SHEAR AND ANCHORAGE STUDY OF REINFORCEMENT IN INVERTED T-BEAM BENT CAP GIRDERS

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SUMMARY REPORT 113-4 (S)

SUMMARY OF

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Inverted T-Beams

Beams constructed in the form of an inverted **T** possess on each side of the web a shelf that provides a convenient supporting surface for precast members. Inverted T-beams are used frequently as bent cap beams in order to reduce to a minimum clearance requirements beneath the bent cap. The reduced visible depth of bent cap beams enhances the appearance of bridge superstructures.

Application of loads to the lower portion of concrete beams creates tensile forces not ordinarily encountered in T-beams. Reinforcement for the flanges of the T presents special problems of shear, flexure, and bar anchorage. Typical forces and stress types in such beams are illustrated in Fig. 1.

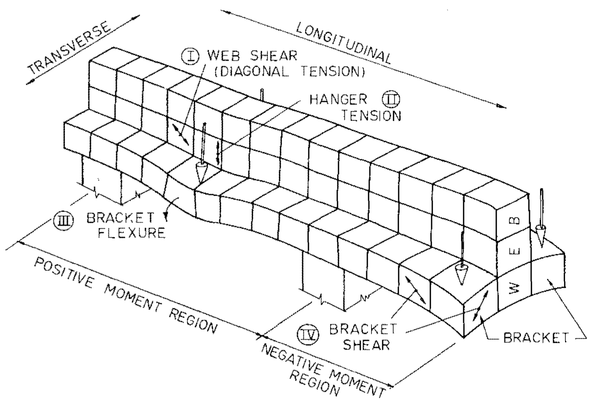

Fig. 1. Inverted T-beams.

Project Objective

The purpose of this study is to provide recommendations for the design of reinforcement in inverted T-beams. Reinforcement details for the flanges of the T-beam must accommodate flexure and shear forces on the short, cantilevered shelf. Shear reinforcement in the T-beam web must resist shear forces caused by loads applied to the lower part of the web. Several different arrangements of reinforcement were used in test specimens in order to reveal the effectiveness of each.

Physical Tests

Two full scale specimens with reinforcement details similar to those already used by the Texas Highway Department were constructed for the principal purpose of studying flange reinforcement details. Only one of ten load patterns applied to the full scale beams resulted in a failure, because the loading system was inadequate to break the large beams. Four specimens, approximately one-third the size of full scale beams were constructed for studies of web shear behavior as well as further studies of flange reinforcement behavior. All 14 load patterns on the one-third scale specimens developed a failure in some part of the specimens.

All specimens contained steel with a yield stress very near 60 ksi. The compression strength of sand and gravel concrete was nominally 4000 psi, varying from 3740 to 4680 psi among standard cylinders broken on the same day as the test of the specimen with which each cylinder was cured.

Forces in selected reinforcing bars during the various tests were monitored by means of electric resistance strain gages bonded to the bars before concrete was cast.

Test Results

Flexural failures occurred eight times in flanges and six shear-compression failures developed in beam webs. For four tests, stirrups yielded enough to indicate failure as hangers. One shear-friction failure was observed in a flange at the face of the beam web, and there were two web "shear" failures after diagonal cracks penetrated to the compression face of the web.

Attempts were made to describe analytically the resisting forces on structural components under observed failure conditions. By means of such analyses, failure mechanisms useful for design could be established. Records of crack propagation together with the measured strains from reinforcing bars helped indicate load paths for the various tests.

Conclusions

Tests of full scale specimens indicated that

(1) Brackets reinforced with horizontal bars for flexure and with supplementary horizontal reinforcement parallel to flexural steel near the third point of the bracket depth (Fig. 2a) performed as well as brackets that were reinforced with a diagonal bar extending from the lower exterior edge of the bracket diagonally upward toward the center of the T-beam stem (Fig. 2b).

