HEAVY MOVABLE STRUCTURES, INC.
ELEVENTH BIENNIAL SYMPOSIUM

November 6-9, 2006

Mechanical Component of the Residential Engineering and Inspection Program for the Replacement of the Third Avenue Bridge

By: James D. Stevens, E.I., Raymond M. Moran, P.E.,
Michael J. Elza, P.E., - Parsons Brinckerhoff
with
Balram R. Chandiramani, P.E. – Director of Movable Bridges - NYCDOT

Parsons Brinckerhoff and
New York City Department of Transportation
Division of Bridges

DOUBLETREE UNIVERSAL STUDIOS
ORLANDO, FLORIDA

CONTENTS

Introduction

Resident Engineering and Inspection (REI) defined

Resident Engineering and Inspection services can be defined as providing all services necessary and required for the inspection, management and administration of a construction project, so that the required work is properly executed, completed in a timely fashion, and conforms to the plans, specifications and requirements of the construction contract using best construction practice. In general, the Resident Engineer serves as the representative of the client at the site and is responsible for the inspection, management, and administration of the work. Resident Engineering and Inspection services can include the following elements of work:

- Administration / Record Keeping
    - Implementing procedures for the processing of submittals
    - Preparing correspondence and other communications in order to advance the Project
    - Verifying that the contractor has obtained all necessary permits, certificates, and licenses or approvals required for the performance of the work
    - Keeping accurate and detailed written records of the progress of the Project during all stages of planning and construction
    - Maintaining daily detailed time and material records regarding the use of labor, equipment and material for the Project
    - Maintaining a log book describing all activities which occurred on the Project on a daily basis including: all work accomplished, the number of workers, the number of hours worked, material shortages, labor difficulties, weather conditions, visits by officials, decisions reached, specific problems encountered, general and specific observations, and all other pertinent data relative to the performance of the construction contract
    - Maintaining accurate, orderly, and detailed files of written records and documents regarding the Project including: correspondence, minutes, reports, shop drawings and other submissions, contract documents and all other Project related documents
    - Preparing record (“as built”) drawings
    - Scheduling and conducting job meetings with the contractor, regulatory agencies and any other entities or individuals involved with the Project to discuss procedures, performance, progress, problems, scheduling and related issues

- Scheduling / Budget
    - Reviewing and advising on proposed Progress Schedule
    - Monitoring compliance with the Progress Schedule

  - Reviewing the adequacy of the personnel and equipment and the availability of necessary materials and supplies to ensure compliance with the Progress Schedule
  - Advising and making recommendations as to methods that may be adopted to make up for lost time
  - Rendering assistance when required to minimize delays to the Project caused by labor disputes
  - Reviewing and advising on all requisitions for payments
  - Verifying all estimates for payments of work performed, computations, as well as field measurements and sketches necessary for payment purposes
  - Reviewing and advising on applications for extensions of time

- Inspection / Design
  - Providing offsite plant inspection of fabricated and/or raw materials to be used on the Project to insure conformance with the material specifications of the construction contract
  - Taking appropriate action to prevent the installation of work, or the furnishing of material or equipment, which has not been properly approved or otherwise fails to conform to the requirements of the construction contract
  - Supervising the performance of all detailed inspection and field-testing of materials and items of work, quality control tests, or any other tests required by the construction contract, to ensure that such tests are performed in a satisfactory and timely fashion.
  - Performing minor design services for the Project
  - Making recommendations regarding proposed subcontractors and material vendors
  - Reviewing and evaluating the means and methods of construction proposed by the contractor and advising if such proposed means and methods may constitute or create a hazard to the work, persons, or property, or will not produce finished work in accordance with the construction contract
  - Monitoring conditions at the site for conformance with the construction contract, and coordinate with city agencies and public and private utilities so that the contractor provides a safe environment for both workers and the general public
  - Interpret the Drawings and Specifications and add explanatory information consistent with the construction contract

REI Importance

The importance of the resident engineering effort lies in the inherent shortcomings associated with current design-bid-build practice. In many jurisdictions, little consideration is given to factors beyond the qualified contractor's bid price when awarding a construction contract. While the intent of this practice is to ensure tax payers receive the best return on their investment, it often pits the contractors desire to maximize profits against the owner's desire for the best possible product at a reasonable cost. As such, it is important that the owner take an active role in managing the project. However, it is impractical for an owner to continuously maintain a staff qualified to manage a project with all the complexities associated with the construction of a movable bridge. This leads to the need for an outside consultant with expertise in movable bridge construction to act as the owner's representative, thus the need for a Resident Engineer.

