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REPLACEMENT & REHABILITATION

OF

THREE FOUR - LEAF BASCULE BRIDGES

I. INTRODUCTION

Hardesty & Hanover has over the past five years undertaken the design of three projects which all involve four leaf bascule spans. All are Chicago-type trunnion configurations and have numerous design similarities. These projects are the rehabilitation of the Wantagh Parkway Bridge over Goose Creek , the replacement of the Greenpoint Avenue Bridge over Newtown Creek and the replacement of the Albany Avenue Bridge over Inside Thorofare. Though similar in many respects the details of design and construction of these three projects where strikingly different. This paper will examine these similarities and differences, specifically in the construction and operation of the completed project.

II. BACKGROUND

The four leaf bascule as it is being used in this paper is essentially two bascule bridges built side by side. Most common was to have the two adjacent superstructures on the same side of the channel on one substructure unit. In many cases the spans were tied together structurally while having independent machinery drives for each leaf. Electrical systems are most often run from one location. At times the two leaves on each side of the channel are tied together mechanically. This mechanical tie can take different forms but the attempt is to eliminate differential span travel between adjacent leaves.

The three projects in this paper involve five different bridges. Three of the bridges, Wantagh Parkway which was rehabilitated, and Greenpoint and Albany Avenue Bridges, which were demolished, were all constructed in the late 1920's and were all constructed in one construction stage. The proposed Greenpoint and Albany Avenue Bridges, designed in the late 1980's, were configured as four leaf bascules,similar to their predecessors and to permit vehicular traffic to continue with as little interruption as possible during construction.

The three completed projects have similar trunnion configurations, similar rack and pinion arrangements,similar floor systems, similar lock machinery, and other similar features. They differ in many ways also. The Wantagh Bridge has a pivoting counterweight, four independent leaves and drive systems and a span control system utilizing relay logic and motor speed control by secondary resistance of rotor windings for a-c wound-rotor motors. The Greenpoint and Albany Avenue Bridges have fixed counterweights, two drive systems tying adjacent leaves and structurally tied adjacent leaves. Albany Avenue Bridge has no forward live load bearings while Wantagh and Greenpoint do. Greenpoint Avenue has a solid state control system and Albany Avenue has a P.C. control system. These are some of the variations which exist and will be discussed in detail later in this paper.

As a consulting engineer my views are through a designers eye but after over four years of ongoing construction supervision and support all my views are tempered with the reality of the builder.

The bridges will be discussed in chronological order as they were completed with Wantagh Parkway being completed in 1988, Greenpoint Avenue completed in 1989 and Albany Avenue not yet completed at the time of this writing.

III. WANTAGH PARKWAY BRIDGE OVER GOOSE CREEK

This project involved the complex structural, mechanical and electrical rehabilitation and structural widening of this four leaf bridge.

The Wantagh Parkway Bridge is located on the south shore of Long Island ,New York. It was one of three bridges on the first causeway connecting the barrier islands to Long Island and was part of a grand scheme to form a large series of parkways along a great length of pristine beach-front. It was the idea of the late Robert Moses, New York State's most famous planner-builder.

Built in 1929 the Wantagh Parkway Bridge was part of an enormous project covering vast areas of beach, large splendid building complexes and roads and bridges. The Wantagh Parkway movable span was designed by what was then the New York State Department of Public Works. The structural configuration was similar to one of the Strauss patent's very common at the time. The main trunnions as mentioned previously were of the simple trunnion or Chicago style. The trunnion shaft is rigidly connected to the bascule girder while supported in bearings on either side of the girder. The bearings at Wantagh are supported on trunnion columns which make up the rear leg of a truss. The forward leg of the truss is the live load column and the diagonal truss members serve as machinery supports for the open gearing and shafting.

The unique feature of the design is the hung counterweights. These counterweights are supported off tension members called hangers which pivot about trunnion shafts at the rear of the bascule girder. Each girder hanger is kept vertical by links pinned between hanger and the main trunnion tower. As the girder opens the rear counterweight trunnions rotate allowing the hanger to remain vertical, provided that the links are functioning, and the counterweight rides neatly into the space between the trunnion towers.

The bascule span structural configuration was typical for most spans of the time and remains typical today. The individual bascule leaves were made up of two bascule girders with floorbeams framing into the girder webs. Steel stringers frame into or sit on top of the floorbeams depending on the depth of the floorbeam. The 1929 deck consisted of timber planks with an asphalt block wearing course. Sidewalks were all timber and the original railing was white oak with bronze retainer straps and bolts. In 1969 the timber decks and railings were removed and an open steel grating was installed.

The Wantagh Parkway Bridge was originally tied together structurally by interlocking finger plates at the toe floorbeam, however these finger plates were removed very early in the life of the structure as old photographs show. The bridge had four independent drive systems at no time mechanically connected between adjacent leaves. The two span lock systems were located on the north leaves with the receiving sockets on the south leaves. There are four lock bars, two per leaf. All electrical operations were run from the northeast bridge house of this north-south oriented bridge.

The original bascule span mechanical system for the main drive was not modified or repaired until our 1987 construction project with the exception of some worn coupling seals and grease fitting replacements. The original screw type lock system was replaced in 1933 with an articulated sytem of cross arms, cranks and push rods which drove and pulled the lock bars. As with the main drive system no major work on this system until our 1987 repair contract. That these systems operated the span for almost 60 years with little maintenance other than lubrication and almost no repair work is a credit to both the original designer and builder.

