Lessons Learned from Handling Long-Span Precast, Prestressed Concrete Bridge Girders

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The Washington State Department of Transportation (WSDOT) recently completed two Interstate 5 (I-5) bridge projects near Tacoma, Wash.—the Wapato Way Bridge and the Puyallup River Bridge—with precast, prestressed lightweight concrete bridge girders having record-setting lengths of over 220 ft. Both bridge projects used the wide flange WF100G girder shape, which has a depth of 100 in. excluding camber and extended reinforcing bars.[1] This girder shape has been used with normalweight concrete to span beyond 200 ft. However, at this depth, the ability to transport WF100G girders by truck is a major design consideration due to vertical clearance restrictions, hauling weight limitations, and concerns about girder stability.

The use of lightweight aggregate concrete was an important tool to increase span capability while allowing the girders to be hauled by truck. Although the use of lightweight concrete reduced the reinforced deadweight of the girders by 15%, it is important to also note that the design elastic modulus was reduced by 35% as compared with that of normalweight concrete. Thus, the appropriate handling of slender precast concrete girders is a critical part of building longer-span precast concrete girder bridges. Whenever normal practice is pushed to new limits, there are challenges to overcome and opportunities to improve the standard of practice. The aim of this article is to share lessons learned from the erection of these extremely long and flexible girders.

Torsional Flexibility

To design girders that can be successfully lifted and transported, it is essential to follow the recommendations published in the Precast/Prestressed Concrete Institute's (PCI's) *Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders*.[2] One of the fundamental assumptions of the stability analysis theory detailed in that publication is that girders are very stiff in torsion and the effects of twist are small and can be neglected. Although neglecting torsion is not conservative, it greatly simplifies the stability analysis.

After the 222-ft 3-in.-long girders for the Wapato Way Bridge over I-5 in Fife, Wash.,[3] were erected in the summer of 2020, field measurements indicated that the webs were out of plumb. Additionally, the slope of the web was greater at midspan than at the ends of the beam, which suggested that there was torsional deformation in addition to lateral deflection. The greatest measured difference in web slope was 3% or about 1.7 degrees of twist. Measurements for sweep, which was within tolerance for all girders, had been taken at the fabricator's plant prior to shipment. Plumbness was measured in the field after erection.

One of the likely contributing factors of the torsional deformation is the lower shear and elastic moduli of lightweight concrete. The angle of twist is proportional to girder length; therefore, twisting effects are magnified on longer girders compared with shorter spans. Given the torsional deformation observed in the field and the uncertainty about the true factors of safety with respect to cracking and ultimate strength of long girders subjected to torsional deformations, WSDOT initiated a research project to investigate the effect of torsion on the stability of long-span, lightweight concrete bridge girders. It is hoped that this research will yield simple modifications that can be applied to PCI's recommended stability analysis to account for torsional deformations.

Bracing During Erection

For prestressed concrete girders, lifting points are typically kept close to the girder ends to minimize the required concrete strength, even though roll stability during lifting is improved when lifting points are located away from girder ends. However, for long, slender girders, stability governs many aspects of the design, and lifting points can be 20 to 30 ft away from the girder ends. With these long overhangs, the deflected shape while hanging can be significantly different from the girder shape when seated.

The Puyallup River Bridge over I-5 in Tacoma, Wash., used 223-ft-long lightweight concrete WF100G girders with a top flange modified from the standard width of 49 in. to 61 in. to improve stability and lower stresses during handling, hauling, and erection (see the Creative Concrete Construction article in the Fall 2019 issue of *ASPIRE*® for more information). The curves in **Fig. 1** show the combined prestress and self-weight deflection calculated between the girder ends and the midpoint for hanging and seated Puyallup River Bridge girders. While hanging, the girder is supported 26 ft from its ends. Once erected, the girder is supported on an elastomeric bearing pad at one end and an oak block at the other end. The bearing

