NORTH AVE BRIDGE RECONSTRUCTION – FIELD PRECASTING OF A HIGH PERFORMANCE CONCRETE SPAN

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ABSTRACT

The North Ave Bridge over the Chicago River is a $23 million, fixed span, suspension/cable stay hybrid structure. The post-tensioned High Performance Concrete beams and integral deck were erected in an innovative manner to overcome several engineering challenges associated with economy and site limitations.

The center span of the bridge was shored, formed, and poured on three integrated barges several hundred yards away from the jobsite in the Chicago River. The 800 ton fully composite pre-cast center span was lifted into position from the barges with a hydraulic jacking system. The center span of the bridge was suspended over the river temporarily until the permanent cable stay and suspension cable structural system could be later assembled and stressed. This unique construction method was primarily chosen because clearance requirements would not allow for any shoring of the bridge over the water due to daily barge traffic.

Keywords: Cable-stayed bridge, Cable-stayed, suspension hybrid, Composite Pre-cast, High performance concrete, Integral bridge deck, North Ave. Bridge, Suspension bridge, Incremental launching truss.

1. INTRODUCTION

The North Avenue Bridge spanning the Chicago River has been a part of Chicago history for over 100 years. The original structure was one of the oldest bridges in the city—a steel trunnion bascule bridge, built in 1907, shown in its first year of operation in Figure 2. The bridge had significant historical value, but was in a state of deterioration and did not meet the needs of the high traffic volume traveling over the bridge each day between two rapidly changing neighborhoods. The design for a new bridge, with a comparable degree of structural distinction and durability was initiated by the Chicago Department of Transportation (CDOT).

Fig. 1: Rendering of North Ave Bridge [1]

Fig. 2: North Ave Bridge built in 1907[2]

The new structure rendered in Figure 1 is a $23 million, fixed span, suspension and cable-stayed hybrid bridge. The new bridge, having double the traffic capacity, was opened on Dec. 20, 2007. The 10-in. (255-mm) thick deck and integral 4-ft (1.22-m) deep longitudinal beams are post-tensioned, high performance concrete (HPC). The suspension system uses gravitational anchor blocks to counter-balance the center of the bridge. The cable stays attach to steel pylons founded on micropiles. The elevation drawing in Figure 3 and cross-section in Figure 4 show the main structural features of the bridge. The post-tensioned High Performance Concrete beams and integral deck were built on shoring and later attached to the structural system.

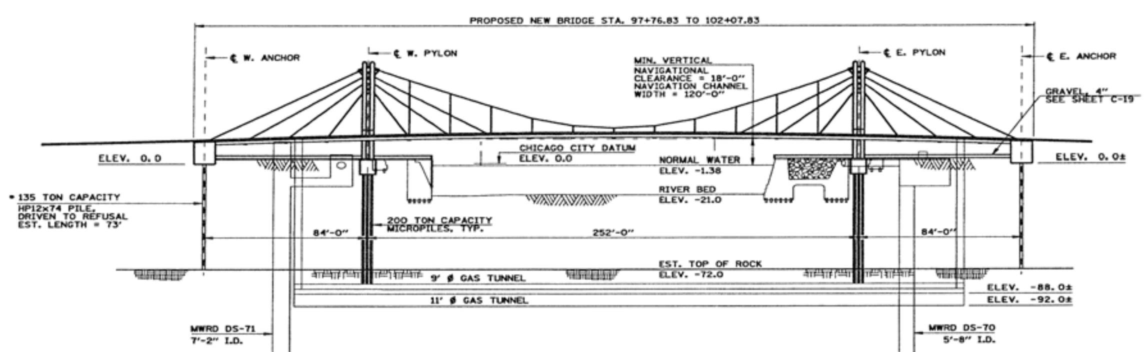

Figure 3: Bridge Elevation View, *Courtesy of McHugh Construction / Bridge Concepts*[3]

