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TECHNICAL PROPOSAL NO. 1 - COMPOSITE ASSEMBLAGES UNDER LATERAL LOAD

by

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ABSTRACT

This paper proposes the experimental investigation of six steel-concrete composite beams under varying geometry and bending moment conditions; three to be tested under positive moment (slab in compression), two under negative moment (slab in tension) and one under combined positive and negative moments. The results obtained from the first five beams will be used to predict the behavior of the sixth. The purpose of this investigation is to develop a method of analysis for unbraced frames containing composite beams and subjected to combined lateral and gravity loads.

1. INTRODUCTION

The stage has been reached where an unbraced frame can be accurately analyzed to determine its behavior under both gravity and combined gravity and lateral loads.[1,2,3,4]* Reference 1 presents a method whereby the load-deflection curve of an unbraced frame or a portion of it can be obtained up to the stability limit load. Due to the method of solution however the unloading part of the curve cannot be obtained. Reference 2 presents a method for determining the complete (loading and unloading) load-deflection curve for a one-story assemblage. Experimental verification of this method is presented in Ref. 3. An alternate method of analysis for unbraced frames is presented in Ref. 4. In the method, the complete (loading and unloading) load-deflection curve for an unbraced frame or a portion of it may be obtained.

In an actual building, however, the structure may consist of the steel frame plus the concrete floor slabs acting compositely with the beams. A multi-story frame under combined loads, is shown in Fig. 1(a). Consider a one-story assemblage from the frame consisting of the composite beams and steel columns as shown in Fig. 1(b). From the deflected shape of the composite beams, it is evident that they contribute to the lateral strength of the frame by resisting the joint moments caused by the lateral loads. The effect of the concrete slab working compositely with the steel beams, is to increase the stiffness and strength of the beams, thus providing greater stiffness to the frame as a whole and greater capacity for resisting the applied story moments. However, in this case, the strength and stiffness of the frame will be dependent on the sign of the bending moments in the composite beams.

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* Superscripts are used to denote reference numbers. References are listed at the end of the report.

Consider again the composite beams in Fig. 1(b). Because of the rigid connection of the steel beams to the columns, the columns will apply end moments to the beams when the frame undergoes lateral displacement. A positive end moment (slab in compression) is applied at joint A, which will decrease the gravity load moment in the beam at that point. At joint B a negative end moment (slab in tension) is developed, which will increase the gravity load moment in the beam at end B. Similarly for beam BC. The relative magnitudes of the applied end moments will depend on the flexural stiffnesses of the beams and columns at each joint. For a composite beam under positive moment, the flexural stiffness can be based on the full cross-section consisting of the steel beam plus the concrete slab. Under negative moment, the steel beam plus the slab reinforcement contribute to the flexural stiffness of the beam. The contribution from the concrete in tension is significant at low loads and can be considered by using a slab participation factor.(5) The same applies with respect to the flexural strength of the beam except that the contribution of the concrete slab in tension will be very small at high loads. Clearly, therefore, the strength and stiffness properties of the composite beams and thus the frame depend on the sign of the applied bending moments.

The strength and stiffness of the composite beams are also dependent on the effective slab width. For simple span composite beams under positive bending moments the effective width has been determined and is defined for design purposes in the AISC Specification.(6) For a frame subjected to combined loads, a different situation will exist especially near the ends of the composite beams. Assume that a negative bending moment exists at end D of beam BD shown in Fig. 1(b). At the face of the column at D, only the steel beam can be relied upon to carry the negative moment. At some distance from the column face, the concrete slab starts to act compositely with the steel beam. The effective slab width, therefore, increases from zero at the column face to its full value some distance away. Thus, there is a transition zone in the vicinity of the column D. At end A of beam AB, the slab butts against the column face. Under positive bending moment the column exerts a compressive force on the slab over a width equal to the column face width. Again some transition zone in the region of column A can be expected. Previous pilot tests have shown that it might be possible to consider substantial composite action near the face of column A, even though a compressive force is exerted on the slab only over a limited width.[7] At column B, positive and negative moment conditions exist in the composite beams on either side. Even though end B of beam AB is under negative moment, the slab reacts against the leeward column face due to continuity of the slab reinforcement. Additional force is exerted against the leeward column face due to the slab compression in end B of beam BD. The pilot tests in Ref. (7) have indicated that the strength of beam AB at B can be evaluated using the steel section and the longitudinal slab reinforcement.

It can thus be seen that the behavior of a frame with composite beams is much more complex than that of the bare steel frame. Though accurate methods of analysis do not exist as yet, preliminary investigations have shown that with composite beams the increase in the resistance of a frame under combined loads can be fairly large. Consider the example shown in Fig. 2. Two load-deflection curves for a one-story assemblage are shown; one for a steel frame and the other for a steel frame with composite beams. Comparing the two curves, the following features stand out clearly: (1) Initially, the stiffness of the frame with composite beams is more than twice that of the bare steel frame, (2) After initial yielding this difference is even greater, (3) the stability limit load of the frame with composite beams is about twice that of frame with steel beams, (4) the deflection of the frame with composite beams at the stability limit load is about half the deflection of the steel frame.

From the above discussion it is clear that the increase in stiffness and strength of a frame due to composite action with the slabs is significant. This increase must be considered in the design of a multi-story frame in order to produce an economical design.

2. OBJECTIVE AND PURPOSE

The objective of this investigation is to study the behavior of composite beams under varying end moment conditions. Thus it follows up the recommendations of Ref. (7). The proposed test program will yield information on the strength and stiffness properties of the composite beams and the presence and extent of any transition zones near the columns.

With the information obtained from the proposed test program, it will be possible to formulate a general method for analyzing unbraced frames with composite beams. It is planned to check the proposed method of analysis by subsequently testing a one-story assemblage having composite beams. Tests of the one-story assemblage are not part of this investigation.

