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Composite Assemblages Under Lateral Load

TECHNICAL PROPOSAL NO. 1

COMPOSITE ASSEMBLAGE EXPERIMENTS

by

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1. Problem Statement

Experience with plastic design of unbraced multi-story steel frames indicates that although strength requirements are easily achieved, reasonable working load drift limitations often cannot be met due to the relative lateral flexibility of such frames. To meet working load drift limitations steel beam sizes must be increased sometimes by a factor of two or more.

The work of AISI Project 173(1,2,3,4) shows that unbraced multi-story composite frames, by taking into account the composite action of the floor slabs, should largely overcome this problem. Many composite frames, due to their increased stiffness under lateral loads, should be able to meet drift requirements with no increase in steel, even sometimes with a small reduction in steel, while still maintaining the required strength.

In Ref. 3 a general method for analyzing unbraced multi-story frames with composite beams was developed. In order to formulate design recommendations for unbraced composite frames it is now necessary to check the proposed method by testing two one-story composite assemblages.

The proposed composite assemblages are similar in size to the steel assemblages SA-1 and SA-2 of AISI Project 150 so that the experimental results can be compared(5).

2. Background and Significance of the Work

To determine the approximate second-order elastic-plastic behavior of a story in an unbraced multi-story frame the sway subassemblage method of analysis was developed(6). In the method, a story called a one-story assemblage is isolated from the frame as shown in Fig. 1. The lateral load vs. drift curve is then determined by a superposition of the load-drift curves of each subassemblage in the one-story assemblage.

An extensive program of experiments was conducted in AISI Project 150 to verify the subassemblage theory for steel assemblages. The tests showed a good agreement of the predicted behavior with the experimental behavior of the assemblages.

In order to extend the sway subassemblage theory to composite frames a test series of composite beam-to-column connections were carried out(1,2). A significant increase in strength and stiffness due to the concrete slab was found at the composite beam-to-column connection. Based on these results a method for analyzing unbraced composite multi-story frames was developed(3). The method includes the effects of the reinforcement, the flexibility of the shear connector, discontinuities in the floor slabs and cracking of the concrete slabs. Example problems analyzed in Ref. 3 show that the floor slabs can significantly increase the maximum strength and stiffness of the bare steel frame. Consequently, substantial savings in steel weight should be possible by including the composite action of the floor system in the design of the steel frame to resist wind loads.

As it was earlier considered necessary to test one-story steel assemblages and compare the test results with the predictions obtained from a sway subassemblage analysis, it is now important to obtain experimental results from composite assemblages. The experiments will yield the complete lateral load vs. drift behavior of a one-story composite assemblage and show the increase of strength and stiffness through composite action.

Based on the results of the proposed tests and on the work of Ref. 3, it will be possible to formulate design recommendations for unbraced frames with composite beams under combined lateral and gravity loads.

3. Objective

The objective of the first phase of this project is to analyze and test two composite one-story assemblages under lateral load. The assemblages simulate the behavior of a story in an unbraced composite multi-story frame. The two composite assemblages CA-1 and CA-2 have identical steel frames, but CA-1 has a solid slab while CA-2 has a slab with metal deck.

The objective of the second phase of the project is to develop specification recommendation for composite frames.

This workplan describes in detail the work of phase 1.

4. Work Plan

4.1 Description of Composite Assemblages CA-1 and CA-2

The composite assemblage CA-1 consists of three columns and two composite beams forming two equal bays of 15 ft. and a story height of 10 ft. as shown in Figs. 2 and 3. The column shapes are W8 x 28 A36 steel for the exterior columns and W8 x 48 A36 for the interior. The two composite beams consist of a 6'-6" x 3½" reinforced concrete slab connected to a W10 x 19 A36 steel beam by means of 5/8" diameter shear connectors. All sections are oriented for strong axis bending. The column tops are connected by a pinned strut designed to maintain a nearly constant distance between the column tops as shown in the figures. The columns are supported on roller bearings. Each column is braced at the top and at the level of the beams by means of specially designed lateral bracing. The bracing prevents lateral movement of the test specimen but does not offer restraint to in-plane movement. The braces are attached to an independent supporting frame. No lateral bracing is provided for the steel beams, as the concrete slab prevents any lateral movement of the beams. The reinforcement of the slab is shown in Fig. 4a.

Vertical loads are applied approximately at the quarter points of each composite beam through a spreader beam which is attached at its midpoint to the tension jack of a gravity load simulator as shown in the schematic Fig. 5. The concentrated beam loads approximate a uniform gravity load. The amount of the beam loads is chosen so that the lateral service load is in reasonable proportion to the stability limit load. Larger beam loads would cause a premature plastification of the beam section adjacent to the leeward end column.

Horizontal drift increments are applied at the top of an exterior column by a mechanical screw jack mounted between the test specimen and the independent supporting frame. (Fig. 5)

The assemblage CA-2 is identical to CA-1 with the exception that the 3½" solid slab is replaced by a 4 in. concrete slab on formed metal deck with 1½" deep ribs running transverse to the steel beam as shown in Figs. 4a and b. The deck selected is one of the standard types in commercial use. Details of the deck are also shown in Fig. 6. A small area of the deck in front of the beam-column connections is flattened to provide full depth of concrete as recommended in Ref. 2. Transverse ribs as opposed to longitudinal ribs were selected since analysis indicates that a larger difference from solid slab behavior will result.

The slab width of both assemblages were selected as large as possible within the limits of the test bed, so that the problem of the equivalent slab width can be studied in detail(3).

The shear connectors are designed for full composite action according to the AISC specifications(7).

Some dimensions of assemblages CA-1 and CA-2 (e.g. bay width, story height) are the same as in assemblages SA-1 and SA-2 of AISI Project 150(5). This facilitates both the comparison of the test results and the use of the same test equipment.

Unlike the tests of SA-1 and SA-2 no column axial loads are proposed for the tests of CA-1 and CA-2. The behavior of the composite beams in the composite assemblage is the main concern in this investigation. The assemblages were therefore designed so that no plastic hinges would form in the columns. The effect of axial load and PΔ moments on assemblage behavior was thoroughly studied in AISI Project 150.

Although column axial loads could be considered in this investigation it is not recommended for two reasons.

