well as commercial traffic for delivery of goods and services throughout the five boroughs.

The bridge lies directly beneath the Gowanus Expressway which stands approximately 30 m overhead and is the entrance point to the Gowanus Canal. The canal was formerly a working waterway of Brooklyn with numerous industrial and commercial businesses utilizing the waterway for access. The changing face of Brooklyn has led to a reduction in the use of the canal for commercial purposes for most of its length. This shift in use, however, has not occurred at the southern end (entrance end) of the canal.

Figure 2-Project Site

The area between the Hamilton Avenue and Ninth Street Bridges continues to thrive as a commercial center. This segment of canal is the home of a major fuel oil distributor, a material reclamation center, and a concrete production plant. These three facilities rely extensively on the canal for the movement of material and the nature of these three businesses result in activity on the waterway throughout the year with no seasonal lulls. On average, the bridge opens approximately 900 times per year to clear vessels through the channel. The bridge is staffed full time by operations personnel from the New York City Department of Transportation, the bridge owner, and opens on-demand for vessels.

Bridge Concept Development

The knee-girder bascule spans currently under reconstruction are the second bridges at the site. The prior structure was a rolling lift bridge with a skewed deck. This type of framing was common for moderately skewed crossings with the deck in the shape of a parallelogram to match the channel crossing. The main structural elements of the rolling lift span (girders) are normal to the channel and are not parallel to the edges of the deck.

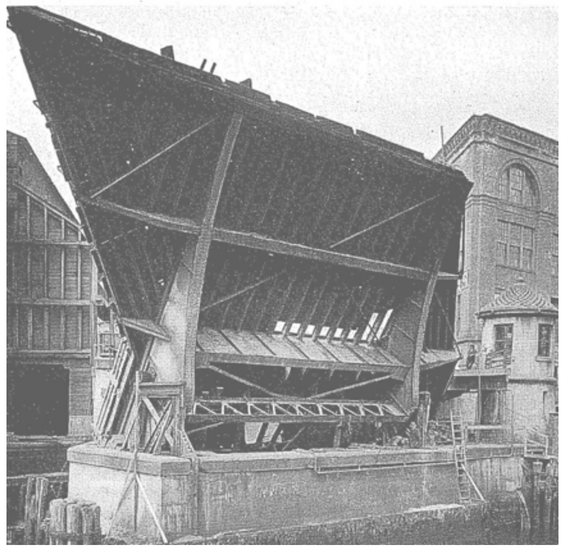

Figure 3-Original Skewed Deck Bridge in Open Position

There are a number of disadvantages to this framing configuration. The two large triangular portions of deck are cantilevered from the bascule girders with varying length floorbeam extensions. This results in variable flexibility of the deck system. In addition, the girders must be placed closer together than desirable in order to circumscribe the parallelogram about the rectangle formed by the girders and end floorbeams. This reduces the available space for both the counterweight and operating machinery. The efficiency of the bracing system is also moderately reduced but this is not of significant impact.

As the original bridge exhibited operational issues due to the design deficiencies noted above, which were compounded by the rolling lift nature of the span, Hanover, as lead engineer for the Department of Public Works of New York City, sought to improve the solution for the skewed crossing.

Figure 4-Bridge circa 1945

The end result of Hanover's efforts was the development of a knee-girder single leaf bascule span in which the main supporting elements are bent at rigid joints to accommodate the skew. This concept was patented by Hanover in 1943 prior to joining Waddell & Hardesty in 1945.

Bridge Theory and Analysis

As with any bascule bridge, the location of the center of gravity of the moving mass is of critical importance to the operational efficiency and performance of the bridge. This importance is accentuated in the knee-girder bascule design due to the geometric properties of the structure. It is readily seen that the center of gravity of the forward portion of the leaf is laterally much closer to the inner trunnion than the outer trunnion. From this it is easy to conclude that the center of gravity of the counterweight should be much closer to the inner trunnion. This location of the "natural" center of gravity of the counterweight would yield extremely heavy loads on the inner trunnion and substantially reduce the advantage of the large counterweight created by the rear portion of the bascule girders, referred to as tail girders. On the contary, if the center of gravity of the counterweight was placed at the geometric center of the counterweight the span would be subject to racking and warping. This would yield torsional stresses in the bascule girders and be highly undesirable.

The framing system of the forward portion of the span and the inclusion of the rigid knee joints eliminates the conditions noted above. This is done by using the cross girder (heel end floorbeam) as the key component of the structural system.

The tendency for warping is counteracted by the cross-girder and the framing layout of the floorbeams. The cross-girder carries moments from the tension and compression forces in the bascule girder flanges at the knee joints. Since the angular relationship of the bascule girder and tail girder portions for the two sides are equal, the moments induced are additive. The resulting counterbalancing forces of the cross-girder are then an upward force on the outer girder and a downward force on the inner girder at the knee joints. These forces tend to locate the center of gravity of the span nearer to the inner trunnion and the "natural" center of gravity discussed above.

