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Project Summary Report 0-4371-S
Project 0-4371: Examination of the AASHTO LRFD Strut-and-Tie Specifications
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PROJECT SUMMARY REPORT

Design for Shear in Reinforced Concrete Using Strut-and-Tie Models: A Summary

The shear strength of reinforced concrete beams was investigated in this project. The research focused on deep beams similar to that shown in Figure 1. With the introduction of the AASHTO LRFD Bridge Design Specifications, structures such as those shown in Figure 1 must be designed using strut-and-tie models rather than sectional models. The bottle-shaped struts shown in Figure 2 represent a portion of the strut-and-tie model for the bent cap shown in Figure 1. The cracks shown in Figure 2 are due to the tension induced from the lateral spread of compression under service load.

When the AASHTO LRFD specifications are used for strut-and-tie modeling, the strength of a strut is calculated based on the strain of the tie which adjoins the strut in question. Design engineers have had difficulty applying these procedures because of this strain term.

What We Did...

The purpose of this research was to examine the AASHTO LRFD specifications for strut-and-tie modeling and simplify the procedures to develop a straightforward design method. In order to do examine the current provisions, a series of 26 isolated strut tests (Figure 3) and 25 deep beam tests (Figure 4) was undertaken. Additionally, a database of approximately 1,200 test