1. The resulting test set-up is greatly simplified.

2. The composite beam behavior will be the same regardless of whether the beam bending moments arise from a combination of lateral load plus PΔ moments or from lateral load moments alone. As column axial loads increase, the lateral loads are reduced. Experience with the tests in AISI Project 150 indicated that as the lateral loads decrease, the experimental error in measuring the lateral load increases because of the sensitivity of the PΔ moments and the consequent effect on the measured lateral load to frame distortions. The two composite assemblages were designed therefore so that the measured lateral loads would be large and the PΔ effect arising from the vertical beam loads would have a minimal effect on the lateral loads. The analysis of the assemblages and the expected results discussed in Art. 4.4 include the PΔ effects due to the beam loads.

4.2 Instrumentation

The instrumentation used in the tests will provide strain data to calculate the applied loads, determine deformations and calculate the internal stress resultants in the assemblages. Calibrated dynamometers are used to measure the applied loads.

Figure 7 shows the instrumentation of the steel beams and columns. Four SR-4 electrical resistance strain gages are used at each instrumented cross section, two on each flange. Five cross-sections are gaged on each beam and each column is gaged above and below the beam-to-column connection. Two displacement gages are used to measure the drift at the top and at beam level of an end column. The joint rotations are measured using electrical rotation gages.

Figure 8 shows the location of the strain gages on the concrete slab and the reinforcing bars. Three cross-section of the concrete slab are gaged in the positive moment region on the windward side of each bay. In the negative moment region close to the intermediate column strain gages are placed on the reinforcing bars of the slab.

4.3 Test Program

It is proposed to use the same test program for each composite assemblage as follows:

4.3.1 Calibration Tests of Steel Members

Tensile tests will be performed on coupons cut from the steel used to fabricate the beams and columns. The residual stress pattern will also be obtained.

4.3.2 Erection of Steel Assemblage

During erection of an assemblage the three columns are first placed on their pin-base supports lightly attached to the supporting frame and aligned in the correct position. There the beams are welded to the columns. Before and after welding readings of strain and deflection are taken to isolate the effect of welding.

4.3.3 Preliminary Steel Assemblage Test

Before pouring the concrete slab the bare steel assemblage is tested in its elastic range. Beam loads are first applied, then the drift is gradually incremented using the horizontal screw jack at the column top. The maximum drift is limited so that the elastic capacity of any section of the assemblage is not exceeded. Readings of strain and deflection are taken at each drift increment.

4.3.4 Construction of Concrete Slab

After testing the steel assemblage in its elastic range all loads are removed. Then the concrete slab is cast while the assemblage is in a zero drift position. Concrete cylinder compression tests and tensile tests on the reinforcing bars are performed.

4.3.5 Composite Assemblage Test

After the concrete slab has attained the required strength, beam loads are applied. Then the lateral drift is gradually incremented until the total drift exceeds the drift corresponding to the stability limit load. Readings of strain and deflection are taken at each drift increment.

4.4 Expected Results

The two computer programs COMPFRAME and SOCOFRANDIN developed in Ref. 4 were used to predict the lateral load vs. drift behavior of the composite assemblage CA-1, as shown in Fig. 9a. In this analysis the plastic hinges forming in a beam cross-section adjacent to the columns are assumed to occur at the face of a column(5).

For the composite assemblage CA-2 with metal deck a theoretical analysis of the stiffness is not available. It is assumed that CA-2 has the same stiffness as a composite assemblage with a solid slab of the same thickness. The lateral load vs. drift curve of CA-2 is shown in Fig. 10a.

Figures 9a and 10a also show the theoretical lateral load vs. drift curves of the bare steel assemblages CA-1 and CA-2 before casting the slab. Only the first segment of these curves can be verified by the preliminary tests in the elastic range (Art. 4.3.3).

The expected plastic hinge patterns are shown in Fig. 9b and 10b. The assemblages are designed so that all plastic hinges occur in the composite beams. This corresponds to the behavior of a story near the bottom of a real multi-story composite frame. Composite assemblages with plastic hinges in the columns were not considered. The behavior of such assemblages can be predicted from a knowledge of the combined steel and composite assemblage behavior.

Comparing the experimental results of the preliminary steel assemblage tests (Art. 4.3.3) with the results of the composite assemblage tests, the increase in stiffness through composite action will be obtained. The increase in strength through composite action will also be obtained by comparing the experimental results of the composite assemblage tests with the predicted curves for the bare steel assemblages.

5. Summary

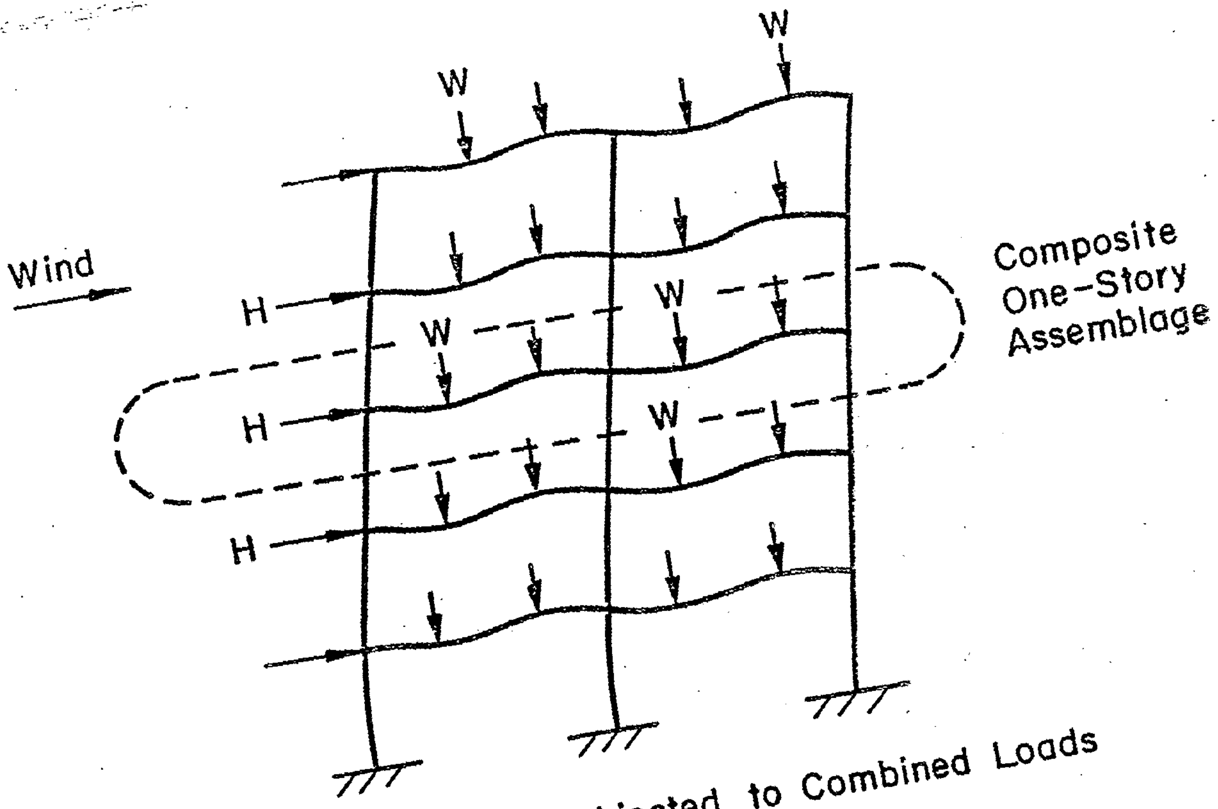
Tests of two one-story composite assemblages under lateral load are proposed. The lateral load vs. drift behavior of these assemblages will provide information about the increase in strength and stiffness of composite frames due to the composite action of the floor slabs.