3. TEST SPECIMENS

The test program is divided into three phases namely Phases I, II and III. Phase I consists of beams tested under positive moment as shown in Fig. 3(a). Three test specimens are proposed as shown in Figs. 4(a) and 5(a); all have 4" reinforced concrete slabs connected to W12x36 A36 steel beams by means of 1/2" diameter shear connectors. The concrete slabs will be reinforced by one layer of longitudinal and transverse reinforcement as shown in Fig. 5(c). Beam No. 1 has a slab width of 24" which is equal to the column face width. Beam Nos. 2 and 3 have slab widths of 5'-0" and 9'-0". In these two beams the slab will project beyond the column face. Each beam has a W12x106 stub column welded to its end through which the beams will be bolted to a rigid K-frame that will provide a fixed support as shown in Fig.7(a). Beam No. 1 will serve as a reference beam because it will exhibit full composite action over its whole length. Beams 2 and 3 have slab width-to-thickness ratios of 15 and 27 respectively. Beam 2 approximates a slab width as determined from AISC Specification while Beam 3 was chosen to obtain data from a much wider slab width. Comparing results from Beams 2 and 3 with those of Beam 1 will indicate how their behavior with respect to stiffness and strength differ from full composite action. They will also show the extent of the transition zone near the column and the actual width in compression in this area. Comparing the results of Beam 3 with Beam 2 will indicate whether the greater confinement of the concrete near the column has a marked influence on the stiffness and strength.

Phase II consists of testing beams under negative end moment as shown in Fig. 3(b). Two test beam specimens are proposed. They are numbered 4 and 5. Construction details are the same as for Beams 2 and 3 but in addition the slabs extend beyond the rear face of the columns so that the columns are completely embedded as shown in Figs. 4(b) and 5(b). As was explained earlier, the tension in the reinforcement is developed through the slab pulling against the rear column face. The purpose will be to see whether the stiffness and strength properties are dependent on the slab width (and thus the amount of reinforcement) only or whether it also depends on the area under compression between the slab and column.

Phase III involves the testing of one composite propped cantilever beam under gravity load as shown in Fig. 3(c). Construction details are shown in Fig. 6. It will be noticed that this beam corresponds closely to Beam 2. Reinforcement and shear connectors shown in Fig. 6(b) are the same as that of Fig. 5(c).

Beam 6 gives some representation of a composite beam in an unbraced frame subjected to combined loads. The behavior of this beam will be predicted from the results obtained from Beams 1 to 5. If the predicted behavior corresponds well with the actual behavior, then a general method for analyzing composite beams in unbraced frames subjected to combined loads can be formulated.

4. TEST PROGRAM

4.1 Calibration Tests

Actual testing will be preceeded by calibration tests on the materials of the beams. This includes concrete cylinder compression tests and tensile tests on sections cut from the reinforcing bars and steel beams. The residual stress pattern in the beams will also be obtained.

4.2 Phase I

Beams 1, 2 and 3 will have a vertical load applied at the free end by means of a hydraulic jack as shown in Fig. 7(a). The vertical displacement and slip at the free end will be measured. A calibrated dynamometer will measure the applied load. Strain readings from SR-4 strain gages, spaced evenly over a length of 5 ft. from the column and placed above and below the slab and on the web and flanges of the steel beam will be taken at each load increment. An electrical rotation gage fixed to the K-frame at beam level will record any possible rotation of the fixed end. Any vertical movement of the fixed end of the beam due to slip in the bolts, will also be recorded. The development and spreading of cracks in the concrete slab and any signs of yielding in the steel beam will be noted. Loading will continue until the ultimate capacity of the composite beams has been reached.

The readings obtained through the strain gages during the loading period, will enable determining of the neutral axis and plastic centroid of the composite beam. It is expected that the neutral axis position will vary from its lowest position at the face of the column to its normal position, for a composite beam, some distance away. From this information the slab width in compression may be calculated and, thus, the stiffness of the beam.

4.3 Phase II

Loading will proceed in the same way as for Phase I except that the beams are turned upside down as shown in Fig. 7(b). SR-4 strain gages will again be placed on the steel beam as described for Phase I. The slab reinforcement will also be strain-gaged with SR-4 strain gages. They will be placed at 24" center-to-center on the bars starting from the slab end behind the column and continuing up to 5 ft. from the front column face. These strain gages will be protected from the concrete by tubular metal sheaves placed over the gages before the concrete is cast. All readings will be taken as for Phase I. Of particular interest will be the compressive stress in the concrete at the rear column face as well as the distribution of slab stresses along the beam.

4.4 Phase III

The test setup for Beam 6 is shown in Fig. 8. This composite beam will be tested as a propped cantilever, the fixed end being at the stub column. The beam will be turned upside down. This means that when a vertical load is applied at the midspan and a fixed end condition is maintained at the stub column, the beam will be under positive moment (slab in compression) at the column face. Under the applied load at midspan, negative moment (slab in tension) will also exist. To assure a fixed end condition, the beam rotation at this end must continuously be kept zero during the course of loading.

Loading will be applied at the midspan and will continue until the beam capacity is reached at the midspan or column face. After each increment of applied load in the span, the beam rotation at the column face will be brought back to zero by applying a force at the leeward cantilever end as shown in Fig. 8. The rotation will be checked with an electrical rotation gage.

After each increment of loading, all strain gages, positioned as for Beam 4 will be read. From these readings it will be possible to determine what negative moment is developed at the column face. With this value the moment at the column centerline may be calculated which should then correspond with the moment caused at this point by the correcting force.

The point of inflection in the beam span will be carefully located through the readings from the strain gages and the derived bending-moment diagram, because this point will figure prominently in the method to be proposed for analyzing composite beams under combined loads. Correlation between the actual point of inflection and its predicted position will be of prime interest.

As was mentioned earlier, if the behavior of this beam can be accurately predicted, then the way is open for proposing a generalized method of analyzing composite beams in frames subjected to combined loads.

5. SUMMARY

This paper proposes the testing of six composite beams under varying end moments in order to determine their comparative behavior up to ultimate load. The end moment-rotation behavior obtained from these tests will provide the required information to analytically evaluate the strength and stiffness properties of composite beams under end moments.

The test beams consist of composite beams of different slab widths. Five are set up as cantilever beams with a vertical force being applied at the free ends to create an end moment at the fixed ends. The sixth beam will be tested as a propped cantilever with a vertical load applied at the midspan.