Details of the Mechanical Component of REI

The mechanical component of REI includes the administration / record keeping, scheduling / budget, and inspection / design issues discussed above as they relate to the mechanical systems of the movable bridge. Depending on the type of bridge (pivot, lift, or bascule), these systems can include the following:

- Center Pivot
- Main Drive Machinery including: gearing, shafts, bearing, brakes, and hydraulic equipment
- Balance wheels
- End lifts, center wedges
- End locks, center locks, tail locks
- Emergency drive, backup generator
- Live load shoes
- Trunnions, trunnion bearings
- Wire rope, drums, sheaves
- Centering device

Executive Summary

Abstract

The Resident Engineering and Inspection contract (REI) for the recent replacement of the Third Avenue Swing Bridge for New York City Department of Transportation was an expansive effort which included an in-depth inspection of virtually all mechanical components of the swing span from fabrication to erection. This effort canvassed 11 states and three countries and included inspections at virtually every level of manufacturing, machining, assembly, and coatings. Specific inspection included, verification of materials testing (ultrasonic and magnetic-particle), providing dimensional analysis and visual inspections of castings and forgings, verifying dimensional accuracy of machined parts, verifying the quality assurance processes of labs, manufacturing processes of factories, performing load and no-load testing of reducers, and finally performing testing of assembled machinery both before and after installation.

The extensive REI efforts provided for the machinery systems used in the replacement of the Third Avenue Bridge uncovered several significant deficiencies very early and usually at the points of origin, saving quite probably months of loss time waiting for replacement for the defective elements to be produced. With the importance of this bridge to vehicular, pedestrian, and marine traffic, one could argue that the expanded REI efforts were very valuable from a scheduling and public impact perspective alone.

Additionally, the quality of the bridge's mechanical systems will undoubtedly be higher, with machinery that may last longer and operate more reliably with proper maintenance since such a high level of scrutiny has been given to its fabrication and construction.

Brief History of REI

How long has REI been around?

One can imagine that Resident Engineering Inspection, or REI, has been around for almost as long as engineering itself. Of course, the earliest engineering would have been out of necessity, developed by those in need of food and shelter, and those doing the construction would most likely have also been the "Engineers". But as society developed and engineering took on a more specialized role in providing people's needs, the need for experts to bridge the gap between design and construction has become increasingly important.

In most historical cases of what are considered to be major engineering/construction feats, the construction was supervised by the engineer that designed the device or structure. This was primarily due to the fact that very few people could understand the intricacies and tolerances of complicated machines and structures as well as the design engineer, so supply and demand tended to dictate the course of events. In addition, engineered solutions often had to be developed during construction and the designing engineers, with their reputations on the line, would lead the charge toward a solution. Some notable examples of the design engineer supervising the construction are the Eiffel Tower (Gustave Eiffel, 1889), and the Brooklyn Bridge (John A. Roebling and Washington A. Roebling, 1883).

How has REI developed over the years?

Modern day construction projects are arguably more intricate and complex than those of the past, from both design and construction viewpoints, not to mention the coordination of efforts to minimize negative impacts to the public.

Growth of society – providing more schools of higher education – and discoveries related to strength of materials, construction methods, and manufacturing processes have over time increased the need and the number of engineers qualified to design and inspect the construction of large projects such as the replacement of the Third Avenue Bridge.

But with progress has come new challenges for Resident Engineers. Pushing limits of design through better understanding of material properties and confidence brought about by more reliable manufacturing processes have placed a high importance on ensuring that close tolerances of size and fit, tightness of fasteners, and quality of welds and coatings be maintained throughout virtually every phase of construction.

Emphasis on delicate coordination of efforts have gained significance since the public strongly demands that their lives be minimally disrupted even during an effort as complicated and involved as replacing a bridge. And often considered most important, project costs are almost always expected to meet budget regardless of the unfolding of unforeseen situations requiring today's Resident Engineers to be creative in finding solutions that satisfy all concerned parties while minimizing costs.

To say that REI and CEI roles and duties have changed over time would be an understatement. Whereas historically Resident Engineers were more concerned with translating design to the field and solving engineering problems as they were discovered, today's Resident Engineering services are very complicated and wide in scope with the management and documentation of scheduling, management of traffic, budgeting, billing, as well as ensuring very high levels of quality to exacting standards for virtually every facet of construction.