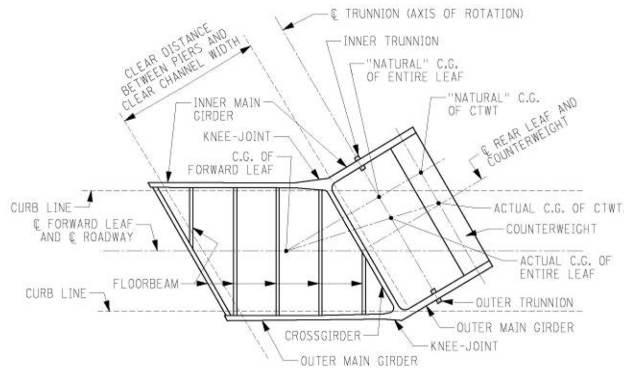

Figure 5-Key Elements of the Structural System

The floorbeams connect to the outer main girder at points further from the knee joint than the corresponding ends do on the adjacent girder. As the deck weight is nearly uniformly distributed, this results in higher moments at the knee joint of the outer bascule girder than at the inner bascule girder. This differential in moments between the inner and outer girders is offset by the cross-girder counterbalancing forces discussed above.

The combination of the cross-girder effect at the knee joint and the framing of the floorbeams relative to the knee joints alters the cumulative loads so that the loads at the trunnion are nearly equal and the center of gravity of the counterweight is located nearer the geometrical center.

This innovation design allowed the bridge to be specifically adapted to the crossing with a minimal use of material. In addition, simple shear connections are used throughout with the exception of the knee joint connections of the cross-girder, bascule girder (forward portion) and tail girder (rear portion).

Project Summary

As part of its ongoing bridge evaluation and maintenance program, the bridge owner, the New York City Department of Transportation (NYCDOT), conducted an in-depth evaluation of the existing bridge in 1998. The conclusion of the study, performed led by prime consultant Greenman-Pedersen, Inc. (GPI) and Hardesty & Hanover as the movable bridge specialists, was that the bridge superstructure possessed a number of nonconforming roadway features (lane widths, bridge railings, etc) and was functionally obsolete. The original bridge was designed by the firm of Waddell & Hardesty who would later be named Hardesty & Hanover after Hanover joined the firm in 1945.

Additionally, the bridge machinery and electrical systems were nearing the end of their useful service life. The bridge substructure exhibited signs of age but the robust original design permitted the existing substructure to be retained. Based on these conditions, NYCDOT determined a superstructure replacement was the most cost-effective solution to improve both the span operation as well as the flow of traffic on Hamilton Avenue and in the canal beneath the movable bridge.

During the study phase of the project, July and August were determined to be the lowest vehicular traffic months. The reduced traffic was a result of the summer school recess (less school bus and car travel to schools) during the summer months. As a result, NYCDOT concluded a roadway closure for one direction of Hamilton Avenue was feasible for these two months and the bridge superstructure replacement must be completed in this 64 day period.

During the roadway closure period, traffic would be maintained on the adjacent roadway using bi-directional traffic on the formerly one-way roadway. Contraflow lanes were used to address peak northbound traffic demands (morning peak traffic).

During this roadway closure period, only intermittent navigation closures were permitted due to the continuous demand of the waterway users. The constrained site, limited construction duration and active waterway, combined with the inherent complexity of the skewed bascule design, made this project a highly complex enterprise for the project team.

Replacement Bridge Design

The replacement bridges share many of the same geometric characteristics of the original spans. Each leaf spans the Gowanus Canal with a clear channel width of 14.3 m between the fenders. The clear distance between the bascule and rest piers is 15.5 m with the piers oriented parallel to the channel. The roadway is skewed to the channel crossing at an angle of 56.3° and includes four-3.35 m wide lanes (total roadway width of 13.4 m on each leaf increased from 12.8 m on the original). Each leaf also includes a 600 mm access walkway for operation and maintenance personnel at the median side and a 2.45 m sidewalk at the outboard fascia for pedestrians and cyclists.

Figure 6-New East Span-Gowanus Expressway Above

The bascule girders are spaced 13.4 m center to center and the distance from the centerline of trunnion to the toe bearings is 20.4 m. The girder and floorbeam spacing was maintained due to the interaction of the movable span with the existing pier to remain. The wider traffic lanes on the new bridge result in a wider out-to-out dimension of the leaf. This required modifications to the bridge seat at the rest pier and the front wall of the bascule pier to accommodate the new span. The new span weighs approximately 600 metric tons and opens to an angle of 74°.