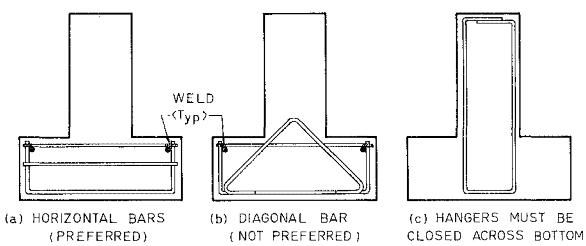

Fig. 2. Bracket reinforcement.

(2) Stirrups in the stem of the T-beam act as hangers to deliver bracket loads into the flexural compression region of the T-beam stem. The stirrups must be able to develop by bond the tension force each must sustain. Since most flanges have a depth inadequate for the development of the stirrup bar forces, hangers should be closed across the bottom of the T-beam, as shown in Fig. 2c.

(3) The practice of welding bracket flexural steel to an anchor bar parallel to the longitudinal axis of the T-beam provided anchorage adequate to develop the yield strength of the flexural steel in the top of the bracket.

Conclusions derived also from test data for one-third scale specimens include

(4) The width of bracket that can be considered effective in flexure caused by a concentrated load should be no greater than the width of the bearing plus five multiples of the distance a between the face of the web and the center of the bearing (see Fig. 3). Near the longitudinal end of a flange, the effective width of flange for flexure cannot be greater than twice the distance c from the end of the flange to the center of the bearing. See Fig. 3b.

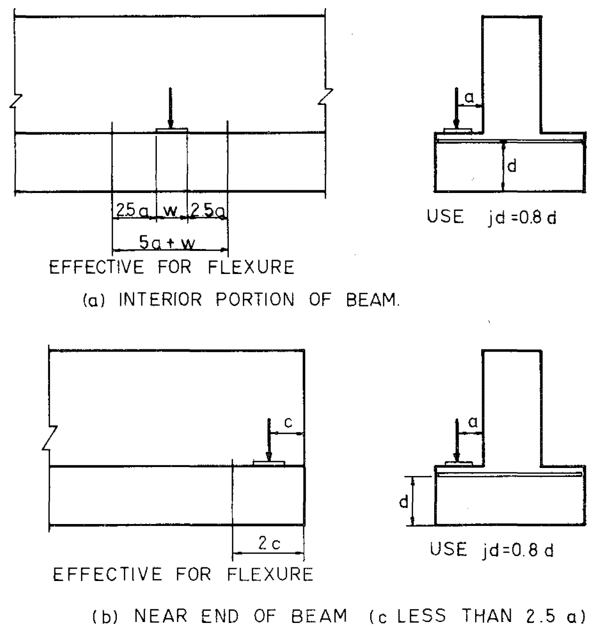

Fig. 3. Effective width of bracket for flexure.

(5) For flexural calculations of bracket reinforcement, the effective distance jd between the centroid of compression and the centroid of tension should be taken as 0.8d.

(6) The depth of bracket d required to fulfill shear friction requirements should be taken no less than

$$d_{min} = 1.5V_u/af'_c \qquad (1)$$

V_u = ultimate load applied to bearing plate

f'_c = design compressive strength of standard concrete cylinders

Equation (1) is determined on the basis of the shear friction capacity of concrete over an effective width of 4a plus the width of bearing. Within the effective width an area of reinforcement A_{vf} must extend into the flange in order to maintain the shear friction force.

$$A_{vf} = V_u/1.2f_y \quad (2)$$

f_y = yield strength of reinforcement

(7) Stirrups should be designed to resist all ultimate shears above those resisted by concrete. For design purposes it is not necessary to superimpose loads on stirrups acting as hangers and loads on stirrups acting as shear reinforcement.

(8) At every concentrated load applied to the flange of an inverted T-beam stirrups must be provided to act as hangers within a web depth d centered about the concentrated load. The capacity of hangers must be greater than the applied ultimate load.

The full text of Research Report 113-4 can be obtained from R. L. Lewis, Chairman, Research and Development Committee, Texas Highway Department, File D-8 Research, 11th and Brazos Streets, Austin, Texas 78701 (512/475-2971).