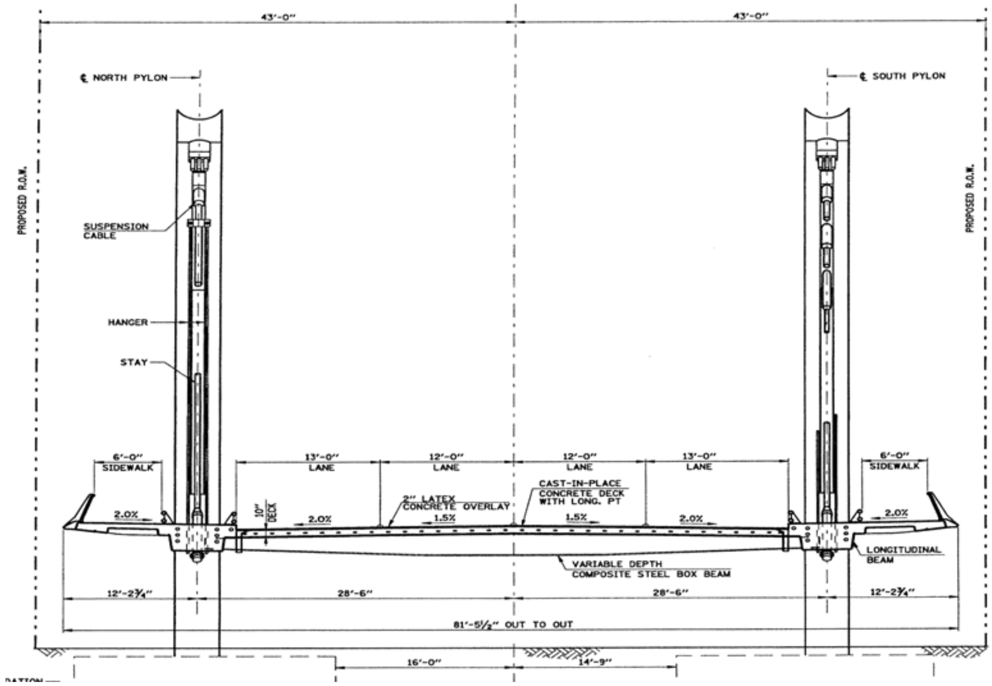

Figure 4: Bridge Cross-Section, *Courtesy of McHugh Construction / Bridge Concepts*[3]

Table 1: General Bridge Dimensions

Dimension	Length ft	Length m
Bridge Length	431	131.37
Main Span Over River	252	76.81
Bridge Width	81	24.69
Roadway Width	50	15.24
Navigation Channel Width	120	36.58
Minimum Vertical Navigational Clearance	18	5.49

Cable-stayed bridges are commonly built by a balanced cantilever method which requires staged shoring underneath the bridge. The designer created the bridge in its complete form, but it was up to the contractor to design the various construction means and methods to get to that point. Because of the complexity of the suspension and cable-stayed system, and construction limitations, the contractor opted for an innovative erection method.

Due to river traffic clearance limitations necessary for consistent barge traffic, shoring of any kind over the navigational channel was not feasible, making an off-site construction method an optimal solution. The 109-ft (33.2-m) long center span was, therefore, shored and formed on three barges just off-site. The HPC 10-in. (255-mm) thick deck, the 4-ft (1.22-m) deep beams, and the sidewalk were monolithically placed with concrete pumped from the shore. Additional, temporary post-tensioning was added to the beams to provide enough rigidity to lift the center span into place. The 800-ton (7.2-MN) HPC center span was floated up the river, adjusted into position, and jacked up from a temporary structural system consisting of launching trusses sitting on temporary piers. A total of sixteen 100-ton (890-kN) jacks lifted the center span into its final position.

This paper describes the design method of the field pre-casted center span, the high performance materials, and the construction procedure to lift the pre-cast center span.