Figure 7-Interior Knee Joint Connection

The bridge maintained the knee-girder design developed by Mr. Hanover. The elegance of the original design was recreated during the design phase of this project. The classical design methodology developed by Hanover was used to initially proportion the main structural members. This analysis and design was combined with more modern finite element methods and computer modeling. The results of the two methods had a very high level of correlation which reinforced the soundness of the assumptions of the original design concept.

In order to mitigate the potential erection issues in the field during the constrained construction period, the contract required full shop assembly of the bascule spans prior to shipment to the project site.

Project Status

The construction phase of the project began in August 2005 with the site preparation and mobilization phase. During this phase, extensive project technical and teaming meetings were held amongst NYCDOT, the designers and the contractor to prepare for the first roadway closure period in July/August 2007. The overall schedule includes replacement of the East Span in summer 2007 followed by the West Span in summer 2008. The period between the two closures (September 2007 through June 2008) was used for the rehabilitation of the architectural elements including the bridge operator's control house and the gate tender's house as well as the construction of an auxiliary generator house. The architectural work was designed by the project prime design consultant, GPI.

Due to the limited construction duration of the closure period (62 days), the design included the use of temporary hydraulic drive motor system for the operation of the span . As an alternative proposal, the contractor opted to utilize hydraulic cylinders attached to the rear of the tail girders for span operation. The use of a temporary operating system permitted the bridge to be returned to traffic use and operation for marine traffic without the final alignment of the gear train. The final alignment work is highly specialized and requires skilled millwrights to ensure proper alignment. It was determined by the project team that the long term interests of the bridge were better served by performing this work after the 62 day closure period.

In July and August 2007, the East Span was removed and replaced with the new span. Similar work for the West Span was performed in the same months of 2008. Currently, traffic is operating on the two replacement spans of the Hamilton Avenue Bridge. Final field alignment and operational testing is on-going. The project is scheduled for completion in early 2009 after final movable bridge operational testing and commissioning.

Structural and Machinery Interface

From a structural and machinery standpoint, the rear portion of the leaf (portion behind the cross girder) is similar to most simple trunnion style bascule bridges. The rear portion comprises the two tail girders and trunnions supported on steel trunnion towers and the counterweight for span balance.

The mechanical systems for the Hamilton Ave Bridge includes: Trunnion; Span Lock; and Operating Machinery Systems. The installation of the components of these systems requires close coordination with the structural work.

Figure 8-Trunnion Tower and Gearing

Trunnions

There are two trunnions that support each bascule span. A trunnion shaft is connected to each bascule girder using a hub and ring assembly. Each end of each shaft rests in a bearing, which allows the bridge to rotate about the trunnion axis. The bearings are bronze cylindrical sleeve type, which are grease lubricated. The trunnion shaft is essentially a simply supported beam of circular cross section.

The trunnion bearings are supported on trunnion towers. The trunnion towers are basically a truss frame which transmits the dead and live loads down the counterweight pit floor and walls. The trunnion towers also support the main pinion bearings and one of the two bearings for each of the secondary gearing pinion shafts.

Figure 9-Trunnion and Girder Assembly

Span Locks

Each leaf is equipped with two span locks located inboard of each girder and are mounted on the rest pier. There is a socket located on the toe floor beam inboard of each girder which accepts the lock bar to secure the span in the down position. The lock bar itself is basically a cantilever beam supported by two guides and is inserted into a socket when driven. Each bar is operated by a crank and connecting rod mechanism. Both cranks for each leaf are driven by a central reducer and motor.

Operating Machinery

The span operating gear train for each bascule span is comprised of (2) sets of racks & pinions, (2) secondary sets of open gearing (2) secondary reducers and (1) primary differential. Power is generated by an electrical motor (1 of 2 is used at a time) which is coupled to the differential reducer. The torque of the primary reducer is equalized to two output shafts by internal differential gearing. The output of each shaft is than connected to the input shaft of a secondary reducer by a floating shaft. Each secondary reducer is coupled to a secondary pinion/gear set which in turn drives a pinion shaft. Each pinion drives a rack which is mounted to each of the bascule girders, such that the pitch diameter is concentric with the trunnion shaft. The bridge is rotated by applying the required operating force to the rack. Braking force is applied by (2) motor brakes and (2) machinery brakes. The motor brakes are mounted on each input shaft to the primary reducer and there is a machinery brake mounted to each of the input shafts of the secondary reducers.

Figure 10-Operating Machinery

Auxiliary machinery is also provided as an alternate method to the electrical motors for span operation. The main auxiliary backup system is a hydraulic motor coupled to the primary reducer. The hydraulic motor is driven by a hydraulic power unit (HPU). A secondary auxiliary system consists of additional gear reduction coupled to the primary reducer. However it is noted that the secondary auxiliary operation is very slow and intended for only small span movements.

