COLUMN TEST PROPOSAL

INTRODUCTION

Recent theoretical investigations at Lehigh University[1] have shown that the critical combination of axial load, bending moment and slenderness ratio can be predicted for beam columns subjected to bending moments in the plane of the web, provided the members are sufficiently restrained against lateral movement. More recent work, as yet unpublished, shows that for certain conditions of loading the column strength can be predicted even when lateral-torsional buckling is permitted. Theory has been compared, where this was applicable, to test results, and the correlation has been good.

The attention of the majority of the former work at Lehigh and elsewhere has been concentrated, both in theory and experiment, on determining for a given slenderness ratio the combination of moment and axial force which causes the inception of instability. Very little attention has been given to what happens to the column after buckling has started*. The deflections and end-rotations measured at the time when the column

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* An exception to this is Progress Report R, "Moment Rotation Characteristics of Beam-Columns", by Robert L. Ketter and Lynn S. Beedle, Fritz Laboratory Report No. 205A.11, November 1952.

(1) Galambos, T. V., Ketter, R. L., "Columns Under Combined Bending and Thrust", Progress Report No. 26, Fritz Engineering Laboratory Report No. 205A.21, April 1956.

reaches its maximum strength are relatively small. However, if the column is part of a frame which has been designed by the plastic method, the possibility exists that its end may have to sustain rotations of considerable magnitude in order to develop the remaining plastic hinges in the structure. The question with which the tests proposed herein are concerned is the extent to which these columns can maintain their maximum strength level.

OBJECTIVE OF THE PROPOSED TEST SERIES:

The objective of the tests is to determine the influence of the following variables on the behavior of beam columns, with special emphasis being placed on the observation of the behavior of the columns after their maximum strength is reached, that is, to determine the amount of inelastic end-rotation the member can undergo at near maximum loads. At the present time no adequate theory is available for this.

The variables will be:

1. Loading Condition
2. Lateral bracing
3. Slenderness-ratio
4. Ratio of P/P_y
5. Cross-sectional shape

It should be pointed out that information obtained from the previous test series December 14, 1951 (refer to Proposal) can answer certain of these questions for relatively low axial thrust values ($\frac{P}{P_y}$ = 0.12). It is necessary, however, to study this problem for higher values of this parameter.

PROPOSAL

It is proposed to test a limited number of full sized columns to destruction. The data pertaining to these tests are listed on Table 1. The variables to be studied in each test series are summarized in Table 2. Table 3 illustrates graphically where certain of the tests would "fall" on the interaction curves(1).

1) Loading Conditions

The loading conditions to be considered are shown diagrammatically in Figure 1.

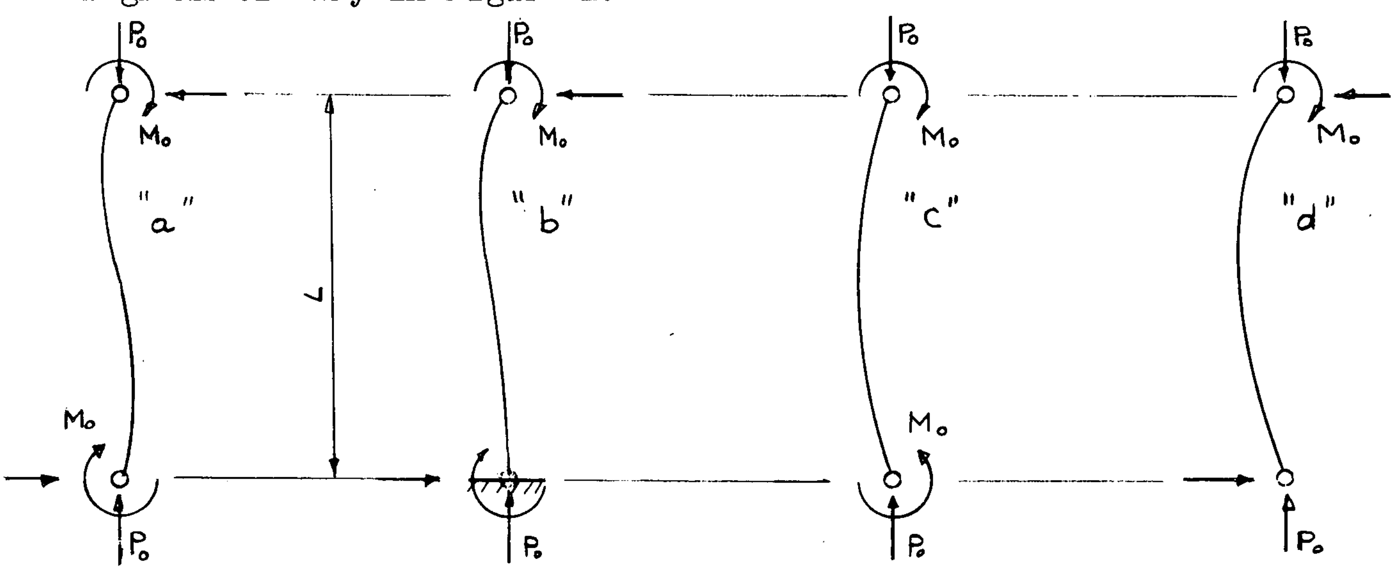

Figure 1

Fifteen of the twenty tests that have been proposed will be loaded in a condition "d" manner. Three condition "c" tests are planned and one test each for loading conditions "a" and "b" have been suggested. The predominance of condition "d" tests is because of its correspondence to the columns in a pinned-base frame. Condition "c" rarely occurs in practice, and considerable information is already available on columns loaded in this manner[1].

It should be noted that for all of the tests, the plane of bending will be the plane of the web (i.e. strong axis bending).

2) Loading Sequence

The sequence of loading which will be employed is the following: A constant axial thrust, the non-dimensional magnitude of which is given in Table 1 as the ratio P_o/P_y, will first be applied to the column. Bending moments will then be imposed and will be increased until the member fails. The anticipated end-moments (in non-dimensional form) are also tabulated in Table 1 as the ratio M_o/M_p.

3) Material

The columns are to be of as-rolled, mild structural grade (A-7) steel. The following three shapes will be used:

8WF31

4WF13

8B13

The 8WF31 and 4WF13 material is available in the laboratory and is from the same heat as the members tested in the previous column test series. Material properties, residual stress measurements, stub column tests, etc., have been carried out for these materials and the information is available(2)(3). For the 8B13 members it will be necessary to purchase additional material.

4) Test Set-Up

It is proposed to carry-out the tests in the 5,000,000# Universal Testing Machine and to do so, it will be necessary to alter the available equipment. The general test set-up will be as shown in Figure 2 and will use the end-fixtures available from the previous test series(4). Figures 3, 4, 5 and 6 show the details of the proposed set-up in the testing machine.

