Designing Precast, Prestressed Concrete Bridge Girders for Lateral Stability: An Owner's Perspective

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The Washington State Department of Transportation (WSDOT) investigates initial lifting, hauling, and erection conditions during the design of precast, prestressed concrete bridge girders. The design engineer's objective, stated simply, is to be reasonably satisfied that safe handling of girders can occur at all stages of construction.

The following excerpts from the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] show that constructability, safety, and stability must be considered by the design engineer.

> Article 1.3.1 Bridges shall be designed for specified limit states to achieve the objectives of constructability, safety, and serviceability, with due regard to issues of inspectability, economy, and aesthetics, as specified in Article 2.5.
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> Article 2.5.1 The primary responsibility of the Engineer shall be providing for the safety of the public.
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> Article 2.5.3 Constructability issues should include, but not be limited to, consideration of deflection, strength of steel and concrete, and stability during critical stages of construction. Bridges should be designed in such a manner that fabrication and erection can be performed without undue difficulty...
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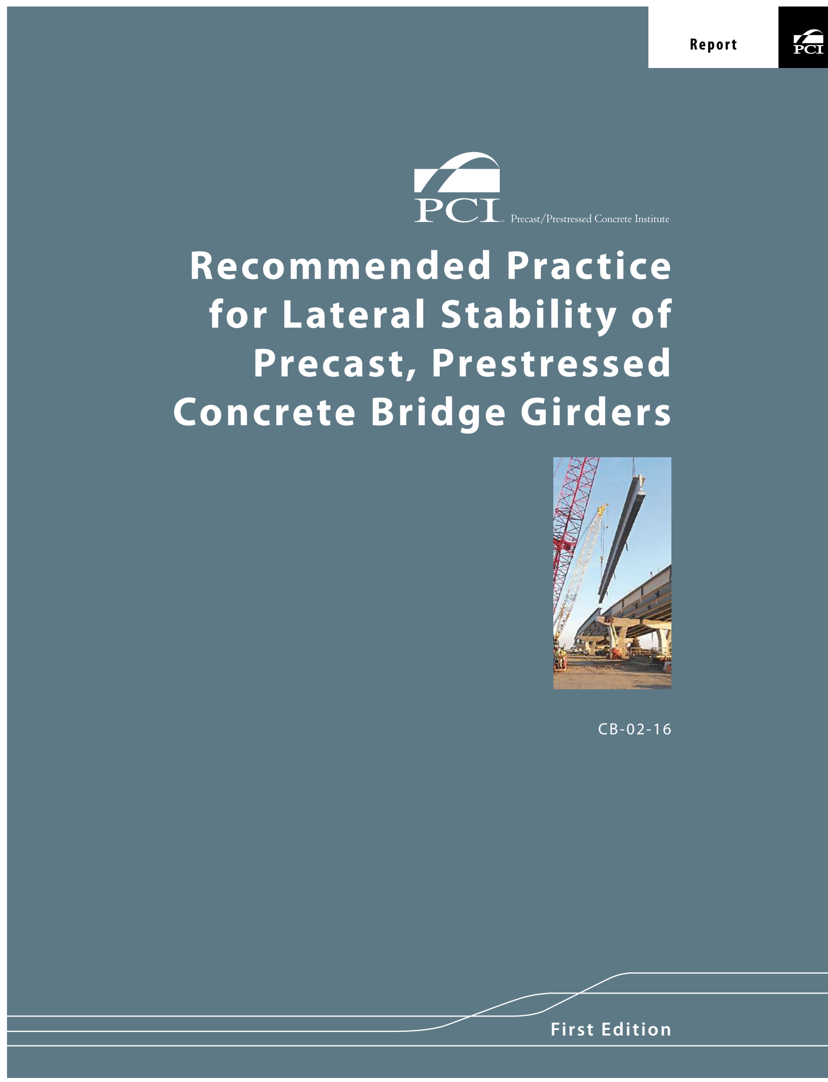
> Article 5.5.4.3 Buckling of precast members during handling, transportation, and erection shall be investigated.

The lateral stability of precast, prestressed concrete bridge girders is an important constructability and safety concern. Lateral bending failures are sudden, catastrophic, costly, and they pose a serious threat to surroundings and people, including the traveling public during transportation of girders from fabrication facilities to bridge sites. Investigation of potential instability conditions is well within the purview of the design engineer.



Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders contains state-of-the-art analysis techniques and best practices for lateral stability of precast, prestressed concrete bridge girders.

Lateral-Stability Design

WSDOT has designed precast, prestressed concrete girders for lifting and hauling for more than 25 years. When spans were generally less than 120 ft long, 120 ft long, bulb-tee and wide flange girder sections were not particularly deep, and stability was not a significant concern. Handling design consisted of evaluating stresses during lifting from the form and hauling to the bridge site.

High-performance/high-strength concrete (HPC/HSC) is now a standard material for the fabrication and construction of precast concrete girders. Among many other advantages, HPC/HSC offers higher concrete strength that allows girders to accommodate a greater precompression force from pretensioning. The increased precompression force, achieved by utilizing 0.6-in.- or 0.7-in.-diameter strand, translates to the design of significantly longer girder spans.

Some owners are extending the spans of typical AASHTO-type girders. These shallow Type II, III, and IV girders have relatively narrow flanges and may not have adequate lateral stiffness to resist lateral bending forces during handling. Other bridge owners have developed wide-flange girders to accommodate precompression forces commensurate with the strength of HPC/HSC and to provide greater lateral stiffness. These girders offer span lengths in excess of 200 ft.

Long-span girders fabricated with HPC/HSC present many challenges. Of primary concern are the lateral stability of long, slender girders and fabrication of these girders in existing stressing beds that were not designed for the larger pretensioning forces and girder sections. Working with local fabricators, WSDOT developed a new design methodology. The primary goal is to support optimized fabrication by determining the least required concrete strength at transfer and lifting, while achieving adequate stability of the girder during lifting and hauling operations. Brice, Khaleghi, and Seguirant[2] give a detailed description and example of this design procedure. The design outcomes include support locations during lifting and hauling, minimum concrete strengths at lifting and shipping, and, if necessary, temporary top-strand requirements.

Stability Design Parameters

The key stability design parameters are camber, sweep, dynamic loading effects, hauling vehicle characteristics, and maximum superelevation along the haul route. Other parameters can include lifting device rigidity and eccentricity, and bunking locations and eccentricity, depending on testing or experience. A common argument against consideration of lateral girder stability by the design engineer is that the contractor's means and methods, and thus many of the key parameters, are unknown at the time of design.

Successful past practices, contractual requirements, measurements, and conservative estimates are reasonable bases for setting the necessary parameters. Design engineers routinely estimate camber. Construction specifications typically provide tolerances for sweep, lifting device placement, and bunking locations. The maximum superelevation can be determined for likely project-specific haul routes or, more generally, the existing roadway infrastructure throughout a region. For other parameters, the design engineer can assume conservative values that increase predicted stresses and reduce factors of safety related to lateral stability.

Haul-truck characteristics are the most difficult parameter to establish. Fabricators in Washington state have been proactive regarding stability and have probable values of hauled weight per axle, overhangs, rotational stiffness per axle, and height of girder center of gravity above axle for typical girder transport vehicles. The WSDOT *Bridge Design Manual* incorporates these values as standard stability design parameters.[3] (A standard method for measuring rotational stiffness is not available. Mast,[4,5] and Seguirant[6] report placing girders on haul trucks and measuring rotations to determine stiffnesses.)

WSDOT recently collaborated with local fabricators and haulers to develop a new method for incorporating haul-truck rotational stiffness into lateral-stability design. Rather than using measured values for a specific hauler's equipment, engineers instead estimate the minimum rotational stiffness needed to satisfy hauling design requirements. This method results in a proposed hauling scheme that is compatible with a variety of hauling equipment.

Communicating Assumptions and Responsibilities

At the time of design, engineers do not know the means and methods for lifting and transport of girders. Reasonable estimates are the basis for stability design. WSDOT provides a proposed lifting and hauling scheme in contract documents and lists all relevant assumptions, including the estimated minimum haul truck rotational stiffness. When contract documents provide design assumptions, bidders can plan alternative lifting and shipping schemes and account for cost and schedule implications, leading to more accurate bids. Based on this experience, other owners are encouraged to work with local fabricators, haulers, erectors, and contractors to establish reasonable stability design parameters.