2. DESIGNED TO LIFT

As the backspans of the bridge were built on shoring, and the gravitational anchor blocks and pylons were poured and erected, the construction of the center span began. The construction method selected allowed for flexibility within the construction schedule. Neither construction operation was dependant on each other. Therefore the critical path of the schedule was not affected by either construction operation until the bridge was complete and ready for load transfer into the hybrid structural system.

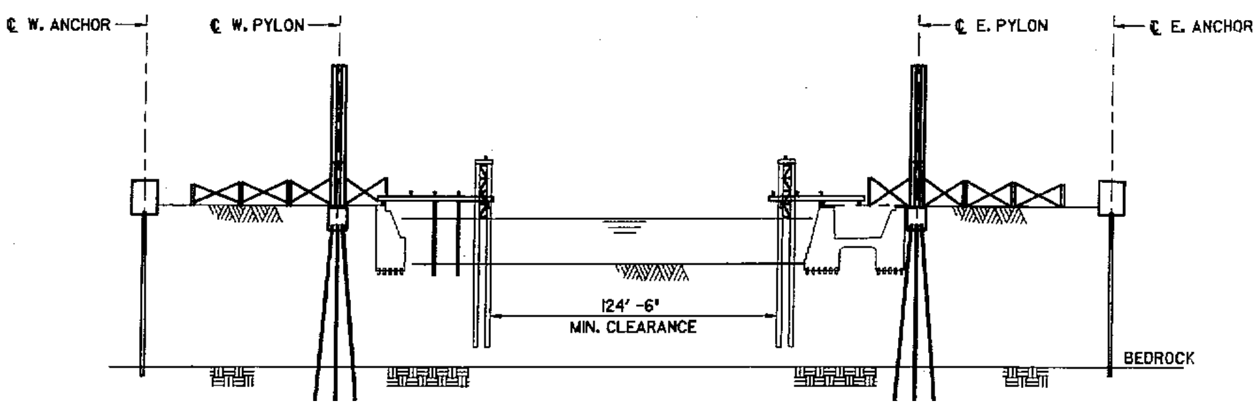

Figure 5: Bridge Elevation Prior to Center Span Lifting System Installation, *Courtesy of McHugh Construction / Bridge Concepts*[3]

2.1 FULLY COMPOSITE PRE-CAST CENTER SPAN

While work progressed at the site of the proposed bridge, three barges, were delivered to the site. The barges, built in 1929 were interconnected with five, 100-ft (30.48-m) long W33x131 beams. This system was used to restrain the barges against movement with respect to each other. The magnitude of the forces of this movement was determined through structural analysis. The barge system was treated as a transverse beam supported by hydrostatic forces from the river and loaded with distributed dead load forces from the shoring, beam supports, span components and concrete. The live load was considered at each of the various stages of the concrete pour itself. Longitudinal timbers laid out on the barge were also used to distribute the heavier forces of the span to multiple beams of the barge.[3] These barges were used as the starting point and foundation for the construction of the center span of the bridge. These barges would later be used as a platform to lift the bridge span into position.

