EFFECT OF RESIDUAL STRESSES ON THE CAPACITY OF BATTENED COMPOSITE COLUMNS UNDER MINOR AXIS BENDING

BY:

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To my family and all my friends

The Examining Committee considers this thesis satisfactory and acceptable for the award of the Degree of Master of Science in Civil Engineering

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ABSTRACT

A computer program for calculating the effect of residual stresses on the maximum strength of pin-ended battened composite columns, subjected to uniaxial bending about minor axis is presented.

The method is based on classical inelastic column theory, using the well known Newmark method of numerical integration.

Five selected sections will be analyzed, for each section five slenderness ratios and five eccentricity cases will be considered.

The sections will be analyzed with and without residual stresses.

The effect of concrete strength and steel strength; on the effect of residual stresses on the maximum strength are investigated in this study.

ACKNOWLEDGEMENT

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LIST OF TABLES

NOTATION

A_c	Area of concrete
A_s	Total cross sectional area of structural steel
B	Width of channel section
D	Depth of the column section
Dn	Depth of the nuetral axis.
E_c	Modulus of elasticty of concrete.
E_s	Modulus of elasticity of structural steel
e	Eccentricity of the load
F_s	Applied stress on the steel
F_c	Applied stress on concrete.
F_{cu}	28-day concrete cube strength.
H	Width of the column section.
L	Length of the column
M	Bending moment
M_u	Ultimate bending moment
n	Number of nodes along the column length
P	Axial load
P_u	Squash load of the column
S_i	Uncorrected slope at node position i
t_f	Thickness of the channel flange.
t_w	Thickness of the channel web

α_c	Concrete contribution factor
β	Eccentricity ratio; (small end bending moment divided by the larger one), $-1 \leq B \leq 1.0$
ϵ_c	Strain in concrete.
λ	Length of the column divided by number of nodes;L/n
μ	Numerical factor equal to $\sqrt{EI/P}$
Φ	Curvature

CHAPTER I

INTRODUCTION

1.1 GENERAL.

A composite steel-concrete column is a member with a cross-section consisting of steel section (or sections) and concrete which act together to resist axial compression and bending. Two types of composite columns are commonly used, these, as can be seen in Figure 1.1, are the steel sections encased in concrete and hollow sections filled with concrete. A new type of composite column, the battened composite column , has recently been suggested for use in multi-storey framed structures. It consists of two steel channels battened together to form a rectangular shape and then filled with concrete , this section is shown in Figure 1.2.

1.2 PREVIOUS RESEARCH.

In 1905, first recorded tests on built-up composite columns were carried out by Emperger [5]. This and other early investigation on the behaviour of this type of sections were essentially experimental and were confined to the case of conccentric loading only.

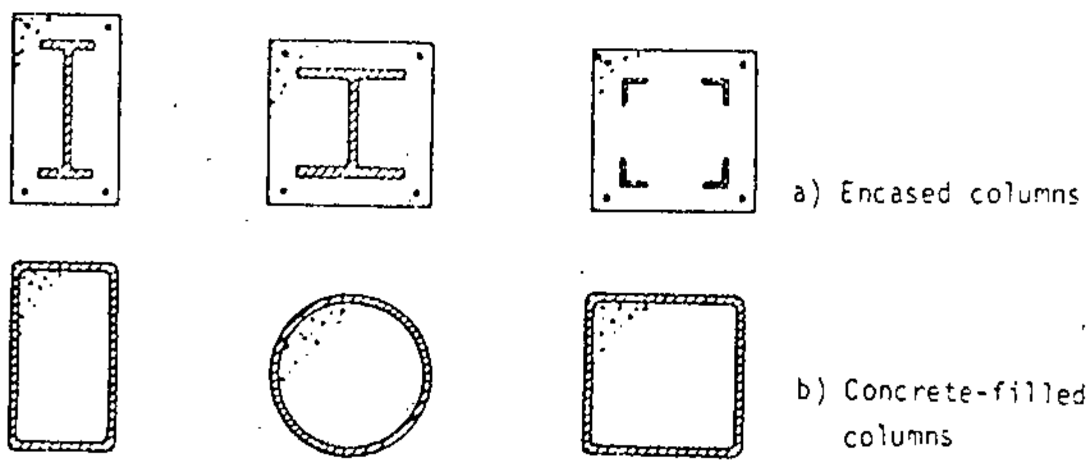

Figure (1.1) - Typical cross-sections of composite columns

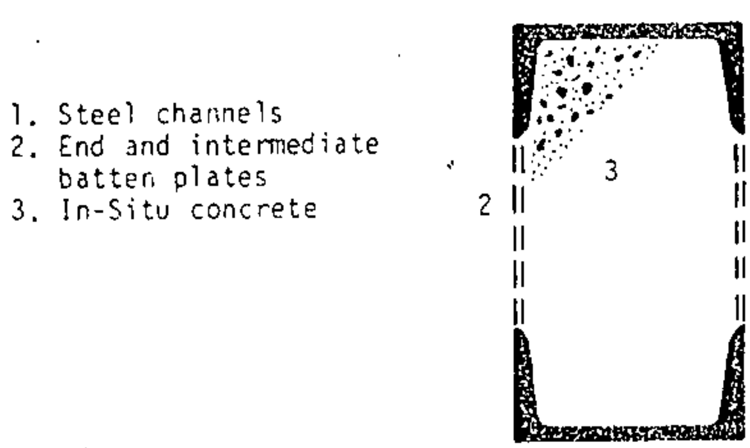

Figure (1.2) - Section in the battened composite columns.

Later in 1935, tests on encased built-up sections were carried out by Bondale [5] to investigate the behaviour of such members under eccentric loading. Since then, the research on the built-up composite columns has declined until, in the mid 1960's, some more tests were reported [3,4,9].

Furthermore, in the 1970's some experimental and theoretical works were carried out on such columns [5,15,16]. It should be mentioned that most of the studies on the behaviour of the built-up composite columns were dealt with built-up sections encased in concrete [3,4,5,6,13,15,16].

In 1980's, some tests were carried out at the University of Manchester, to investigate the behaviour of battened composite columns under eccentric loading [8,14]. Also some experimental and theoretical works were carried out at the University of Jordan to investigate the behaviour of the battened composite columns subjected to eccentric loading and biaxial bending [2,7,12].

Many experimental results with rolled or built-up short steel columns show lower critical loads than the theoretical results, because of early yielding in the cross-section due to residual stresses.

Recent research was carried out by Litzner and Crisinel [10] to investigate the effect of the residual stresses in steel sections on the load carrying capacity of steel concrete composite columns. It was concluded that the effect of residual stresses on the carrying capacity of composite column is less than that on a bare steel column.

Table 1.1 : Summary of some of the references in previous research.

Author & reference number	Year	Type of column considered	Point of investigation
Faber [6]	1956	Cased stachions	General behaviour
Stevens [13]	1959	Encased stachions	General behaviour
Jones & Rizk [9]	1962	Encased stachions	General behaviour
Basu [3]	1967	Encased stachions	Failure loads
Basu & Hill [4]	1968	Encased stachions	Failure loads
Viridi & Dowling [15,16]	1973 1976	Encased and filled composite columns	Design methods and s-trength under biaxial bending.
Bridge & Roderick [5]	1978	Encased built-up columns	General behavbiour
Litzner & Crisinel [10]	1981	Encased and filled columns	Effect of residual s-tresses on th carryi-ng capacity
Tayler, Shakir and Yee [14]	1983	In-filled battened composite columns	General behaviour
Hunaiti [8]	1985	In-filled battened composite columns	General behaviour un-der large eccentric.
Ghanam [7]	1989	In-filled battened composite columns	General behaviour un-der biaxial bending
Ryalat, S. [12]	1990	In-filled battened composite columns	Failure loads under major axis bending
Al-Hallie [2]	1990	Inifilled battened composite columns	Failure loads under minor axis bending

1.3 OBJECTIVES OF STUDY.

No research has been carried out to investigate the effect of residual stresses on the ultimate strength of the battened composite columns .

The usual manner in the analysis is to use elasto-plastic stress-strain curve for steel, and assuming complete absence of residual stresses across the steel sections; however, since residual stresses are quite common in structural rolled steel and other sections, it is worthy to consider the effect of residual stresses on the ultimate load-carrying capacity of the battened composite columns. The subject of this investigation is to study the effect of residual stresses on the capacity of battened composite columns bending about minor axis.

CHAPTER II

MATERIAL PROPERTIES

The mechanical properties of steel sections and concrete affect the ultimate strength of battened composite columns, as any other structural members.

2.1 CONCRETE PROPERTIES.

The stress-strain curve for concrete used in the analysis is based on the experimentally observed relations of tested specimens.

The stress-strain relationship for concrete as it exist in the column under uniaxial bending differs from that of test specimens, it is a common practice to reduce the stress ordinate by a reduction factor; this factor usually has values varying between 0.8 and 0.9, and corresponds closely to that relating cylinder to cube strengths. Also the concrete strength varies throughout the column; an additional reduction factor on the cube strength is often used to account for this variation. The stress ordinate is usually reduced to two-third of the cube strength.

The stress-strain curve recommended by CP110 is shown in Fig. (2.1), and this will be used throughout this study. The parabolic part of the curve is represented by the following formula:

$$F_c = 0.67 F_{cu} \left[\frac{2\epsilon_c}{\epsilon_o} - \left(\frac{\epsilon_c}{\epsilon_o} \right)^2 \right] \qquad (2\text{-}1)$$

In which :

$$\epsilon_o = \frac{2 \times 0.67 F_{cu}}{E_c} \qquad (2\text{-}2)$$

$$E_c = 5500 \sqrt{F_{cu}} \qquad (2\text{-}3)$$

Where :

- E_c : Initial modulus of elasticity (N/mm^2).
- F_{cu} : Concrete cube strength (N/mm^2).
- ϵ_{cu} : Ultimate compression strain for concrete.
- ϵ_o : Concrete strain at begining of horizontal plateau.
- ϵ_c : Concret strain.

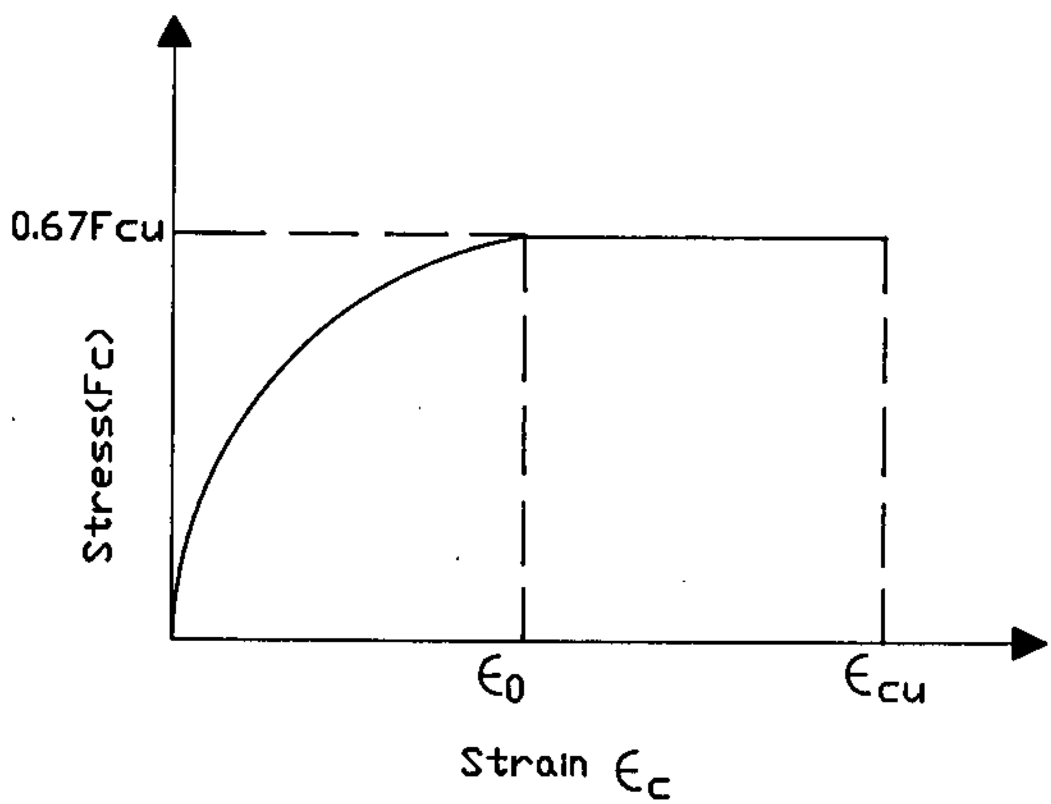

Fig.(2.1) Idealized stress-strain curve for concrete.

2.2 STEEL PROPERTIES.

Strength of structural steel members is most affected by the compressive yield stress.

Because of the risk of buckling in compression tests, it is therefore a general practice to determine material properties from the tension test and to assume identical behaviour in tension and compression.

For computational purposes, the stress-strain relationship is idealized. It is common practice to adopt an elastic-perfectly plastic (bilinear) curve for steel as shown in Fig. (2.2).

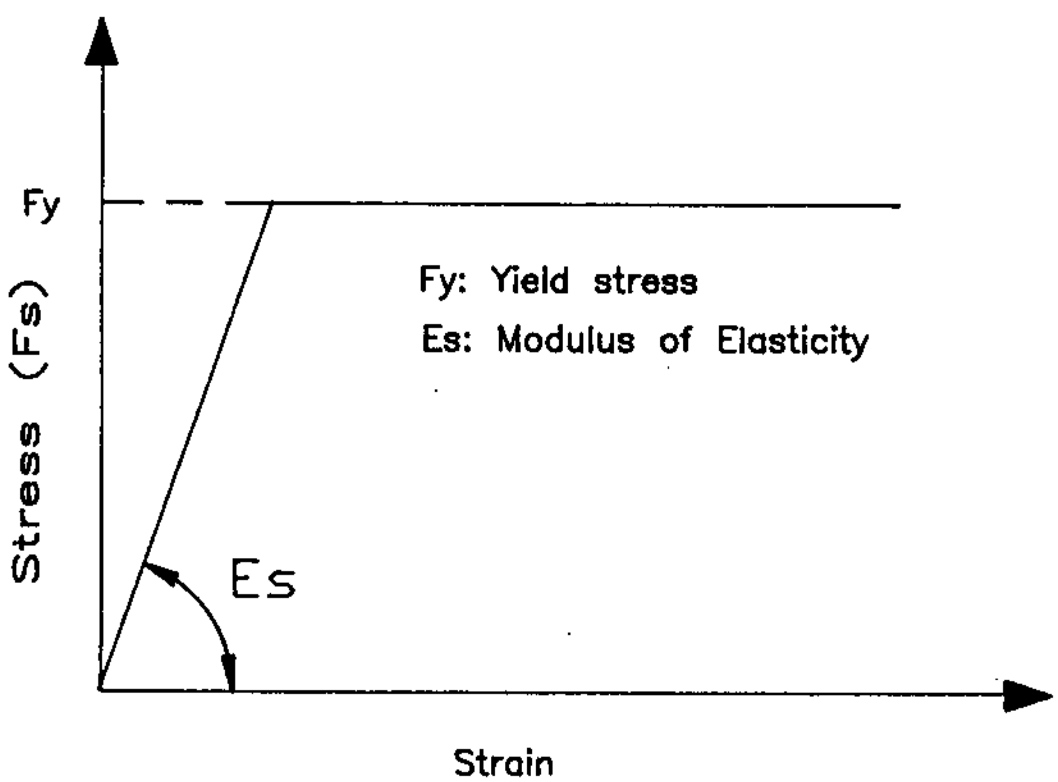

Fig.(2.2) Idealized stress—strain curve for steel.

2.3 RESIDUAL STRESSES.

Residual stresses are stresses that remain in unloaded member after it has been formed and erected.

Residual stresses resulted from plastic deformations which, in structural steel, may be caused by several sources, such as :-

- I : Uneven cooling, which occurs after hot-rolling of strucural steel shape.
- II : Cold bending or cambering during fabrication.
- III : Punching of holes and cutting operations during the fabrication process, and;
- IV : Welding.

In hot-rolled structural shapes and in welded sections, the residual stresses from uneven cooling will be taken into account in this research only in calculating the failure loads.

The portion of the member that cools most slowly develops residual tension stresses which are balanced by residual compression stresses in other portions of the member.

Residual stresses from cooling are approximately constant along the length of the member, where as cold-straightening stresses frequently occur only at particular locations where the member has been straightened.

In this study, for theoretical computational purposes, the residual stresses distribution in the channel sections is taken as shown in Fig (2.3) [5]

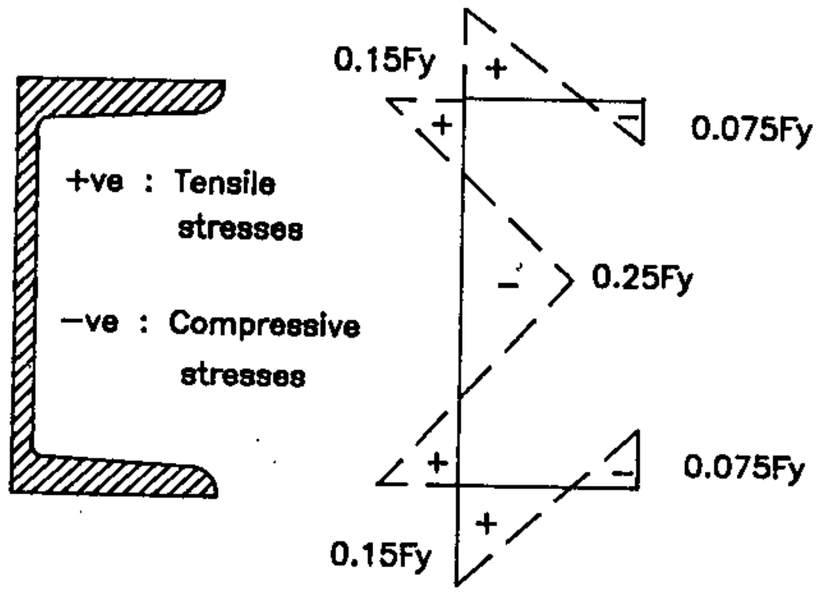

Fig.(2.3) Theoretical residual stresses distribution.

2.4 IDEALIZATION OF THE CHANNEL SECTIONS.

To ease the computations, the channel sections have been idealized as shown in Fig. (2.4).

The area of idealized channel section , A_{si}, is given by :-

$$A_{si} = 2b\, t_f + t_w(d - 2t_f) \quad (2.4)$$

Where :

d : Depth of section.

b : Width of section.

t_f: Thickness of flange.

t_w: Thickness of web.

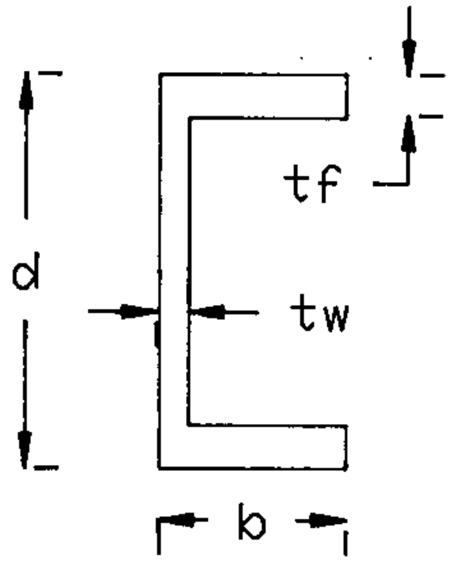

Fig.(2.4) Idealized channel section.

The idealized centroid of the channel section, Cy_i, is given by :-

$$Cy_i = [b^2 t_f + (d-2t_f) t_w^2/2]/As_i \qquad (2.5)$$

and the second moment of area about the major axis is given by :-

$$Ixx_i = \frac{d^3 * t_w}{12} + \frac{1}{6}(b-t_w)t_f^3 + \frac{1}{2}(b-t_w)(d-t_f)^2 t_f \qquad (2.6)$$

The results of the idealization of the channel sections are given in Table (2.1).

Table (2.1). Idealized properties of channel sections.

Channel size mm	Depth of section d mm	Width of section b mm	Web thickness tw mm	Flange thickness T_f mm	Area of section Ass cm^2	Area of idealized sect. cm^2	% Error	Centroid of section Cy (cm)	Centroid of ideal. sect. Cyi (cm)	% Error	Moment of inert. I_{xx} cm^4	Moment of inert. I_{xxi} cm^4	% Error
432x102	431.8	101.8	12.2	17.3	83.49	83.60	0.13	2.32	2.49	7.33	21399	21474	0.35
381x102	381.0	101.8	10.4	16.8	70.19	70.24	0.08	2.52	2.74	8.73	14894	14957	0.42
305x102	304.8	101.8	10.2	15.2	58.83	58.84	0.02	2.66	2.91	9.40	8214	8234	0.24
305x89	304.8	88.9	10.2	14.1	53.11	53.20	0.18	2.18	2.36	8.26	7061	7084	0.33
254x89	254.0	88.9	09.1	14.1	45.52	45.54	0.04	2.42	2.64	9.09	4448	4474	0.58
254x76	254.0	76.2	08.1	11.4	36.03	36.10	0.20	1.86	2.04	9.68	3367	3392	0.74
259x89	228.6	88.9	08.6	13.8	41.73	41.80	0.22	2.53	2.79	10.28	3387	3416	0.86
229x76	228.6	76.2	07.6	11.6	33.20	33.30	0.27	2.00	2.20	10.00	2610	2632	0.84
203x89	203.2	88.9	08.1	13.4	37.94	38.10	0.46	2.65	2.93	10.57	2491	2520	1.16
203x76	203.2	76.2	07.1	11.6	30.34	30.46	0.39	2.13	2.36	10.80	1950	1970	1.03
178x89	177.8	88.9	07.6	12.7	34.15	34.16	0.04	2.76	3.07	11.23	1753	1766	0.74
178x76	177.8	76.2	06.6	10.7	26.54	26.63	0.34	2.20	2.46	11.82	1337	1350	0.97
152x89	152.4	88.9	07.1	11.9	30.36	30.30	0.23	2.86	3.21	12.24	1166	1173	0.60
152x76	152.4	76.2	06.4	09.4	22.77	22.88	0.47	2.21	2.51	13.57	852.5	860.6	0.95

CHAPTER III

THEORY

3.1 GENERAL.

No general analytical solution exists for the stability problem of composite beam-columns under various loading conditions, the difficulty is caused by the inability to obtain general direct solutions to the govering differential equations.

Many analytical methods have been reported on the generation of interaction curves. One feature common to all of them, that is, it is first necessary to obtain the moment-curvature relations of a cross-section as a function of the axial load on the section.

Once these curves are established, the true equilibrium shape of the deflected column can be obtained by an iterative numerical procedure.

3.2 ASSUMPTIONS.

In the present study, the major assumptions are as follows :

1- The tensile strength of concrete is neglected.
2- The effect of strain hardening in steel is ignored.
3- There exist complete interaction between steel and concrete, that is, the strain in steel and concrete at their interface are assumed compatable.

4- The strain distribution a cross the section is assumed to be linearlly varying in proportion to the distance from the neutral axis.

5- Residual stress distribution is assumed to be as can be seen in Figure (2.3).

3.3 CALCULATION OF THE COLUMN SECTION PROPERTIES:

3.3.1 CALCULATION OF THE SQUASH LOAD; Pu :-

The theoretical squash load for the battened composite column Pu is given by :-

$$Pu = Fy\ As + 0.67 Fcu\ Ac \qquad (3\text{-}1)$$

Where:

As : Total area of steel.

Ac : Total area of concrete.

Fy : Yield stress of concrete.

Fcu: 28-day cube strength of concrete.

The effect of residual stresses on the squash load for the battened composite column is ignored [11].

3.3.2 CONCRETE CONTRIBUTION FACTOR; α_c:

Concrete contribution factor is a parameter which gives the proportion of the squash load carried by the concrete alone. This parameter is known as α_c, and is given by:

$$\alpha_c = 0.67 Fcu\ Ac/Pu \qquad (3\text{-}2)$$

Where:

Fcu,Ac,Pu as defined before.

3.3.3 CALCULATION OF THE PLASTIC BENDING MOMENT; Mu:

The plastic bending moment; Mu, (when axial load is equal to zero), of the column section is determined by considering equilibrium across a fully plastic section. the calculation of the equilibrium condition is based on the standard practice of assuming rectangular stress blocks in both steel and concrete, as shown in Figure (3.1).

