Design, Fabrication, and Erection of a Curved, Prestressed Concrete Bridge with Continuous Girders

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ABSTRACT

A five-span, prestressed concrete bridge has been constructed for the Pennsylvania Department of Transportation at the Philadelphia Airport. The five curved, post-tensioned, box girders for the bridge are continuous over two and three spans, respectively. Approximate lengths are 139 and 126 ft for the two-span girders and 92, 135, and 92 ft for the three-span girders. Radius of curvature is 478 ft for the two-span girders and 326 ft for the three-span girders. Curvature of the girders was achieved by incremental chords 20 ft long, and field splicing was done only at piers with cast-in-place diaphragms. The bridge was analyzed assuming that the girders and diaphragms act as a two-dimensional grid system. A conventional program based on a matrix method of analysis was used to find the bending moments, shear forces, torsional moments, and displacements. Post-tensioning forces were analyzed using a space frame matrix method of analysis. Girders were prefabricated in lengths corresponding to the five spans and were transported by truck to the job site. Each span length of the girder was partly post-tensioned for shipment, and final post-tensioning for continuity over the piers was done in the field. The design, fabrication, transportation, erection, and final post-tensioning of the continuous curved girders are described in this paper. Details of the composite deck are also discussed.

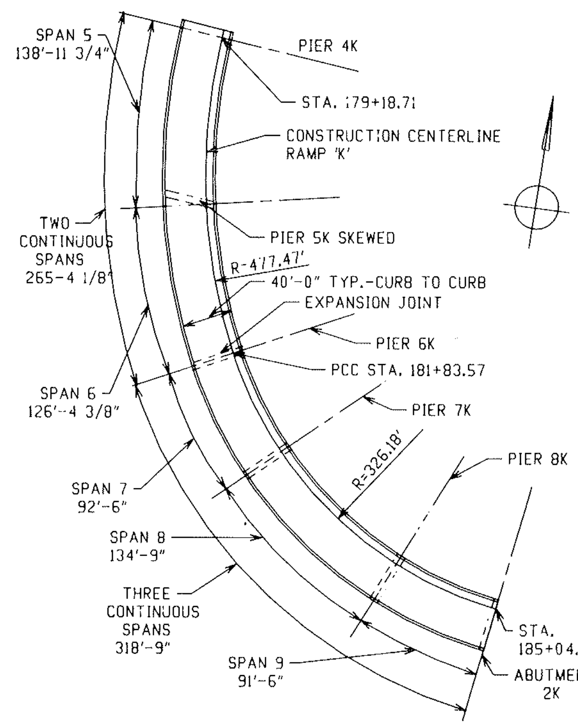

FIGURE 1 General layout of ramp K at Philadelphia International Airport.

A five-span, prestressed concrete bridge has been constructed for the Pennsylvania Department of Transportation on Legislative Route (LR) 795 (Interstate 95) in Philadelphia, Pennsylvania. This structure, which is located on a compound horizontal curve, is identified as ramp K over LR 67054. The ramp provides vehicular access to the Philadelphia International Airport.

The original design of ramp K was a curved, steel-plate-girder bridge, but an alternate design for a continuous, curved, prestressed, concrete bridge was submitted and approved. I.A. Construction Corporation was the general contractor for this project, and the prestressed concrete components were fabricated and supplied by Schuylkill Products, Inc., Cressona, Pa. Schupack Suarez Engineers, Inc., were the designers for the project with assistance from R.M. Barnoff and Associates, Inc., who performed the analysis of the continuous structure.

DESCRIPTION OF STRUCTURE

The compound horizontal curvature of ramp K dictated the use of two separate structures as shown on Figure 1. A two-span continuous structure, with spans of 138 ft 11-3/4 in. and 126 ft 4-3/8 in., was selected for the portion of the curve that has a radius of 477.41 ft. Three continuous spans of 92 ft 6 in., 134 ft 9 in., and 91 ft 6 in. were used for the remainder of the ramp that is located on a curve with a radius of 326.13 ft. One end of each of these structures has a common bearing on pier 6 as shown in Figure 1. All dimensions shown in Figure 1 and given previously are on the construction centerline.

Ramp K has a roadway width of 24 ft plus a 10-ft shoulder on the outside of the curve and a 6-ft shoulder on the inside. The overall width of the structure is 43 ft 6 in., and a slope of 0.05 ft/ft is maintained across the roadway. A vertical curve along the entire length of the bridge further complicates the geometry.