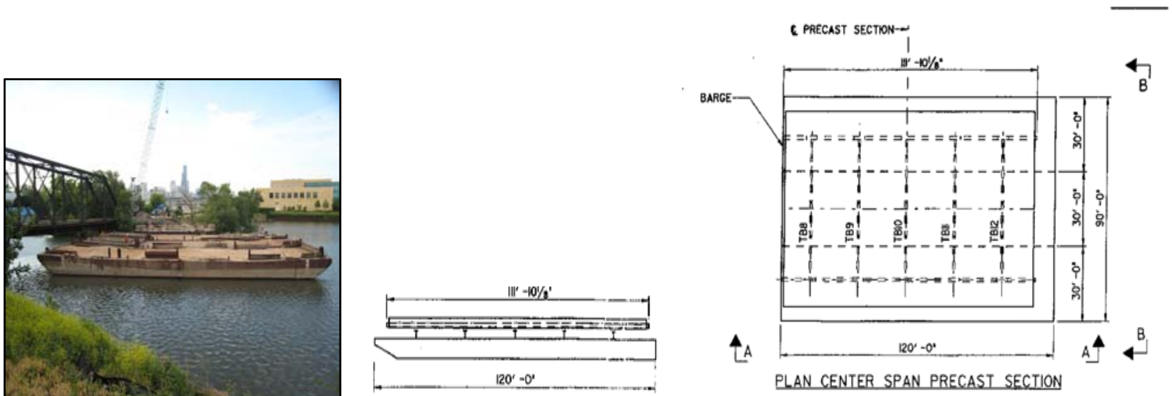

Figure 6: Picture of the barges[4], sectional, and plan views[3]

The center span of the North Avenue Bridge is 100-ft (30.48-m) x 80-ft (24.38-m). The span was constructed on a barge and set on 5-ft (1.52-m) high falsework. The entire deck was constructed in the same manner as the bridge backspans which were built in the traditional shored manner. Force distribution of temporary point loads such as those from equipment and materials were taken into consideration with the shoring design.

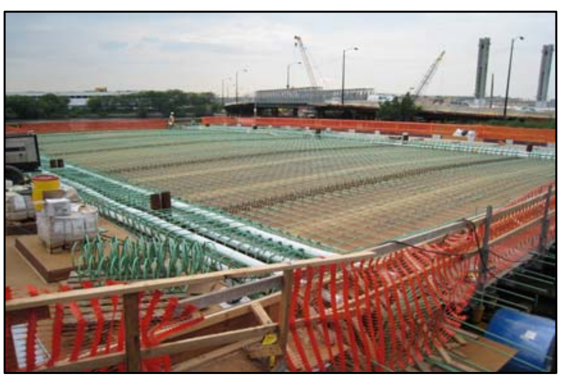

Figure 7: Center Span floating on the River During Construction, *Courtesy of Richard Dolan, URS Corporation*[4]

The construction of the barges, falsework, and composite pre-cast span progressed over a two month period. The pour was a challenge due to balancing issues created by the buoyancy of the barge. A detailed placement procedure and constantly surveyed deck elevations ensured a uniform and safe pour.

The loaded barge, before the pour, was 2.3-ft (0.70-m) lower in the water than prior to construction. When the pour was completed the barge was an additional 2.6-ft (0.79-m) lower in the water leaving approximately 2.0-ft (0.61m) of the barge above the water. The total supports of the system weighed 618-ton (5.6-MN) and the completed span weighed 834-ton (7.5-MN) with a combined total weight of 1493-ton (13.4-MN) as calculated from Table 2 below.[3]

Table 2: Total Weight of Barge Support and Span Components[3]

SUPPORT	Unit Weight	Quantity	Total Weight, Tons
Barges	150.0 tons	3 ea	450
Transverse Support Beams (5)	141.0 lb/ft	480 ft	34
Formwork & Supports	30.0 lb/ft^2	8904 ft^2	134
SPAN STEEL AND CONCRETE			
Transverse Beams (5)	193.0 lb/ft	279 ft	27
Steel Tubes in Girders	211.0 lb/ft	224 ft	24
Reinforced Concrete Longitudinal Beams	155.0 lb/ft^3	3313 ft^3	257
Reinforced Concrete Deck	155.0 lb/ft^3	5008 ft^3	388
Reinforced Concrete Sidewalks	155.0 lb/ft^3	1615 ft^3	125
Additional Concrete used inside Girders	155.0 lb/ft^3	174 ft^3	13

The concrete pour was designed to take place over two consecutive days in order to maintain balance of the barge throughout the pour. The best way to accomplish this was to pour the sidewalks and longitudinal beams first and the deck the following day. Two concrete pumps allowed for an easy transit of the material from the shore to the barge tied off just at the river’s edge.

