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"The Design and Construction of the Ninth Street Vertical Lift Bridge in Brooklyn"

by William E. Nyman, P.E.
Hardesty & Hanover, LLP

Design and Construction of the Ninth Street Vertical Lift Bridge In Brooklyn

William E. Nyman, PE
Principal Associate
Hardesty & Hanover, LLP

1 - Introduction:

Hardesty & Hanover was selected by the New York City Department of Transportation to prepare a Bridge Reconstruction Project Report and subsequently to prepare the preliminary and final design and provide construction support services for the Ninth Street Bridge over the Gowanus Canal in the Borough of Brooklyn. Since then, numerous design and construction challenges were met and the bridge is now open to traffic. This paper gives background information on the design constraints and the evolution of the unique design which fits a new vertical lift bridge directly below an overhead transit structure carrying four elevated subway tracks. However, the focus of this paper is the construction of the bridge along with the methods by which the challenging design was implemented in the field.

2 - Project History:

The 100 foot wide Gowanus Canal was constructed in the 1840's by dredging and bulkheading the shallow Gowanus Creek thereby allowing sailing vessels to access points further inland in northwestern Brooklyn. At the time, this area was undeveloped swampland. The mile and a half long canal resulted in heavy industrialization of the area it serves. The canal continued to be very busy with navigation until the 1960's when the maritime activities in the New York City area generally declined. The area around the canal is still heavily industrial but the uses are less canal dependent. Ninth Street has crossed over the Gowanus Canal in Brooklyn, New York for over 100 years. A swing bridge was constructed at this site in the 1800's to tie Ninth Street on the east side of the canal with West Ninth Street on the west side of the canal. It was one of five movable bridges providing continuity of the city street grid across the canal.

By 1903, the swing bridges with their pivot piers in the center of the narrow canal were found to be inadequate for the demands of navigation and a replacement was found necessary. The Third Street, Union Street and Ninth Street bridges were all replaced with Scherzer double leaf rolling lift bridges of similar design. The rolling lift bridge at Ninth Street provided a 45 foot channel centered on the canal. The substructure consisted of two unreinforced concrete piers supported on timber piles in the canal and reused granite abutments from the swing span. In 1960, the entire superstructure on the Ninth Street bridge was replaced in kind, but the substructure was retained. Prior to construction of the new vertical lift bridge, the Ninth Street Bridge consisted of abutments from the 1800's vintage swing span, piers from the 1903 vintage rolling lift bridge and a rolling lift superstructure built in the 1960's.

In the 1930's, the predecessor to the New York City Transit Authority built an elevated structure providing a ninety foot clearance over the Gowanus Canal directly above the Ninth Street Bridge. The structure carries four tracks for use by the "F" and "G" trains as well as the Smith - Ninth Street Station. The structure has large multi-column braced bents on either side of the canal roughly 30 feet from the bulkhead line. The column loads of up to 4000 kips each are supported on footings with timber friction piles.

Several major users of the canal account for 980 openings per year (roughly 3 openings per day). The users include an oil storage facility and a gravel plant. Most users run loaded barges up the canal at high tide due to the shallow canal depths at the north end of the canal. All bridges over the canal are operated by NYCDOT on call.

3 - Study Phase - Scheme Selection:

As part of the study phase, we did an in-depth inspection of the structure. The piers were found to be in very deteriorated condition due to weathering, ship impacts and continual exposure to the heavily polluted canal. The piers were found to be progressively tilting and were being monitored. Ship impact had destroyed much of the existing fender system and damaged certain superstructure elements. Other problems noted in the study phase included difficult access to the machinery for maintenance, poor span operation, and counterweights that dipped into the canal. These deficiencies resulted in the need to replace this bridge. The study included investigation of four primary schemes for on-line bridge replacement as well as a reconstruction scheme. Traffic demands were too high to eliminate the bridge and alternate alignments were not possible due to right of way acquisition problems and the Transit Authority columns in the area. The replacement schemes which were advanced included a single leaf bascule, a double leaf bascule, a vertical lift bridge and a single leaf overhead counterweight bascule.

This site offered many very difficult and, at times, conflicting constraints. The main constraints are as follows:

1) Transit Authority Structure Overhead

The overhead transit structure limits the height of a vertical lift bridge and the opening angle for a single leaf bascule.

2) Transit Authority Footings

The footings for the elevated Transit Authority structure are very close to the location of footings for the new bridge. The new bridge footings need to be designed to avoid the TA footings both horizontally and vertically. A deep footing adjacent to the existing footings could have resulted in a need to underpin the existing footings.

3) Clearance Above Canal

The new bridge should be high enough above the canal to avoid immersion of bridge elements during periods of high water. When open, the bridge should be high enough to allow passage of current and future canal users.