Each test assemblage consists of three steel columns and two composite beams. One assemblage has a solid slab, the other a ribbed slab on a metal deck. All other dimensions are the same for both assemblages.

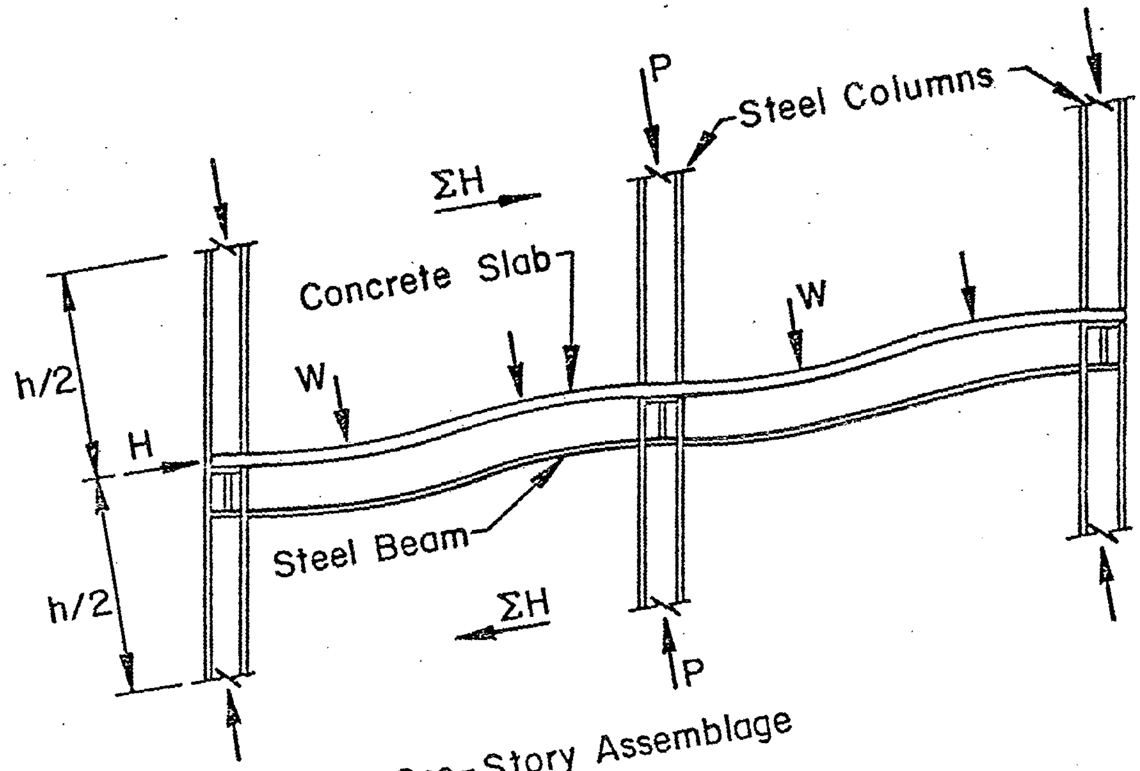
The test program for both assemblages is divided into two main phases: First the bare steel assemblage is tested in its elastic range. After casting the concrete slab the composite assemblage is tested to beyond its stability limit load.

Based on the results of these tests and on the theoretical method developed in earlier work, design recommendations for unbraced frames with composite beams will be formulated.

