Linn Cove Viaduct Demonstrates Geometrical Versatility of Precast Segmental Concrete Bridges

The Linn Cove Viaduct, located near Grandfather Mountain in North Carolina, may be the most complicated bridge ever built. Its horizontal alignment includes spiral curves going into circular curves with radii as small as 250 ft, and curvature in two directions to give the bridge an S-shape. Only a small portion of the bridge is on a tangent. The superelevation goes from a full 10 percent slope in one direction to a full 10 percent slope in the other direction and part way back again. No two of the 153 segments have the same dimensions and only one segment is straight. The vertical alignment includes both vertical curves and tangents. The bridge, 1243 ft long, includes every kind of alignment geometry used in highway construction.

Another factor affecting the complexity of the project is the location. The terrain is among the most rugged and environmentally sensitive in the eastern part of the United States. The bridge is located near the eastern continental divide at an elevation of approximately 4500 ft above sea level.

The bridge, when completed, will carry the Blue Ridge Parkway on its final link from Blowing Rock to Linville. Grandfather Mountain, where the viaduct is located, is privately owned and is one of the top tourist attactions in North Carolina. One of the many reasons for not completing the Blue Ridge Parkway for the past 30 years was the problem of construction damage to the mountain area, which is very steep and has numerous rock outcrops and extensive vegetation.

In order to preserve the natural beauty of the area, the environmental constraints include provisions that prevent damage to major rock outcrops or the cutting of any trees that are not directly beneath the bridge. These constraints, combined with the fact that the bridge site is literally on the side of a mountain, made it impossible to use heavy equipment for conventional bridge construction.

Jean Muller, Technical Director of Figg and Muller Engineers, Inc., of Tallahassee, Florida, who designed the project for the owners (the National Park Service), developed an innovative scheme for building the bridge without doing any damage to the environment. This involved building the entire structure, including substructure components, from the top and in one direction.

The precast segmental bridge is being erected by progressive placing. The final structure will consist of spans 180 ft long. One-direction erection is being accomplished with 9-ft-deep precast segments that measure 8 ft 6 in in length and weigh approximately 50 t. While progressive placing generally uses temporary cable stays to help support the cantilever, the torsional effects of the 250-ft-radius horizontal curves influenced the designers to incorporate temporary bents at midspan.

The complicated geometry greatly affected the control of segment casting by requiring much more accurate controls than normal. During the casting operations, the contractor positioned the cast-against segment and determined the exact position with survey instruments. The contractor was then checked independently by the designers. To achieve sufficient accuracy, Figg and Muller transformed the coordinate system on which the bridge is laid out to a three-dimensional global coordinate system applicable to the machine that cast the segments. This required the writing of several extensive computer programs, as well as taking all measurements to an accuracy of 1/1000 of a foot.

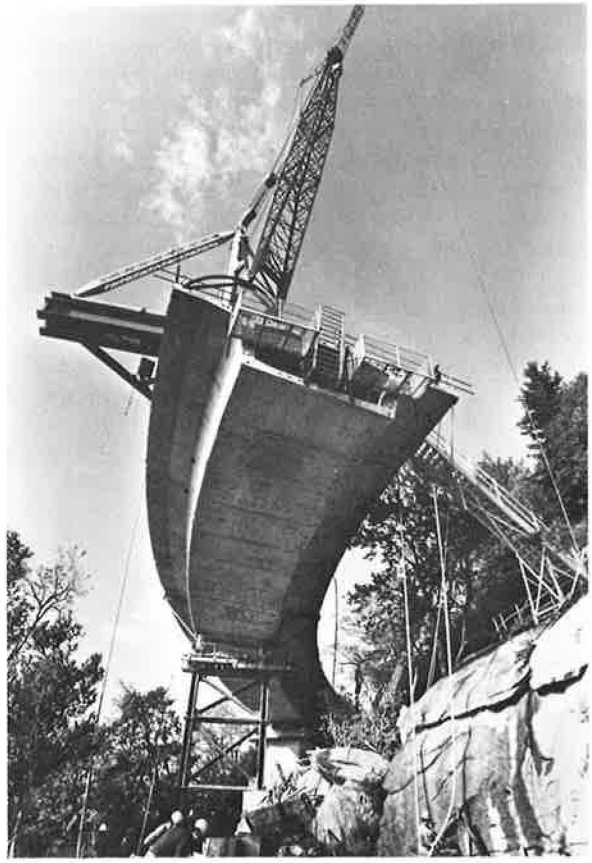
Normally the control points on precast segments are placed 2-3 in from the joint, but assumed to be at the joint for purposes of calculation. However, the severity of the curvature of the Linn Cove Viaduct resulted in too much error with that assumption, and the control points had to be relocated at the joint.

The resulting accuracy has been exceptional. During the first half of the erection, where the superelevation completely reversed and the bridge formed a complete S-curve, the position has matched the predicted location at all times. During the casting operation, no segments were rejected.

The contractor has exercised an option to modify the erection equipment that originally included a swivel crane fastened to the end of the completed portion of the bridge for lifting and placing segments. The contractor is actually using a stiffleg crane to lift the segments along with moving drilling equipment and materials over the end of the bridge. The stiffleg is moved each time a segment is erected that has proven to be the controlling factor in determining the rate of erection. It generally takes 4-6 h to move the stiffleg crane from one segment to the next. The average segment erection rate is four segments per week.