Figure 8: Composite Center Span Pour in the River, *Courtesy of Richard Dolan, URS Corporation*[4]

Additional temporary post-tensioning in the longitudinal beams allowed the span to have enough rigidity during the lifting process and to be simply supported from the temporary structural system. This enabled the load of the span to essentially hang from the truss supported system. The temporary post-tensioning was de-tensioned after the load of the bridge was transferred from the temporary system to the suspension and cable stays. Afterwards, the temporary ducts were grouted.

2.2 HIGH STRENGTH MATERIALS – HIGH PERFORMANCE CONCRETE

The Chicago Department of Transportation requires extensive prequalification and rigorous testing of the proposed High Performance Concrete (HPC) from each supplier. The mix used was specifically formulated for use on the North Avenue Bridge Reconstruction Project.[7]

The HPC for the project had two quality components: strength and durability. The specification required a 28-day compressive strength between 6000 and 9500 psi (41 and 66 MPa). The average 28-day strength of the concrete was 7400 psi (51 MPa). Test results confirmed that the mix design met the specified properties for resistance to freeze-thaw cycles, salt scaling, shrinkage, chloride ion penetration, and chloride permeability. These characteristics make the mix superior to conventional concrete, in that the concrete is designed to withstand a severe environment and sustain a longer service life.[7]

Table 3: Concrete Mix Proportions[7]

Materials	Quantities (per yd^3)	Quantities (per m^3)
Portland Cement, Type I	605 lb	359 kg
GGBFS, Grade 100	120 lb	71 kg
Silica Fume	30 lb	18 kg
Fine Aggregate	971 lb	576 kg
Coarse Aggregate	1844 lb	1094 kg
Water	264 lb	157 kg
Air Entraining	as required in the field to meet air void specifications.	
Retarding Admixture	4 to 15 fl oz	150 to 580 mL
High-Range Water-Reducing Admixture	30 to 60 fl oz	1160 to 2320 mL
Water-Cementitious Materials Ratio	0.35	0.35

To achieve the required strength and reduce shrinkage, the specified curing method involved immediately placing cotton mats over the finished concrete and soaking the mats with a mist, placing soaker hoses, and then polyethylene sheeting for a curing period of 7 days. The concrete temperature was monitored to ensure that it was between 50 and 150°F (10 and 66°C). The concrete was placed in the early morning hours so that ambient air temperatures were not above 80°F (27°C) during the placement. The temperature requirements are very important due to less excess available free water than a standard concrete mix and to prevent plastic shrinkage cracking and drying or thermal shrinkage. Ground-granulated blast-furnace slag (GGBFS) and silica fume were used to help achieve the strength and durability properties.[7]

2.3 TEMPORARY SUPPORT SYSTEM

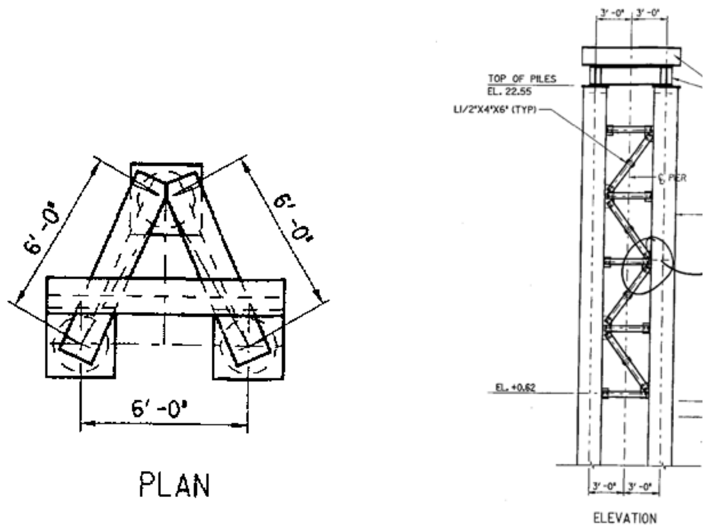

Figure 9: Plan and Elevation Views of the Temporary Structural System, *Courtesy of Bridge Concepts*[3]

While work was continuing on the barges and west backspan bridge deck, trusses were assembled and launched from the East side of the river to the West side. First, 4 clusters of three, 24-inch (61-cm) diameter shell piles were driven in the river and made into a temporary pier to support the trusses as shown in Figure 9. The contractor purchased 120-ft (36.58m) long by 15-ft (4.57-m) high trusses which were used previously on another bridge project over a decade ago. Each weld was inspected and repaired if necessary, sandblasted, and given a new coat of paint. This choice was an economical one, saving the time and expenses of fabrication.

