Precast Concrete – A Unique Application

Sikorsky Bridge, Stratford, Connecticut

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As most structural engineers will attest, precast concrete has many uses. Most times it is utilized in the pristine environment of permanent construction. However, during construction of Pier 3 for the new Sikorsky Bridge in Stratford, Connecticut, precast concrete took on a most unusual form – a "no frills" temporary cofferdam in the Housatonic River. In designing and building this cofferdam, many challenges were faced by Balfour Beatty Construction, the general contractor on the project, and GeoDesign, Inc, the temporary cofferdam designer for Balfour Beatty.

The original Sikorsky Bridge, constructed in the 1930s, was a four-lane multi-span steel plate girder structure with a steel open-grid deck that carried the Merritt Parkway (Connecticut Route 15) over the Housatonic River near the Sikorsky Aircraft headquarters. The main girders were supported on steel columns and concrete piers. The new bridge replaced the old Sikorsky Bridge and was built in two stages to maintain traffic on Route 15. Construction began in 2001 and was completed in 2006. The new bridge consists of two abutments and four piers, which in turn support new twin five span multi-plate girder superstructures with a concrete deck. In Stage 1, the northbound half of the new bridge was built adjacent to the existing bridge while maintaining traffic on the existing bridge. Once completed, traffic was shifted to the newly constructed northbound half. The old bridge was then removed and the southbound (Stage 2) portion of the bridge was completed.

Pier 3 is located in the navigable, middle portion of the Housatonic River. The pier is supported on twelve 6-foot diameter reinforced concrete drilled shafts. The overall dimensions of the Pier 3 footing are 200 feet by 36 feet by 10 feet thick. The pier was also constructed in two stages (Stage 1 and Stage 2) with the pier footing in each stage approximately 100 feet long. The bottom of the pier was set at the low tide line, which is approximately 20 feet above the bottom of the river.

The contract plans called for construction of a temporary cofferdam to enclose the formwork support system, and to permit dewatering of up to ten feet of water within the cofferdam to allow pier construction to be performed under dry conditions. This temporary cofferdam consisted of steel sheetpiles which were to be driven deep into the river bottom to cut off the water. Steel wale bracing was to be installed around the inside of the sheetpiles near the top to provide lateral support of the sheetpiles as the cofferdam was dewatered.

The falsework system within the cofferdam consisted of fourteen 24-inch diameter driven pipe piles supporting seven pairs of W36 beams. The pairs of beams were suspended at each end from the tops of the pipe piles with double channel beams and high strength threaded steel rods. *Figure 1* shows a section of the pier, the temporary cofferdam and the suspended formwork support system. The contract plans called for the pier footing to be cast in one pour for the full 10-foot thickness. However, in order to limit the heat of hydration during curing and to minimize the total weight of wet concrete that had to be supported by the suspended formwork system, a horizontal construction joint was introduced into the bottom four feet of the pier footing. An additional layer of reinforcement was added to the bottom four-foot thick pour to support the weight of the wet concrete in the top six-foot pour.

During driving of the steel sheet piling for the Stage 1 portion of the cofferdam of new Pier 3, large riprap obstructions were encountered below the mudline. This riprap had been placed decades earlier to prevent scouring of the existing pier of the old bridge, which was in close proximity to the new Pier 3. Balfour Beatty had already removed a portion of the riprap as part of the contract. However, the extent and depth of the riprap was greater than anticipated. As a result, a portion of the sheeting could not be driven more than a few feet below the mudline. This precluded the cofferdam from being dewatered, thus halting construction of the pier. During this period, the six concrete drilled shafts were installed, and construction of the remaining three piers and abutments continued along with erection of the new steel superstructure extending from the abutments toward Pier 3.

In August of 2002, a meeting was convened between the Connecticut Department of Transportation, Balfour Beatty, Parsons Brinckerhoff, (the Engineer of Record), Berger, Lehman Associates, P.C., (the inspection consultant), and GeoDesign, to decide on a course of action to construct the pier.

Many options were discussed, including over-sizing the cofferdam to encompass the riprap obstructions, removing more of the riprap from the river, and/or placing a concrete tremie seal within the cofferdam. However, these options were not considered acceptable. Removal of more riprap had the potential of exposing the existing bridge pier to scour. Over-sizing the cofferdam was also not possible, since this would exceed the "area of disturbance" specified in the project's environmental permit. A concrete tremie seal generally consists of an unreinforced concrete slab several feet thick that is cast underwater within a steel sheetpile cofferdam to brace the bottom of the sheeting and cut off the water. However, in this case, the tremie seal would have extended above the mud line, encroaching into the navigable portion of the river, and thus would have needed to be removed once the pier was completed.

