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PROPOSAL FOR TESTS OF FULL SIZE BEAM-TO-COLUMN CONNECTIONS SUBJECTED TO MOMENT, SHEAR, AND HIGH AXIAL LOADS

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1. INTRODUCTION

The work done on the analysis of beam-to-column connections before 1962 did not take into consideration the combined effect of shear, axial load and moment. It should be expected, however, that the high axial loads, which occur in the lower parts of multi-story frames, affect the behavior of the connections considerably. In fact, during tests on subassemblages of multi-story frames it was observed that the shearing deformation of beam-to-column connections was largest for the connections with the highest axial loads, though the shear forces and the moments were equal for all connections.[1]

Some of the connections tested had diagonal stiffeners to resist shearing deformation. In some of these connections tested under a relatively high axial load, yidlding occurred in the stiffener before the plastic moment in any of the adjacent members had been reached.

The current AISC design specifications, however, do not take into consideration this influence of the axial load on the behavior of beam-to-column connections.

1.1 Past Work

The first study to include these effects was done at the University of Tokyo by T. Naka et al.[2] This project was limited to the elastic range.

In 1966 a research project on the behavior of beam-to-column connections was initiated at Lehigh University sponsored jointly by the American Iron and Steel Institute and the Welding Research Council.

A series of 7 pilot tests on small size beam-to-column connections, salvaged from earlier tests on multi-story frames was done. Special attention was given to the behavior of the specimen subassemblages in the plastic range. This series of tests included unstiffened connections and stiffened connections with diagonal stiffeners in compression or tension. At the same time a theoretical study was started, including both upper and lower bound solutions. The results of the series of experiments and of the theoretical work have been reported.[3] A report describing recent progress on theoretical work is under preparation.[4] Both the test results and the theoretically derived expressions show a considerable influence of the axial load in the column on the behavior of the connection. Therefore a modified design procedure which takes care of this effect has been suggested.

On the basis of the results of the series of pilot tests done last year and of the theoretical work, a list of recommendations for future work on this topic has been assembled.[3] One of the major points of these recommendations was to investigate both theoretically and experimentally the influence of the size of a connection on its behavior.

Therefore, tests are needed on connections of practical size
to check the theoretically derived expressions for the influence
of the dimensions on the behavior of the connections. In particular,
the influence of the thickness of the flanges of the column on the
resistance against shearing deformation of the connection should be
investigated. On the basis of the theoretically derived expressions
a considerable influence must be expected for heavy columns. The
information obtained from these tests on full-scale connection sub-
assemblages, and the results of the theoretical study will then be
used to evaluate the present design formula, and, if desirable, to
develop an alternative design method.

In the following chapters of the report, a pilot test is pro-
posed for a series of tests on full-scale connection subassemblages.

Objectives of this pilot test are to check, and, if necessary,
to improve the following items:

1)   The geometry of the connection subassemblage to be tested.

2)   The test setup

3)   The instrumentation

4)   The test procedure.

The experience obtained, from this pilot test on a full-size
specimen and from the previous series of tests on small-sized
specimens will be used for the final preparation of the series of
tests on full-size specimens, to be executed during spring 1969.

2. THE GEOMETRY OF THE CONNECTION SUBASSEMBLAGE

2.1 The Choice of the Members

The test is to be made on a connection subassemblage consisting of an appropriate combination of a beam section and a column section. The choice of members in the connection subassemblage is to be based on theoretically derived interaction curves for the thrust and the bending moment applied to the subassemblage. These curves consisted of a number of upper bound and lower bound solutions for the failure of connection subassemblages. The upper bound solutions are based on several assumed mechanism patterns. An envelope of the solutions is plotted to form a shaded area in Fig. 1. The functions are plotted in terms of P/P_y the ratio of column thrust to yield thrust, and $(M/M_p)_{col}$ the ratio of column moment to its plastic moment. The solutions are compared with a line defining the failure solution implied by the plastic design provisions of the 1963 AISC Specification. A report on the theoretical derivation of the solutions is under preparation.[4]

A test connection designed to observe the phenomena of interest during connection failure should satisfy the following conditions:

1) No failure should occur in the beam.