5) Lateral Support

In eighteen of the twenty tests, lateral bracing will be provided at the points indicated in Tables 1 and 3, to insure

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(2) Huber, A. W., and Beedle, L. S., "Residual Stress and the Compressive Strength of Steel", (Final Report on Pilot Program) Welding Journal, 33(12), p. 589-s, December 1954.

(3) Ketter, R. L., Beedle, L. S., and Johnston, B. G., "Column Strength Under Combined Bending and Thrust", Progress Report No. 6, Welding Journal, (31(12) p. 607-s, December 1952

(4) Beedle, L. S., Ready, J. A., and Johnston, B. G., "Tests of Columns Under Combined Thrust and Moment", Progress Report No. 2, SESA Proceedings, 8(1), p. 109, December 1950

failure of the member by excessive deflections in the plane of the applied moments. The unsupported lengths have been chosen such that they approximately correspond to recommendations for unsupported length of beams that have been previously proposed.

$$\frac{L}{r_y} = 60 - 40 \frac{M}{M_p} \quad (5)$$

The details of the lateral support system are shown in Figure 7.

6) Data

The following data will be taken during the tests:

a. end bending moments,

b. axial thrust

c. deflections along the length of the member in the plane of bending,

d. end-rotations,

e. lateral deflection and twist at certain points along the length of the member, and

f. bracing forces required at the points of support, (see Figure 7).

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(5) "Plastic Design in Steel" American Institute of Steel Construction (Manuscript copy), New York, 1958

(b) No need to test because we believe it would not exhibit needed strength and rotation capacity

(c) Most needed, perhaps — Longer L/r checked theory of strength and longer L/r (60) correlated with theory.
Defer pending Theo study RC.

(d) Replaced by A6

(e) Plenty of strength data from other tests
RC for "C" column is passé

205A.22 6-23-58

7/18/58 Ltr File
Rev. See 7/20/59 attached
See 3/31/59

TABLE 1

Test Number	Loading Condition	Test No	Section	Axial Load Ratio, P/P_y	Expected Maximum Moment, M_o/M_p	Slenderness Ratio L/r_x (Length between knife edges)	Slenderness Ratio L/r_y (Actual Column Length)	Lateral Bracing
~~1~~	~~"d"~~		~~8WF31~~	~~0.3~~	~~(0.75)~~	~~59~~	~~96~~	~~None~~ (b)
2	"d"	A3	8WF31	0.3	0.78	59	96	*
3	"d"	A4	8WF31	~~0.4~~ 0.45	0.65	59	96	*
4	"d"	A4	8WF31	~~0.5~~	0.51	59	96	*
5	"d"	A2	8WF31	0.6	0.39	59	96	*
5a	a		8WF31	0.6		59		none
~~6~~	~~"d"~~		~~8WF31~~	~~0.6~~	~~0.46~~	~~45~~ 31	~~72~~	~~*~~ (c)
~~7~~ (a)	~~"d"~~		~~8WF31~~	~~0.3~~	~~0.80~~	~~31~~	~~48~~	~~L/2~~
8	"d"	A1	4WF13	0.3 ✓	0.66	90	145	*
~~9~~	~~"d"~~	~~A6~~	~~4WF13~~	~~0.5~~	~~0.36~~	~~90~~	~~145~~	~~*~~ Delete (d)
10	"d"	A5	4WF13	0.3	0.48	118	194	*
11	"d"	A7	4WF13	~~0.4~~ 0.15	0.24	118	194	*
11a	d	A6	4W13	~~0.6~~ 0.5	(?)	118	194	
12	"d"		8B13	0.3	0.78	60	232	*
13	"d"		8B13	0.4 (.45)	0.64	60	232	*
14	"d"		8B13	0.5 (.45)	0.52	60	232	*
15	"d"		8B13	0.6	0.39	60	232	*
~~16~~	~~"c"~~		~~4WF13~~	~~0.3~~	~~0.46~~	~~90~~	~~146~~	~~*~~ Delete (e)
~~17~~	~~"c"~~		~~4WF13~~	~~0.3~~	~~0.50~~	~~63~~	~~97~~	~~None~~ Delete (e)
~~18~~	~~"c"~~		~~4WF13~~	~~0.3~~	~~0.61~~	~~63~~	~~97~~	~~*~~ Delete (e)
19	"a"		4WF13	0.3	0.80	90	146	* Same as 5a
20	"b"		4WF13	0.3	0.75	90	146	* Defer until Rev. ...

This should be done. ... Rest ... (c)

* Determined by the method of Ref. 5.

(a) only if A1 & A2 show ... value

TABLE 2

Test Number \ Variable	Loading Condition	Ratio of P/P_y	Slenderness Ratio	Cross-Sectional Shape	Lateral Bracing
1					x
2		x	*	x	x
3		x		+	
4		x		*	
5		x	x	o	
6			x		
7			*		
8	x	*	o		
9		*			
10		o	o		
11		o			
12		+		x	
13		+		+	
14		+		*	
15		+		o	
16	x		+		
17					*
18			+		*
19	x				
20	x				

NOTE: On any one column of this table (i.e., for the investigation of a particular variable) corresponding tests are denoted by the same symbol.

