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Forces In Beam-to-column Connections

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by

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Abstract

Forces on the detail components of three types of beam-to-column connections are analyzed employing a new approach using a linear structural analysis program and beam-type elements. The key to the procedure is use of dummy rigid members to space angles or plates fastened to the outer surfaces of beam or column at the proper distance from member centerlines. Use of correct coordinate geometry results in better equilibrium calculations. Realistic values for stiffness of joint components as well as main beams and columns provide for determination of displacements. The dummy rigid members serve to invoke the plane-sections-remain-plane concept of typical mechanics of materials solutions.

For a weak axis beam-to-column moment connection, top-and-bottom horizontal connection plates provided for moment resistance are found to carry about 50 percent of the total vertical shear. As a result, serious bending occurs both out of the plane of the plate and in the plane of the plate, also adding to forces on edge welds.

In a top-and-bottom tee-stub connection, bolts in the vertical legs of the tee-stubs are found to be pulled inward toward the tee stem in the top tee and pushed outward in the bottom (compression) tee.

Top angles of a top-and-seat-angle connection are found to carry from 50 percent to 84 percent of the vertical shear on the end of the beam, in contrast to some design methods which assume that only the seat angle carries vertical load.

From the results of this type of study, rules of thumb could be modified or developed to permit design of appropriate connections without requiring a computer analysis for every problem.

1 Introduction

As part of the preparation for an experimental program on connections, several analyses were conducted on three types of beam-to-column connection details. Schematic diagrams of the resulting force distributions reveal some interesting findings.

2 Model of Connection Details

In the design of structural connections, it is valuable to have information on the forces in the detail material added to enable connecting the major members, i.e., continuity plates, shear tabs, angles, stiffeners and fasteners. Usually assumptions of forces are made in order to allow the application of routine mechanics of materials. This method, however, provides very little chance of discovering unexpected force paths. On the other hand, the application of finite element methods with large numbers of miniscule geometric shapes, amounts to overkill with reams of excess information.

A compromise can be made using ordinary linear structural analysis programs and modelling the added detail materials as complete beam or truss members with the appropriate geometry and stiffness for the complete member. Since the main structural members are modelled as one-dimensional "sticks", the trick is to position the connecting elements at the correct distance away from the centerlines of beams and columns so that their forces will be invoked with proper leverage (Fig. 1). Dummy rigid members inserted between beam or column centerline and the points of attachment of detail material will enable the proper equilibrium to be invoked while engaging the real stiffness of the detail material. Since the dummy members displace with the deflection or rotation of beams and columns, the concept of "plane sections remain plane" is preserved. Procedures fro executing this concept were presented by (Driscoll, 87a).

3 Structural Assemblages

In order that the connected structural members will apply the proper combination of forces to a connection model, realistic structural assemblages must be assumed. Two assemblages were assumed in the examples studied: a single-bay, two-story frame, and a cantilever beam connected to a mid-height of a column fixed at its top and bottom. In the single-bay two-story frame, the connection to be studied is at each end of a beam located at the top of the first story and subjected to a central vertical concentrated load. Connections ranging from fully-rigid to pin-ended may be studied using this model. The model may be cut in half by the application of symmetry when only vertical loads are involved. The cantilever beam model stimulates a test setup recently used in cyclic loading of weak axis moment connections.

4 Weak-Axis Beam-to-Column Moment Connection

A weak axis beam-to-column connection tested by Heaton provides the first case (Heaton, 987b). Field bolts connect the beam web to a web plate while full penetration groove welds connect the beam flanges to flange connection plates. All of the detail material is fillet welded to the column flanges and web. The linear forces V and the bending moments VL on the separate parts are shown in exploded view of the connection (See Fig. 2.). The top and bottom connection plates carry the expected large normal forces from the beam flanges to the column flanges and web. In addition, each of the connection plates carries a vertical force of about 36 percent of the vertical shear V of the beam. In each horizontal plate about two-thirds of its vertical shear is transmitted to the column flanges at the edges of the plate, and the remaining third passes into the web plate as a vertical bearing force. The net effect is that about half the beam shear passes to the column web from the web plate and the edges of the horizontal connection plates. The other half passes to the column flanges through the side edges of the horizontal connection plates.

