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Strength of Beam-and-Column Subassemblages in Unbraced Multi-Story Frames

TECHNICAL PROPOSAL NO. 2 - COMPARATIVE BEHAVIOR OF TWO, ONE -STORY ASSEMBLAGES

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1. INTRODUCTION

The sway subassemblage method of analysis, recently developed at Lehigh University, accomplishes three objectives which are useful when designing unbraced multi-story frames.[1,2,3,4]

1. It allows a story-by-story preliminary design of an unbraced frame to be made considering realistic constraints such as working load drift and maximum lateral load capacity, for example;

2. It enables comparative lateral-load versus sway-deflection analysis of a single story of an unbraced frame to be made under alternate loading conditions up to and beyond the maximum lateral-load capacity of the story; and

3. It provides an exact lateral-load versus sway-deflection analysis of a single-story multi-bay unbraced frame which satisfies the geometrical loading and boundary conditions of a one-story assemblage.[3]

In this method, a one-story assemblage with known member sizes is subdivided into sway subassemblages. Each sway subassemblage is then analyzed either manually with the help of various charts or with a computer for its load-deflection behavior.[1,4,5,6] The lateral-load versus sway-deflection curve of the one-story assemblage is determined by combining the resulting load-deflection curves of the component sway subassemblages. This curve gives the complete load-deflection behavior of the one-story assemblage up to and beyond the maximum load.

The sway subassemblage method of analysis is based on an extension of restrained column theory.[7] This theory considers the effect of a constant rotational restraint stiffness at the top of a restrained column which is permitted to sway. The sway subassemblage method extends the restrained column theory to include the effects of a variable restraint stiffness.[3] A recently completed experimental program, conducted as Phase I of this investigation, has shown that good agreement exists between the theoretically predicted and experimentally obtained behavior of restrained columns permitted to sway.[8,9] The studies under Phase I provided a vital first step in the experimental verification of the sway subassemblage technique as a useful analytical method.

Since the sway subassemblage method of analysis predicts the behavior of a one-story assemblage as the superposition of restrained column behavior, the next step is to verify experimentally the predicted behavior of a one-story assemblage, which is the basic assemblage at each story level of an unbraced multi-story frame.

In an actual unbraced frame under combined gravity and lateral loads, where the gravity loads are held constant, the distribution of total axial loads to all the columns at a given story will vary with the applied lateral load. An assumption of the sway subassemblage method considers that the distribution of axial loads to the columns will remain constant with variation in applied lateral load. Analytical predictions of the behavior of one-story assemblages indicates that within the range of expected column loads, this assumption is quite reasonable. This assumption should also be verified experimentally.

The objective of this phase of the investigation (Phase II) is therefore two fold:

1. To compare the predicted and experimentally obtained behavior of a one-story assemblage under a constant distribution of axial loads in the columns, and

2. To compare the predicted and experimentally obtained behavior of a one-story assemblage under the assumption of a variable distribution of axial loads in the columns.

2. PROPOSED TEST PROGRAM

2.1 Description of Test Frames

Two one-story assemblage tests, Frame D and Frame E, are proposed as shown in Fig. 1. Both frames are identical and are to be fabricated from ASTM A36 rolled steel sections. Each frame consists of two 10B19 beam sections rigidly welded to three 6W20 column sections. The tops and bottoms of all the columns are pinned connected to the loading mechanism and supports respectively. The beams and columns in each test frame are to be bent about their strong axis. The nominal strong axis slenderness ratio of the columns is 22.6.

2.2 Test Loads

As shown in Fig. 1 constant vertical loads of 13.0 kips are to be applied to each beam in each test, at approximately the quarter points. The magnitude of the beam loads was determined so that a specific identical pattern of plastic hinges would occur in each test frame. The particular hinge pattern was chosen to emphasize the comparative behavior of the two frames, which is the purpose of the investigation.

The test variable in this investigation is the distribution of the total constant vertical force to each of the restrained columns (portion of column below the restraining beams). It is proposed that the axial load ratios, P/P_y, in the restrained columns of the first frame to be tested, Frame D, be maintained constant throughout the test, at 0.25, 0.50 and 0.75 respectively, as shown in Fig. 1. This would require a readjustment of the column loads after each increment in horizontal load, δQ, to maintain the column axial loads constant.