2) No failure should occur in the column outside the connection.

3) The beam and the column should form a connection of a realistic shape and size.

The first condition requires a beam with a sufficient plastic modulus. This plastic modulus must be found in the thickness of the flanges rather than in the depth of the beam. An increase of the depth of the beam would increase the strength of the actual connection proportionally, so that the danger of a failure in the beam before the connection fails is not diminished. The safety factor against failure outside the actual connection must be ample, since strain hardening has not been taken into account in deriving the interation curve for the connection. Therefore, of beams with equal depths, only those with the largest thickness of the flanges have been taken into consideration.

As can be seen in Fig. 1, the interaction curves for the actual connection and for the column outside the connection are very close for relatively high P/P_y ratios. This is not appreciably influenced by the size of the column. Therefore, in order to diminish the danger of failure in the column outside the connection before the actual connection fails, the P/P_y ratio must be kept smaller than 0.6.

The combination of beam and column must be realistic. Though the forces on the specimen subassemblage must leave an ample safety margin during the pilot test, they must be large enough to make a proper evaluation of the behavior of the test setup possible.

It is expected, that a connection subassemblage consisting of a 24WF160 beam and a 14WF184 column will fulfill these requirements satisfactorily.

2.2 The Geometry of the Connection Subassemblages

The geometry of the specimens of the previous series is shown in Fig. 2. It was satisfactory except for the following points:

1) Local buckling occurred in both the beams and the columns.

2) The length of the column was too short. As a result, the shear force in the column was high and cancelled out a large part of the shear force in the connection.

These two factors generally caused failure of the connection subassemblage outside the actual connection. The AISC design formulas have been used to check for local buckling during this test. It is expected that the shear force in the column will be reduced sufficiently by taking a length of the column between inflection points of 10'.

The length of the beam may be determined later. Factors in this decision are the capacity and stroke of the available jack, and the difference between the axial loads in the top and bottom parts of the column.

Except for these changes, the geometry of the specimen of the pilot tests is similar to the previously tested specimens. Horizontal stiffeners will be applied according to the AISC design specification.

2.3 The Test Set-Up

The proposed test set-up is shown in Fig. 3. The axial load
in the column will be applied by a 5,000 kip universal testing
machine. The moment will be introduced into the connection by a
tension jack on the beam. Thus the loading condition of a floor
load on a frame is imitated.

It would be preferable to equip the specimen with pin-ends.
This would improve the stiffness of the specimen and more certainly
give the desired stress distribution. For the subassemblage to be
tested as a pilot test, the shear force at the ends of the column
would be in the order of 130 kips, while for heavier column shapes
these forces may reach 400 kips. In the past months an extensive
study has been made of the possibilities of adapting the pin-end
fixtures available at Fritz Laboratory for these forces, or to
obtain the desired pin action by other means, within the financial
limits of the project. No satisfactory solution has been found
however. Therefore the subassemblage column will have fixed ends.

The head of the testing machine would probably be jammed by the
large horizontal shear force in the column. Therefore the top end
of the column will be supported by a heavy beam with the strong axis
in the horizontal plane, which will conduct this force to the
columns of the testing machine (Fig. 3). The bottom end plate of
the column simply will be bolted down to the testing machine table.

3. INSTRUMENTATION

Each specimen will be instrumented with electrical resistance strain gages at locations on the flanges of the column and the beam and the horizontal stiffeners   Rosette gages will be used for the web panel of the connection, and the webs of beam and column near the face of the connection (Fgi. 4).

Special care will be given to the instrumentation of the column, in order to be able to observe the influence of the difference in the axial load in the upper and lower parts of the column.

The same type of gages (SR4) will be used as in the previous series of tests. These gages make it possible to obtain strain readings well into the plastic region. The reading in the plastic region however is only of qualitative value due to local effects.

