UNIVERSITY of HOUSTON

PROJECT SUMMARY

Texas Department of Transportation

0-6905: Performance of Skewed Reinforcing in Inverted-T Bridge Caps (Phase 2)

Background

Offering a practical means to increase vertical clearance and being aesthetically pleasing, reinforced concrete inverted-T bridge caps (ITBCs) have been widely used in Texas bridges. Many ITBCs are skewed when two roads are not aligned perpendicularly. Due to the unsymmetrical projection of the ledges and unsymmetrical loading on both sides of the web, the torsion effect is significant in skewed ITBCs. This torsional effect increases with the increase in the skew angle. Any kind of improper detailing can cause poor placement of concrete and induce significant concrete cracking, which would reduce the load-carrying capacity and increase future maintenance costs. Skew transverse reinforcing provides an alternative approach that reduces design complexities and the construction period significantly. The Structural Research Laboratory (SRL) of the University of Houston conducted tests to investigate whether the skewed arrangement of transverse reinforcements weakens the structural performance or alters the failure mechanism of ITBCs.

What the Researchers Did

The SRL developed an extensive experimental and analytical programconsidering three parameters: (1) skew angle, (2) detailing of the transverse reinforcement, and (3) amount of the transverse reinforcement. Based on those variables, the SRL fabricated 13 skewed ITBC specimens and used the test results to calibrate the 3D Finite Element (FE) simulation in ABAQUS. The test results showed that skew transverse reinforcement can be an alternative to the traditional method of flaring in the design of ITBCs; the project was extended to develop preliminary FE models of actual large-scale ITBCs. Three bent caps of a seven-span bridge under construction were selected: Bent Cap 2, 6, and 7 with a skew angle of 43°, 33°, and 33°, respectively. The FE analysis was performed using ABAQUS to understand the overall structural behavior of skew reinforcement in ITBCs and determine the critical loading patterns during the load test and crucial strain gauge locations. Figure 1 shows Bent Cap 2.

Later, the SRL conducted FE analyses considering the following parameters: (1) skew angle (43° or 33°), (2) detailing of transverse reinforcements (skew transverse reinforcement or traditional method of flaring), (3) end bars (with or without U1 Bars, U2 Bars, U3 Bars, and G Bars), size of S Bars (minimum, current design, 20% more or 40% more than current design), (4) size of G Bars (No. 3 to No. 7), and (5) concrete strength (5 or 7 ksi). This cost-benefit analysis considered 96 models to compare the stiffness of the bent caps under the service load, maximum crack width under the service load, and the ultimate strength of the bent caps.

What They Found

The structural tests on the ITBC specimens showed that the skewed arrangement of transverse reinforcements neither weakens the structural performance nor alters the failure mechanism of an ITBC. The laboratory tests showed that the cracking performance of ITBC specimens is enhanced by evenly spacing skewed transverse reinforcement, decreasing flexural shear, shear, and torsional cracks as well as lower crack widths as compared to the ITBC specimens designed with the traditional transverse reinforcement. The FE analysis results are summarized below.

- The ideal locations to paste the strain gauges and attach LVDTs are the cantilever end faces of the bent caps. The significant bent caps with skew transverse reinforcing are safe under the service loads and the ultimate loads.
- The skew transverse reinforcement achieves better structural performance compared to the traditional

Research Performed by:
University of Houston

Research Supervisor:
Yi-Lung Mo

Researchers:
Jiaji Wang
Satya Sapath Roy
Yagiz Oz
Thomas T.C. Hsu
Bhagirath Joshi

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transverse reinforcement with notably reduced construction cost.

- Skew reinforcing results in fewer cracks and smaller crack widths.
- The increase of the S Bar area notably enhances the stiffness and the ultimate strength and reduces the crack width. The parametric simulation results indicate the current design of the S Bar area is adequate for structural safety and crack resistance.
- Having end bars (U1 Bars, U2 Bars, U3 Bars, and G Bars) significantly reduces the crack width on skewed ITBCs.
- The increase of the G Bar area notably reduces the maximum crack width with negligible influence on the stiffness, the ultimate strength, and the construction cost. The current design of the G Bar (No. 7 bars) of the selected bent caps is adequate for crack control.
- When the concrete strength increases from 5 ksi to 7 ksi, the ultimate strength and the stiffness of ITBCs increase with reduced crack width, and the construction cost is negligible.

What This Means

Following are the proposed design recommendations:

- Use skew transverse reinforcement for the design of skewed ITBCs since it achieves better structural performance compared to the traditional method of flaring—with notably reduced construction cost. (FE results show that all the significant bent caps with skew transverse reinforcing are safe under the service and the ultimate state loading.)
- Design double S Bars throughout the bent cap. The spacing of S Bars can be increased at the location of column support, but no greater than 12 inches.
- Pair M Bars and N Bars at equal spacing—equal to or an integer multiple of the spacing of S Bars—for skewed ITBCs.
- Place No. 6 U1 Bars, U2 Bars, and U3 Bars at the end faces, and No. 7 G Bars at approximately 6-inch intervals at the first 30 inches to 35 inches of the end of the bent cap. The end bars (U1 Bars, U2 Bars, U3 Bars, and G Bars) notably reduce the maximum crack width.
- Achieve a concrete compressive strength of at least 5 ksi. While the TxDOT Bridge Design Manual limits the minimum concrete compressive strength to 3.6 ksi, FE models in this project show that concrete strength notably increases the ultimate strength and the stiffness of ITBCs and reduces crack width.
- Perform a field test to calibrate and update the FE models using the real data of the selected bent caps.

In terms of proposed changes to TxDOT practice, the researchers recommend the following: instead of fanning out the hanger and the ledge stirrups to match the skew angle of the bridge, skewed transverse reinforcing should be utilized throughout the bent cap, maintaining the required spacing set by TxDOT. This will create uniform spacing and dimensions for the ledge and the hanger stirrups along the bent cap (unlike the traditional method of flaring) and provide an alternative approach that will significantly reduce the design complexities and the cost. However, to validate the proposed changes, field tests are required.

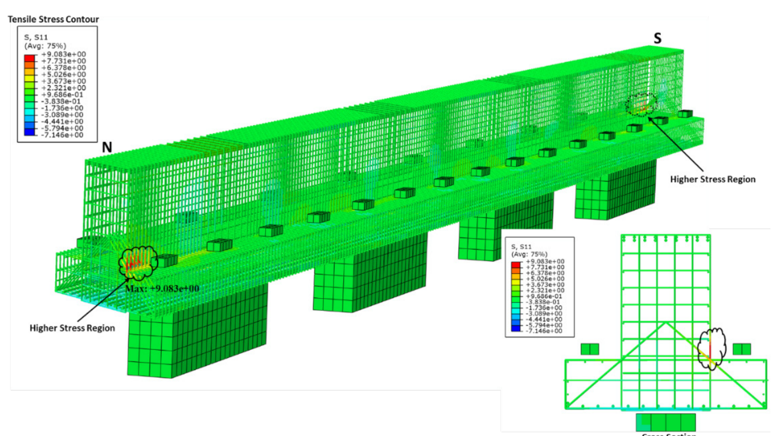

Figure 1. FE Model of Bent Cap 2

For More Information

Research and Technology Project Manager:
Jade Adediwura, RTI (512) 486-5061

Research Supervisor:
Yi-Lung Mo, University of Houston (713) 743-4274

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Research and Technology Implementation Office
Texas Department of Transportation
125 E. 11th Street
Austin, TX 78701-2483

www.txdot.gov
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