This information about forces can provide some guidance in the proportioning of plates and welds for such connections.

5 Tee-Stub Connection

As a semi-rigid connection, the tee-stub connection approaches a fully rigid moment connection. Tests on such connections are planned in the ATLSS Engineering Research Center ((Chasten, 1987)). The force distribution depicted in Fig. 3 represents a stage of loading at the limit of elastic range. The overall moments for the structures are shown in the moment diagram and they are essentially the same as would be obtained with fully rigid joints. (Some obvious information is omitted to reduce clutter.)

The forces on the beam in the vicinity of the connection are carried out into the horizontal stems of the two tees. A large couple with horizontal forces 2.72 times the beam shear makes up the axial forces in the two tee stub stems. The vertical shears carried into the tee stems are each approximately half of the beam vertical shear. Very small bending moments are also imposed on the tee stems, but they approach the maximum bending capacity of the stems.

The horizontal forces passed from the tees to the column pull at the top and push at the bottom as would be expected. However, an interesting combination is noted in the vertical forces. On the top tee, the vertical forces in the tee flanges are both in tension, with 0.73V upward and 0.23V downward with a net effect of 0.5V upward. The sketch labelled TEE BENDING shows that deformation could be expected to cause an inward pull against the fasteners. The reverse situation occurs on the bottom tee which is in compression. The vertical forces on the tee are both inward toward the stem, but their net vertical resultant is the appropriate half of the beam shear acting upward on the beam.

6 Top-and-Seat Angle Connection

The top-and-seat angle connection (without a stiffened seat) was analyzed in the elastic range and step-by-step up to ultimate load (Driscoll, 87a). It was studied in the two-story single-bay frame assemblage. A series of connections of similar type are proposed to be tested in the ATLSS Center (Chasten, 1987).

Surprisingly, in the elastic range (See Fig. 4.), the top angle carried 84 percent of the beam vertical shear while the seat angle carried 16 percent. As the load increased, redistribution of forces increased until both top and seat angle each carried 50 percent of the vertical shear (Fig. 5). As the load increased, the axial force in the beam increased from 0.04V to 1.04V because of the bearing of the heel of the seat angle on the column flange caused by rotation of the beam ends.

7 Conclusions

- The studies reported here provide information that is probably accurate enough for use in proportioning fasteners and details of connections for design.

- Rules-of-thumb could be developed or modified to permit design without conducting the computer analysis for every problem.

- On the other hand, the method requires few enough added node points in a line-type structure that it could be feasible to model an entire structure with some semi-rigid connections.

- This admittedly crude analysis can provide valuable guidance in the interpretation of results from "serious" finite element solutions.

Better knowledge of the behavior of connections will help in the understanding of the performance of structures and in the development of innovations for design of the structures of the future.

