# NEW CROTON DAM SPILLWAY BRIDGE

WILLIAM E. NYMAN, P.E.

## BIOGRAPHY

William E. Nyman is a Principal Associate with Hardesty & Hanover, LLP Consulting Engineers in New York. He received his BSCE and MSCE from Case Western Reserve University and is presently a registered Professional Engineer in five states. Mr. Nyman's experience with Hardesty & Hanover has encompassed all phases of bridge design and construction for both fixed and movable bridges. His experience has included the design of every major type of movable bridge including single and double leaf bascules, rolling lifts, swing spans as well as vertical lift spans. He is also experienced in the fields of bridge rehabilitation and historic preservation.

In addition to the New Croton Dam Spillway Bridge project, some highlights of Mr. Nyman's career include the design and construction support for the Ninth Street vertical lift bridge (NSBA Prize Bridge, 2001); design and construction support for the Rehabilitation of the Marine Parkway Bridge (NSBA Prize Bridge, 2003); the design of the $300M Willis Avenue Bridge swing bridge; and the design and Construction support for the Sough Slough single leaf bascule bridge in Charleston, Oregon.

## SUMMARY

The historic New Croton Dam is a key element of the New York City reservoir system. A steel arch bridge over the spillway is a focal point of this monumental stone masonry dam. The original steel arch bridge was replaced in 1975 with a less aesthetically appealing simplified modern arch. Emergency bridge closure of the 1975 bridge offered the opportunity for replacement and overall aesthetic improvements.

This paper describes the design and construction of the replacement for the New Croton Dam Spillway Bridge. The initial measures taken to stabilize the 1975 bridge are discussed as well as the design and the innovative erection techniques employed. Creative detailing allowed the contractor to support both a work platform and erection shoring from the existing bridge to facilitate rapid, economical erection. Materials and design features were selected for longevity and to meet the project aesthetic goals. Materials included metalized structural steel and a high performance concrete deck with solid stainless steel reinforcing. Steel was a natural choice for this project in that it provided a historically context sensitive solution but also because it could be crafted to an efficient form which was both light in appearance and timelessly durable.

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## INTRODUCTION

The historic New Croton Dam was completed in 1906 and continues to serve as a key element of the reservoir system providing water to New York City. A steel arch bridge over the spillway is a focal point of this monumental stone masonry dam and is the topic of this paper. The historic steel arch bridge was replaced in 1975 with a simplified modern arch that wasn't as aesthetically appealing as the original. Arch base displacements and other problems necessitated emergency closure of this newer bridge to traffic and offered the opportunity for replacement and overall aesthetic improvements.

This paper describes the design and construction of the replacement for the New Croton Dam Spillway Bridge. The initial measures taken to stabilize the 1975 bridge are discussed as well as the fast track design and approval processes and the innovative erection techniques employed. Creative detailing allowed the contractor to support both a work platform and erection shoring from the existing bridge to facilitate rapid, economical erection. Materials and design features were selected for longevity and to meet the project aesthetic goals. Durable materials included metalized structural steel and a high performance concrete deck with solid stainless steel reinforcing. Steel was a natural choice for this project in that it provided a historically context sensitive solution but also because it could be crafted to an efficient form which was both light in appearance and timelessly durable.

## HISTORY OF THE BRIDGE

**Figure 1: Historic New Croton Dam under Construction Circa, 1900**

In connection with the development of upstate watersheds from which the City of New York obtains its potable water, the City undertook various obligations including the responsibility for certain roads and bridges. Even though the New Croton Dam and Spillway Bridge are located in the Town of Cortlandt roughly 40 miles north of New York City, it is owned by New York City. The New Croton Dam was the most significant high masonry dam of its era and a major engineering and construction achievement. Figure 1 shows the New Croton Dam under construction. Croton Dam Road over the bridge was originally to serve as access for dam construction and serve as access for maintenance of the dam and aqueduct, but later the road became a public road.

In 1904, the Aqueduct Commission awarded the construction contract for a steel arch bridge over the spillway to Baltimore Bridge Company at a cost of $40,500. Work on the superstructure was completed and accepted just one year after award of the contract. Figure 2 shows the shoring used to erect the 1905 arch bridge. Note that the spillway was dry since water was routed through diversion tunnels. Figure 3 shows the completed historic steel arch bridge.