The electrical system underwent a complete replacement in the 1950's. The new system for control for the span drive utilized relay logic with a-c wound-rotor motors. Motor speed was controlled by changing the resistance to the rotor windings utilizing fully magnetic contactors engaged by master drum switches on the desk. With this method of control high starting torques could be obtained with low starting currents,yet with the resistors cut the motor characteristics approached that of a squirrel-cage motor. This was the system which was essentially what the original designers installed. The system as originally installed and even incorporating current technology has one major drawback. It responds poorly for an overhauling load resulting in poor seating characteristics. The system was selected by the client because it was within the capabilities of their maintenance group and for over 50 years served the State with relatively little trouble. The ability to be able to service the equipment " in-house" was considered a paramount concern at a site so traffic sensitve especially during summer months.

The 1950's replacement did not alter the basic span drive control system, however additional limit switches were installed and a new squirrel-cage motor for the lock system was installed. In 1979 the original submarine cables were replaced.

This was the general state the bridge was in when we begin our in-depth inspection for the State of New York in 1985. After several months of field inspection we presented our findings. In short we determined that the bascule span structral steel was in good condition provided some minor repairs were made and major roadway safety features would be installed. The mechanical system required replacement as did the electrical system, the control house required major alterations to provide the level of service the State requested and the counterweight trunnions and hangers be examined as part of the repair contract. After preliminary plans were completed the State made a major change to the plans by requesting the roadway be widened and the bikeway be widened. The widening created problems of framing the new and old steel but most critical was the clearances betwwen fixed and moving structural elements. Major changes to the bridge had to be made to accomodate the widened sections.

As stated previously the Wantagh Parkway Bridge is located on one of the major routes to the Jones Beach State Park. The road is subject to seasonal traffic pattern changes with summer traffic being extremely heavy and winter traffic being light. The design plans had to account for this pattern by providing the normal three traffic lanes in each direction during the peak season and one lane one of traffic in each direction during the off season. In addition to the vehicular traffic restrictions the United States Coast Guard required that the span open for marine traffic at all times.The project was further complicated by the fact that major work on the concrete approach spans was required and the replacement of the entire superstructure of the next bridge south of Goose Creek was also part of the contract.

Given the requirement that vehicular and marine traffic was to be permitted throughout the project we determined that the location of the control house had to be changed. This would allow one half of the structure to be operated from the old control house while the new one was being constructed. We decided that the northwest corner would be the best location for the new control house.

The State allowed the Contractor 30 months to complete the project with the period from September 15 to May 15 considered off season. The contract was awarded in April of 1987. This date was critical because of the lenghty lead times involved for delivery mechanical and electrical equipment as well as preparation of structural steel. The seven months between the date the Contractor could have access to the bridge allowed time to get most equipment ordered and even have some steel shipped to the site.

Our original concept was not to do any major work during year one. We envisioned that the roadway safety improvements, minor structural work between the two spans, off structure electrical work and basic prep work would be the only work in year one.

In year two, starting on September 15, we planned to do work on the west half of the structure. This included roadway widening, new safety walk, constuction of the new control house, modifications of the south west house and new machinery in the two west spans. Since we did not expect the electrical system to be in place we developed a procedure to allow reuse of the old motors. This work would have to be completed by May 15 to allow the full number of traffic lanes for summer traffic.

All attempts to provide the Contractor the ability to work on the new electrical system was made. The control house was a steel frame with limestone facing. This would decrease the time it would take to have a waterproof shell to work in as opposed pouring concrete walls. The new electrical system was 480 volts as opposed to the existing 220 volts and the new power was delivered to the control house from the side opposite the old power lines and provisions to place new pier wall conduits were made.

During the year three of the contract the east side of the bridge was to be built. This work, again done during the off season, would repeat west side work except the bikeway would be on this side and modifications to both houses would have to be done. During this phase the new electrical system would go on line and the State operators would be trained in the new system.

The Contractor had an ambitious scheme to cut one year off the 30 months. Everything had to be worked precisely. The Contractor proposed to combine the first two years into one. The third year work would be done in year two and the result of this scheme would be that the time to actually get the electrical system working was somewhere in the 26 to 28 month range whereas the structural and mechanical work would be done in two years.

It was during the construction that the complexity of the movable bridge became apparent to builder, inspector and designer. The area where most problems arose was the structural steel and mechanical interfaces. The erector, designer and inspector had to have several meetings to develope procedures which would give results that would meet the specifactions. Procedures to locate the new rack accurately,to set gears, shafts, bearings and the preassembled components on the base frames in the houses were all required. The procedure for installing the locks went through several versions when it was realized that the guide castings could not be installed in the toe floorbeam webs in the shop. The need to assure a good fit of the lock components required very specific grinding and erection. Even with the special provisions outlined in the contract documents, several field discussions refined installation procedures.

The most complex erection problem was the installation of the trunnion tower diagonals which served as the machinery support steel.

The original gear train had four sets of reduction gears. The new drive system has only one set of open reduction gears plus two enclosed gear boxes. The general arrangement of the machinery was modified by taking out the set of reduction gears at the center of the bascule leaf and substituting an enclosed gear box at the same location as well as placing a gear box in the machinery room of the houses.

