DEVELOPING PRESTRESSED CONCRETE GIRDER CROSS-SECTIONS FOR LONGER SPANS AND NEW MATERIALS

Quarterly Progress Report
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1. Background and Introduction

The pursuit of structural efficiency and reduced environmental footprint have motivated the use of ever longer spans in the world of ABC. Simultaneously, novel materials are also permitting the use of more slender cross-sections. These trends will inevitably amplify the significance of stability considerations in the transport and handling of long-girders. It is not currently known whether existing cross-sections are sufficient, let alone optimal, for long-span applications, but field reports with long girders have shown visible lateral displacements that suggest that the girders are nearing their stability limits. Thus, careful re-consideration of cross-section geometry, with a focus on providing sufficient lateral and torsional stiffness to avoid lateral instability, is necessary.

This work seeks to characterize long-span girder performance (strength, weight, and lateral buckling load) as a function of girder design choices. The outcome will be guidance on recommended cross-section configurations for ranges of girder length. A particular focus will be placed on characterizing torsional flexibility and its effect on lateral instability. The effect of torsional flexibility has historically been ignored in stability calculations, but, as slenderness increases, this simplified approach becomes increasingly unsafe.

2. Problem Statement

Precast, prestressed concrete girders are the work-horses of the bridge construction industry. Their initial cost-effectiveness and their low maintenance requirements lead to low life-cycle costs and make them ideal for building short- to medium-span bridges, such as freeway over-crossings. However, spans of such bridges are relentlessly increasing, due to constraints caused by environmental restrictions and urban congestion, and the consequent difficulties in locating columns. The longer spans require deeper girders to sustain the in-service bending moments, but they also pose challenges with respect to stability during handling and transportation. Recent experiences in Washington State with very long girders showed clearly the lateral displacements and rotations that are associated with instability failure, and emphasized the need for a re-assessment of the present methods of evaluating stability. That work is now taking place through a grant from WSDOT.

Demands for even longer girders will, no doubt, arise. At the present record span (223 ft) the cross-sections in present use (WSDOT WF sections, Florida Bulb tees, PCI bulb tees, etc.) are close to their stability limits. While increases in elastic modulus help (e.g. UHPC), the section geometry is much the most influential parameter. Therefore, new cross-sections will be needed. Criteria for their selection will include both in-service bending and shear capacities, and stability during transportation. These are hard, unavoidable, constraints. In addition, the shipping weight of such long girders is also increasing, so there is pressure to design the girder sections to have the greatest strength/weight ratio possible, which implies the use of lightweight concrete and minimization of dimensions wherever possible. However, lightweight concrete typically has a lower elastic modulus, which lowers the buckling load, and the benefits of using it depend on the relative magnitudes of the changes in weight and stiffness. Furthermore, new, high-strength materials such as UHPC can contribute to the solution but, because their strengths in different modes (shear, tension, compression) do not appear in the same relative proportions as in existing concretes, the optimization of the girder cross-sections will require careful consideration of all these characteristics.

3. Objectives and Research Approach

The objective of the work is to develop a family of girder cross-sections that will allow girders to be built that are longer than those in use today. As discussed below, they will have to satisfy a number of criteria.

The work will be based on the results of an ongoing project, funded by WSDOT, in which the effect of torsional deformations on stability are being investigated. That work, in turn is being built on an earlier study (Galik et al, 2022) funded by PCI, in which the influence of torsional deformations on the linearized elastic buckling load were established.

These preliminary studies filled a knowledge gap that has existed for some 60 years; almost all previous investigators (e.g. Labelle, Swann and Godden, Burgoyne, Mast, Plaut) have made the simplifying assumption that the girder is rigid in torsion, in which case lateral buckling is a function of lateral bending stiffness alone. That greatly simplifies the analysis but is non-conservative (i.e. unsafe). The few who have included torsional deformations have done it through numerical means, which do not allow the development of design equations. Mast's work is perhaps the best known, and forms the basis for the PCI methodology for verifying lateral stability. The assumption of torsional rigidity, albeit unsafe, was sufficiently accurate for the girders in use at the time, but today's girders are about 50% longer and significantly heavier than those considered by Mast. Both characteristics make the torsional deformations more important. For example, Burgoyne quotes the longest girder he was aware of, which had a length of 40m (132 ft).