The segment to be erected is delivered by truck over the completed portion of the bridge to the end of the cantilever. There the crane lifts the segment, swings it

Bridge construction is shown as it reaches the halfway point. Exact geometry and casting controls enabled the structure to be erected in virtual conformance with the theoretical geometry.



The bridge turns on a 250-ft radius around a rock outcrop. A stiffleg derrick is at the lead of the cantilever with a steel temporary support shown in the background.

out over the end of the cantilever, and lowers it within approximately 6 in of the end of the cantilever. Here epoxy is applied to the joint face while the segment is supported by the stiffleg. Once the epoxy is in place, the segment is moved horizontally to the end of the cantilever where post-tensioning thread bars are installed and stressed. The thread bars extend through intermediate stiffeners cast on the segment that provides complete access both during stressing and removal later. After the temporary thread bar tendons are stressed, the segment is completely supported and the stiffleg is released.

The last step of the erection process is the threading and stressing of the permanent tendons, which are made of 19 0.5-in strands. The erection, or negative moment tendons, are located in the top of the box girder section and generally extend from the end of the cantilever to a symmetrical point on the opposite side of the first support. The live end, or stressing end, of the tendon is located at the cantilever end junction of the top slab and web, with the dead end coming out inside the box girder at a stiffener location.

The second family of tendons, known as positive moment tendons, is located in the bottom of the section with both ends terminating at intermediate stiffeners.

An unusual aspect of the Linn Cove project is the stress conditions at the temporary bent locations. As erection crosses the bent and the cantilevers beyond, the section at the bent is subjected to large negative moment stresses that are counteracted by erection tendons passing through the section. However, when the bent is released for removal, the superstructure bent segment undergoes a complete stress reversal since it is now at midspan instead of at a support. After the stress reversal occurs, post-tensioning tendons are needed at the bottom of the section and not the top. Therefore, during the bent release process, bottom tendons have to be stressed and the top tendons released. The physical release of the temporary strand tendons is done by acetylene torch burning the anchor wedges of the strands one at a time. The strands are burned individually to minimize the shock to the bridge. The operation has gone very smoothly and without incident.

To date, no structural problems due to post tensioning or other reasons have occurred. The segments fit together exactly with no problem of achieving joint thicknesses of considerably less than 1/16 in. The joints are smooth enough that an overlay would not be required if it were not part of a waterproofing system required by the National Park Service.

The precast segmental vertically post-tensioned hollow box piers are erected from the top, according to the designer's original concept. The pier shafts are founded on 9-in-diameter microshaft piles and variable cast-in-place footings. The footing concrete is the only cast-in-place concrete required for the substructure.

The microshafts consist of three bars grouted in predrilled holes. The microshaft drilling is the only operation that occurs ahead of superstructure erection. All other operations requiring heavy equipment or materials are done from the end of the cantilever including the pouring of the footings and the erection of the temporary bents.

The pier shafts are either 6 ft or 9 ft in height, with a maximum weight of 30 t. All segments, including the cap that tops each pier, were match-cast to ensure a perfect fit at the joints.

The first segment of the shaft is placed and aligned before casting the footing. The alignment procedure recognizes casting variances as well as the exact position of the superstructure so the top of the pier will be located in the proper position.

All pier segments are trucked from the storage area over the completed portion of the bridge to the cantilever. There the stiffleg crane picks up the segment from the truck, swings it around, and lowers it over the end into the proper position. Epoxy bonding agent is then applied to the match-cast joint, and the new segment is stressed to previously erected segments with vertical thread bar tendons. After all segments have been erected, and before the pier cap is placed, all vertical thread bar tendons are grouted for bond and corrosion protection.

The cap is the last pier segment to go in place. Once the cap is in place, eight 12-strand post-tensioning tendons are installed, starting at the top of the pier and extending through and out the side of the footing. The tendons are then stressed and grouted in place.

Even though Linn Cove is located in North Carolina, the 4500-ft elevation results in rather severe winter weather with cold temperatures and high winds. Like most precast segmental bridges with epoxy bonding agent, this project is subject to a specification prohibiting the application of epoxy when the concrete substrate temperature is below 40°F. In an effort to continue erecting segments through the winter of 1981, the contractor proposed developing a system for heating the joints to cure the epoxy.

The designers instituted a test program with instrumented segments to determine thermal properties of the segments as related to ambient air temperatures. The Federal Highway Administration, which is administering the contract, used the results of the test program to evaluate contractor proposals for the heating system.

The system proved very effective. From the middle of November 1981 until the middle of March 1982, more than 20 segments were erected. The heating system allowed the project to continue through the winter. The development of the heating system is significant, as such a system has not been previously used in the United States. The test results and system development on the Linn Cove project will be applicable to other precast segmental projects in the northern part of the United States and Canada. (Further information on the winter segment erection is obtainable from Figg and Muller Engineers, Inc., 424 North Calhoun St., Tallahassee, FL 32301.)