The absolute rotations of both the top and bottom end plate of the column and of the end of the beam will be measured by 20" level bars. The rotations of the top and bottom parts of the column and beam relative to each other will be measured by a system similar to that used in the previous test series.[3] (Fig. 5). This system consists of rods which are spot welded to the web of the member at a short distance from the joint. The displacements of these rods relative to each other, will be measured by wires, which are stretched between one rod and a dial gage mounted on another rod. From these relative displacements the rotations can be calculated.

The diagonal displacements of the web panel of the connection will be measured in a similar way.

The deflection of the end of the beam will also be measured using a wire stretched between a dial gage mounted on the beam and the surface of the machine. Also, the relative deflections of the flange of the column in the connection opposite the beam will be measured by dial gages. This may give some additional information about the failure mechanism of the connection.

The beam load applied by the hydraulic jack will be measured by a dynamometer.

4.   THE TESTING PROCEDURE

Figure 3 shows a connection subassemblage ready to be tested. First the specimen will be aligned, for which the gages at the four flange edges at both the top and the bottom of the column will be used. Alternatively, the location of the specimen in the universal testing machine will be adjusted and a small moment will be applied to the subassemblage in order to take the slack out of the end fixtures.

Then the axial load on the column will be built up gradually to about 0.5 P_y. The ratio P/P_y is to be kept relatively low, since for a higher axial load the interaction curves for the specimen column and for the actual connection are very close. Therefore for a P/P_y ratio larger than about 0.65 failure may occur in the column outside the connection. A test in this region would not provide information about connection strength.

After the desired axial load in the column is reached, the beam load will be applied in steps. After each load increment the axial load in the column will be adjusted to the desired value. The beam deflection will be observed until it appears to be constant, which will be taken as an indication that a stable state has been reached.

Then all gages will be read. This procedure will be repeated for each load increment.

5. SUMMARY

The results of theoretical studies of welded beam-to-column connections show a much higher ultimate strength than indicated by the current design criteria. Also, high axial loads are expected to have a considerable effect on the behavior of this type of connections. This effect has not been taken into consideration by the present design method. In order to check the theory and to obtain more information about the behavior of the connections in the plastic range, tests are needed.

In this report a pilot test is proposed on a full-size beam-to-column connection. The results of this pilot tests will be used in the preparation of a series of tests on connections of practical dimensions.