4) Suitable Roadway Profile

The roadway profile is constrained by the bracing for the TA columns above, tie-in to the existing roadway and various building entrances on either end and vertical geometry which provides adequate stopping sight distance.

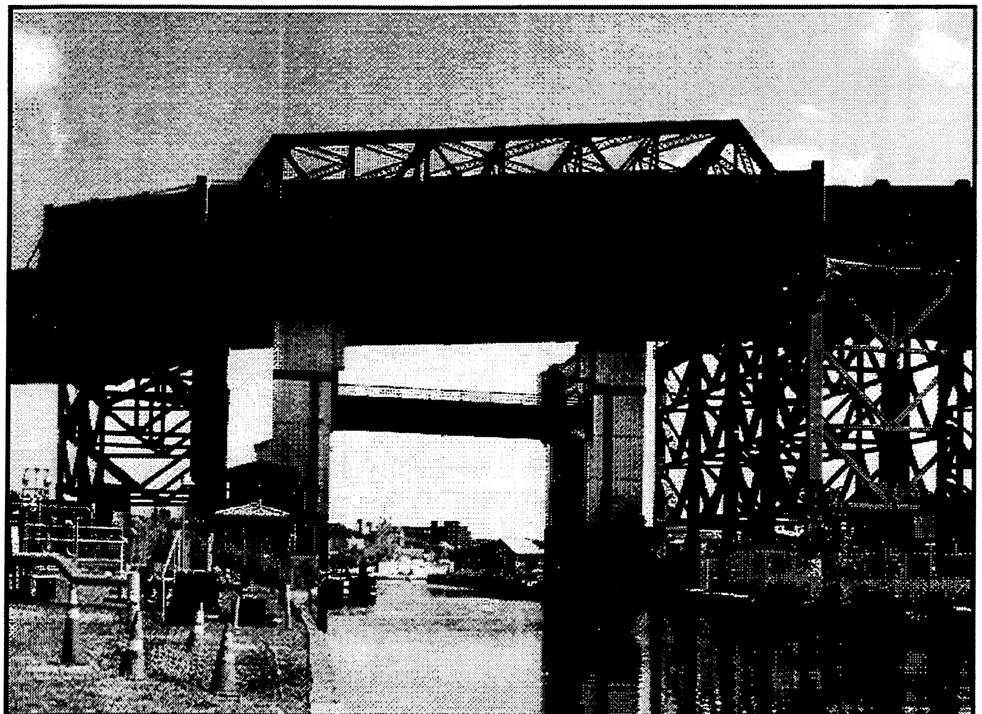
The Gowanus Canal is currently used by barge traffic. Frequent ship impacts made a widening of the channel at the bridge desirable. However, the Transit Authority footings limited the amount of widening that could be made. The bridge is very low to the water making raising the profile desirable. However, tie in with the existing roadway system limited raising. Providing adequate vertical clearance for passage of barges with high masts was important. However, the overhead transit structure limited new bridge types and configurations. The close proximity of Transit Authority footings put severe constraints on the substructure construction methods.

The schemes were compared using a matrix identifying the major advantages and disadvantages of each scheme. The vertical lift bridge proved to be the recommended scheme primarily because it provided a wider channel and minimized the potential for disturbing the Transit Authority footings. The new Ninth Street Bridge is shown in **Figure 1**.

4 – Design Phase:

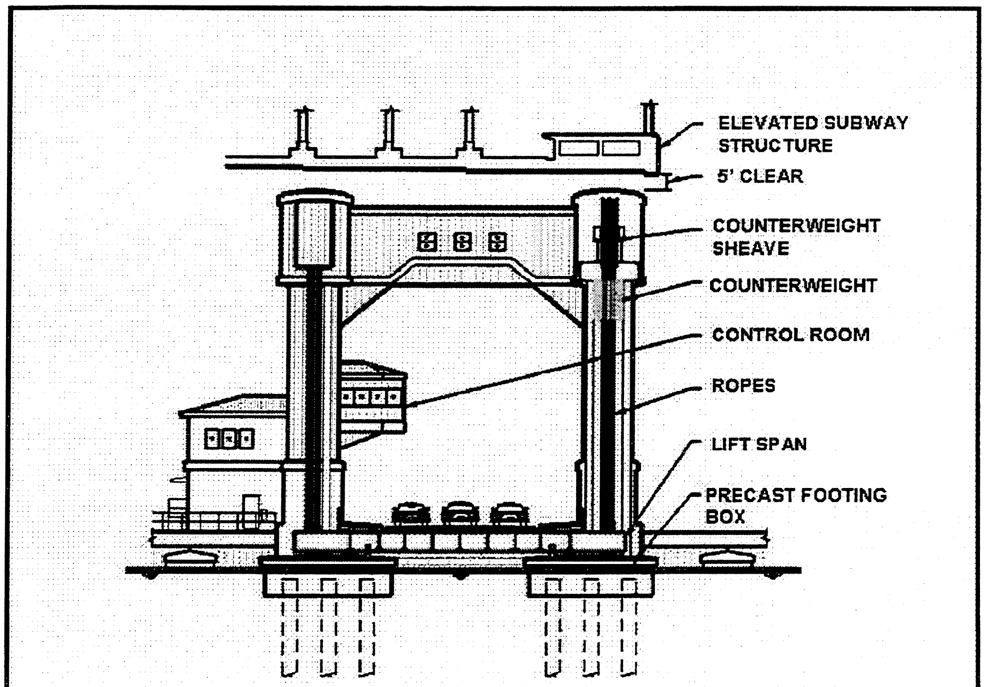
Once the basic scheme was selected, it was refined to address the needs of NYCDOT, other city agencies and permitting agencies. Initially it was thought that a two counterweight vertical lift span would be preferred. However, the barges navigating the canal have high masts. This made a larger vertical clearance, with the span open, desirable and helped obtain Coast Guard approval. By using four independent cast iron and lead counterweights located at the corners of the bridge, outside of the roadway and adjusting the configuration of the counterweight ropes, the counterweight travel could be increased thereby increasing the vertical clearance from 53 to 60 feet. The counterweight arrangement is shown in the bridge cross sections in **Figure 2**.

The details of the substructure and the associated construction methods were carefully designed to minimize impacts on the adjacent Transit Authority footings. The process of evaluating appropriate substructure construction and protective measures for the Transit Authority Structure started with an analysis of the Transit Authority structure column bents adjacent to the canal. Each bent consisted of two rows of concrete encased steel columns braced at various levels to form a



New Ninth Street Vertical Lift Bridge Built below
Elevated Subway Structure

Figure 1



Cross Section

Figure 2

very rigid structure. The east bent has nine columns while the west bent has seven columns. Each footing is supported on friction piles. It was assumed that the footings adjacent to the canal could move horizontally or vertically due to construction activity. The sensitivity to these movements was evaluated for various combinations of horizontal and vertical movement. It was found that movements on the order of 1/4 inch would overstress the columns. Since movements of this magnitude could not be precluded, installation of repositioning apparatus which can relocate the columns horizontally or vertically was called for. A rigorous monitoring and repositioning program was called for throughout construction. Substructure details were selected to minimize the impacts on the Transit Authority structure as well as provide durable construction. Soil conditions and the potential for differential movement possibly causing a misalignment of the span guides led to selection of caissons installed to rock roughly 160 foot below grade. Since potential obstructions exist in the area of the existing bulkhead which will be straddled by the new piers, the pier footings were raised as high as possible above potential obstructions and the number of caissons reduced to a minimum. Each tower pier was designed to consist of a precast concrete box type footing filled with concrete supported on five 30 inch diameter caissons. The caissons were required to have saw toothed tips and to be rotated into position. The caisson installation techniques were selected to minimize the potential for vibrations and loss of ground during installation, thereby minimizing the chance of disturbance to the footings.

The vertical lift bridge has four towers, each with four columns. The two towers on each side of the canal are connected together at the top with a machinery room. The entire bridge including the superstructure and substructure was analyzed using a multimodal spectral analysis for seismic design in accordance with the latest New York State requirements. The tower bases are enclosed in concrete walls and the upper portion of the towers and machinery rooms are enclosed in stainless steel panels. The architectural details were reviewed and approved by the New York City Art Commission.

The lift span consists of a half depth filled steel grating supported on nine longitudinal girders and two transverse lifting girders. The span carries two westbound and one eastbound lane as well as two 7'-6" wide sidewalks over a 60 foot wide channel. The pier protection system was designed for the latest AASHTO vessel impact criteria and consists of circular sheet pile cells with granular fill and concrete caps along with timber dolphins and wales.

The operator's room had to be carefully positioned to give the optimal view of the roadway and canal. Due to the maze of Transit Authority bracing above the roadway, locating a suitable position for the operator's room proved to be quite difficult. The best position of the operator's room was found to be high above the roadway at the southwest corner of the bridge. Supporting the operator's room using a cantilever arrangement rather than spanning completely across the roadway was found to give an improved view of the area below the operator's room. A good vantage point was particularly important as it gives a better view of pedestrian traffic in the urban area of the Ninth Street Bridge. A two story control house was designed to be built at grade with stairs leading up to the operator's room. The control house footings were configured to fit around the TA footings and be supported on minipiles designed to minimize disturbance to the TA footings.