The plastic bending moment; Mu, is given by:

$$Mu = M1+M2+M3+M4+M5+M6 \qquad (3\text{-}3)$$

where:

$$M1 = 2.t_f\ b\ Fy\ (X+0.5t_f) \qquad (3\text{-}3\text{-}a)$$

$$M2 = tw\ Fy\ X^2 \qquad (3\text{-}3\text{-}b)$$

$$M3 = 0.67Fcu\ S\ t_f\ (X+0.5t_f) \qquad (3\text{-}3\text{-}c)$$

$$M4 = 0.67Fcu\ X^2\ (h-2tw)/2. \qquad (3\text{-}3\text{-}d)$$

$$M5 = 2.t_f\ b\ Fy\ (d-1.5t_f+X) \qquad (3\text{-}3\text{-}e)$$

$$M6 = tw\ Fy\ (d-2t_f-X)^2 \qquad (3\text{-}3\text{-}f)$$

X : the loacation of the neutral axis, which gives the zero axial load, as shown in Figure (3.2), and is given by:

$$X = \frac{(2.)\ 5tw\ d\ Fy-0.67Fcu\ S\ t_f}{4.\ tw\ Fy\ 0.67Fcu\ (h-2\ tw)} \qquad (3\text{-}3\text{-}g)$$

Where :

Fy,Fcu : as defined before.

d,h,b,t_f,tw,S : are defined in Figure (3.1)

The effect of residual stresses on the plastic bending moment for the battened composite column are ignored [11].

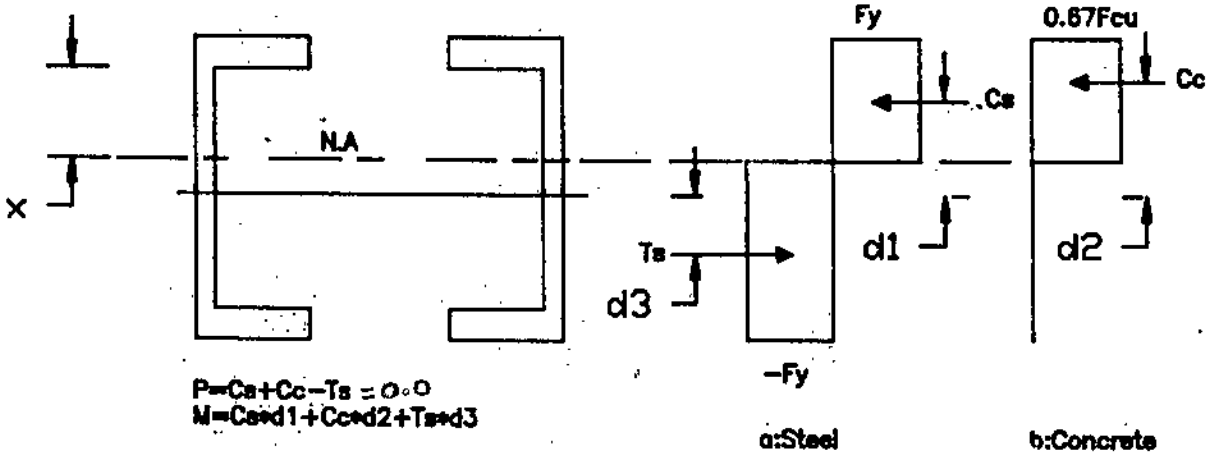

Fig.(3.1) Stress block diagram of the battened composite column.

3.4 ULTIMATE STRENGTH FOR ZERO LENGTH COLUMN :

The ultimate strength of the column section is determined by considering equilibrium across a fully plastic section. And as mentioned in section 3.3, the calculations of the equilibrium conditions are based on the standard practice of asuming rectangular stress blocks.

The method of calculating the cross-section strength is summarized in the following steps:-

1- Increment of axial load P is assumed.
2- The location of neutral axis X, which gives the axial load P, as shown in Figure (3.2), is calculated.
3- The bending moment M, at this location of the neutral axis X is computed.

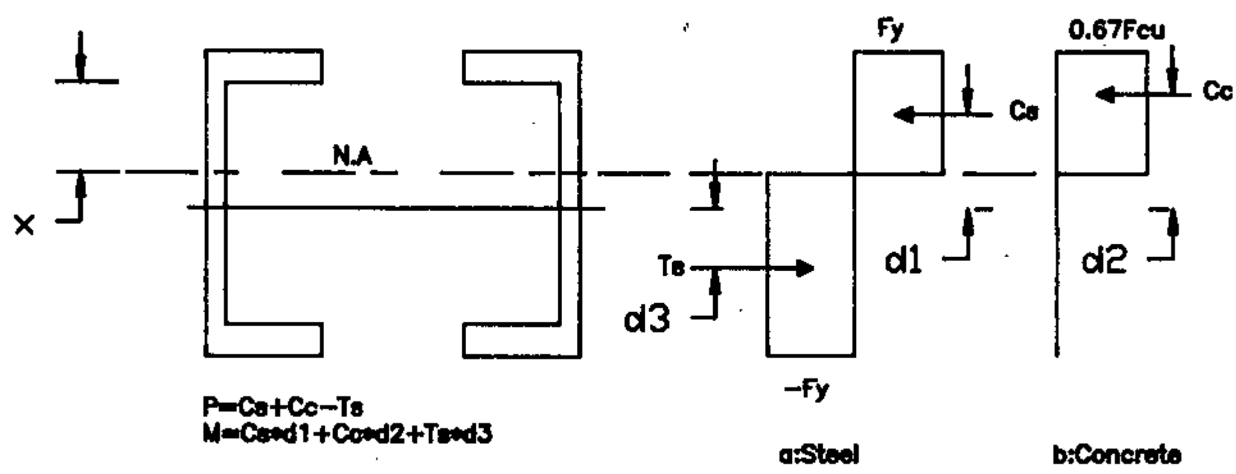

Fig.(3.2) Stress block diagram of the battened composite column.

The effect of residual stress on the ultimate strength of zero length column, is calculated as follows:

1- An Increment of axial load P is assumed.
2- The location of neutral axis X, which gives the axial load P, after substracting the existing residual stresses in the steel block is computed, as shown in Figure (3.3).
3- The bending moment M, at this location of the neutral axis X, taking into account the existing residual stresses in the steel is computed.

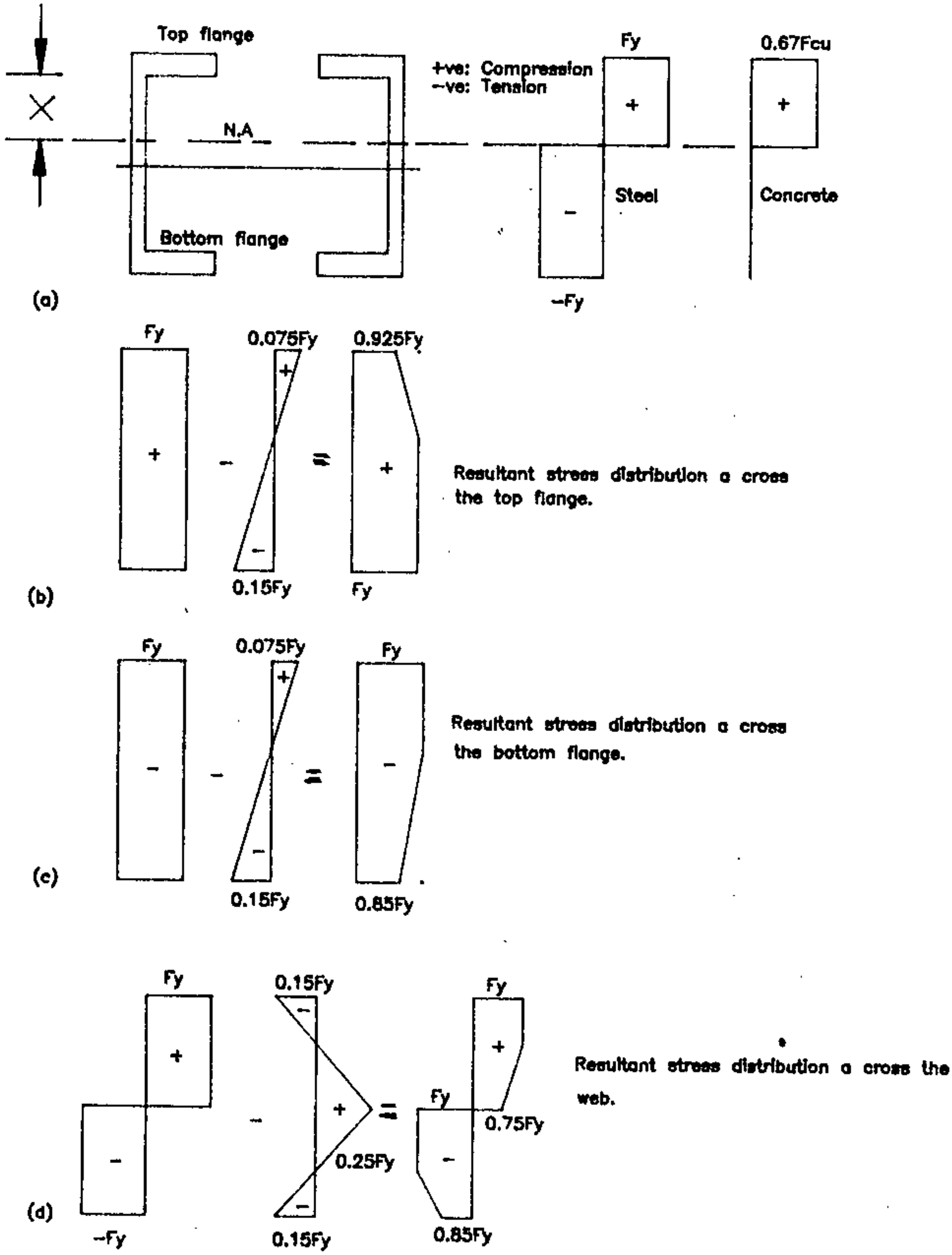

Fig.(3.3) Resultant stress distribution a cross the column section

3.5 ULTIMATE STRENGTH FOR SLENDER COLUMN:

3.5.1 MOMENT-CURVATURE-THRUST RELATIONS:

For a given combination of axial load and bending moment acting on a section. there exists a unique value of curvature, this means that the deformation of a section depends only on the final values of the axial load and bending moment, and that the actual history of loading does not affect the amount of the resulting curvature.

The moment-curvature-thrust relationship, in the case of uniaxial bending, involves four quanities; axial load P, uniaxial moment M, distance of neutral axis Dn from point O, and curvature Φ as shown in Figure (3.4). By assigning all possible values to any two of the variables, the other two can be found.

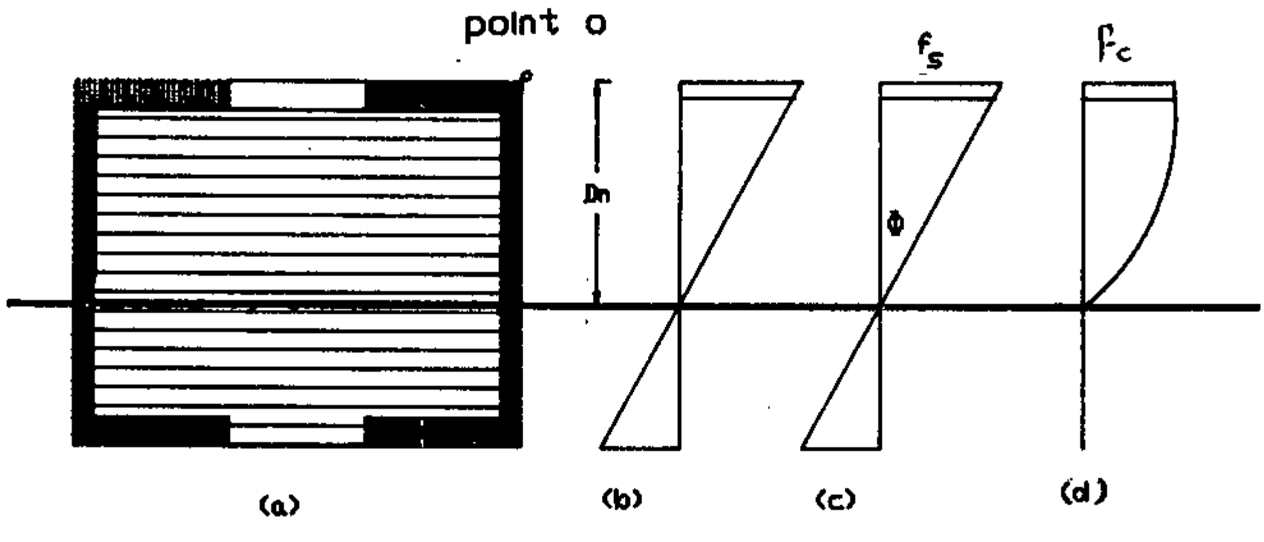

Fig.(3.4) (a) Discretization of the column x-section.
(b) Strain distribution
(c) Steel stresses
(d) Concrete stresses.

One course that can be taken is to assign values to Φ and Dn, in this case no iterations are involved, and the P and M can be directly be computed. However, it should be mentioned that any meaningfull representation of results would involve some form of interpolation.

Values of Φ are assumed, and distance of the neutral axis Dn is varied between specified limits. For each position of the neutral axis, the strain, stresses and forces in each elemental area are computed, taking into account the stress-strain characteristics of concrete and steel as the case may be. Summations over the section are carried out for the moment due to the elemental forces.

Thus, for different locations of the neutral axis, sets of values of the axial force and bending moment are obtained. Inorder to obtain moment-curvature values for specific values of P, linear interpolation is used.

The effect of residual stresses on the moment-curvature-thrust relationship is calculated as follows:

1- A suitable value for curvature Φ is selected.
2- A suitable value for neutral axis Dn is selected.
3- Strains, stresses in concrete and steel are computed.
4- Residual stresses are then subtracted.
5- Axial force P, and moment M due to the resultant stresses in steel and concrete are computed, as shown in Figure (3.5)

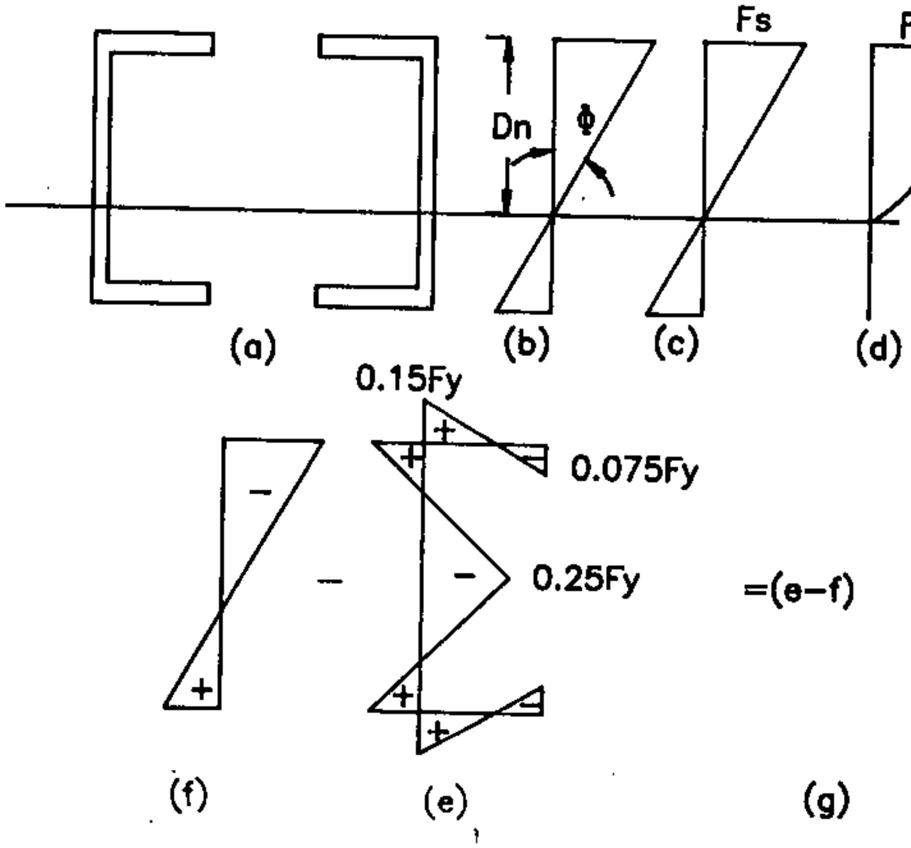

Fig.(3.5) (a) Discretization of the column cross-section
(b) Strain distribution.
(c) Steel stresses.
(d) Concrete stresses.
(e) Residual stresses.
(g) Resultant stresses.

3.5.2 DETERMINATION OF EQUILIBRIUM SHAPE:

The theory presented below is in a general form, so that it can be applied to any eccentrically loaded pin-ended column, assuming that the moment-curvature chatacteristics have already been established.

Consider a column of length L, as shown in Figure (3.6), loaded with an axial load P, and having different end eccentricities e and βe respectively, where β is a constant called the eccentricity ratio ($-1 \leq \beta \leq 1$).

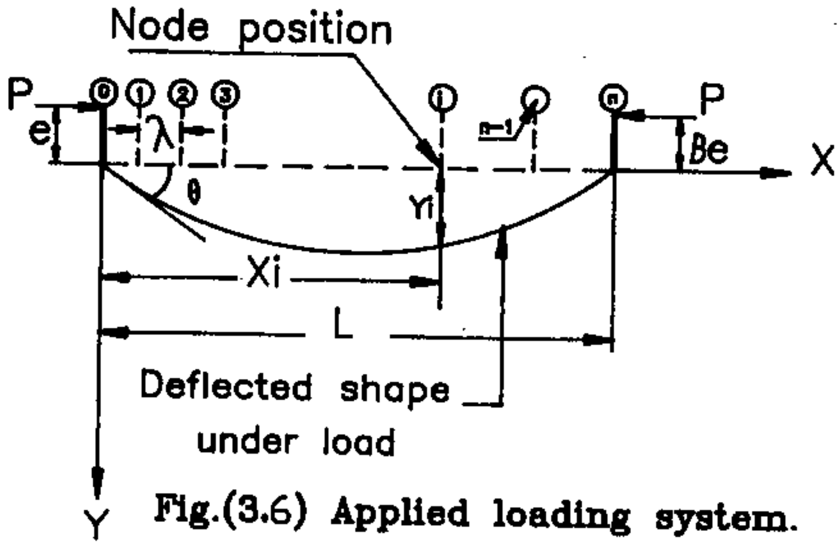

Fig.(3.6) Applied loading system.

The numerical method proposed by Newmark is used here to determine the equilibrium shape of the column. This method is based on assuming values for the deflection Y to loading. For convenince, the deflection obtained from an elastic solution for the column is used as an intial approximation, and is given by :

$$\bar{Y}i = e\left[\frac{\sin \mu L(1-i/n)}{\sin \mu L} - (1-i/n)\right] + e\beta\left[\frac{\sin \mu L(i/n)}{\sin \mu L} - i/n\right]$$

$$i = 0,1,2,\ldots\ldots,n \qquad (3\text{-}4)$$

Where:

$\mu = \sqrt{P/EI}$

EI= Elastic flexural rigidity of the column section.

n = Number of nodes.

e = Eccentricity.

Having obtained values for the assumed deflections, Newmark's numerical procedure is used successively to correct these values until the true deflected shape of the column is obtained to the desired accuracy.

The following steps summarize the Newmark's procedure :-

1- The bending moments due to the deflectetions at the node points are computed, as follows:

$$Mi = Pe\left[1-(1-\beta)i/n\right] + P\,Yi \qquad i=0,1,2,\ldots,n \qquad (3\text{-}5)$$

2- Based on the M-Φ curve for the axial load P, and by interpolation, the curvatures at node points are computed, corresponding to the node moments computed above.

3- Concentrated angle changes $(\Phi\lambda)$; are computed at each node point.

4- Values for the uncorrected slope at each node position are computed, as follows:

$$S_o = 0.$$

$$S_i = \sum_{k=1}^{i} (\Phi\lambda)_k \qquad i = 1,2,...,n \qquad (3\text{-}6)$$

Where:

$\lambda = L/n$

5- Uncorrected deflections using Newmark's method are computed as follows :-

$$U_o = 0.$$

$$U_i = \sum_{k=1}^{i} \lambda S_k \qquad i = 1,2,....,n \qquad (3\text{-}7)$$

6- A linear correction will be applied to these deflection at both ends of the column, and therefore a new set of values for deflections due to load will be obtained as follows:

$$\bar{Y}_i = U_i - i\, U_n/n \qquad (3\text{-}8)$$

7- The assumed value for Y_i used in step 1 will be replaced by the new values $\bar{Y}_i$ calculated in step 6 , and steps 1 to 6 will be repeated until convergence is obtained to the desired accuracy. For the purpose of this study, this condition is assumed satisfied if for all nodes :

$$|Yi-Yi| \le 10^{-4} \quad i=1,2,\ldots,n \qquad (3-9)$$

3.5.3 COMPUTATION OF FAILURE LOADS.

If the required convergence can not be obtained within a reasonable number of cycles (depending on the accuracy desired), or if the moment at any node during the iterations exceeds the ultimate moment of the section corresponding to the applied end load, it is concluded that the load is too high for equilibrium to be possible.

CHAPTER IV

COMPUTER PROGRAM

The computational procedure described in chapter III was programmed by FORTRAN-77 language, using VAX-8700 computer, located in the Faculty of Engineering and Technology at the University of Jordan. A simplified flow chart of the main program is shown in Figure (4.1). A listing of the program is presented in a seperate report submitted to the Department of Civil Engineering.

The program starts by calling subroutine DATA, which reads and prints the input data, related to the geometrical properties of the column, the material properties, eccentricity ratio (β), number of nodes along the column length desired to be used in the analysis. The squash load (Pu) and the concrete contribution factor (α_c) are also computed using subroutine DATA. Pure plastic bending moment (P=0.0); Mu is computed using this subroutine.

Subroutine ZERO-LENGTH is then called by the main program to compute the failure loads for the battened composite column section bending about the minor axis. These failure loads are computed as non-dimensional values of the axial load (P/Pu) and bending moment (M/Mu) for the case of zero-length column.

Subroutine MOMENT-CURVATURE is then called by the main program to compute the moment-curvature (M-Φ) values for the battened composite column section for a given increment of axial load.

Subroutine NEWMARK is then called by the main program to compute the failure loads, for a given eccentricity ratio (β), and for slenderness ratio of L/D=10,20,30,40.

Subroutine DRAW1 is then called by the main program to plot the moment-curvature (M-Φ) values for the given load increments computed previously by subroutine MOMENT-CURVATURE.

Subroutine DRAW2 is then called by the main program to plot the failure loads (P/Pu Vs. M/Mu), which is computed previously by subroutine ZERO-LENGTH and subroutine NEWMARK.

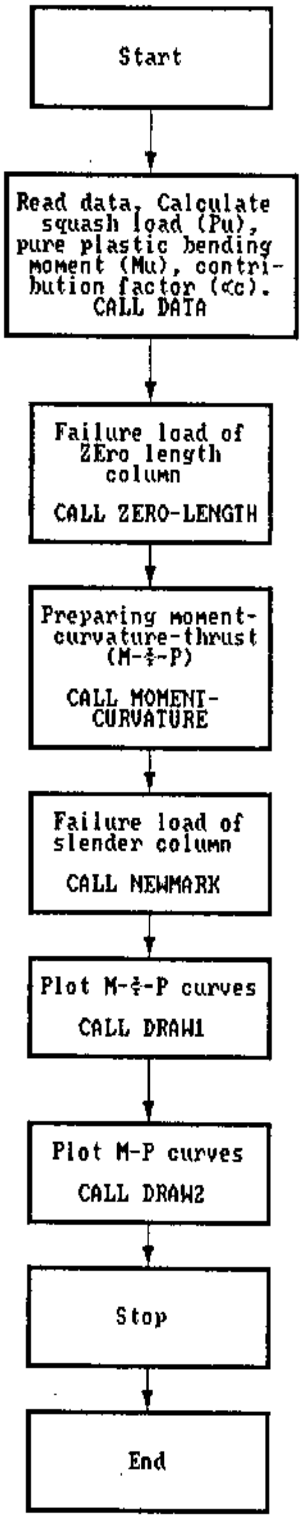

Figure (4.1). Simplified flow chart of main program.

4.1 ZERO-LENGTH ROUTINE:

The computation procedure described in section (3.5) of chapter III is used in this subroutine to calculate the ultimate resistance of the battened composite column section, bending about minor axis. A simplified flow chart of ZERO-LENGTH routine is shown in Figure (4.3).

The battened composite column section is subdivided in to a large number of small size strip elements as shown in Figure (4.2).

In each strip element, for a given value of depth of yielding (Dn), the stresses are computed depending on the material composed in this strip element, taking into account the existing residual stresses. Then the values of P and M can be caculated for each strip, and by summation, the axial force and bending moment in each block is computed. The resultant P and M will be evaluated for the specific value of Dn, by adding the axial loads and bending moments for all blocks.