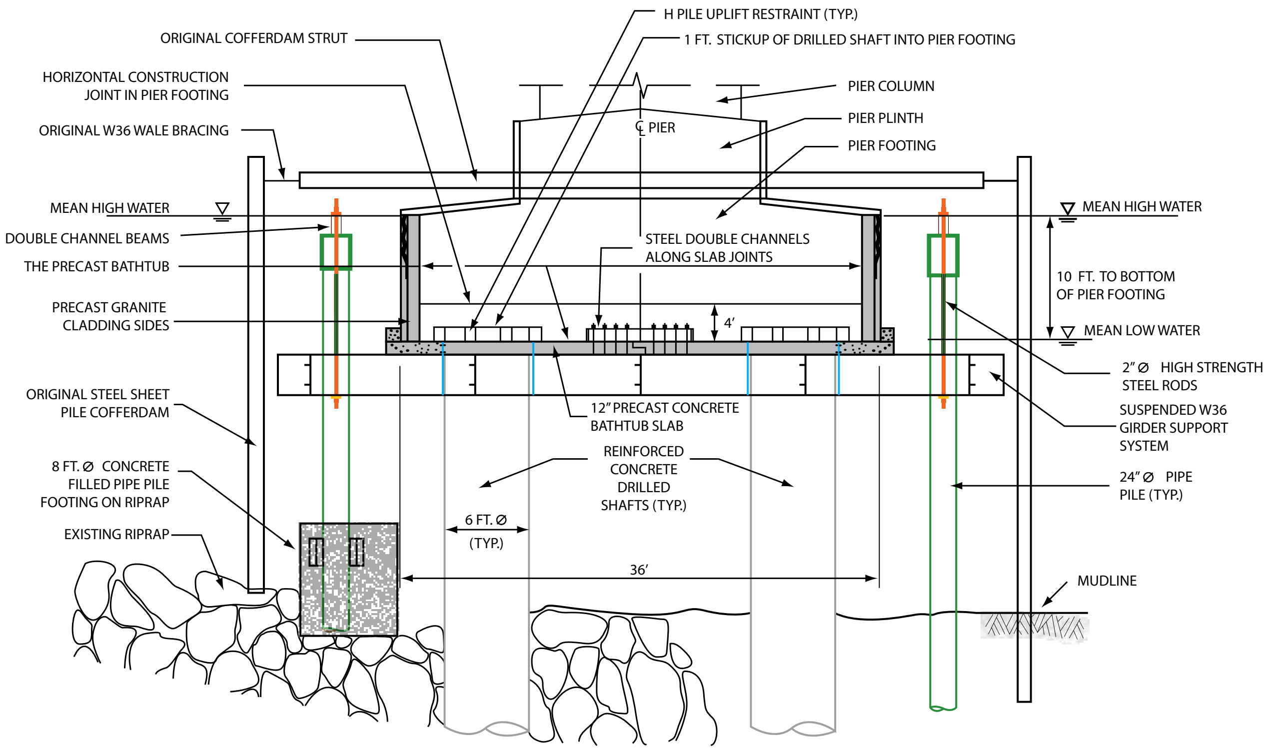

Figure 1: Typical Section Showing Pier, Precast Bathtub.

During the meeting, an idea for an unusual solution began to develop. A watertight precast concrete bathtub cofferdam, supported on the suspended formwork system and sealed around the drilled shafts could be installed inside the steel sheetpile cofferdam. The permanent vertical granite cladding, which would be cast into the exterior sides of the new pier, could also serve as the sides of the temporary precast bathtub. The bathtub could then be dewatered to allow for placement of the pier footing concrete in the dry. There had been precedents for this type of construction using a precast box, such as for the Four Bears Bridge in North Dakota. However, to the authors' knowledge there was no precedent for a box of this size, with these span configurations between drilled shafts, and the numerous design and construction challenges as will be described below. Also, we had to design the bathtub to meet contract requirements since the pier was not intended to be constructed this way.

Balfour Beatty and GeoDesign were faced with numerous questions and challenges. *Figure 2* highlights some of the dimensions that made this project especially challenging.