The operating machinery includes four 13'-4" diameter counterweight sheaves. Provisions for lifting the sheaves for installation directly below the TA structure were incorporated in the tower design. There are four 2" diameter wire ropes per sheave. Pairs of sheaves are driven from a central set of operating machinery. Because of space limitations, the lock machinery is located on the span. Four sets of crank type lock machinery are provided, one per corner. This tower drive vertical lift bridge has AC SCR drives and PLC skew controls.

5 – Construction Phase:

The Construction Contract was awarded to Schiavone Construction Co./August C. Lozano - Joint Venture and notice to proceed was given on September 19, 1994. Construction proceeded, and after overcoming foreseen and unforeseen obstacles, the bridge opened to traffic in 1999.

Construction started not a minute too soon. After award, but prior to closing the bridge to traffic, a barge hit the bridge and knocked off the sidewalk. This section was quickly removed, but it served as a reminder as to how narrow the existing bridge was and how important it is that mariners continue to navigate in a safe channel throughout construction.

5.1 - Hazardous and Contaminated Materials encountered During Demolition:

Demolition of the existing bridge proceeded while some anticipated environmental obstacles were overcome. Lead paint had to be abated at cut lines necessary for the removal of the structure and asbestos needed to be abated in the control house. However, removal of the existing piers was put off for a while so the contractor could use them to support work platforms.

Due its heavy industrial past, the Gowanus Canal was notoriously polluted. This pollution resulted in a thick accumulation of Contaminants in the sediments. Contaminants were largely petroleum hydrocarbons. Since the sediments had been tested during the design phase, the nature of the problem was already known and provisions for settling basins for dewatering of the sediments were made. A primary and secondary filtration system were set up on site so that dewatering fluids could be returned to the canal and solids could be shipped off site to a hazardous waste landfill in Canada.

5.2 - Foundation Construction:

Since the Gowanus Canal was built in the area of the former Gowanus Creek, upper layers of the soil were silty marsh deposits overlain by fill and were quite poor. Below the silt deposits, there is roughly 120 feet of sand, several layers of till including a very bouldery till and then sound rock at 165 feet depth. Due to the need to minimize disturbance to the adjacent Transit Authority foundations which were built on relatively short piles, use of driven piles for the new bridge was precluded. Further, since the new vertical lift span needs to be properly aligned as tilting will effect proper operation, founding the bridge on rock was found necessary. The installation method for the caissons called for rotating saw-toothed steel shells down to rock. The contractor opted to revise the design slightly to allow for a step tapered caisson. This minimized the number of splices and allowed a fresh set of carbide teeth to be used from 100 feet depth down to rock. Some adjustments were also made in the reinforcement. The caisson configuration is shown in **Figure 3**. Minimizing the number of splices proved useful in that the field welded splices were time consuming and the caisson shells remained above grade and tended to hinder other operations while splices were being made. With the revised configuration, the caissons could be installed below the Transit Authority structure with only two welded splices each.

The contractor advanced the caissons as planned, cleaning out using augers and rock grabs as necessary and taking care to maintain a positive hydraulic head in the shell by use of a bentonite slurry. This minimized the chance of loss of ground into the caisson shell and the associated potential settlements at the adjacent Transit Authority footings. The slurry further served as a lubricant and cooling medium for the cutting edge. Advancing the shells using a custom equipment mounted turntable was relatively easy in the upper layers but progress proved quite slow in the area of bouldery till. The socket quality was verified by NX coring into rock beyond the socket as well as using video inspection. Reinforcing cages were installed and the caissons tremied full of concrete.