6. Figures



a) Unbraced Frame Subjected to Combined Loads



b) Composite One-Story Assemblage

Fig. 1 Unbraced Frame and Composite One-Story Assemblage

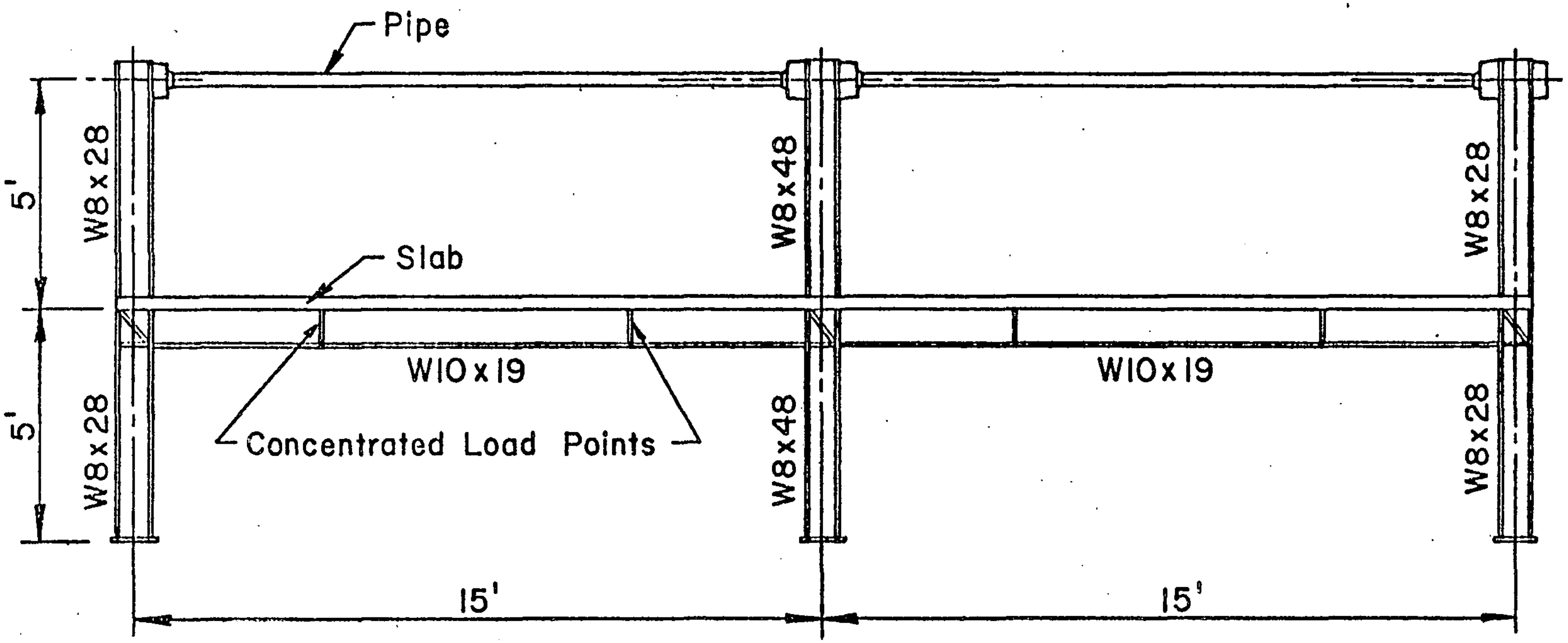