Five precast, post-tensioned, concrete box girders were selected as the main structural components for the two structures. Figures 2 and 3 are framing plans showing the geometry of the girders and the location of the exterior cast-in-place diaphragms. The girders were curved by fabricating them with incremental chords 20 ft in length. End chords of all girders deviated from the 20-ft length to accommodate the required center-to-center bearing length of the girders. Radially curved girders were not feasible because of fabrication difficulties.

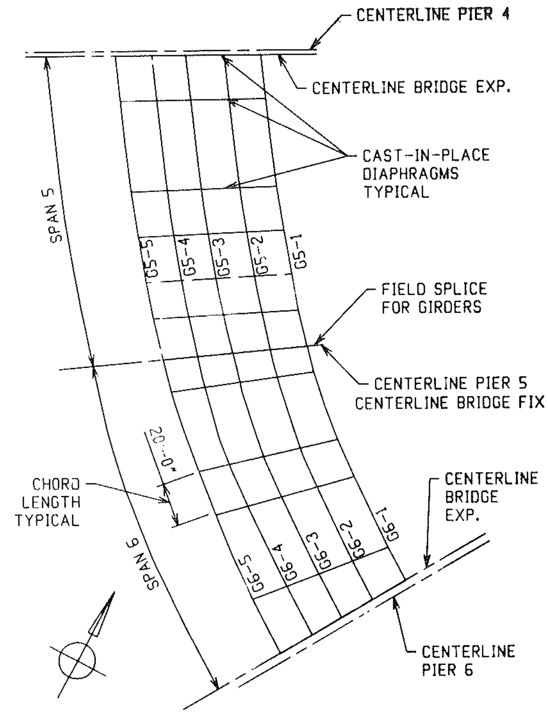

FIGURE 2 Framing plan for spans 5 and 6.

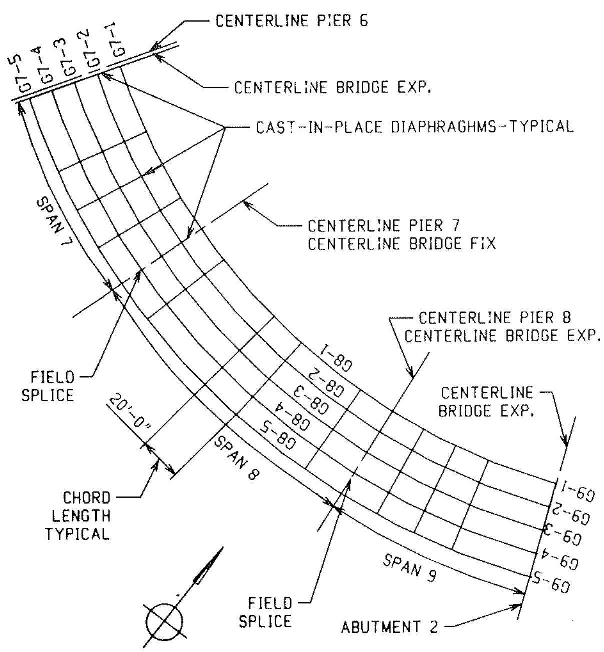

FIGURE 3 Framing plan for spans 7, 8, and 9.

The girders were fabricated and shipped in lengths corresponding to the five different spans. Continuity for the two- and three-span bridges was provided by splicing the girders at the piers with exterior cast-in-place diaphragms and applying post-tensioning for the full length of the spliced girders. For ease of fabrication all girders in spans 5 and 6 were fabricated with a common radius at the horizontal centerline of the 20-ft chords, and all girders in spans 7, 8, and 9 also have a common radius.

Dimensions and details of the girder cross section are shown in Figure 4. Voids were formed in the girders with Styrofoam, and internal diaphragms were provided at the junction of each 20-ft segment. Polyethylene ducts were provided for the multistrand post-tensioning tendons. Each girder received some post-tensioning at the fabricating plant to counteract the dead load stresses produced by the weight of the girders. Final post-tensioning of the continuous structure was done in the field after the diaphragms were constructed. The ducts for the tendons were in the voids of the box beam and the tendons were not bonded to the girder.

