NORTH AVENUE BRIDGE OVER CHICAGO RIVER

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ABSTRACT:

The North Avenue Bridge utilizes a hybrid structural system, a combination of a self-anchored suspension bridge and cable-stayed bridge. The bridge consists of a 252-ft main span which is supported by suspension cables in the middle half and by cable stays for the remainder of the span, and two 84-ft back spans which are supported by cable stays. The use of HPC for the bridge deck will provide greater durability and strength characteristics, and lower permeability characteristics, compared to normal concrete. This project is a pioneer effort in applying the innovative cable stayed – suspension hybrid system. The design will serve as a good opportunity to study the behavior of such a unique structural system and provide valuable knowledge for its future applications.

Keywords: HPC, Cable-stay, Suspension, Hybrid, Self-anchored, Post-tensioning

INTRODUCTION

The project is located at approximately 3 miles northwest of Chicago's Central Business District. North Avenue is a Strategic Regional Arterial (SRA) under the guidelines established by Illinois Department of Transportation (IDOT). North Avenue, is a primary east-west thoroughfare providing access to the J.F. Kennedy Expressway (I-90/94), Lake Shore Drive (U.S. 41), and to the many industrial, commercial and retail businesses in the area.

The existing, historic bridge is a Chicago-style, double-leaf, three-truss trunnion bascule bridge constructed in 1907. The bridge is currently inoperable since portions of the opening machinery and electrical systems are non-functioning. The bridge center break has also been structurally locked, and the bridge has not been opened since 1972.

DESCRIPTION OF THE PROJECT

This project consists of removing the existing, inoperable bascule bridge and constructing a wider, fixed span bridge in the same location. Portions of the east and west roadway approaches will be reconstructed, and street appurtenances will be upgraded. The construction of the new bridge is planned to be completed by December 2005.

The proposed structure will span 252-ft over the river and will have two 84-ft back-spans. The bridge will have a total width of 80-ft, will carry two lanes of traffic in each direction and will have sidewalks along each side (See Figures 1 and 2).

The selected structural form for the bridge is a hybrid system, a combination of a self-anchored suspension bridge and a cable- stayed bridge. Between the quarter points of the center span, the bridge is supported by a suspension system comprised of a catenary cable and pairs of vertical hangers. The remainder of the center span is supported by both the suspension system and inclined cable stays, where cable stays run between two parallel hangers. The back-spans are supported only by cable stays which have a semi-harp configuration as seen in Fig. 3.

The superstructure is comprised of a 10-inch thick longitudinally post-tensioned, cast-in-place High Performance Concrete (HPC) deck and stiffening girders that are supported by transverse steel box beams spaced on 21-ft centers, which act compositely with the deck (See Fig. 2). Due to the vertical navigational clearance limitations the transverse box beam depth is limited to 2'-8".

The pylon will be fabricated from Grade 50 steel and has basically three different cross-sections along its height as seen in Figure 4.