Third Avenue Bridge General Information

Brief bridge history

The new Third Avenue Bridge is the fourth bridge and the third movable bridge to be placed into service where Third Avenue crosses the Harlem River between the Bronx and Manhattan. Table 1 summarizes the crossings at this location. Opened in 1898, the old bridge was designed to carry horse-drawn carriages and trolleys. One hundred years later the bridge had become a major artery carrying four lanes of traffic and nearly 80,000 vehicles a day. By 1995, with substandard geometry & live load capacity, obsolete mechanical & electrical systems, and a fire which had devastated the pivot pier fender system's upper portion, it had become clear that the bridge had nearly reached the end of its economic life and the design of the new Third Avenue bridge begun. In 2001, with the design complete and a Contractor and Resident Engineer selected, the NYCDOT pushed forward with plans to replace the bridge.

TABLE 1: Structure History

	Coles Bridge	Second Bridge	Third Bridge	New Bridge
Construction Cost	?	$2 million	$4 million	$119 million
Service Period	1797 – 1868 71 years	1868 – 1893 25 years	1898 – 2003 105 years	2005 - ? ? years
Movable Span Type	Fixed	Cast and Wrought Iron Swing	Steel Through Truss Swing	Steel Through Truss Swing
Operating System	NA	Hydraulic (water) / Steam	Steam / Electro-Hydraulic	Electric Motor
Movable Span Length (ft)	NA	218	300	350
Movable Span Roadway Width (ft)	NA	52	52	61
Clearance (ft)	12	13	25	26.5
Channel Width (ft)	NA	80	102	116

Brief bridge design information

The movable span of the new bridge is a 350 foot long steel through truss swing span carrying five lanes of traffic. With 8 foot sidewalks on each side, the total width of the span is 88 feet. In the closed position, the span provides 26 feet 6 inches of clearance for marine traffic. When the swing span is open there is a 116 foot navigation channel on each side of the pivot pier. The control house is located at the center of the span above the roadway. The main load-carrying members of the swing span superstructure are two parallel Warren trusses for which the individual truss members are welded steel boxes. The grid deck is steel grating filled with lightweight concrete.

The Machinery Design

The mechanical systems related to the swing span include the following:

- Center Pivot
- Main Drive Machinery
- Balance Wheels
- End Lifts
- Centering Locks
- Center Wedges
- Emergency Hydraulic Drive

During operation, the entire dead load of the span (approximately six million pounds) is supported by the center pivot. The center pivot consists of a 5 foot diameter spherical roller thrust bearing submerged in an oil bath (See photo 1). A portion of the main drive machinery is located in the control house and consists of a 150 horse power motor coupled to a primary differential reducer. The output shafts of the primary reducer are connected to bevel gear boxes located on either side of the control house. The output shafts from the bevel gear boxes pass down through the trusses located on either side of the roadway to the secondary reducers located under the deck. The two secondary reducers, located 180 degrees apart, drive pinions that engage a 360 degree 58 foot diameter rack. There are two motor brakes and two machinery brakes located in the control house. Photos 2 through 4 show the general layout of the machinery.

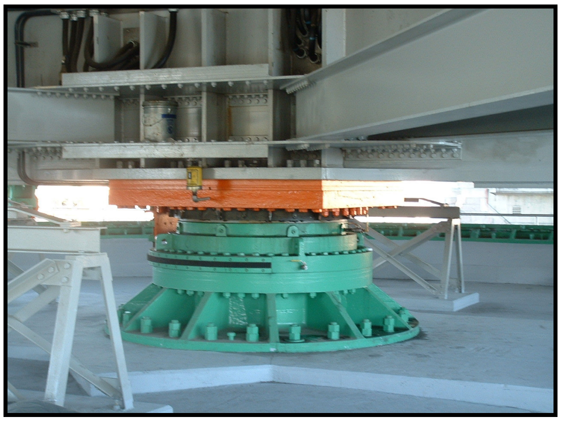

Photo 1: The Center Pivot housing

Photo 2: Differential Reducer which accommodates 2 - 150hp electric motors and a backup hydraulic system.