The support of shafts and bearings remained both on the upper and lower diagonals just as the original machinery was designed. The new diagonals had to be installed to meet the proper geometrics of the machinery. The contractor had to field verify the trunnion location, the rack location and incorporate this data into the shop drawing details. The erection was achieved by subdrilling all members, dowelling the peice and reaming to full size after the geometrics were verified. As appears obvious the machinery installation was to proceed from the low speed end or the rack and main pinion end. The final alignment of the machinery components was then acheived by shims under the bearings. All bearings bases were drilled from the solid in the field. Minor problems came up when the machinery in the house was set prior to the machinery on the peir wall. Errors in the alignment were made up in the angular misalignment available in the couplings and by not lining up gear pitch circles at the various open gears.

After the contractor completed one leaf, which took over two months, the speed which it took to complete the other leaves increased, almost cutting the time in half. The bascule span structural work went relatively quickly. The machinery and related structural supports took the majority of the time. The electrical work lagged the most. The bridge was simply too small to fit the number of structural and electrical people required to complete the work in the time frame proposed. The electricians were told to wait.

Without an electrically operable span the temporary operation of the span became a problem. The solution was that the contractor petitioned the Coast Guard to temporarily shut the bridge to marine traffic. The Coast Guard agreed. With the span closed to marine traffic the contractor could concentrate on the electrical work and the minor clean up items.

By the end of the winter the span was operational electrically and mechanically. The structural work had been essentially completed at the end of the second off season and the minor work on pile repairs was to be scheduled for the third summer. The last of our involment with the bridge was the balance of the span and the fact the west leaf toes were over one inch different in height with the locks drawn. The determination of the balance was a point of minor dissagreement between State and contractor and correction of toe heights had become a problem.

We observed the seated west leaves and had measurements taken of the forward live load tower shims and the clearance in rear the live load anchaorage seats. After review of the measurements we felt the shim stacks under the south live load tower were too thin. We directed the contractor to add trial shim plates until the toes were even and remeasure the clearances at the rear anchorage. After the addition of 3/16 inch shims the toes were aligned, the lock bars drove without interference and proper rear clearence was obtained.

The balance of the span was monitored throughout the work by calculating the weight of components removed and replaced. Over the years as the balance of the span changed for a variety of reasons and various types of balance blocks were added; railroad track, steel plates, concrete blocks and other scrap metal. As part of this contract we called to have all the existing extra weight removed and replaced by large steel plates and smaller uniform sized steel balance blocks. The weights were added on top of the counterweight and would balance the horizontal moments. To balance any changes in the vertical moments as a result of the rehabilitation we placed concrete in the new rack supports. This was necessary because the counterweight trunnion has a fixed location in the rear of the bascule girder and does not allow sufficient fine tuning. The calculations were further complicated because of the staged construction. Still the span seemed to operate satisfactory throughout the construction.

To check the final balance we ran drift tests while monitoring the power drawn during these tests. Although we have used more sophisticated methods of determining span balance no method gives the result as simply and inexpensively as drifting the span and observing its behavior. It was found that all four leaves needed minor adjustments, some were span heavy, some span light. Trial and error was used to get the final balance adjustments. The drift testing took less than an hour and the final balancing took the contractor one work day.

At the time of the writing of this paper the bridge is complete with the exception of minor landscaping work. The first summer season is looked on by the State maintenance with excitment now that the construction is over and cleared and a new trouble free structure has been turned over to them.

IV. GREENPOINT AVENUE BRIDGE OVER NEWTOWN CREEK

The next project is the Greenpoint Avenue Bridge. This project called for the replacement of the existing four leaf double bridge with a new four leaf bascule bridge.The replacement was essentially on-line requiring that the new structure be built in two seperate construction stages.

The Greenpoint Avenue Bridge is located in both the boroughs of Queens and Brooklyn in the City of New York and spans the Newtown Creek. The bridge was built in 1927 by the City of New York's Bureau of Plant and Structures and is today one of the busiest movables in the entire city with an average of 3000 openings per year. In addition to accomodate heavy marine traffic, Greenpoint Avenue is a major local route with heavy commercial and passenger vehicle traffic trying to find the quickest, least congested route.

The old bridge was a four leaf simple trunnion bascule of large proportions. The channel had an unlimited vertical clearance for 150 horizontal feet. The bridge is also slightly skewed to the channel which necessitated a distance between trunnions of 180 feet. The size of the span and its proximity to the water, approximately 15 vertical feet at the fenders with the span in the closed position, made a closed bascule pier pit necessary. The basic span configuration had the counterweights connected to the heels of the bascule girders. The four leaf configuration had adjacent superstructures on one bascule pier.

The roadway had four lanes of through traffic and two sidewalks, typical of any urban street. Outboard of the sidewalks a bridge house was located at each of four corners with the southwest house fitted out as the control house.

All four leaves had independant mechinery drives and the adjacent spans were tied together structurally and originaly mechanicilly as well. The span was controlled in the conventional method of secondary resistance of wound-rotor motors. The four leaves were controlled as a double leaf bascule.

A major problem with the old structure was that the bascule piers were rotating toward midspan. The toes of opposing leaves were getting closer together and binding was getting worse. Old boring logs seemed to indicate that the piles were shorter than required and that the sand layer the piles were driven to lay just above a large clay layer. Because of this foundation condition, it was determined that any repair to the structure would be short term and that the old span should be replaced.