The test program is divided into three parts, namely Phase I, II and II. The information obtained from the testing of the five beams of Phases I and II will be used to predict the behavior of the propped cantilever of Phase III.

Instrumentation is provided to measure the vertical displacement and slip at the free ends. All the beams will have extensive strain gages in the vicinity of the fixed end to enable location of the neutral axis and plastic centroid in this area. From this information the slab width in compression and thus the stiffness of the beam as a whcle can be calculated.

These proposed tests will provide the material to develop a method of analyzing unbraced frames with composite beams.

6. ACKNOWLEDGMENTS

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Sincere thanks to Miss Karen Philbin for typing this manuscript.

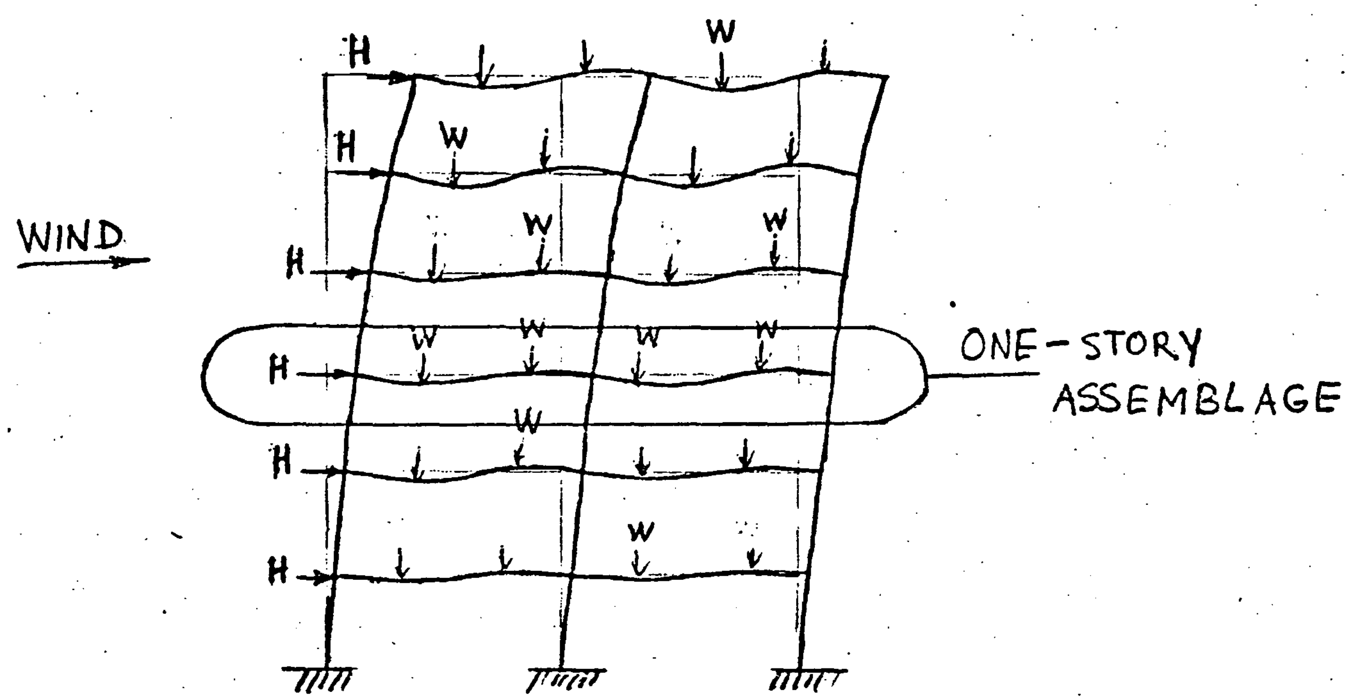


Fig.1(a) MULTISTORY FRAME UNDER COMBINED LOADS.

