PROJECT SUMMARY

Texas Department of Transportation

0-6416: Shear Cracking in Inverted-T Straddle Bents

Background

Diagonal web cracking of inverted-T straddle bent caps has been reported with increasing frequency in Texas, triggering concerns about current design procedures for such elements. To address these concerns, this project was developed with the objectives of obtaining a better understanding of the behavior of inverted-T beams and developing strength and serviceability design criteria that will minimize such cracking in the future.

A recently completed research project, TxDOT Project 0-5253, examined the application of strut-and-tie models to the design of rectangular bent caps. From that project, recommendations were made to the AASHTO LRFD specifications to improve the strength and serviceability behavior of bent caps. This project aimed to evaluate the applicability of the recommended provisions, which were calibrated for compression-chord loaded beams, to inverted-T, or tension-chord loaded beams.

What the Researchers Did

In order to accomplish the objectives mentioned above, a comprehensive literature review was conducted to expose the current state of knowledge on inverted-T beams. Most of the tests results found were either not applicable to the inclined cracking focus of this project or conducted on beams drastically smaller than the bent caps in service in Texas. Moreover, very limited serviceability information regarding diagonal crack widths was available.

Next, a detailed assessment of the condition of distressed in-service bent caps was performed. Eight bent caps in four Texas cities were inspected to determine the extent of diagonal cracking and record details about the geometry of the caps.

An extensive experimental program was developed to uncover the main factors affecting the web diagonal cracking behavior of inverted-T beams. Thirty-three full-scale specimens were constructed and tested with varying ledge lengths, ledge depths, reinforcement ratios, number of point loads, and web depths to encompass all variables found in typical inverted-T bents. The beams were loaded in shear, and crack widths were recorded to monitor the behavior of the beams.

What They Found

Observations on the strength and serviceability effects of the variables investigated in the experimental program are as follows:

- Increasing the ledge length increases the web shear strength of inverted-T beams and delays the appearance of the first diagonal crack in the web. The length of the ledge was not found to have an appreciable effect on the width of diagonal cracks.

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- Increasing the ledge depth had no appreciable effect on the strength or serviceability behavior of the inverted-T specimens.
- Increasing the amount of web reinforcement in the shear span was found to increase the strength of all specimens in the experimental program, regardless of the shear span length. Web reinforcement did little to influence the shear load at first diagonal cracking but did reduce diagonal crack widths at larger levels of load.
- Within the full-scale web depth range tested (42 to 75 in.), web depth did not influence the strength or serviceability behavior of the inverted-T specimens.
- A comparison between the ultimate shear capacity obtained from the test result and the nominal shear capacity from the STM calculations revealed conservative strength estimates for every specimen. The beams that were found to have the lowest safety margin were those constructed with the shortest, "cut-off" ledges.

What This Means

TxDOT Project 0-5253 STM provisions are recommended for the design of inverted-T bent caps. The design provisions were found to yield accurate and reasonably conservative results for tension-chord loaded beams. Within these provisions, a minimum web reinforcement ratio is recommended as 0.3 percent in each orthogonal direction. That minimum web reinforcement quantity worked well for inverted-T beams both in terms of developing strut/node strengths and limiting diagonal crack widths at service levels. It is recommended to provide that minimum reinforcement ratio in inverted-T beams.

It is recommended to avoid the use of "cut-off" ledges in inverted-T beams, i.e., ledges that are terminated, or cut off, at the edge of the exterior loads. Such ledges were shown to result in lower web shear strengths than beams with longer ledges. Cut-off ledges were also found to reduce the load at first diagonal cracking in the web. Moreover, cut-off ledges increased the risk of ledge failures.

A simple and reasonably conservative equation to estimate the diagonal cracking load of deep beams is recommended for use with inverted-T beams. As in Project 0-5253, the diagonal cracking load of inverted-T beams was found to be mainly a function of the shear area, the square root of the compressive strength of concrete, and the a/d ratio. With this equation, the service level shear in the member can be checked to limit diagonal cracking.

Finally, a simple inspection chart was developed to correlate the maximum diagonal crack widths to the load acting on the member, quantified as a percent of its ultimate capacity. As the other variables investigated in the experimental program had limited effects on the width of the diagonal cracks, the chart is only a function of the amount of web reinforcement in the member. This chart provides a simple means to make an informed decision regarding the amount of distress in a diagonally cracked inverted-T bent cap when a more sophisticated means of evaluation is unavailable.

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