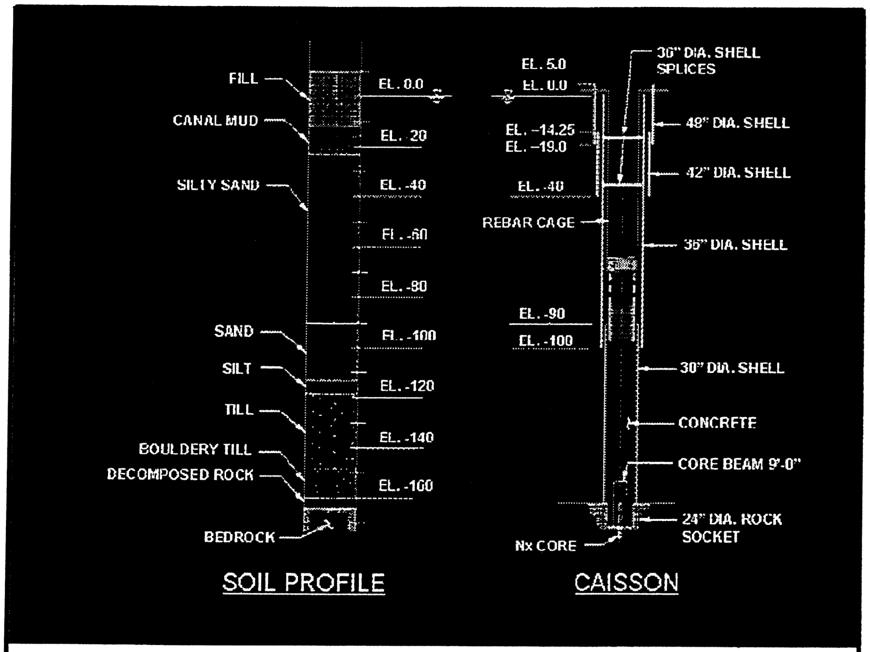
Once the five caissons were complete at a given tower location, temporary seats were installed on top of the caissons and a precast box was lifted in place to form the footing. Due to site constraints and the capacity of available equipment, the box was fabricated in two pieces, trucked to the site, lifted into position and spliced together. Each box was then sealed and the concrete footing formed in it. See **Figure 4** for a photo of the precast footing installation.

In order to minimize disturbance to the TA structure, foundations for the control house and sewers were built on minipiles. This work proceeded quickly and with no noticeable effect on the Transit Authority footings.

Once substructure work was complete, the work platforms were no longer needed, so the piers could then be demolished. The contractor opted to use blasting within cofferdams to remove the piers. Each pier was core drilled, blasted and removed. Blasting was chosen as breaking up the piers by other means would be either less certain to be effective and/or would cause sustained vibrations. Carefully designed charges proved effective yet did not produce much vibration. Seismographs were used to monitor nearby Transit Authority footings. Peak vibrations were on the order of 1 ips. Since the east pier removal occurred after movements to the east side TA columns had occurred, additional coring and extra care was taken in blasting this pier.

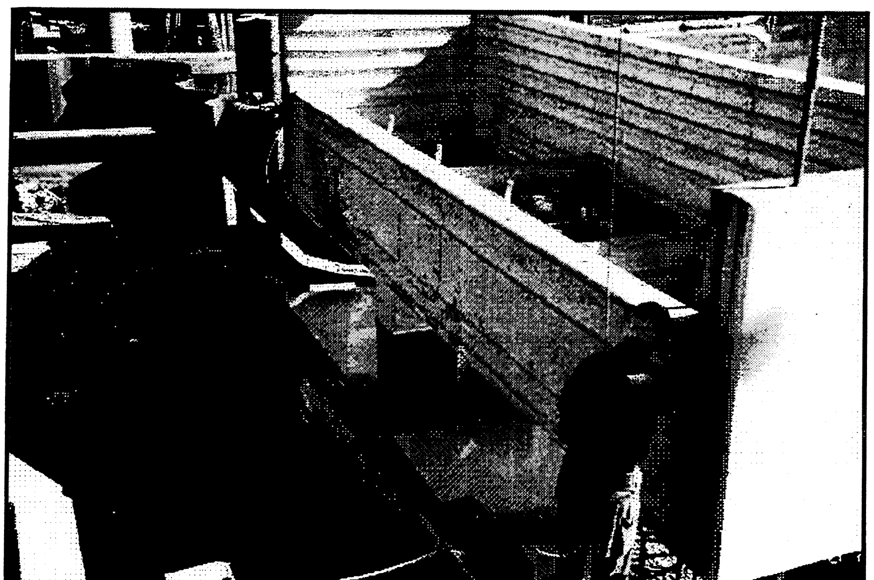
5.3 – Superstructure Construction:

The lower part of the towers are enclosed in concrete walls. This section of wall was built while the towers were being shop assembled to assure proper fit and alignment. Preassembled tower sections were then installed between the walls. All work was done in a tight overhead environment. Pre-assembled subassemblies were used whenever possible. The counterweight



Caisson Details

Figure 3



Precast Box Installation and Splicing

Figure 4

sheaves had to be erected directly below the TA structure. In order to accomplish this as well as allow for any future removal of the sheaves, the roof of the sheave house was designed to allow for extension of hoisting equipment. This proved very effective and the sheaves were easily lifted into place with less than five feet of headroom. The contractor opted to hoist each 24 ton counterweight sheave by using a ground based hoist with ropes running to the top of the tower. He also used Hillman Rollers to move the sheaves back into position as opposed to the rail system originally envisioned. The lift span was erected in the open position to allow vessels to continue to pass below it.

