ADVANCED AESTHETIC EMBEDMENT IN PRESTRESSED GIRDER

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ABSTRACT

For the recently completed Cotton Lane Bridge over the Gila River in Goodyear, Arizona, architectural form liners were embedded into the outboard face of the exterior modified AASHTO Type VI girders. The girders were modified by increasing the web thickness and by curtailing the top flange on one side to create a C-shaped section. The resulting deep outboard girder face received a relief pattern of lizards and cacti. The asymmetric girder cross section required a modified prestressing strand pattern. Due to the non-symmetry additional torsional shear stresses and weak axis bending were introduced. Increased torsional rigidity of the modified girder compared to the non-modified interior girders influences the live load and composite dead load distribution. Eccentricity between centroid of prestressing strands and centroid of section caused horizontal bowing. The unsymmetrical girder needed to be adequately braced during concrete deck placement to minimize both additional torsional stresses and non-uniform pressure on the bearing pads. The paper discusses these and other design issues as well as the construction of the Cotton Lane Bridge in detail.

Keywords

Aesthetics, Concrete, Unsymmetrical, Prestressing, Precast

INTRODUCTION

Design of the new Cotton Lane Bridge was driven by Goodyear, Arizona's rapid growth and suburbanization, and the resulting need to span the Gila River with an attractive, cost-efficient structure. In order to create a visually interesting structure, architectural relief patterns were cast directly into the prestressed concrete bridge girders. Each panel was embedded with a Southwestern-themed lizard and cacti pattern, eliminating the need to hang patterned panels after girder placement, and thereby decreasing construction time. This approach enhanced aesthetics without sacrificing economy. However, incorporating this pattern into prestressed girder sections increased the complexity of both the design and construction, as will be shown in this paper.

Recently constructed, the Cotton Lane Bridge over the Gila River is a 17 span, 2,067-foot long bridge with a bridge deck that is 114-feet wide. Each span measures approximately 122-feet from pier to pier, and consists of 12 girder lines spaced at 9'-5" centers. The cast-in-place deck is eight inches thick. Each pier was made from cast-in-place concrete and consists of a 5-foot wide pier cap, supported on four columns, each 5-foot in diameter which transition directly into drilled caissons that are 6-foot diameter. The outside face of all 34 exterior girders received a relief pattern of lizards and cacti, totaling approximately 4,080 linear feet. The ten interior girder lines consist of typical AASHTO Type VI modified prestressed girders. Figure 1 shows the modified exterior girder at the precast yard. Figures 2 and 3 are in-construction pictures taken at the job site.

The bridge owner is Maricopa County Department of Transportation and the general contractor is Peter Kiewit & Sons. The girder precaster is T-PAC.

Fig. 1 Exterior Girder at Precast Yard (After Stripping)

Fig. 2 Girder Placement at Job Site (Before Deck Pour)

Fig. 3 Exterior Girder at Job Site (After Deck Pour)

DESIGN CONSIDERATIONS

This section examines the unique design considerations that are associated with using embedded form liners within prestressed bridge girders. The architectural pattern is 3’-6” deep with ¾ in. maximum relief depth. The inboard face of the girder has the same profile and dimensions as the AASHTO Type VI section. Web thickness was increased to 14-inch, which resulted in a 24-inch wide bottom flange and a 31-inch wide top flange. These modifications resulted in the C-shaped asymmetric section shown in Figure 4.