By the 1970's, the 1905 superstructure had deteriorated due to the constant exposure to the spillway spray and lack of maintenance at this relatively inaccessible site. The superstructure was replaced with a new weathering steel open spandrel arch in 1974-75. Papers describing the 1970's bridge replacement along with

**Figure 2: Historic New Croton Dam Bridge under Construction, 1905**

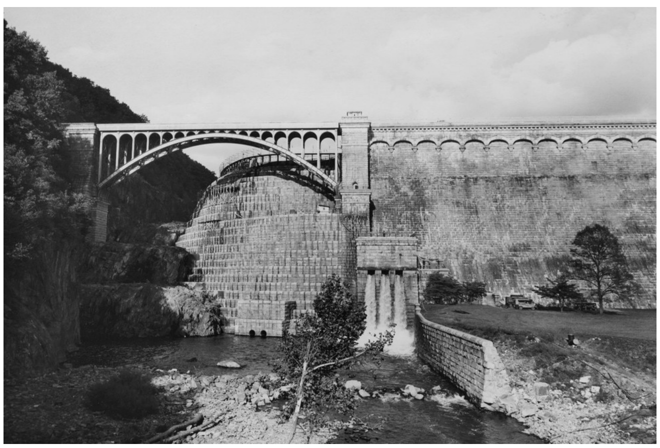

**Figure 3: Historic New Croton Dam Bridge, 1905**

**Figure 4: Open Spandrel Arch Bridge completed in 1975**

discussions with the designers and the resident engineer for the bridge construction gave some insight into problems experienced during construction. Apparently, the new bridge was erected with the arch ribs inboard of the old bridge and the old bridge was used as a working platform. During construction, spray over the spillway caused difficult working conditions and water accumulation in the box arch rib sections prior to welding. The nontraditional detailing exacerbated construction problems in the already difficult site conditions. This bridge is shown in Figure 4.

# STUDY PHASE

The New York City Department of Environmental Protection (NYCDEP) retained Hardesty & Hanover, LLP to evaluate 12 bridges in the Croton Watershed including the New Croton Dam Spillway Bridge. The 1970's vintage New Croton Dam Spillway Bridge in place at the time carried two lanes of traffic over the spillway. The bridge superstructure was a 212-foot long two-hinged open spandrel steel arch. The original bridge substructure remained from the 1890's and consisted of a granite abutment at the north end and the New Croton Dam at the south end. The bridge carried roughly 1200 vehicles per day and was posted for 10 tons.

The superstructure consisted of two welded closed box steel arch ribs and girders spaced at 12'-0" center-to-center. Arch ribs and deck girders were box sections 3'-0" deep and 2'-0" wide with the box girders rigidly welded to the arch ribs at midspan. The ribs were braced with box members in a vierendeel arrangement with no diagonal bracing at the arches or at deck level. The monolithic concrete deck had an epoxy grit wearing surface. The deck girders were supported by steel sliding expansion bearings at the abutments. The arch rib bearing plates are seated on the granite skewbacks but no provision was made for anchoring to them. Among other things, the inspection found that the arch rib bearing plates exhibited large upward displacements at the north skewback with smaller displacements at the south skewback. The skewback granite masonry had notches to receive the stepped bearing plates at the ends of the arch ribs. This detail prevented rib end movements down the plane of the skewbacks but upward movements were unrestrained. The

Figure 5: Arch Base displacements of the 1975 bridge were up to 14 inches

substantial arch base movements continued a trend measured in the previous inspection cycles. Figure 5 shows a displaced arch base. The box arch ribs remained in the elastic range and bearing plates showed no signs of distress due to the arch base displacements.

All exterior welds were checked visually for defects and discontinuities. At one location, there was significant localized crevice corrosion at the interface of the inside web and lower flange plates. Apparently, moisture had penetrated between the plate edges at this location causing corrosion, which locally bowed out the base of the web plate. Ultrasonic and magnetic particle testing were performed at areas adjoining the damaged weld to look for cracking resulting from the plate bowing and/or stress concentration but no further damage was detected. The interior sections of the box arch ribs were inaccessible for inspection.

Due to uncertainty in the degree of fixity at the arch base, two conditions were analyzed in the load ratings, first a fixed arch and second a two hinged arch. Although the arch was not physically anchored to the skewbacks, it would act fixed if sufficient thrust existed to keep the thrust line in the center third of the rib. In this condition, the base plate would not uplift. Arch type bridges perform efficiently under uniform load. Since this particular arch was only loaded with a point load at the center, there was a significant bending moment in the arch under dead load alone. The thrust line did not follow the rib and in fact fell outside the member. The arch base movements may have been attributed to the self-correcting of the arch base to reduce eccentricity of the thrust (See Figure 6). This condition may have combined with repetitive live loading and environmental factors to allow base movement. If a pinned arch is assumed in the analysis, the thrust line was found to pass through the hinged support.