The steel trusses were erected by the incremental launching method from the east temporary pier system. 50-ton (445-kN) rollers were placed incrementally on the east span on raised timber mats. The shoring was designed to be fortified under the point loads. The roller system is shown in Figures 10 and 11. The launch was powered by hand using come-alongs and a grip hoist. Occasionally throughout the launch, come-alongs in the direction perpendicular to the truss were used to maintain the truss alignment during the launch. A simple braking system was placed behind the truss and connected to the last section to restrain the forward launch if necessary. Each truss section was pre-assembled and lifted by crane onto the rollers. A light structural steel launching nose was used. The nose landed on a separate set of launching rollers on the opposite temporary pier once it made the crossing and lifted the cantilevered truss up to the support elevation. Welded steel side guides provided alignment. Each of the two trusses was launched in three stages coinciding with each section.

Figure 10 and 11: Roller Used to Launch the Truss, Timber Mats Used to Support the Load. *Courtesy of M. Mateen, Infrastructure Engineering*[5]

Figure 12, 13: 50 ton rollers, along with come-alongs and a grip hoist were utilized to launch the trusses across the river, *Courtesy of Richard Dolan, URS Corporation*[4]

After the trusses were completely spanning the river while being supported by the temporary pier, four 6-ft (1.83-m) long W40x431 cross-beams were placed on top of the trusses as shown in figures 14 and 15 below. These beams became the support for the lifting jack assemblies placed at the four corners of the beams as shown by the small red beams in Figures 14 and 15.

Figures 14, 15: Cross beams were used to support the lifting jack assemblies at the four corners of the bridge. *Courtesy of Richard Dolan, URS Corporation*

Four sets of four 100-ton (890-kN) lifting jacks were installed at each of the corners of the proposed center span. The jacks were interconnected by adjustable manifolds to a central hydraulic mechanical system.

Figure 16: Center Span Lifting Assembly, *Courtesy of Carlos del Val Cura, McHugh Construction*[6]

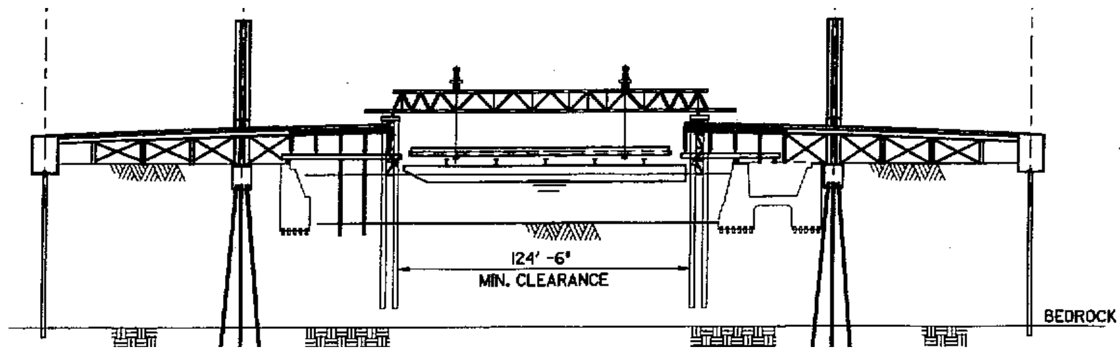

Figure 17: Cross-sectional view of the completed center span lifting assembly. *Courtesy of McHugh Construction / Bridge Concepts*[3]

3. LIFTING PROCEDURE

In comparison to the months of design work involved, preparation of the lifting system and the field pre-cast construction of the composite center span, the lifting portion itself was only a full two day affair. The lifting was slow and tedious with attention in great detail to the monitoring of the four corners of the bridge. The jacking process took nearly 30 hours to align the center span with the two backspans.