Figure 1.Rendering of the Bridge Structure

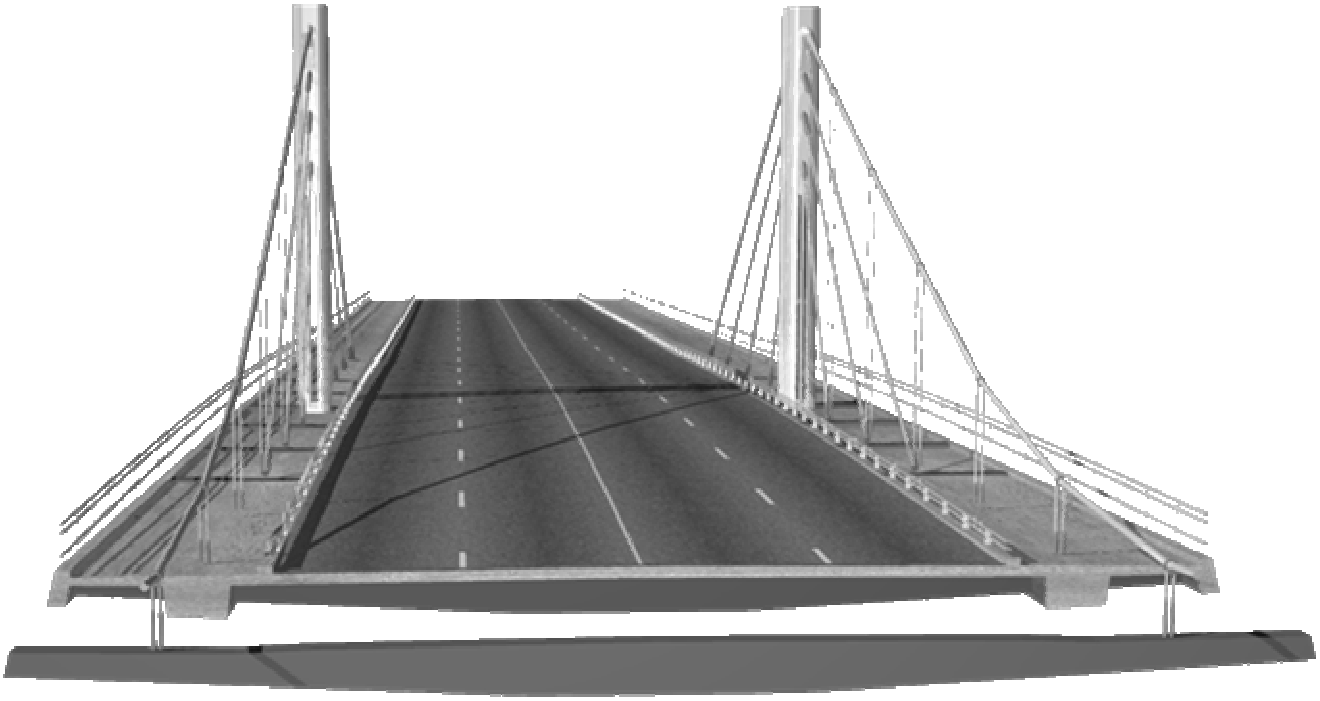

Figure 2.Rendering of the Bridge Structure

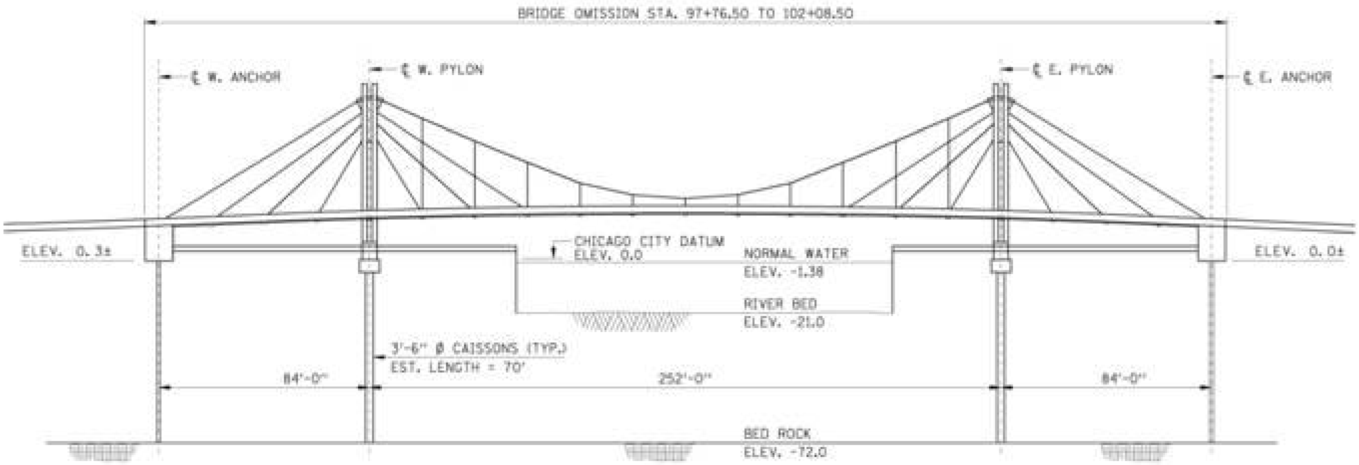

Figure 3.Elevation View of the Bridge Structure

Epoxy coated seven-wire prestressing steel strands will be used for the cable stays, whereas galvanized structural strands will be used for the main suspension cable and hangers.