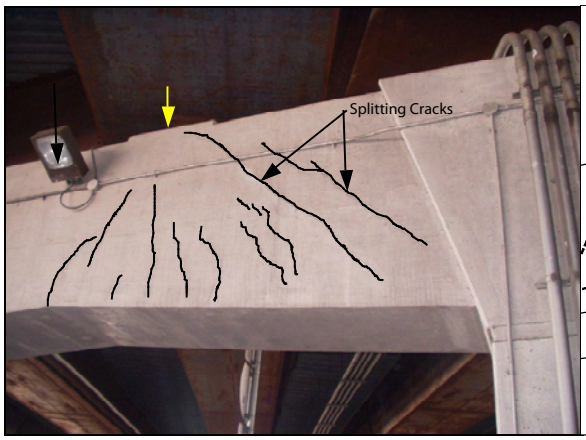


Figure 1: Bent Cap

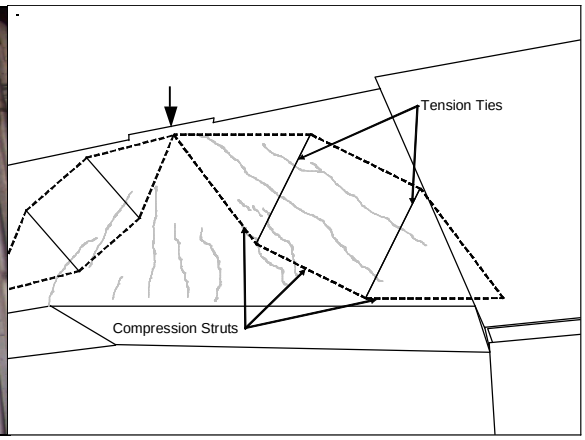


Figure 2: Bottle-Shaped Struts in Bent Cap

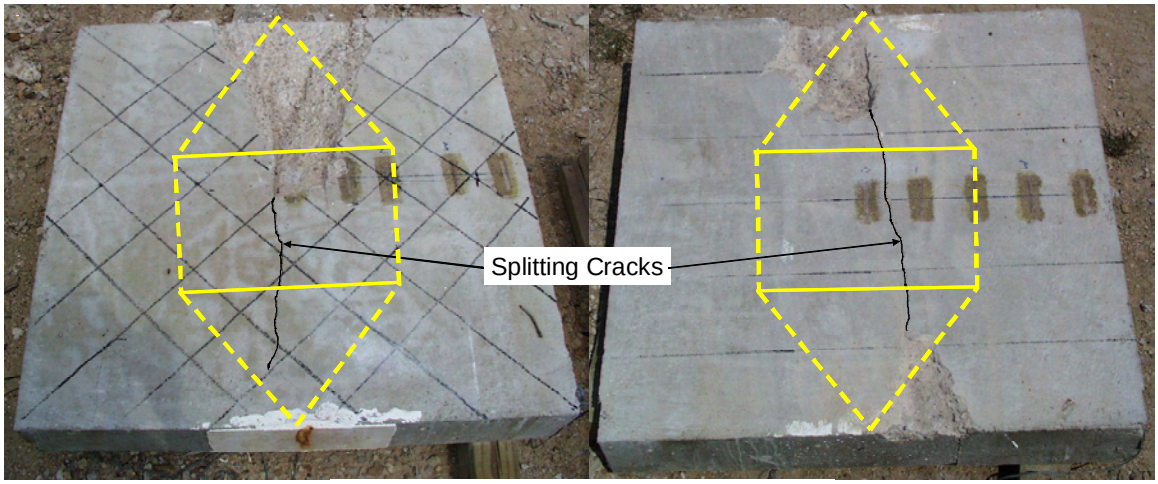


Figure 3: Isolated Strut Test

results was compiled. That database was used to examine the levels of conservatism in both ACI 318-05 and AASHTO LRFD strut-and-tie provisions.

What We Found…

The use of AASHTO LRFD Strut-and-Tie provisions produced conservative estimates of strength for the beam tests specimens. However, the use of AASHTO LRFD strut-and-tie provisions produced unconservative strength estimates for some of the specimens in the database. The crack control reinforcement required when using AASHTO LRFD strut-and-tie provisions is much greater than that needed for strength purposes in a bottle-shaped strut. A direct strut mechanism (as shown in Figure 2) forms for beams in which the shear span-to-depth ratio is less than 2.

The use of ACI 318-05 strut-and-tie specifications also resulted in nominal strength less than the measured capacity of the test specimens. Levels of conservatism when applying the ACI 318-05 provisions to the specimens in the database were less than those when using AASHTO LRFD. The loads at which cracking occurred in the test specimens was unaffected by the amount of transverse reinforcement within the test specimen.

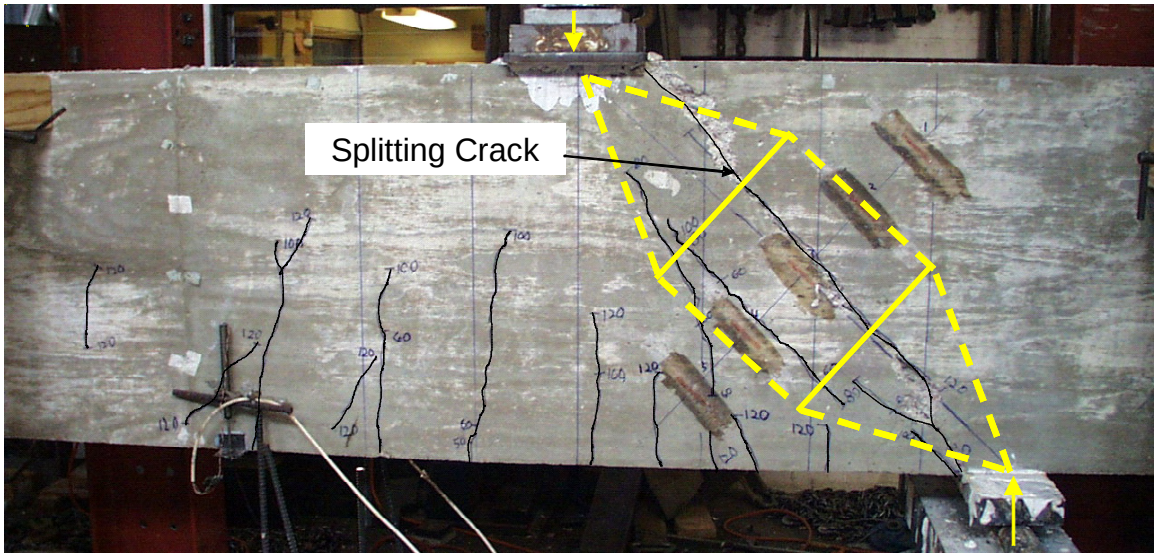
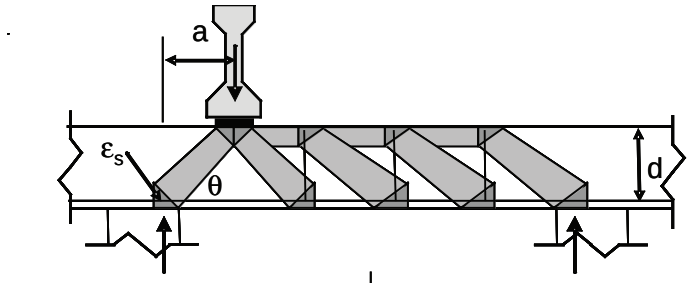


