Precast Concrete Segmental Substructures

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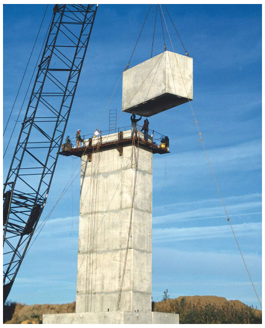

Left: Chesapeake & Delaware Canal Bridge precast concrete column erection, 1995. Photo: American Segmental Bridge Institute (ASBI). Middle: Entire column ready to be erected at the South Norfolk Jordan Bridge. Photo: FIGG. Right: O'Callaghan-Tillman Memorial Bridge precast concrete. Photo: ASBI.

Bridges utilizing precast concrete segmental substructures have been built in the United States since the 1970s, but they are not nearly as common as bridges with segmental superstructures. This article describes the use of precast concrete segmental columns, explores their benefits, and establishes reasons why a contractor in particular might choose this construction method.

What Are Precast Concrete Segmental Substructures?

Examples of precast concrete segmental substructures can include footings and pier caps, but this article will focus on the classic segmental model of precast concrete column units that are stacked on top of each other and then made continuous with vertical post-tensioning. The column segments can be simple rectangular shapes, such as those used on the Chesapeake & Delaware Canal Bridge, the South Norfolk Jordan Bridge, and the O'Callaghan-Tillman Memorial Bridge. Alternatively, the segments can consist of a more-complex shape, chosen for aesthetic or other project-specific reasons. Some examples of these types of column segments can be seen in the Sunshine Skyway Bridge and the Linn Cove Viaduct. In general, the shape of the column segments is a balance among the structural requirements of the design, the aesthetic goals of the owner, and the weight limits of the contractor's transportation and erection equipment.

Benefits

The benefits of using a precast concrete substructure are similar to the benefits achieved from using a precast concrete superstructure. Speed of erection of precast versus cast-in-place

Installing a pre-tied reinforcement cage into the column segment form for the Sarah Mildred Long Bridge. Photo: Cianbro.

Finishing a column segment for the Sarah Mildred Long Bridge is a simple operation because most surfaces are formed. Photo: Cianbro.

concrete is the most obvious benefit. Precasting the column segments means that forming, installing reinforcement, placing concrete, and curing all take place off the critical path. The column segments can then be transported to the jobsite when needed and quickly stacked in place. The speed of erection is only limited by how fast the rigging can be installed, the access can be established, and the crane can swing. With good field planning for the operation, entire columns can be built in 1 day. This can be a critical factor on a project with a short construction season (such as a bridge located in a harsh climate, or in an area with severe environmental restrictions), but precasting concrete in a precast yard can often occur year round. If the bridge is over water, reducing the time spent working over water could potentially reduce insurance costs for the project as well.

Another benefit is the reduced impact to the traveling public, if the bridge is located near public roadways or railways. A cast-in-place concrete operation requires a much longer time for the contractor to occupy each column site to allow for the forming/stripping crew, reinforcement crew, and concrete finishers to do their work, along with required curing time. In addition, materials such as formwork and reinforcement must be delivered, and timely access must be provided for the pump truck and ready-mix concrete trucks on concrete-placement days.

Another benefit of using precast concrete substructure is the quality and durability of the finished product. Concrete structures produced in a casting yard, as opposed to placed in the field, are generally recognized to be higher-quality structures. The repetitive nature of precasting eliminates the surprises and disruptions that can lower the quality of field-placed concrete. Use of high-performance concrete, consistent application of controlled steam or heat curing, and the ability to achieve reliable concrete cover are all hallmarks of a good precasting operation, and all improve the durability of the finished structure.

Finally, improved safety for construction workers is another benefit of using a precast concrete substructure. Precast yards are typically established away from heavy traffic areas, so work crews and suppliers making deliveries are not exposed to traffic zone dangers, as they might be at the actual bridge site. Additionally, casting beds for column segments are typically only two segments high, and are built in a stationary location so that proper access and work platforms can be installed. This eliminates most work that would occur high off the ground for a tall cast-in-place concrete column, which in turn greatly reduces the hazards of the crew falling or of being struck by falling objects.

Segment Casting and Erection

Column segments are typically match-cast in their actual vertical orientation to ensure a precise fit during erection. The bottom segments are cast first, then casting proceeds upwards. For survey control, the segments are located with respect to plumb control lines—note that two orthogonal faces must be monitored to ensure that the column will be plumb in both directions.
The reinforcing cages, which include reinforcement, post-tensioning ducts, and any necessary embedded items, are usually pre-tied for maximum efficiency during the casting process. After forms for the new segment are set and surveyed on top of the previous match-cast segment, the reinforcing cage is set into the forms. Keyway block-outs in the top surface and mandrels to hold the post-tensioning ducts in place are attached to the forms to ensure their correct position throughout the concrete placement.