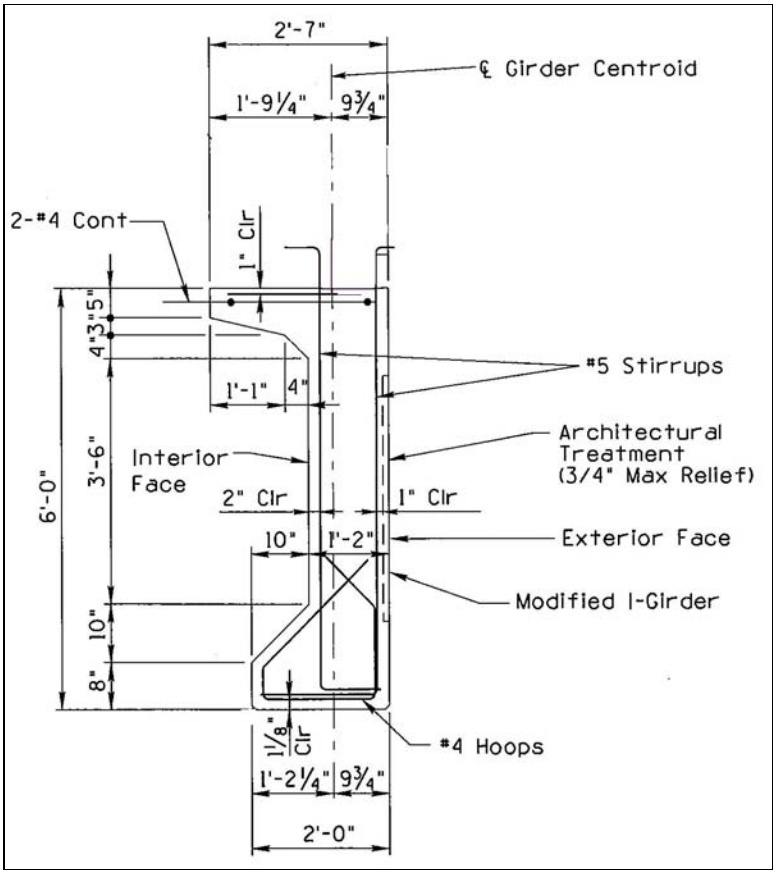

Fig. 4 Typical Cross Section

Due to the asymmetry, the principal axes do not coincide with the vertical and horizontal directions. The deviation is very small (less than 1.3 degrees) so that principal section properties do not differ much from the properties about the original axes. However, it is important that the applied moments are properly decomposed into principal axes components. Moments about the horizontal axes due to prestressing and dead load are large and thus cause appreciable moments about the weak principal axis which cannot be ignored for stress and deflection calculations. An additional complication is that the shear center is about 6-inch horizontally eccentric with respect to the centroid, which creates additional torsional stresses.

Figure 5 is the strand pattern that was used for these modified exterior girders. The girder is prestressed using 53 - 0.6-inch diameter 270-ksi low relaxation strands stressed to 202.5-ksi. Forty-one of these strands are straight, while the remaining twelve strands are harped with hold-down points located at a distance of 12-feet on either side of the midpoint of the girder.

Because of the draped pattern, debonding of strands to control stresses near the girder ends was not necessary. The specified 28-day concrete strength was 6,500-psi.

This asymmetric section required a modified prestressing strand pattern. The modified strand pattern shown in Figure 5 was chosen, in part, to minimize the horizontal eccentricity between centroid of section and center of gravity of prestressing. The final eccentricity was only ¼ inch. However, even with such a small eccentricity the effects on girder stresses and deflections need to be accounted for in design due to the small stiffness of the girder about its weak axis.

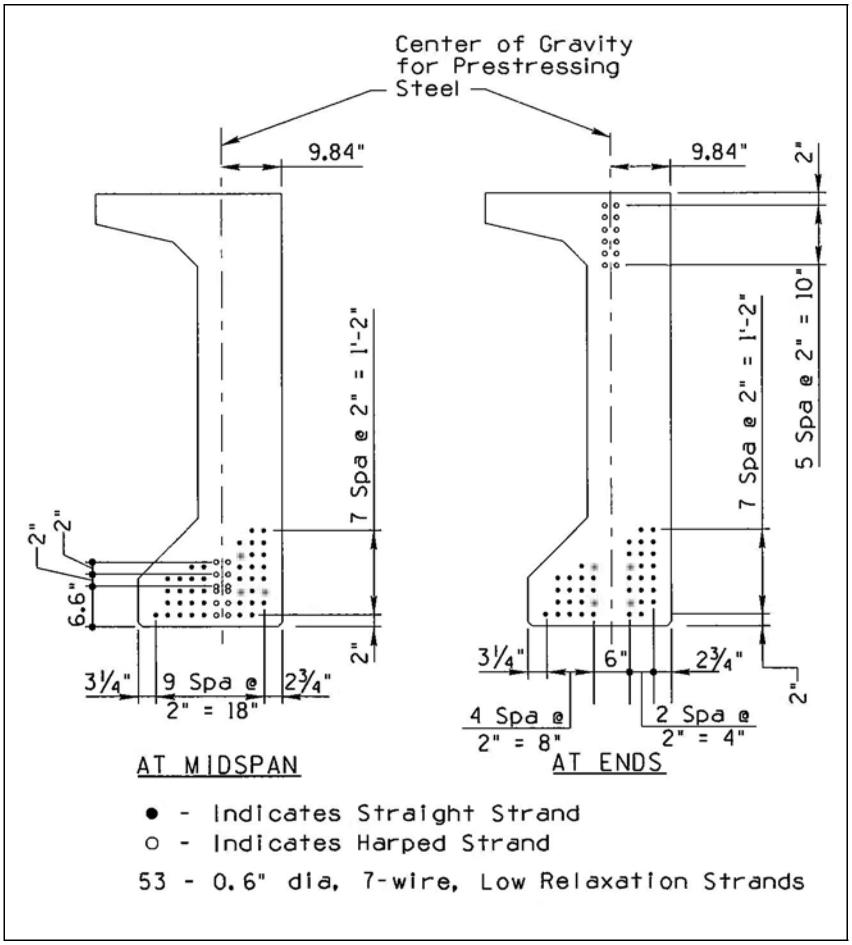

Fig. 5 Prestressing Strand Pattern

At various locations along the girder, additional tensile and compressive stresses reaching up to 300 psi resulted from the weak axis bending under prestressing and non-composite dead loads. These additional stresses, either tensile or compressive, were appropriately combined with the traditional stresses to ensure the code limits were not exceeded. For loads on the composite system the stiffness of deck and diaphragms prevents horizontal girder displacements, which justifies the common assumption that vertical and horizontal axes are principal directions of the composite edge girder.