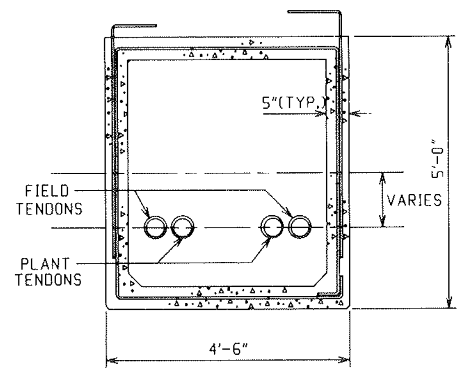

FIGURE 4 Typical girder details.

External cast-in-place diaphragms were heavily reinforced and tied into the girders. Post-tensioning was used to provide continuity in the direction transverse to the span of the girders. Essentially, the diaphragms were constructed so that the continuity between the girders and diaphragms resulted in a structural grid in the horizontal plane.

A composite deck was placed over the grids, and Pennsylvania Department of Transportation (PennDOT) standard parapets and safety curbs were constructed to complete the structure. The composite deck consisted of 2.5-in.-thick precast, prestressed concrete panels that span the box girders and a 5-in.-thick cast-in-place topping over the panels. Details of the deck are shown on the typical cross section in Figure 5. Mild steel reinforcement used in the cast-in-place portion of the slab was epoxy coated in accordance with PennDOT specifications.

ANALYSIS AND DESIGN

The location of the structure, the method selected for fabrication, the transportation of the girders, and the existence of roadways and utilities under the bridge created several design constraints. Some of these were

1. The five girders for each span were fabricated individually for the full span length between supports.
2. During construction the girders were erected and functioned as simple beams between supports to carry their own dead load plus the dead load of the exterior diaphragms. Plant post-tensioning was supplied to accommodate the dead load stresses in the simple beams. Obstructions at the site prevented the use of temporary shoring.
3. A constant radius of 477.41 ft was used for all girders on spans 5 and 6, the two-span continuous structure. Girders in spans 7, 8, and 9, the three-span continuous structure, were fabricated with a radius of 326.13 ft.
4. Pier 5K, the interior support for spans 5 and

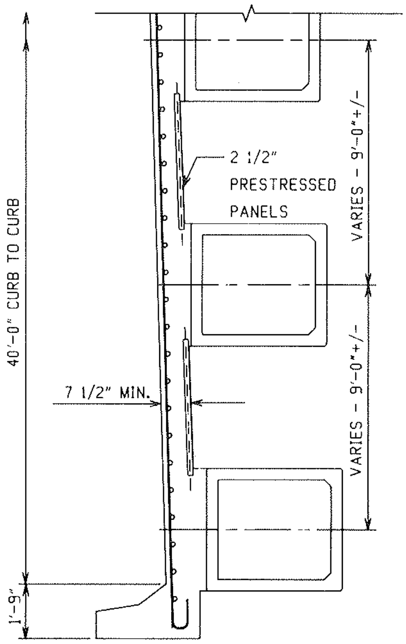

FIGURE 5 Typical cross section and deck details.

6, was skewed in relation to a radius of the curve. This resulted in all girders for these two spans having significantly different lengths. All other piers, and the abutment at the far end of span 9, were oriented so that their transverse centerline was on a radius.

5. Curvature of the girders caused a torque at each end when the simple spans were erected and before the diaphragms were placed. Struts were cast on the ends of the girders and jacks were used during erection to counteract this torque. The struts became part of the diaphragms at the supports after the cast-in-place concrete construction was completed.

6. The post-tensioned grids consisting of the continuous girders and the exterior diaphragms were designed so that the deck could be removed and replaced without overstressing any of the structural components. This condition required that the post-tensioning of the continuous girders be done before the deck concrete was placed.

The five individual girders for each span were analyzed in the conventional manner as simple beams. Stresses were computed for the dead load of the girders and dead load of the exterior diaphragms. Stresses due to the lifting and transporting operation were also evaluated. The magnitude of post-tensioning required to counteract these stresses was found and applied at the fabricating plant before the girders were moved from the casting bed.

Analysis of the two-span and three-span grids consisting of the girders and their connecting external diaphragms was accomplished using a stiffness matrix method of analysis. Each straight beam segment and diaphragm were considered to be a structural member of the grid, resulting in 114 members and 75 joints for the two-span structure and 133 members and 90 joints for the three-span structure. Coordinates for each joint were computed and became part of the input data for the analysis, along with assumed cross-sectional properties.

Moments, shears, torque, and displacements at each end of each member were found for the following loading conditions.

