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# BEHAVIOR AND DESIGN OF CURVED COMPOSITE BOX GIRDER BRIDGES

## PROBLEM STATEMENT

Composite steel-concrete box girders are commonly used in curved bridges, interchanges, and ramps. Curved composite box girders are suitable for such applications because they have a number of unique qualities, including (1) their structural efficiency, which allows designers to build long slender bridges that have an aesthetically pleasing appearance, and (2) their torsional strength, which allows them to efficiently resist the large torsional demands created by horizontal bridge curvature and vehicle centrifugal forces.

Analysis and design of curved composite box bridges is complicated by many factors, including composite interaction between the concrete deck and steel U-girder, local buckling of the thin steel walls making up the box, torsional warping, distortional warping, interaction between different kinds of cross-sectional forces, and the effect of horizontal bridge curvature on both local and global behavior.

Current codes pertaining to analysis and design of curved composite girders are mostly based on experimental and analytical research conducted over 30 years ago as part of project CURT (Consortium of University Research Teams), funded by the Federal Highway Administration (FHWA). A new Curved Steel Bridge Research (CSBR) project is currently being conducted under the auspices of the FHWA. Although the CSBR project is expected to provide much needed information on behavior, analysis, and design of curved composite bridges, it focuses more on I-girders than on box girders.

## OBJECTIVES

The overall objective of this project is to obtain information that will complement existing data and that will be useful for formulating comprehensive design guidelines for composite curved box girders. Specific objectives include the following:

- Investigate and quantify the effect of non-uniform torsion on the behavior and design of existing curved box girders.

- Study the adequacy of existing distribution factors for curved box girder bridges.

- Provide information that is helpful in identifying suitable locations for placement of access hatches in the steel box. Access holes are needed to allow maintenance crews to periodically inspect the interior of box girders.

# FINDINGS AND CONCLUSIONS

Researchers developed a computer program for simulating the behavior of curved box girders. It is graphically interactive and features a general-purpose beam-column element that can account for the effect of warping. The program was used to conduct a detailed investigation of warping-related stresses in eighteen existing box girder bridges chosen from the Florida Department of Transportation inventory. The bridges were carefully selected to cover a wide range of design parameters including horizontal curvature, cross sectional properties, and number of spans. They were designed by different firms and constructed at different times, and they are considered to be representative of current design practice. Forces were evaluated from analyses that account for the construction sequence and the effect of warping. Loading was considered per the 1998 AASHTO-LRFD provisions. The effect of warping was evaluated by comparing the stresses calculated by taking into account warping and those calculated by ignoring warping.

Researchers also studied load distribution factors promoted by current specifications. Single girder and detailed grillage models were created for a variety of bridges and analyzed using the developed program. The following parameters were investigated:  the number of girders, roadway width expressed by number of lanes, girder spacing, span length, and radius of horizontal curvature. The distribution factor results were compared with those obtained using the equations recommended by AASTHO in the commentary of the guide specification for horizontally curved bridges. Results showed that the recommended equation overestimates the distribution factor by as much as 25% with an average of about 15%. In some cases, AASHTO's equation yielded unconservative results.

Access hatches (holes) in curved box girder bridges are usually provided in the bottom flange immediately before or after an expansion joint. If additional access hatches are required after the bridge is built, they must be placed in such a way that (1) they satisfy important practical constraints such as feasibility, accessibility, water leakage, traffic impact, and unauthorized access; and (2) they do not adversely affect the structural behavior of the bridge, i.e. their installation should neither impair serviceability nor decrease ultimate strength or fatigue life. Researchers identified approaches suitable for identifying appropriate locations for access hole placement.

The following are the most important findings and conclusions:

- The differences between stresses obtained by taking into account warping and those calculated by ignoring warping demonstrated that warping has little effect on both shear and normal stresses in the limited sample of bridges considered. These results should not be construed to imply that warping is not important. Rather, this work points out that there could be a large subset of bridges where the warping effect is small enough to be ignored in structural calculations, which knowledge would be particularly useful to designers since warping calculations are complicated and time consuming. Additional work is needed to define relevant parameters that can be used to identify bridges where warping calculations are warranted. There is also a need for a validated approximate design method that accounts for the effect of warping, without which it is hard to envision designers performing detailed analyses such as those presented in this research.

- Existing distribution factor equations are in need of substantial improvement. More variables should be considered in developing the new expressions, including torsional rigidity of the box.

- Access hatches can be installed without additional strengthening in low stress regions in the bottom steel flange. Low stress regions can be found using the program developed in this research.

## BENEFITS

The primary product of this project is an improved understanding of the structural behavior of curved box girder bridges, which will eventually lead to better design specifications that will enhance the economy and reliability of curved bridges. This project has also provided a framework for placing new inspection access hatches in existing box bridges without compromising the structural integrity of the bridges. Increasing the number of access hatches in box bridges improves working conditions for inspection crews and promotes their safety.

This project was conducted by Sherif El-Tawil, Ph.D., P.E., at the University of Central Florida. For more information, contact Tom Beitelman, Project Manager, at (850) 414-4855, thomas.beitelman@dot.state.fl.us.