The first major hurdle was the development of a preliminary design for new city bridge. The project had to respond to both

State and City of New York requirments and had to placate the local concerns of two boroughs. Concerns of maintaining traffic both marine and vehicular were paramount. Local businesses were under the approach spans and the maintenance of their operations was an issue. One approach to the bascule span ran above a commuter and freight rail line which had to be maintained. Even supplying power from the Queens or the Brooklyn power network, both Con Edison supplied power, was both a physical and political challenge.

Accomodating all the design parameters given produced some unusual geometry in the new structure. The typical cross section of the roadway was four lanes of 12 foot wide and two 10 foot sidewalks. The total width of the structure was ___ out to out. The entire structure, 1100 feet, was on a horizontal curve which tied into the highway intersections at each end of the bridge. Because the bascule span was tangent to the curved approaches and not on a horizontal curve itself, detailing was simplified. The vertical profile was fit to the various needs of the site. It resulted in the trunnion locations which were at different elevations across the channel. The vertical profile also necessitated a very shallow girder at the toe.

The need to keep vehicular traffic on the structure at all times led to the four leaf configuration. Our scheme was to partially demolish a corner of the old bridge to allow the construction of half of the new piers and half of the superstructure. One lane of traffic on the old structure in each direction could be maintained while construction of the first portion of the structure was underway. After the first stage was completed and two new lanes were open to traffic, demolition of the remaining portion of the old bridge could be completed and the second half of the new bridge constructed. The State determined that 30 months would be a reasonable time for completion. In 1986 the ground breaking ceremomy took place.

As is the case with most movables, the start of work is controlled by the lead time for delivery of the mechanical and electrical components. It is usual that the structural steel shop drawing process is completed before the other disciplines and deliveries of steel arrive at the site relatively early. The Greenpoint Bridge had the curved approach span girders fabricated by one supplier and the bascule span fabricated by another supplier. This helped keep the steel on track since any one supplier would likely have had problems with the volumes in steel for this project.

Problems with construction started early as demolition of the corner of house nesecessary to permit the new pier could not be done by hand methods and explosives had to be used. The steel shell caisons gave the contractor problems at first and the rate of the construction appeared to be quite slow compared to the submitted critical path schedule. As the bascule pier was constructed from the bottom of the cofferdam, the bascule span was being fabricated and shop assembled. It was felt that the time spent for shop assembly would more than pay for itself in construction time and cost savings. Pieces were called to be matchmarked prior to dissassembly and only those components whose final location would be a function of the field erection would be reamed in the field from subpunched or subdrilled holes. An example of typical subdrilled members were the tie plates between the two adjacent bascule leaves.

As previously mentioned the bridge is a four leaf configuration. It is a simple trunnion arrangement with the centerline of trunnions 202 feet on centers. The distance from the trunnion to the heel is 31 feet making each girder 133 feet long. The girder is 15 feet deep at the trunnion, five feet deep at the toe and 15 feet deep at the centerline of the counterweight,by any standard a large plate girder bascule. The bascule span is typical floorbeam and stringer framing. The floorbeams are space at 22 feet 4 1/2 inches on centers and frame into the bascule girder. The stringers are continuous over the floorbeams and are spaced typically at 4'-6" centers. The stringers support a five inch deep steel grating which is partially filled with an epoxy binder with basalt aggregate. The sidewalks are a full depth filled grating two inches deep.

The two bascule girders are 30'-6" apart and the two center bascule girders are 2'-10" feet apart. At the bascule span itself the details between the two adjacent leaves were simple. Each girder had a short cantilever bracket framed opposite the floorbeam on the inboard side. The two inboard bascule girders would have short tie plates connecting the two brackets after the second stage steel was erected.

The design for the trunnion columns was simple in detail but required special consideration. The space between girders was so tight that it was necessary to have both inboard girder trunnions supported on one column. The column would be loaded and operational with the first stage leaf for a considerable period of time until the second stage leaf was ready for erection. Because axial shorting of the column when the stage two leaf was added could have produced undue wear or binding of the trunnion bearings already in place, we had the center column designed to meet what we felt was appropriate limits for axial misalignment of the trunnion shafts. We also had columns which supported the outboard bascule girders cambered for dead load axial shortening.

The length of the live load arm made forward live load supports desirable. Similar to the Wantagh Bridge the forward towers became part of the truss with the trunnion columns becoming the rear leg. The trunnion tower trusses were made up of welded plate horizontal and diagonal members with the diagonals also supporting the main pinion bearings. The truss members were bolted together after the accuracy of the erection was verified. At the rear of the bascule girder live load anchorages were installed. These components were embedded in the large backwall pours of the bascule pier to assure adequate engagement of mass concrete to resist uplift.

With the simple trunnion configuration, a tower supported uplift to each trunnion bearing. On the outboard towers, transverse bracing to the concrete walls was installed; on the inboard towers a cross girder was detailed which also supported the deck over counterweight span. With a span of this size, getting the heel joint close enough to the center of rotation so that in the open position a vehicle will not be able to drive between deck over counterweight and the open leaf becomes a problem. At the Greenpoint Avenue Bridge we supported the stringers with "delta" support weldments on top of the trunnion cross girder. These "delta" supports were two I-shaped weldments which formed a "V" at the top of the cross girder. This geometric configuration enabled us to pull the heel joint much closer to the trunnion. For this detail we received the Lincoln Arc Welding Foundation award of merit.