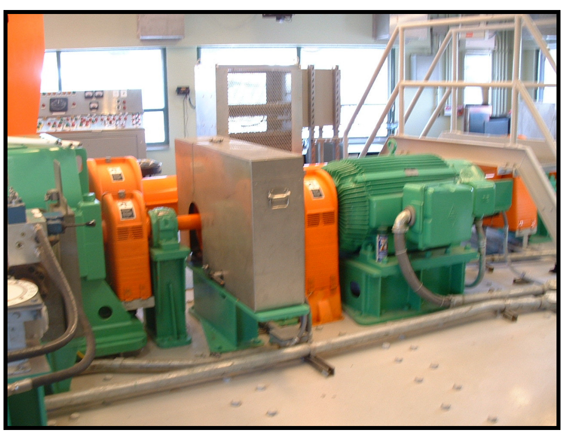

Photo No. 3: Motor Brake, 150hp motor, with secondary resistors and control desk In the background

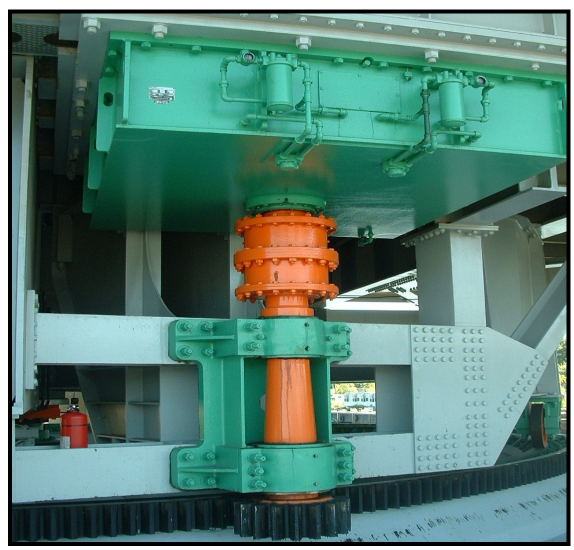

Photo No.4: R1 reducer, pinion shaft, pinion bearings, main pinion, and rack.

To account for wind loads and other unbalanced loads, the movable span has ten balance wheels spaced around the center pivot that run along a 55 foot diameter track.

Photo No.5 (seen left): Two balance wheels seated on the track during bridge operations with the rack gear in the foreground.

When in the closed position, the ends of the movable span are supported by the end lifts on the rest piers. Each set of end lifts has its own independent operating machinery. Eccentric shaft assemblies located at the corners of the span are driven through a parallel shaft reducer by a 25 horse power motor.

Photo No. 6 (seen above): Full view of the west end lift machinery (east is identical).

Photo No. 7 (seen left): A side view of end lift machinery from R5 reducer to end lift wheel in raised/driven position.

The movable span is locked in the closed position with span locks located at the ends of the movable span. The span lock machinery consists of a lock bar on the movable span that engages a receiver on the rest pier. The lock bar is operated by a 5 horse power electric motor through a right angle reducer that in turn operates a crank to pull and drive the lock bar.

Photo No. 8 (seen left): The centering lock guide with lock bar engaged with the centering lock receiving socket located on the rest pier.

When in the closed position, a portion of the load at the center pier is carried by the center wedges. There are two center wedges located on opposite sides of the center pivot. The center wedges are operated independently. The center wedges consist of a bronze wedge that is suspended from the underside of the truss and driven between the truss and a column on the center pier. The wedge is operated by a 5 horse power electric motor through a right angle reducer that in turn operates a crank to pull and drive the wedge. Photos 9 and 10 show the general layout of the center wedge machinery.