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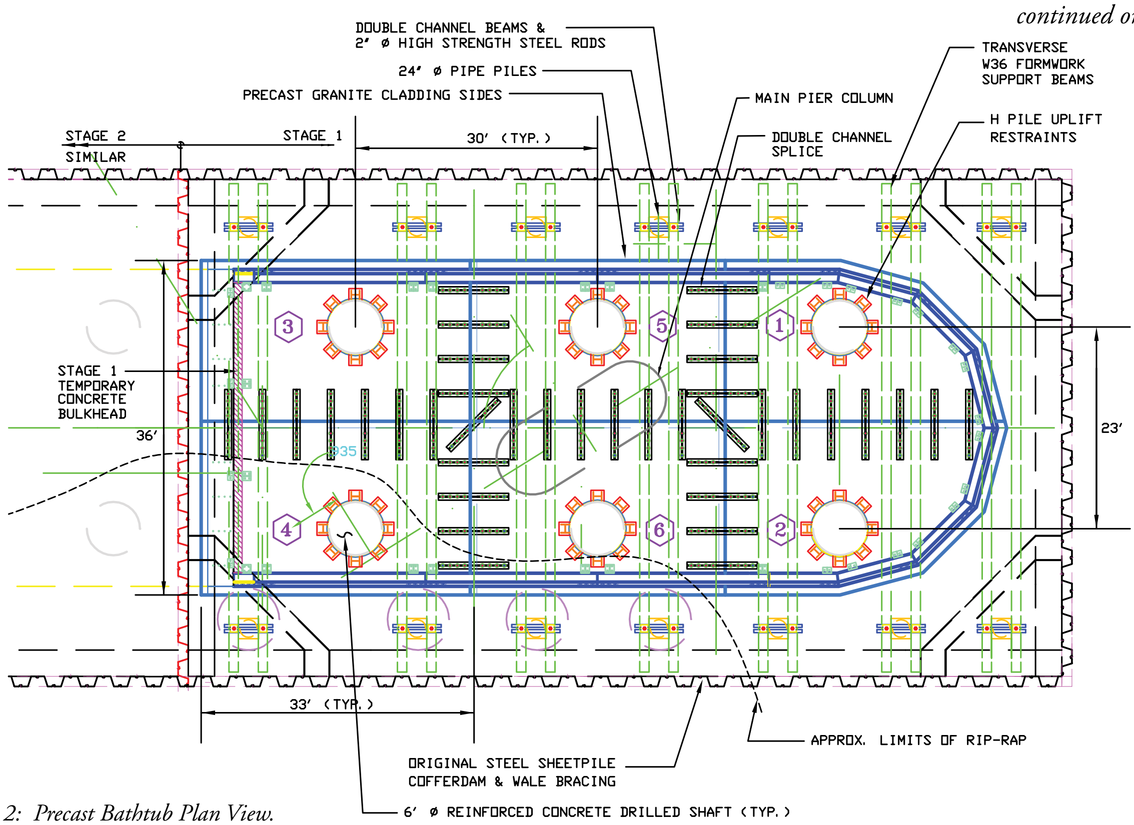

Figure 2: Precast Bathtub Plan View.

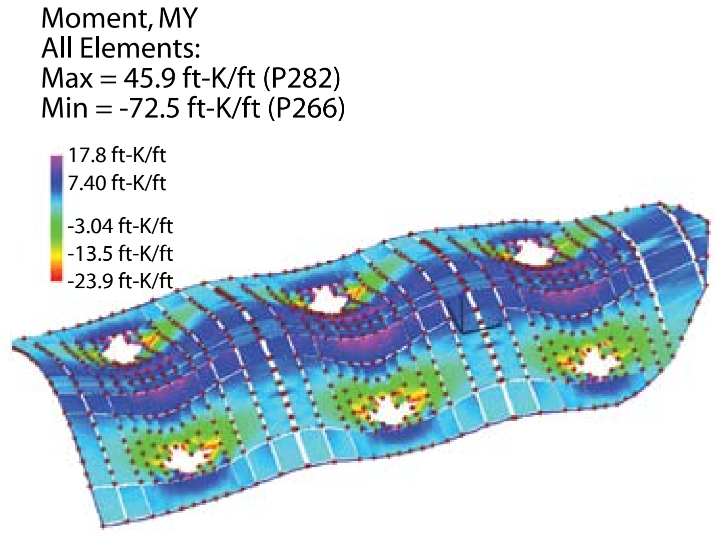

Figure 3: Finite Element Model of the Precast Bathtub.