Fig. 2 Elevation View of CA-1 & CA-2

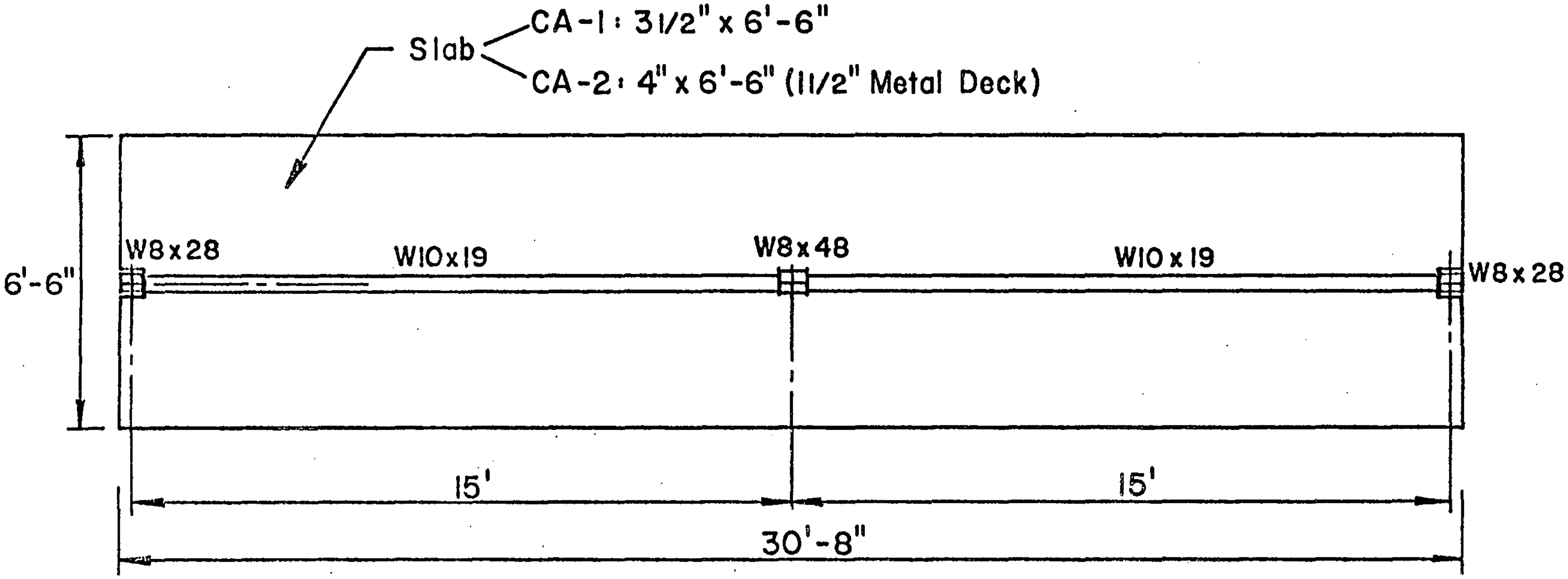


Fig. 3 Plan View of CA-1 & CA-2

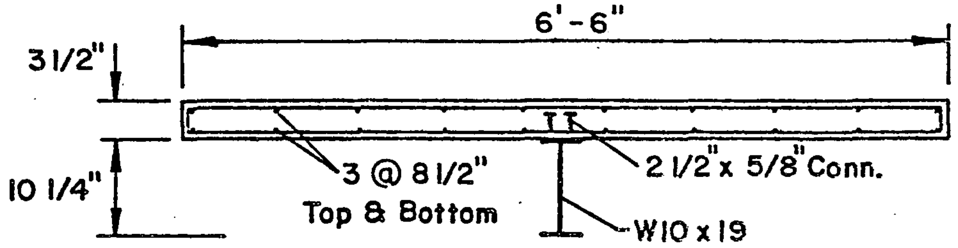


Fig. 4a Section of Beam CA-1