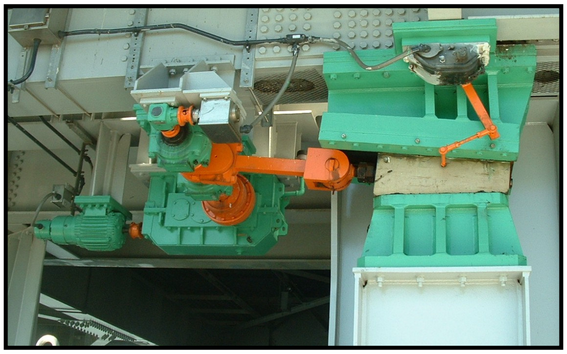

Photo No. 9 – Center Wedge Machinery
Side view – driven position

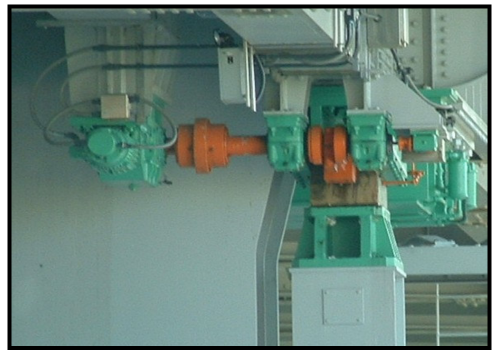

Photo No. 10 – Center Wedge Machinery
Rear view - driven machinery

Emergency back-up operation of the movable span is provided by a hydraulic drive. The hydraulic drive consists of a hydraulic power unit driven by a diesel engine that operates a hydraulic motor attached to the main drive primary reducer. Photo 11 (shown below) shows the hydraulic power unit located just outside of the control house.

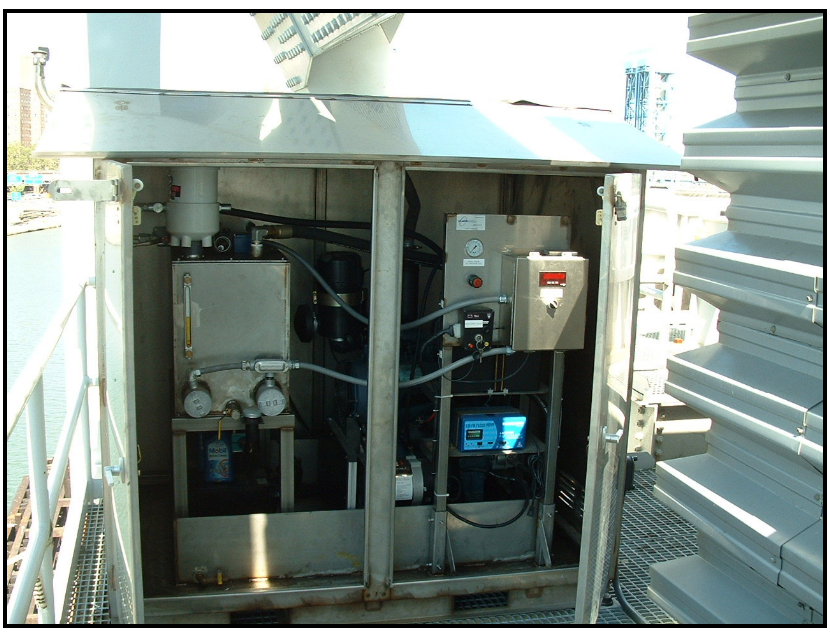

Photo No. 11 – Diesel Driven Hydraulic Power Unit for Auxiliary Bridge Operation

When did the construction start and by whom?

Fabrication of the Bridge Machinery started in January 2003 with the enclosed gear reducers manufactured by Horsburgh and Scott (Cleveland, OH), as the enclosed gear reducers were the longest lead item and the most intricate machinery components on the bridge. The Main reducers (R1) have gear ratios of 8:1 and encase 200 gallons of oil each. Each are equipped with two external pumps. The second machinery component was the track and rack sections fabricated by Quality Electrical Steel Company (Houston, TX). Theses castings required a large amount of machining to get the final profile and the rack teeth were eventually machined pre-assembled in a concentric circle at the Warrior River Steel Plant. Overall, 20 fabrication facilities and machine shops were used to build the components used in the machinery as selected by Kiska Construction and G & G Steel, with the approval of NYCDOT through NYCDOT QA-FMS and Parsons Brinckerhoff. The following is a list of facilities involved in the fabrication process and their location to show the breadth of the fabrication and inspection effort required for the Replacement of the Third Avenue Bridge. Off site fabrication of components was completed in October of 2004 with deliveries of the end lift machinery to the Harlem River.

Alabama Copper and Brass – Birmingham, AL
Atlantic Industrial Technologies – Long Island, NY
Barnett Machine – Edison, NJ
Composite Forge
EDM Wirecraft
G&G Steel – Russellville, AL
Highway Machine Corp
Horsburgh and Scott – Cleveland, OH
Johnson Brass
Link Control Systems – Ronkonkoma, NY
Maynard Steel Castings – Milwaukee, WI
Metaltek – Chattanooga, TN
Oakes Foundry
Patriot Forge – Erie, PA, and Erie, Canada
Quality Electrical Steel Castings – Houston, TX
Rotek
Reuland Electric - California
Scott Forge
SKF Bearing – Sweden
Warrior River Steel – Russellville, AL

Details of Third Avenue Bridge REI Effort

The Third Avenue Bridge Project Resident Engineering and Inspection services were originally scoped to include REI services on site in NYC. The effort encompassed construction inspection, schedule review, office engineering, community liaison and outreach effort, MPT inspection, and specialty engineering services for float-in and movable bridge component installation and testing.