The dominant considerations in building this bathtub were minimizing weight and delays to the construction schedule. Given the dimensions of the Pier and the fact that some of the drilled shafts, which had already been installed through the riprap, had strayed slightly from their theoretical locations and plumbness, it was deemed necessary to split the precast bathtub into six pieces. Each piece was lowered individually around each drilled shaft, using a large barge mounted crane, and connected together. Also, the base slab could not be more than 12 inches thick; otherwise, the pieces would become too heavy. This gave rise to more challenges:

- The precast slab spanned almost 30 feet between drilled shafts and had to resist the pressure from 10 feet of dewatering. The maximum design moments (and maximum reinforcement) would occur at the holes in the slab for the drilled shafts. Hence, the slab was discontinuous at the support points.
- In addition, moment continuity had to be achieved at each of the joints between precast panels in order for the slab to be continuous between drilled shafts.
- Two million pounds of uplift force, generated over the bathtub footprint during dewatering, had to be resisted by the six drilled shafts. However, the permanent steel casing on each drilled shaft was only allowed to stick up 12 inches into the bottom of the pier footing to transfer the uplift force on the slab to the drilled shafts.
- The slabs were precast to have a 6-inch annulus between the shaft and the slab. Sealing off this annulus and the joints between the slab pieces to obtain good watertightness was critical.
- A system of pile-supported beams suspended from high strength steel rods had to be designed to support both the weight of four feet of wet concrete and the weight of the bathtub while it was being assembled.
- Some of the pipe piles for the suspended formwork system along the south side of the cofferdam could not be driven though the riprap. As a result, they were encased in 8-foot diameter tremie concrete footings which were founded on the riprap.
- The end of the precast slab at the stageline had to extend past the Stage 1 portion of the pier footing to allow for mating up with the Stage 2 portion of the pier to create a watertight seal.
- Fabrication and construction of the bathtub had to occur in the middle of winter.

A three dimensional finite element model (FEM) was created to obtain an accurate estimate of the slab moments and the deformations. The slab was modeled using plate elements. Holes were created at each of the shafts in the model to simulate discontinuity of the slab. *Figure 3* shows the bending moment contours in the FEM model under the uplift pressures. *Figure 4* shows the rebar details of the bathtub at the location of a drilled shaft. The moments obtained from the analysis were pretty significant for the 12-inch slab. Using the Load and Resistance Factor Design approach (LRFD), a safety factor of approximately 1.2 was computed between the ultimate and actual slab moments. However, given the certainty of the loads, the relatively short duration of the dewatered state of the bathtub, and the sophistication of the analysis, this narrow safety margin was deemed acceptable. Construction would later prove out the validity of this design assumption.

To account for the fact that the rebar had to terminate from all sides at each shaft, an innovative radial rebar pattern was designed (*Figure 4*). Each rebar was threaded and bolted to a one-inch thick, twelve-inch high steel ring which was cut from an eight-foot diameter steel pipe. The ring was cast into the precast slabs and acted as a balanced tension ring to allow the rebar to develop the tension forces.

To achieve moment continuity of the slab across the shiplap joints, bolted double channel connections were designed,