In the very early morning of the first day, the center span and supports were moved from the staging area approximately 500-ft (152-m) down the river into position under the bridge with two tug boats as shown in Figure 18. The coast guard was notified and permitted the river to be closed during the operation. First the span was pulled under the bridge longitudinally and rotated into position due to constrictions in the width of the temporary bridge.

Figure 18: Center Span on the Chicago River, *Courtesy of Richard Dolan, URS Corporation*[4]

The center span was lifted into place with 2.5-in (6.4-cm) diameter steel rods, lifting the span in 10-in (25.4-cm) increments. A total of 16 incremental stages were needed to lift the span into position. Each rod had a threaded nut that was continuously lowered by ironworkers as the rods came up to ensure that the span was secure. An iron worker was positioned at each of the jacking stations to monitor the lift as well. Sixteen – 100-ton (890-kN) powerpac jacks were used to power the lifting operation. The jacks can be seen in Figure 21, they are green in color between the red beams. Each set of four jacks had a manifold with hydraulic valves to control the pressure to each jack separately if any of the jacks or the corner itself came out of alignment. It was impossible to maintain perfectly exact pressure to each jack due to uneven pressure losses through the entire hydraulic system. This leveling process was tedious and time consuming. Surveyors and ironworkers took measurements and reported them through radio to the central hydraulic control station, in order to maintain and coordinate any necessary adjustments. It must be emphasized strongly the importance and necessity of monitoring that the pressure on the jacks remains even and imperative that the span is completely leveled at all times. This type of jacking device cannot withstand any transverse induced forces. If any of the corners of the bridge becomes out of horizontal alignment it is possible to induce a transverse force into the jack, causing the jack to blow out, posing a safety threat to workers and to the structure itself. Below in Figures 19, 20, and 21, the lifting jack assembly is shown in all of its components.