Heavy concrete anchor blocks located at each end of the structure serve as abutments and resist the vertical component of the suspension cable force with their self-weight. The horizontal force component from the suspension system is transferred into the superstructure.

The following factors played a role in the adoption of such a structural form:

- The City of Chicago decided to replace the existing structure with an aesthetically pleasing signature bridge for the community. The bridge will serve as the focal point for the overall public and private revitalization of the area.
- Vertical navigational clearance requirements and site constraints limit the superstructure depth to no more than 3'-10" which translates into span/depth ~ 66.
- Combined suspension and cable stayed form benefits from the advantages of both systems. Material savings can be obtained in the hybrid structural form compared to a pure suspension system since the load carried by the stay cables will require less material than if carried by hangers and suspension cables.
- One of the ultimate goals is to achieve harmony with the surroundings. The optimum height-to-span ratio for a fan or semi-harp configured cable-stayed bridge will depend on the superstructure dead load. For heavy concrete girders the optimum pylon height would be about 25% of the main span length[1]. This would translate to a pylon height of over 60-ft which was deemed, aesthetically to be too high for this location. The use of a hybrid structural system reduces the pylon height to 44-ft, thereby achieving tower height-to-span ratio of 0.17.

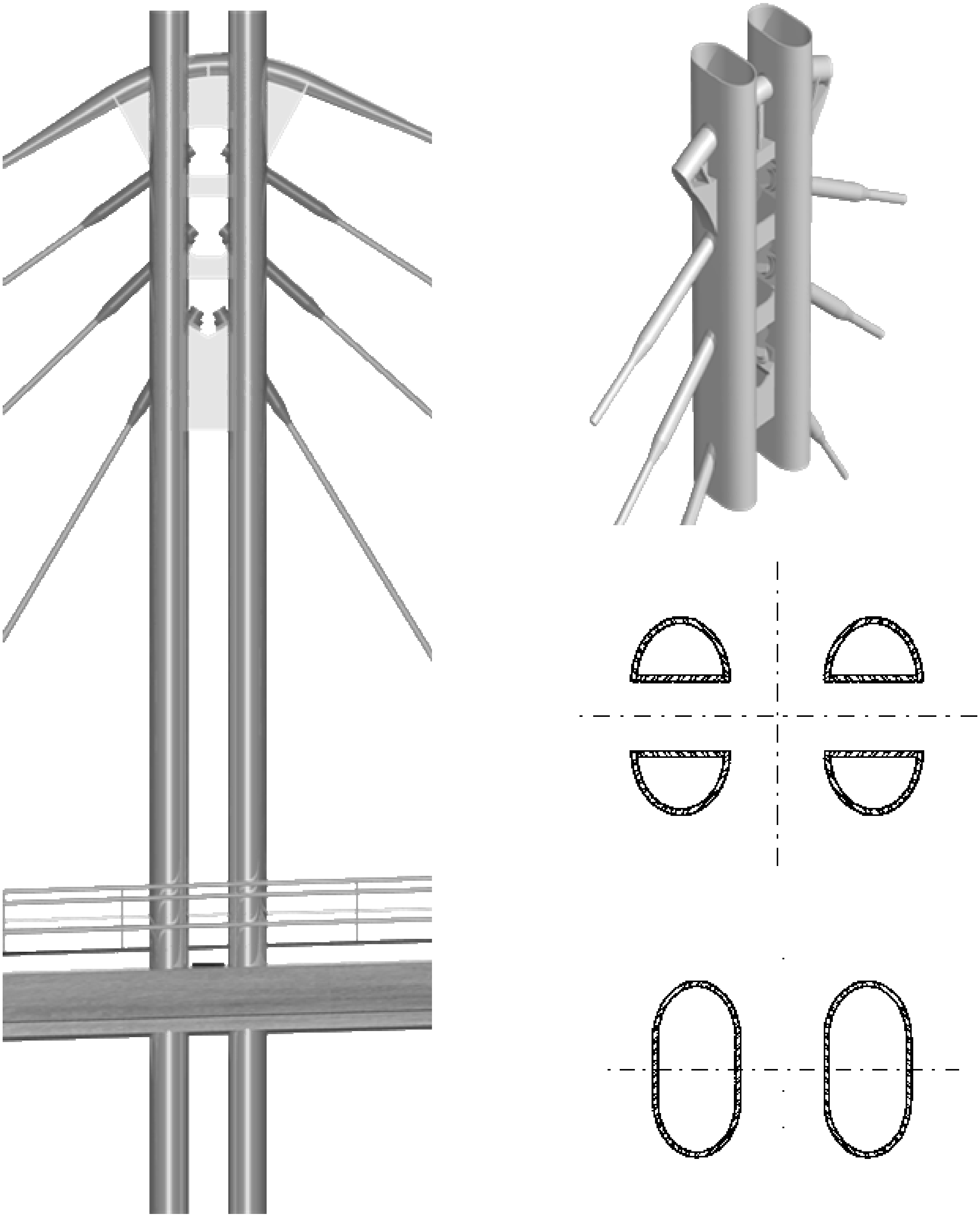

Figure 4.Rendering of Pylon and Pylon Cross-sections

- The weak mechanical properties of the existing soil and the high number of utilities at both banks of the river favored a self-anchored system.
- A concrete longitudinal stiffening beam is preferred because a steel girder would make an inefficient use of steel due to girder depth limitations and would cause high live load deflection.

This project is a pioneer effort in applying the innovative cable stayed – suspension hybrid system. The design will serve as a good opportunity to study the behavior of such a unique structural system and provide valuable knowledge for its future applications in various bridge structures.

ANALYSIS AND DESIGN

AASHTO Specifications[2], PTI Guide Specifications[3], and IDOT Specifications[4] were used for design and analysis of the bridge structure. AASHTO HS25 live load was used for strength and fatigue design.