Once the lift span was complete except for the fill in the grating and the machinery had been installed, the lift span was lowered. The span operations at this time were done using air motors connected to the main gear reducers. These air motors provided for simple operation during construction prior to the completion of the electrical system but also provided a permanent backup system. Typically the lift span was lowered during the day to expedite construction and then it was raised in the evening. The deck fill was placed with the span in the lowered position and the span was rebalanced by adding blocks to the counterweights.

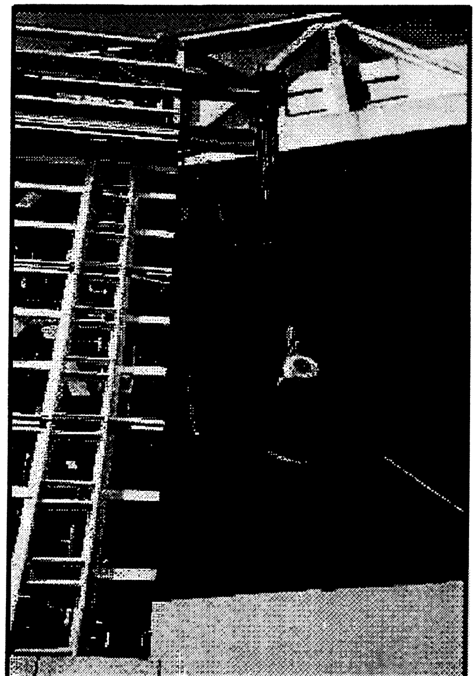
5.4 – Mechanical and Electrical Systems:

The operating machinery for the Ninth Street Bridge consists of two sets of machinery, one at the top of the towers on each side of the canal. The machinery is synchronized using electronic skew controls. A main differential reducer can be driven by either of two 30 HP motors with the other motor serving as a backup. Shafting runs from the central operating machinery base to the counterweight sheaves located outboard of the roadway. Overhead cranes allow for future maintenance activities in the machinery rooms and facilitate raising of equipment and supplies up from roadway level.

Redundant electrical systems allow the bridge to be run either with PLC controls or e hardwired backup system. Redundancy in the event of a power failure is provided via a natural gas powered generator. During construction prior to the completion of the electrical controls, air motors allowed for daily span operations. The air motors remain for future use, if needed.

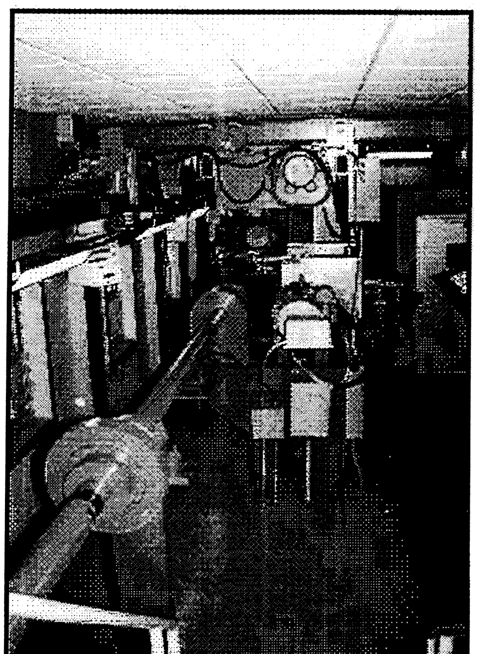
Crank type span locks are mounted below the sidewalk at each corner of the lift span to serve as safety interlocks preventing accidental span operation.

Traffic signals, warning gates and barrier gates are provided at each approach. Placement of the gates was made to avoid the overhead transit structure. The energy absorbing feature of the gates allowed considerable elongation of the cables. The function of the gates was improved for this site by placement of gate blocks along the curb line around which an impacted gate can deflect.



Counterweight Sheave being Installed Below Subway Structure

Figure 5



Operating Machinery

Figure 6

5.5 – Architectural Work:

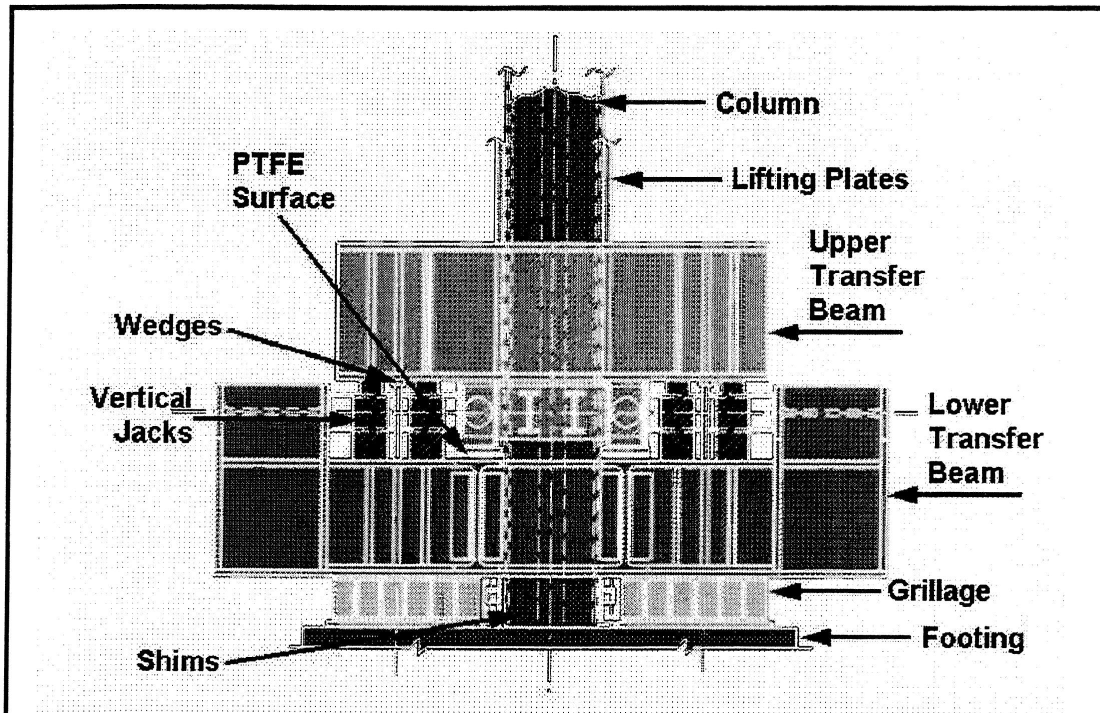
The Ninth Street Bridge has architectural treatments that were necessary to enhance its functional use as a base of operations for the bridge operators but also to protect the machinery and ease maintenance. The operating machinery was housed in machinery rooms at the top of the towers. Since the rooms needed to be completely enclosed and the towers were to house the counterweights and stairs to the machinery room as well, the complete towers and machinery rooms were enclosed. The stainless steel siding was selected for durability and appearance. Painted siding accent pieces as well as matching standing seam roofing and painted structural steel on the lift span completed the overall architectural design. Concrete at the control house, generator room and tower base enclosure walls was cast-in-place architectural concrete with added pigment, and several architectural aggregates. Special forming procedures were used and the concrete was finished by sandblasting and applying an anti-graffiti coating.

The finished control house provides the operator with a spacious operator's room located above the roadway with a good view of the roadway and sidewalk between the TA bracing. It also provides a locker room and restroom facilities necessary due to the long hours the operators to man the bridge.

6 - Transit Authority Structure Movements:

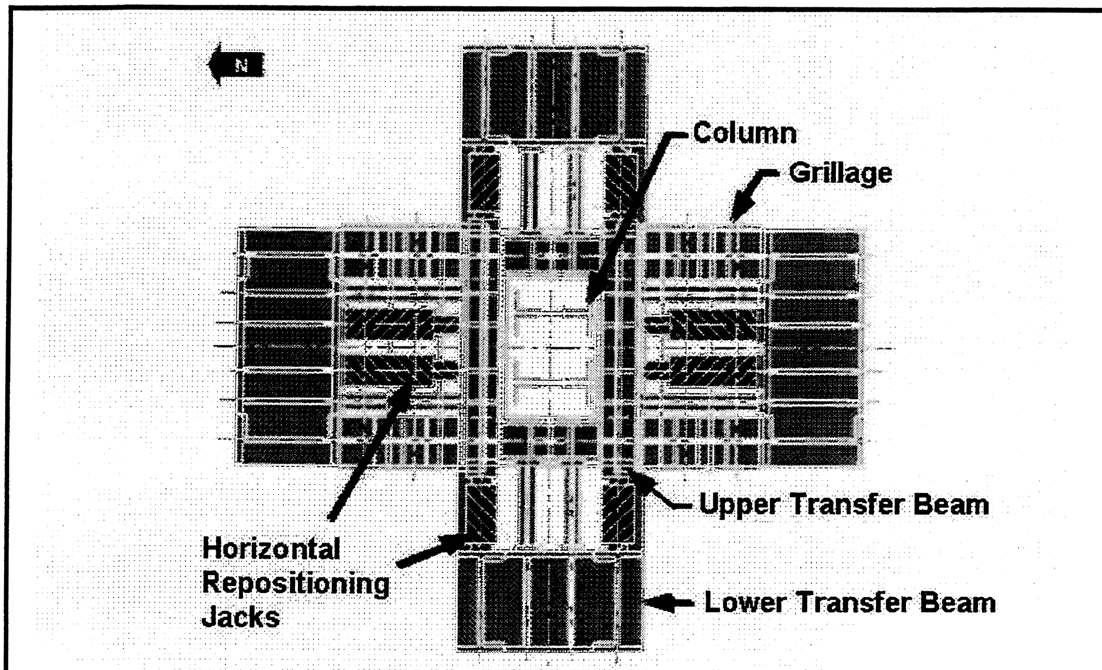
The contractor mounted monitoring prisms to the two rows of columns closest to each side of the canal and established fixed benchmarks for use in monitoring potential horizontal or vertical movement at the column bases. A total station instrument was used to determine coordinates of the prisms on a daily basis and the data was reduced and given to the engineer for review. Caisson installation on the west side of the canal proceeded relatively smoothly with no significant settlements of the TA columns. However, when caisson work began on the east side of the canal, settlements occurred at two of the columns. At this time, cracks were also noted in the upper portion of the footing. The cracks were old but the condition of the lower portion of the footings at columns to be jacked was called into question. The two footings were exposed and some deterioration was noted including one pile that was totally detached from the footing. As a result, a strapping system was installed at the footings. Strain gages were installed on the Dywidag bars of the strapping system.