The increases in girder length over the past decades are unlikely to stop today, and longer girders are almost inevitable. Even if single-piece girders become too heavy to be delivered by truck, spliced girders still have to be assembled and spliced on site These may spliced in their final position, but sometimes are also then lifted into place after splicing. One recent example is a 270' girder that was placed after splicing in Texas. Spliced girders (even those much shorter than 270') are just as vulnerable to instability during that lifting operation as are single piece girders during handling and trucking. The use of single piece girders offers economy in that it avoids the need for time and space on site to set up, align, splice and post-tension the final girder, if splicing is chosen.

The problem to be addressed here is development of new cross-sections that will enable longer girders to be used. That goal requires that several different, and possibly competing, requirements be resolved. They include:

- Providing sufficient strength and stiffness to resist the applied loads at both the SLS and ULS conditions.
- Minimizing weight for handling, trucking and lifting into place.
- Ensuring stability, in a broad sense, during those operations, including the potential increased significance of torsional deformations for long girders.

The problem is complicated by the fact that some DOTs are now planning to use totally precast members such as Deck Bulb Tees in order speed up on-site construction and to embrace the goals of ABC. Such members are inevitably heavier than standard I-girders, and the large top flanges also change the section properties, such as cgc height.

4. Description of Research Project Tasks

The following is a summary of the five tasks presented in the original proposal with status updates.

Task 1 (Completed) – Identify critical parameters and select target length ranges: A coarse parameter study was carried out to identify and characterize parameters that control the performance of long-span precast girders. The parameters of interest were concrete type (LWC vs. NWC), span range, depth, and cross-section geometry.

Task 2 (Ongoing) – Initial choices, and subsequent optimization of, sections: With the parameter sensitivities characterized from the first task, promising cross-section geometries are being identified within each length range. The necessary analysis to inform the optimization has been completed. That will now be used to guide improvements to optimize performance, likely with different configurations for LWC and NWC. The primary performance goals relate to strength, weight, and buckling resistance. However an analysis of practical design considerations such as available space for reinforcing and trucking weight has also been completed. It is expected that no single shape will be universally optimal, but rather that a “feasible design space” can be identified in which all the sections are nearly optimal. That outcome would allow producers and DOTs to fine-tune the section shapes to their particular environment, but commercial pressures are likely to lead to a single family of shapes being used throughout a region. This task is iterative, in that it will be revisited after discussions with stakeholders.

Task 3 (July, 2023) – Verification with other disciplines: We are collecting input through periodic meetings with stakeholders. This input will be used to iterate on the optimization steps within Task 2. Fortunately, Washington State has been at the forefront of prestressed girder design, production and use for about 70 years, so expert advice is near at hand, in the form of the WSDOT (design, ownership), Concrete Technology Corporation (production), Van Dyke trucking (transportation and delivery), the State Association of General Contractors (on-site handling and implementation), etc. We have good working relations with all of those agencies, and have already spoken with them during the ongoing research programs. PCI also has interests at several levels, for example through their member producers, their sponsorship of a UHPC research program and through their Lateral Stability Committee.

Task 4 (One Round Complete, Awaiting Feedback) – Prepare design examples: A suite of design examples have been produced. The design framework and examples are being evaluated by WSDOT bridge engineers. Once that feedback has been gathered (as note in Task 3), further examples with varying spans and cross-sections will be added.

Task 5 (Future Work) – Final report: The methods, results, and examples will be collected into a final report.

5. Expected Results and Specific Deliverables

The research will result in guidelines for selecting new girder shapes, and some specific recommended shapes, which will permit prestressed concrete girders to be used on spans that are longer than those in use today. Design examples will be included to show how the guidelines can be implemented to arrive at final shapes. We expect that local conditions may influence the optimal shapes.

6. Schedule

Progress of tasks in this project is shown in the table below.

Table 1: Task Completion Update

Item	**% Completed**
Task 1	100%
Task 2	60%
Task 3	60%
Task 4	60%
Task 5	40%

Table 2: Schedule

Task	Activity Quarter	1			2			3			4	
1	Identify controlling parameters	🟥	🟥									
2	Iterative optimization of section		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟦	
3	Verification with other disciplines			🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟦	
4	Design examples and guidance								🟥	🟥	🟦	🟦
5	Final report										🟦	🟦

🟥 Completed
🟦 To be Performed