Acknowledgements

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Figures

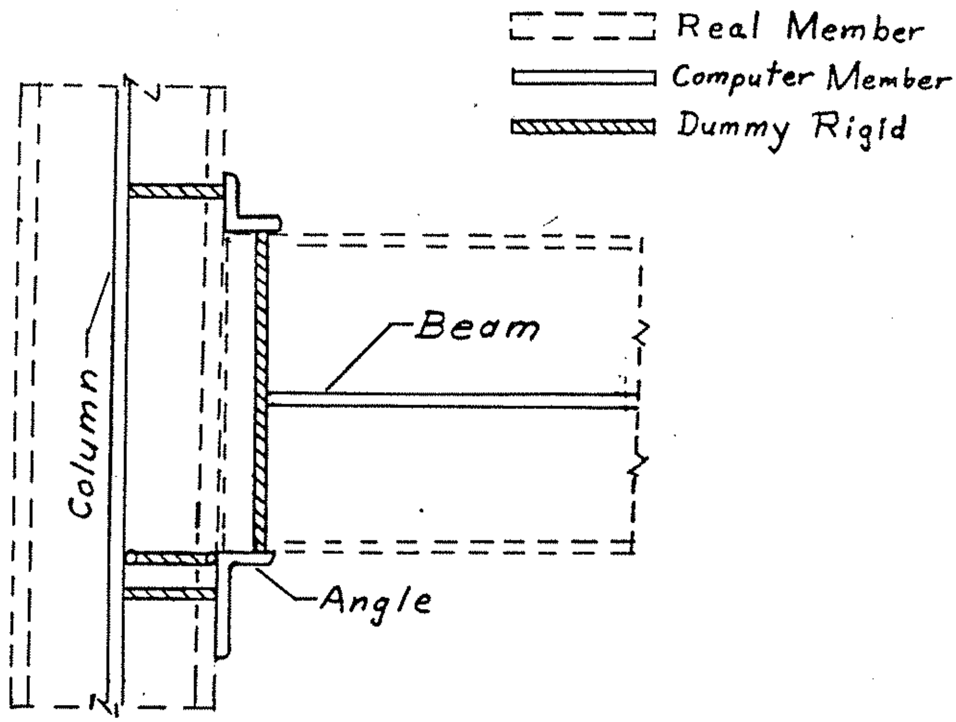

Figure 1: Dummy Rigid Members Space Connection Details for Proper Equilibrium