After the concrete is placed and finished, the segment is cured overnight and typically achieves strength for stripping by the following morning.

Column segment erection is fairly simple. The footing is usually prepared with a keyway slightly larger than the column cross section. The first segment is set partially into the keyway, then surveyed plumb and shimmed off the bottom to achieve the desired accuracy.

Preparing to strip forms for a column segment for the Sarah Mildred Long Bridge. Photo: Cianbro.

Completed tower column segment for the Sarah Mildred Long Bridge. Photo: Cianbro.

The level of accuracy required for this operation is a function of the height of the column, because any error in setting the initial segment will be projected to the top of the column. After the segment is shimmed, post-tensioning ducts between the footing and segment are coupled, and high-strength grout is placed into the keyway to join the segment to the footing.

After curing the grouted joint, erection of the remainder of the segments can proceed. The segments are joined by placing epoxy on the top of the last segment just prior to setting the next segment. Each segment is simply set atop the previous one, since geometry has already been established in the precasting operation. The segments are placed until either the contact time for the epoxy is approaching the specified limit, or the stacked column reaches the limit of stability. At this time vertical post-tensioning is applied to the column to achieve either the minimum epoxy squeeze pressure or the minimum stress required for stability, whichever is greater. Note that for shorter columns, no intermediate stressing may be required. The final segment to be erected is the pier cap segment, which typically has a solid section and special reinforcement to accommodate the bearings and distribute the superstructure and post-tensioning forces to the overall column cross section.

After all of the segments in a column are erected, the permanent vertical post-tensioning is installed and stressed. These tendons loop down through the footing and have both anchorages located in the pier cap segment. All stressing operations take place from the top, with the tendons double-end stressed from the pier cap.

Case Study—Sarah Mildred Long Bridge Lift Towers

The Sarah Mildred Long Bridge is a two-level precast concrete segmental box-girder bridge connecting Kittery, Maine, to Portsmouth, N.H., across the Piscataqua River. When it opens in 2017, it will carry vehicular traffic on its upper deck and a rail line on its lower deck. The new bridge will have a 300-ft-long movable lift span over the river navigation channel, supported by four 194-ft-tall concrete lift towers. The contract delivery method for this project is construction manager/general contractor (CM/GC).

The four lift towers were originally designed to be cast-in-place, but during the CM/GC process it became clear that switching to precast concrete would reduce both cost and schedule. The contractor estimated that it would take 4 months per tower to cast them in place, and because it was on the critical path, they would have to work on at least two towers simultaneously. The two foundations for the towers would also need to be constructed simultaneously to meet the project schedule. With the switch to precast concrete, the tower erection was compressed to 5 weeks at each location, which allowed one foundation to be constructed at a time, reducing the amount of temporary works. The savings in cost and schedule at the time of the estimate was projected to be significant.

The 88 lift tower segments (22 per tower) are essentially rectangular hollow sections with outside dimensions of 19 ft by 27.5 ft by 8 ft tall, with a minimum wall thickness of 1.5 ft. They contain 50 yd^3 of concrete each, for a total weight of approximately 101 tons per segment. The total vertical post-tensioning force on each tower when complete will be approximately 4000 tons.

Closing Remarks

There are several cases where utilizing precast concrete segmental substructures instead of cast-in-place concrete on a bridge project could be beneficial to a contractor. It could be an economic solution on a project with extensive repetition of common piers, and where site preparations or time-consuming deep foundations provide lead time for the precasting operation, such as the Sarah Mildred Long project. It could be the best solution on a project with unique (yet repetitive) column shapes that require high-quality concrete or geometry control,

Moving a completed column segment for the Sarah Mildred Long Bridge to storage. Photo: Cianbro.

Sarah Mildred Long Bridge lift tower column segments in storage. Photo: Cianbro.

or extreme durability. Finally, it could be the best construction plan for a project where site access is severely limited by either time or space constraints. In all of these cases, where a bridge project has been designed with cast-in-place substructure columns, there may be an opportunity for the contractor to work with the designer to replace the conventional design with a precast concrete segmental design.

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EDITOR'S NOTE

This article is based on a presentation given by the author at the 2016 ASBI Construction Practices Seminar held in May 2016 in Broomfield, Colo. The presentation focused on Chapter 8, "Segmental Substructures" of ASBI's Construction Practices Handbook for Concrete Segmental and Cable-Supported Bridges.