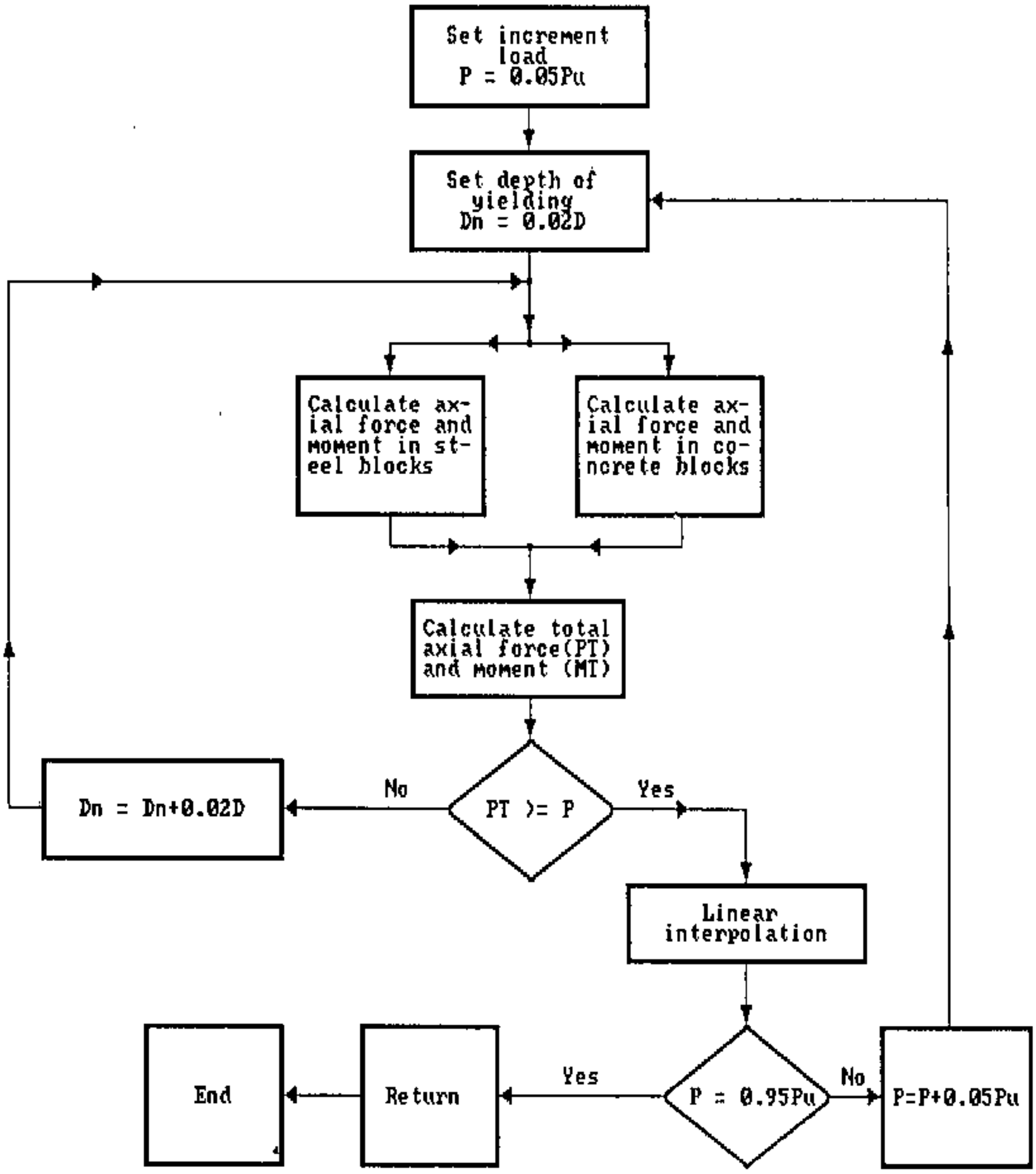

Figure (4.2) Simplified flow chart for ZERO-LENGTH routine.

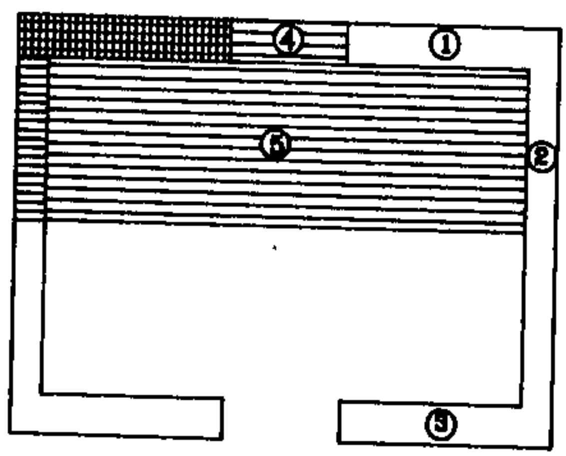

Fig.(4.3) Discretizaion of the column cross-section.

4.2 MOMENT-CURVATURE ROUTINE:

Subroutine MOMENT-CURVATURE is called by the main program. The computation procedure described in section (3.5.1) of chapter III is used in this routine, to compute the moment-curvature (M-Φ) values of the battened composite column section for a given increment of axial load. A simplified flow chart of this routine can be seen in Figure (4.4).

The computation of M-Φ values involves the moment M, the axial load P, the curvature Φ and the distance of the neutral axis Dn, The last two specify the strain distribution across the section.

The battened composite column section is subdivided into two blocks of concrete and three blocks of steel as shown in Figure (4.3).

In each strip element, depending on the strain distribution, stresses are computed making use of the assumed stress-strain curves of material composed in this strip element, taking into account the existing residual stresses. Then the values of P and M can be caculated for each strip, and by summation, the axial force and bending moment in each block is computed. The resultant P and M will be computed for the specific values of Dn and Φ, by adding the axial force and bending moments for all blocks.

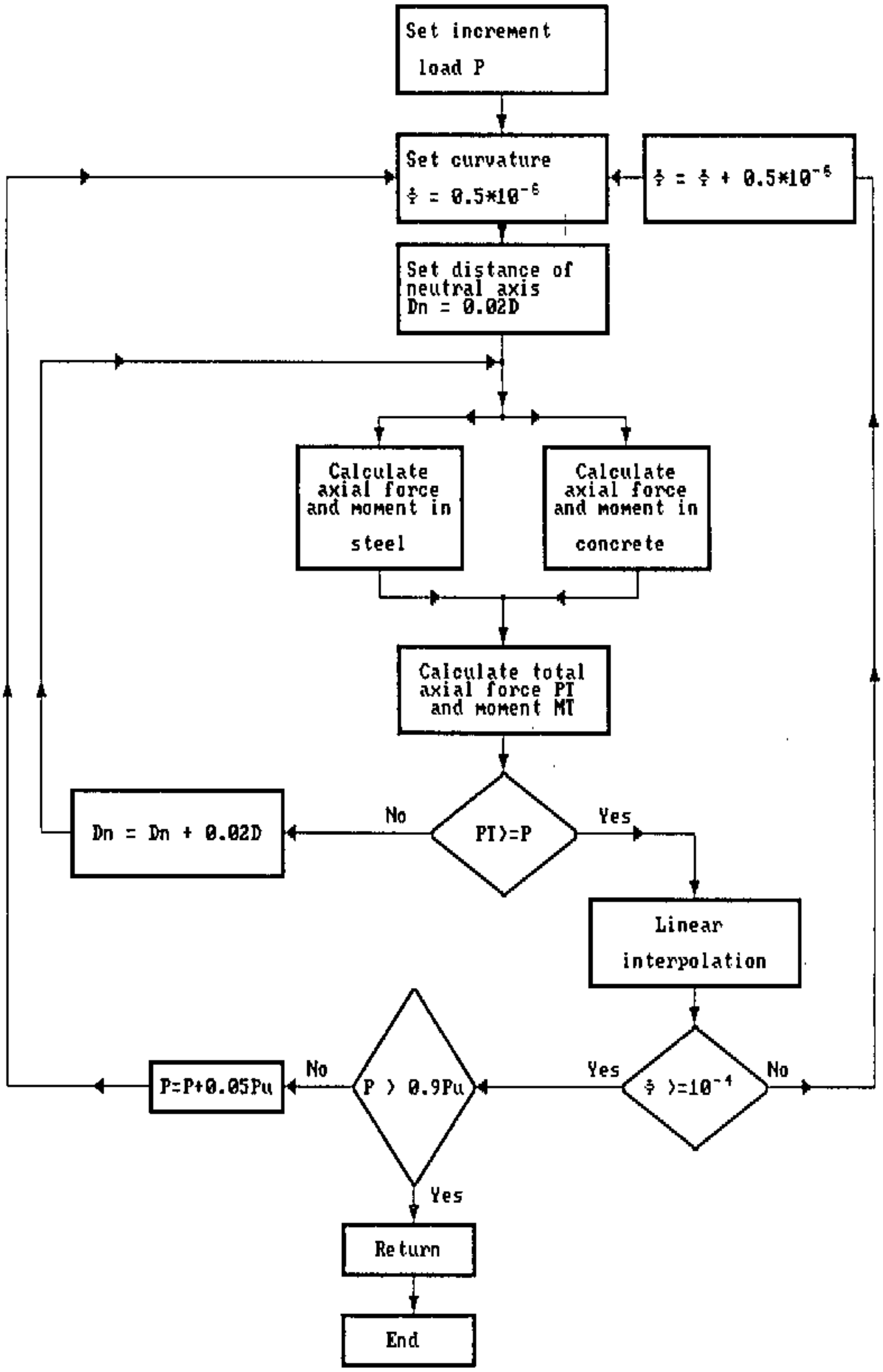

Figure (4.4) Simplified flow chart for MOMENT-CURVATURE routine.

4.3 NEWMARK ROUTINE:

Subroutine NEWMARK is called by the main program to compute the failure loads, using the maximum eccentricity criterion described previously in section (3.5) of chapter III. A simplified flow chart of this routine is shown in Figure (4.5).

In computation the critical maximum end moments, increment of 0.005 Mu were incorporated until the ultimate moment corresponding to the applied end load at any node during iterations is exceeded, or the required convergence cannot be obtained within "the fourty cycle" used in this research as a limit of the convergence process.

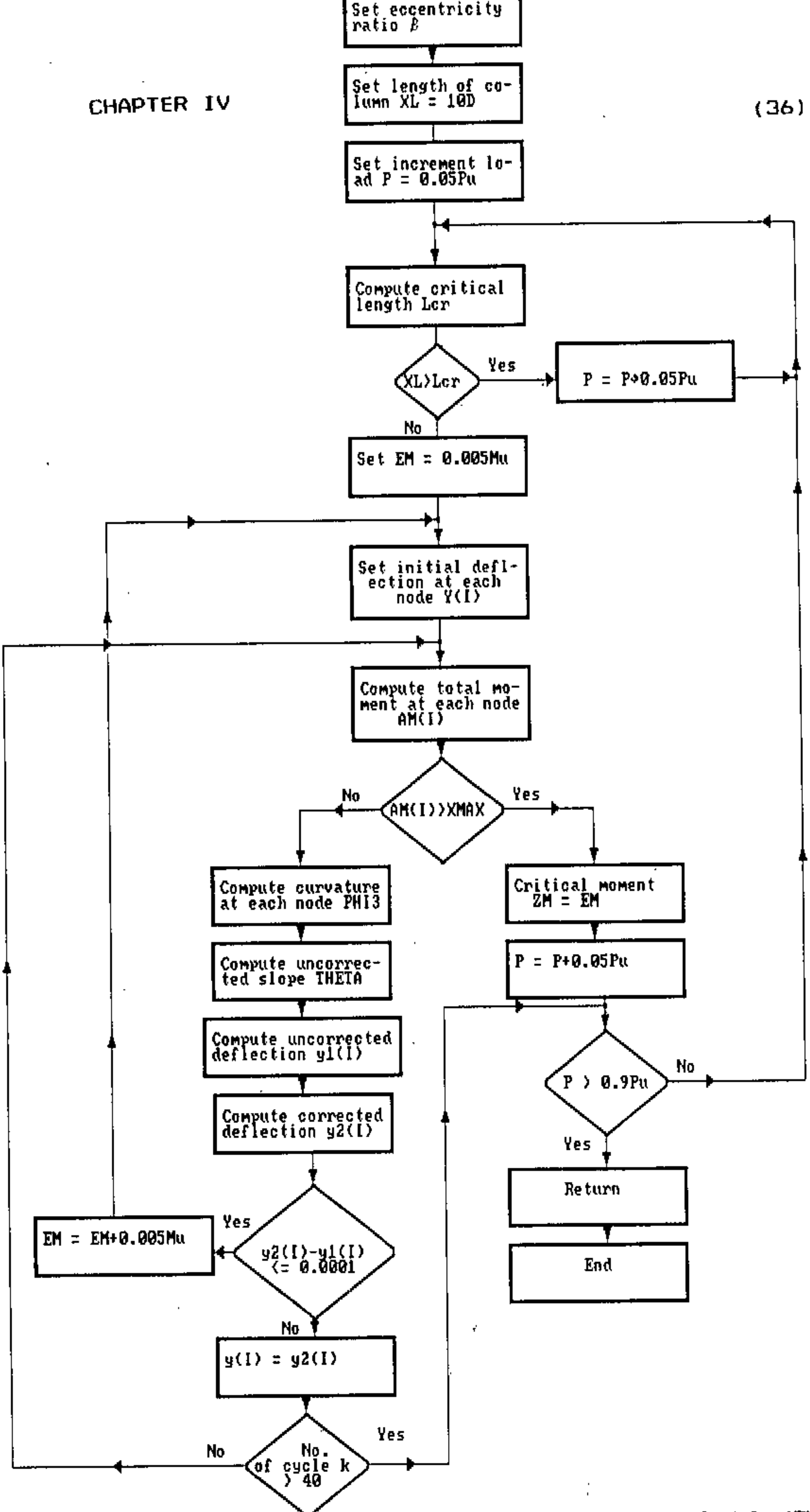

Figure (4.5) Simplified flow chart for NEWMARK routine.

CHAPTER V

NUMERICAL RESULTS AND DISCUSSION

The maximum strength of a beam-column can be expressed by an interaction curve showing the reduction in the ultimate load with increasing moment. In the analysis to calculate the strength, equilibrium conditions of the member and the moment-curvature-thrust relationships of the section are the two basic requirements.

In this chapter, the effect of residual stresses on the maximum strength of the battened composite column bending about minor axis is discussed.

5.1 PROPERTIES OF THE COLUMN SECTION:

Column strength depends on two basic factors; the ultimate strength of the section and the slenderness of the column. The strength of the column and its section properties have been non-dimensionalized in this study. Also in preference to the slenderness function adopted as a design parameter, a simple variable was used. The slenderness was represented by the ratio of the column length to the depth of the section.

In the column section for the analysis, the following limitations were applied:

1- The smallest channel included was 152x76x6.4
2- The largest channel included was 381x102x10.4
3- The sectional dimensions of the column were such $D < H < 3D$

Twelve sections were selected for the analysis, and the properties of the sections are given in Table (5.1).

For each section, five loading conditions were investigated. These conditions, shown in figure (5.1), are as follows:

CASE I : End moment applied at one end of the column (β = 0.0).

CASE II : End moment applied at one end, and half of that moment is applied at the other end (β = 0.5).

CASE III: Equal end moment at both ends of the column (β = 1.0).

CASE IV : End moment applied at one end, and half of that moment, but in opposite direction, is applied at the other end (β = -0.5).

CASE V : Equal moments at both ends of the column with opposite sense (β = -1.0).

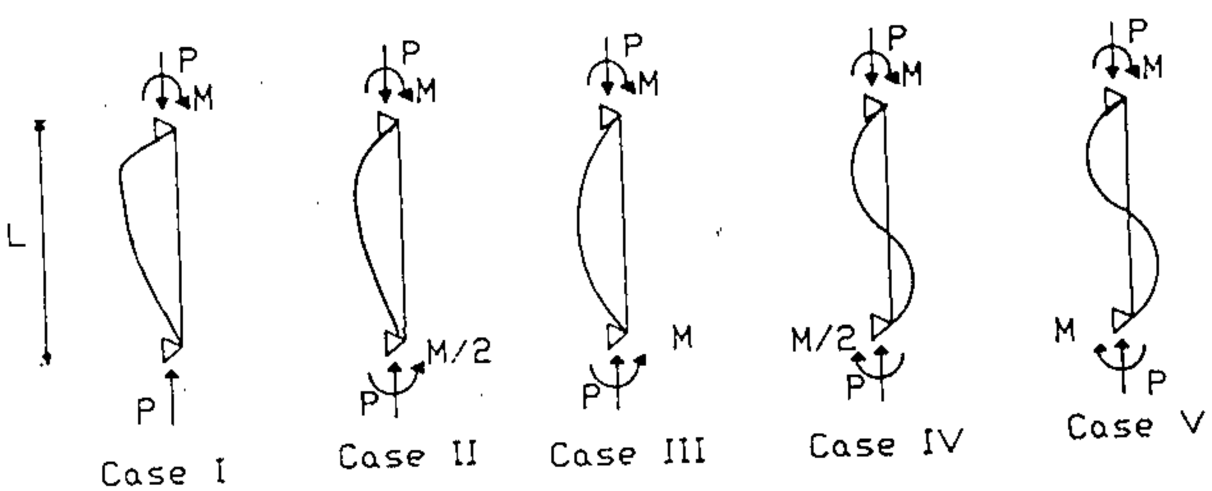

Figure (5.1) – Cases of Loading

Table (5.1) Physical properties of battened composite columns.

Section number	H mm	d mm	b mm	tw mm	t_f mm	Fy MPa.	Fcu MPa	αc	Pu KN	Mu KN.m
1	275	152.4	076.2	6.4	9.4	276.0	30.0	0.374	2007.27	79.604
2	375	203.2	088.9	8.1	13.3	276.0	30.0	0.397	3472.49	177.084
3	450	254.0	088.9	9.1	14.04	276.0	30.0	0.457	4625.00	263.980
4	525	304.8	101.8	10.2	15.14	276.0	30.0	0.479	6224.77	410.082
5	600	381.0	101.8	10.4	16.72	276.0	30.0	0.527	8184.00	614.680
6	275	152.4	076.2	6.4	9.4	248.0	30.0	0.399	1881.63	72.070
7	275	152.4	076.2	6.4	9.4	345.0	30.0	0.323	2321.385	98.290
8	275	152.4	076.2	6.4	9.4	276.0	20.0	0.285	1757.00	77.880
9	275	152.4	076.2	6.4	9.4	276.0	40.0	0.443	2257.55	80.900
10	275	152.4	076.2	6.4	9.4	248.0	0.0	0.0	1130.81	64.703
11	275	152.4	076.2	6.4	9.4	276.0	0.0	0.0	1256.45	71.892
12	275	152.4	076.2	6.4	9.4	345.0	0.0	0.0	1570.56	89.865

* Es = 200 MPa.

The results are presented in a series of non-dimensionalized interaction curves. The ordinates of these curves are the critical load divided by the squash load and the critical bending moment divided by the ultimate moment (i.e : Pcr/Pu Vs. Mcr/Mu).

Most of the moment-curvature-thrust curves and interaction diagrams are presented in appendix (A).

5.2 EFFECT OF RESIDUAL STRESSES ON THE MAXIMUM STRENGTH OF ZERO LENGTH COLUMN

As can be seen from Tables 5.2,5.3,5.4 and 5.5, that, the effect of residual stresses on the maximum strength of the battened composite column of zero length increase as the axial load increase, except for the axial load equal to 0.2Pu.

AS can be seen from Tables 5.2,5.6 and 5.7, that, the effect of residual stresses on the maximum strength of battened composite column of zero length increase as the yield stress (Fy) of steel channel increase.

AS can be seen from Tables 5.2,5.8 and 5.9, that, the effect of residual stresses on the maximum strength of battened composite column of zero length decrease as the concrete strength (Fcu) increase.

As can be seen from Table 5.10, that, the effect of residual stresses on the maximum strength of zero length steel column increase as the axial load increase.

As can be seen from Tables 5.2 and 5.10 , that, the effect of residual stresses on the maximum strength of zero length steel column is greater than the effect of residual stresses on the maximum strength of zero length battened composite column.

As can be seen from Tables 5.2,5.3,5,4 and 5.5, that, the effect of residual stresses decrease as the depth of steel channels increase for the axial load varies between 0.1Pu to 0.4Pu, and increase as the axial load varies between 0.5Pu to 0.9Pu.

5.3 EFFECT OF RESIDUAL STRESSES ON THE MAXIMUM STRENGTH OF SLENDER COLUMN

As can be seen from Tables 5.11 and 5.12, that, the effect of residual stresses on the initial slope (EI) of moment-curvature curve is increase as the axial load increase.

As can be seen from Tables 5.11 and 5.12, that, the effect of residual stresses on the peak of the moment-curvature curve is increase as the axial load increase.

As can be seen from Tables 5.13 and 5.14, that, the effect of residual stresses on the maximum strength of battened composite column decrease as the length of column increase.

As can be seen from Table 5.15, that, the effect of residual stresses on the maximum strength of steel column decrease as the length of column increase.

As can be seen from Tables 5.16,5.16,5.17 and 5.18, that, for L/D=10, their is no effect of cases of loading on the effect of residual stresses on the maximum strength, for eccentricity ratio (β = 0.0,-0.5,-1.0).

As can be seen from Tables 5.19,5.20 and 5.21, that, for L/D=40, the effect of residual stresses on the maximum strength is increase as the eccentricity ratio (β) decrease.

As can be seen from Table 5.22, that, the effect of residual streses on the maximum strength of battened composite column decrease as the concrete strength increase.

As can be seen from Tables 5.23 and 5.24, that, the effect of residual stresses on the maximum strength of column increase as the yield stress of steel channel increase from 248 MPa. to 276 MPa.

Table (5.2) Effect of residual stresses on the maximum strength of zero length column No. 1.

$\frac{P}{Pu}$	$\frac{Mw}{Mu}$ *	$\frac{MR}{Mu}$ **	Diff % $\frac{Mw-MR}{Mu}$*100
0.1	1.0562	1.0269	2.93
0.2	1.0714	1.0425	2.89
0.3	1.0456	1.0143	3.13
0.4	0.9787	0.9433	3.54
0.5	0.8707	0.8305	4.02
0.6	0.7217	0.6767	4.5
0.7	0.5498	0.5039	4.59
0.8	0.3726	0.3253	4.73
0.9	0.1889	0.1407	4.82
Average % = 3.9056			

* Without residual stresses.

** With residual stresses.

Pu = 2007.272 KN.
Mu = 79.60439 KN-m.

Table (5.3) Effect of residual stresses on the maximum strength of zero length column No. 2.

P/Pu	Mw/Mu *	MR/Mu **	Diff % (Mw-MR)/Mu *100
0.1	1.0626	1.0335	2.91
0.2	1.0831	1.0546	2.85
0.3	1.0641	1.0307	3.07
0.4	0.9976	0.9628	3.48
0.5	0.8916	0.8519	3.97
0.6	0.7433	0.6984	4.49
0.7	0.5677	0.5214	4.63
0.8	0.3849	0.3379	4.70
0.9	0.1957	0.1477	4.86
Average % = 3.8844			

* Without residual stresses.

** With residual stresses.

Pu = 3472.485 KN.
Mu = 177.0838 KN-m.

Table (5.4) Effect of residual stresses on the maximum strength of zero length column No. 3.

$\frac{P}{Pu}$	$\frac{Mw}{Mu}$ *	$\frac{MR}{Mu}$ **	Diff % $\frac{Mw-MR}{Mu}$*100
0.1	1.0773	1.0491	2.82
0.2	1.1113	1.0836	2.77
0.3	1.1021	1.0723	2.98
0.4	1.0495	1.0153	3.42
0.5	0.9536	0.9137	3.99
0.6	0.8145	0.7684	4.61
0.7	0.6322	0.5809	5.13
0.8	0.4290	0.3763	5.27
0.9	0.2183	0.1637	5.46
Average % = 4.05			

* Without residual stresses.

** With residual stresses.

Pu = 4625 KN.
Mu = 263.9795 KN-m.

Table (5.5) Effect of residual stresses on the maximum strength of zero length column No. 4.

$\frac{P}{Pu}$	$\frac{Mw}{Mu}$ *	$\frac{MR}{Mu}$ **	Diff % $\frac{Mw-MR}{Mu}$*100
0.1	1.0836	1.0555	2.81
0.2	1.1230	1.0956	2.74
0.3	1.1184	1.0889	2.95
0.4	1.0695	1.0357	3.38
0.5	0.9765	0.9368	3.97
0.6	0.8393	0.7933	4.60
0.7	0.6580	0.6052	5.28
0.8	0.4464	0.3923	5.41
0.9	0.2271	0.1711	5.60
Average % = 4.0822			

* Without residual stresses.

** With residual stresses.

Pu = 6224.768 KN.
Mu = 410.0815 KN-m

Table (5.6) Effect of residual stresses on the maximum strength of zero length column No. 6.

$\frac{P}{Pu}$	$\frac{Mw}{Mu}$ *	$\frac{MR}{Mu}$ **	Diff % $\frac{Mw-MR}{Mu}*100$
0.1	1.0632	1.0338	2.94
0.2	1.0841	1.0555	2.86
0.3	1.0628	1.0321	3.07
0.4	0.9992	0.9646	3.46
0.5	0.8933	0.8540	3.93
0.6	0.7452	0.7007	4.45
0.7	0.5683	0.5227	4.56
0.8	0.3852	0.3384	4.68
0.9	0.1955	0.1476	4.79
Average % = 3.86			

* Without residual stresses.

** With residual stresses.

Pu = 1881.63 KN.
Mu = 72.07 KN-m.

Table (5.7) Effect of residual stresses on the maximum strength of zero length column No. 7.