Due to weak axis bending and principal axes rotation, horizontal bowing at transfer is much larger than for conventional, symmetric girders. For the Cotton Lane Bridge the calculated horizontal displacement at midspan under self weight and prestress was 1.70 in. on 119’-8” girder length. Because horizontal bowing can impact deck forming operations as well as intermediate diaphragm forming operations, the contractors needs to be informed of and plan for the anticipated horizontal bowing. This is best done by indicating the anticipated bowing at release on the contract drawings. The precaster is typically limited to a sweep tolerance of 1/8 inch per 10-feet of girder length (Ref. 1). If horizontal bowing is anticipated, then the tolerance limit should only be applied to the deformation difference from the anticipated value. Similarly to camber growth, horizontal bowing will grow with time due to creep until diaphragms in the completed structure restrain further growth.

Increasing the torsional rigidity of the modified exterior girder influenced both the live load and composite dead load distribution to the girder. The modified load distribution needs to be investigated and determined before the girder can be properly designed. Performing a grid analysis provides a more realistic estimate of how the live loads and composite dead loads will distribute to the girder lines.

Fig. 6 Girder Elevation with diaphragms

Per Reference 2 torsional rigidity does not significantly influence life load distribution as long as the moment of inertia is at least ten times greater than the torsional stiffness. For the Cotton Lane Bridge this requirement was just satisfied. However, in order to better understand the likely distribution of loads between the girder lines a grid line analysis was performed and compared to the AASHTO LRFD distribution factors. The grid analysis results were found to be within 10% of the AASHTO values and the AASHTO values were used for design.

Self weight and initial prestressing force introduced torsional shear stresses up to a maximum of about 90-psi, due to the approximately 6-in. eccentricity of the shear center with respect to the centroid of the section. Concrete diaphragms were installed prior to placement of the deck concrete in order to minimize the introduction of additional torsional stresses due to superimposed dead loads. The intermediate diaphragms were located at the third points between all girder lines and the end-bracing diaphragms were located five feet from the girder ends between exterior and first interior girders only (Figure 6). The location of the end-bracing diaphragms was selected to not interfere with the pier diaphragms, which were placed concurrently with the concrete for the deck.

These end-bracing diaphragms provided an added benefit in that they prevented rotation at the girder ends. By preventing this rotation, the non-uniform pressure on the elastomeric bearing pads was limited to that caused by the weight of the girders themselves.

CONSTRUCTION CONSIDERATIONS

This section presents several of the unusual construction considerations that arose from the use of the C-shaped edge girders with embedded form liners and the on-going dialogue between the designer and the precaster from early design to construction.

Fig. 7 Unloading Girder at Job Site

In early design, the local precasters were contacted in order to discuss various aesthetic modifications to standard girder sections and to understand their constraints and limitations. For special projects such as this, a good relationship must be established between the designer and the precaster. Before deciding on the use of the C-shaped edge girders with embedded form liners, several other aesthetic enhancements were considered. Precast patterned panels hung on traditional exterior girders were considered and dismissed because of the lesser aesthetic qualities (vertical joints between the panels) and long-term maintenance needs. Trapezoidal tub girders in lieu of AASHTO girders were considered and dismissed because of the high cost of purchasing the necessary steel forms.

One consideration associated with the C-shaped sections is that the modified girder was heavier due to the increased web thickness. Therefore, local precasters were contacted to determine the maximum efficient girder shipping weight. If a girder is too heavy, special transportation vehicles and hauling permits may be required, which will impact cost and time. Additionally, lifting devices need to be checked for adequacy. During the Cotton Lane Bridge project, the local precaster was able to accommodate and ship the 80 ton girders to the job site. Figure 7 shows the exterior girder being unloaded at the job site. Figure 8 shows the custom form created for the outboard face.

Once stripping is complete, the precaster must evaluate which way the girders will face while being stored in the yard prior to shipping. Girders should be oriented in such a way that bowing caused by environmental temperature changes are minimized. Further, the direction the girder is bowing due to the eccentricity between the prestressing and the section centroid should also be considered. The Cotton Lane Bridge spans primarily North-South which means the exterior girders on one side face East and face West on the other side. Once the girders were placed at the job site and prior to placing diaphragms and deck, the East facing exterior girders experienced additional bowing due to temperature differences. At night, the girders all cooled down. At sunrise, the outboard face of the East facing girders rapidly heated up while their inboard faces remained cooler causing the temperature difference and additional on-site bowing. Since the West facing girders did not experience direct sunlight exposure until the afternoon, there was not a large temperature difference between the inboard and outboard faces.

