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

Quarterly Progress Report

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1. REPORT OVERVIEW

This report summarizes the overall research tasks and schedule as initially proposed by the PIs. Thereafter, the activities of Winter 2023 towards the overall goals are discussed.

2. PROJECT SUMMARY

The anticipated project activities and schedule, as listed in the research proposal, are listed below:

Task 1 – Identify critical parameters and select target length ranges: A coarse parameter study will identify and characterize parameters that control the performance of long-span precast girders. Some of the expected parameters of interest are: concrete type (LWC vs. NWC), span ranges, depth, and cross-section geometry.

Task 2 – Initial choices, and subsequent optimization of, sections: With the parameter sensitivities characterized from the first task, the second step will be to identify promising cross-section geometries within each length range. The cross-sections will then be optimized, likely with different configurations for LWC and NWC. The primary performance goals will relate to strength, weight, and buckling resistance. However, additional performance metrics will likely include limits for production (e.g. length of stressing beds, strength of stressing abutments), roadway superelevations for trucking, etc. 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 envisaged as being iterative, in that it will be revisited after discussions with stakeholders as detailed in the following task.

Task 3 – Verification with other disciplines: We expect to seek input from a number of disciplines 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 – Prepare design examples: Design examples for different representative permutations of material and span will be provided. They will illustrate the principles on which the new sections have been developed. The process for selecting the design examples that will be the most useful will also be a topic of discussions with stakeholders.

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

Table 1: Proposed Schedule

Task	Activity Quarte	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												

3. RESEARCH ACTIVITIES

We have not yet hired a student to work on this specific project, nor have we spent any of the funds, but have nonetheless made progress towards the project goals, by piggy-backing on work conducted in a prior project, sponsored by others. The work involves very complex analysis and requires a particularly talented student. The project funds became available when only a few students, inevitably the weakest, were left without projects.

3.1 Winter 2023 - Parametric Study for Girder Stability Study

The primary research efforts in the Winter quarter have focused on Task 1: identification of controlling parameters. This was done through a parametric study which includes the destabilizing effects of Lateral-Torsional-Roll Buckling (LTRB) and cracking. The modeling tool, Rollbuck, that is being used for this study is the result of prior research of the team, and support by both PCI and WSDOT. Rollbuck accounts for most of the parameters needed for the identification of critical behaviors. It is sufficiently complex that it could not have been developed within the scope of a typical ABC Center grant, so it is fortunate that we were able to develop it in prior research, and that it is now available for use in this project. The program inputs for this study are:

- concrete properties including Young's modulus, shear modulus, density (NWC and LWC), and strength
- span-to-depth ratio
- overhang length
- top-flange width

All of these have a direct influence on the girder's lateral stability. The first aspect of this task was to develop a "Standard Configuration" which ensures that the parametric study explores input parameters that are representative of real-world applications. Thereafter, a parameter range about the Standard Configuration was explored to determine the effect of each parameter.

Figures 1 and 2 provide an examples of how the results are being organized to allow for interpretation of the complex interactions between parameters. These figure shows the ratio of the effective cracked moment of inertia of a girder versus roll angle to the uncracked (pristine) moment of inertia prior to rolling. I_{eff} is defined as the moment of inertia of a prismatic girder that has the same lateral deflection as the real girder, with cracking that varies along the span, under the same loading conditions.

Important components of this curve are the angle at which cracking initiates (where the curve initially drops below unity), the angle at which failure occurs (denoted by an x on each curve), and the shape of the curve between these two points. This characteristic curve captures the effect of (and interaction between) LTRB and cracking to provide a summary of the stability of the girder during lifting and transport. Ideally, a girder would maintain uncracked to arbitrarily large angles, or at least to roll angles much larger than anticipated during handling. Large drops in this curve, indicate a "brittle" response type where the initiation of small cracks leads to a significant reduction in effective lateral stiffness. While this plot is for a displacement-controlled "controlled roll" case (the horizontal axis is roll angle), a real girder would be load-controlled, and roll angle would exhibit a sudden jump after cracking initiates, because the cracking causes an increase in lateral deflection, which in turn causes increases in the driving moment and hence the roll angle. The "Mast Curve" shown in both of these figures is an empirical estimate provided by Mast, which is intended to provide a lower bound.