In 2003 the face of the project began to change as the Contractor, Kiska Construction Corp. (KCC) and their swing span structural steel and machinery fabricator proposed to erect the swing span structural steel elements in Mobile, Alabama and then float the entire pre-assembled swing span steel structure to the NYC work site via ocean going barge instead of delivering the components to a site closer to the final destination in the Harlem River. Concurrent activities at the Harlem River work site, in regards to the bridge approaches and swing span foundation, would have made the swing span structural steel and machinery erection incredibly difficult in the small amount of space provided in the staging area on the upper east side of Manhattan. In addition to the off site structural steel work, the machinery assemblies mounted to the swing span structure including: the upper turning machinery, centering lock machinery, and center wedge machinery were to be preliminarily installed in Mobile, AL. The amount of critical work scheduled to take place in Mobile, AL coupled with the enormous amount of fabrication and testing of the machinery components which were proposed to take place in over a dozen locations throughout the country at any one time and forced NYCDOT to react.

Why did the client decide on this level of REI?

NYCDOT reacted quickly as it realized that merely reviewing material certifications and spot inspecting components during fabrication or inspecting components upon delivery may not yield the level of quality required by NYCDOT specifications in critical machinery components. The thought of finding fabrication or machining errors in key components of construction items on the critical path of the project upon delivery to the erection site was unacceptable as one item that slipped through the manufacturer's or Contractor's Quality Control oversight could negatively impact the entire project's construction schedule. NYCDOT also realized that the level of effort required to provide full time off-site inspection at over a dozen locations at any one time could not be accomplished by an already taxed NYCDOT – QA – Fabrication Management Services alone. NYCDOT – Division of Bridges and Parsons Brinckerhoff reacted quickly to the projects changing needs and signed a supplemental agreement for PBCS to provide the off-site structural steel and mechanical inspection. PB was the obvious choice as the project staff that would provide oversight of the off-site REI effort was already familiar with all the components of the project, the Contractor, and NYCDOT - QA requirements. Then Project Engineer, Raymond Moran, P.E. coordinated the off site inspection program under the guidance of Sam Scozzari, P.E. Resident Engineer and Balu Chandiramani, Director of Movable Bridges, NYCDOT, under the oversight of Tom Deluca, P.E. NYCDOT-QA-FMS.

PBCS utilized the expertise of the PB Movable Bridge Service Center located in Tampa, Florida, the Mechanical and Electrical Expertise in their NYC Structures division along with machining, welding and coatings inspection services provided by sub-consultant MACTEC Engineering from Jacksonville, Florida to provide full-time on site inspection services at each shop to supplement the efforts of NYCDOT-QA-FMS and their inspection agency Pennoni Associates.

What REI PB did with regards to the machinery

The PB/Mactec team provided the following services

- Qualification review of all sub contractor and fabrication facilities preparing parts for G & G steel
- Pre-qualification inspection of all proposed shops
- In-shop inspection of all castings and forging
- In-shop inspections and testing of enclosed gear reducers
- Inspections and dimensional verification of all machined parts
- No load testing of all manufactured assemblies
- Coatings application inspection
- Inspection of delivered items after shipping
- Inspection of assembly and installation

Effectiveness/Value of REI Effort

Cost comparison

The final cost of the machinery REI effort by PB/Mactec was approximately $1.3 million in labor and travel expenses. These costs covered all off-site inspections, no load testing, installation of machinery on the swing span truss system in Mobile, and some NYC on-site support services during installation and testing, including review of O&M Manuals. Costs to the client were minimized as much as possible by utilizing the Tampa Service center to provide inspection services in the Southeast United States, utilizing PB-NY for inspection in Long Island and New Jersey, and by utilizing Mactec's local resources wherever possible in the midwest and northeast United States.

Schedule impacts

We can quote savings in schedule only in finding and correcting deficiencies during fabrication such as H&S reducers which needed modifications, rack segments that needed replacement or additional work at the foundry, tolerance and finish of main pinion machining, use of specified couplings and fasteners, and quality of coatings and surface protection/preparation.