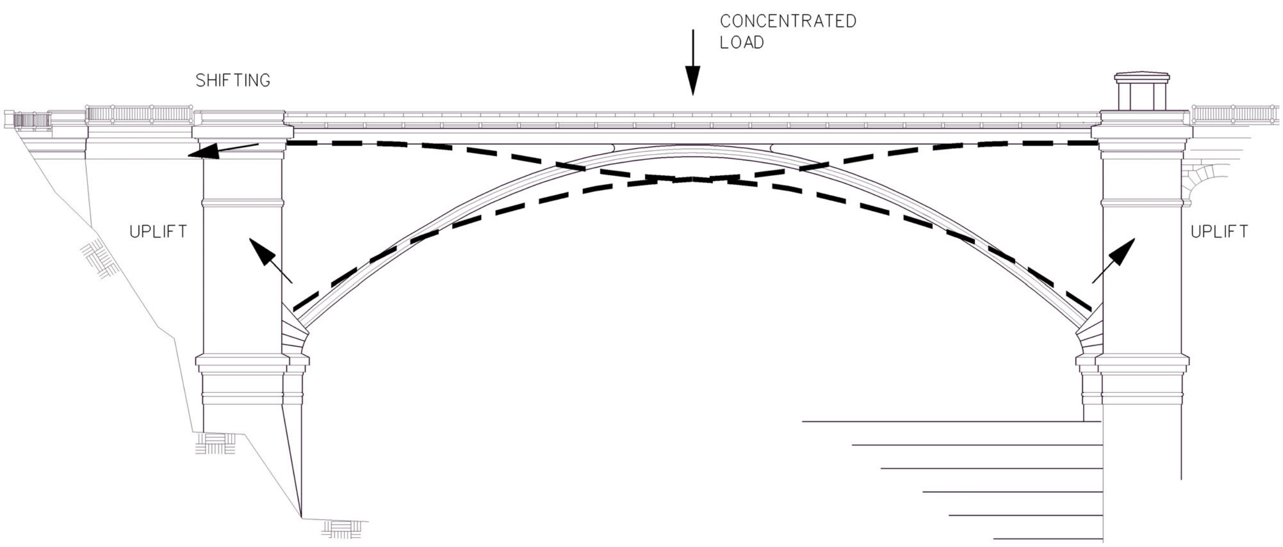


Figure 6: Existing Bridge Behavior

Assessment of the member capacities was difficult since they do not meet current standards. In particular, the arch webs are very thin. At 3/8” thickness, these plates do not meet the current AASHTO d/t requirements. The webs would buckle under load before reaching full member allowable stresses. A rating could therefore not readily be calculated for a majority of the members. This was overcome by discounting the buckled portion of the web in the rating calculations. Since there was no record of the displacements prior to 1991, it was assumed that the displacement occurred some time after construction was complete. Therefore, stresses were calculated due to the displacements. The displaced arch bases and limited displacement at the deck level resulted in increased bending stresses and a reduced load rating. Since there was a zero live load capacity as determined by the working stress method, the load factor method was used. Reduced web and flange sections were used to account for the local bucking of these elements. The as-built inventory rating was determined to be HS17 and the rating in the as-inspected, displaced condition was found to be HS8. In addition, there was concern with the quality of the complex welds and in particular with the field welded arch rib splices. One of the welds was broken and separating. Lastly the seismic capacity of the bridge was inadequate due to lack of anchorage at the arch bases and poor deck bearing details.

# INITIAL REPAIR CONTRACT

Various strategies were assessed for stabilizing the existing bridge and increasing its load carrying capacity. Since most elements of the bridge were serviceable and could be repaired, rehabilitation was favored over replacement. In addition, although the traffic volumes were light, the detour was long and inconvenient. Therefore, long-term closures of the bridge, which would be necessary for replacement, were not initially favored. A rehabilitation scheme, which allowed the arch bases to be jacked back into position to restore the as-built capacity, was considered. In order to reach a capacity greater than HS17, longitudinal stiffeners could be welded on the arch ribs and eliminate web buckling concerns. The stiffeners would be costly and difficult to install, would create additional locations for accumulation of moisture and debris and would adversely affect the appearance of the bridge. By replacing the sliding bearings with multi-rotational bearings at deck level and securing the arch bases, seismic performance would be improved. In addition, welds could be repaired. Since rehabilitation would cost less than 30% of replacement, rehabilitation plans for the bridge were prepared. The rehabilitation work at the New Croton Dam Spillway Bridge was packaged with three other bridge rehabilitation / repair projects into a single construction project.

By the time the contract was awarded and the contractor mobilized on site and accessed the arch bases to field measure for installation of the anchor beams, the bases were found to have displaced significantly further. The contractor expressed concern with the ongoing displacements and his ability to stabilize the structure.

The engineer was notified and an emergency inspection was done. The bridge was immediately closed to traffic and inspectors secured equipment and accessed the arch bases within hours of the reported additional displacements. The contractor’s findings were confirmed and accurate measurements were made at all corners of the arch bases and at deck level. Once these measurements were input in the analysis model, it was found that the bridge had inadequate capacity to remain open to traffic. The bridge remained closed while the contractor stabilized the arch bases in their displaced position. The ongoing movements raised concern with the effectiveness of stabilizing the bridge and the long-term reliability of the details of the bridge. The site was relatively inaccessible allowing potential problems to go undetected. In addition, the aesthetics of the 1970’s bridge were not favored at this highly visible DEP facility. Therefore, it was ultimately decided to save the remaining rehabilitation budget and apply it to an accelerated replacement project.