Figure 1 shows the results for a study on the top-flange width for an otherwise standard precast girder available in Washington state. Increasing the top flange width is a simple approach to increase the minor-axis stiffness, and potentially improve stability. However, this figure shows that the result of making such a change is more complex. Wider top flanges increase the cracking onset angle (beneficial), but lead to a more brittle response after cracking as indicated by a steeper drop off in the moment of inertia ratio. This may be caused by the fact that the wider flange leads to a higher centroid and hence less favorable stability characteristics. Figure 2 includes results for PCI-AASHTO girders, which have relatively narrow top flanges. It shows that not all cross-sections remain above the intended lower-bound threshold provided by Mast.

It should be noted that the results presented here constitute a continuation of efforts that were funded by WSDOT and focused on both developing the analysis tools to handle LTRB with the effect of cracking and updating the current design equations (which do not include torsional deformations). That work, however, didn't include the study of cross-section optimization. The transition between the WSDOT project and this project are: (i) to explore changes in the cross-section from current standards to optimize performance (e.g., wider top-flange); and (ii) to include both stability and final service conditions in optimizing cross-section geometry.

3.2 Spring 2023 – Anticipated Activities

The research activities prior to the start of this project provided the toolset. The research activities of the Winter quarter provided an extensive data set of the effect of the girder parameters on the stability of girders. In the Spring quarter, the research will transition to interpreting (from the parametric study data), parameters or groups of parameters that lead to improved stability of girders, while also ensuring good in-service behavior, at which time roll is expected to play no role. Specific cross sections that may provide excellent performance will be identified, and directly analyzed for stability with Rollbuck, as well as for in-service conditions (using other in-house software developed for the design and analysis of prestressed concrete girders). It is expected that some iteration may be required. The findings of this work (Task 2 of the proposal) will also be shared with PCI members and other stakeholders in Spring or Summer to gain feedback on both technical and practical issues of any new cross-sections (Task 3 of the proposal).

Another important task will be hiring a student to take on the bulk of the analytical work. The graduate student who has been conducting the parameter study under the WSDOT contract is graduating at the end of the Spring quarter.