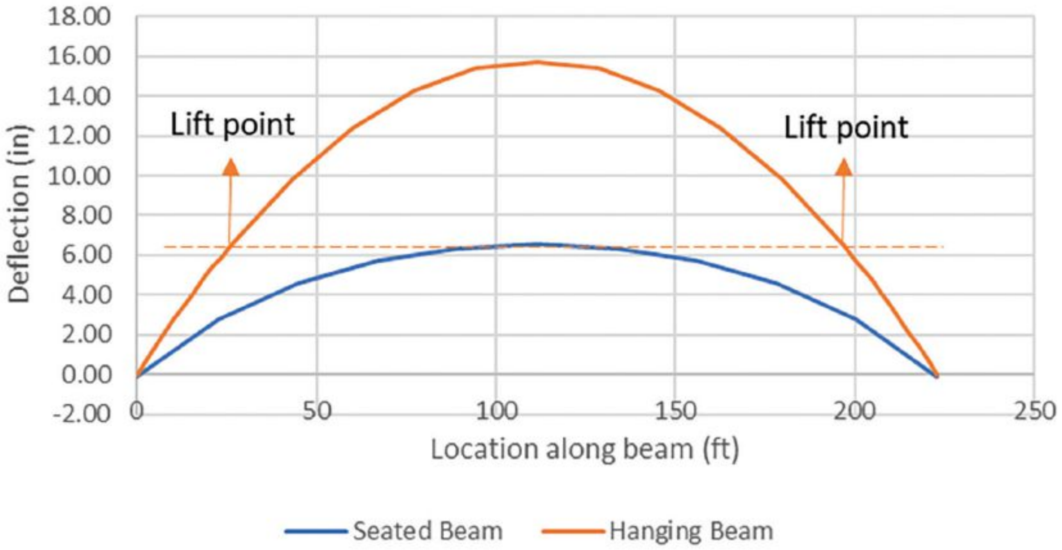

Figure 1. Comparison of seated and hanging beam total deflection calculated relative to the ends of the beam using the properties of girders from the Puyallup River Bridge in Tacoma, Wash. All Photos and Figures: Washington State Department of Transportation.

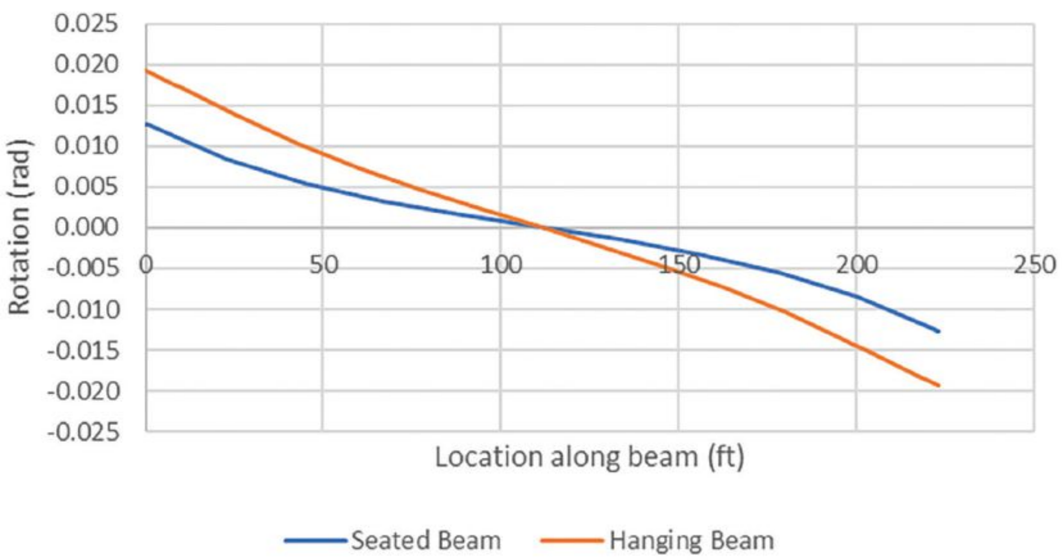

Figure 2. Comparison of end rotations of seated and hanging beams for the Puyallup River Bridge girders.

supports are 8 in. from the ends of the girder. **Figure 2** plots the slope of the elastic curve (rotation) along the length of the deformed beam while hanging and seated; the data for the curves were computed using standard beam formulas. These comparisons illustrate how significantly the deflected shape of the girder changes during erection.

For safety and stability, WSDOT requires that girders be braced at least at midspan and each end during and after erection. Typically, when the second and subsequent girders are erected in a span, cross bracing is installed between the hanging girder and the previously erected girder. As the hanging girder is lowered into contact with its bearings, there can be a large differential camber between the adjacent girders (**Fig. 3**). If in-span bracing is installed before significant load is transferred from the lifting lines to the bearings, force is induced in the diagonal bracing with a horizontal reaction component that tends to roll the girders as the hanging girder deflects downward into its fully seated position.

While this effect can exist for any concrete girder, the magnitude becomes significant for longer girders. To avoid locked-in bracing forces and undesired girder deformation, the erector should develop a precise sequence of load transfer and bracing installation for inclusion with the erection plan. Adjustable-length bracing components, while certainly not required, could also be used to reduce any locked-in bracing forces.