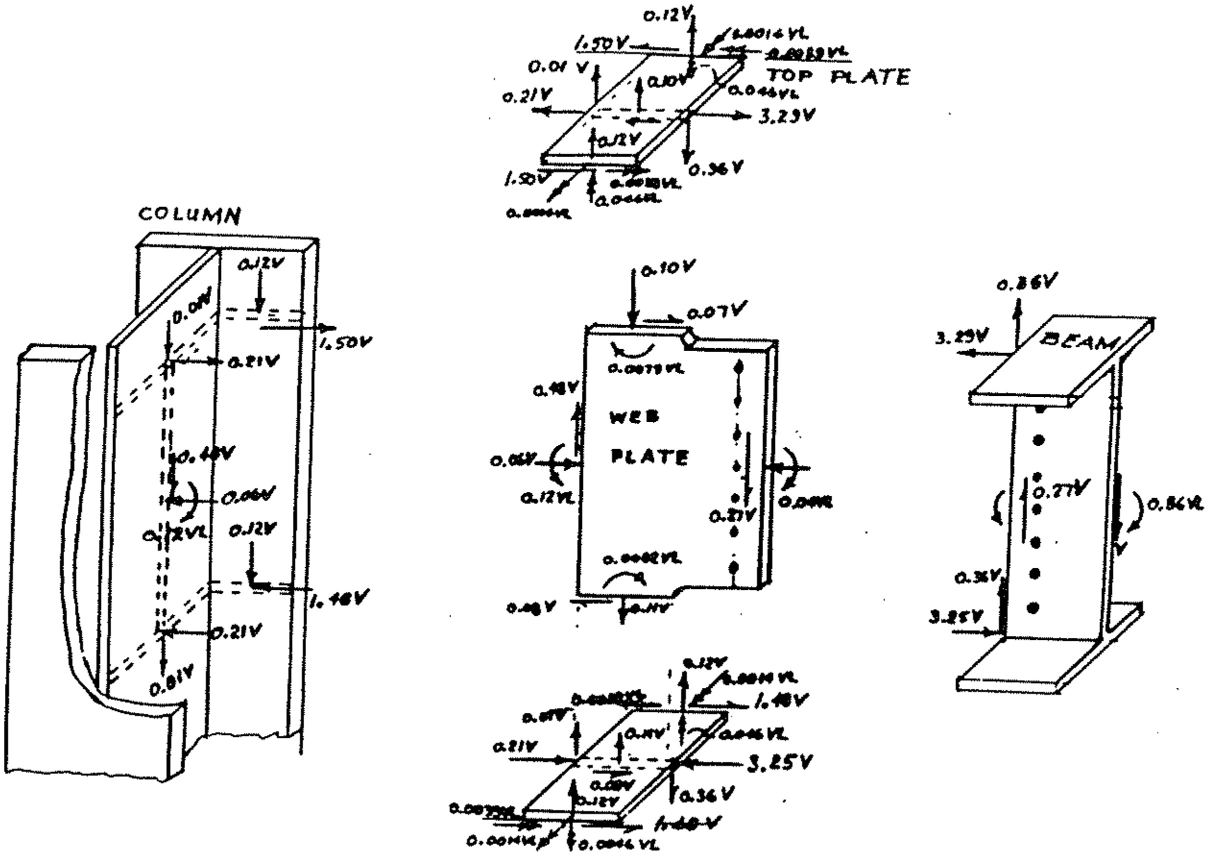

Figure 2: Exploded Diagram of Connection Showing Member Forces

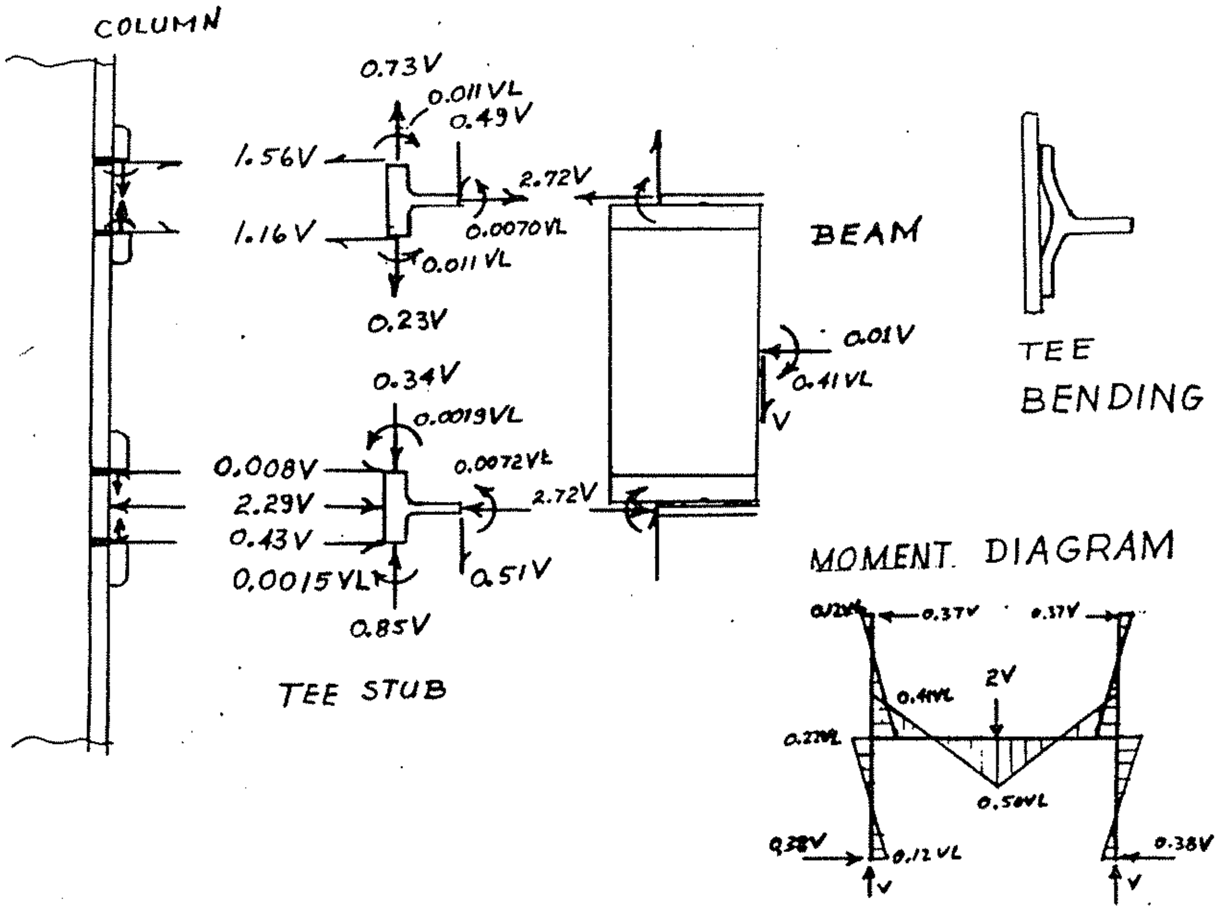

Figure 3: Forces on Tee-Stub Connection