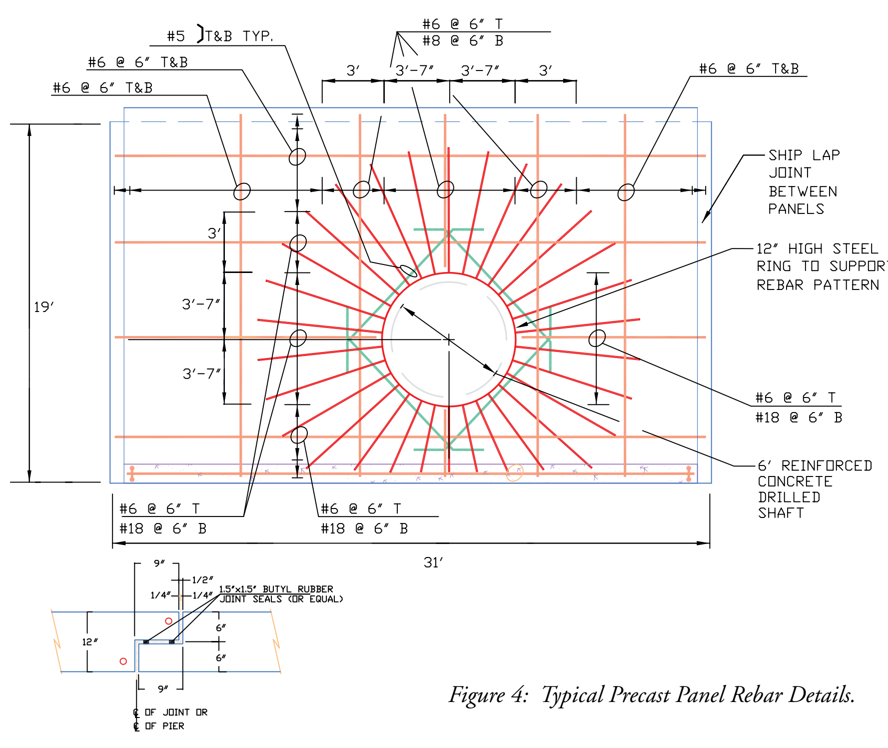

Figure 4: Typical Precast Panel Rebar Details.

Figure 5: Precast Bathtub Nearly Complete. Courtesy of Morgan Kaolian/Aero, Inc.

between the slabs, which were installed at a four-foot spacing to stitch the slab sections together. These channels maintained the stiffness of the 12-inch slab at the joints and were bolted to each slab using 1.25-inch diameter ASTM A325 "J" bolts. The channels were limited to a 12-inch depth so as to avoid interference with the continuous bottom reinforcement of the pier footing.

To achieve water tightness, compressible rubber was used at all slab-to-slab shiplap joints. The annulus between the slab sections and the drilled shaft casings were sealed with an underwater grout mixture. The vertical joints between the granite cladding panels were sealed with an epoxy grout. Additional grouting was performed by divers to seal intermittent leaks, as required. Some leakage occurred at the

Figure 6: Rebar Installation Inside the Bathtub. Courtesy of William J. Frank, P.E.

joints; however, Balfour Beatty was able to maintain dewatering using diesel pumps.

To transfer the uplift force from the slab to the drilled shaft casings, eight H pile stubs were installed around the perimeter of each drilled shaft casing. These stubs were welded to the drilled shaft casing using half-inch fillet welds. To avoid performing such critical and large size welding underwater, the drilled shaft steel casings were left sticking up above mean high water. Initially, four 10-foot long sections of H pile with bottom base plates bearing on the precast slab were placed around the steel casing and welded to the casings above the mean high water. After dewatering the bathtub, the bottom 12 inches of the four H piles were welded to the shaft casing and four additional stub sections were welded in place using half-inch fillet welds. The portion of the H piles and casing above the 12-inch allowable stickup were then cut off.

Since construction occurred during the winter, the precast slabs were cast on barges and winter-cured prior to being set in place. This allowed for simultaneous construction of the pile supported formwork support system. A large barge mounted crane was used to lift and place the precast segments onto the formwork support system. Construction crews worked around the clock to fabricate and assemble the precast bathtub.

Figure 5 (*page 37*) shows the completed bathtub for Stage 1. During dewatering, the seals held, the slab worked as anticipated, and the welded uplift restraints functioned as designed. The precast cofferdam remained dewatered for approximately a month to permit rebar installation and, ultimately, the pouring of the footing concrete in early April 2003. *Figure 6* shows the pier rebar installation inside the dewatered bathtub. The Stage 1 portion of the bridge was completed and opened to traffic in November 2003.

During Stage 2, with the luxury of more time, the precast cofferdam was modified to precast the entire slab in one piece on the suspended formwork system and to install the granite cladding sides in the dry above the high tide line during the winter of 2005. The bathtub was then lowered into place utilizing a hydraulic jack system and the suspended rods, which were connected to double channel beams located at the tops of the pipe piles. Link seals and prefabricated steel plate rings were installed in and over the annulus between each drilled shaft and welded in place to provide uplift restraint and a watertight seal.

Pier 3 was concluded in the spring of 2005, allowing the remaining construction to be completed in a speedy manner. The Stage 2 portion of the new bridge was opened to traffic in the spring of 2006.

The innovative design and construction of the precast bathtub during Stage 1, minimized the delay impacts for the construction of the bridge, and effectively removed the pier from the critical path. Both the bridge and the Pier 3 cofferdam won American Council of Engineering Companies (ACEC)/CT and Connecticut Society of Civil Engineering (CSCE) awards, and the bridge was recognized in 2007 by Roads and Bridges Magazine as one of the top ten bridges in the country.▪

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