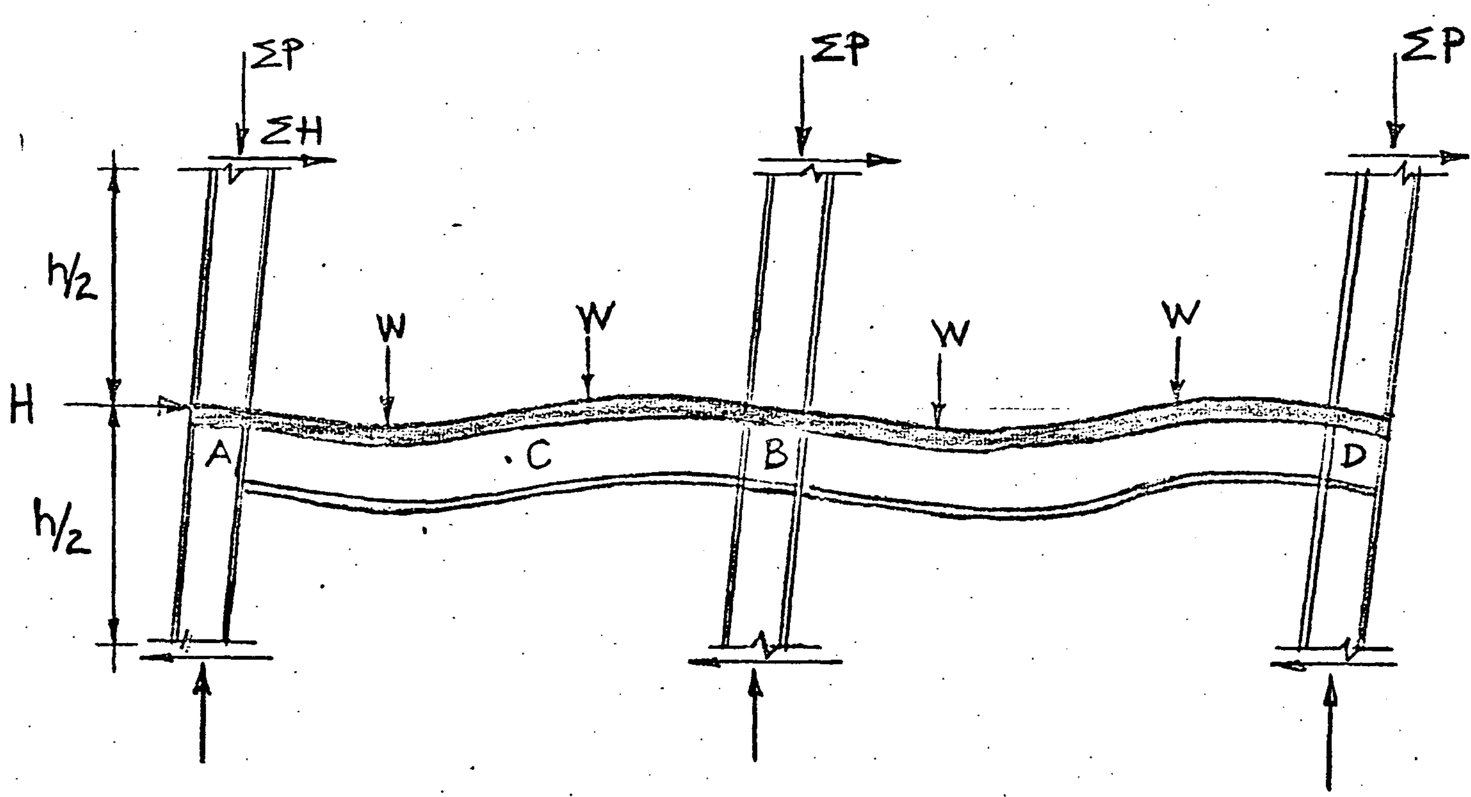
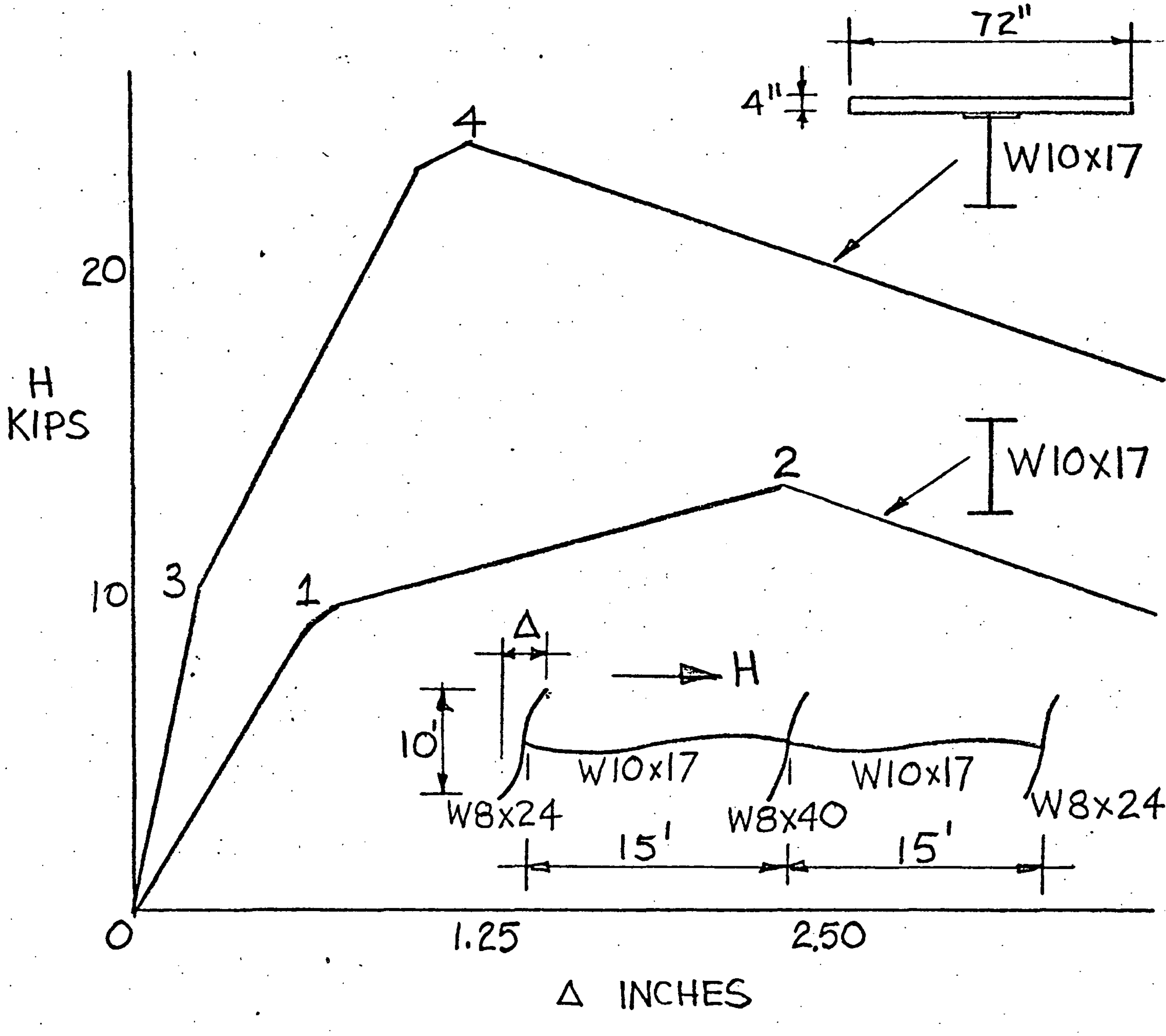