Any horizontal bowing will impact deck forming operations. The contractor needs to be informed of the anticipated horizontal bowing caused by the asymmetric exterior girders. By indicating the anticipated horizontal bowing on the plans, the contractor can properly account for it with respect to their deck forming operations.

The precaster and contractor should carefully evaluate and accommodate the requirements for lateral stability (Ref. 4) in combination with horizontal bowing with respect to girder shipping, picking, placing, and temporary stability before deck & diaphragm placement.

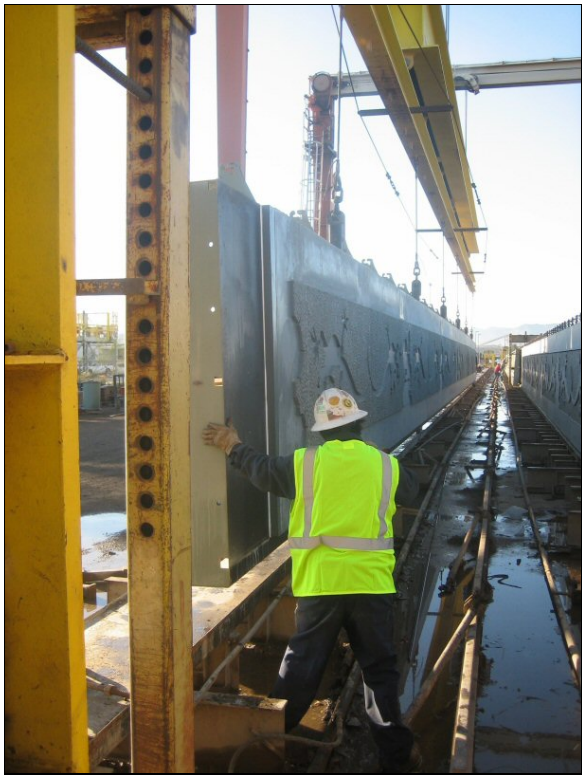

Fig. 8 Precaster's Custom Form for Outboard Face

CONCLUSIONS

The recently constructed Cotton Lane Bridge over the Gila River in Goodyear, Arizona utilized artistic form liners embedded in the outboard face of the prestressed exterior girders. Even with the complexities resulting from using an asymmetric section, this architectural enhancement still proved economically reasonable.

Design needs to account for the rotation of the principal axes relative to the vertical and horizontal axes. Prestress and self weight induce significant moments about the principal weak axis which causes bowing and additional stresses. Additional torsional and thus principal stresses arise from the offset of the shear center relative to the centroid of the section. Finally, the C-section has greater torsional rigidity due to its thicker web which influences live load and composite dead load distribution.

The use of end-braces and intermediate braces (diaphragms) will limit torsional stress to that caused only by self weight and prestressing. End-bracing diaphragms placed prior to the pouring of the deck concrete provide the added benefit of preventing end rotation, which will, in turn, minimize non-uniform pressure on the bearing pads under the fascia girders.

The asymmetric section required a modified prestressing strand pattern. Any horizontal eccentricity between prestressing center of gravity of prestressing and section centroid will cause horizontal camber and additional flexural stresses through weak axis bending.

Major construction considerations on the Cotton Lane project included increased horizontal bowing due to temperature differences, transporting & lifting the heavier section and using due diligence with respect to lateral stability.

The tremendous versatility offered by precast and prestressed concrete makes the creation of an asymmetric section with embedded form liner quite feasible and practical from both a design and construction perspective. While hanging aesthetic precast panels on standard exterior girders is also quite feasible & practical, embedding the aesthetics into the exterior girder section prior to prestressing has the added benefits of increased aesthetics (no vertical joints between the panels) and elimination of long-term maintenance on the panels.

REFERENCES

1. “Tolerance Manual for Precast and Prestressed Concrete Construction,” MNL 135-00, Precast/Prestressed Concrete Institute, Chicago, IL, 2000.

2. Hambly, E.C., “Bridge Deck Behavior”, John Wiley and Sons, Inc., New York, NY, 2nd Edition, 1991.

3. AASHTO 2004 LRFD Bridge Design Specifications, Customary U.S. Units, 3rd Edition, American Association of State Highway and Transportation Officials, Washington, D.C.

4. Mast, Robert F., “Lateral Stability of Long Prestressed Concrete Beams – Parts 1 & 2”, PCI JOURNAL, V. 38, No. 1, January – February 1993