$\frac{P}{Pu}$	$\frac{Mw}{Mu}$ *	$\frac{MR}{Mu}$ **	Diff % $\frac{Mw-MR}{Mu}*100$
0.1	1.0435	1.0141	2.94
0.2	1.0481	1.0184	2.97
0.3	1.0137	0.9811	3.26
0.4	0.9405	0.9033	3.72
0.5	0.8283	0.7861	4.22
0.6	0.6789	0.6331	4.58
0.7	0.5168	0.4701	4.67
0.8	0.3495	0.3016	4.79
0.9	0.1771	0.1283	4.88
Average % = 4.0033			

* Without residual stresses.

** With residual stresses.

Pu = 2321.385 KN.
Mu = 98.29 KN-m.

Table (5.8) Effect of residual stresses on the maximum strength of zero length column No. 8.

P/Pu	Mw/Mu *	MR/Mu **	Diff % (Mw-MR)/Mu *100
0.1	1.0346	1.0052	2.94
0.2	1.0318	1.0015	3.03
0.3	0.9915	0.9577	3.38
0.4	0.9137	0.8751	3.86
0.5	0.7984	0.7545	4.39
0.6	0.6505	0.6041	4.64
0.7	0.4949	0.4473	4.76
0.8	0.3343	0.2859	4.84
0.9	0.1693	0.1199	4.94
Average % = 4.086			

* Without residual stresses.

** With residual stresses.

Pu = 1757.0 KN.
Mu = 77.88 KN-m.

Table (5.9) Effect of residual stresses on the maximum strength of zero length column No. 9.

$\frac{P}{Pu}$	$\frac{Mw}{Mu}$ *	$\frac{MR}{Mu}$ **	Diff % $\frac{Mw-MR}{Mu}$*100
0.1	1.0768	1.0473	2.95
0.2	1.1089	1.0806	2.83
0.3	1.0963	1.0666	2.97
0.4	1.0389	1.0058	3.31
0.5	0.9368	0.8991	3.77
0.6	0.7900	0.7475	4.25
0.7	0.6055	0.5603	4.52
0.8	0.4106	0.3648	4.58
0.9	0.2088	0.1614	4.74
Average % = 3.7689			

* Without residual stresses.

** With residual stresses.

Pu = 2257.55 KN.
Mu = 80.9 KN-m.

Table (5.10) Effect of residual stresses on the maximum strength of zero length column No. 11.

$\frac{P}{Pu}$	$\frac{Mw}{Mu}$ *	$\frac{MR}{Mu}$ **	Diff % $\frac{Mw-MR}{Mu}$ *100
0.1	0.9844	0.9498	3.46
0.2	0.9378	0.8981	3.97
0.3	0.8600	0.8144	4.56
0.4	0.7520	0.7018	5.02
0.5	0.6330	0.5822	5.08
0.6	0.5116	0.4601	5.15
0.7	0.3876	0.3352	5.24
0.8	0.2610	0.2077	5.33
0.9	0.1318	0.0774	5.44
Average % = 4.8056			

* Without residual stresses.

** With residual stresses.

Pu = 1256.45 KN.
Mu = 71.892 KN-m.

Table (5.11) Effect of residual stresses on the moment-curvature curves, for column No. 1.

P/Pu	Maximum moment			(1/mm) Maximum curvature*10^-5			N-mm² Flexural rigidity*10^12		
	Mw/Mu *	MR/Mu **	%	Φw *	ΦR **	%	(EI)w *	(EI)R **	%
0.1	1.052	1.0237	2.83	9.3	8.9	4.3011	5.2064	5.2021	0.0826
0.2	1.0647	1.037	2.77	7.3	7.3	0.0000	5.0527	5.0482	0.0891
0.3	1.0357	1.0049	3.08	6.1	5.9	3.2787	4.8899	4.8853	0.0941
0.4	0.965	0.9286	3.64	5.1	5.0	1.9608	4.7167	4.7117	0.1060
0.5	0.8341	0.7907	4.34	4.8	4.7	2.0833	4.5309	4.5256	0.1170
0.6	0.6800	0.6364	4.36	4.4	4.4	0.0000	4.3298	4.324	0.1340
0.7	0.5200	0.4762	4.38	4.1	4.1	0.0000	3.8665	3.5515	8.1469
0.8	0.3534	0.3089	4.45	3.8	3.8	0.0000	2.4564	1.9914	18.9301

* Without residual stresses.

** With residual stresses.

Pu = 2007.27 KN.
Mu = 79.604 KN-m.

Table (5.12) Effect of residual stresses on the moment-curvature curves, for column No. 5.

$\frac{P}{Pu}$	Maximum moment			(1/mm) Maximum curvature$*10^{-5}$			N-mm^2 Flexural rigidity$*10^{12}$		
	Mw/Mu *	MR/Mu **	%	ϕ_w *	ϕ_R **	%	(EI)w *	(EI)R **	%
0.1	1.096	1.0693	2.67	4.1	4.1	0.0000	1.1510	1.1506	0.0348
0.2	1.1474	1.1218	2.56	3.4	3.2	5.8824	1.2352	1.2311	0.3319
0.3	1.1504	1.1233	2.71	2.8	2.7	3.5714	1.1792	1.1746	0.3901
0.4	1.1048	1.0731	3.17	2.3	2.3	0.0000	1.1129	1.108	0.4403
0.5	1.0121	0.9738	3.83	2.0	2.0	0.0000	1.0479	1.0426	0.5058
0.6	0.8522	0.8055	4.67	1.9	1.8	5.2632	0.9641	0.9549	0.9543
0.7	0.6631	0.6141	4.90	1.7	1.7	0.0000	0.8824	0.8317	5.7457
0.8	0.4589	0.4068	5.21	1.6	1.6	0.0000	0.5718	0.5087	11.0353

* Without residual stresses.

** With residual stresses.

Pu = 8184 KN.
Mu = 614.68 KN-m.

Table (5.13) Effect of column length on the effect of residual stresses on the maximum strength, for column No. 1.

P/Pu	L = 10D			L = 20D			L = 30D			L = 40D		
	Mw*/Mu	MR**/Mu	*100 (Mw-MR)/Mu	Mw*/Mu	MR**/Mu	*100 (Mw-MR)/Mu	Mw*/Mu	MR**/Mu	*100 (Mw-MR)/Mu	Mw*/Mu	MR**/Mu	*100 (Mw-MR)/Mu
0.1	1.0150	0.9900	2.5	0.9450	0.9200	2.5	0.8650	0.8400	2.5	0.7550	0.7350	2.0
0.2	1.0000	0.9750	2.5	0.8850	0.8600	2.5	0.7350	0.7100	2.5	0.5500	0.5300	2.0
0.3	0.9500	0.9200	3.0	0.7800	0.7500	3.0	0.5550	0.5250	3.0	0.3350	0.3200	1.5
0.4	0.8500	0.8100	4.0	0.6200	0.5850	3.5	0.4050	0.3800	2.5	0.1850	0.1750	1.0
0.5	0.6950	0.6550	4.0	0.4850	0.4550	3.0	0.2850	0.2650	2.0	0.0500	0.0500	0.0
0.6	0.5450	0.5050	4.0	0.3650	0.3300	3.5	0.1750	0.1550	2.0	-	-	-
0.7	0.4000	0.3600	4.0	0.2450	0.2150	3.0	0.0750	0.0500	2.5	-	-	-
0.8	0.2600	0.2200	4.0	0.1000	0.0600	4.0	-	-	-	-	-	-
	Average % = 3.5			Average % = 3.125			Average % = 2.4286			Average % = 1.3		

* Without residual stresses.

** With residual stresses.

P_u = 2007.27 KN.
M_u = 79.604 KN.-m
D = 152.4 mm.
β = 1.0

Table (5.14) Effect of column length on the effect of residual stresses on the maximum strength, for column No. 5.

$\frac{P}{P_u}$	L = 10D			L = 20D			L = 30D			L = 40D		
	$\frac{M_w}{M_u}$ *	$\frac{M_R}{M_u}$ **	$\frac{M_w-M_R}{M_u}$ *100	$\frac{M_w}{M_u}$ *	$\frac{M_R}{M_u}$ **	$\frac{M_w-M_R}{M_u}$ *100	$\frac{M_w}{M_u}$ *	$\frac{M_R}{M_u}$ **	$\frac{M_w-M_R}{M_u}$ *100	$\frac{M_w}{M_u}$ *	$\frac{M_R}{M_u}$ **	$\frac{M_w-M_R}{M_u}$ *100
0.1	1.040	1.020	2.0	0.945	0.935	1.0	0.830	0.825	0.5	0.695	0.690	0.5
0.2	1.060	1.040	2.0	0.905	0.890	1.5	0.720	0.705	1.5	0.490	0.480	1.0
0.3	1.035	1.010	2.5	0.830	0.805	2.5	0.555	0.530	2.5	0.250	0.250	0.0
0.4	0.965	0.930	3.5	0.685	0.650	3.5	0.400	0.385	1.5	0.130	0.130	0.0
0.5	0.835	0.790	4.5	0.540	0.510	3.0	0.275	0.260	1.5	-	-	-
0.6	0.660	0.615	4.5	0.405	0.375	3.0	0.155	0.130	2.5	-	-	-
0.7	0.490	0.445	4.5	0.265	0.230	3.5	-	-	-	-	-	-
0.8	0.310	0.270	4.0	0.105	0.070	3.5	-	-	-	-	-	-
	Average % = 3.4375			Average % = 2.688			Average % = 1.667			Average % = 0.375		

* Without residual stresses.

** With residual stresses.

P_u = 8184 KN.
M_u = 614.68 KN-m.
β = 1.0
D = 381 mm.

Table (5.15) Effect of column length on the effect of residual stresses on the maximum strength, for column No. 11.

$\frac{P}{Pu}$	L = 10D			L = 20D			L = 30D			L = 40D		
	$\frac{Mw^{*}}{Mu}$	$\frac{MR^{**}}{Mu}$	$\frac{Mw-MR}{Mu}*100$	$\frac{Mw^{*}}{Mu}$	$\frac{MR^{**}}{Mu}$	$\frac{Mw-MR}{Mu}*100$	$\frac{Mw^{*}}{Mu}$	$\frac{MR^{**}}{Mu}$	$\frac{Mw-MR}{Mu}*100$	$\frac{Mw^{*}}{Mu}$	$\frac{MR^{**}}{Mu}$	$\frac{Mw-MR}{Mu}*100$
0.1	0.9550	0.920	3.5	0.9050	0.8700	3.5	0.845	0.810	3.5	0.770	0.735	3.5
0.2	0.8900	0.850	4.0	0.7900	0.7500	4.0	0.675	0.635	4.0	0.550	0.515	3.5
0.3	0.7800	0.730	5.0	0.650	0.6100	4.0	0.520	0.480	4.0	0.380	0.350	3.0
0.4	0.6500	0.605	4.5	0.525	0.4800	4.5	0.390	0.355	3.5	0.250	0.225	2.5
0.5	0.5300	0.485	4.5	0.410	0.3700	4.0	0.285	0.255	3.0	0.150	0.130	2.0
0.6	0.4150	0.370	4.5	0.310	0.2700	4.0	0.200	0.165	3.5	0.075	0.050	2.5
0.7	0.3050	0.260	4.5	0.210	0.1650	4.5	0.080	0.040	4.0	-	-	-
0.8	0.1950	0.1450	5.0	-	-	-	-	-	-	-	-	-
	Average % = 4.4375			Average % = 4.0714			Average % = 3.643			Average % = 2.833		

* Without residual stresses.

** With residual stresses.

Pu = 1256.45 KN.
Mu = 71.892 KN-m.
β = 1.0
D = 152.4 mm

Table (5.16) Effect of cases of loading on the effect of residual stresses on the maximum strength, for column No. 1.

P / Pu	β = 1.0			β = 0.5			β = 0.0			β = -0.5			β = -1.0		
	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%
0.1	1.015	0.99	2.5	1.055	1.025	3.0	1.055	1.025	3.0	1.055	1.025	3.0	1.055	1.025	3.0
0.2	1.0	0.975	2.5	1.065	1.04	2.5	1.065	1.04	2.5	1.065	1.04	2.5	1.065	1.04	2.5
0.3	0.95	0.92	3.0	1.04	1.005	3.5	1.04	1.005	3.5	1.04	1.005	3.5	1.04	1.005	3.5
0.4	0.85	0.81	4.0	0.97	0.930	4.0	0.97	0.93	4.0	0.97	0.93	4.0	0.97	0.93	4.0
0.5	0.695	0.655	4.0	0.835	0.795	4.0	0.835	0.795	4.0	0.835	0.795	4.0	0.835	0.795	4.0
0.6	0.545	0.505	4.0	0.67	0.630	4.0	0.68	0.64	4.0	0.68	0.64	4.0	0.68	0.64	4.0
0.7	0.4	0.36	4.0	0.495	0.455	4.0	0.520	0.48	4.0	0.520	0.48	4.0	0.520	0.48	4.0
0.8	0.26	0.22	4.0	0.32	0.280	4.0	0.355	0.31	4.5	0.355	0.31	4.5	0.355	0.31	4.5
	Average %=3.5			Average %=3.625			Average %=3.6875			Average %=3.6875			Average %=6.6875		

* Without residual stresses.

** With residual stresses.

Pu = 2007.27 KN.
Mu = 79.604 KN.m.
L = 1.524 m.

Table (5.17) Effect of cases of loading on the effect of residual stresses on the maximum strength, for column No. 3.

P/Pu	β = 1.0			β = 0.5			β = 0.0			β = -0.5			β = -1.0		
	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%
0.1	1.03	1.005	2.5	1.08	1.055	2.5	1.08	1.055	2.5	1.08	1.055	2.5	1.08	1.055	2.5
0.2	1.035	1.015	2.0	1.12	1.095	2.5	1.12	1.095	2.5	1.12	1.095	2.5	1.12	1.095	2.5
0.3	1.005	0.975	3.0	1.11	1.08	3.0	1.11	1.08	3.0	1.11	1.08	3.0	1.11	1.08	3.0
0.4	0.925	0.89	3.5	1.06	1.025	3.5	1.06	1.025	3.5	1.06	1.025	3.5	1.06	1.025	3.5
0.5	0.785	0.745	4.0	0.955	0.91	4.5	0.96	0.915	4.5	0.96	0.915	4.5	0.96	0.915	4.5
0.6	0.62	.575	4.5	0.77	0.725	4.5	0.795	0.75	4.5	0.795	0.75	4.5	0.795	0.75	4.5
0.7	0.455	0.415	4.0	0.57	0.52	5.0	0.615	0.565	5.0	0.615	0.565	5.0	0.615	0.565	5.0
0.8	0.29	0.25	4.0	0.365	0.315	5.0	0.425	0.37	5.5	0.425	0.37	5.5	0.425	0.37	5.5
	Average % =3.4375			Average % =3.8125			Average % =3.875			Average % =3.875			Average % =3.875		

* Without residual stresses.

** With residual stresses.

Pu = 4625 Kn.
Mu = 263.98 KN-m.
L = 2.540 m.

Table (5.18) Effect of cases of loading on the effect of residual stresses on the maximum strength, for column No. 11.

$\frac{P}{Pu}$	β = 1.0			β = 0.5			β = 0.0			β = -0.5			β = -1.0		
	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%
0.1	0.955	0.92	3.5	0.985	0.95	3.5	0.985	0.95	3.5	0.985	0.95	3.5	0.985	0.95	3.5
0.2	0.89	0.85	4.0	0.94	0.90	4.0	0.94	0.90	4.0	0.94	0.90	4.0	0.94	0.90	4.0
0.3	0.78	0.73	5.0	0.86	0.815	4.5	0.86	0.815	4.5	0.86	0.815	4.5	0.86	0.815	4.5
0.4	0.65	0.605	4.5	0.75	0.70	5.0	0.75	0.70	5.0	0.75	0.70	5.0	0.75	0.70	5.0
0.5	0.53	0.485	4.5	0.625	0.575	5.0	0.625	0.575	5.0	0.625	0.575	5.0	0.625	0.575	5.0
0.6	0.415	0.73	4.5	0.495	0.445	5.0	0.505	0.455	5.0	0.505	0.455	5.0	0.505	0.455	5.0
0.7	0.305	0.26	4.5	0.37	0.315	5.5	0.38	0.33	5.0	0.38	0.33	5.0	0.38	0.33	5.0
0.8	0.195	0.145	5.0	0.235	0.185	5.0	0.250	0.20	5.0	0.255	0.205	5.0	0.255	0.205	5.0
	Average % =4.4375			Average % =4.6875			Average % =4.625			Average % =4.625			Average % =4.625		

* Without residual stresses.

** With residual stresses.

P_u = 1256.45 KN.
M_u = 71.892 KN-m.
L = 1.524 m.

Table (5.19) Effect of cases of loading on the effect of residual stresses on the maximum strength, for column No. 1.

$\frac{P}{P_u}$	β = 1.0			β = 0.5			β = 0.0			β = -0.5			β = -1.0		
	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%
0.1	0.755	0.735	2.0	0.94	0.92	2.0	1.055	1.025	3.0	1.055	1.025	3.0	1.055	1.025	3.0
0.2	0.55	0.52	3.0	0.710	0.68	3.0	0.93	0.900	3.0	1.065	1.035	3.0	1.075	1.04	3.5
0.3	0.335	0.32	1.5	0.445	0.42	2.5	0.62	0.585	3.5	0.87	0.825	4.5	1.04	1.00	4.0
0.4	0.185	0.175	1.0	0.245	0.23	1.5	0.355	0.335	2.0	0.575	0.545	4.0	0.945	0.895	5.0
0.5	0.05	0.05	0.0	0.065	0.065	0.0	0.10	0.10	0.0	0.185	0.185	0.0	0.745	0.69	5.5
	Average % =1.5			Average % =1.8			Average % =2.3			Average % =2.9			Average % =4.2		

* Without residual stresses.

** With residual stresses.

P_u = 2007.27 KN.
M_u = 79.604 KN-m.
L = 6.096 m.

Table (5.20) Effect of cases of loading on the effect of residual stresses on the maximum strength, for column No. 3.

$\frac{P}{P_u}$	β = 1.0			β = 0.5			β = 0.0			β = -0.5			β = -1.0		
	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%
0.1	0.715	0.705	1.0	0.905	0.895	1.0	1.055	1.035	2.0	1.08	1.055	2.5	1.08	1.055	2.5
0.2	0.515	0.49	2.5	0.67	0.645	2.5	0.895	0.87	2.5	1.085	1.06	2.5	1.12	1.095	2.5
0.3	0.29	0.275	1.5	0.385	0.365	2.0	0.55	0.530	2.0	0.84	0.805	3.5	1.11	1.07	4.0
0.4	0.135	0.135	0.0	0.18	0.18	0.0	0.26	0.26	0.0	0.45	0.45	0.0	1.01	0.955	5.5
	Average % =1.25			Average % =1.375			Average % =1.625			Average % =2.125			Average % =6.625		

* Without residual stresses.

** With residual stresses.

P_u = 8184 KN.
M_u = 614.68 KN-m.
L = 10.160 m.

Table (5.21) Effect of cases of loading on the effect of residual stresses on the maximum strength, for column No. 11.

P/P_u	β = 1.0			β = 0.5			β = 0.0			β = -0.5			β = -1.0		
	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%
0.1	0.77	0.735	3.5	0.94	0.905	3.5	0.985	0.95	3.5	0.985	0.95	3.5	0.985	0.95	3.5
0.2	0.55	0.515	3.5	0.70	0.66	4.0	0.875	0.835	4.0	0.94	0.90	4.0	0.94	0.90	4.0
0.3	0.38	0.35	3.0	0.495	0.455	4.0	0.64	0.60	4.0	0.80	0.745	5.5	0.86	0.805	5.5
0.4	0.25	0.225	2.5	0.33	0.295	3.5	0.45	0.405	4.5	0.61	0.555	5.5	0.745	0.69	5.5
0.5	0.15	0.13	2.0	0.20	0.175	2.5	0.285	0.245	4.0	0.43	0.375	5.5	0.60	0.545	5.5
0.6	0.075	0.05	2.5	0.10	0.065	3.5	0.15	0.10	5.0	0.255	0.20	5.5	0.465	0.41	5.5
	Average % =2.833			Average % =3.5			Average % =4.167			Average % =4.917			Average % =4.917		

* Without residual stresses.

** With residual stresses.

P_u = 1256.45 KN.
M_u = 71.89 KN-m.
L = 6.096 m.

Table (5.22) Effect of concrete strength on the effect of residual stresses on the maximum strength.

$\frac{P}{Pu}$	(1) Fcu = 20			(2) Fcu = 30			(3) Fcu = 40		
	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%
0.1	0.995	0.970	2.5	1.015	0.990	2.5	1.030	1.005	2.5
0.2	0.970	0.940	3.0	1.000	0.975	2.5	1.030	1.005	2.5
0.3	0.905	0.870	3.5	0.950	0.920	3.0	0.990	0.965	2.5
0.4	0.790	0.745	4.5	0.850	0.810	4.0	0.900	0.865	3.5
0.5	0.640	0.600	4.0	0.695	0.655	4.0	0.745	0.710	3.5
0.6	0.505	0.465	4.0	0.545	0.505	4.0	0.585	0.545	4.0
0.7	0.370	0.330	4.0	0.400	0.360	4.0	0.430	0.390	4.0
0.8	0.240	0.195	4.5	0.260	0.220	4.0	0.275	0.235	4.0
Average % = 3.75				Average % = 3.5			Average % = 3.1325		

* Without residual stresses.

** With residual stresses.

(1) Pu = 1757 KN. Mu = 77.88 KN-m.

(2) Pu = 2007.27 KN. Mu = 79.604 KN-m.

(3) Pu = 2257.55 KN. Mu = 80.9 KN-m.

β = 1.0

L = 1.524 m.

Table (5.23) Effect of steel strength on the effect of residual stresses on the maximum strength.

P/Pu	(1) Fy = 248			(2) Fy = 276			(3) Fy = 345		
	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%
0.1	1.020	0.995	2.5	1.015	0.990	2.5	0.995	0.970	2.5
0.2	1.015	0.990	2.5	1.000	0.975	2.5	0.970	0.945	2.5
0.3	0.970	0.940	3.0	0.950	0.920	3.0	0.910	0.875	3.5
0.4	0.875	0.840	3.5	0.850	0.810	4.0	0.790	0.750	4.0
0.5	0.725	0.685	4.0	0.695	0.655	4.0	0.640	0.605	3.5
0.6	0.565	0.530	3.5	0.545	0.505	4.0	0.505	0.465	4.0
0.7	0.415	0.380	3.5	0.400	0.360	4.0	0.370	0.330	4.0
0.8	0.270	0.230	4.0	0.260	0.220	4.0	0.235	0.195	4.0
	Average % = 3.3125			Average % = 3.5			Average % = 3.5		

* Without residual stresses.

** With residual stresses.

(1) Pu = 1881.62 KN. Mu = 72.07 KN-m.

(2) Pu = 2007.27 KN. Mu = 79.604 KN-m.

(3) Pu = 2321.385 KN. Mu = 98.29 KN-m.

$\beta = 1.0$

L = 1.524 m.

Table (5.24) Effect of steel strength on the effect of residual stresses on the maximum strength.

$\frac{P}{Pu}$	(1) Fy = 248			(2) Fy = 276			(3) Fy = 345		
	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%	Mw/Mu *	MR/Mu **	%
0.1	0.945	0.915	3.0	0.955	0.920	3.5	0.950	0.920	3.0
0.2	0.875	0.835	4.0	0.890	0.850	4.0	0.885	0.845	4.0
0.3	0.755	0.710	4.5	0.780	0.730	5.0	0.770	0.725	4.5
0.4	0.630	0.585	4.5	0.650	0.605	4.5	0.645	0.600	4.5
0.5	0.510	0.465	4.5	0.530	0.485	4.5	0.525	0.480	4.5
0.6	0.400	0.355	4.5	0.415	0.370	4.5	0.410	0.365	4.5
0.7	0.290	0.245	4.5	0.305	0.260	4.5	0.305	0.255	5.0
0.8	0.175	0.125	5.0	0.195	0.145	5.0	0.190	0.135	5.5
	Average % = 4.3125			Average % = 4.4375			Average % = 4.4375		

* Without residual stresses.
** With residual stresses.

(1) Pu = 1130.81 KN. Mu = 64.703 KN-m.
(2) Pu = 1256.45 KN. Mu = 71.892 KN-m.
(3) Pu = 1570.56 KN. Mu = 89.865 KN-m.

β = 1.0
L = 1.524 m.

CHAPTER VI

SUMMARY AND CONCLUSSION

The effect of residual stresses on the maximum strength of pin-ended battened composite columns loaded concentrically or eccentrically and bending about the minor axis is studied numerically.

The method of calculation is based on inelastic column theory, through which Newmark's integration procedure is used for computing the true equilibrium shape of the deflected column.

The effect of inclusion of residual stresses in the calculation of the maximum load carrying capacity of the battened composite columns can be summarized as follows for the cases considered:

1. The average reduction of strength for zero-length (L/D=0,10) battened composite column is 4% of the ultimate strength (Mu), for the same axial load.