Fig 1(b) ONE-STORY ASSEMBLAGE



COMPARATIVE BEHAVIOR OF ONE-STORY ASSEMBLAGES

Fig. 2

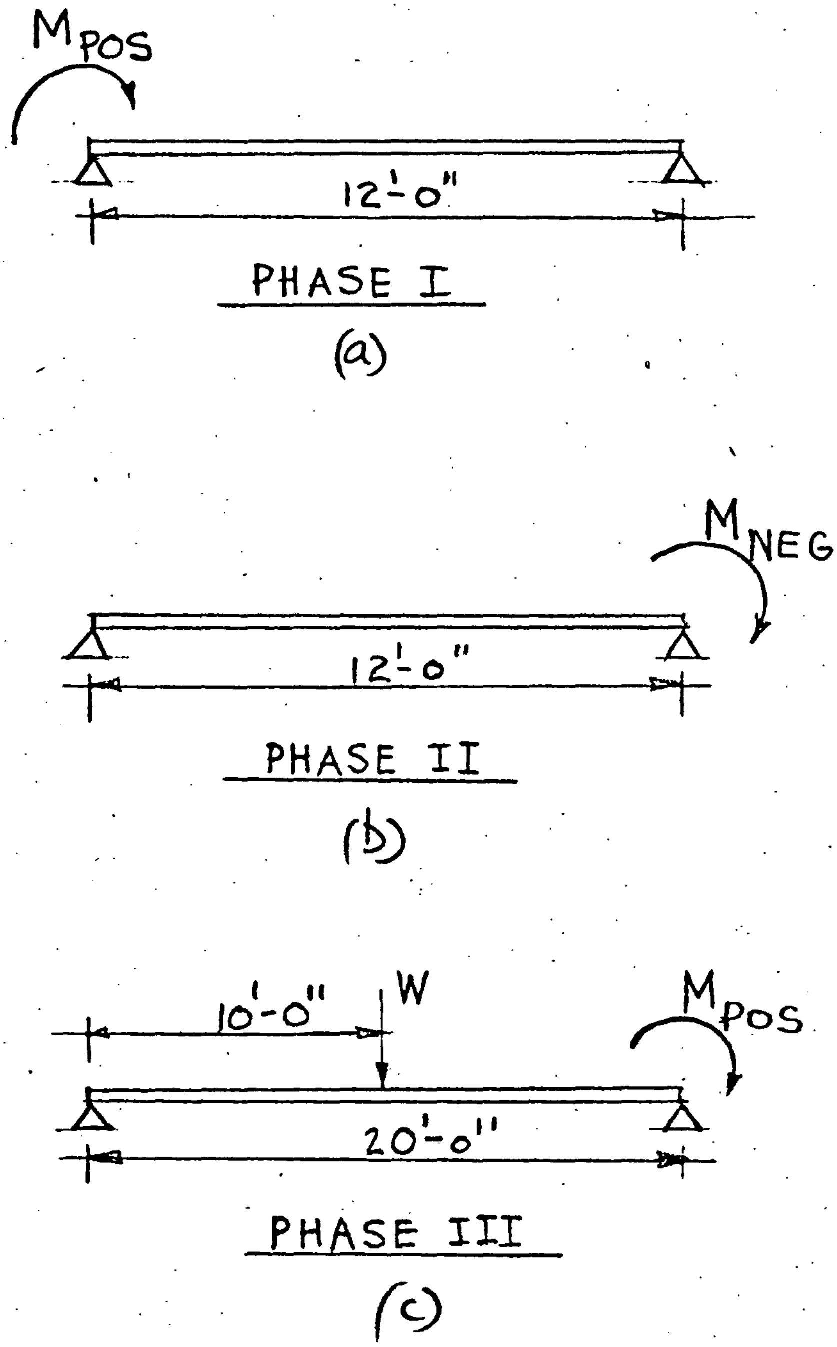
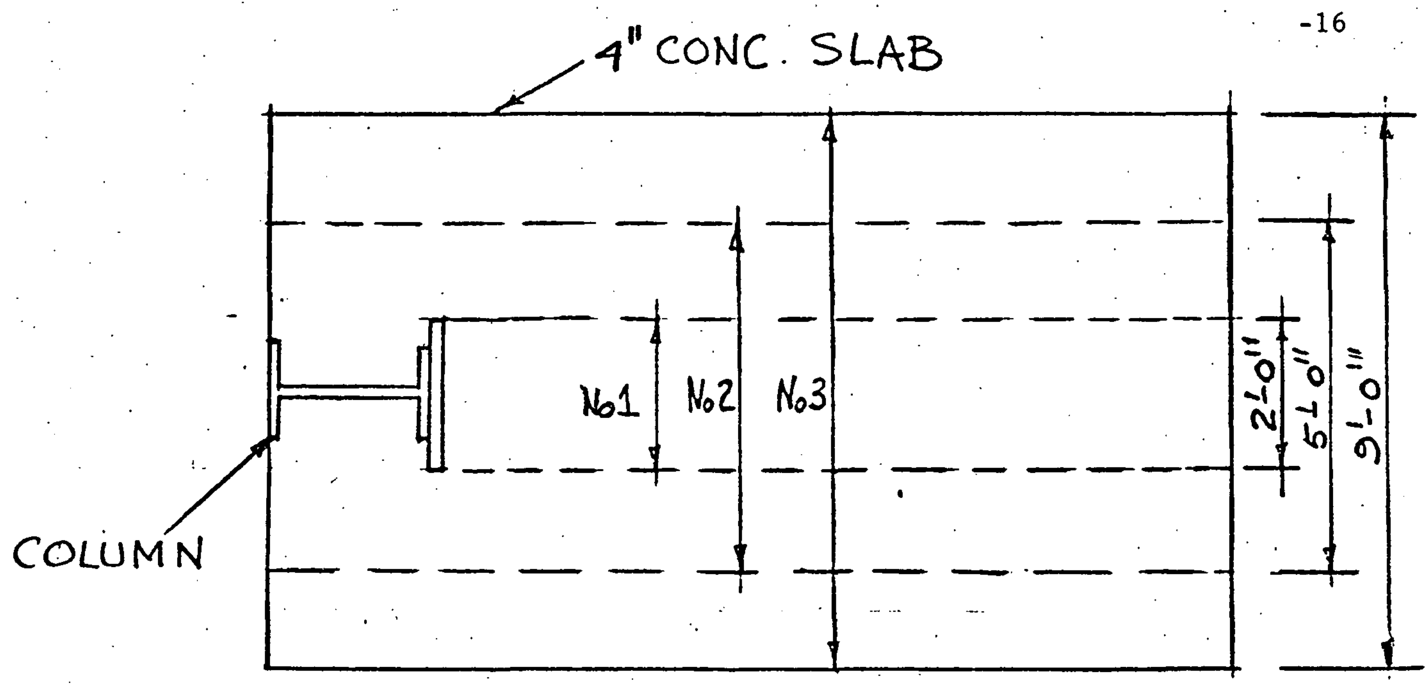
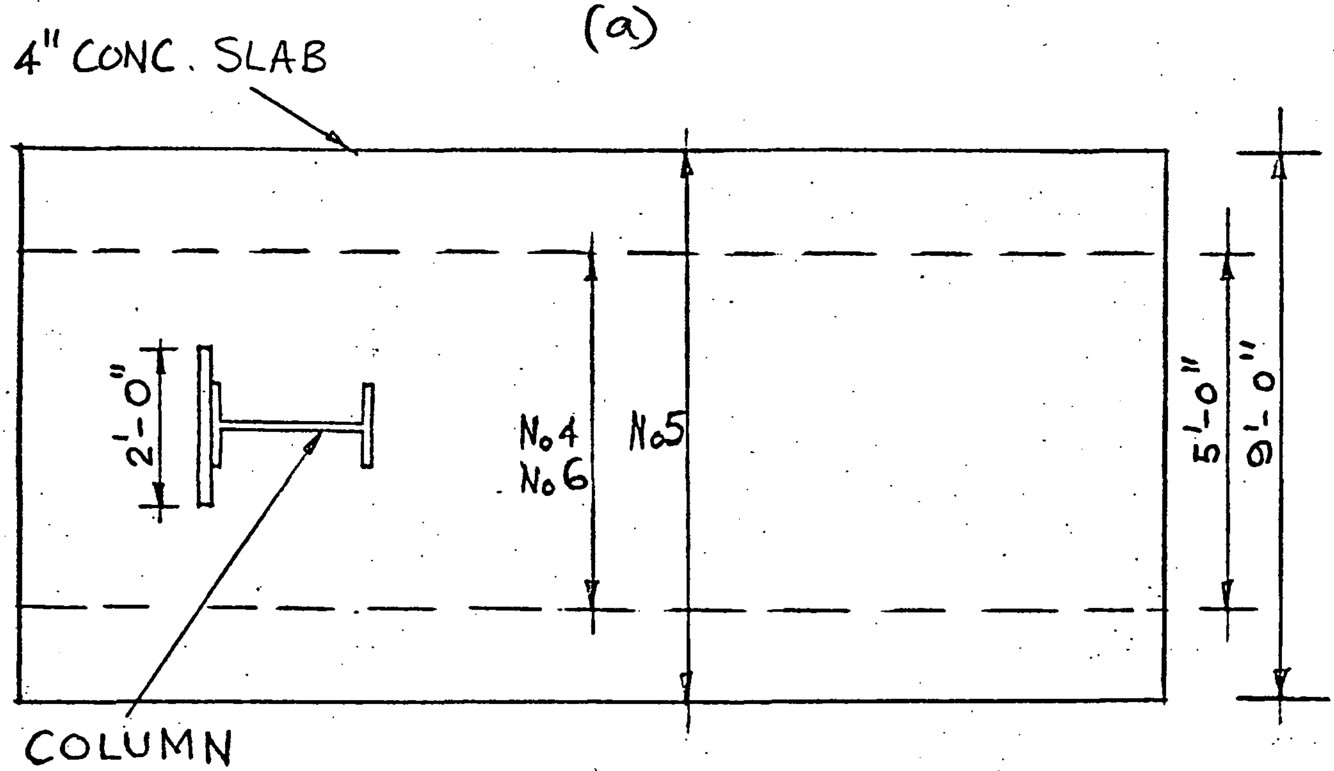