# BRIDGE REPLACEMENT DESIGN

Once the decision was made to replace the bridge, the design was completed and all permits / approvals were obtained in a three month compressed schedule.

The new bridge would need to meet current AASHTO and NYSDOT design standards yet be context sensitive in appearance. When one designs a new structure to fit with a historic setting as was the case here, one is faced with a dilemma as to whether to attempt a replication of the original structure or create a visually distinct yet context sensitive structure. For this particular site, the 1905 original had been gone for 25 years allowing the 1970's bridge to establish itself as a part of the history of the site. Fortunately, there were no advocates for maintaining the appearance of the 1970's structure. To be fair, this structure was a simple arched structure, which was intended to not detract from the appearance of the dam. Weathering steel appeared to function fairly well in the mist of the spillway, yet its dark patina was considered visually incompatible with the stone masonry. The traffic railing was a simplified modern design, which recreated the basic lines of the parapet on adjoining sections of the dam. There was a general consensus that the new bridge should be an improved and more durable version of the 1905 original. Modern materials and current design standards would need to be used and the bridge would need to be designed for maximum service life and minimum maintenance.

In addition to the context sensitive steel arches, another basic design element of any replacement bridge would be spandrel columns. These columns distribute deck loads over the length of the arch as opposed to concentrating at the center. Spandrel columns not only allow the span to function efficiently as an arch but they also serve to hold down the arch bases to prevent displacement and would serve as a basic design element in recreating the appearance of the 1905 original bridge. Another basic design element would be a lateral seismic restraint at deck level. Since the bridge mass is concentrated at deck level, this would be the best place for a restraint. By allowing the deck system to be partially supported by the abutments, multi-rotational bearings could serve double duty as seismic restraints. The new arch bases would be anchored at the skewbacks.