2. The average reduction of strength for zero-length (L/D=0,10) battened steel column strength is 5% of the ultimate strength (Mu), for the same axial load .

3. The average reduction of strength for slender (L/D=20,30,40) battened composite column strength is 2.9% of the ultimate strength (Mu), for the same axial load.

4. The average reduction of strength for slender (L/D=20,30,40) steel column strength is 4.2% of the ultimate strength (Mu), for the same axial load.

5. Steel strength has no influence on residual stresses effect on the maximum strength of battened composite column and steel column.

APPENDIX A

MOMENT-CURVATURE CURVES

&

INTERACTION DIAGRAMS

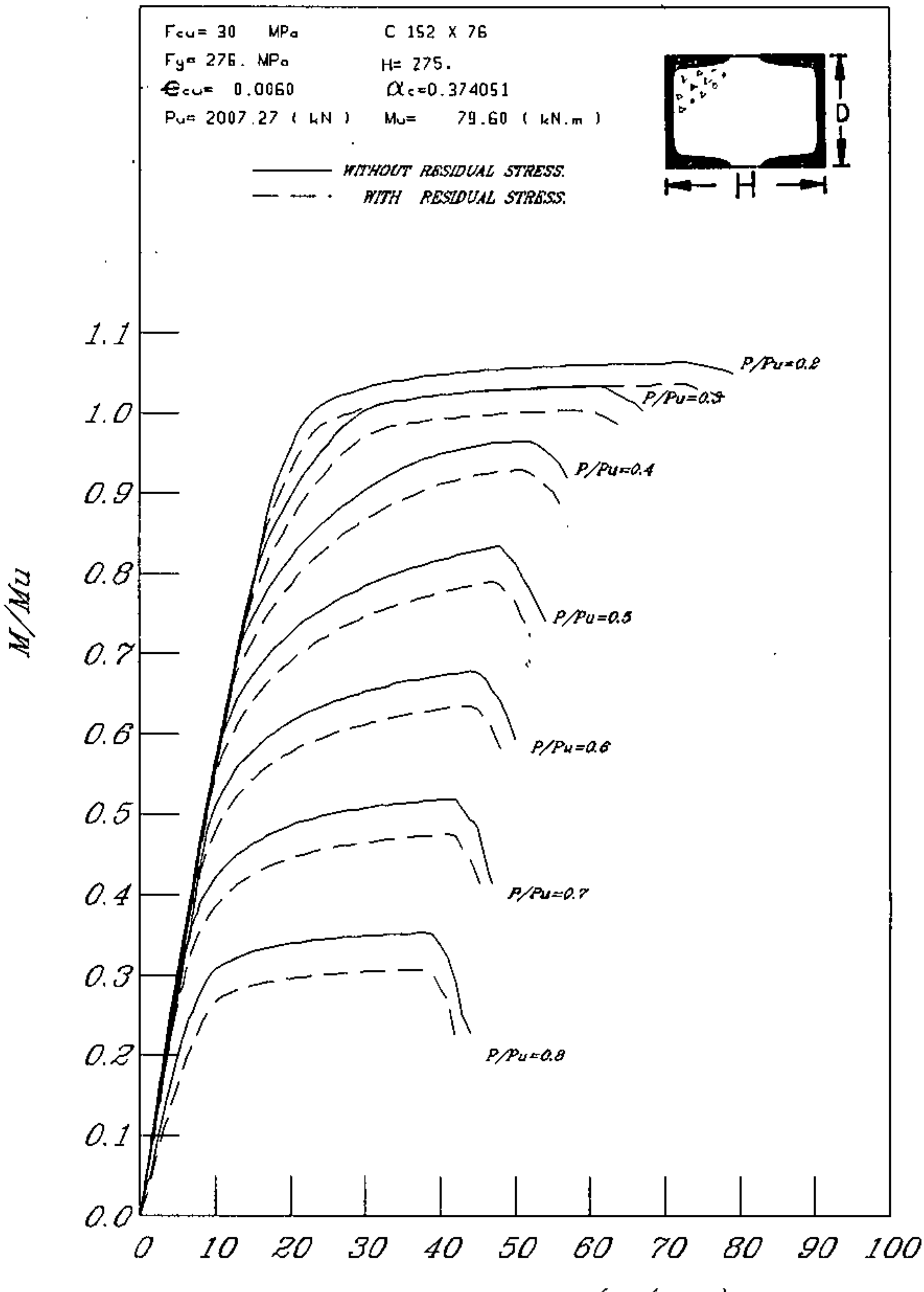

FIG. **(A.1)** : MOMENT - THRUST - CURVATURE CURVES UNDER UNIAXIAL BENDING ABOUT MINOR AXIS

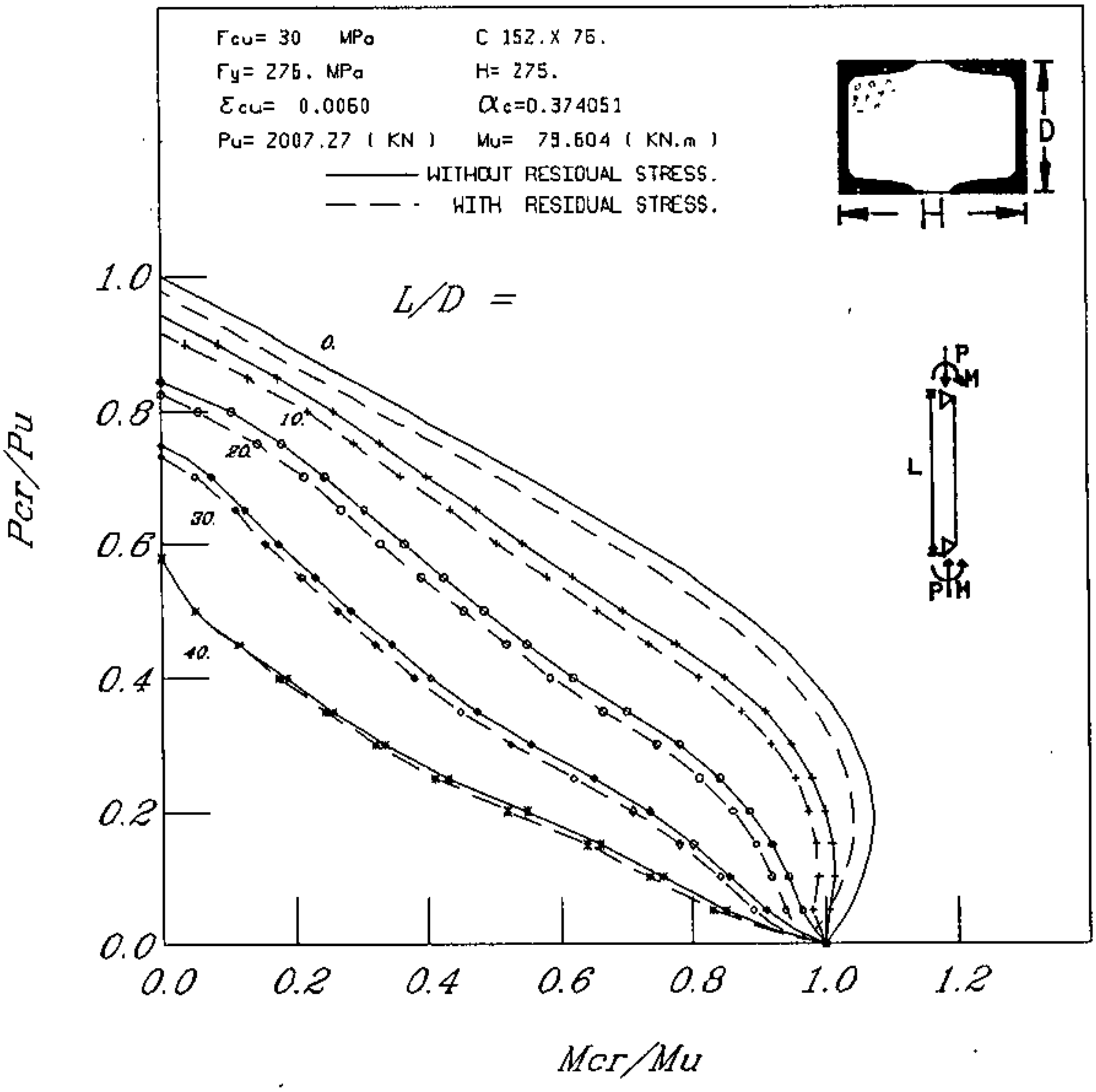

FIG. **(A.2)** :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

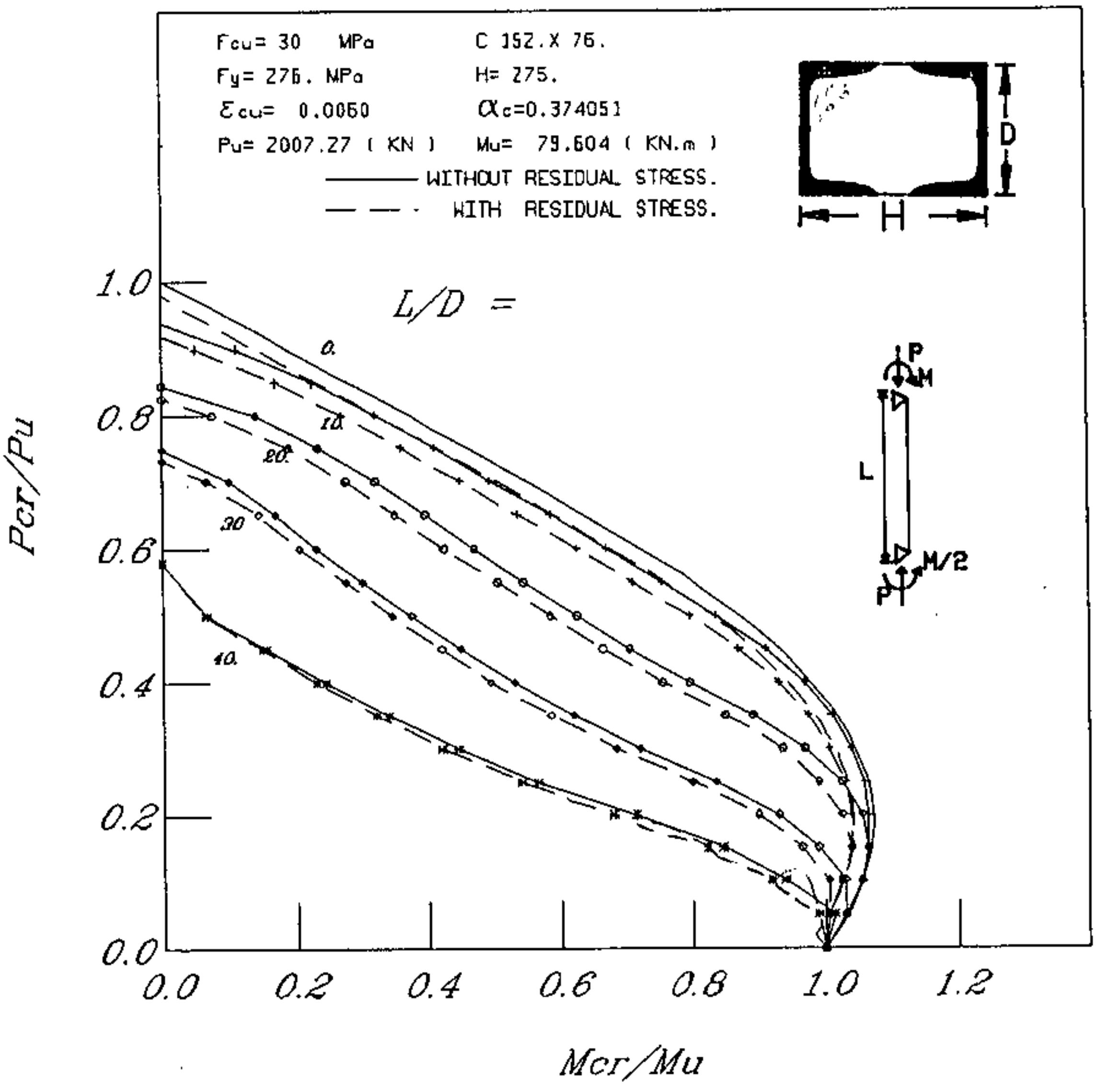

FIG. (A.3) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

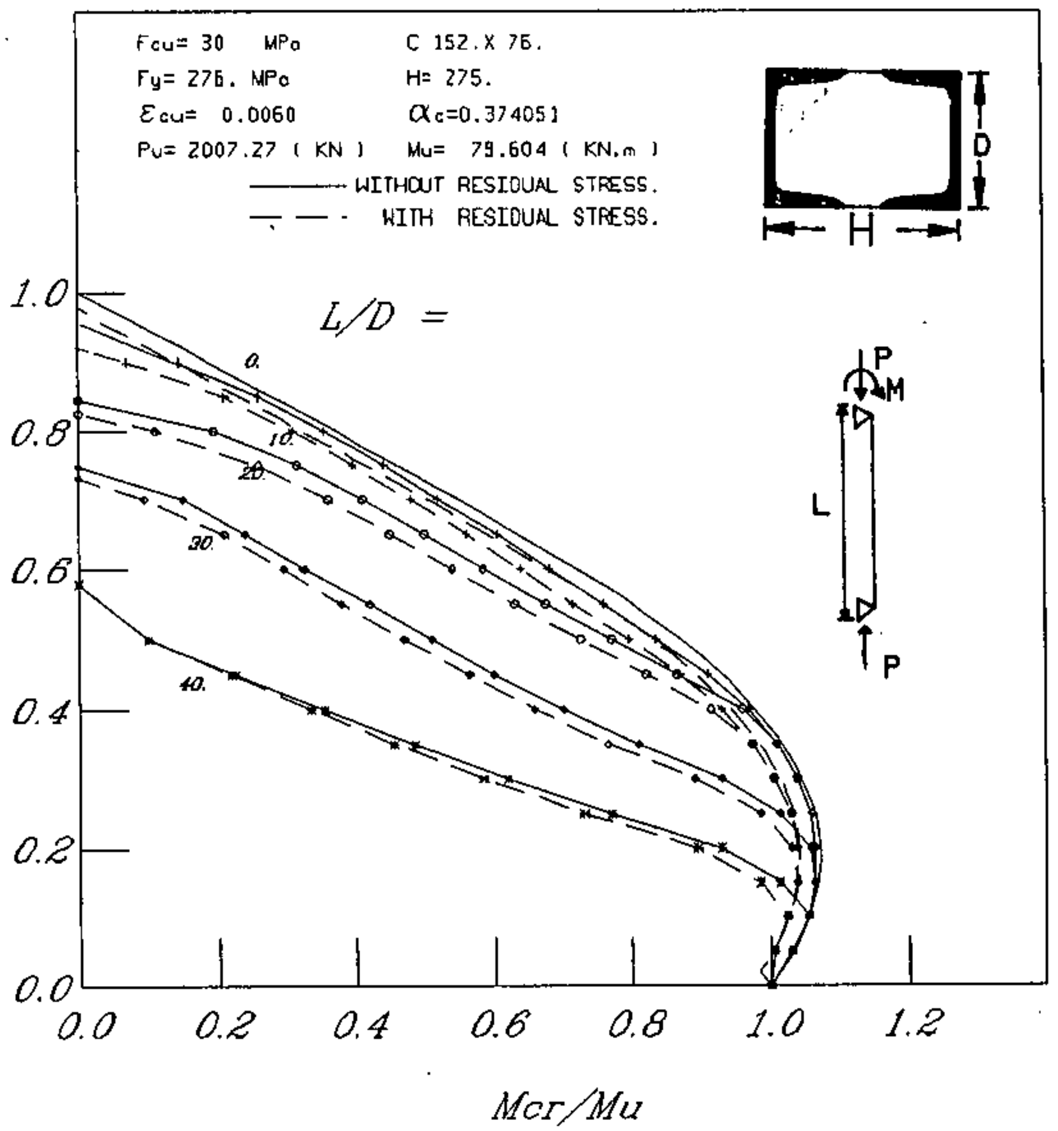