Fig 3. SCHEMATIC PRESENTATION OF TEST BEAMS



PHASE I

(a)



PHASES II & III

(b)

Fig 4. BEAMS FOR PHASES I, II & III

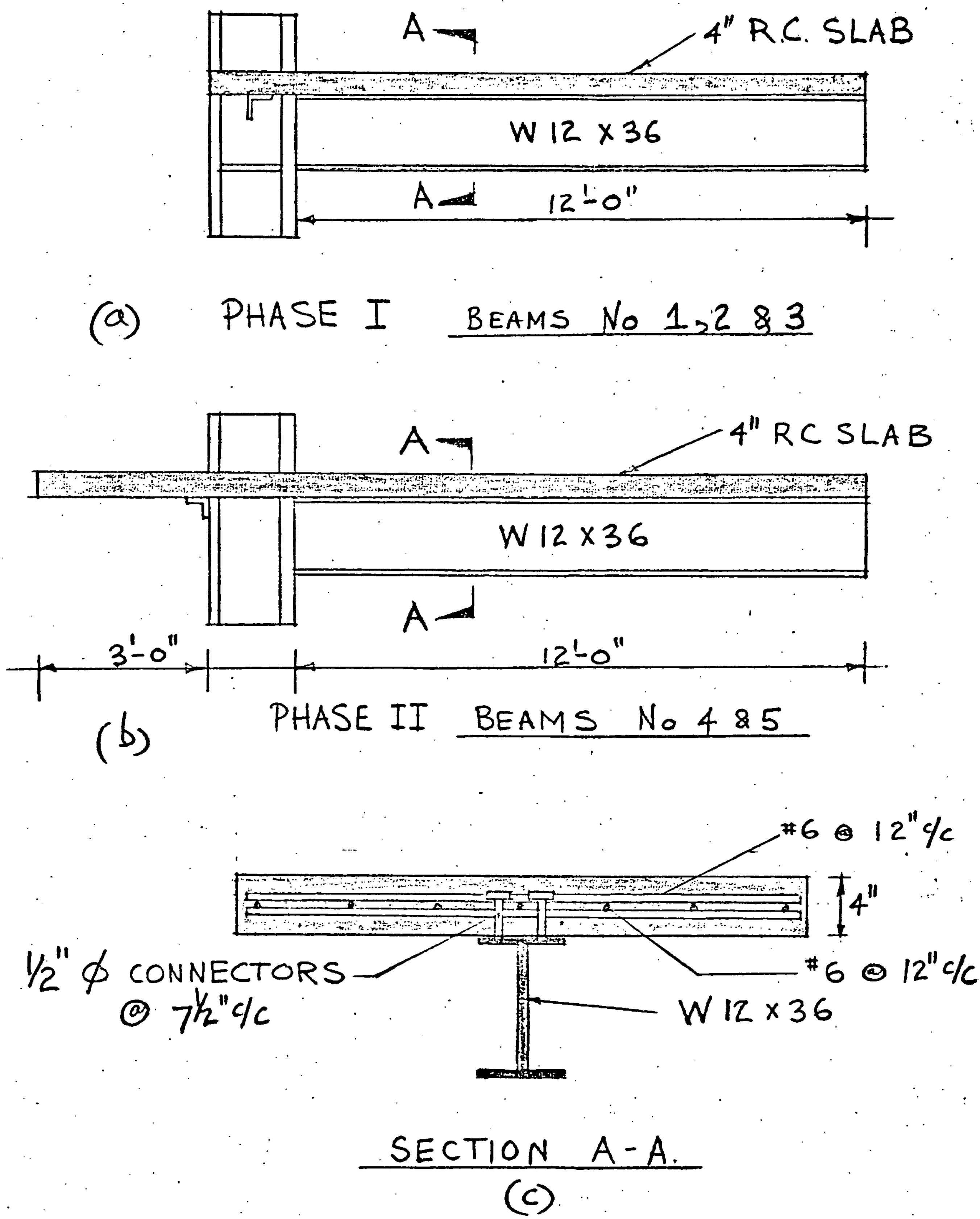


Fig 5. DETAIL OF TEST BEAMS 1 to 5

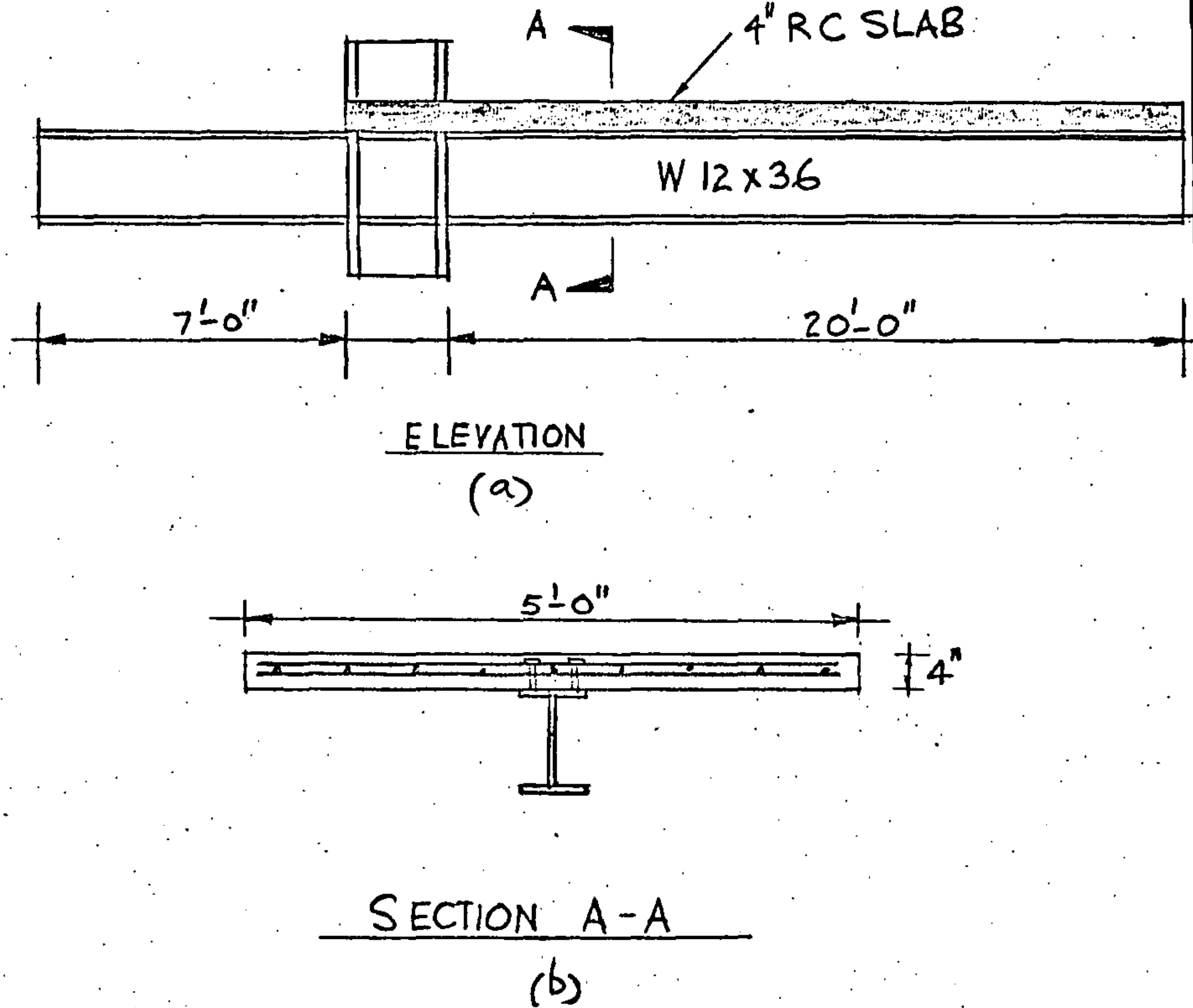


Fig 6. PHASE III DETAIL OF BEAM No 6.