6. <u>FINANCES</u>

The regularly contracted funds furnished for this project by the American Iron and Steel Institute through the Welding Research Council will be used for this pilot test.
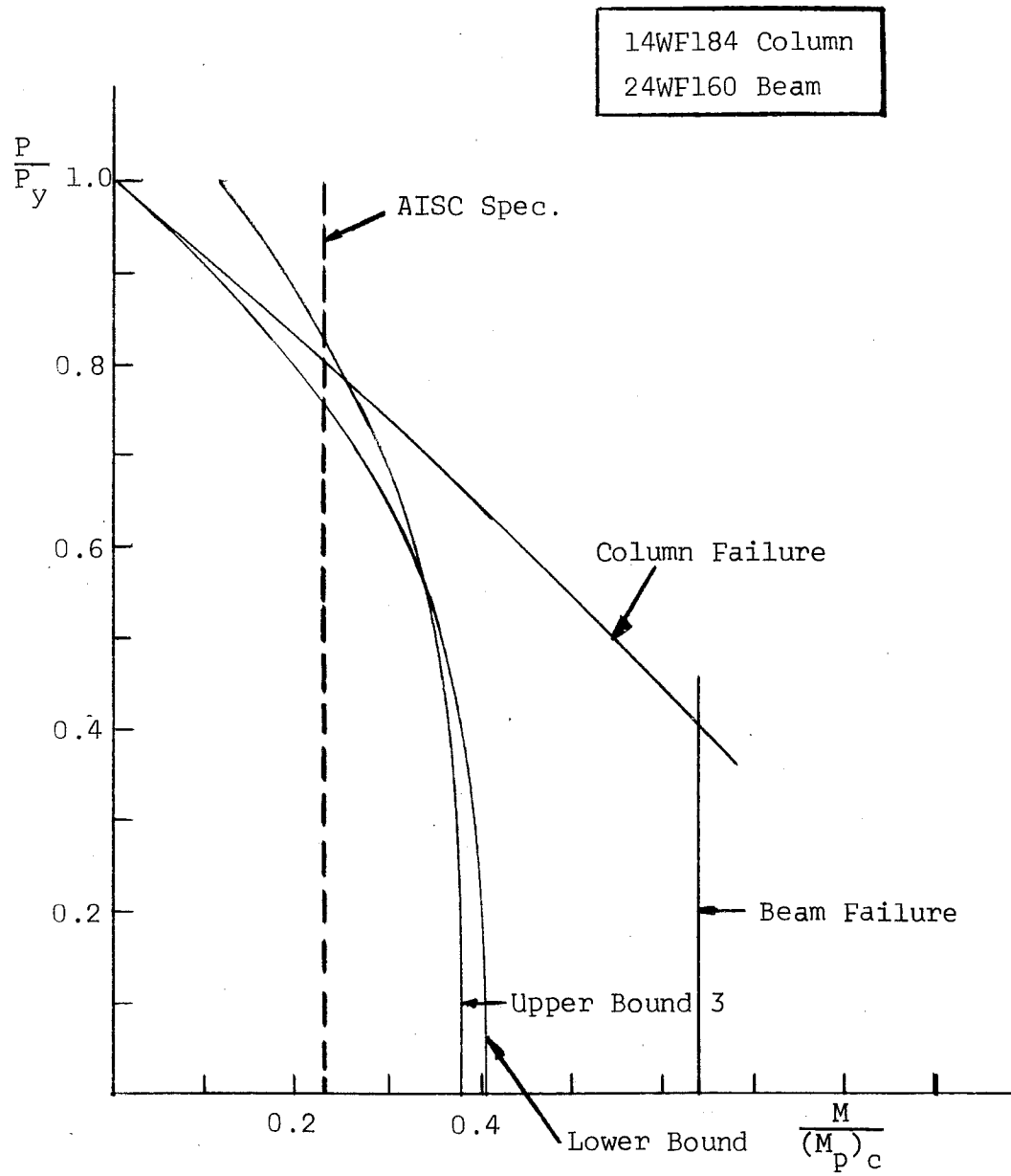
7. <u>FIGURES</u>

Fig. 1   Envelope of Theoretical Upper Bound and
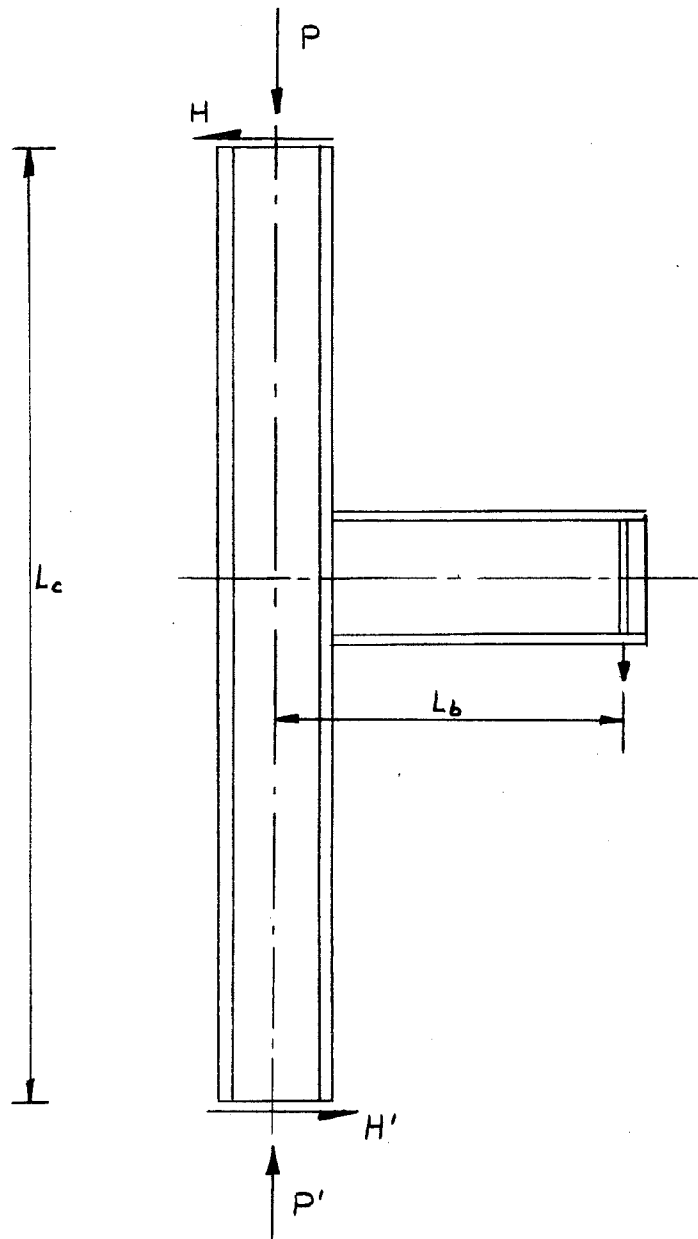   Lower Bound Curves for a Connection