1. Dead load of beam haunches,
2. Dead load of 2.5-in.-thick prestressed panels over the entire length of the bridge, and
3. Dead load of cast-in-place deck concrete in the positive moment portion of the girder spans.

All of these data were found using a STRUDL grid analysis program. After the dead load actions were determined, the section properties in the girder were modified to account for the composite action of the deck slab. The grids were then analyzed for the following loading conditions.

1. Dead load of cast-in-place deck concrete in negative moment portion of the girder spans,
2. Dead load of parapets,
3. Dead load of future wearing surface, and
4. Live loads plus impact.

Preliminary analyses were conducted to determine the positions and types of live loadings that would produce the maximum actions in the various members of the grid. AASHTO HS20 loading was used in the live load analysis. Truck loads, lane loads, and overloads were investigated; and the maximum internal member actions at the joints were used in the final analysis for stresses.

Analysis of the continuous grids for stresses due to field post-tension, which had a variable eccentricity, was done by modeling the structures as three-dimensional rigid frames. Typical profiles of the field post-tensioning tendons are shown in Figure 6. Forces from the field post-tensioning were applied at the interior diaphragms and at each end of the grids. At each end of each member the applied forces consisted of an axial force (adjusted for friction loss), a vertical force, and a moment about the horizontal axis of the cross section. At the ends of each structure the applied actions consisted of the axial prestressing force and a moment, due to the eccentricity of the prestressing force, about the horizontal centroidal axis. Five separate analyses were done for each span with an assumed value of the prestressing force applied to individual girders for each of the five analyses. Results

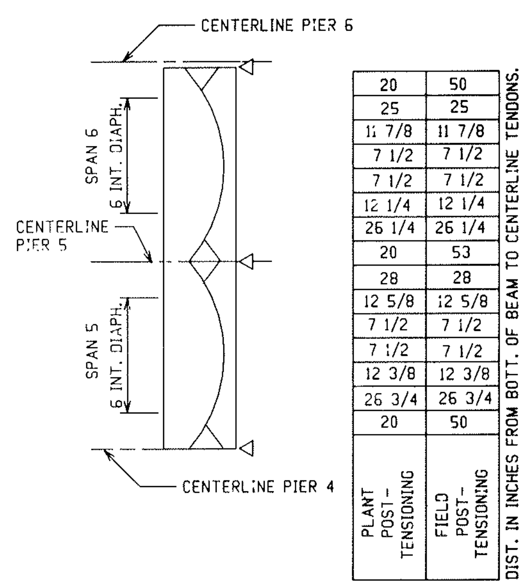

FIGURE 6 Strand profile for spans 5 and 6.

from the five analyses were combined using various percentages of prestressing force for individual girders and combining the prestress with stresses due to the various loading conditions until the required prestressing force in each girder was determined. Normal losses due to shrinkage and creep were also considered.

Special attention was given to the torsional moments in the girders that were caused by the gravity loads acting on the curved, continuous, grid systems and by the eccentricity and change in direction of the prestressing force. Additional mild steel reinforcement, in the form of stirrups and longitudinal reinforcement, was used where needed to accommodate the stresses caused by the torsional moments.

Conventional design procedures were used in selecting the reinforcement and prestressing tendons for the deck components. The prestressed deck panels were designed to support the full dead load of the deck and to act in a composite manner with the cast-in-place topping to carry the superimposed dead and live loads. AASHTO HS20 loading was used as the design live load for the deck. PennDOT specifications and design standards were used to select concrete components and reinforcement for the deck.

FABRICATION AND ERECTION

The twenty-five individual girders were fabricated by Schuylkill Products Inc., at their Cressona, Pennsylvania, plant. Steel forms were used on the two sides and bottom of the girders and Styrofoam was used to form the internal voids. Reinforcement was preassembled into cages and secured in the forms. Polyethylene post-tensioning ducts were used for the multistrand tendons. Because the tendons could not be bonded to the girder concrete except at the internal and cast-in-place diaphragms, care was taken to electrically insulate the tendons to reduce the possibility of corrosion. Fabrication methods used in producing the girders are shown in Figures 7 through 10.

Lifting hooks were provided at the internal diaphragms that were closest to the balance points of the girders. After the plant post-tensioning was applied the girders were moved from the casting bed and stockpiled. All girders were shipped by truck from the Cressona plant to the construction site at Philadelphia, a distance of approximately 94 miles. Large tractors with hydraulically steerable dollies were used to transport the girders, some of which weighed 115 tons, were 147 ft long, and had a maximum shipping width of 13 ft 6 in. and a shipping height of 12 ft. To equalize tire loads and eliminate static overturning moment, the girders were loaded so that their weight was transferred to the vehicle through their balance points. The size and magnitude of the loads dictated use of a vehicle with eight axles and thirty wheels.