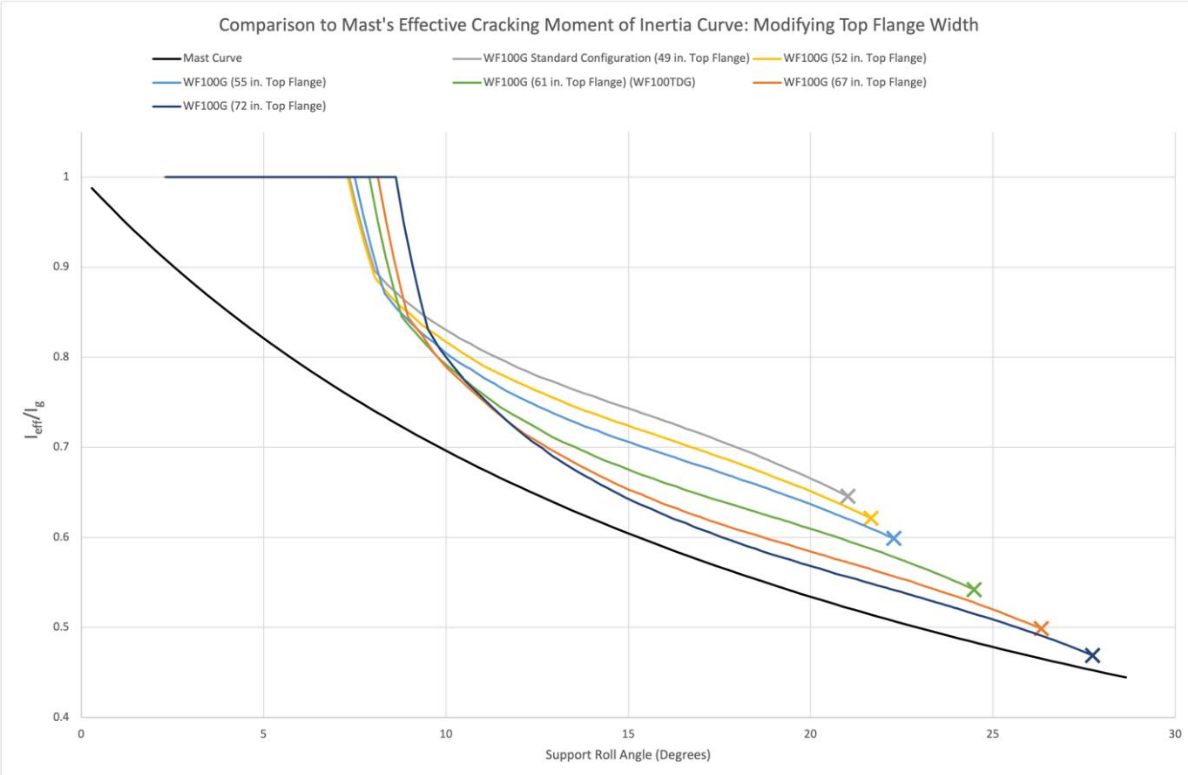

Figure 1: *Ratio of cracked to uncracked moments of inertia for girders with different top flange widths.*

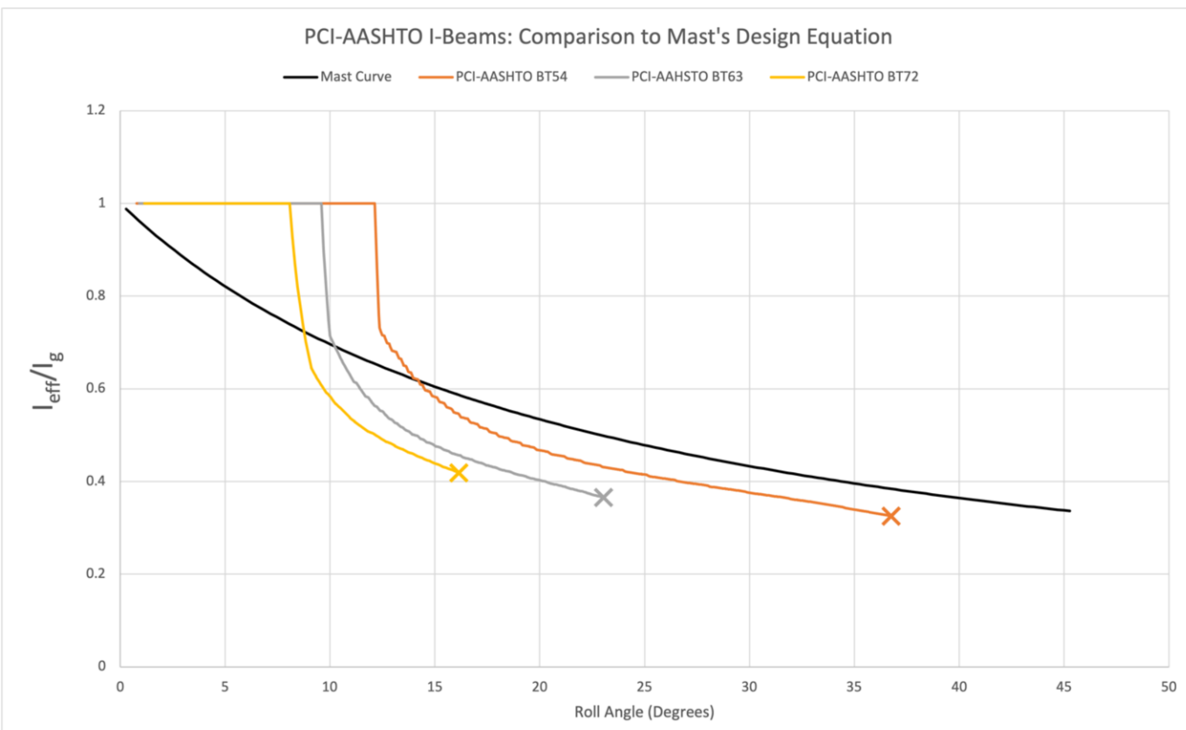

Figure 2: *Ratio of cracked to uncracked moments of inertia for series of PCI-AASHTO Girders.*