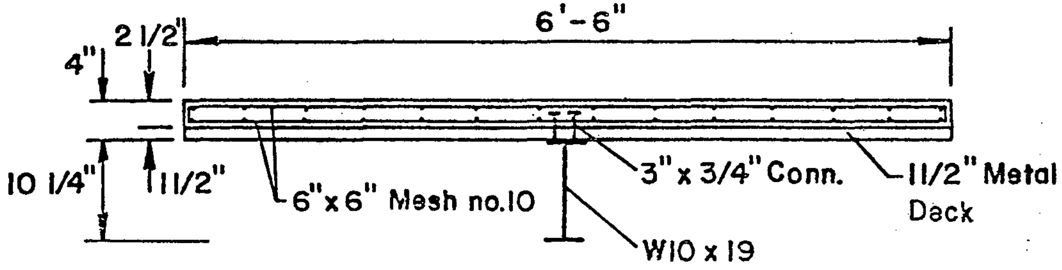


Fig. 4b Section of Beam CA-2

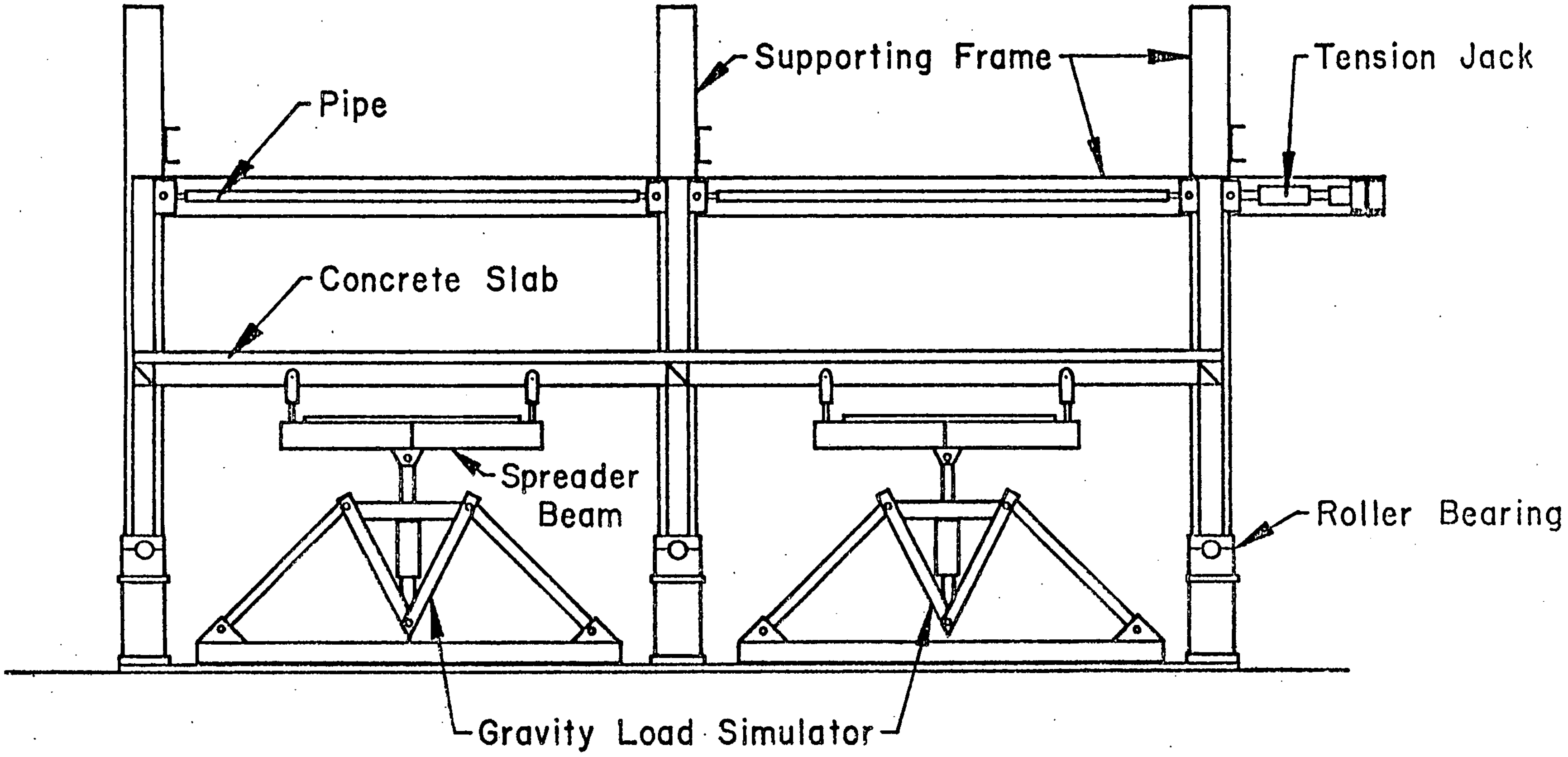
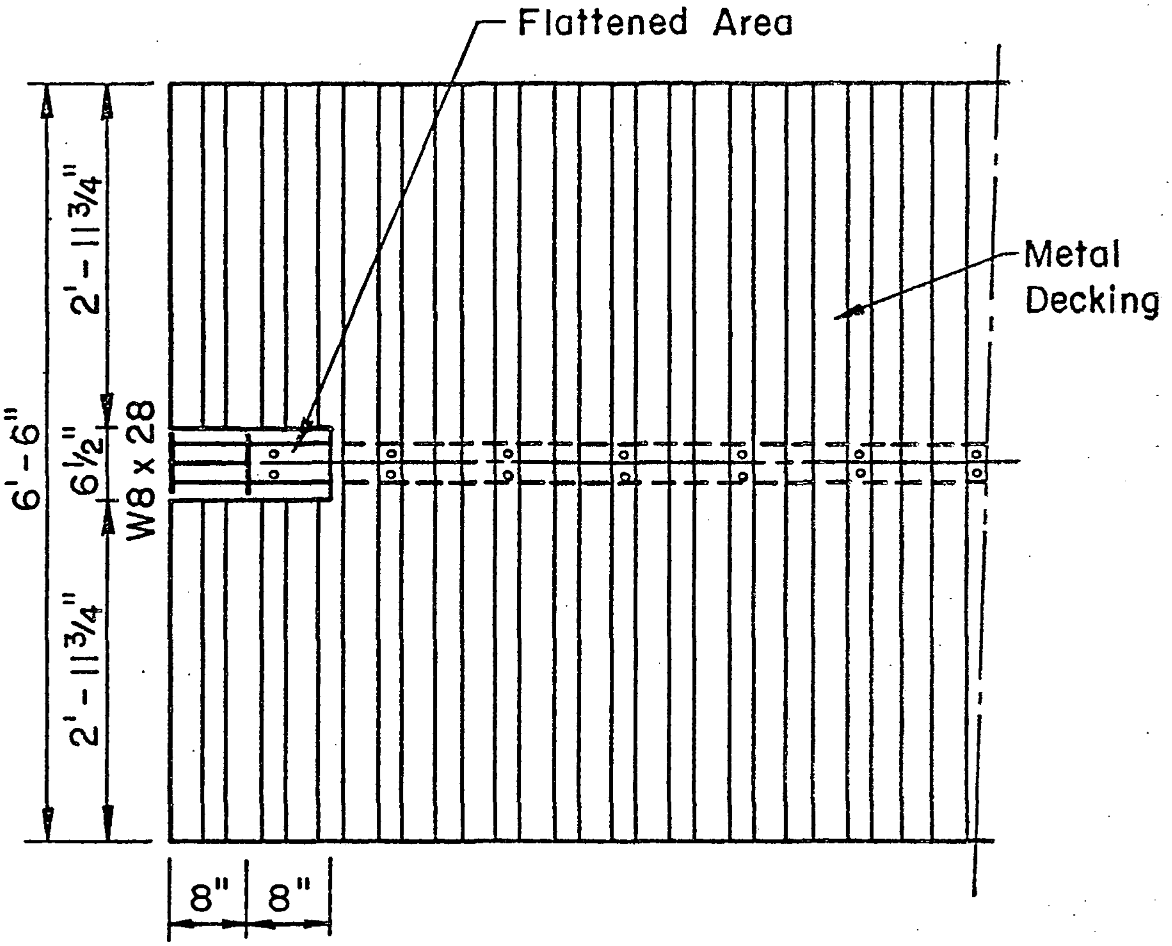
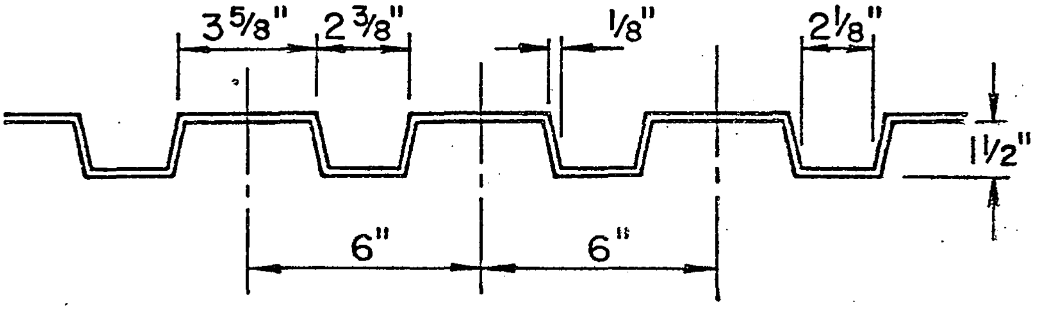