WSDOT provides design assumptions in contract documents by listing assumed stability parameters common to all projects, such as lifting device rigidity and eccentricity, girder lateral sweep, and dynamic loading factors, in the WSDOT *Standard Specifications for Road, Bridge and Municipal Construction*.[7] Project-

Maximum midspan vertical deflection at shipping	L	L_1	L_2	K_q Minimum shipping support rotational spring constant	W_{cc} Minimum shipping support center-to-center wheel spacing
3⁷/₈ in.	5 ft 0 in.	10 ft 0 in.	10 ft 0 in.	50,000 k-in./rad	72 in.

Example of a girder schedule showing stability parameters. Figure: Washington Department of Transportation. Note: L = Distance from end of girder to lifting point; L_1 = Distance from one end of girder to support point during shipping; L_2 = Distance from other end of girder to support point during shipping.

specific parameters, such as lift and bunk locations, camber, and haul-truck rotational stiffness and wheel spacing, are shown in a girder schedule in the contract plans. The figure on the previous page shows an excerpt from WSDOT girder schedule.

The design engineer, when considering lifting and hauling stability concerns, does not bear full responsibility for safety throughout the duration of the construction project. Means and methods of girder handling, transport, and erection are well within the scope of work of the fabricator, hauler, erector, and contractor. Contract documents must clearly assign responsibilities to these parties. Section 6-02.3(25)L1 of the WSDOT *Standard Specifications for Road, Bridge and Municipal Construction* states that "the contractor is responsible for safely lifting, storing, shipping and erecting prestressed concrete girders." Recent amendments to these specifications provide parameters for performing lateral-stability analyses as well as clarification of requirements and responsibilities. The contractor and subcontractors, the fabricator, haulers, and erectors then assign responsibilities among themselves.

Consequences of Ignoring Stability During Design

Designs that do not consider girder stability are more likely to require postbid design modifications. These modifications are highly undesirable. They can lead to extensive redesign of girders, lengthy review cycles, delays in schedules, and significant changes to material quantities and geometric aspects of the bridge.

Design engineers are required to check girder stresses at transfer and to indicate the minimum concrete release strength on plans. If a lack of stability prevents the lifting of the girder from the casting bed, these computations become meaningless. Higher concrete strengths and restranding may be necessary. Other than the cross section, the revised girder may not bear any similarity to the original design.

Stability improves when handling support locations are moved in from girder ends. Temporary strands reduce tensile stresses at the support and harp-point locations. However, temporary strands affect long-term camber, and changes to camber affect the slab haunch buildup and bridge geometric elements such as bearing seat elevations. Significant changes in slab haunch concrete quantities can be the result for girders with wide top flanges. Additional prestressing force may be needed to accommodate an increased dead load.

WSDOT approach adopts the practice that the first line of defense against these types of postbid changes is the design engineer.

Implementing Stability Design

State-of-the art analysis techniques, best practices, and industry recommendations have been developed and published.[2,8] Girder stresses and stability at initial lifting and hauling are integral elements of the design process. Lifting and hauling conditions are often a governing design case. Designing for optimized fabrication and girder stability involves complex, iterative analytical procedures. Properly implemented tools are essential for lateral-stability design to be a common and routine practice.

WSDOT has successfully implemented the practice of lateral-stability design with sophisticated software tools. WSDOT's prestressed concrete girder design software—PGSuper™ for pretensioned girders, PGSplice™ for post-tensioned spliced girders, and PGStable™ for general precast concrete girder stability analysis—incorporates the necessary analytical procedures to enable engineers to arrive at acceptable design solutions quickly. These tools are part of the BridgeLink™ suite of bridge engineering software that provides the critical link between the state-of-the-art and everyday practice (see http://www.wsdot.wa.gov/eesc/bridge/software/index.cfm?fuseaction=software_detail&software_id=69).

Summary

As bridge owners make use of longer, more slender girders, stability becomes a serious concern. Engineers should become familiar with these concerns and address them during design. Stress and stability considerations during lifting and hauling should become a routine part of precast, prestressed concrete bridge girder design. Excellent design tools and resources are available (see references). Providing complete design assumptions in contract documents enables prospective bidders, fabricators, haulers, and erectors to address and account for possible changes to proposed lifting and hauling schemes during the bidding process.

References

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8. PCI (Precast/Prestressed Concrete Institute). 2016. *Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders*. CB-02-16-E. Chicago, IL: PCI.

EDITOR'S NOTE

A Perspective article on this important topic written by a consulting engineer and a precast plant engineer, both of whom were instrumental in the writing of the PCI Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders*, appeared in the Fall 2017 issue of* ASPIRE®*.*