The mechanical drive of the bridge was dictated by the requirements of the City and State and the staged construction. The bulk of the components had to fit in the stage one machinery room. This included the two electric motors and motor brakes, the main differential reducer for the stage one leaf and associated machinery brakes, shafts, couplings and bearings and the high speed differential reducer. The reducer had a differential lock out feature to enable stage one operation without the second leif in place. The stage two machinery room appeared almost desolate with only the main differential reducer, machinery brake and shafting, etc.

The span lock machinery was placed in the last panel at the toe of the span to reduce the amount of push-pull linkages. One motor with reducer drove two lock bars on the inboard side of the bascule girders of each east leaf. The reiceving sockets were on the west leaves.

The bascule span electrical system selected was a solid-state a-c crane control system with wound-rotor induction motors. Motor speed was controlled by varying the effective voltage applied to the motors. These power controlling elements were to be silicon-controlled rectifiers or SCR's.

Many arguements for and against the use of these solid-state control systems can be made and form the basis of their own paper but the system when operating as deisgned provides excellent seating characteristics saving the span from undesirable pounding while seating.

Each shop assembled leif was broken down and shipped to the site ready to be installed on the trunnion towers erected and set. In order to set the span, trunnion bearings had to be in place. The work necessary to locate and set the trunnion bearings required substantial effort. The first eight trunnion tower tops were surveyed for their locations in space, both relative to each other as well as relative to the theoretical positions. The use of electronic or laser survey equipment was discouraged due to the internal error of these units. For the short distances involved in trunnion setting, steel tapes are far more accurate. The contractor supplied layouts of the survey data and the trunnion bearings were superimposed on the tower tops. We were not looking for the contracor to repeatedly adjust the towers so their tops were theoretically perfect, but rather, we wanted to have the trunnion bearings erected to the best compromise position possible. It was essential that the trunnions would be square, colinear, and at the same elevation on both sides of the channel.

After agreement as to the best location undersized holes were drilled into the solid tower tops for use during the first stage of construction. It was our intent to refrain from reaming the trunnion bearing bolts full size until the bascule span deck filler was placed. It would then be posible to adjust the leaf within the tolerance of the reaming. It was difficult getting all parties to visualize the trunnions as machinery components subject to the precise tolerances required by machinery and not simply as oversized structural bearings. Trunnion towers and bearings were in place and ready for installation of the spans.

The fabrication of the girders had a forward and rear segments with a moment splice at about 40 feet from the toe. The first stage construction erected the span completely in the field after a total shop breakdown. First the rear segment of the girders was placed on the bearings. The counterweight box was located in the bascule pit on timber blocking and its sections were bolted together while the forward portion of the leaf was erected in the open position to allow marine traffic to pass. The stage one steel erection went quickly with the exception that the forward splice of the northwest bascule gider initially was bolted up incorrectly and had to be broken down and rebolted.

The machinery erection had typical problems associated with it. There were problems acessing machinery supports and components because the reducer bases were too small to get drilling equipment in place. These problems were solved by the erectors ingenuity. The contractor also set up a jig to assist the setting of the pinion bearings. This jig allowed the bearings to be moved along the diagonal support member to obtain the proper mesh with the girder rack. The pinion mounting was then drilled full size from the solid after the locations were accepted.

One problem came up when measurements showed the one rack and pinion to be well beyond acceptable backlash. Further measurements indicated that the rack, which was fabricated in two segments, had one segment which meshed well and a back segment which meshed very poorly. The contractor decided the way to correct this problem was to hand grind the back segment tooth by tooth until the backlash and mesh was acceptable. Unfortunately this work was carried out beneath traffic and was a slow, tedious process.

The electrical work on the bridge lagged the structural and mechanical work, as seems the rule. The submarine cables had problems when one cable showed unacceptable megger readings. When discovered, the bad cable was already installed and wired to the board of the terminal cabinet. It still remains and is not yet removed even though the structure has been operational for months. While the wiring, cabinet installation and other components were being placed, the span was operated by temporary means. The contractor made use of an air motor and compressor to drive the span while it was electrically inoperable.

Stage one was completed on ___ ,1988 about ___ months later than anticipated. The work involved in stage two was in some ways simplier but in some ways more complex. Experience gained during the first stage shortened the time for the second stage. Demolition of the majority of the old bridge had to be completed before the second half of the new substructures could be constructed. This proved a difficult task. Blasting left large portions of the old pier within the tight confines of the second stage cofferdam and required a complicated removal procedure. After the removal of the old pier, the construction of the substructure began. Again the steel shell casions had to be installed and the substructure pours had to meet the point were structural steel could be erected.

The setting of the trunnion towers for the second stage was again the most critical portion of the steel erection. As with the first stage the tower tops were surveyed, but the survey was complicated by the requirement that the new bearings had to be not only square, colinear and at the same elevation for the stage two spans, but had to be square, colinear and the same elevation as the erected stage one. If the setting of the stage one bearings were skewed to the theorectical then the stage two bearings had to continue that error. The completed four leaf structure had to have both adjacent sets of leaves parallel. The leaves could not afford to ride with the toes spreading or closing together. The contractor erected the stage two leaves and surveyed their positions during span travel. After the squareness of the leaves were verified the trunnion bearing bolts were drilled full size. The procedure required numerous submissions of bearing layouts and tedious measurements and alignment checks but it was well worth the time. Errors in the trunnion bearing installation would have required complex and difficult retrofitting.