The axial loads in the columns of the second test frame, Frame E, would be subjected to change with increasing lateral loads as shown in Fig. 1, following the predetermined load program shown in Fig. 2. It is proposed that at the start of the test, an axial load ratio of $P/P_y = 0.50$ would be applied to each restrained column. During the application of the lateral load, Q, the axial load ratio of the windward restrained column would be decreased gradually from 0.50 to 0.25, in equal intervals, while the axial load ratio in the leeward restrained column would be increased gradually from 0.50 to 0.75. Because of frame symmetry, there would be no change in the axial load in the interior column. The total vertical loads in the columns would also be the same in each test frame at any stage of the test.

The total change in axial load ratio P/P_y equal to 0.25 in the windward and leeward restrained column of Frame E was chosen to represent a possible practical variation in axial load ratio for a two bay unbraced frame as the lateral load varies from zero to the mechanism load. It is anticipated that during the test the total change in axial load ratio in these two columns would be effected in approximately 12 to 15 equal increments, while the lateral displacement is incremented from zero to the theoretical displacement corresponding to a mechanism.

2.3 Theoretical Load Deflection Behavior

Frame D

Figure 3 shows the theoretical load-deflection curve of Frame D, based on the clear span dimension of each beam and the center-to-center span dimension of each column. In the figure, the solid line represents the load-deflection curve for Frame D obtained from the computer analysis described in Ref. 6. The sequence of formation of plastic hinges and their locations in the test frame are also shown in Fig. 3.

The lateral load, Q, versus sway deflection, Δ, relationship in Fig. 3 for Frame D indicates that the first plastic hinge occurs in the leeward restrained column relatively early. The maximum value of lateral load is nearly constant over a long plateau after the formation of plastic hinge 3. A mechanism occurs with the formation of the fourth plastic hinge.

Frame E

The theoretical load-deflection curve of Frame E is also shown in Fig. 3. This curve was also calculated using the clear span dimension of the beam and the center-to-center span dimension of each column. The sequence and location of plastic hinges in Frame E is identical to Frame D.

The first plastic hinge in Frame E occurs at a considerably higher lateral load than in Frame D. This is due to the initially lower axial load ratio in the leeward column. The instability load occurs with the formation of the third plastic hinge and considerably before the mechanism load.

3. TEST TECHNIQUE

3.1 Loading

Initially, the vertical beam and column loads will be applied. The beam loads will be maintained at their initial values throughout the duration of the test but the column loads will be adjusted to obtain the desired axial load ratio on each column during the tests. For Frame D, the column loads will be controlled to maintain constant axial load ratios of 0.25, 0.50 and 0.75 in the windward, the interior and the leeward restrained columns, respectively. For Frame E, the axial loads will be gradually varied to satisfy the axial load ratios at every stage of lateral loading, following the program as shown in Fig. 2.

The horizontal load will be applied to the top of the interior column and distributed to the windward and leeward columns through connecting struts as shown in Fig. 1. By varying the sway displacement of the column tops, the lateral load will increase to the stability limit load and then decrease again.

3.2 Test Equipment

The same general test equipment will be used in the tests of Frames D and E as was used for the tests of Frames A, B and C.[8] The vertical beam loads will be applied to the frame through a spreader beam which is attached to a gravity load simulator. The column axial loads will be applied through pins which are connected to the top of each column, by means of two gravity load simulators, one placed on either side of the column.

The horizontal load will be applied by a mechanical screw jack attached to the top of the interior column. Two struts will be placed between the column tops to maintain nearly equal sway deflections of each of the columns. The test frames will be assured of in-plane deformation by the use of lateral braces.

3.3 Instrumentation

Calibrated dynamometers will be used to measure the applied loads. Strains, rotations and deflections will be read from electrical gages attached to test frames. As used in the tests of Frames A, B and C, all readings will be monitored automatically and stored on punched data cards. This will permit the systematic reduction of data by a computer program.

4. SUMMARY

Two two-bay one-story assemblage tests are proposed. The lateral-load versus sidesway deflection behavior of the one-story assemblages will be studied. The experimental results will be compared with the theoretical predictions of the sway subassemblage method.