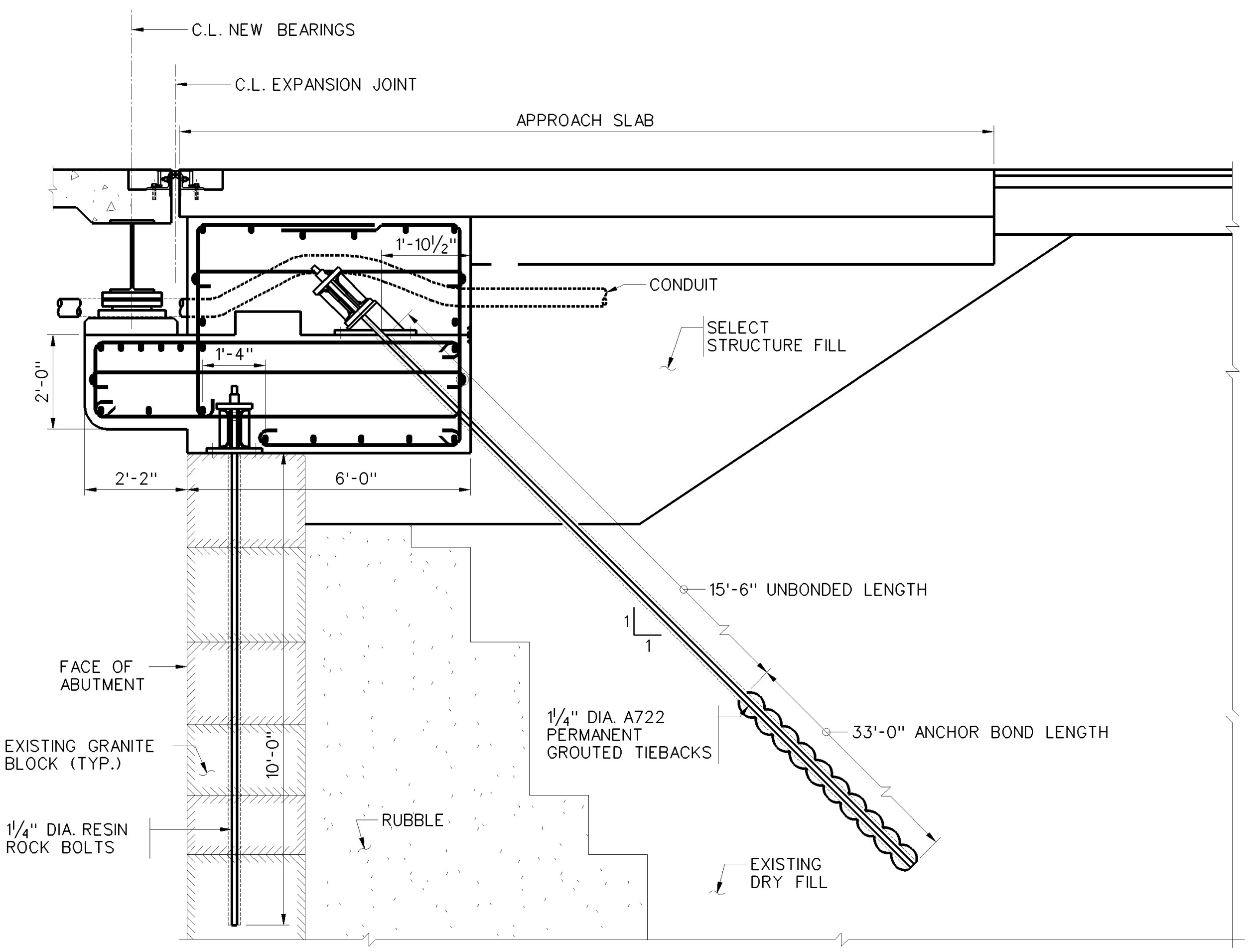


**Figure 7: Cantilevered Seat**

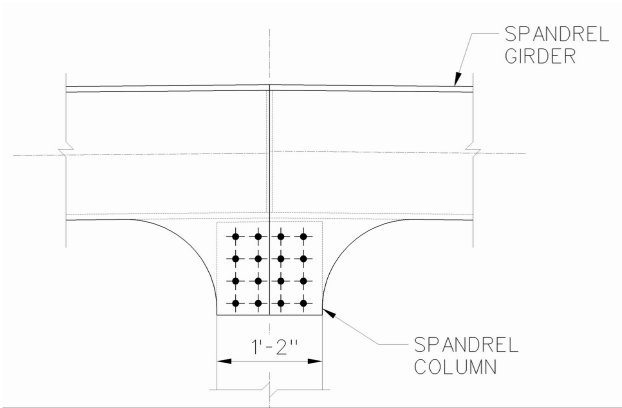


**Figure 8: Spandrel Column/Girder Connection**

The 1905 bridge had a straight joint across the roadway at the abutments, whereas the 1970's bridge had the deck girders nested into and supported on the abutments. In the earlier arrangement, the deck joints formed a "U" in plan with a transverse section and a pair of longitudinal joints at the gutter lines. This arrangement provided an inherently poor deck joint detail. In order to eliminate the longitudinal deck joints, the deck was stopped flush with the face of the abutment. It was decided that a concrete seat would be cantilevered out off of the abutments to support the deck bearings. This seat was visually concealed in the shadows of the deck system. The seat was anchored into the dam with rock bolts and into the rock face beyond the fill at the north abutment (see Figure 7).

The new steel superstructure included two foot by three foot welded box sections for the ribs, welded steel box sections with integral connection plates at the spandrel columns and spandrel girders (see Figure 8) and a rolled beam floorbeam / stringer system. Bracing elements at the columns and arch ribs were sealed structural tubes (see Figure 9). The new arch ribs would be fabricated in three sections with bolted field splices for ease of erection. The new ribs would bear on the existing granite skewbacks at the location where the 1905 bridge was seated. Figure 10 shows cross sections of the 1906, 1975 and new bridges.

Since the 1905 original bridge had deteriorated in the misty spray of the spillway and any bridge would be difficult to access and maintain at this site, all structural detailing was aimed at minimizing corrosion potential. Hence the sealed welded boxes and structural tubing were used. The variety of element types and the desire to coat both the interior and exterior of sealed elements lead to a varied coating system. The visible finish coat of all steel would be a thermally sprayed metalizing. The inaccessible interiors of structural tubes were coated by hot dip galvanizing and the exposed exterior of the tubes was metalized for visual similarity to the other steel. The interior of the sealed welded boxes was painted since hot dip galvanizing could have warped these members. The metalizing was thermally sprayed 85% zinc, 15% aluminum material and was sealed after application but not painted. Field splices and damaged areas were field metalized.