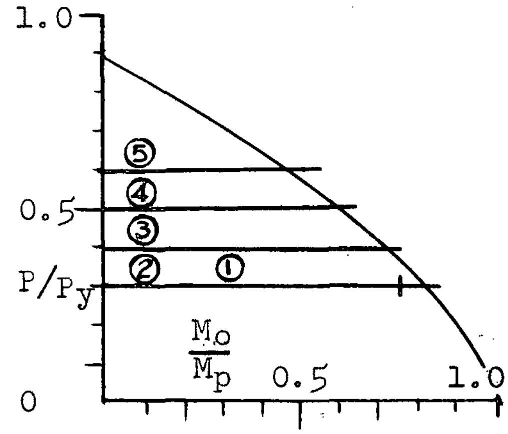
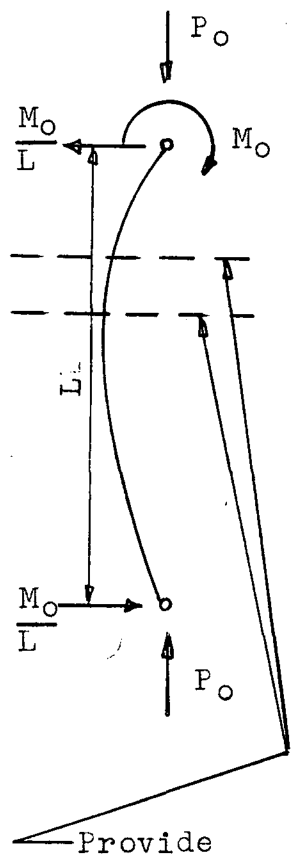
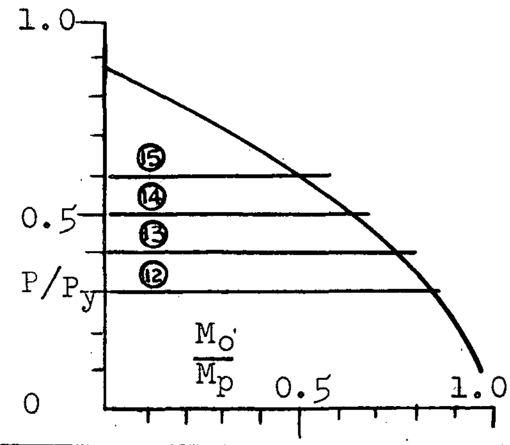
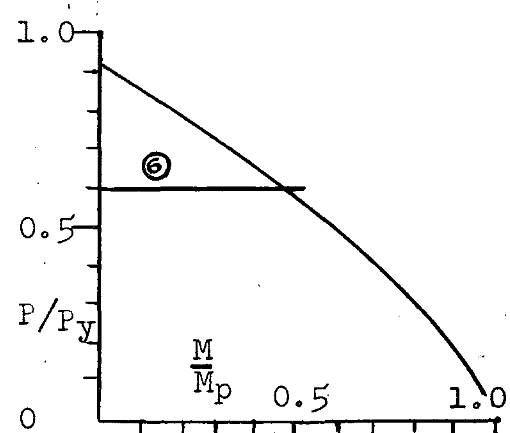
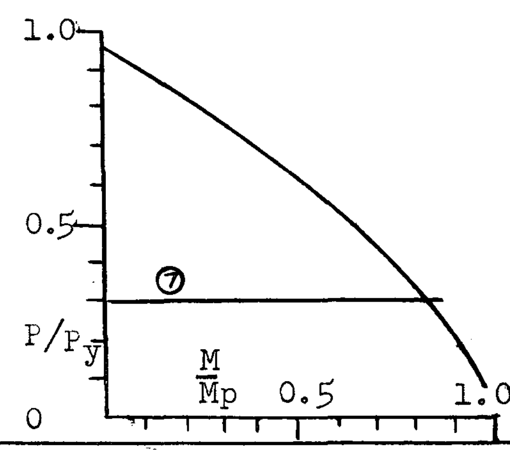
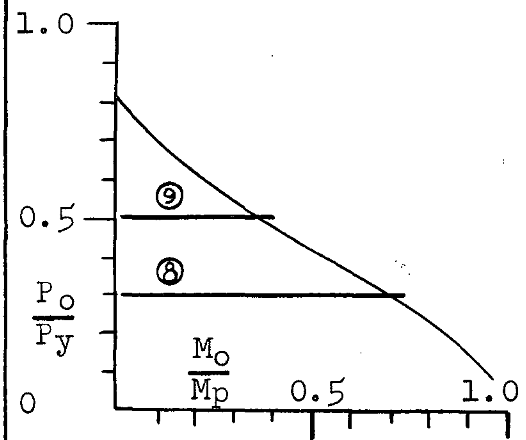
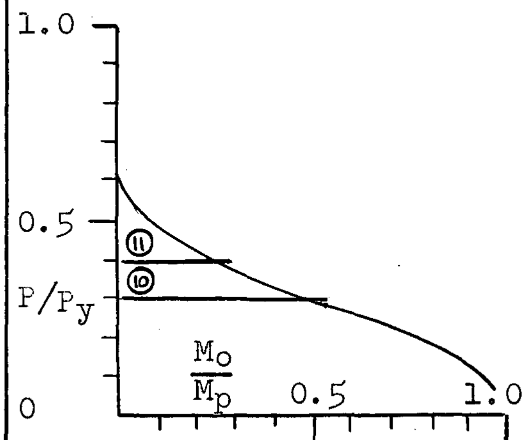
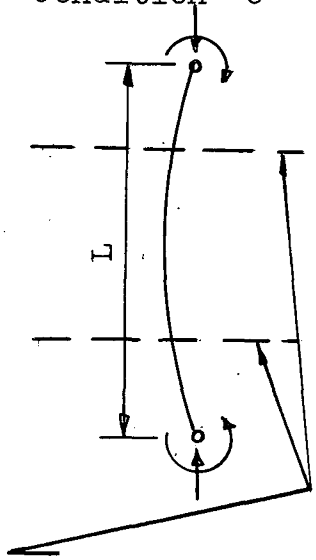
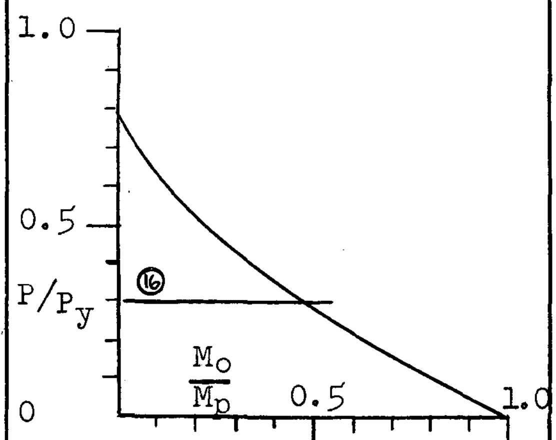
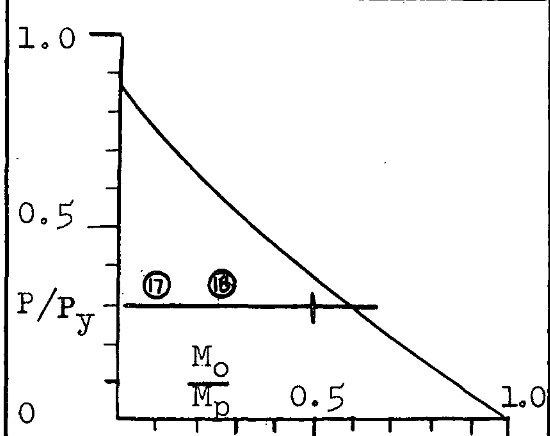
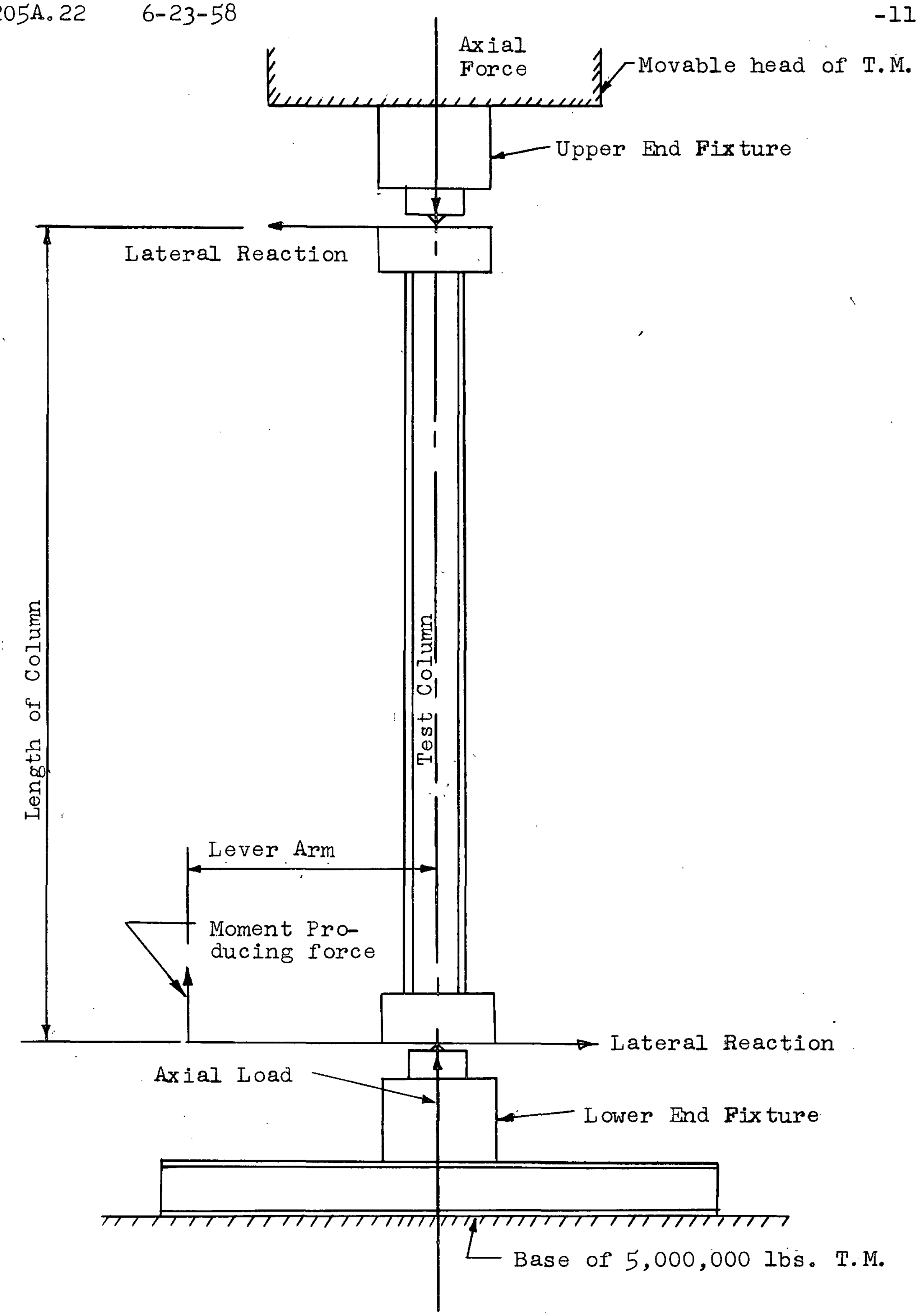
Test No.	Loading Condition	Section	L/r_x	Location of Test on Interaction Curve
2 3 4 5 (1)	Condition "d"	8WF31	59	
12 13 14 15		8B13	60	
6		8WF31	45	
7	Provide lateral support as needed by Ref. 5 or as specified in Table 1.	8WF31	31	