The 28 day concrete strength of the typical cast-in-place superstructure is 6 ksi.

The structure was analyzed using T-187, an HNTB in-house structural analysis software. This software takes into account the time dependent effects of concrete creep and shrinkage, calculates prestressing losses due to steel relaxation, anchorage draw-in, geometric tendon deviations and axial load shedding between deck and longitudinal stiffening beam throughout the service life of the bridge.

The software also allows for the examination of the stresses and deflections at each intermediate phase of the erection sequence.

It is known that the sag of a stay will have an influence on its stiffness which was postulated by H.J. Ernst using a secant modulus. Based on the cable lengths and working stress level the non-linear cable elasticity can be practically ignored for the proposed bridge[5].

Suspension structures are inherently prone to experience high deflections. In an effort to limit the live load deflections within the AASHTO requirements[2], a parametric study has been done to investigate the effect of longitudinal beam stiffness, cable stay size, suspension cable size, and pylon stiffness on the extreme deflections. It has been found that live load deflections are most sensitive to the changes in the suspension cable size in the proposed structural form.

Second order large displacement analyses were carried out to investigate the force redistribution in the structure in case of hanger or stay loss and during hanger or stay replacement.

PYLON

The pylon is composed of elliptic steel pipes. The independent pipes will be braced at deck level to improve flexural stiffness in longitudinal direction and pylon stability. Pylon design is governed primarily by the stay housing dimensions which resulted in a relatively stocky pylon. Therefore pylon buckling was not an issue. Global pylon stability in longitudinal and transverse directions, local stability of the single half elliptic sections, and local buckling of steel plates composing the pylon were checked.

The longitudinal beam splits into two branches and flows around the pylon. There is only a vertical connection between the longitudinal beam and the pylon which enables the superstructure to float in horizontal plane.

The saddle pipe will be fabricated out of stainless steel and have a radius of curvature of 10 ft. The saddle will be allowed to slide during suspension cable stressing; however, after the construction is finished, saddle and pylon will be linked horizontally.