Bearing Design Considerations

Transferring the weight of the girder to the bearings presents its own unique challenges. As girder weight transfers from the lifting lines to the bearings, the camber decreases, causing a change in rotation at the girder ends (**Fig. 4**). The rotation manifests as a longitudinal force at the girder-bearing interface. Firm bearings,

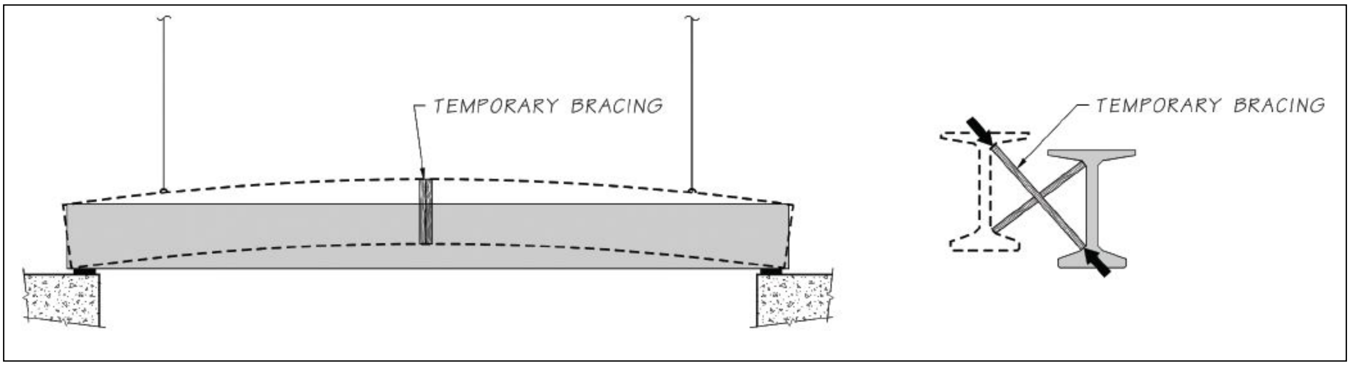

Figure 3. Elevation view of girders showing differential camber at erection and section of adjacent girders showing bracing geometry and forces.

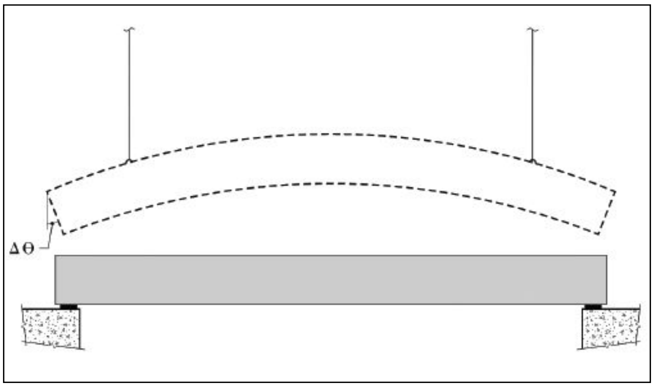

Figure 4. End rotations of a girder in the hanging and seated support conditions.

such as wood blocks, induce a shear force through friction and deform very little in any direction. Elastomeric bearings undergo a shear deformation. For spans with a firm bearing at one end and an elastomeric bearing at the other, the total change in rotation from both ends of the girder is taken up by the elastomeric bearing. **Figure 5** shows bearing scenarios and shear deformations.

The following calculations illustrate the magnitude of bearing shear deformation that can occur. **Table 1** lists the girder properties used in the calculations.

End rotations due to prestress:

$M_o = Pe = (3385)(33.6) = 113{,}736$ kip-in.

$$\theta = \frac{M_o \ell}{2EI} = \frac{(113{,}736)(223)(12)}{(2)(4009)(1{,}612{,}834)} = 0.0235 \text{ rad}$$

where
M_o = moment due to prestress
θ = end rotation

End rotations due to self-weight for the seated girder:

$$\theta = -\frac{w\ell^3}{24EI} = -\frac{(1.07)(223)^3(144)}{(24)(4009)(1{,}612{,}834)} = -0.011 \text{ rad}$$

End rotations due to self-weight for the hanging girder:

$$\ell_h \quad \ell = 223 - \left[2(26)\right] = 171 \text{ ft}$$

$$\theta = \frac{w}{24EI}\left(6a^2\ell_h - \ell_h^3 + 4a^3\right)$$
$$= \frac{(1.07)}{(24)(4009)(1{,}612{,}834)}\left[(6)(26)^2(171) - (171)^3 + 4(26)^3\right](144)$$
$$= -0.004 \text{ rad}$$

where
ℓ_h = length between lifting points
a = length from lifting point to girder end

Change in rotation $\Delta\theta$ as the girder weight is transferred from the lifting lines to the bearing:

$$\Delta\theta = (0.0235 - 0.004) - (0.0235 - 0.011)$$
$$= 0.0195 - 0.0125 = 0.007 \text{ rad}$$

Table 1. Girder properties

Girder length ℓ	223 ft
Area	1118.8 in.^{2}
Moment of inertia I	1,612,834 in.^{4}
Bottom of girder to centroid y_b	49.89 in.
Unit weight of girder, including allowance for reinforcement	0.138 kip/ft^3
Girder self-weight w	1.07 kip/ft
Modulus of elasticity E	4009 ksi
Lifting points from girder ends a	26 ft
Support points from girder ends	8 in.
Total prestressing force (permanent and temporary strands) P	3385 kip
Prestressing force eccentricity e	33.6 in.