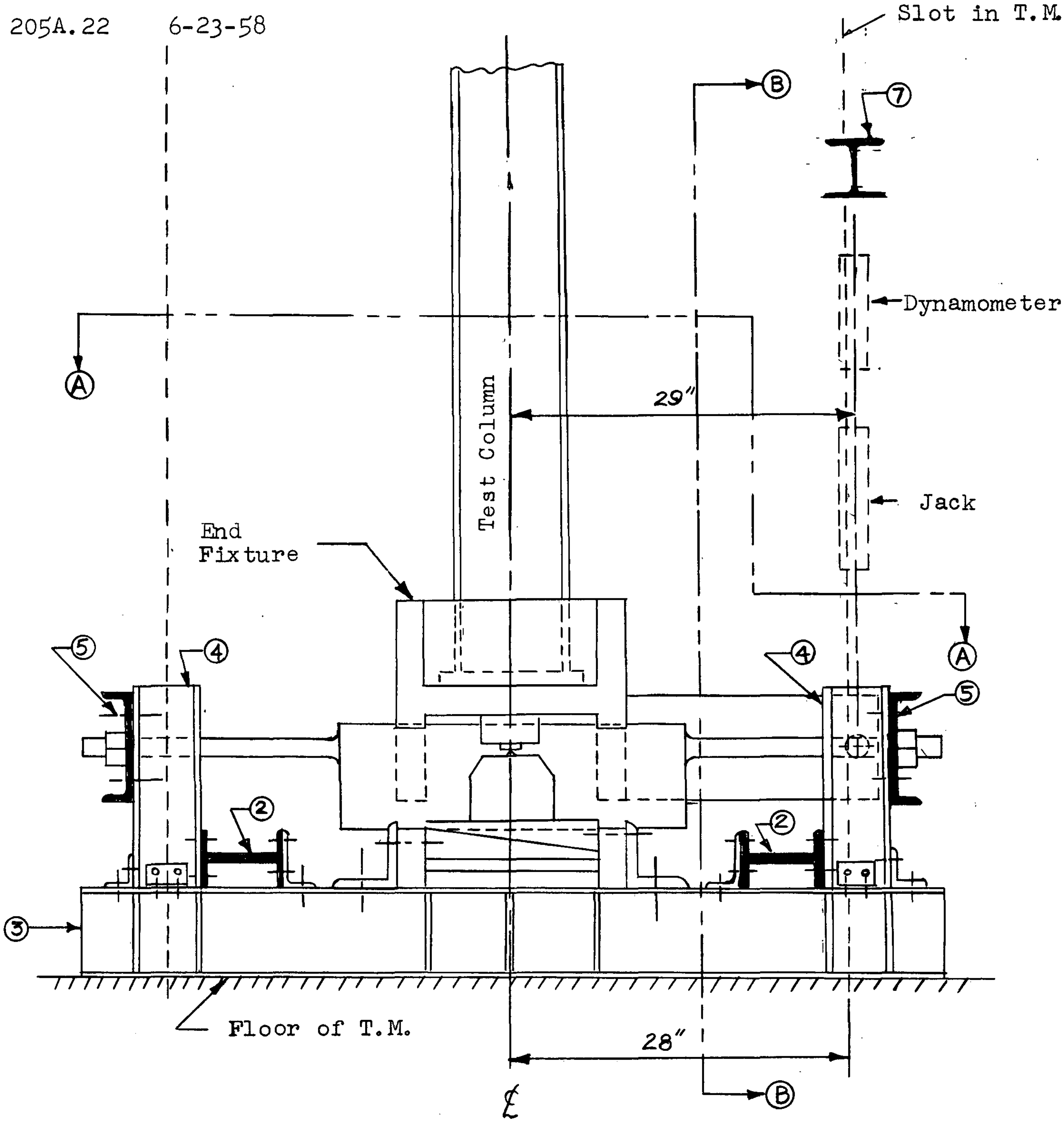
Table 3 (cont.)