Figure 4: Deep Beam Test



AASHTO LRFD Strut-and-Tie Provisions

$$F_{Strut} = \frac{A_{Strut} f_c'}{0.8 + 170\varepsilon_s} \le 0.85 A_{Strut} f_c'$$

$$\varepsilon_1 = \varepsilon_s + (0.002 + \varepsilon_s) cot^2 \theta$$

Proposed Strut-and-Tie Provisions

$$F_{Strut} = \frac{27 A_{Strut} f_c'}{a/d\sqrt{f_c'}} \le 0.85 A_{Strut} f_c'$$

Figure 5: AASHTO LRFD and Proposed Strut-and-Tie Provisions

The Researchers Recommend…

The research led to new design provisions for the use of strut-and-tie modeling. The proposed provisions are compared with the current LRFD provisions in Figure 5. For serviceability reasons, the strut reinforcement recommended in Appendix A of ACI 318-05 should be used in all bottle-shaped struts. Without proper transverse reinforcement, a bottle-shaped strut cannot maintain equilibrium after significant cracking. Reinforcement is needed to maintain the strength of a strut as well as reduce crack widths under service load.

For conventionally reinforced concrete with concentrated loads located less than 2d form the support, the proposed strut-and-tie provisions are recommended. For beams with concentrated loads applied between 2d and 6d from the support, $V_c = 1\sqrt{f_c'} b_v d_v$.

For beams with uniform loads or concentrated loads at greater than 6d from the support, $V_c = 2\sqrt{f_c'} b_v d_v$.

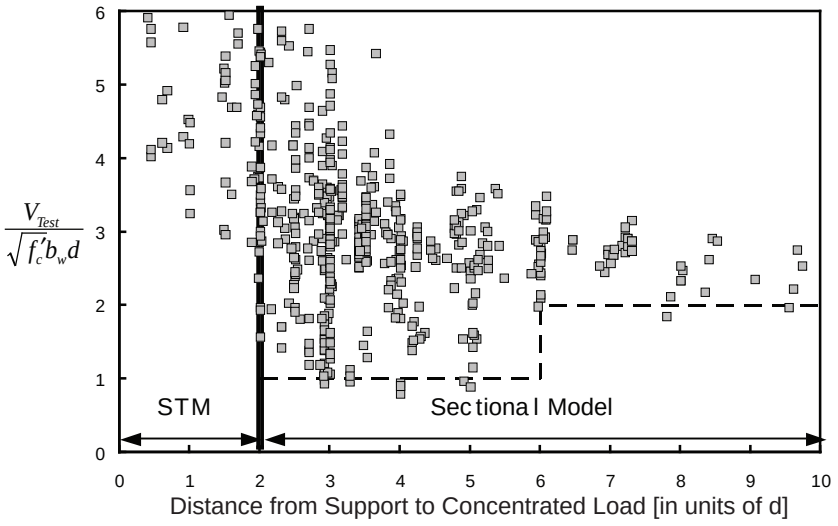


Figure 6: Corroboration with Experimental Data

For More Details...

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The research is documented in the following report:

0-4371-2 *Design for Shear in Reinforced Concrete Using Strut-and-Tie Models*

To obtain copies of a report: CTR Library, Center for Transportation Research,
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For more information, please contact Tom Yarbrough, Research and Technology Implementation Office, (512) 465-7403 or email at tyarbro@dot.state.tx.us.

Your Involvement Is Welcome!

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