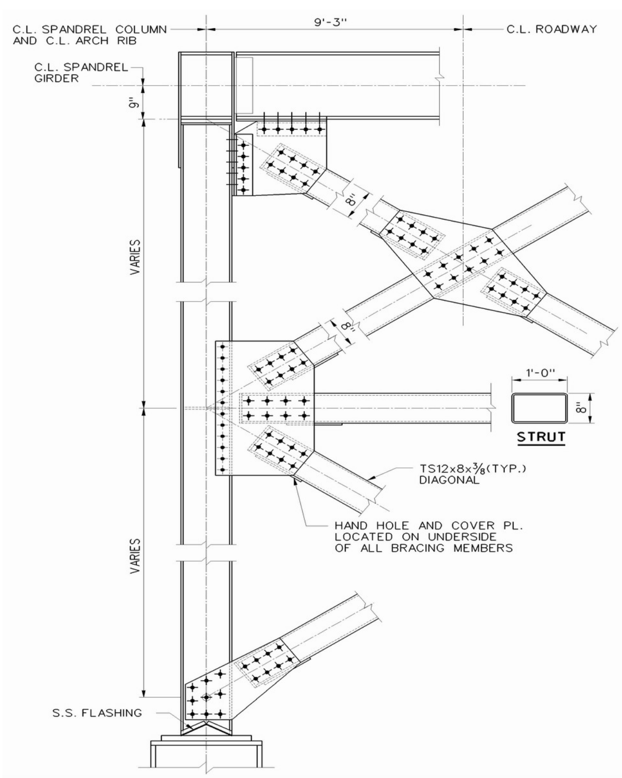


**Figure 9: Typical Column Bracing**

# AESTHETIC DESIGN

The architectural details of the new bridge were considered in the earliest stages of design. The 1905 bridge had varying spandrel column spacing with the columns spaced more widely at the abutments and spaced more tightly at midspan. This arrangement allowed for varied radii on the arched fascia panels. This was an elegant arrangement in that as the spandrel columns became taller near the end of the span the arched panels grew larger and deeper. The arrangement was a purely aesthetic one and appeared