FIG. **(A.4)** :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

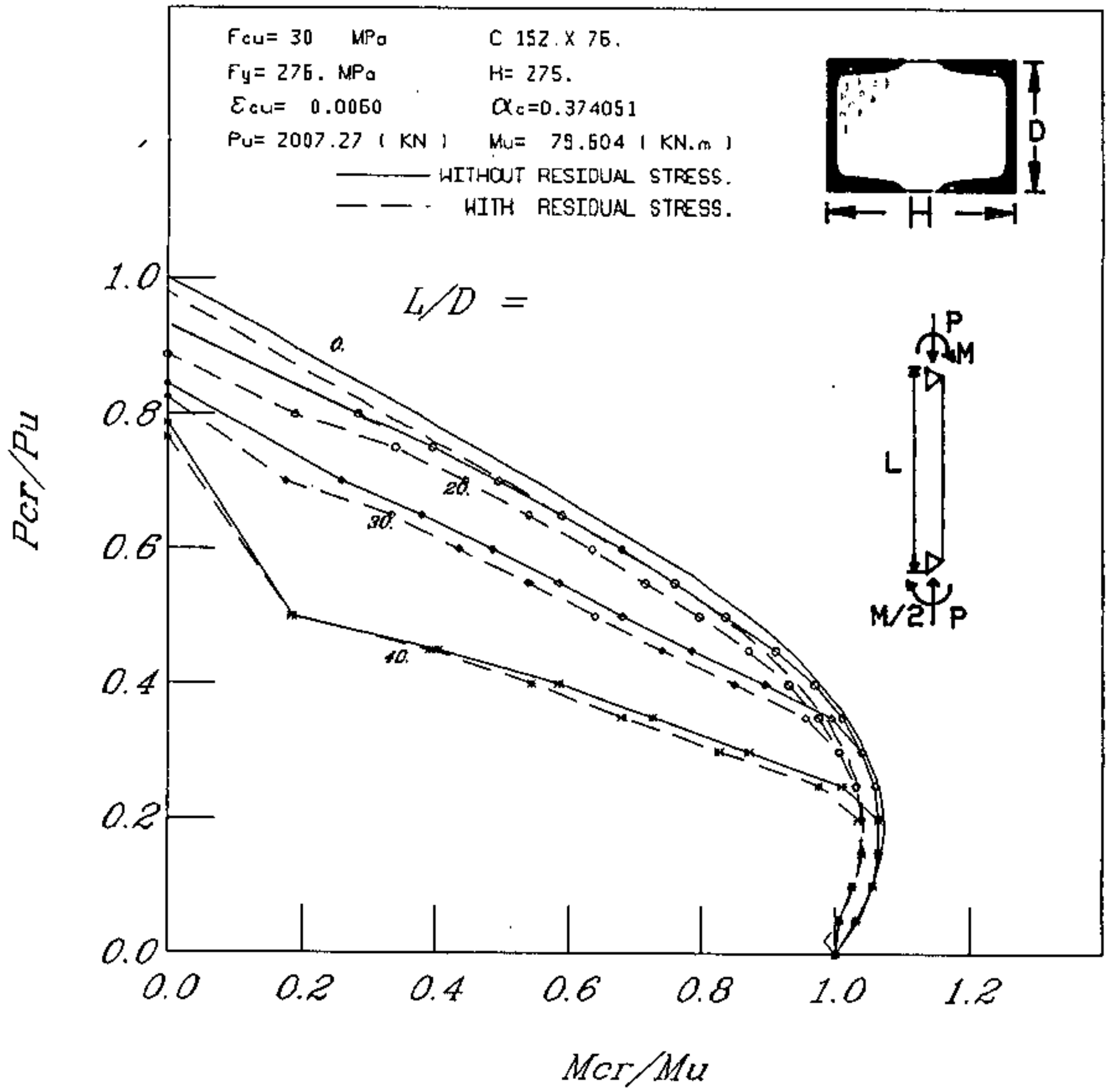

FIG. (A.5) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

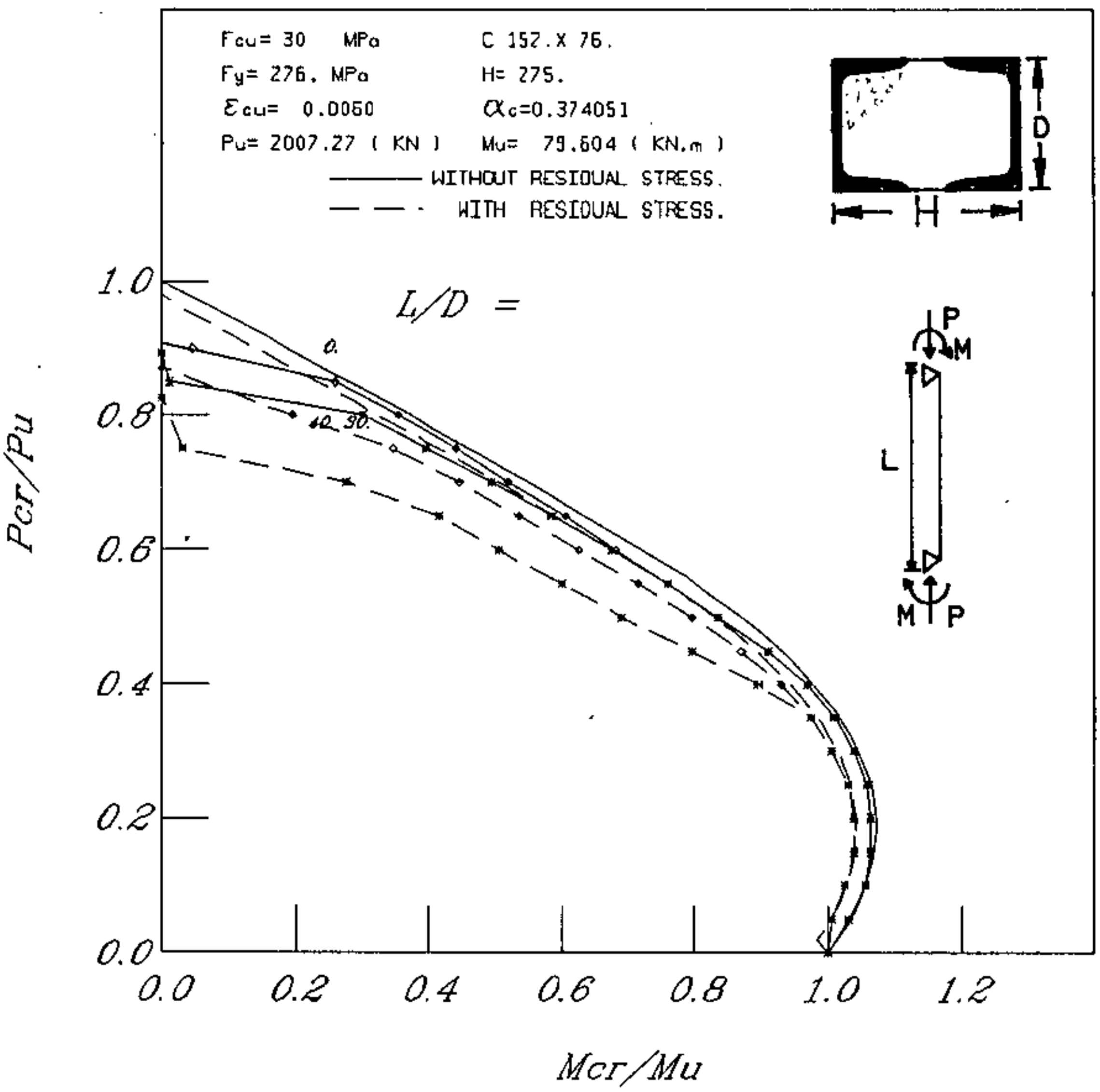

FIG. **(A.6)** :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

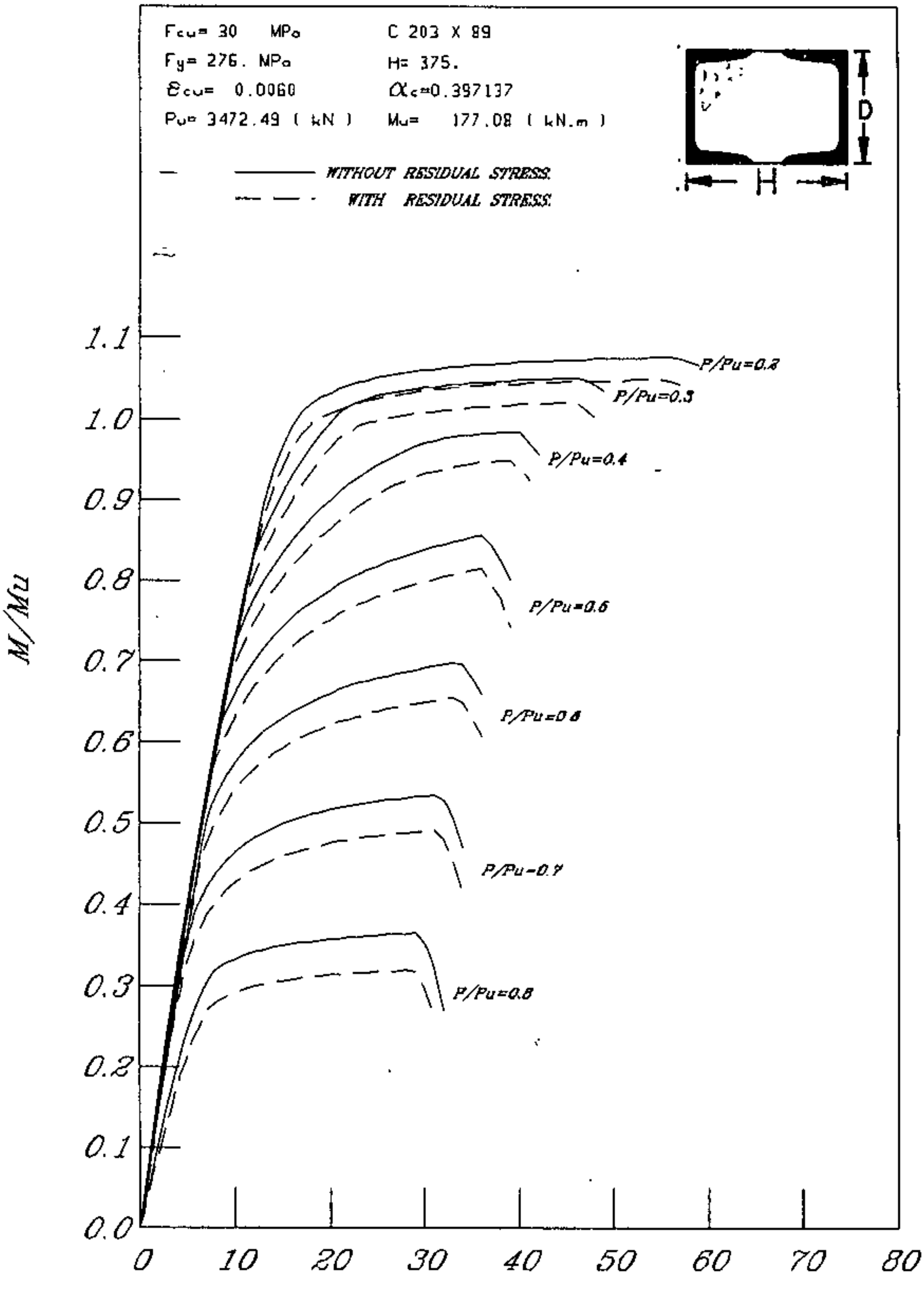

FIG. (A.7) : MOMENT - THRUST - CURVATURE CURVES UNDER UNIAXIAL BENDING ABOUT MINOR AXIS

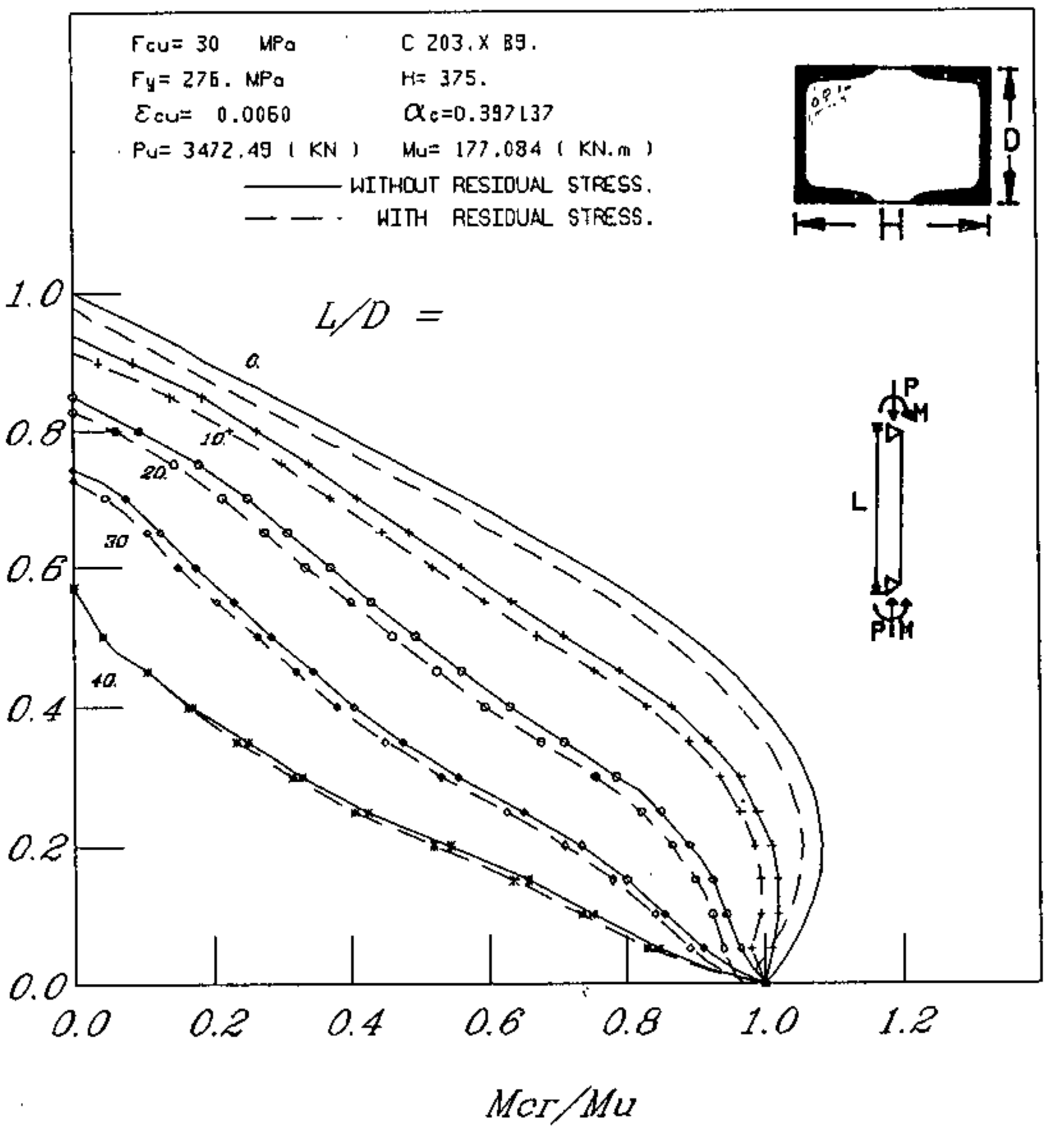

FIG. **(A.8)** :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

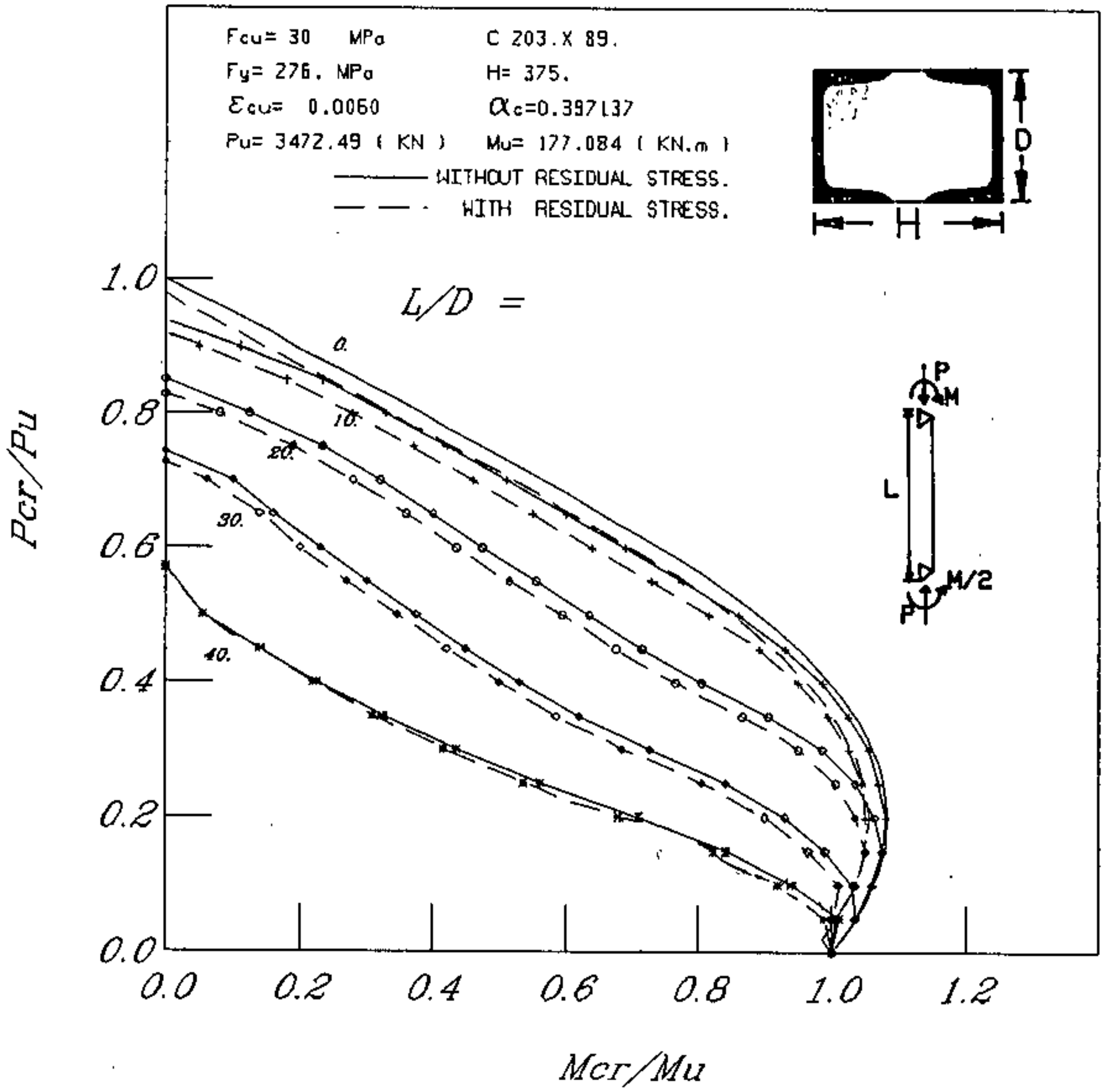

FIG. (A.9) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

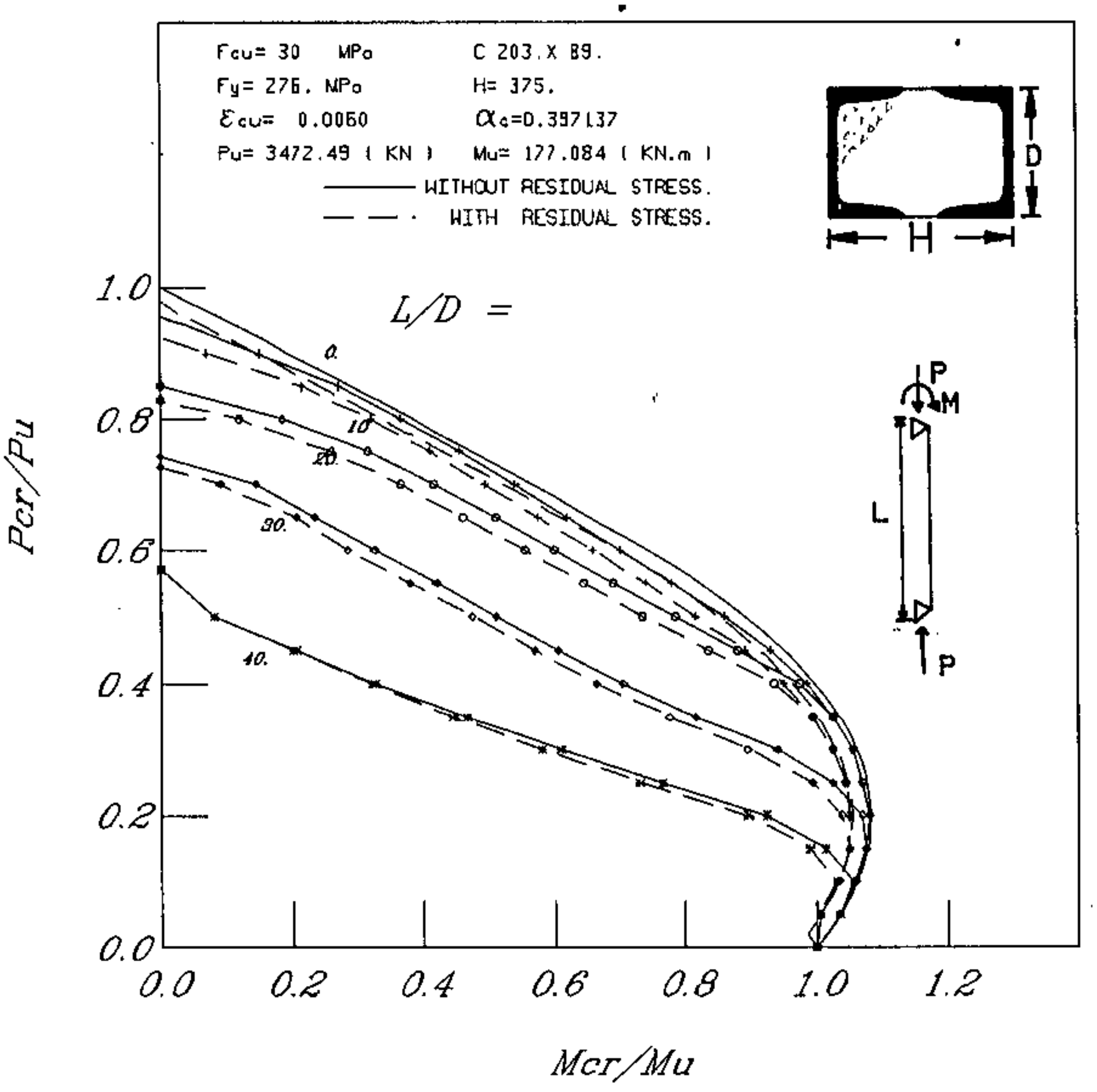

FIG. **(A.10)** : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS . .

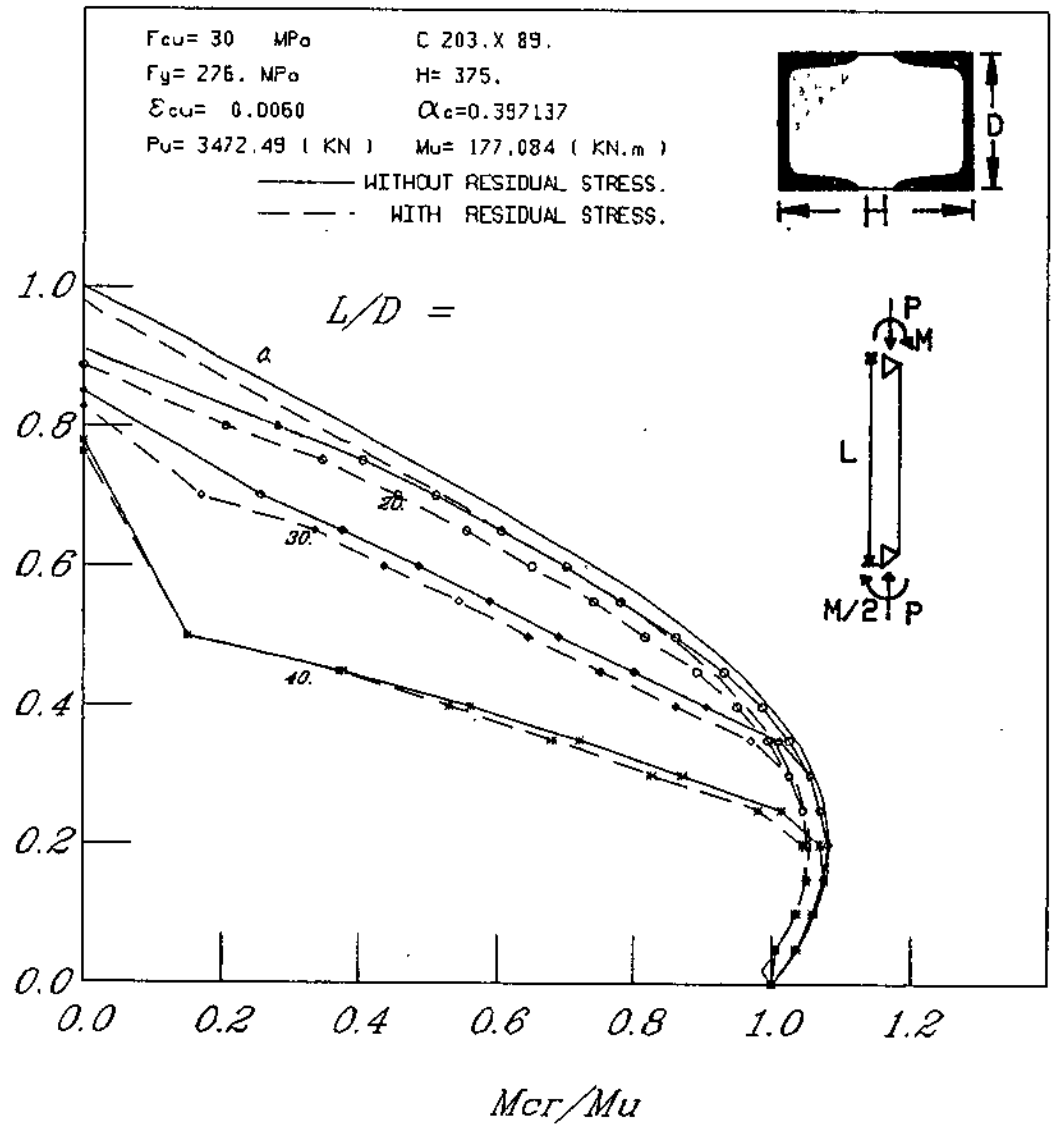

FIG. (A.11) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

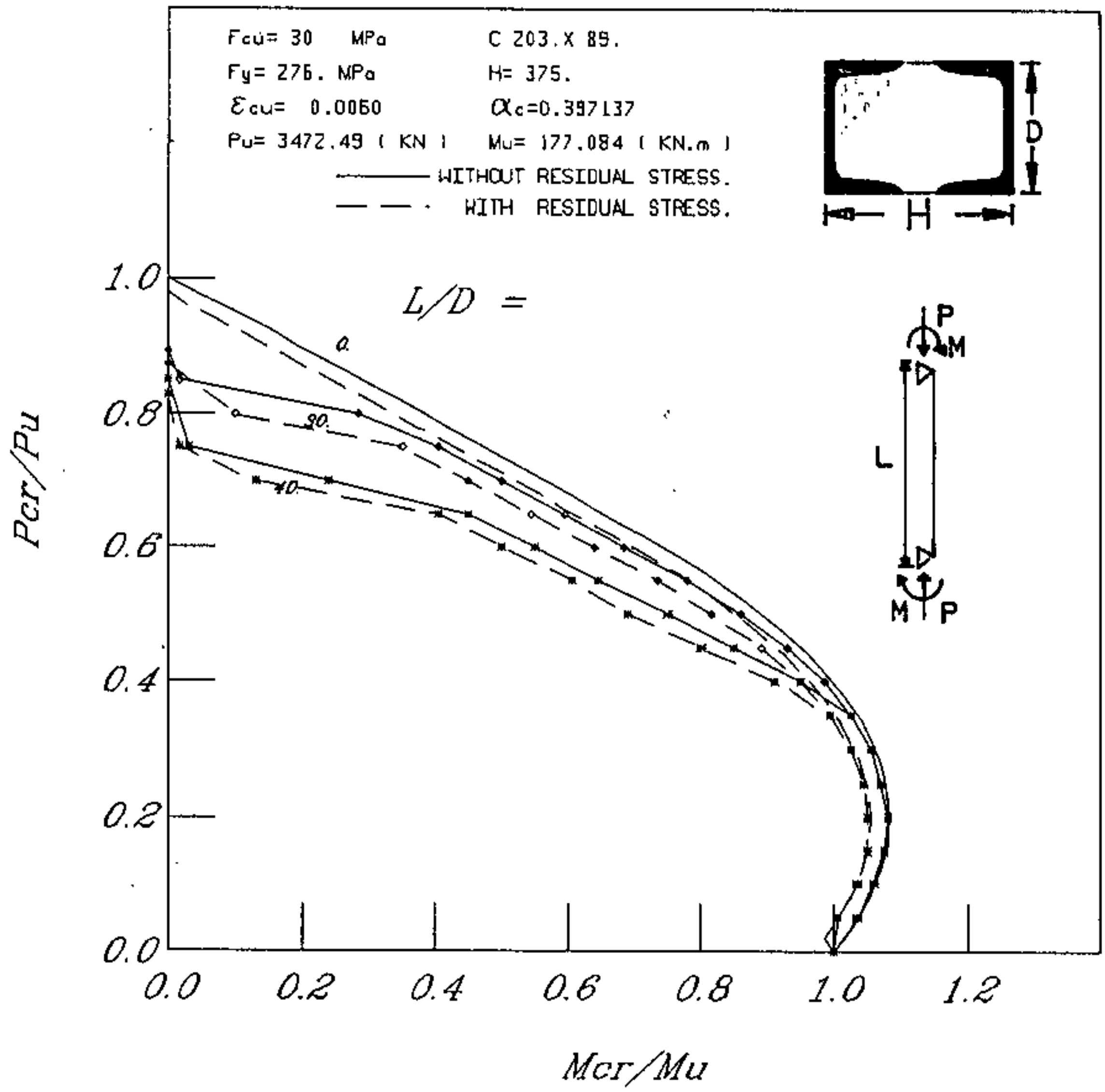

FIG. **(A.12)** : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

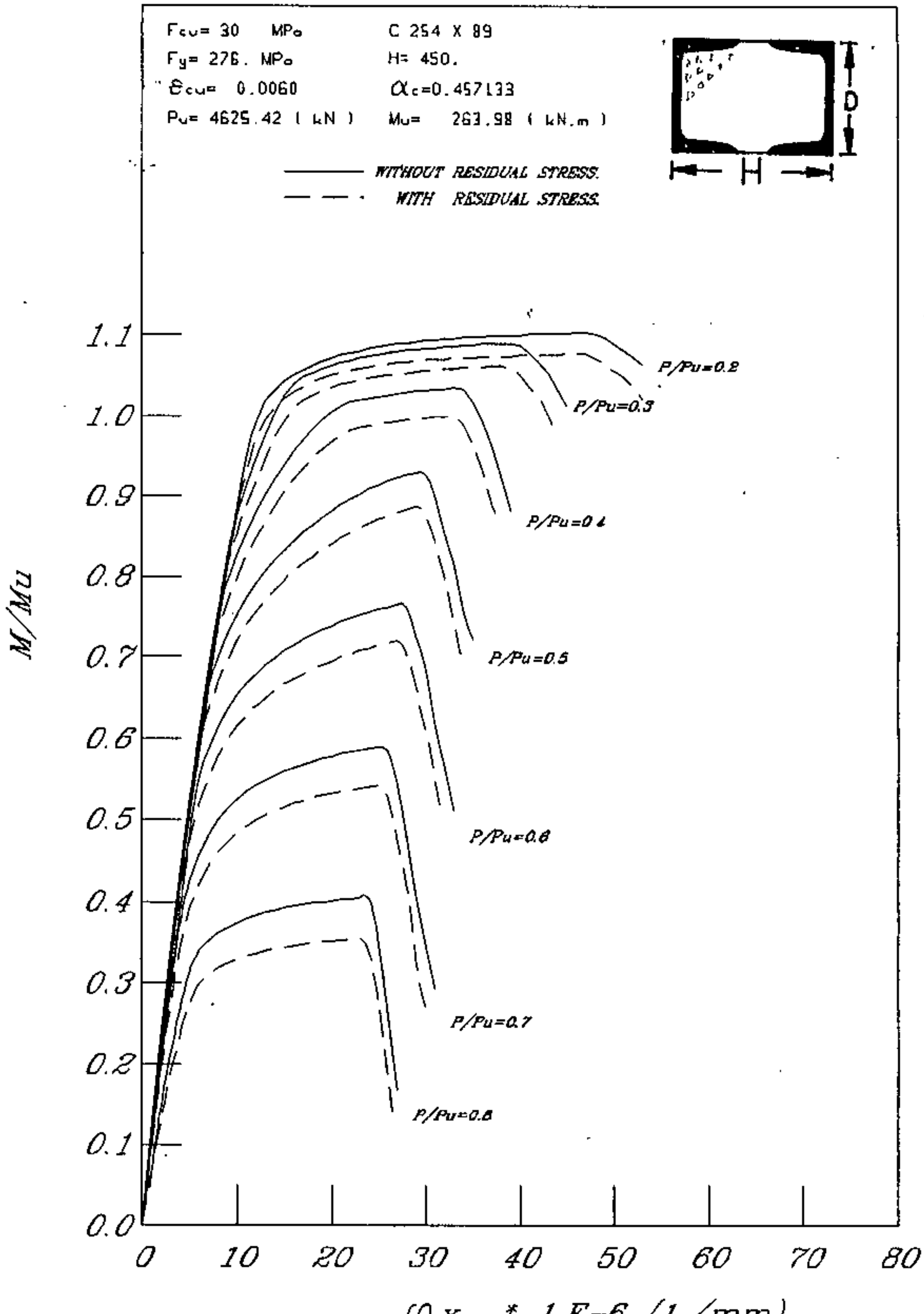

FIG.(A.13): MOMENT - THRUST - CURVATURE CURVES UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