One frame will be subjected to a constant axial load ratio in each column and increasing horizontal loads. For the other frame, the axial load ratio on each column will be varied during the application of lateral loads, following a predetermined load program.

The proposed tests will provide the load-deflection behavior and failure characteristics of one-story assemblages and the effect of the variation of axial loads in columns on the load-deflection behavior. In consequence, this study will provide an experimental verification of the load-deflection analysis of one-story assemblages using sway subassemblage theory. This verification is an important second step in the verification of the sway subassemblage method of analysis as a useful method in the design of unbraced multi-story frames.

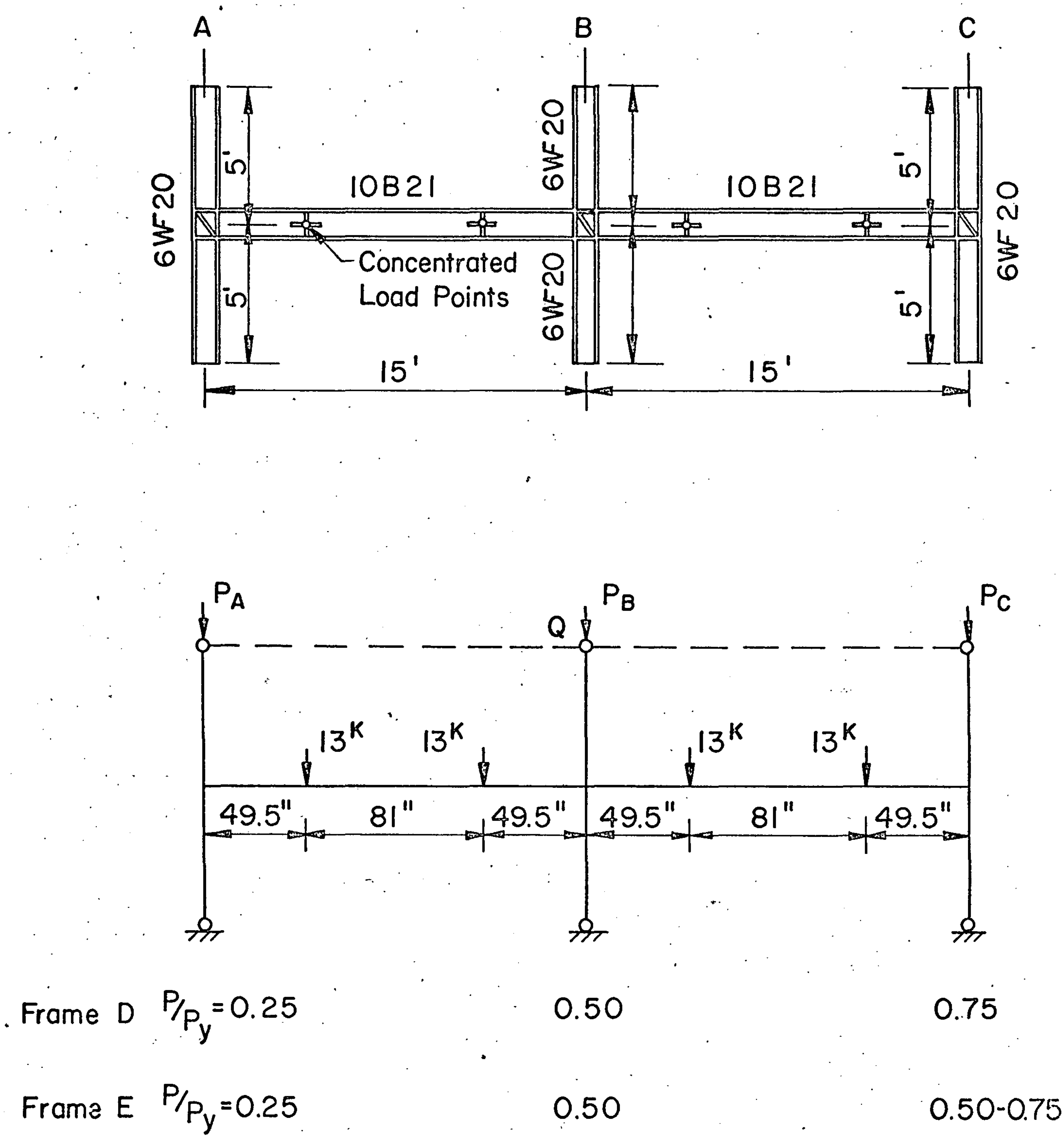

FIG. 1 TEST FRAME AND LOADING FOR FRAME D AND FRAME E

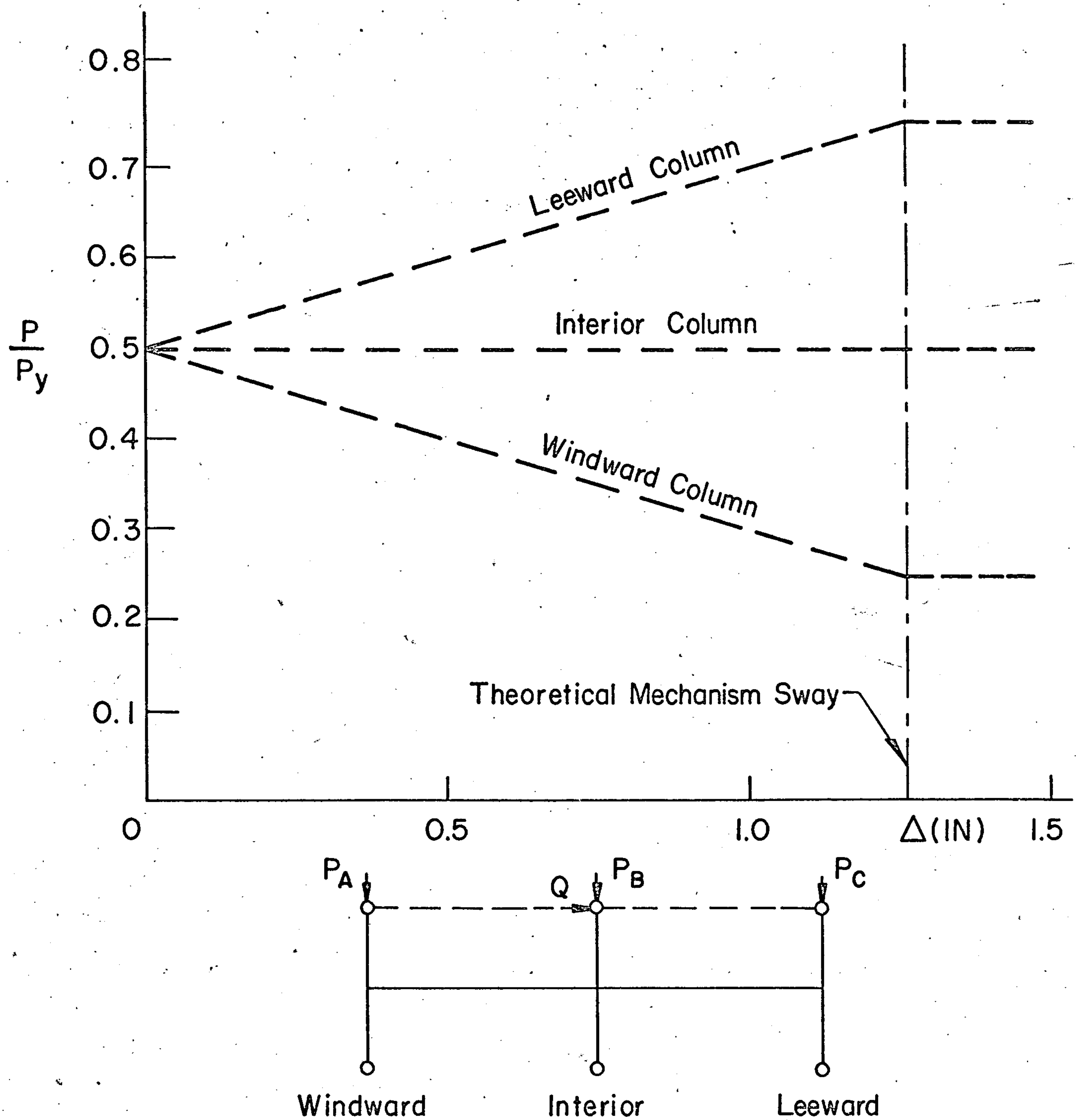

FIG. 2 COLUMN AXIAL LOAD PROGRAM FOR FRAME E

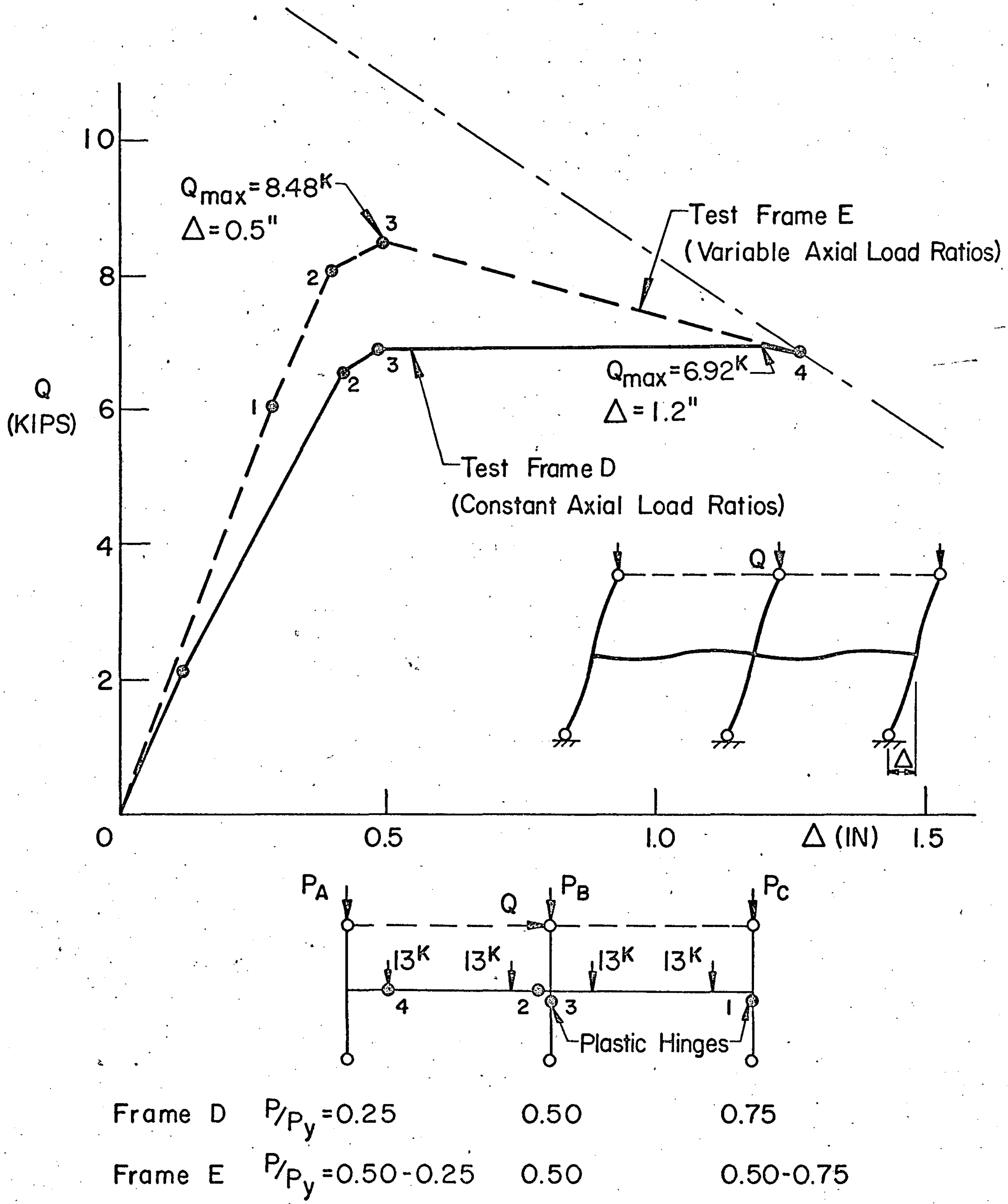

FIG. 3 THEORETICAL LOAD-DEFLECTION CURVE FOR FRAMES D AND E

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