UNIVERSITY of HOUSTON

PROJECT SUMMARY

Texas Department of Transportation

0-6905: Performance of Skewed Reinforcing in Inverted-T Bridge Caps (Phase 1)

Background

Many reinforced concrete inverted-T bridge caps (ITBCs) are skew when two roads are not aligned perpendicularly, some in excess of 45 degrees. Using skew transverse reinforcing can facilitate faster and easier construction and provide an alternative approach that will significantly reduce the design complexities and construction period. To address concerns about whether using skewed transverse reinforcement will provide reasonable structural behavior for the skew ITBCs in terms of overall cracking and structural performance, this project investigated the structural performance of the ITBC with skewed transverse reinforcement and compared its performance to that of traditional ITBC.

What the Researchers Did

This project developed an extensive experimental and analytical program reinforcement considering three parameters—(1) skew angle, (2) detailing of transverse reinforcement, and (3) amount of transverse reinforcement—and four values of skew angles: 0°, 30°, 45°, and 60°. Two types of transverse reinforcement detailing are considered: traditional reinforcing (presently used by TxDOT) and skewed reinforcing (proposed). The amount of transverse reinforcement considered is twice the minimum transverse reinforcement (2M) and the minimum transverse reinforcements (M) specified by AASHTO LRFD (2014). The University of Houston team fabricated 13 skew ITBC specimens; Figure 1 shows the test setup. Out of 13 specimens, seven ITBC specimens (with 2M reinforcement) were tested in Phase 1. In Phase 2, six more specimens (with an M reinforcement) were tested. The test results were calibrated with 3D Finite Element simulation in ABAQUS. Furthermore, a parametric analysis was performed to understand the overall structural behavior of skewed reinforcement in ITBCs, accounting for unexplored parameters in the test matrix.

What They Found

The Phase 1 structural tests and Finite Element Analysis on the ITBC specimens yielded these results.

- The skewed arrangement of transverse reinforcements does not weaken the ITBC's structural performance or alter the failure mechanism, so the skewed arrangement plan is much better than the traditional arrangement for practical applications.
- The cracking performance of ITBC specimens is enhanced with a provision of skewed transverse reinforcement spaced evenly, reducing flexural shear, shear, torsional cracks, and lower crack width as compared to the ITBC specimens with traditional transverse reinforcement.
- The influence of shear and torsion is highly dominant in the bent caps with a higher skew angle. The larger the skew angle is, the weaker the specimen will be. A larger skew angle creates higher asymmetry in the bearing pad's locations, increasing torsion. Therefore, a skew ITBC with a skew angle of more than 45° is prone to torsional failure.
- The locations of exterior loading pads have a profound influence on the skew bent cap's structural behavior. Placing loading pads closer to the end face of the ITBC increases the transverse rebar stresses significantly. This pattern is more prevalent for higher skew angles.

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- The acute angle side of the skew ITBCs is always under the influence of prevailing additive shear responsible for early stage yielding of transverse reinforcement in the given region, developing more cracks than on obtuse angle sides.

What This Means

Following are the proposed essential recommendations for the design and construction of skew inverted-T bridge caps with transverse reinforcing:

- Skew all S Bars (shear and hanger stirrups), M Bars (primary ledge bars), and N Bars (secondary ledge bars) to match the skew angle of the inverted-T bridge cap. Measure the spacing of skew transverse reinforcements from center to center of the hanger and ledge stirrups along the central line of the skew bent cap (not the perpendicular distance between hanger or ledge stirrups).
- Avoid shorter ledges. The distance between the central line of the exterior girder and the end face of the skewed inverted-T bent cap should be maintained at least 24 inches to provide adequate punching shear capacity. This also delays the appearance of the diagonal crack at the re-entrant corner between the cantilever ledge and the web at the end faces of the ITBCs.
- Provide vertical rebars across both end faces of the skewed web at a spacing equivalent to the spacing of shear and hanger stirrups (at least six inches) and along the end face. In addition to restricting the formation of cracks, vertical rebars at the end faces help to reduce the stress concentration of the hanger and shear stirrups at the cantilever end face.
- At the skewed end faces of cantilever spans, adding diagonal bars (G bars) do not help to prevent the formation of diagonal cracks at the re-entrant corner between the cantilever ledge and the web. The most effective variable to control crack width is the distance from the end face to the most exterior loading pad. As the skew angle increased from 0° to 60° the diagonal crack at the junction of ledge and web occurred at a lower load.
- A minimum area of transverse reinforcement is required to restrain the growth of diagonal (inclined) cracking, increase ductility, and prevent the sudden shear failure of the bent cap. The test results of the ITBC specimens with minimum reinforcements show no sudden shear failures. Transverse rebars are considerably yielded before the failure of the specimens. Therefore, the equations in AASHTO LRFD 2014 can be used to design the minimum skewed transverse reinforcing in skewed ITBCs.

In terms of proposed changes to TxDOT practice, the researchers recommend the following: TxDOT should use skewed transverse reinforcing all the way from one end of the skew bent cap to the other end, maintaining the required spacing along the central line of the bent cap (instead of fanning out the hanger and ledge stirrups to match the skew angle of the bridge). This will create uniform spacing and dimensions of ledge and hanger stirrups throughout the bent cap, significantly reducing design complexities and the construction period.

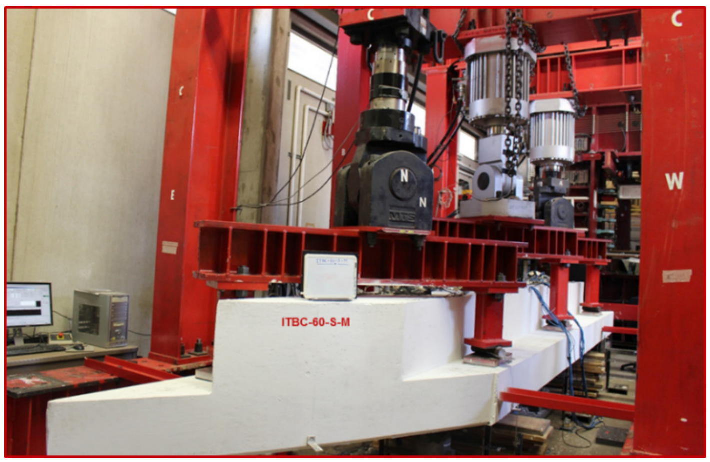

Figure 1. Test setup for ITBC test

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