The individual girders were set in position on the piers and temporary torque forces were applied at the girder ends to counteract the moment due to the curvature of the girders. After the girders had been set in place the external diaphragms were placed. Post-tensioning was then applied to the grid framework consisting of the continuous girders and the external diaphragms. The conduits housing the tendons were filled with grout to act as corrosion protection for the prestressing steel.

Construction of the deck followed the normal procedure for decks with partial depth prestressed panels. The 2.5-in.-thick 8-ft-wide panels were set to grade on grout haunches. The haunches were placed using timber forms bolted to the sides of the box girders and inserts cast into the concrete.

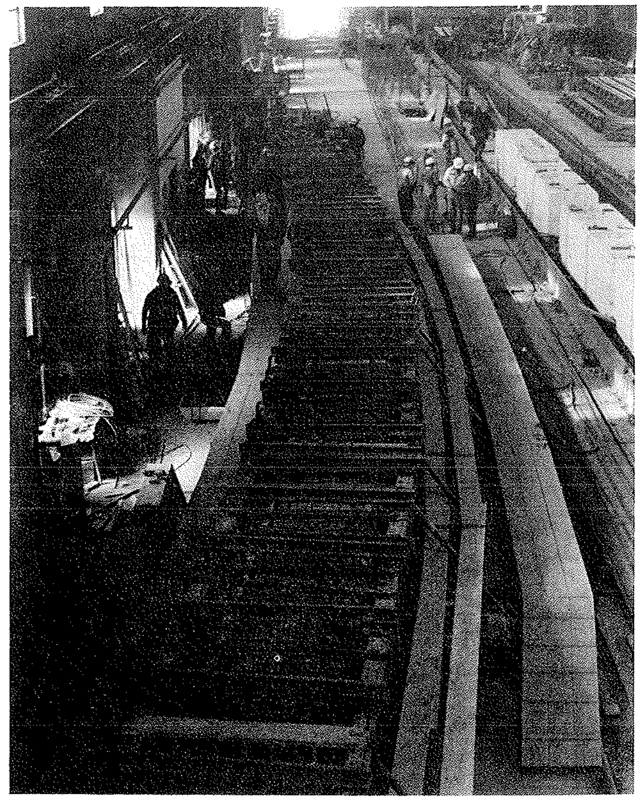

FIGURE 7 Steel forms with reinforcement and voids in place.

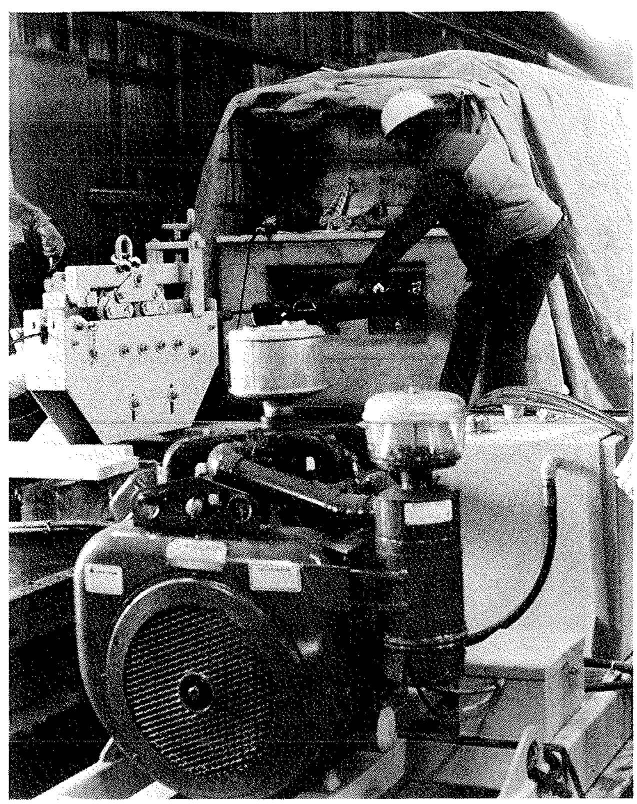

FIGURE 8 Placing tendons for post-tensioning in plant.