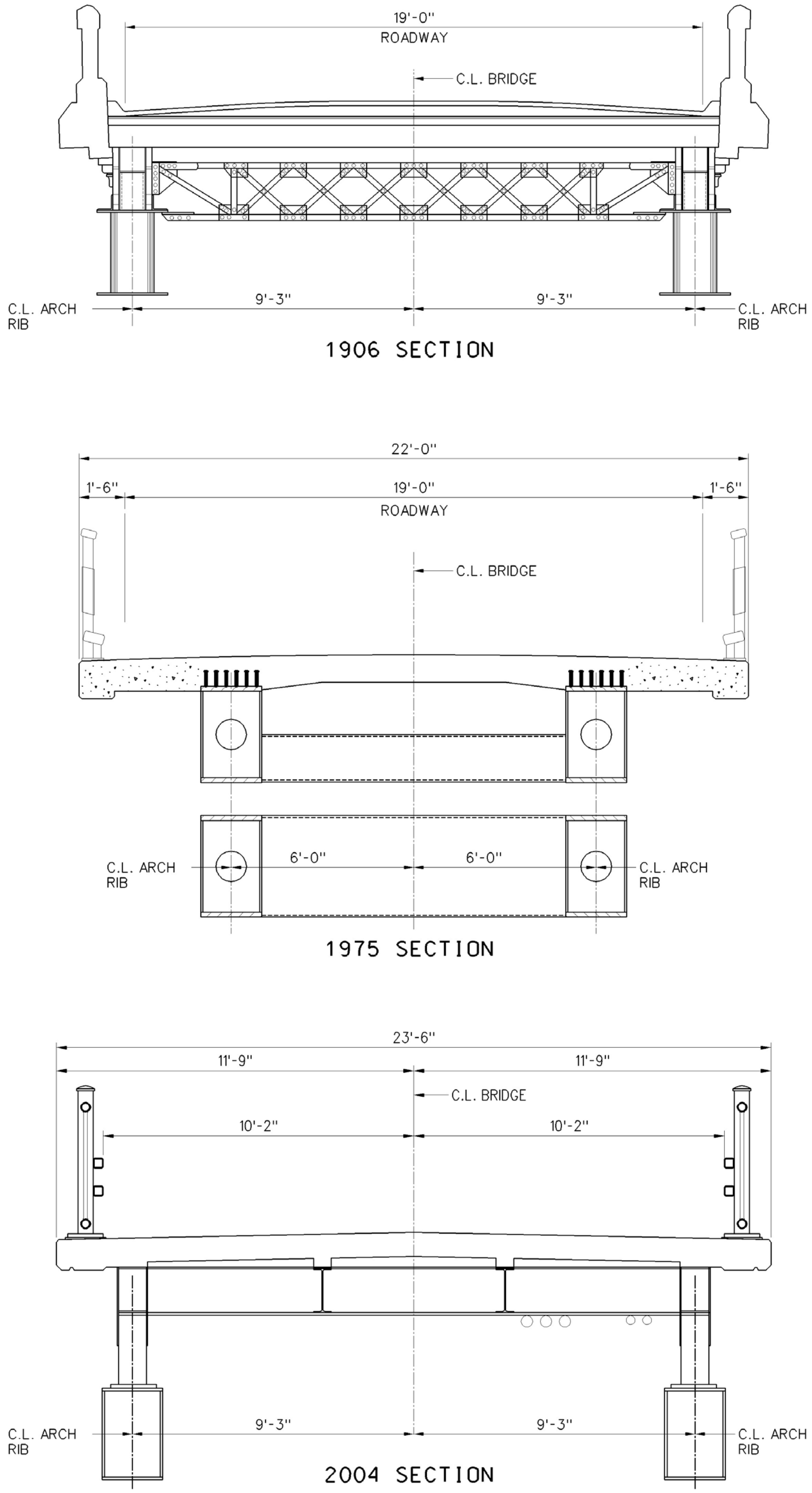


**Figure 10: Cross Sections of Three Bridges**

to have been made for the bridge independent of the adjoining dam details. The dam itself has a uniformly spaced pattern of arched panels at its cornice. In the new bridge, it was decided to space the spandrel columns uniformly and further apart for compatibility with the dam detailing. The arches fascia panels were designed as stiffened steel plates with a tube welded to their arched edge for stiffening and to add visual relief. The panels were set to the back of the spandrel columns to add shadowing and further relief to avoid a flat appearance. Figure 11 shows elevations of the 1906, 1975 and new bridges.

Another key aesthetic element was the bridge railing. There was no good historic precedent for the railing. The entire dam was originally designed with a stone masonry parapet but a design change at the end of the dam contract switched the parapet to a railing. The railing was less costly and provided a better view from the roadway. The 1906 dam railing remains in place and is in fairly good condition. It consists of massive tubular rails with large spherical cast joints and a balustrade. The railing is set atop a tall granite curb and has no traffic rail. The 1905 bridge was designed and constructed prior to the decision to switch from a parapet to a railing on the dam. Therefore the original designers carried the form of the originally intended parapet across the bridge. When construction was complete in 1906, the heavy masonry dam appeared lighter with its open railing while the bridge structure appeared incompatible and top heavy with its solid parapet. The 1970's bridge incorporated a more modern type railing.