Machinery installation for the second stage was much simplier and went quickly. The high speed differential reducer had the lock out feature switched from the stage one non-differential mode to the differential mode with no problems. All pinions in the second stage meshed well with their racks and setting of the lock machinery was on time with relatively minor installation problems.

Electrical system installation went quickly and had no major problems. Normal final adjustments of brakes and speed control settings were completed and final testing of span operation could begin.

The last major construction problem occurred because the stage two deck filler was poured slightly higher than the top of the grating. Instead of being finished flush with the grating, the tops of the bars were covered. This change in depth caused a major unbalance in the span. The problem was compounded by the fact that the bascule span deck filler used was heavier than anticipated in the original design. The east leave counterweight which have to balance the bulk of the lock machinery had pockets which were already filled with counterweight blocks. The overfill required removal of concrete balance blocks and replacment with steel balance blocks.

As with the Wantagh Bridge, the balance was verified by drift tests of the span along with appropriate observations of power meters, ammeters and span travel. On the Greenpoint Avenue Bridge the SCR control system required that a person be down in the electrical room to bypass the setting of the brakes after the motor is cut. Radio communications were required for this work.

The ribbon cutting ceremony was conducted on ______ of 1990 almost ___ years after the start of work. The complexity of the bridge and its construction were evident to all parties involved. The challenge of the project was met and the results were that the longest double leaf bascule in the City of New York's history ready to provide service well into the twenty first century.

V. ALBANY AVENUE BRIDGE OVER INSIDE THOROFARE

The last bridge I would like to discuss is similarly a stage construction four leaf replacement in which the two adjacent spans are constructed independently and tied together at completion.

The Albany Avenue Bridge is located on U.S. Routes 40 & 322 in southern New Jersey. It is the southmost of the three entrances to Atlantic City, one of the barrier islands off the Atlantic seacoast. The Albany Avenue Bridge spans Inside Thorofare, part of the intercoastal waterway which runs north from Florida.

The existing Albany Avenue Bridge was a four leaf bascule span built from a Strauss patent in 1928. This bridge was exhibiting many signs of distress. The bascule span toes were binding due to expansion pressure from approach spans which was rotating the bascule piers. The structural steel was in poor condition as was the limestone of the control houses which were actually moving apart. The stone on the bascule and approach piers was loose and mortar was disintergrating. The machinery was severly worn and the open pier allowed water to flood the motor room so that gears often drove partially submerged. One of the most serious problems was the fact that the counterweights were coming apart. The counterweights were made of concrete with steel punchings necessary to obtain the desired weight. The punchings began to rust and the counterweight began disintegrate in huge sheets.

The State of New Jersey determined that the bridge should be replaced and in 1986 the preliminary bridge plans were developed. The project had many design constraints. The bridge had to maintain marine traffic with partial channel closures during the winter; vehicular traffic had to be maintained at all times with a minimum of one lane in each direction; and all local businesses had to remain open. In addition, the bridge was located next to the Atlantic City Airport. The airport brought FAA regulations and clearance requiremetns into the design which controlled the height of the bridge in the open position, and control house height among other things. A flight path projected from the southerly airport runway. The flight path was trapazoidal in shape and became higher and wider as it moved further from the runway. It was determined that the west bascule span of the existing bridge projected into the flight path when the span was open to marine traffic, and the traffic warning gate projected into the flight path when it was up.

These design parameters had opposing effects on the bridge. The Coast Guard would have liked the span to be raised to permit more marine traffic with the leaves closed. The FAA would not allow any further encroachment into their air space. The State needed a wider bridge to allow for the heavy traffic which used Albany Avenue. The intersection just south of the bridge the needed a storage lane or a turning lane. The bridge could not be widened to the south because of the numerous buildings along this side of the road. Further, the bridge ran parallel to the two water mains which fed the majority of the city's supply. These pipes were just north of the existing bridge and further constrained the new structure.

As stated previously the existing structure was a Strauss four leaf patent bascule . The trunnion to trunnion distance was 80 feet. The total width of the bridge was also 80 feet. The two inboard bascule girders were 12 feet apart. Our proposed structure called to have new centerline of roadway offset to the north by 6 feet from the old. This would permit splitting the existing substructure and superstructure while maintaining the integrity of the structure to remain. It would also leave sufficient room to permit the construction of one half of the proposed structure without interfering with the operation of the old bridge. The existing bridge bascule span was flanked by two 80 foot long steel girder spans. These flanking spans were three girder systems with floorbeam and stringer framing. The center girder support steel was framed into the inboard trunnion towers for the two bascule leaves. The flanking span and bascule spans were all part of the patend drawings.

The proposal to split the old bridge in half was more complex than the partial demolition of Greenpoint Avenue.

We have seen when the two adjacent leaves of four leaf bascules spring apart as they were structurally seperated. As a result, we placed appropriate warnings into the specifications and the plans. We had experience in the mechanical and electrical stage construction and had provisions in the contract for this work. For the substructure we decided to be consevative and line drill the piers in two. Once the units were physically split more distruptive types of demolition procedures could begin. Unlike Greenpoint Avenue we felt any use of explosives would cause damage to the structure designated to remain, both because of the proximity and the poor overall condition of the old bridge.