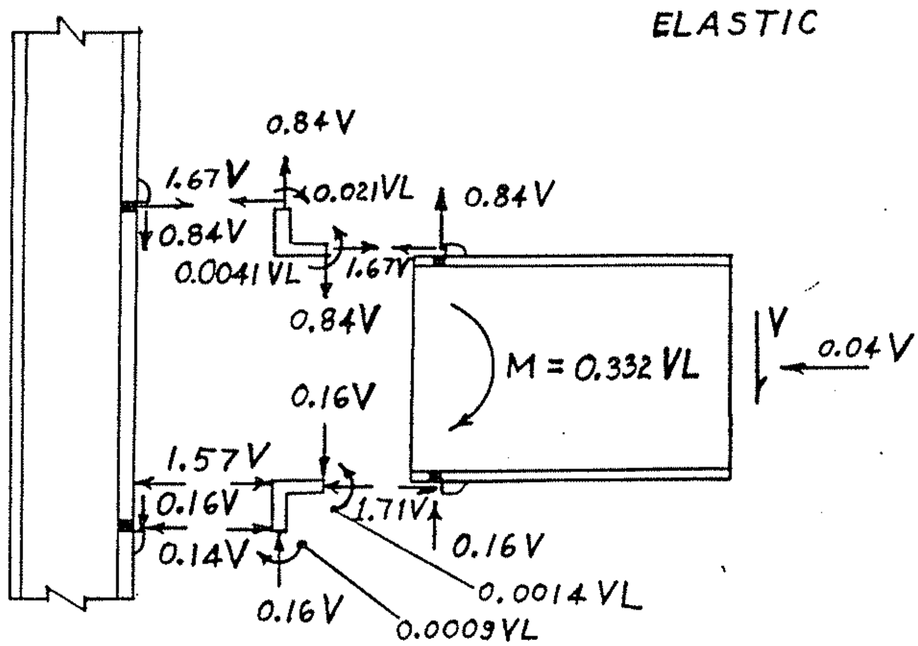

Figure 4: Elastic Forces on Seat-and-Top-Angle Connection

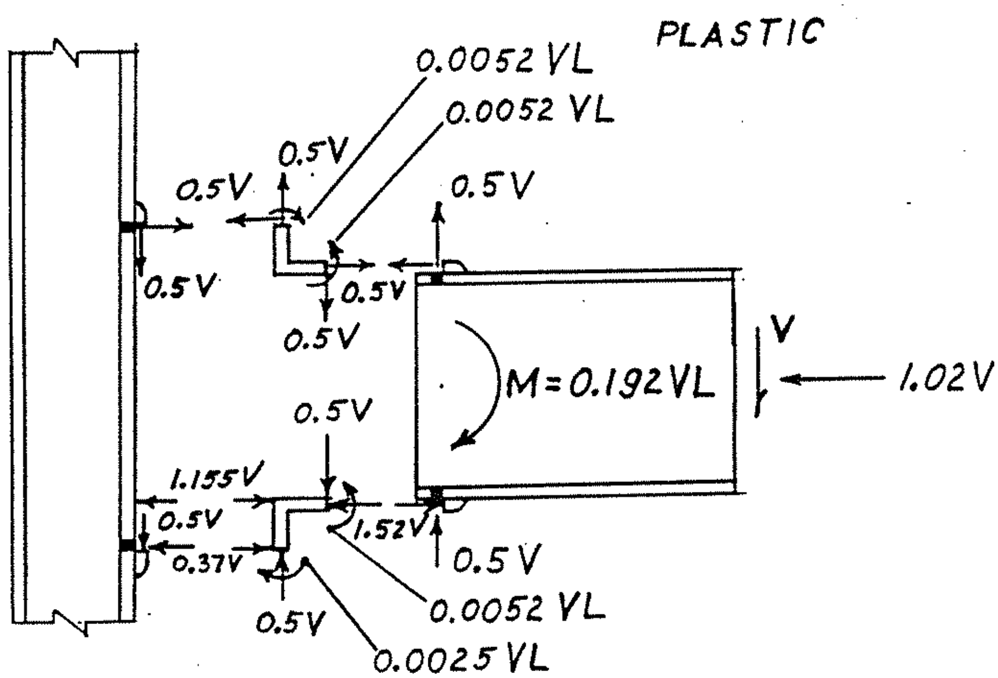

Figure 5: Plastic Forces on Seat-and-Top-Angle Connection