Since it was considered possible that the TA structure might settle or move laterally, the design called for the contractor to install repositioning apparatus at each of the columns closest to the canal. Therefore, jacking frames were installed at five columns on the east side and four columns on the west side. The two settling Transit Authority columns on the east side of the canal were jacked vertically and repositioned horizontally nine times during the course of construction. Repositioning apparatus consisted of eight vertical and eight horizontal jacks. The structure was able to be lifted vertically or jacked sideways while sliding on Teflon pads. Column loads varied from 1300 to 4000 kips per column. The repositioning apparatus is shown in **Figures 7 and 8**.



Elevation
Subway Column Repositioning Apparatus

Figure 7



Plan
Subway Column Repositioning Apparatus

Figure 8

During jacking of the TA structure, tension in the footing strapping rods were monitored but no distress of the footings was detected. At each jacking operation, the footing was pushed further down but the column was raised thus relieving the stress in the column. Since the jacking load was limited to 125 percent of the column design load, in most instances the jacking had to alternate between the two affected columns several times in order to achieve the desired raising. In some instances, the columns had to be shifted sideways as well to their original position. Shims were inserted between the column base and the footing. In general the TA structure proved to be very stiff. It acted as a unit, tilting down uniformly to the north. This was a better situation for the TA columns as it tended to minimize stresses. Differential settlements of columns would have resulted in much higher stresses in individual columns and bracing members.

During lifting operations, the downward movement of the footing was monitored as well as the upward movement of the column. Loads were held and the footings were monitored for residual movement. A backup system of manual measurements was used to supplement the total station measurements during jacking. Behavior of the footing under jacking was examined as is done in a pile load test. Total settlement of Columns 93 and 70 on the east side of the canal was 1.6 inches and 0.9 inches respectively. However, since the footings were pushed down during jacking, the total movement of the footings was 2.5 inches and 1.5 inches respectively. Since the jacking occurred in a planned and timely manner, the structure was not overstressed at any time. After completion of construction on the east side of the canal, it was decided that soil improvements were necessary since settlements has occurred. Ground improvements included compaction grouting of the area around the two footings which had settled. This compaction grouting work was completed prior to opening the roadway to traffic. It was also determined that, prior to leaving the site, the soil at the two northerly columns on the west side of the canal should also be improved by compaction grouting. This compaction grouting work is now complete.

7 – Summary:

A movable bridge normally presents complexities which require specialized engineering expertise in mechanical, electrical as well as structural engineering. Depending on the site, geotechnical issues may also be of concern. In the case of the Ninth Street bridge, there were some significant geometric constraints that a unique combination of structural / mechanical / geotechnical solutions was required to allow the successful construction of the replacement bridge. In a field where bigger is many times viewed as better or at least more complex, in this instance the compactness of the project proved to be the key constraint. The obstacles of the site were overcome by sound engineering and a dedicated contractor and the first new vertical lift span built in New York City in 40 years is now operational and open to traffic.

Acknowledgements:

We would like to thank NYCDOT for recognizing the complexity of this project and working with us when confronted with the many project challenges, allowing the project to be brought to a successful conclusion. Our subconsultant for this project, Mueser Rutledge was invaluable in assisting with the design of the substructure elements, the jacking system for the Transit Authority structure, analysis of settlement data and development of mitigation measures. In addition we appreciate the skill and dedication that Schiavone Construction has shown in their approach to this complex project. We further acknowledge the assistance of Hayden Wegman, the project Resident Engineer in providing many of the photographs used in this presentation.