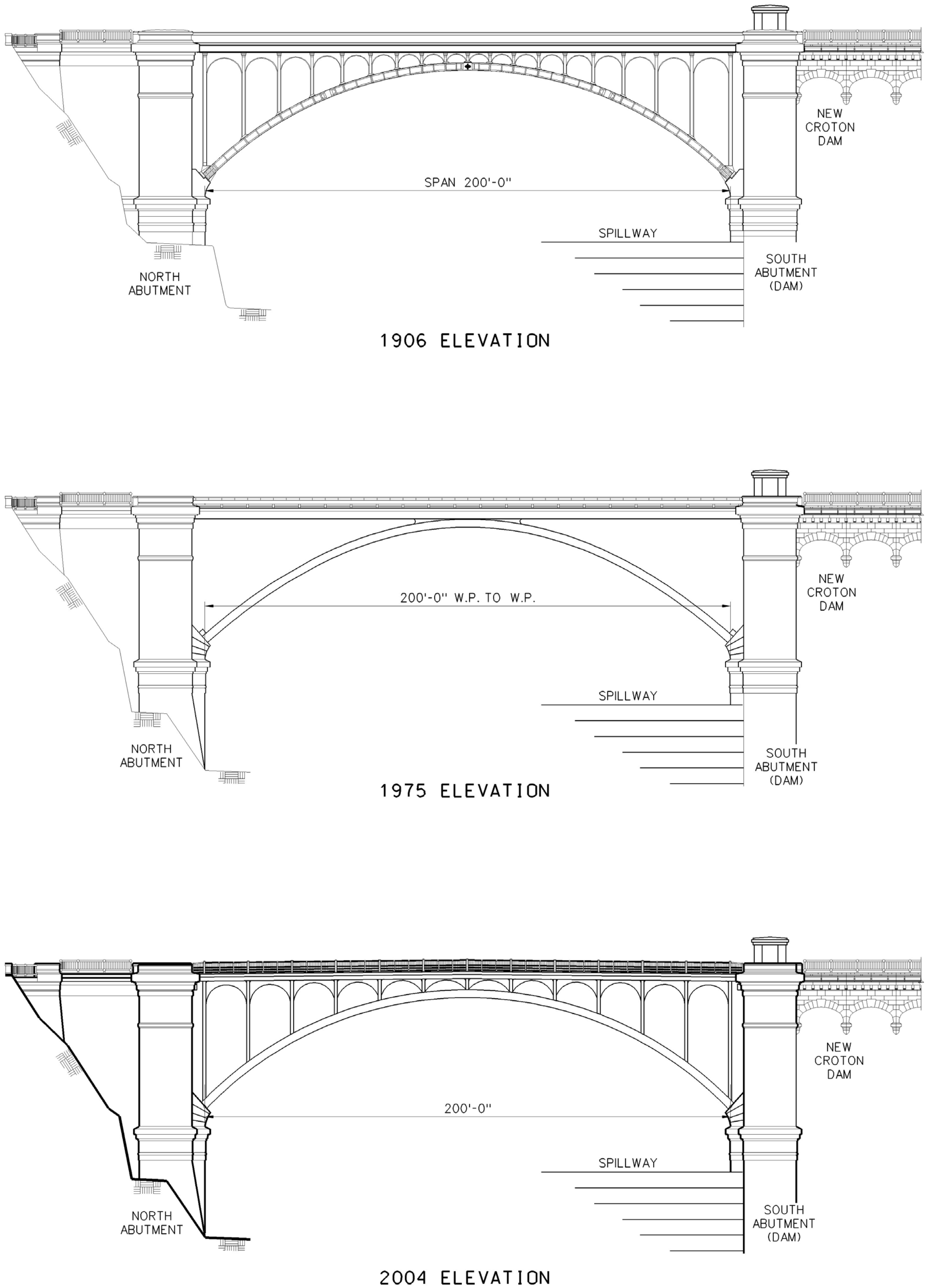


**Figure 11: Elevation of the Three Bridges**

**Figure 12: Main and Secondary Posts of the New Bridge Railing**

The use of a solid parapet like the 1906 bridge was eliminated from consideration due to its aesthetic incompatibility. Thought was given to replicating the dam railing across the bridge but this was eliminated from consideration for a variety of reasons. The decision was made to create a distinct context sensitive railing that incorporated the spherical elements of the 1906 dam railing but at a smaller scale. The new railing would be fabricated from steel castings and tubular elements. The railing would meet height and geometric standards and continuous traffic railings would be provided. Rail elements exposed to traffic were based on NYSDOT Standard details but were not tested as an assembly. The railing incorporated main posts lined up with the spandrel columns and smaller secondary posts evenly spaced between the main ones. The new bridge railing is shown in Figure 12.

The proposed design for the replacement bridge was subject not only to review by the client's architectural group but was also subject to review by the State Historic Preservation Office (SHPO) and the New York City Art Commission. SHPO reviewed the design for visual compatibility with the National Register listed New Croton Dam. The Art Commission is a City agency responsible for review and approval of designs for works of architecture proposed or to be erected on or over City-owned property. Due to the compressed design schedule, there was no time for reworking the design. The best solution needed to be presented and any differences of opinion needed to be resolved expeditiously. The reviews went smoothly and the only substantial comment involved the fascia panel at the end bay of the bridge. This being resolved, the sign-offs were not only obtained but both agencies commended the design.

## DESIGN FOR CONSTRUCTIBILITY

The spillway was a particularly difficult worksite. Not only did the heavy flow in the spillway channel preclude shoring from below but also the entire structure would be difficult to access during the phases of demolition and new construction. While details of the erection scheme were left up to the contractor, it was felt that there would be an advantage to building the new arch ribs outboard of the existing ones. This was the location of the arch ribs for the 1905 bridge and there was ample space for anchoring the arch to the skewbacks at this location. With this arrangement, the new arch ribs could be installed before removal of the existing arches. The existing bridge could then be used for access and staging purposes. Other erection methods including various tieback arrangements could also be considered by potential bidders.

## NEW BRIDGE CONSTRUCTION

The bridge replacement contract was bid and awarded to Kiewit Constructors, Inc. Work started in summer 2003. Initial fieldwork proceeded while shop drawings were prepared and fabrication commenced. Steel was fabricated by High Steel and shop assembled to assure proper fit up.

A key to success of the construction phase was the contractor's innovative overall erection plan. Access and site safety went hand and hand. Care was given to making movement throughout the site easy for workers. Access to the dam end of the bridge was via existing stairways in the dam. At the north abutment, access stairs were installed above the spillway down to the skewbacks. Due to a similar profile of the existing and proposed arches, it was decided to use the existing arches to support the new arch segments being erected.

**Figure 13: Erection of New Bridge Using Existing Bri as Shoring**

**Figure 15: Completed Context Sensitive Replacement Bridge**

Beams were under-slung below the existing arches and cantilevered out to support the new ribs as well as the work platform and protective shield. Figure 13 shows the erection procedure.

The existing deck was removed to lighten the load on the existing arch ribs and eliminate an obstruction to the rib erection. Since the contractor wanted to have the new bridge seats in place so erection of the new bridge could proceed uninterrupted, the ends of the existing deck girders were supported on temporary columns and partially removed to make room for the new seats. Rock anchors for arch anchoring and seat construction were installed using a drilling rig on a platform suspended from a crane.

The new arch ribs were erected with cranes from both ends of the bridge. Alignment and splicing was facilitated by jacking the new ribs up off of the underslung beams. The splices were bolted up and the bases grouted to make the ribs ready to carry load. The under slung beams were connected to the new arches and platform loads were transferred to them. As the existing arches were cut for removal, their loads were also transferred to the new ribs. The original work platform / protective shield remained in service for the entire construction period. The remaining steel was erected using cranes at either end of the bridge (see Figure 14). Deck construction and completion of the bridge followed.

The new bridge is shown in Figure 15. The work went quickly and smoothly. The total construction cost was $4.6 million plus an incentive ($900 per square foot) and the job was completed in 16 months.