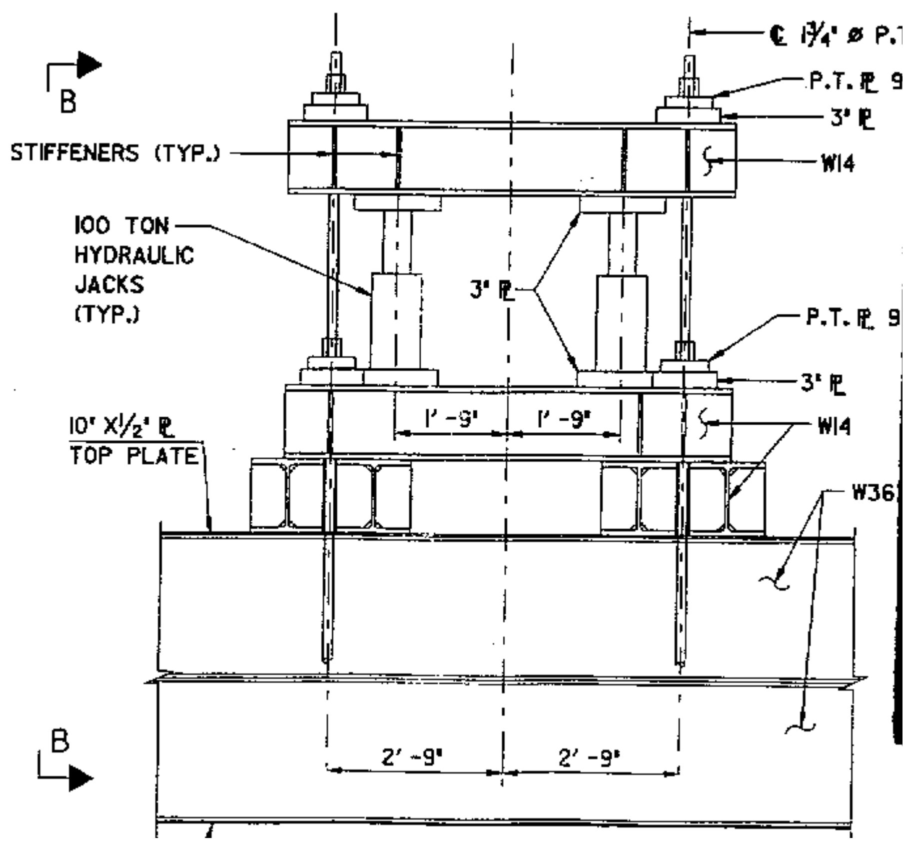

Fig. 19 Lifting Jack Assembly, *Courtesy of McHugh Construction / Bridge Concepts*[3]

Figures 20, 21: Lifting jack Assembly from the Underside of the Span to the Top of the Temporary Structural Support Beam. *Courtesy of M. Mateen, Infrastructure Engineering*[5]

Figure 22: Center Span Lift, *Courtesy of M. Mateen, Infrastructure Engineering*[5]

Figure 23: Center Span in Place Being Supported by the Temporary System, *Courtesy of Richard Dolan, URS Corporation*[4]

Once the center span was completely raised into position, reinforcing steel, post-tensioning ducts and electrical conduit were installed between each of the backspans and the center span. A nine foot wide closure pour was made on each side of the center span to complete the 431 foot long bridge deck. The bridge remained supported by the truss assembly for a period of approximately three months until the entire 400-ft longitudinal beam and deck was post-tensioning and suspension cables and cable stays were completely installed and stressed into their final configuration. After the bridge load transfer was complete, the temporary post-tensioning was de-stressed and grouted. The bridge officially opened to traffic December 20, 2007.

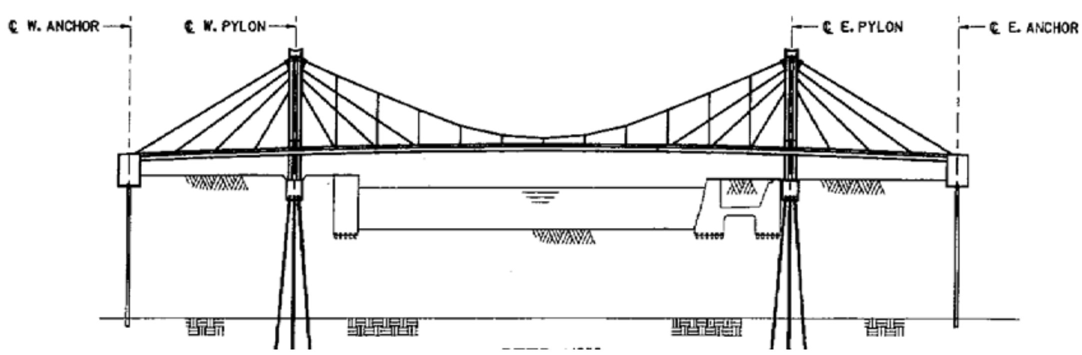

Figure 24: Completed North Ave. Bridge after Load Transfer and Removal of Temporary Structural Systems, *Courtesy of McHugh Construction / Bridge Concepts*[3]

4. CONCLUSIONS

Different options were considered and ultimately the choice was made to build the bridge using an innovative field pre-casting of the center span and lift approach. The field pre-cast design, lifting sequence and materials were used successfully in collaboration with each other to create a signature bridge for Chicago. The ground-breaking bridge design is the first hybrid structural system of its kind used on a bridge in the United States. The method of construction of the center span of this bridge is an excellent example of a prefabricated bridge system that uses accelerated construction to minimize the impact on river traffic. [7] The construction methods implemented, as well as the creative tools and planning that made this method possible, were successful and contribute innovatively to the construction industry.

Figure 25: Completed North Ave. Bridge 2008[8]

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