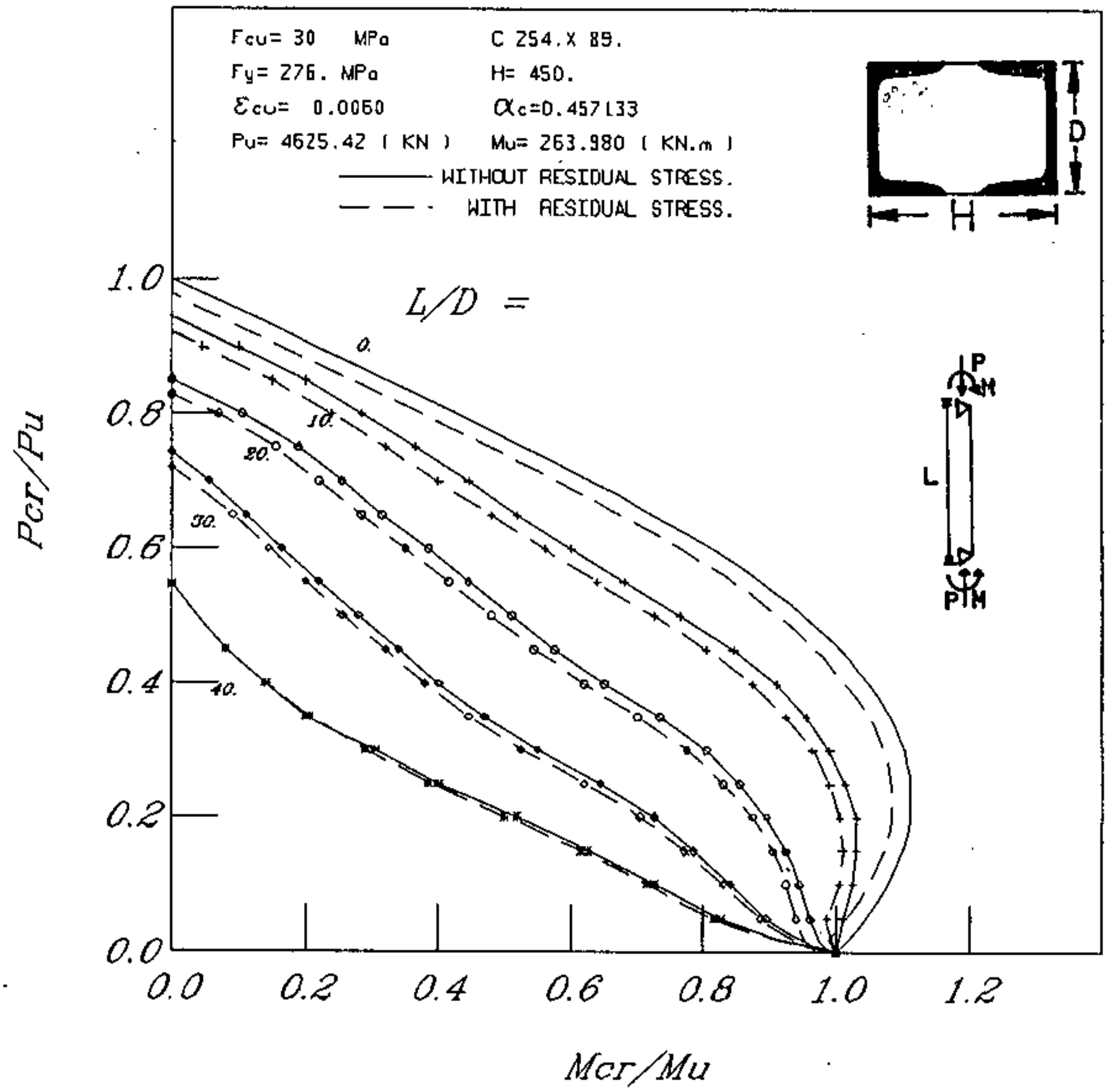

FIG. (A.14) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

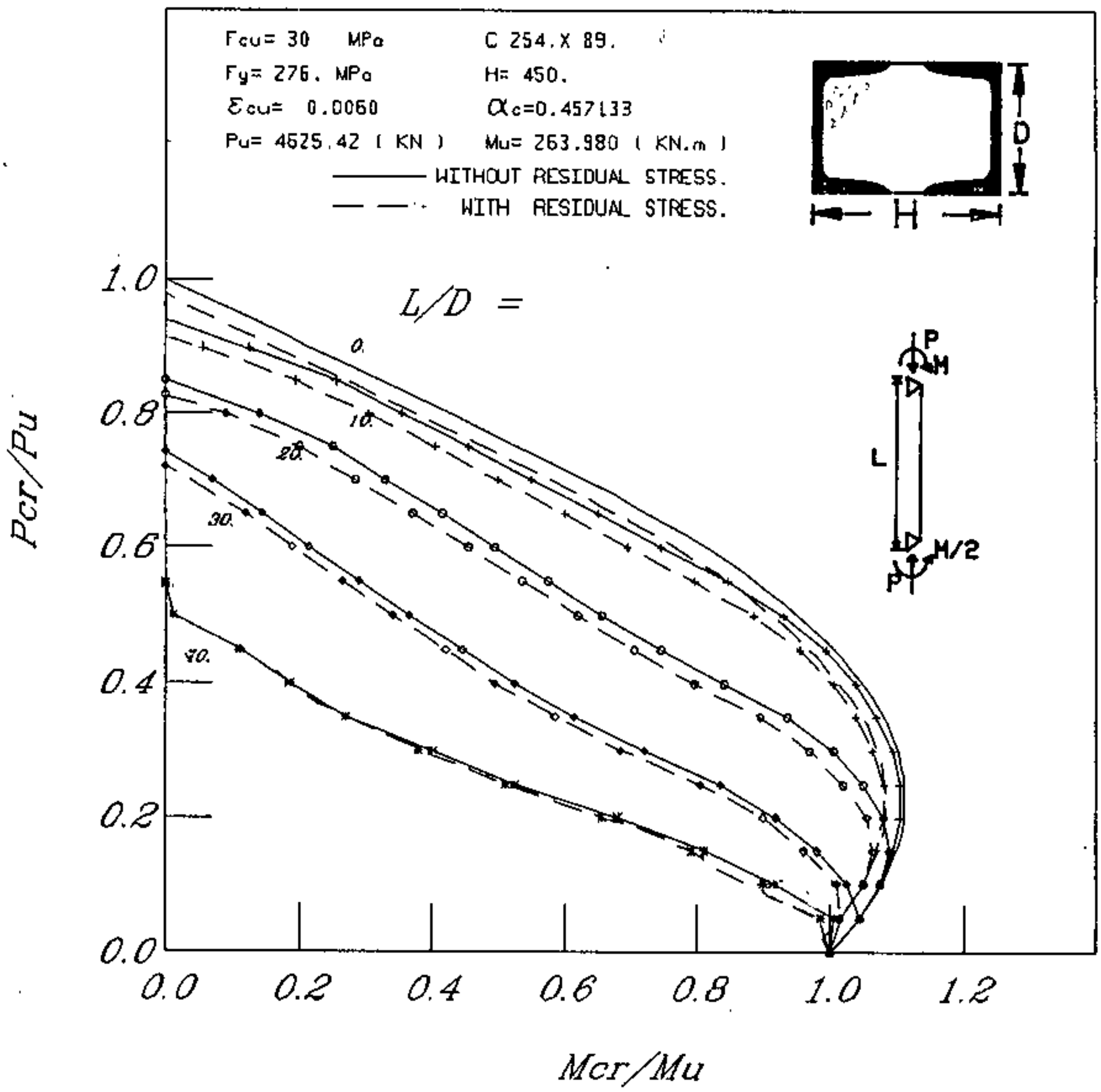

FIG. **(A.15)** :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

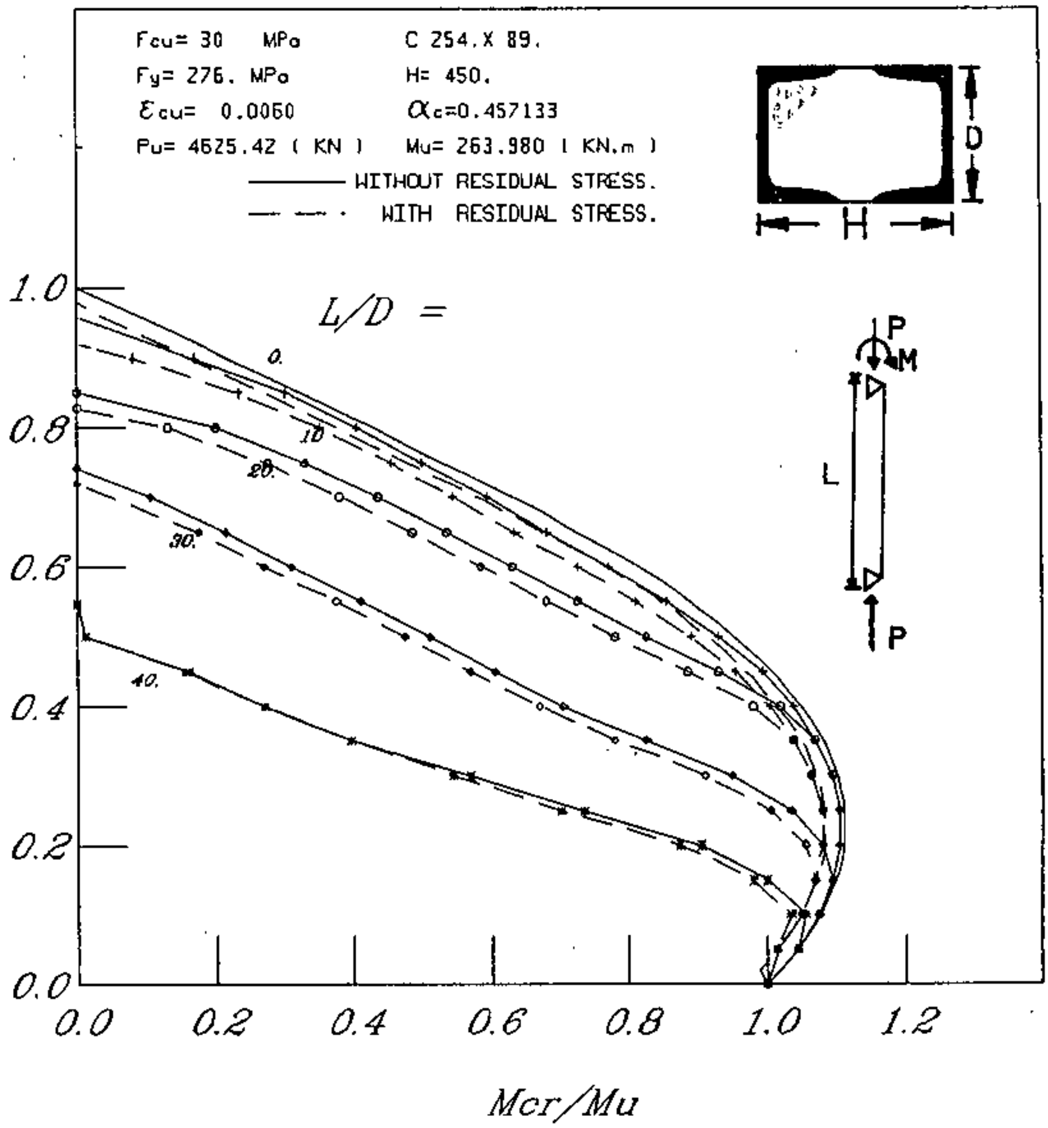

FIG. (A.16) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

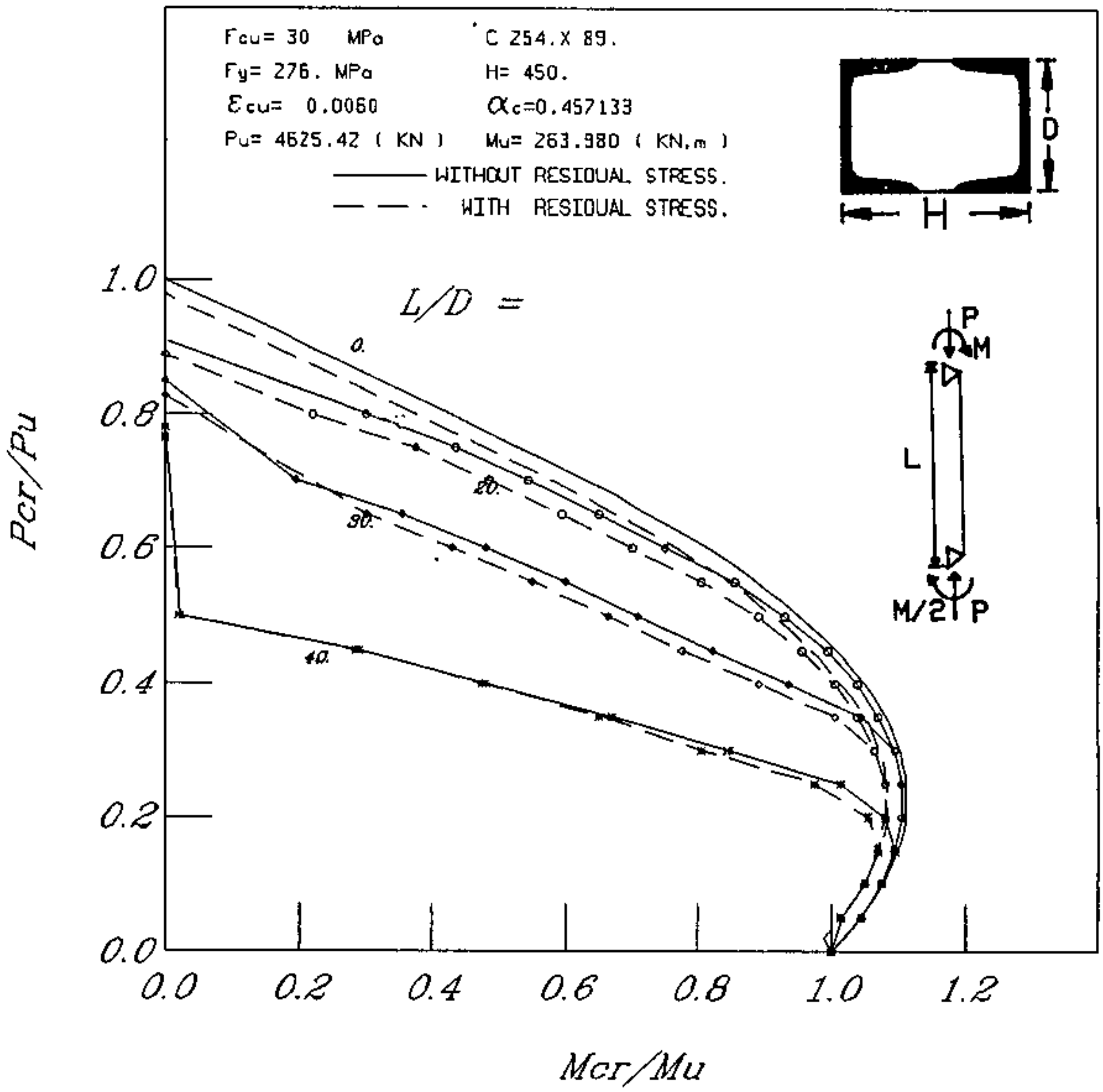

FIG. **(A.17)** : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

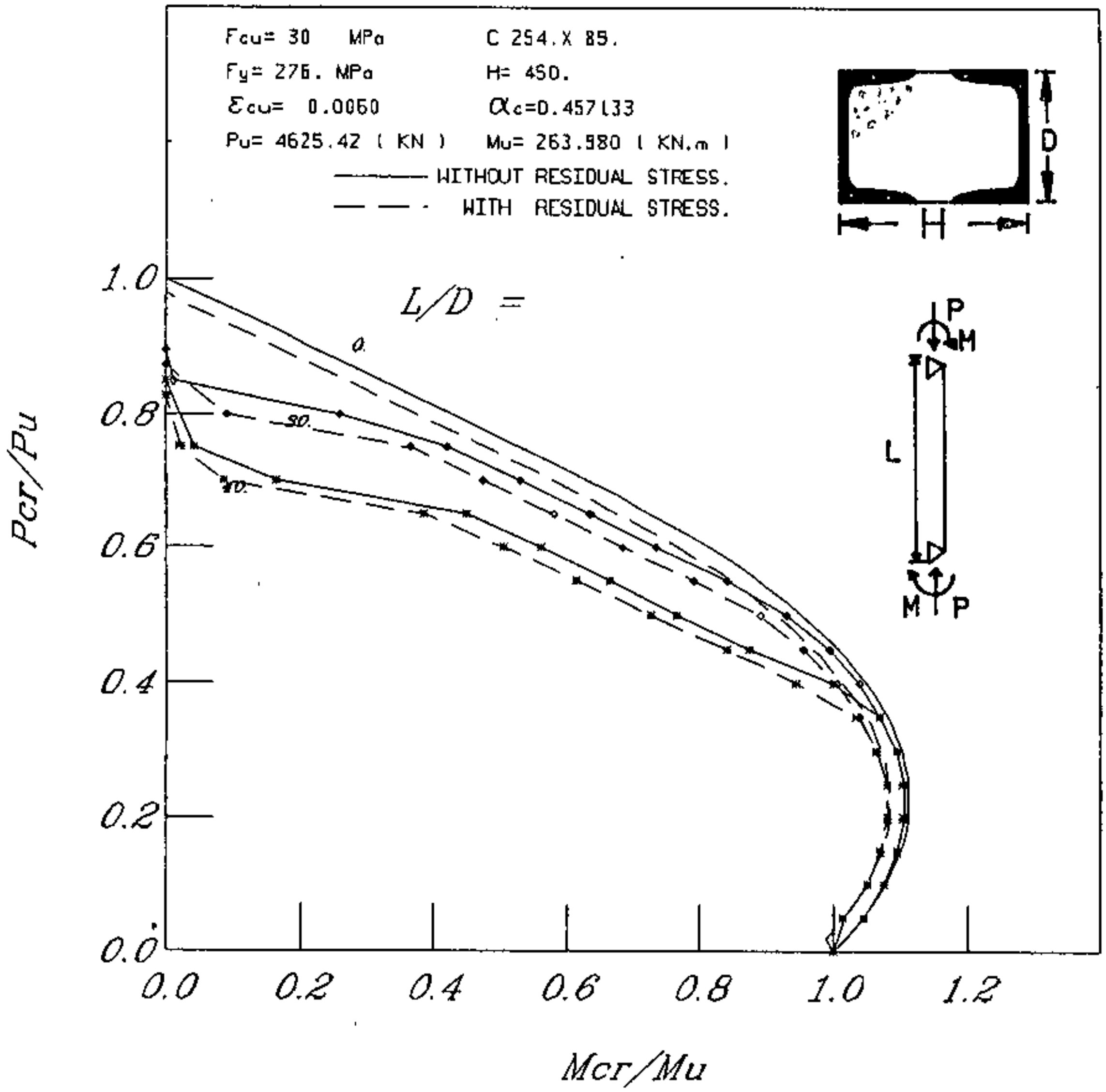

FIG. **(A.18)** :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

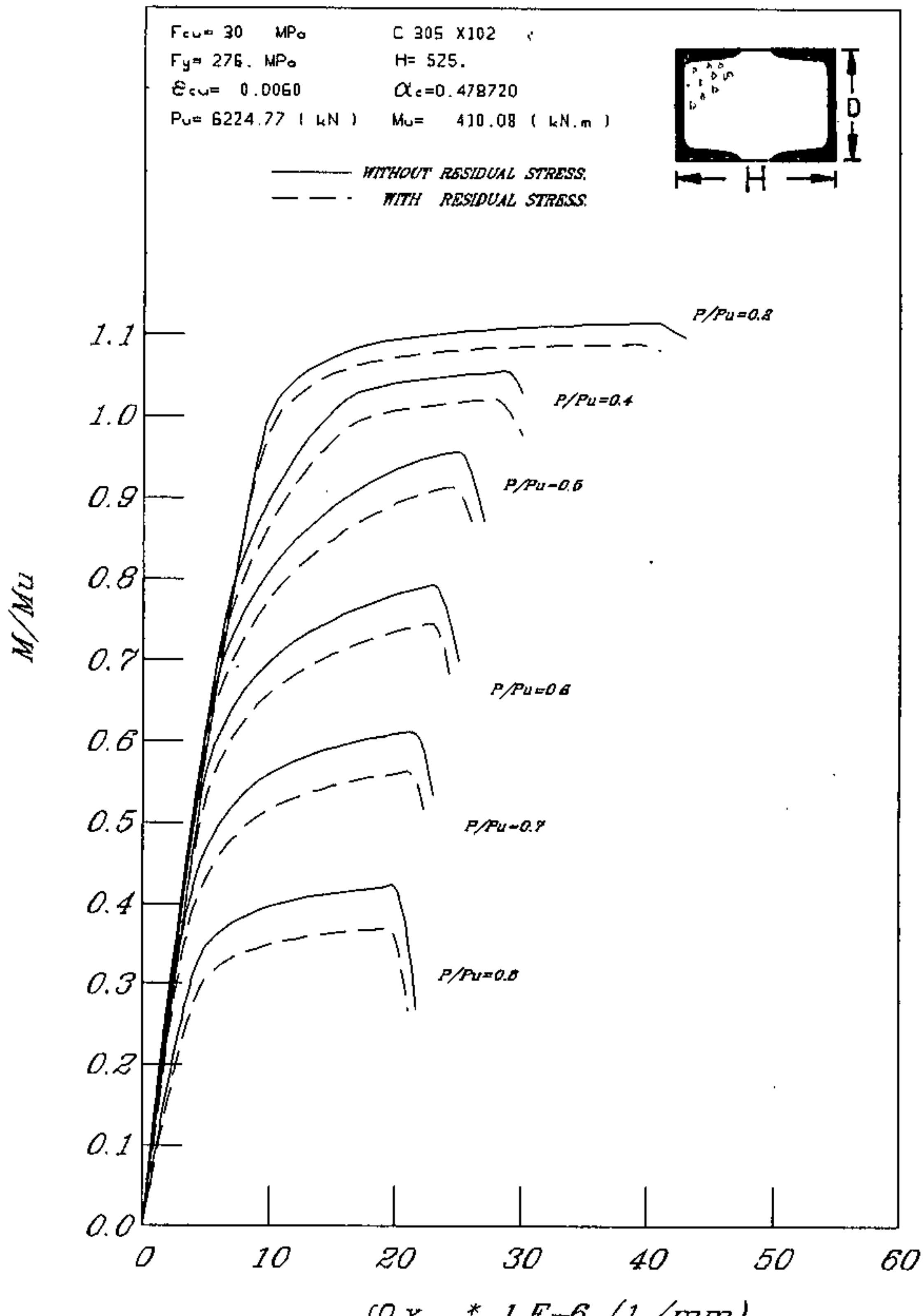

FIG. (A.19): MOMENT - THRUST - CURVATURE CURVES UNDER UNIAXIAL BENDING ABOUT MINOR AXIS

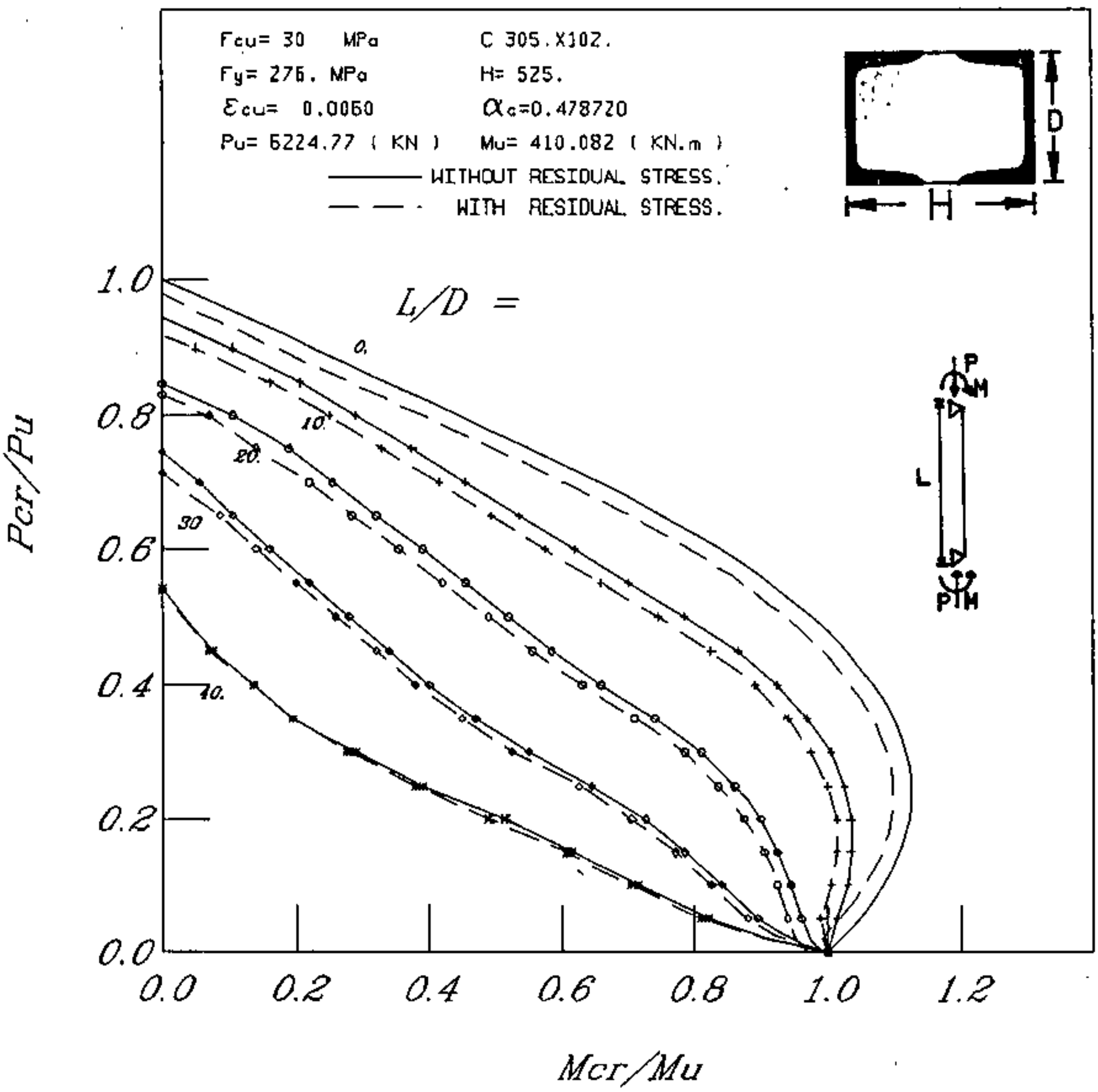

