Project Summary

Texas Department of Transportation

0-4759: Rational Shear Provisions for AASHTO LRFD Specifications

Background

Prestressed concrete I-beams are used extensively as the primary superstructure components of bridges in Texas highways. The goal of this project was to solve one of the most troublesome problems in prestressed concrete beams: shear. Central to the problem is the lack of a rational model to predict the behavior of prestressed concrete structures under shear and the various modes of shear failures. Because of this deficiency, all existing shear design provisions, including those in the ACI Codes and AASHTO Specifications, are empirical, complicated and have severe limitations.

What the Researchers Did

This research project consisted of complementary theoretical and experimental studies, which were divided into two parts. First, researchers wanted to establish the constitutive laws for prestressed concrete membrane elements and to develop an analytical model for predicting the shear behavior of such elements. This objective was accomplished in three steps:

1. Researchers designed post-tensioned concrete panels (elements) that could be tested to simulate the crack patterns of pre-tensioned beams. Crack simulation tests of ten rectangular concentrically prestressed beams showed that the bond condition in pre-tensioned concrete can be simulated by post-tensioned elements with flexible conduits grouted by high-strength, self-consolidating concrete.

2. Biaxial load tests of ten prestressed concrete panels (elements) were performed using the Universal Panel Tester at The University of Houston. These test panels were divided into two groups: TE and TA. In Group TE, the five panels had reinforcement parallel to the applied principal stresses. These panels were subjected to sequential loading in order to study the constitutive relationships of materials (concrete and prestressing tendons). In Group TA, the five panels had reinforcement in a 45-degree direction and were subjected to pure shear in order to study the shear behavior.

3. A Softened Membrane Model for Prestressed Concrete (SMM-PC) was developed which was capable of predicting the responses of prestressed concrete elements under shear. The theoretically predicted behavior showed a close fit with the experimental outcomes of panels in Group TA under shear loads.

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Next, five full-scale Texas Department of Transportation (TxDOT) Type-A beams, 25 feet long, were tested to study their behavior in web shear and flexural shear failures. Three of the five beams (Beams B1, B2 and B3) were designed to fail in web shear, whereas the remaining two (Beams B4 and B5) were designed to fail in flexural shear. One web shear specimen (Beam B3) and one flexural shear specimen (Beam B5) had draped prestressing strands. Three beams (B1, B4 and B5) had a minimum ratio (0.17%) of transverse mild steel, while two beams (B2 and B3) had 1%.

The beams were loaded using two hydraulic actuators placed symmetrically from the beam supports. The loads from the actuators were applied at 3 feet from the supports (both north and south supports) to induce web-shear failure in beams B1, B2 and B3, giving a shear span to depth ratio (a/d) of 1.6. Beams B4 and B5 were loaded at 8 feet from the supports for flexural-shear failure, giving an a/d ratio of 4.1. The load-deflection curves were theoretically obtained for all five beams using flexure analysis. The analytical curves agreed very well with the experimental curves for beams failing in web-shear as well as for beams failing in flexural-shear.

A shear analysis of the beams was also performed using the constitutive laws of prestressed concrete developed in part one of this research. It was confirmed that the concrete contribution V_c to the shear capacity of the beam was caused by the shear resistance of concrete along an inclined failure plane, rather than the tensile resistance of concrete across the failure plane, assumed in the ACI and the AASHTO provisions.

What They Found

The test results and the shear analysis of the five beams were used to develop a new and simple equation for shear design of prestressed girders. In this equation, the shear capacities of prestressed beams are a function of the compressive strength of concrete and the a/d ratio of the beams. The amount of prestressing force and the angle of the failure planes were neglected because they were found to have insignificant effect on the ultimate shear capacity. The new equation was supported by test results of other prestressed beams available in literature. The predicted shear capacities of all the beams were then compared with the shear capacities calculated using the ACI and the AASHTO shear provisions and were found to be more reasonable.

Four design examples were prepared to illustrate the application of the new shear equation for prestressed concrete girders. The shear equation was also extended for application to non-prestressed girders, including an example showing the design of a non-prestressed girder.

What This Means

Prestressed concrete I-beams are used extensively as primary superstructure components of bridges in Texas highways. The development of this new equation for prestressed concrete girders may be of great value to TxDOT engineers in future bridge design and construction.

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