Test No.	Loading Condition	Section	L/r_x	Location of Test on Interaction Curve
8 9	Condition "d" as shown on previous page	4WF13	90	
10 11		4WF13	118	
16	Condition "c" 	4WF13	90	
17 18	Lateral Support (determined by Ref. 5 or as specified in Table 1.	4WF13	63	



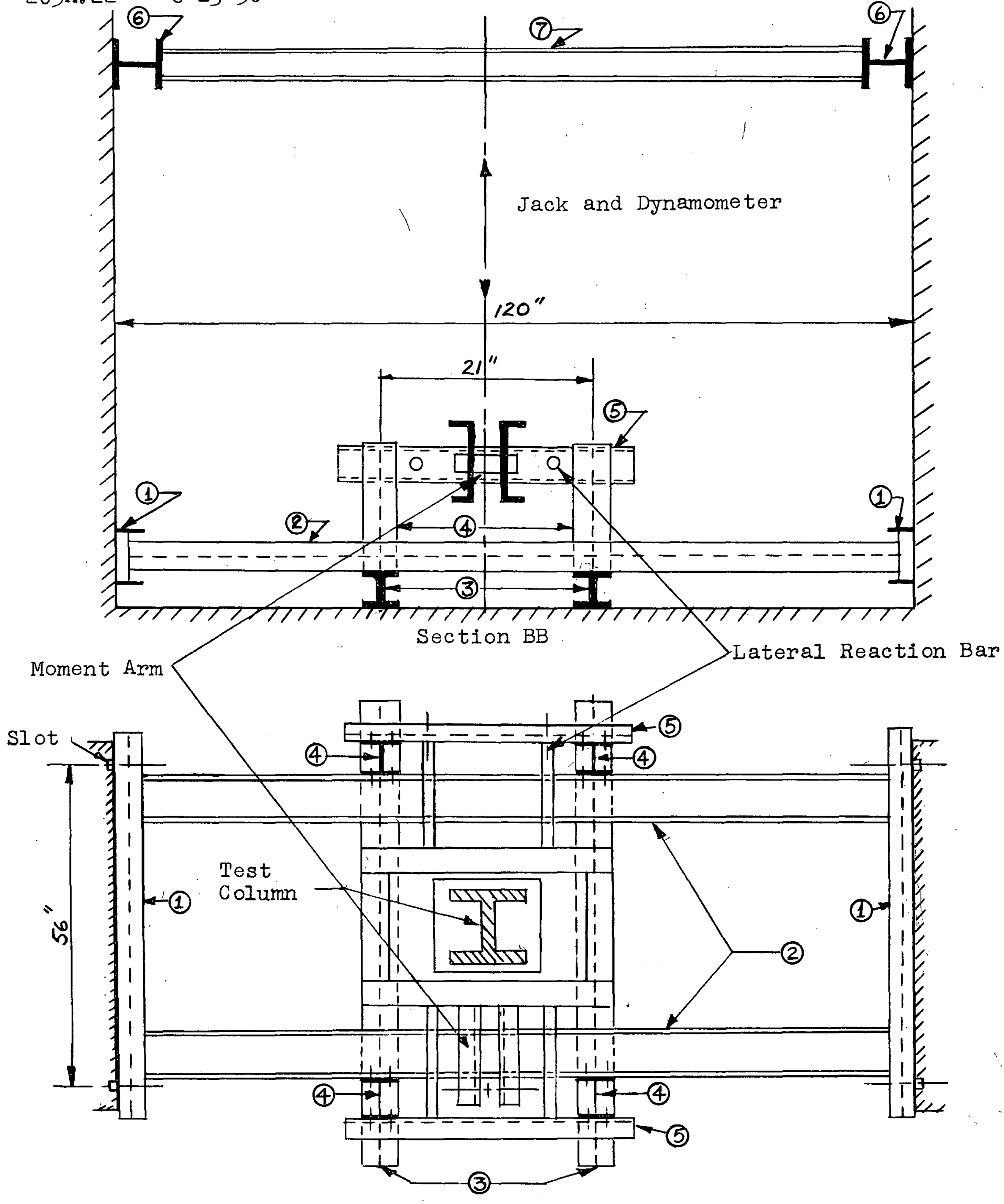
Condition "d" Test Scheme

Figure 2



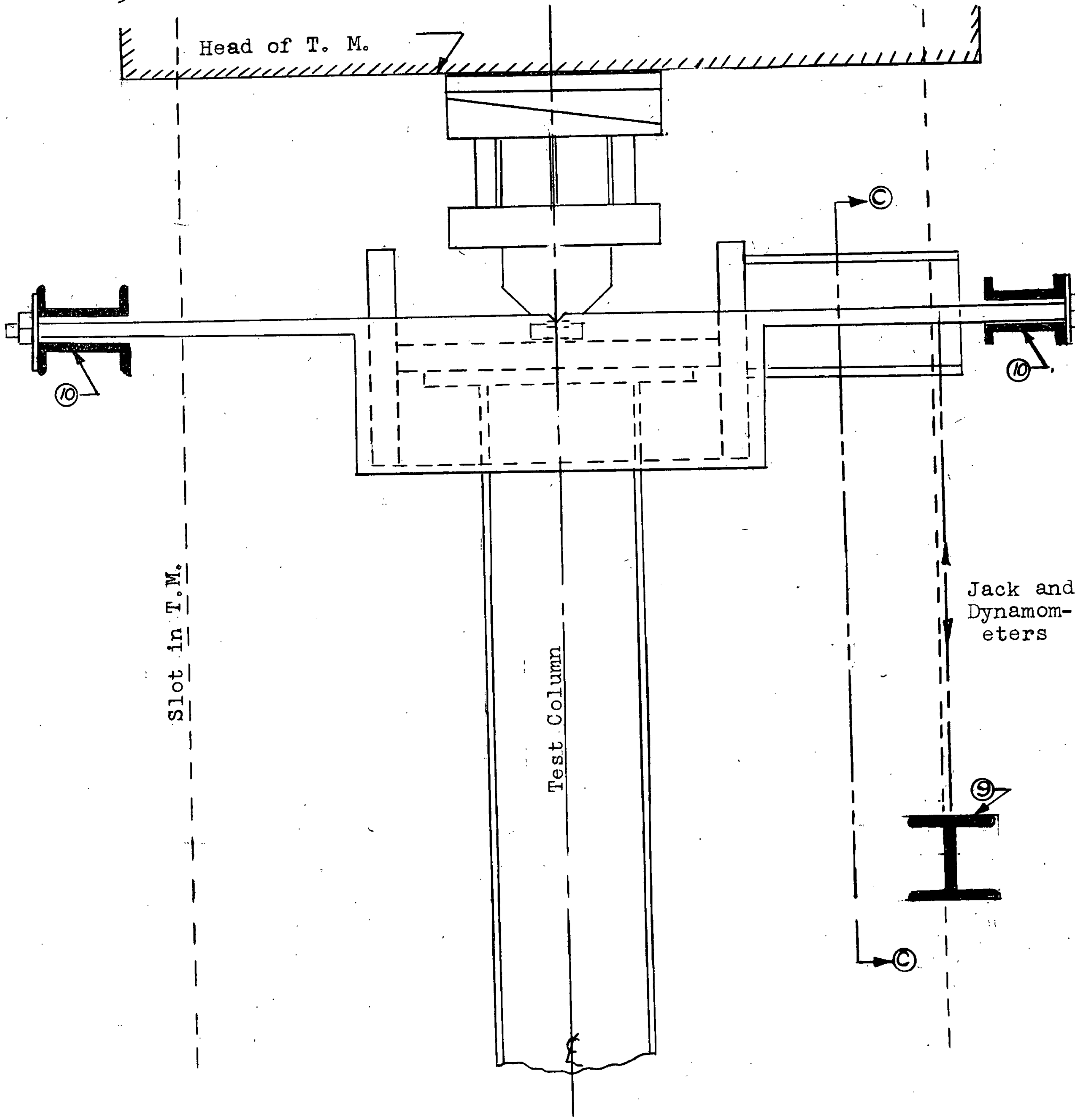
Lower Test Set-up

Figure 3



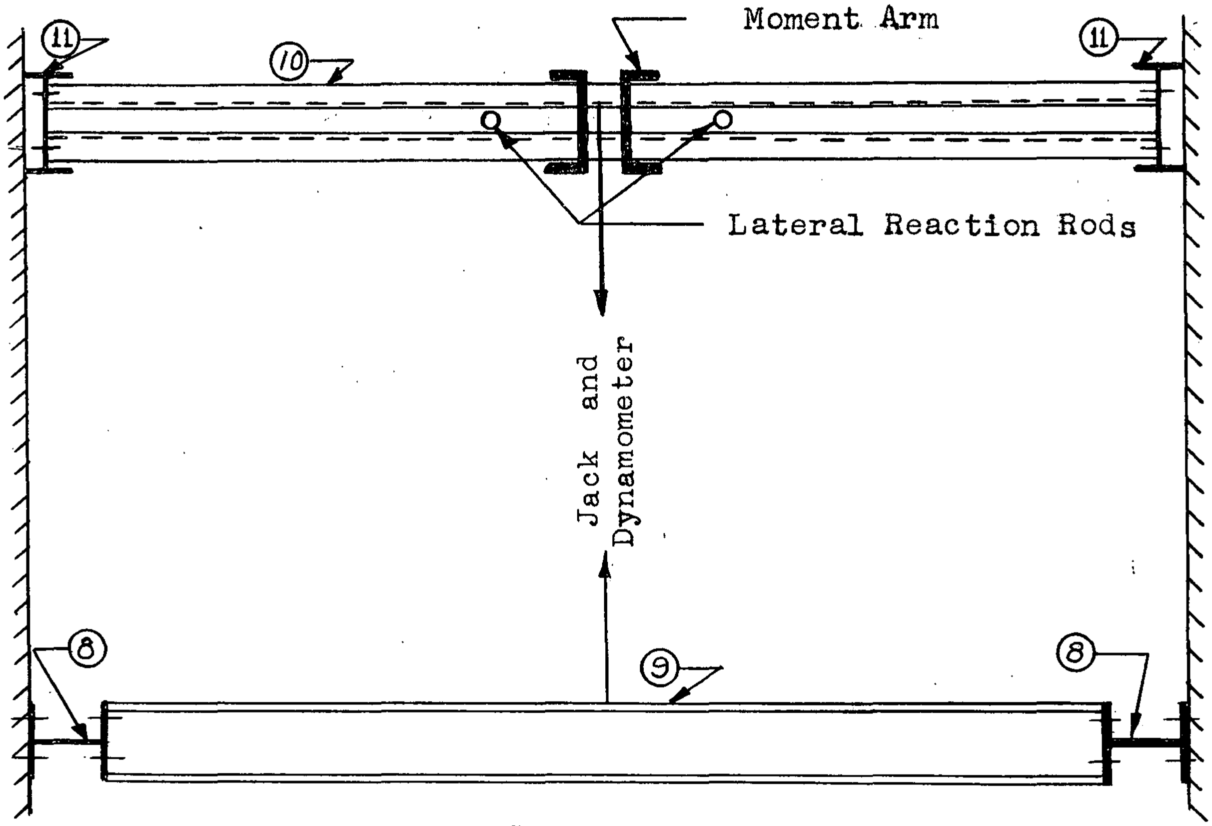
Section AA

Figure 4



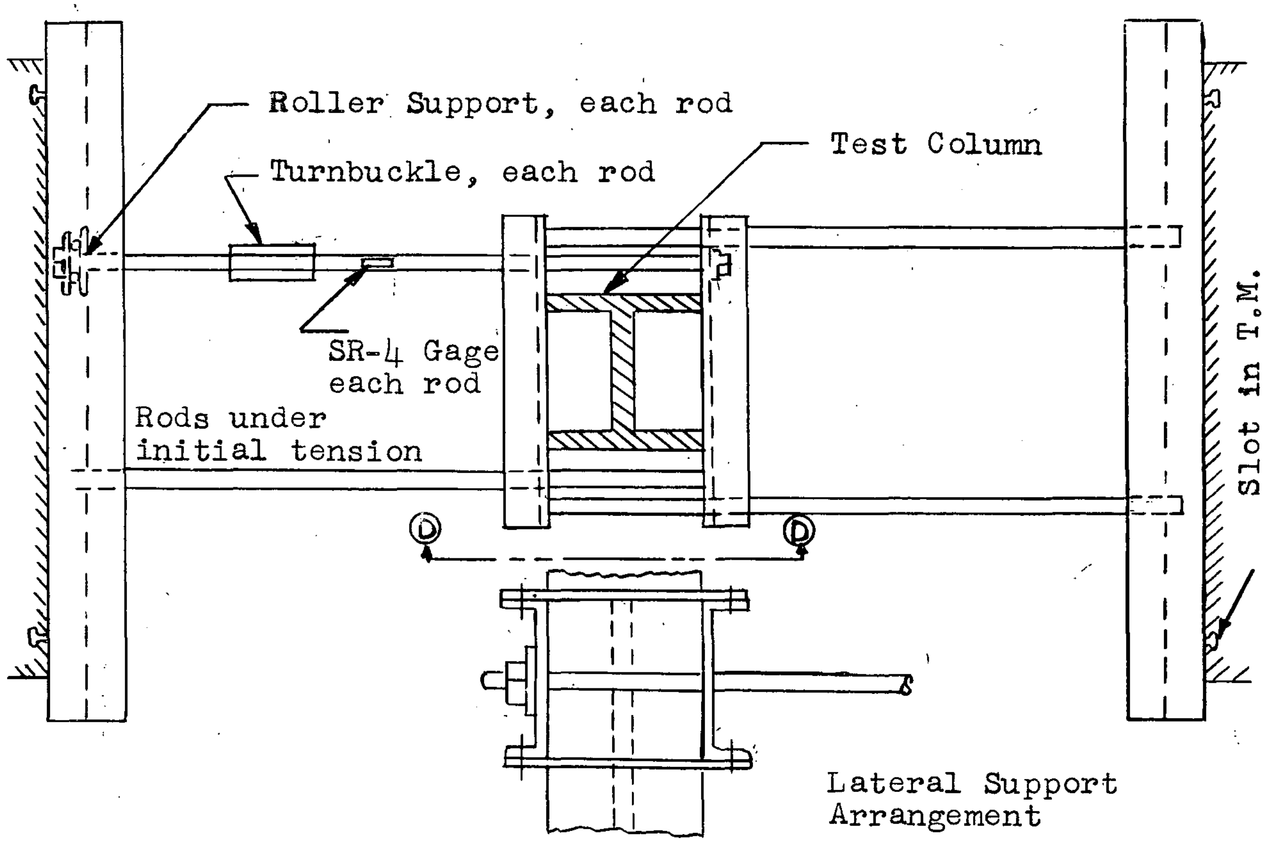
Upper Test Set-up

Figure 5



Section CC

Figure 6



Lateral Support Arrangement

Section DD

Figure 7

L.S. Beedle

(1) TVG
(2) LSB

Excellent ltr. pls see last page

See corrections on last page.
TVG

File: 205A July 20, 1959

Mr. T. R. Higgins
Director of Engineering and Research
American Institute of Steel Construction
101 Park Avenue
New York 17, New York

Dear Mr. Higgins:

We are planning to conduct three further column tests in the 205A column test program (outlined in the proposal 205A.22) within the following several weeks. The pertinent data are:

Length of column: 16'-0"
Size of section: 4WF13
Strong Axis slenderness ratio: 111
Weak Axis slenderness ratio: 185
Loading condition: "d" (bending moment applied at one end only.)

Lateral bracing will be provided for each specimen in accordance with the AISC Plastic Design Manual beam-bracing rules. The axial load ratios will be the following: $P/P_y = 0.3$, 0.5 and 0.15. Originally (see p. 7 of 205A.22) only two tests were proposed for this slenderness ratio (tests 10 and 11 at $P/P_y = 0.3$ and 0.4), but you had suggested in your letter of July 18, 1958 to Dr. Beedle that we add one test, with a P/P_y ratio of 0.6. However, at this high axial load we would be very close to the strong axis Euler buckling load of the column, and so can expect very little, if any, bending resistance. (Weak axis buckling would be no problem because of the lateral bracing). For this reason it was decided to use $P/P_y = 0.5$ as the axial load for one of the tests. This would give us a sufficiently high axial force and yet some moment capacity.

The test with $P/P_y = 0.15$ is included to give us information about rotation capacity at low axial force. We have no reliable information about this, since in the previous test-series lateral-torsional buckling was not prevented.

On one of the enclosed sheets I have marked as an interaction curve the already performed tests in black, and the three proposed tests in red.

On the other enclosed sheet I have shown a table giving the axial load ratios, the slenderness ratios and the rotation capacities of the tested columns. On a graph I have shown the variation of the rotation capacity with axial force. For the presently proposed tests I am very much interested to find out if the rotation capacity still varies linearly at a $P/P_y = 0.15$. In this graph the rotation capacity is defined as shown on the sketch of a moment-end rotation curve at the bottom of the sheet. In this curve, θ_T is the total rotation to the start of local buckling and rapid unloading, at about 96% of the maximum moment.

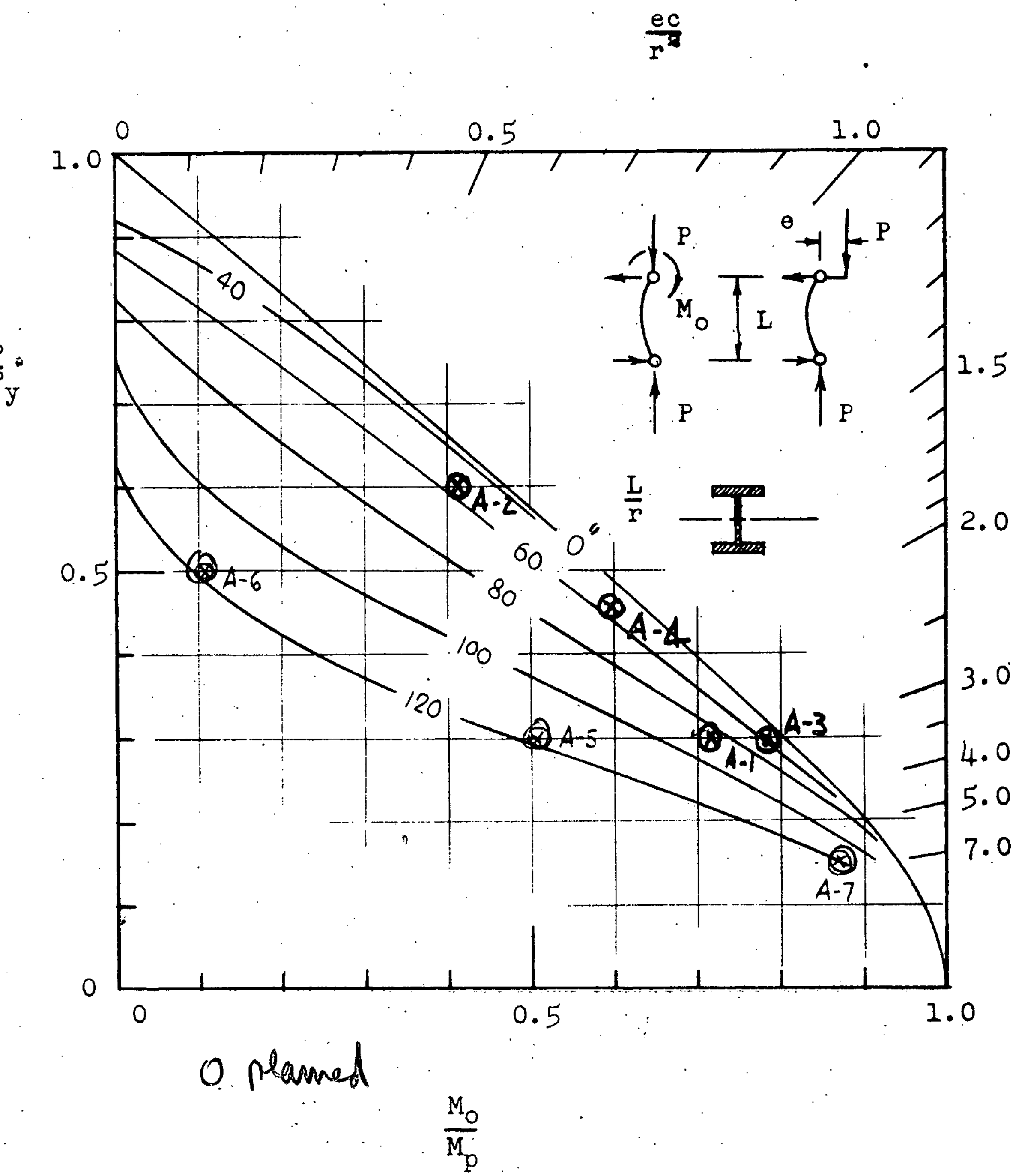
I would be happy to receive an further suggestions that you may have with regard to these tests.