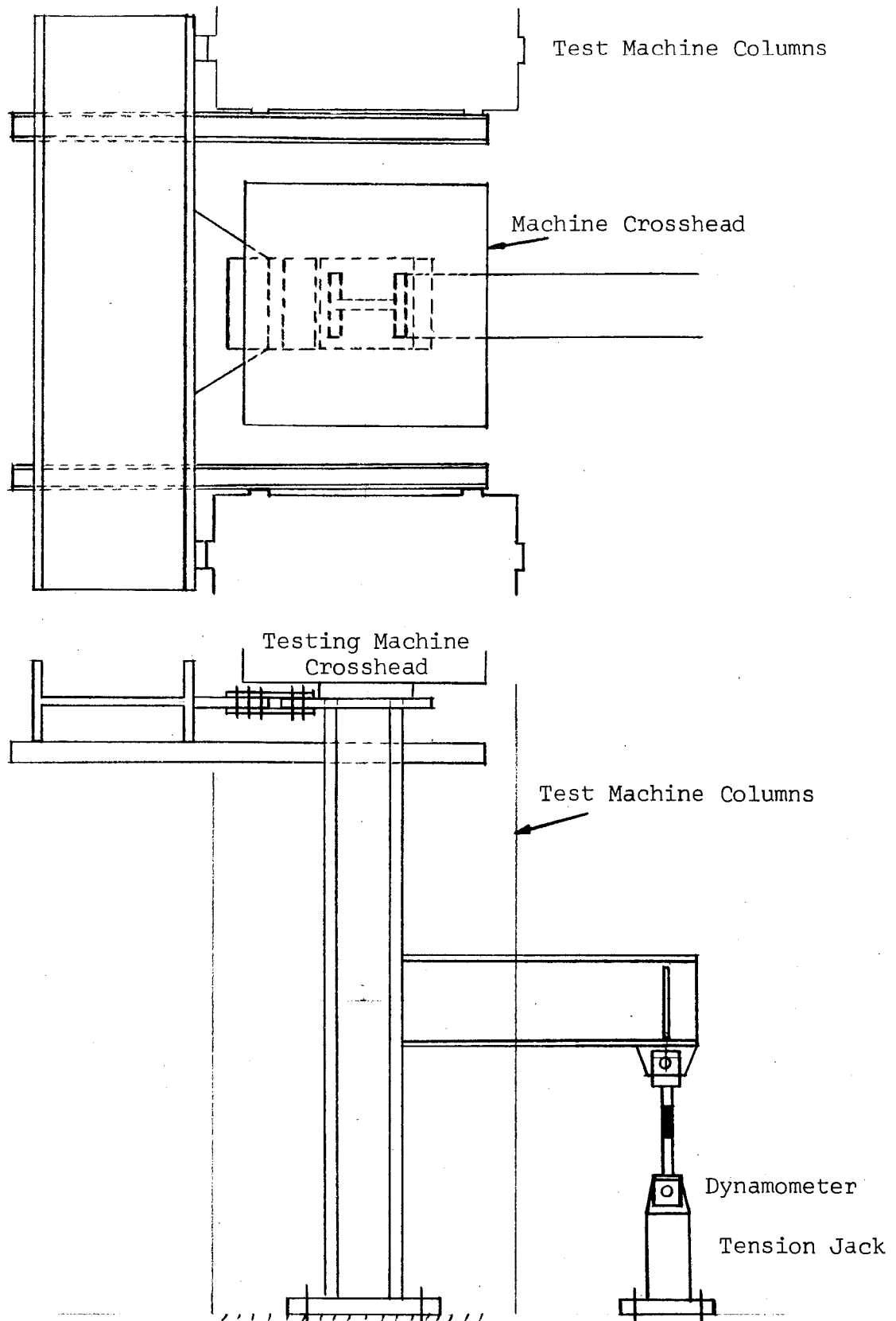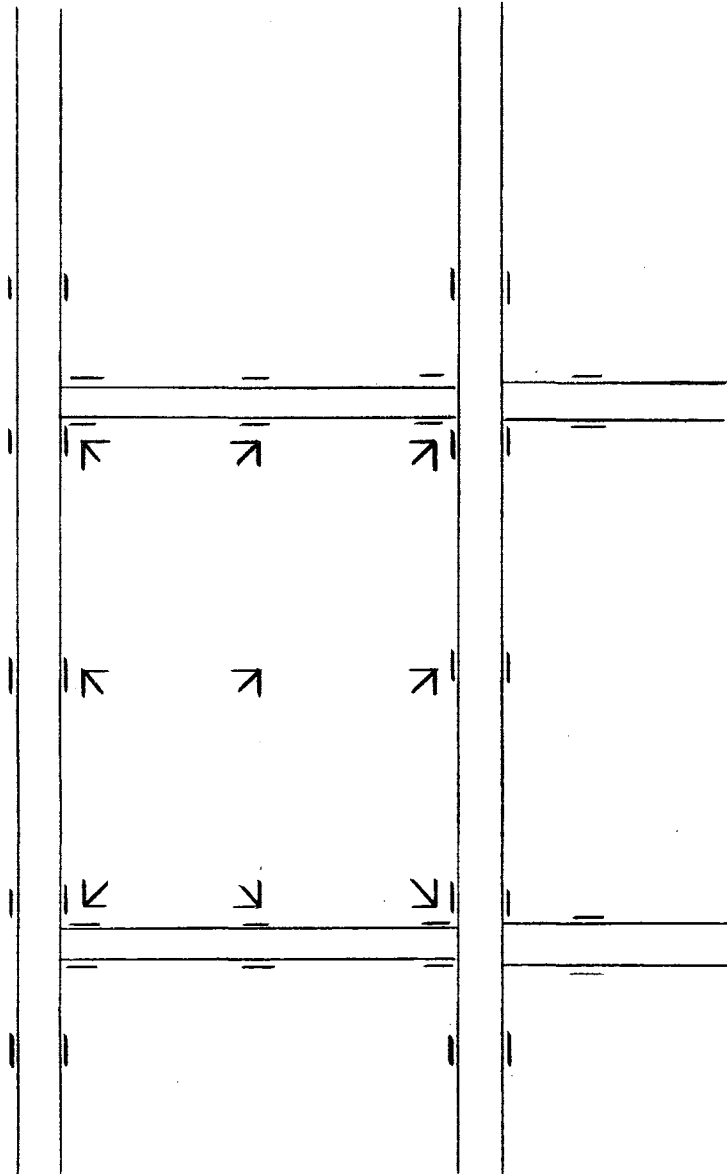Fig. 2 Geometry of Specimens in Previous Test Series

Fig. 3 Proposed Test Setup

| Uniaxial strain gage

↙ Rosette strain gage
   (other side of connection has identical
    number and locations of gages)

Fig. 4 Electrical Strain Gage Locations

Fig. 5   Web Panel Rotation Gages

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