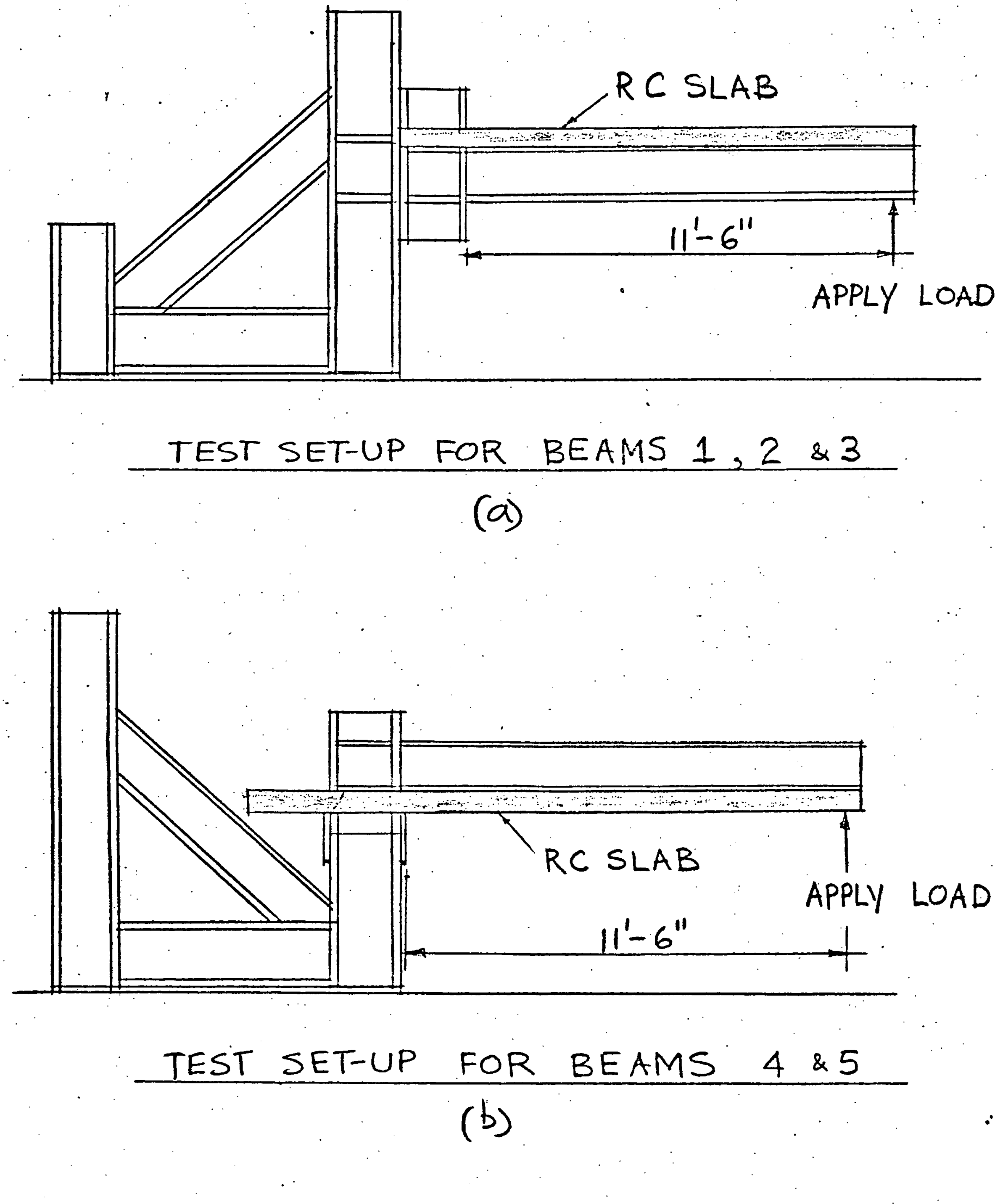


Fig 7 TEST SET-UP FOR BEAMS 1 to 5

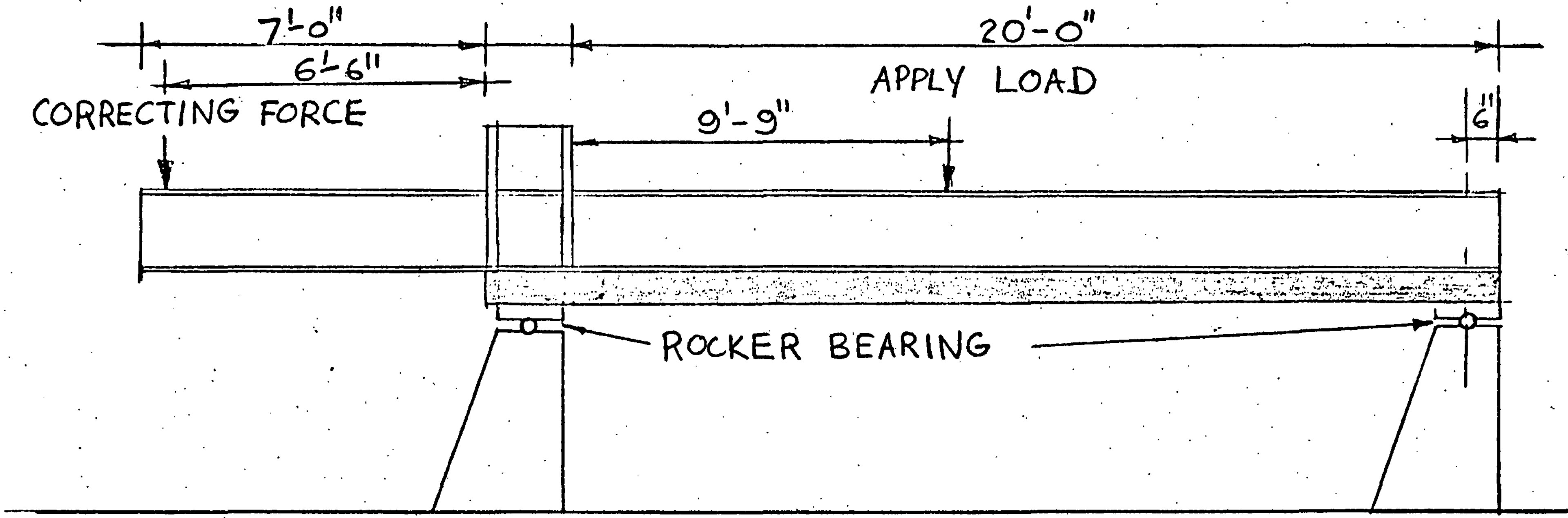


Fig 8 : TEST SET-UP FOR BEAM 6

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