The contract documents required that detailed demolition procedures be submitted prior to the start of any work. The results of the submittals was dissappointing. Due to the tight scheduling it was decided that it would be permissible to procede with the information already submitted allowing the details to be worked out later, so on ____ of 1989 the work splitting the superstructure began.

The proposed structure was to be constructed in two nearly identical halves with the new control house located on the northeast corner of the bridge. This allowed the existing control house on the southeast corner to remain in operation during the first stage. The first portion of the bridge to be constructed was to be the north half so that the new operator's house could be built first. The demolition limit was just north of the centerline of the existing bridge. The installation of temporary barriers was the first work done and it required additional supporting steel and various miscellaneous structural work to provide adequate strength for the barriers. A prefabricated rotating barrier gate was placed at the bascule span floor break designed to swing clear of the leaf as the span opened. All other barriers were typical steel shell or concrete safety shape barriers fixed to the decks.

The contractor had little trouble splitting the approach or the flanking span superstructures. The flanking span decks were timber planking with an asphalt overlay. The steel grating of the bascule span was flame cut at the removal limits and the floorbeam extensions, which were framed between the two inboard bascule girders, were flame cut at their removal limits from the heel to the toe. No problems with locked in or unusual leaf stresses were observed and with the exception of temporary traffic stoppages at critical points in the work the stage construction splitting went very well.

The superstructure of the approach and flanking spans came out in smaller pieces but the contractor proposed to lift the each complete bascule leif out after having removed and dropped the counterweight to the pier. Again, this worked exactly as the Contractor submitted. The entire pick was placed on a barge and floated to a staging site for dissassembly. The counterweight left on top of the pier was broken by jack hammers into managable peices and removed. Initial attempts to use wire saws to cut the counterweight failed because the steel punchings dislodged from the concrete matrix and bound the saw.

The contractor decided that instead of line drilling and splitting at the cut line a series of 4 inch diameter cores at 4 inches on center would be drilled the full depth of the pier. This would cut the pier in two. A second line of core holes would then be drilled several feet north of the first line. The concrete in between these two cuts would be removed by small equipment to permit the driving of the sheet piles for the cofferdam. After the cofferdam for the bascule span was in place, the remaining portion of the pier would be demolished using heavy demolition equipment. The work would all be preformed within the cofferdam to protect the existing bridge as well as the fender and channel from being unsettled.

The proposed demolition went slower than expected. Many unforseen problems arose. The existing timber piles, designated to be removed, had not been driven in rows as shown in the 1928 contract drawings, but rather in clusters. This made pulling difficult. In addition, below the old footing was an even older footing which was not anticipated. The 1928 plans showed the removal of an old 1800's vintage swing span. It was evident that not all the swing span footing was taken out to build the 1928 structure. These problems and the normal difficulty with demolishing so massive a block of concrete led to a slower rate of removal than anticipated.

Like Greenpoint Avenue, the tremie pour and footing pours involved mass placements of concrete. Several components of the structural steel were anchored in the footing, most critical of these was the live load anchorage. As the Albany Avenue Bridge has a relatively short span between trunnions a forward live load column was considered unnecessary. This made the rear anchorage column the restraining member for live load uplift and it's installation was critical. The contractor erected setting struts on top of the cofferdam to hold the anchorage columns in place and vertical during the pours.

Structural steel for the bascule span and deck over counterweight was fabricated in Louisiana. The contract documents required shop assembly of most components. The most interesting aspect of the shop assembly was the fabricator's method for installing the trunnions. The procedure called to have the span assembled with relative elevations verified. Then the two girders of each leaf would each have a combination boring bar and milling machine which was sighted on a common axis and set at the proper position. With this arrangement it was possible to bore out and mill the webs of both girders with one set up. Trunnions were then installed with the girder webs vertical after the boring/milling operation was completed and prior to breaking down the assembled leaf. We permitted the gratings and the stage construction tie plates to be field assembled. The fabrication was proceding as the substructures was emerging from the water. Erection of bascule span steel would soon follow.

The basic framing of the structural steel bascule span was similiar to the Greenpoint Avenue Bridge with floorbeams framing into the bascule girders and stringers framing into the floorbeams. The stringers supported a 5 inch deep steel grating filled half depth and with a 1-1/4 inches overfill thick. The State requested the deck filler be of latex modified concrete. The overfill led to the simple span stringer design which reduced negative moments in the upper region of the bascule span tension field.

The trunnion towers were a conventional configuration. The rear leg supported the trunnion bearings and the forward leg supported the floorbeam which carries the deck over counterweight stringers. Between the two tower legs were horizontal and diagonal members of standard rolled sections. Like Greenpoint, the trunnion columns were box weldments with the box flanges extending as gusset plates for the tower.