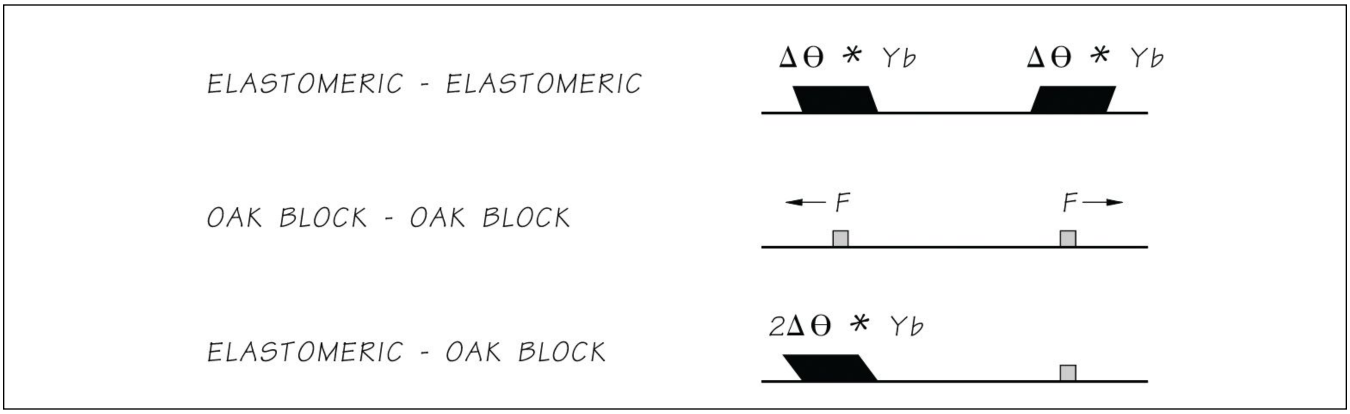

Figure 5. Shear forces and deformations for various bearing support scenarios.

Estimated shear deformation in the elastomeric bearing pad:

$$2\Delta\theta\ y_b = 2(0.007)(49.89) = 0.70 \text{ in.} \approx \frac{11}{16} \text{ in.}$$

Figure 6 shows the bearing shear deformation observed in the field. The measured deformation was approximately ⅝ in. and could not be explained by thermal effects.

Again, while this effect can exist for any concrete girder, the magnitude becomes significant for longer girders supported away from their ends during lifting. This effect could be addressed by applying horizontal load during erection, lifting girder ends after erection to reseat them, or designing end-rotation effects into the bearings themselves.

Design for Lifting

Typically, lifting girders from the casting bed is the critical lifting case because the prestress is at its highest value and the concrete is at its lowest strength and its lowest modulus of elasticity. The locations of the lifting points are determined for this critical case. As the girder ages, the prestress is reduced due to time-dependent losses and the concrete gains strength. For these reasons, the field erection case typically does not govern the stability of the girder. However, when designing long-span girders for constructability, designers should investigate all lifting and handling load cases in an assumed construction process. The challenges of bracing a girder with large differential camber caused by hanging and the accompanying bearing shear deformations can be mitigated by providing additional lifting embedments for erection that are closer to the girder ends. Lifting closer to the girder ends reduces this differential camber and changes in girder end rotation at seating. The reduced prestress and increased strength and stiffness of the concrete at the time of erection as compared to lifting from the form, allow the lifting points to be moved closer to the ends without compromising stability.

Figure 6. A ⅝ in. bearing pad shear deformation was observed after erection of a 223-ft-long WF100G girder on the Puyallup River Bridge.

Conclusion

Handling and erecting very long and flexible girders presents unique challenges. Using secondary lifting embedments for on-site erection is an effective technique to reduce differential camber and shear deformation caused by girder end rotation. The challenge of addressing the destabilizing effect of torsional deformation and its interaction with lateral stability requires additional study. For future projects, WSDOT has limited the lateral slenderness ratio of beams to 310.[4] This limit is an empirical judgment based on recent experience and can be satisfied by widening the girder top flange as needed.

Long-span precast, prestressed concrete girders can be an economical bridge superstructure type for projects that have access to precast concrete fabricators with the appropriate facilities, experienced heavy-load haulers, and a viable delivery route from plant to site. Designers, contractors, and erectors should be aware of the challenges of handling, hauling, erecting, and bracing long-span bridge girders. Constant attention to safety is essential for success.

References

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