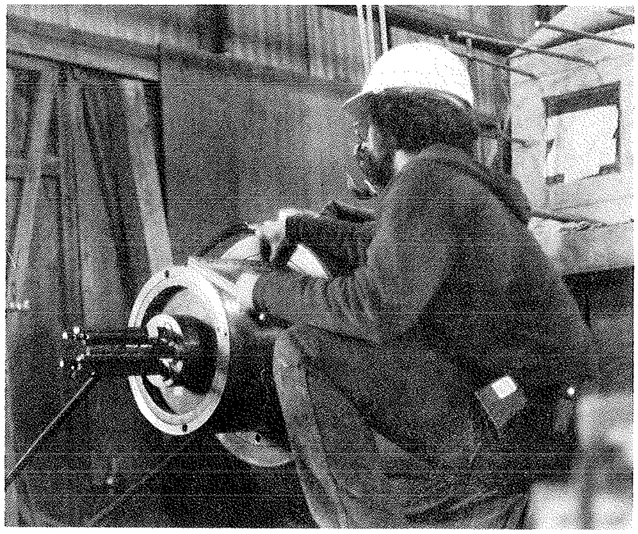

FIGURE 9 Post-tensioning in plant before shipping.

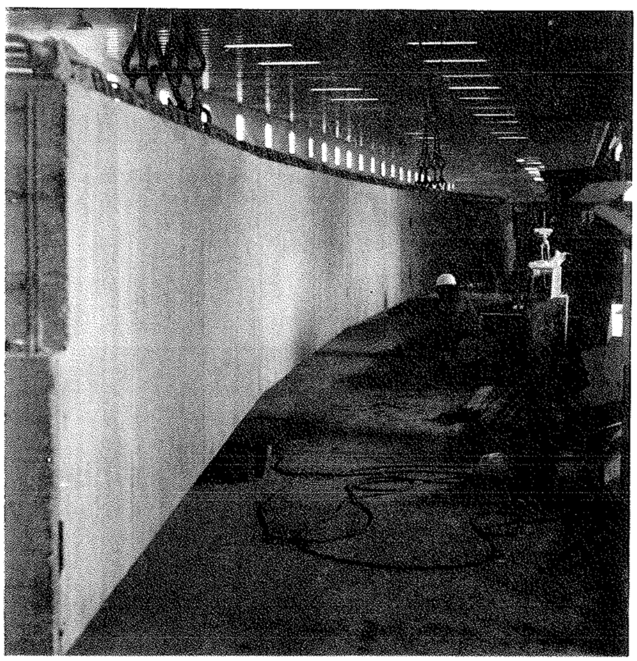

FIGURE 10 Completed girder being prepared for shipment to bridge site.

After the prestressed panels were placed, the top mat of reinforcing steel was set and the cast-in-place concrete topping was placed using conventional screeding and finishing equipment.

The cast-in-place concrete topping was placed in segments along the length of the continuous spans with the first placement being made in the positive moment portions of the continuous structures. This was followed by placement of the deck concrete over the piers in the negative moment portions. Additional longitudinal reinforcing steel was used in the deck slab in the negative moment areas to reduce cracking due to the tensile stresses in the slab and tops of the girders. Concrete and reinforcement for the parapets and safety curbs were placed in the conventional manner using standard forming techniques.

SUMMARY AND CONCLUSIONS

Continuous, curved, prestressed concrete bridges can be built economically using a combination of plant and field post-tensioning. Prefabrication of large girders is necessary to reduce field labor, construction time, and costs. Current technology and modern equipment allow plant fabrication and shipment of girders that are 160 ft long and weigh 90 tons.

Proper analysis and design of curved, continuous, prestressed concrete bridges is essential to achieve proper behavior of the completed structure. Close cooperation among the fabricator, erector, and designer is necessary to prevent overstressing any of the components during the fabrication and erection process. Ingenuity is required of all members of the design, fabrication, and erection teams to develop techniques that will reduce costs and assure good structural behavior of the bridge.

Conventional methods of matrix analysis can be used to find the dead and live load moments, shears, and torques in the prestressed grid. Care is required in evaluating the prestressing forces applied as loads to the structural framework. It was observed that the internal moments and torques were sensitive to slight discrepancies in the applied loads. The complicated geometry of the framework amplifies slight imbalances in the loads and results in computed torques and moments, of small magnitude, that do not agree with recognized theory.

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