Fig. 5 Schematic View of Test Set-up



Plan View of Beam-to-Column Connection



Section View

Fig. 6 Details of Metal Decking (CA-2)

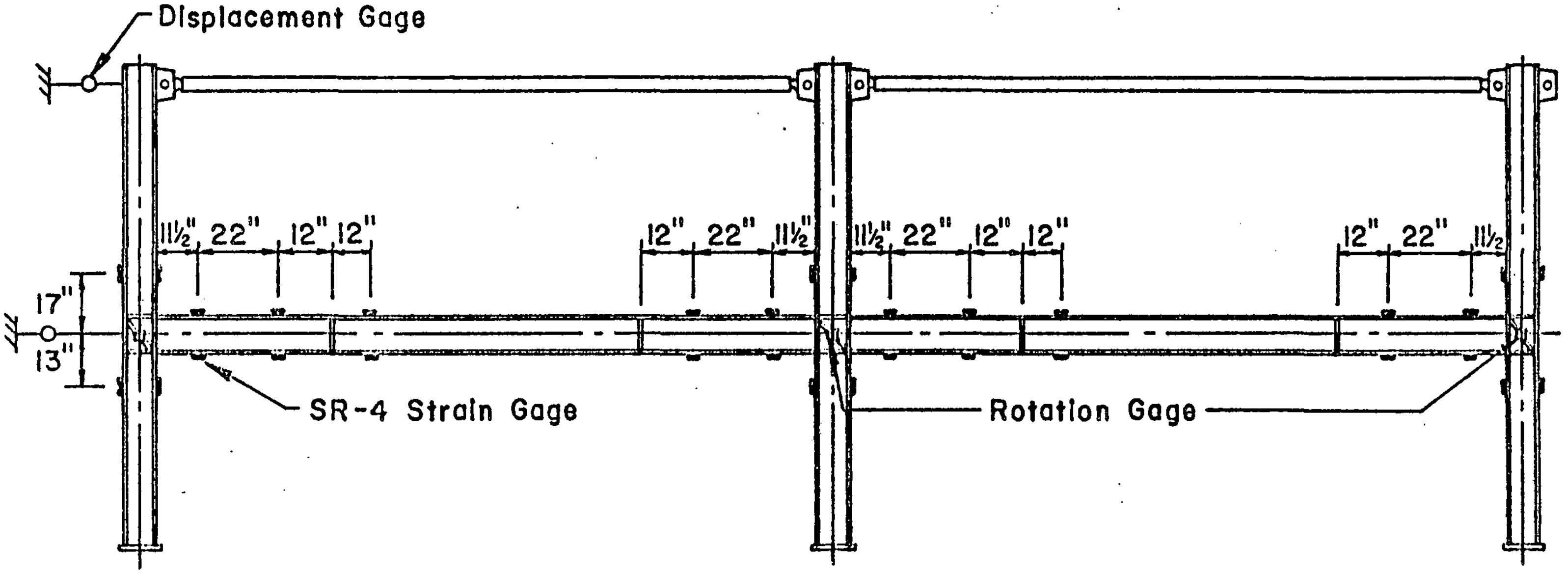


Fig. 7 Instrumentation of Steel Frame

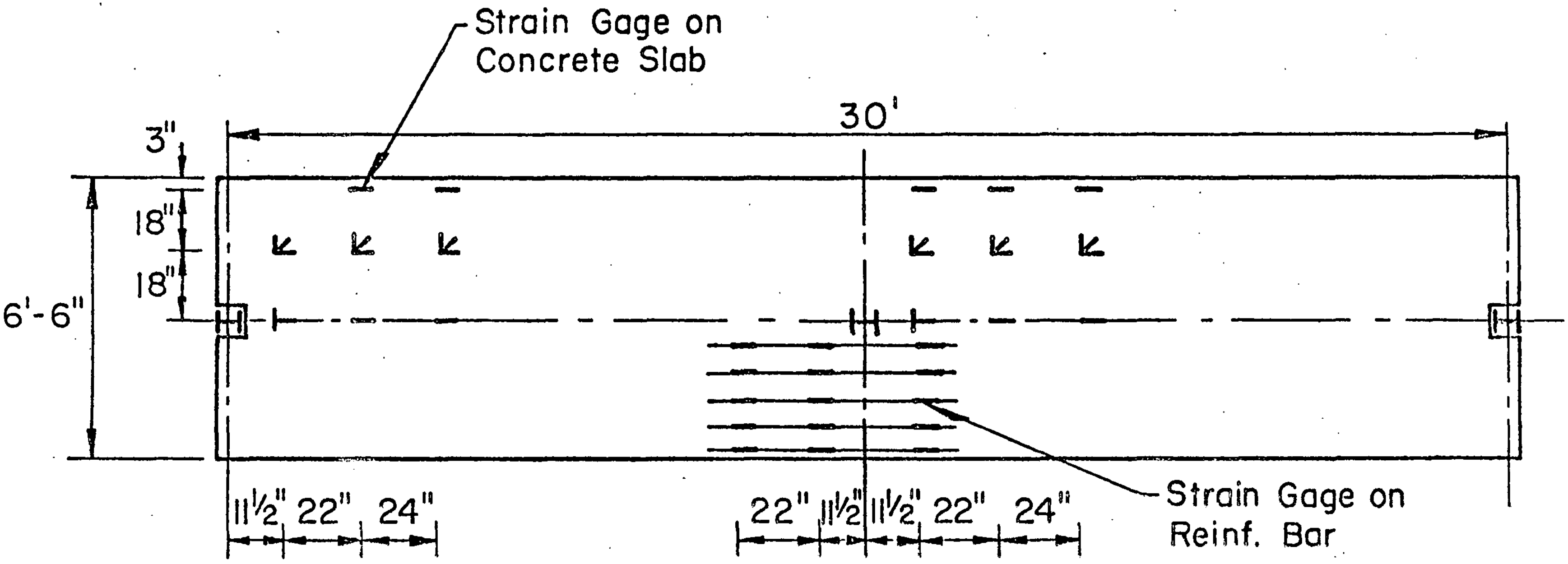


Fig. 8 Instrumentation of Slab

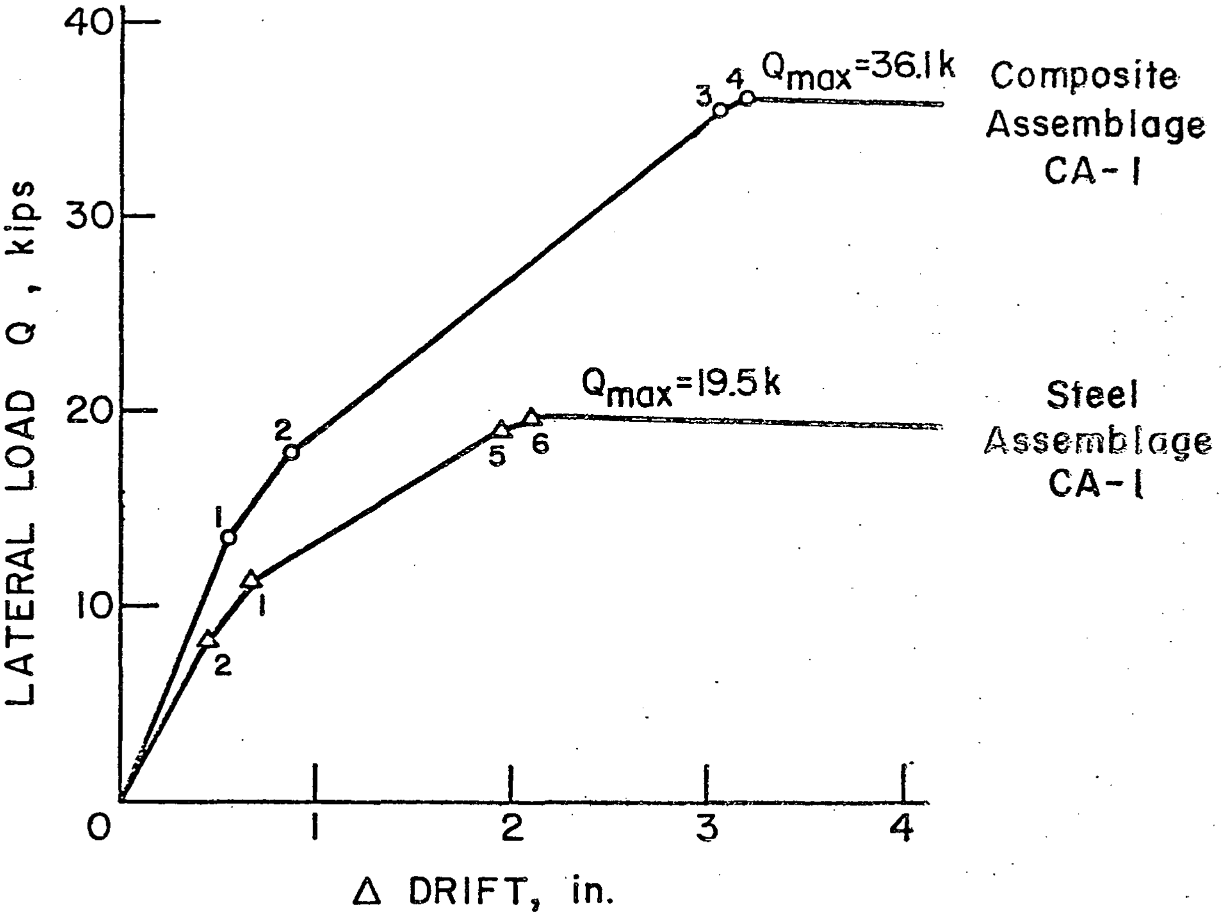