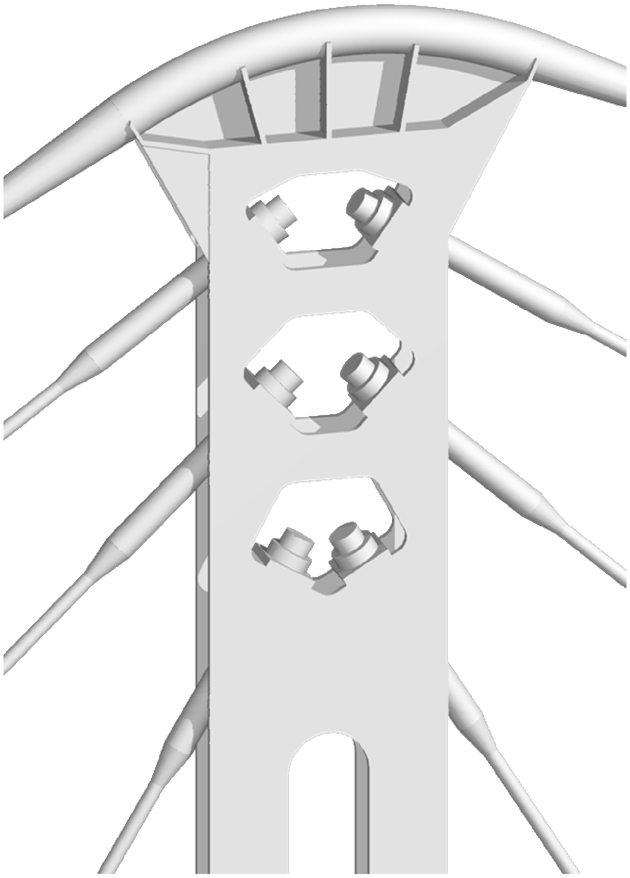

Figure 5.Rendering of Saddle and Staybox

LONGITUDINAL BEAM AND DECK

Both the longitudinal beam and the deck are post-tensioned high performance concrete structures. Due to the inherent flexibility of a suspension structure, the superstructure will deform significantly during the construction period and then sag throughout its service life because of the time effects. In order to compensate the long-term deflection, the suspension cable will be stressed to a level which is more than required to counterbalance the dead loads.

It has been found that tensile stresses will be developed in the middle of the center span at the bottom fiber of the longitudinal beam under live load due to time dependent effects. Therefore the longitudinal beam requires more prestressing force than the deck does.

In order to accommodate this extra prestressing force in the longitudinal beam, a staging method will be followed during the construction. The longitudinal beam will be poured and post-tensioned before the deck is poured. After the post-tensioning force is locked-in in the longitudinal beam, the deck will be poured. An analysis has been carried out to determine the axial force shedding between the longitudinal beam and the deck. It is found that at the end of the bridge's service life of 75 years the remaining force locked-in in the longitudinal beam is adequate to eliminate the tension problem.

The use of HPC for the bridge deck will provide greater durability and strength characteristics, and lower permeability characteristics, compared to normal concrete. HPC superstructure will be able to resist high axial forces especially during the construction due to the combined effect of post-tensioning forces, axial force components of cable stay forces and suspension cable forces. The longitudinal post-tensioning will provide a crack free deck design that will also reduce long-term maintenance costs.

FATIGUE

AASHTO HS25 truck loading is used for fatigue analysis. Fatigue forces were the determining factors for the cable stay design. Since the cable stays are much stiffer than the flexible suspension system most of the truck loads are carried by the stays.

DYNAMIC BEHAVIOR

The proposed bridge has relatively short span length and cable lengths for a cable supported structure. This condition minimizes issues related to dynamic forces. The stiff concrete superstructure has good dynamic stability and its stiffness does not create a seismic hazard since the construction site is "Seismic Category A" (1). The tendency for wind excited oscillations of the individual cables will be suppressed and probably completely eliminated by the cable net formed by the hybrid cable-stay and hanger system.

CONSTRUCTION METHOD

The roadway closure at North Avenue must be minimal due to its strategic location and high average daily traffic volume. Temporary structures will be utilized to detour traffic during the construction of the new bridge.

Requirements for uninterrupted river navigation, soil conditions, and existing utilities dictate a top down construction method.

The cable-stay part of the bridge will be constructed cast-in-place using conventional free cantilever method.

The construction of the pure suspension part of the bridge is more challenging. Since the bridge has a self-anchored suspension system, the structure does not have a self supporting system until at least the concrete longitudinal stiffening beam in the middle of the span gains its stiffness. The main suspension cable cannot support any load until the stiffening girder is in place. Therefore during the construction a steel pipe will be utilized as a compression strut which will pass through the concrete longitudinal beam and the steel transverse beams. This pipe will also allow a direct load path and an efficient connection at the longitudinal beam, transverse beam, cable stay, and hanger junction.

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