Shop Work

The most critical of the mechanical shop work is the trunnion assemblies. The trunnion assemblies include the trunnion shaft, trunnion hub, hub ring, and the bearing assemblies. The installation process starts in the shop. This process includes both the proper fabrication of the mechanical components as well as the structural components.

Figure 11-Shop Assembly of West Span

After the completion of the trunnion components the trunnion shafts were inserted into their respective hubs. This was accomplished by heating the hubs on the East bridge and inserting the shafts at ambient temperature. On the West bridge the assembly process was accomplished by both heating the hubs and cooling the trunnions shafts. After the respective trunnion shafts and hubs were complete the assemblies were ready for installation into their tail girders.

The structural work requires that the span be assembled with the pair of trunnion being collinear. This is first accomplished by machining the girders to accept the trunnion components such that when assembling the bridge structural components the two shafts are collinear.

After completion of the tail girders the trunnion shafts/hubs were assembled in the tail girders. This included installation of the hub ring and fasteners to secure the components in the final assembly. After completion of the tail girders/trunnion assemblies the trunnion bearings were temporarily assembled onto the journals to check the fit around the shaft. This inspection was not only to shop check the fit of the bearing but to use the results during the field assembly to confirm the bearing alignment with respect to the shafts.

Figure 12-Lock Bar and Crank Assembly

The shop tail girder/bridge assembly started with the tail girders, floor beam 6 (floor beam closest to the trunnions) and the counterweight box. The components were put into their respective alignment while achieving the proper trunnion alignment. After this had been completed the bridge assembly continued with the shop connections of the bascule girders and floor beams. After confirming the alignment of the structural components and the trunnions were properly aligned the rear portion of the bridge was removed. The forward span assembly continued with the stringers and grating.

The span locks were fabricated and assembled in the shop as main assemblies for shipment to the field. The main assemblies included the lock bar & guides, crank shaft & bearings and reducer & motor. In the shop the function of the lock bar, crank and connecting rod was checked prior to shipment to the field.

Figure 13-Primary Machinery Assembly

The operating machinery was fabricated as main assemblies for shipment to the field. The main assemblies included primary reducer machinery, auxiliary machinery, secondary gear reducers, secondary pinions, main pinions with secondary gears. After these units were completed, functional tests were performed prior to shipment to the field for installation.

Figure 14-Secondary Machinery Assemblies

Figure 15-Main Pinion Assembly

Field Work

The field machinery installation sequence was a critical path for completing the bridge construction in the milestone requirements. The first task was for the Contractor to install their Temporary Operating System (TOS).

The TOS consisted of two hydraulic cylinders attached to the tail girders behind the trunnions. The cylinders are in the extended position with the bridge closed. To open the bridge the cylinders are retracted. To close the bridge the cylinders are extended.

The TOS allowed the existing bridges to be operated under a hydraulic cylinder system until they could be replaced. After each respective bridge is replaced the same TOS for the existing bridge operation would be reconnected to the new bridges to allow operation until the permanent machinery system could be installed.

The first mechanical task in the installation of the new bridges is to properly align the trunnions. This first started with aligning the new bearings on the new trunnion towers. After this was completed each of the tail girders were than installed. After the tail girders were in place the field assembly of the bascule spans commenced. A piano wire assembly was utilized through the center bore of the trunnion to establish and to continually monitor the condition of the alignment throughout construction of the bascule spans. In addition the bearing fit was also inspected to confirm the bearings were properly aligned to their shaft journals.

Figure 16-Trunnion and Bearing Assembly

During the bascule span construction the span lock work had also been taking place. The machinery was aligned with respect to the bascule span toe floor beam. After the machinery had been installed the operation of the new span locks was integrated with the TOS control system.

After the completion of the span the bridges was put into operation using the TOS. During operation under the TOS the East racks were aligned with respect to the center of rotation about the trunnions. After the proper alignment had been secured permanent connections were made between the rack support and the girder.

With the East racks aligned to their respective girders the next task was to align the open gearing and remaining operating machinery. The alignment for the East operating machinery was secured during night closures using the permanent auxiliary hydraulic system. After an acceptable alignment had been achieved permanent connections were made been the supports and the trunnion towers and machinery floor.

The West rack and operating machinery alignment is scheduled for the Fall/Winter of 2008.

Conclusion

The Hamilton Avenue Bridge project was a successful project through the combined efforts of the members of the project team. This complex project was executed under difficult design and construction constraints and serves a testimonial to the dedication of the owner, designer and constructors to mitigating the impacts of construction on the traveling public while ensuring their safety now and for the future.

Figure 17-New East Span with Existing West Span

Acknowledgements

- New York City Department of Transportation – Owner
- Greenman-Pedersen, Inc. – Prime Consultant
- Hardesty & Hanover, LLP – Movable Bridge Designer
- Kiewit Constructors, Inc. – Contractor
- Urbitran Associates – Resident Engineering Services