Fig. 9a Lateral Load vs Drift Behavior of CA-1

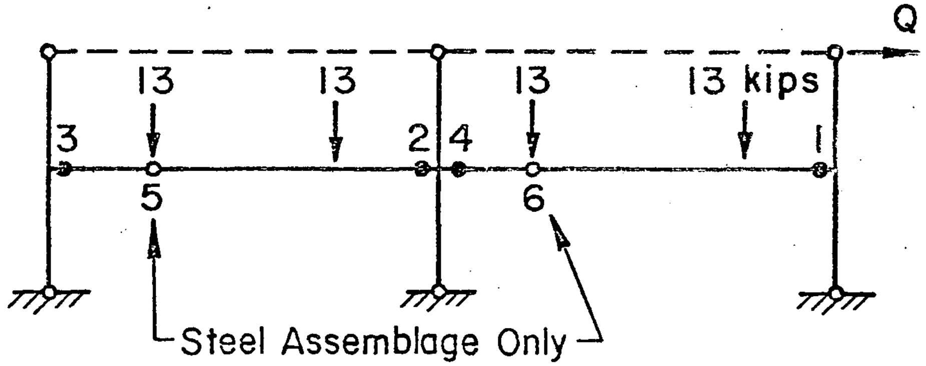


Fig. 9b Plastic Hinge Patterns for CA-1

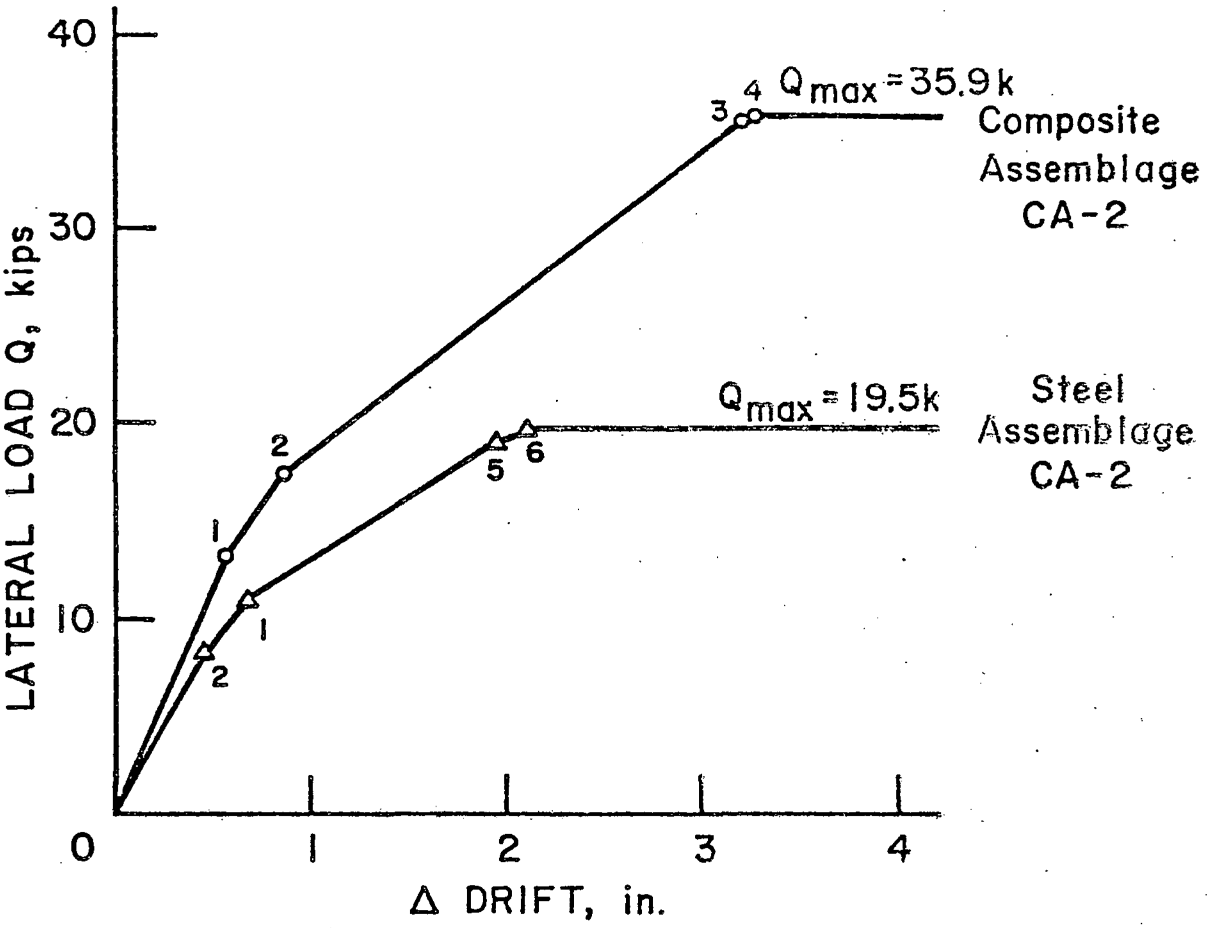


Fig. 10a Lateral Load vs Drift Behavior of CA-2

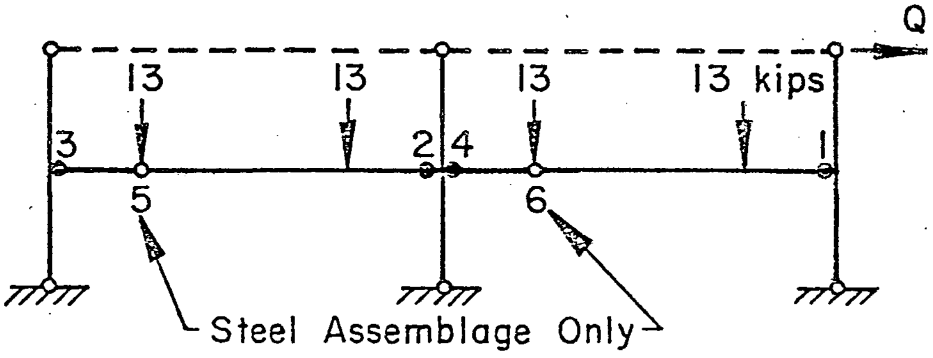


Fig. 10b Plastic Hinge Patterns for CA-2

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