NYCDOT specs were written to eliminate possible schedule busts such as no-load testing the requirement to preassemble machinery assemblies in shop to ensure proper fit before delivery to installation sites.

In addition, there were specific cases in which inspection of critical machinery components revealed shortcoming in the machinery components that enabled the contractor/fabricator to build replacement parts while other machinery work was being performed:

- Grease/Oil mixing in Main Reducers required corrective action
- Instrument Reducers noisy – manufacturer replaced
- Track Sections – undersized – replacements cast
- Protective Coatings on the Motors needed work
- In shop accidents – dropped 5hp motor replaced
- Large Couplings bores did not meet dimensional tolerances – manufacturer replaced
- Castings of the brass center pivot portions were not concentric and were recast
- Initial Center Wedge Casting – did not pass specified chemical testing
- Main drive pinion keyways did not meet dimensional and finish requirements – EDM cutting was permitted to an oversized dimension with shaft keyways machined larger to match
- Corrosion on many machinery parts when received for final assembly in Mobile, AL – parts were thoroughly cleaned and properly protected or lubricated before assembly and shipped on ocean-going barge to New York
- Laydown and no load testing of preassemblies gave early indication of possible shim adjustments to assemblies
- Discovered loss of prime in south R-2 gear box lubricating pump – manufacturer repaired under warranty
- Discovered broken cooling fan shroud on emergency hydraulic pump drive engine – manufacturer replaced under warranty

In addition to the above, all dimensions, tolerances, material properties, fits and finishes were verified as in accordance with the plans and specifications except where a variance was approved by the EOR.

Had the above issues of non-conformity with the Plans and Specifications not been discovered early and on location at the supplier, time delays for completion of the machinery could have been as long as six-months.

Budget impacts

As stated earlier, NYCDOT spent an approximate 1.3 million dollars via change order to perform the additional off-site inspection of machinery as a part of a 2.1 million dollar change order for off-site inspection of structural steel erection and machinery inspection. The PB/Mactec team completed all off site services within the allotted budget of 2.1 million without the need for additional funding. In addition, the PB/Mactec team was able to provide additional on-site construction support in NYC through the completion of installation and initial testing through the funds in the change order.

Bridge quality impacts

To date, the Third Avenue Bridge swing span has been operated successfully approximately 100 times including, preliminary hydraulic and electrical testing, successful openings utilizing both the Bronx electrical power source and the hydraulic power during project level testing, and typical bridge openings to allow oversized vessels through the Harlem River. The machinery components have performed superbly and are a credit to the level of effort by the NYCDOT, NYCDOT-QA-FMS and their inspection agency Pennoni, the PB/ Mactec team, and the Contractors and Fabricators.

Conclusions

Was the additional REI of the Third Avenue Bridge's mechanical systems a good value?

From a scheduling standpoint, the additional REI of the machinery helped minimize probable scheduling delays that NYCDOT make every effort to minimize whenever possible. The level of inspection effort given to the machinery has saved countless delays as deficiencies were identified early on in the fabrication and machining process. By reducing schedule delays, the extensive REI effort reduced impacts to the public and helped preserve the integrity of NYCDOT.

In the short term, the quality of the components has been superb and there is no reason to believe the mechanical components of the span will not outlive the useful life of the swing span. Installation of components has been simplified by ensuring proper fits in the shop. Difficulties encountered during installation have involved solutions based on the adjustment of the structural portions of the bridge and it piers due to minor construction of design layout errors.

NYCDOT and the REI staff fully believe that future problems with the machinery components will be minimal with proper maintenance operations.

The benefits of this level of effort, although evident already in the ease of installation of the machinery and smooth operations of the span will become more evident in the future in comparison with other machinery assemblies built in 2005 with similar loads and uses.

Photo No. 12: The nearly completed Third Avenue Bridge – New York, NY

Acknowledgements

We would like to thank the following personnel for their assistance and guidance throughout this project:

NYCDOT – Division of Bridges: Henry Perahia, P.E., Danial Hom, P.E., Uday Shah
NYCDOT – QA-FMS: Tom Deluca, P.E. Mintso Kuo, P.E.
Hardesty & Hanover: Paul Connolly, P.E., John Gimblette, P.E.
Parsons Brinckerhoff: Mike Abrahams, P.E., Mark VanDeree, P.E., Samuel Scozzari, P.E. William Goodrich, P.E., Dave Nyarko, P.E.
MACTEC: Adil Khan, P.E.