Sincerely yours,

Theodore V. Galambos
Research Ass't. Professor

TVG:cid
cc: Dr. Lynn S. Beedle

Enclosure



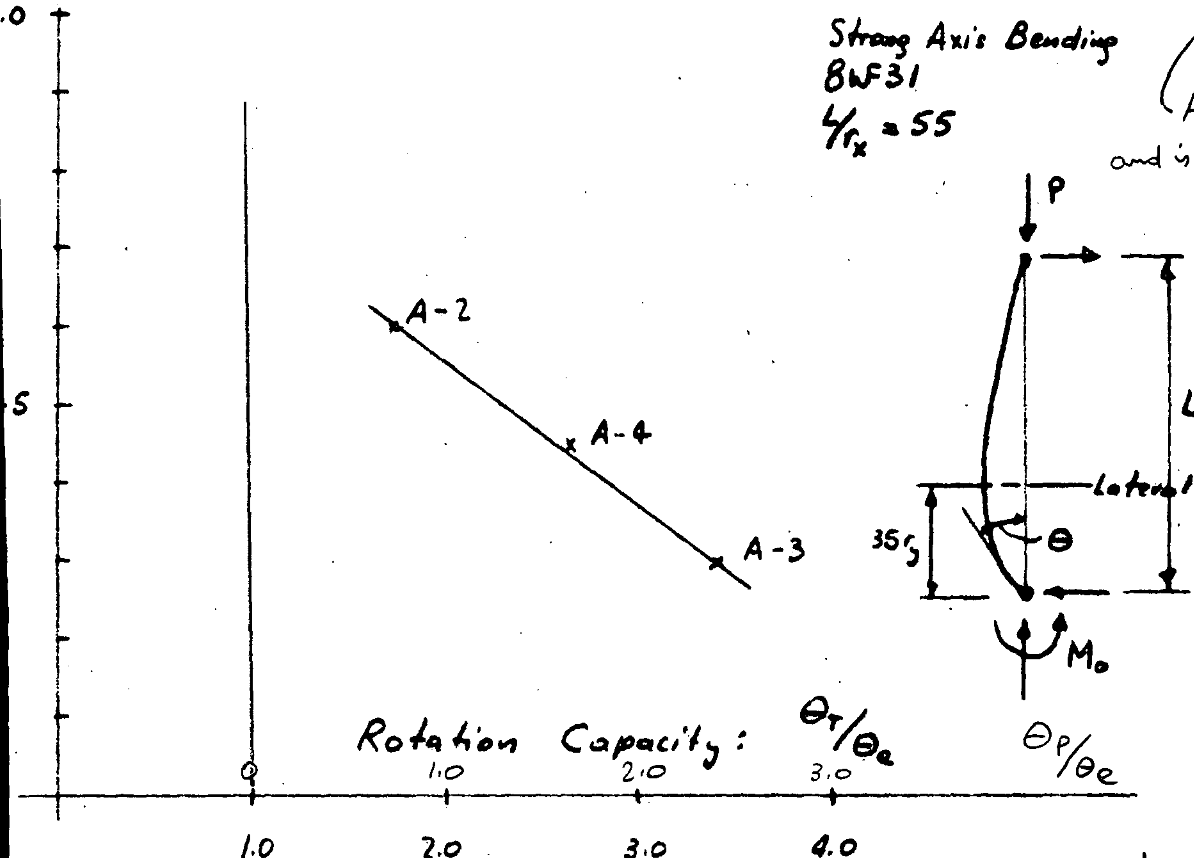
O planed

~~Fig. 7 MAXIMUM CARRYING CAPACITY INTERACTION CURVES FOR CONDITION "a" LOADING (INCLUDING THE INFLUENCE OF RESIDUAL STRESS)~~

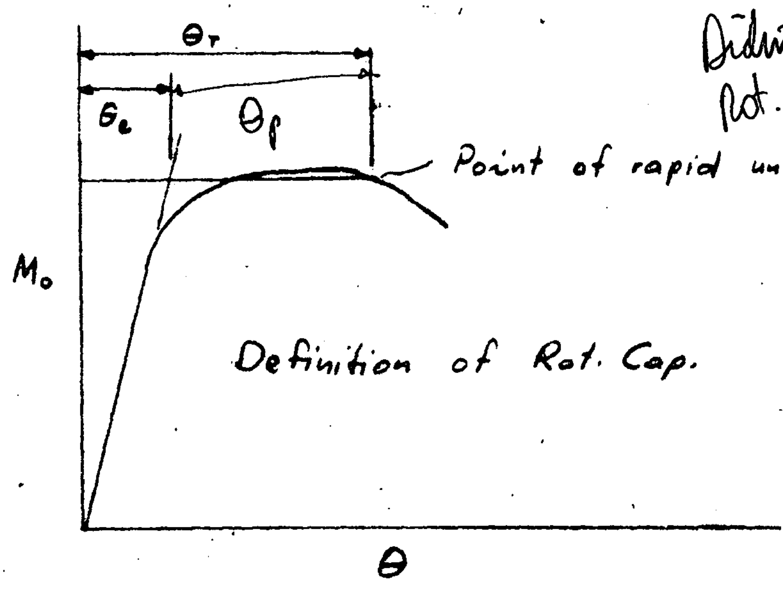
Test No.	P/P_y	L/r_x	Rot. Cap.	θ_p/θ_e
A-1	0.3	84	3.4	2.4
A-2	0.6	55	1.8	0.8
A-3	0.3	55	3.4	2.4
A-4	0.45	55	2.7	1.7

where does A1 plot?

A-1 has $L/r = 84$ and is not plotted here.



Didn't we agree that Rot. cap. function would be in terms of θ_p?



Definition of Rot. Cap.