A design requierment, not previously mentioned, was that the critical drive components be protected from the high tides. The FAA restrictions on the vertical height of the bridge dictated that the new leaves including the racks and machinery components remain at nearly the same elevations as the old bridge. This required that we design a method to get motors, brake thrustors, electrical equipment and the emergency drive diesil engine above the 100 year flood elevation. We designed two platforms: a concrete platform at the normal elevation and one of steel framed into the trunnion towers above the flood level. The electric motors and the emergency drive on the upper platform were connected by right angle reducers and vertical shafting to the high speed differential reducers on the lower platform. This reducer were connected to two main differential reducers which drive the pinions for each leaf. Like Greenpoint, the stage construction necessitated that the majority of the equipment be installed in the first stage making it extremely tight in the pit. The lower platform supported these reducers and the brake wheels and shoes. Brakes were connected to the thrustor unit by vertical rods directly over the brake mechanism. Also, like Greenpoint, the main differential reducer had to incorporate a lock out feature so that the span could operate as a double leaf bascule in stage one with the differentail unit locked out and as a differential for the completed four leaf structure.

The Albany Avenue Bridge lock system was conventional with motors, reducer, cross shafts and cranks at the leaf heel and the lock bars, guides and receiving sockets at the toe. Each east leaf has a lock bar adjacent to the bascule girder. Support of the push rod was a bit unusual as we designed the rod to slide in a lined bearing instead of being supported by cranks or hangers. This rod support saved considerable space in the shallow girder profile .

The electrical system originally planned was to be an SCR package with push button control for the span drive. Design of the system was over 95% complete when the State requested a change to a programable contoller package. It was difficult to make all the appropriate changes to the plans and specifications in the time we had so several compromizes were agreed to in order to meet the tight letting schedule. The plans were bid on time but several of the electrical design features had to be resolved during fabrication of the system.

At the time of the writing of this paper the construction is nearing the completion of stage 1. This is nearly the date of the contractor's proposed completion date for the entire project. The reasons for the delay are many and not appropriately discussed in this forum. Still, the construction of the project to date has provided many insights on the complexity of the movable bridge.

The setting of the trunnion towers was of highest priority. The contractor set the towers and leveled them as well as possible and then proceeded to survey the tops. We desired to obtain the best compromise position for the placement of the trunnion bearings as a result several meetings and many long phone conversations were required. The tower top survey data was obtained and submitted. With that information we were able to locate the trunnion bearings as best as possible. The contractor then ran thin wire in a rectangle at the centerlines of the bearings. The bearing bases were placed under this wire and precisely shimmed and squared . Undersized bolts were installed to hold the bearings in place during stage one.

Erection of the leaves proceeded once agreement of the bearing locations was agreed upon. The contractor, unlike the erector at Greenpoint, choose to erect the span in the down position. To do this and maintain marine traffic the erector installed a winch capable of handling an almost balanced load so that the channel would always have one half open. The erection was sequenced so that as steel was erected forward of the trunnion the winch would be used until the point that the unbalance was too great. At that time the counterweight box would be installed balancing the forward steel. The counterweight was detailed so that span position during erection was not critical nor if the box was in the pit before or after the bascule girders. The erection of more forward steel would then necessitate placing counterweight concrete. The scheme worked well and the spans were erected down with little hardship to marine traffic. The west leaf was erected first and then raised while the east leaf was erected.

After the structural steel for both north leaves was in place the contractor checked the alignment of toes and girders. It was found that the leaves had to be pulled in line with cables after the diagonal bracing was unbolted. This procedure lined up the two leaves. Installation of grating and machinery could then proceede.

The grating was installed and the contractor placed the latex concrete after the winter season. The latex concrete was substantially lighter than the information which the supplier had indicated. Test blocks were inconclusive so the contractor calculated for a range of densities which would be offset by steel balance blocks. The contractor had space in the counter-weight pockets which we did not anticipate because the counter-weight concrete density selected by the contractor was heavier than we used for our design balance.

While structural work was proceeding the lock and span drive systems were installed. The lock system is presently being completed. Problems in obtaining the specified fit between guide castings and receiving sockets and their respective floorbeam webs occured. Solutions to correct the deficiencies have only recently been agreed to.

The main drive machinery is also being worked on at the time of this writing. Problems with main pinion and rack alignment have not been resolved and solutions to the situation are being discussed. The installation of the upper platform components and the main and high speed reducers has been completed as well as right angle reducers, brakes and shafting. Final adjustment of these components will depend on pinion and rack settings.

At this time very little electrical work has been completed. Electrical cabinets and the control desk are in the house but no wire has yet to be pulled inside the bascule pier. Operation of the first stage will for a time be accomplished by mechanical means. Whether the emergency system of the permenent installation is used or some other temporary method employed has not yet been decided.

The begining of the stage two construction is looked at with anticipation. It is hoped that the experiences gained in the erection of the first half will speed the time to completion and provide the first new bascule bridge for the State of New Jersey in decades.

VI. CONCLUSIONS

The three four leaf bascules which were looked at in this paper were all designed by one office. They are different not just in their overall dimensions but in their operating systems and their basic maintenance philosophies. They should provide the three different owners with excellent performance. At times, decisions made by our clients are not decisions we would have made if left to ourselves to decide. As designers we can bring up the merits and disadvantages of the design features as we see them and hopefully leave the client with enough information to make the correct decisions.

That three such similar structures could produce so wide an array of features, construction problems and future maintenance concerns is key. The need for flexibility in design, understanding of short and long term ramifications of design decisions and the ability to convey this information to the owner is critical for modern movable bridge design.

For myself, the three projects were enjoyable to work on and provided a memorable learning experience. I only hope that others who worked on these projects feels the same.