FIG. (A.20) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

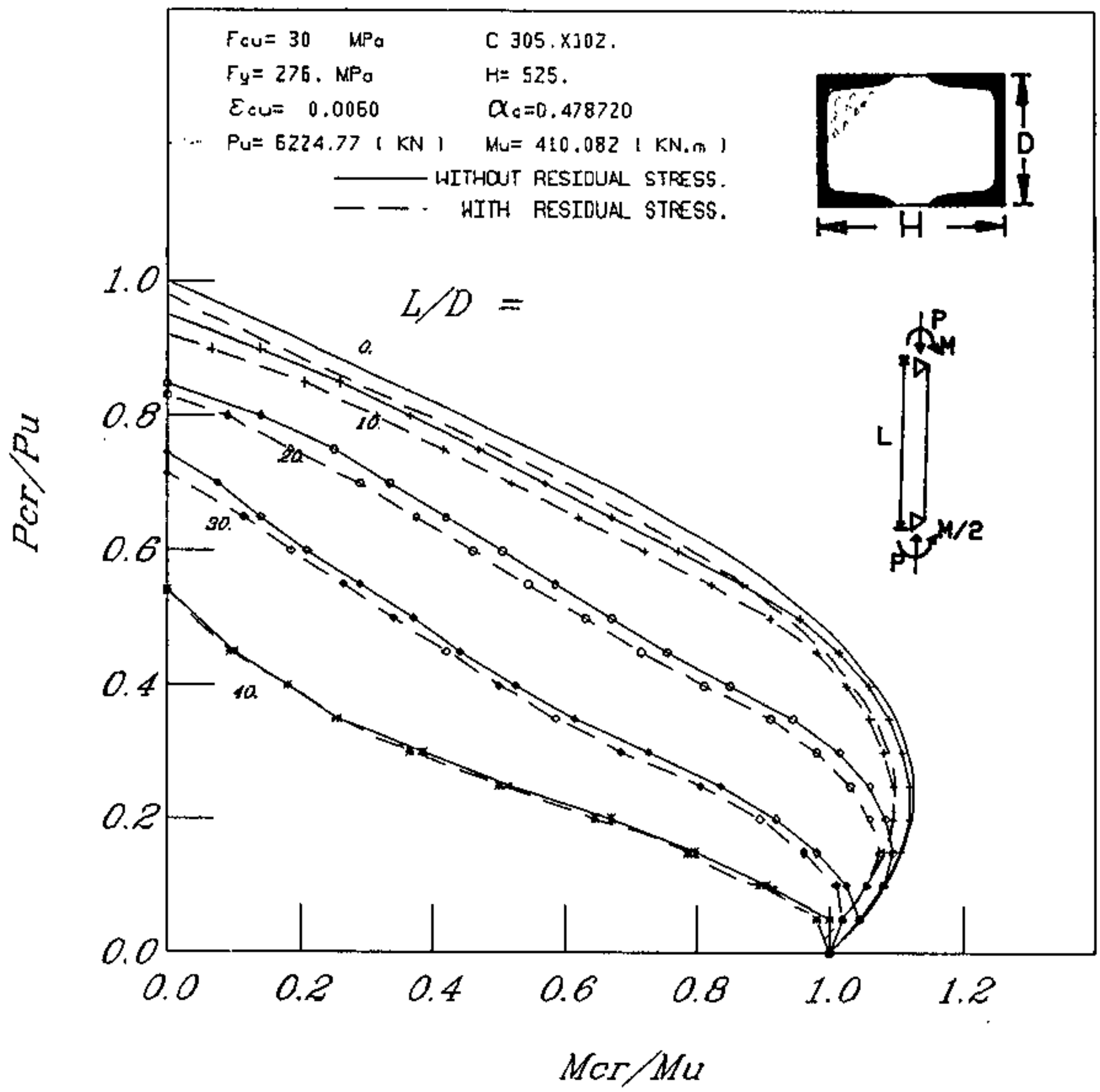

FIG. (A.21) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

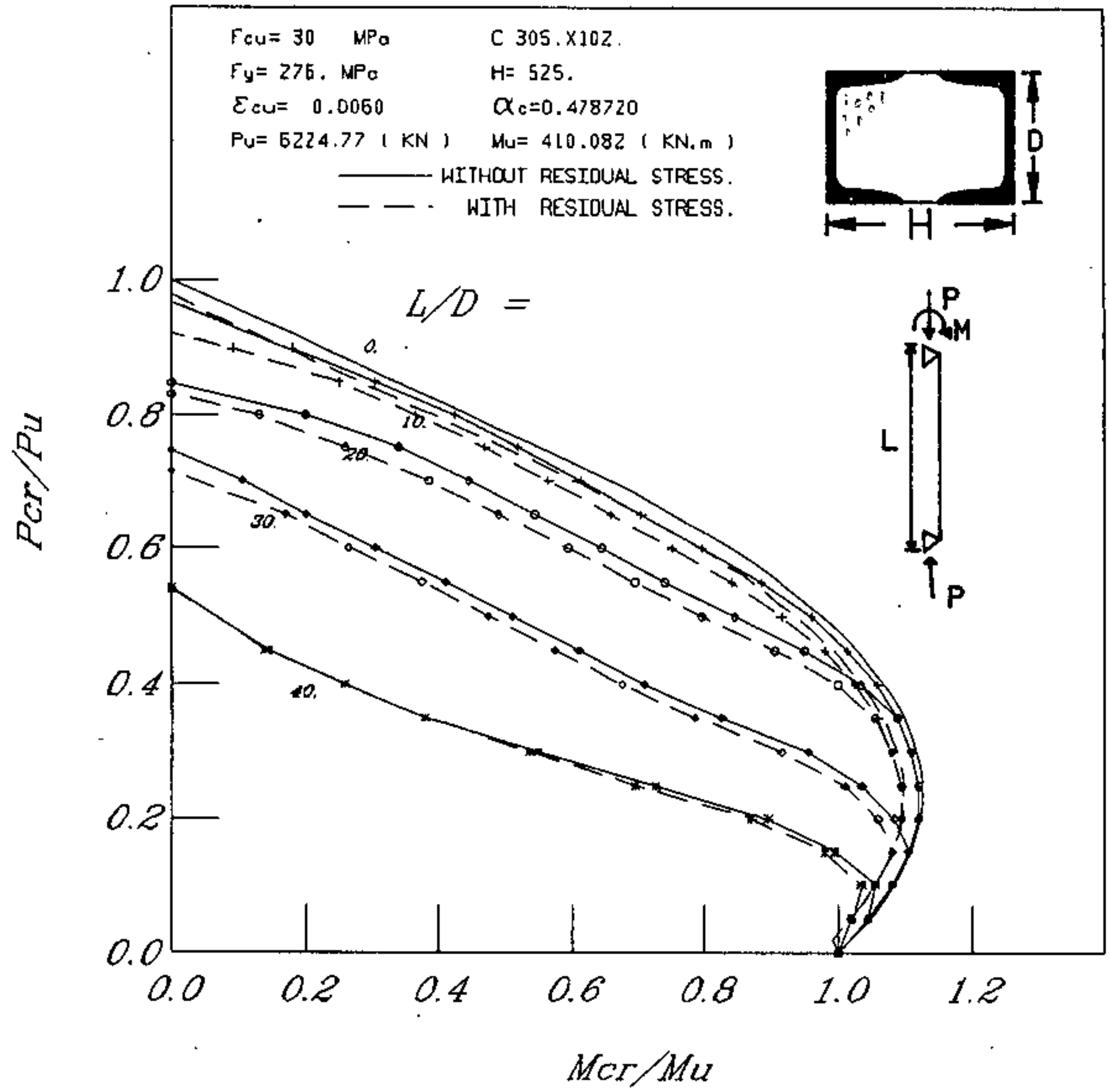

FIG. (A.22) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

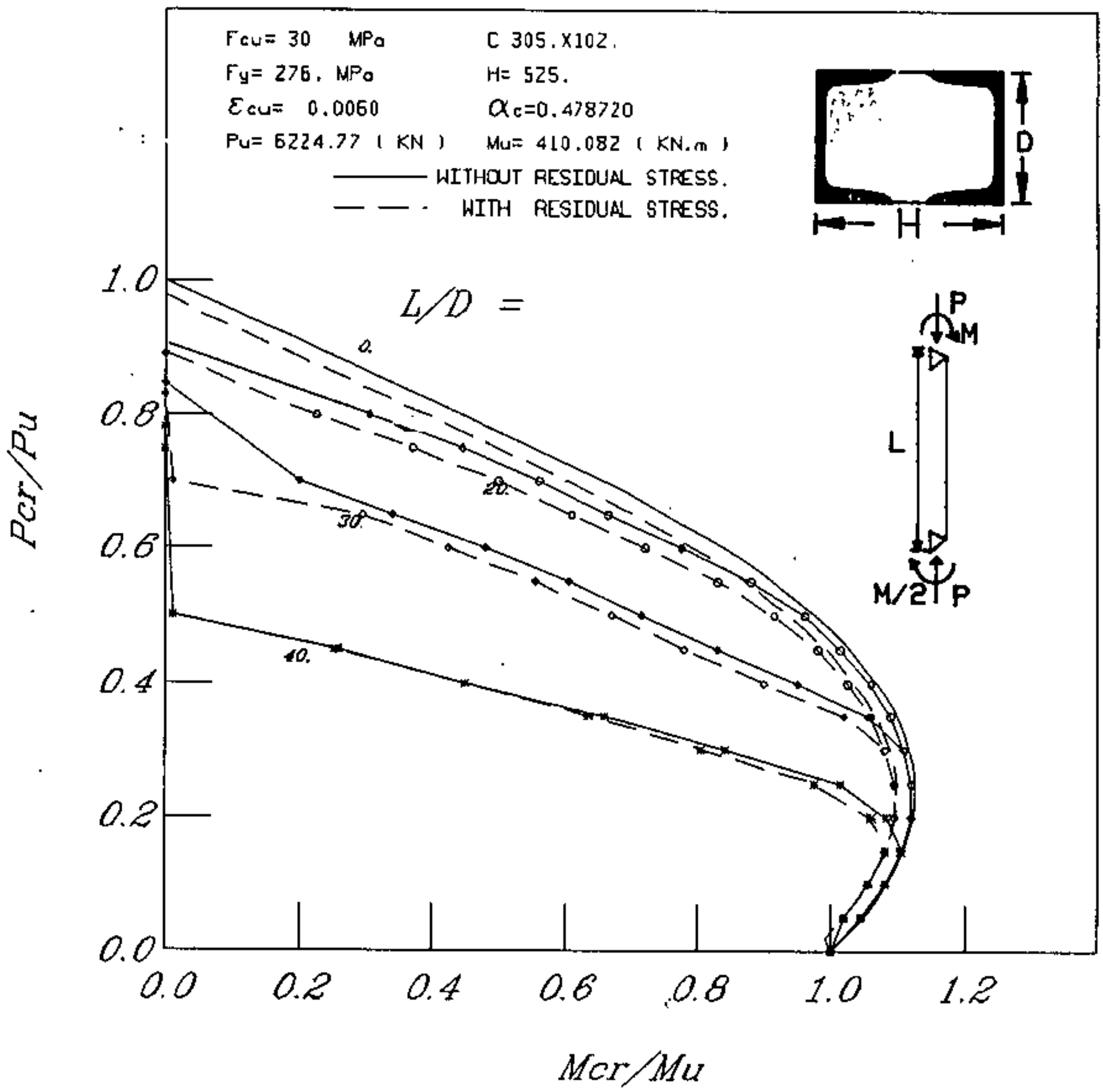

FIG. (A.23) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

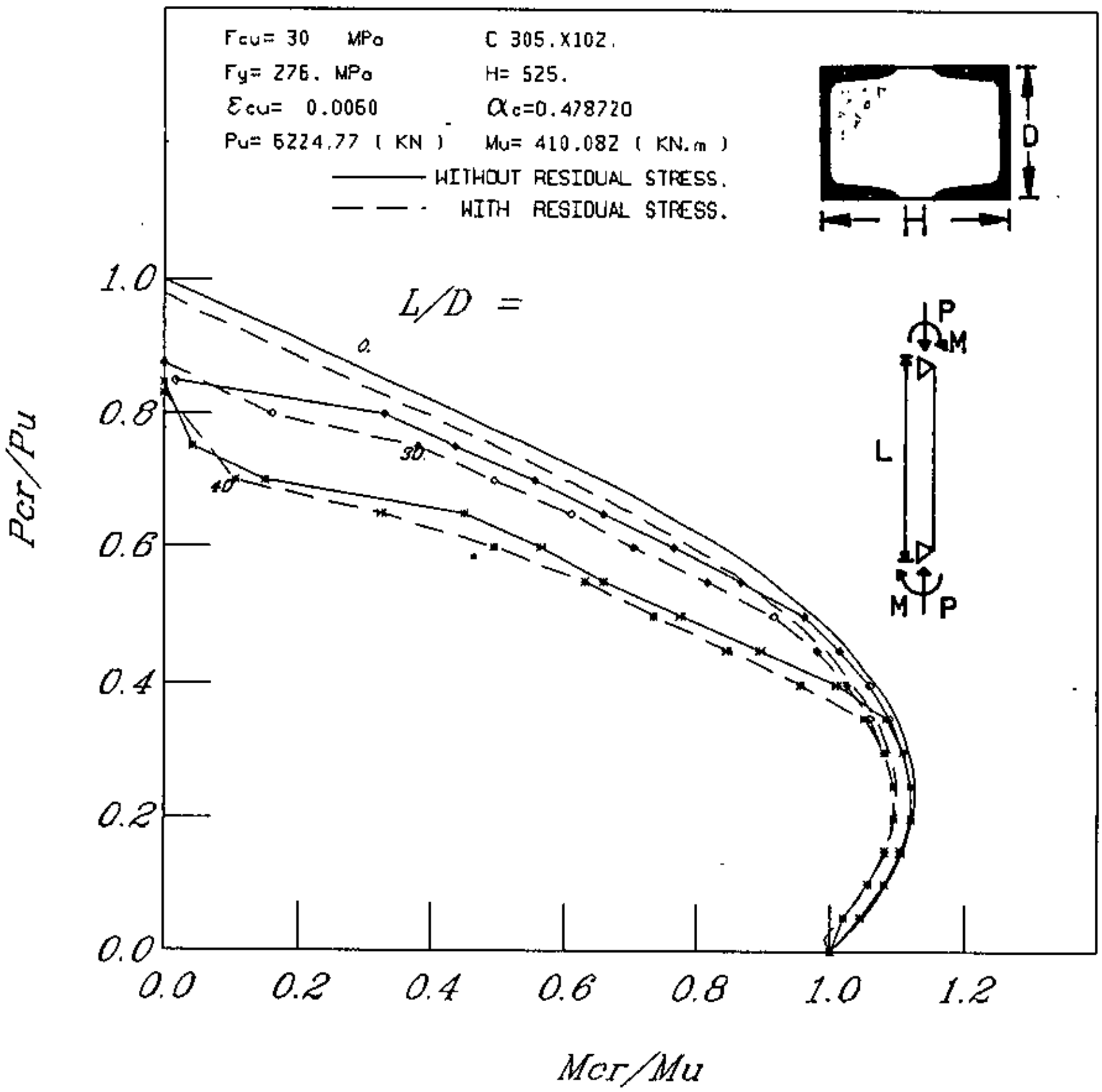

FIG. (A.24) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

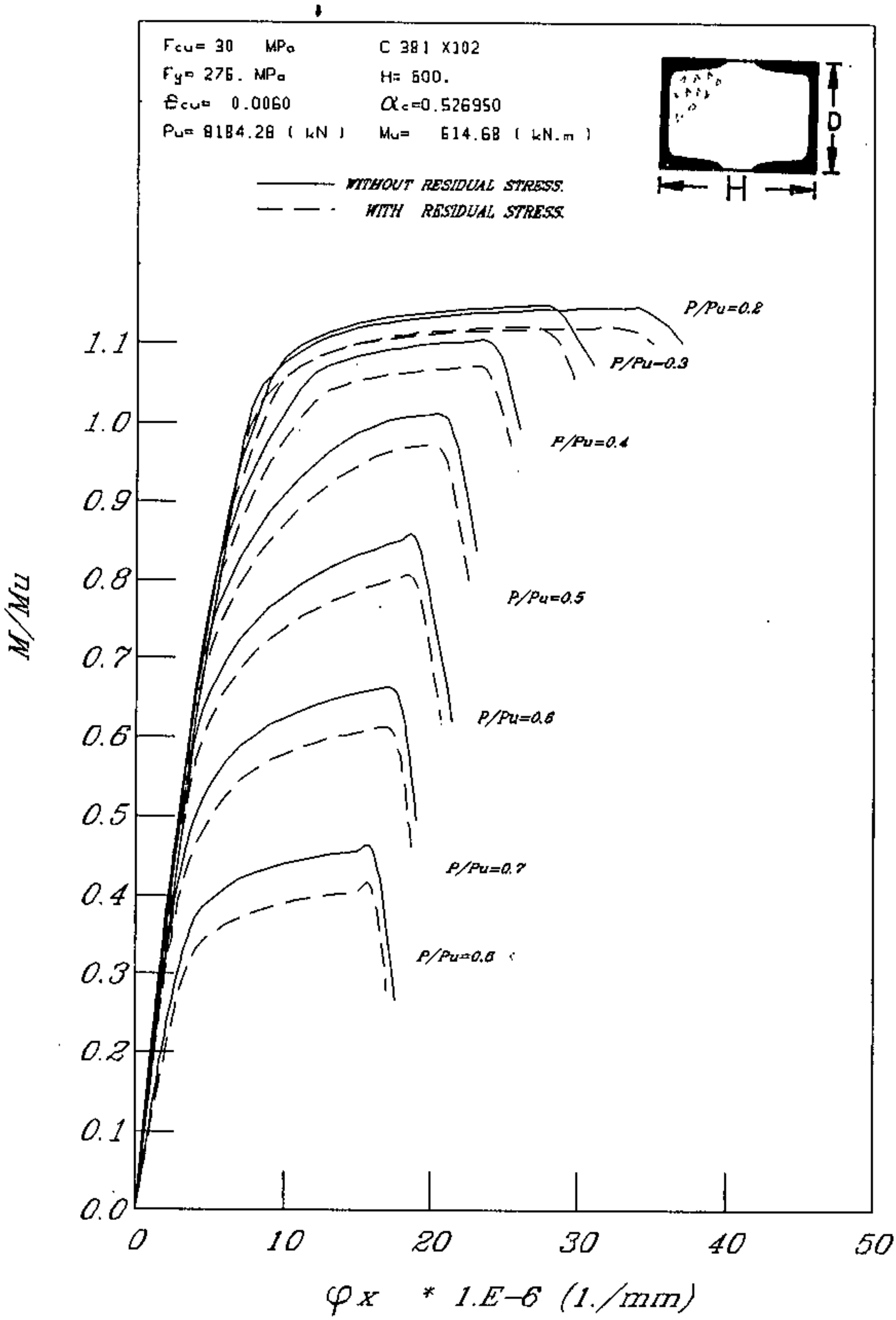

FIG.(A.25) : MOMENT - THRUST - CURVATURE CURVES UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

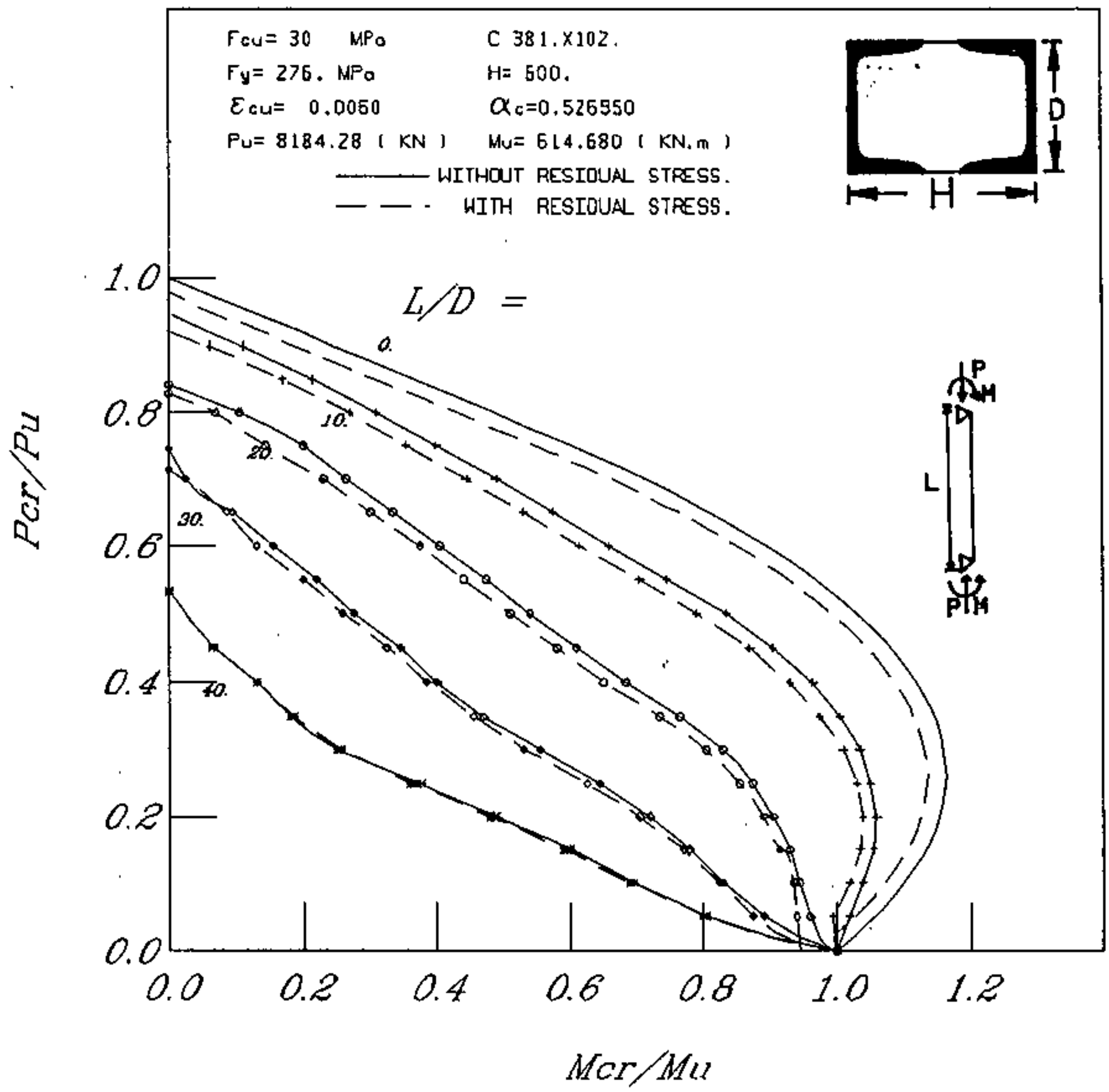

FIG. (A.26) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

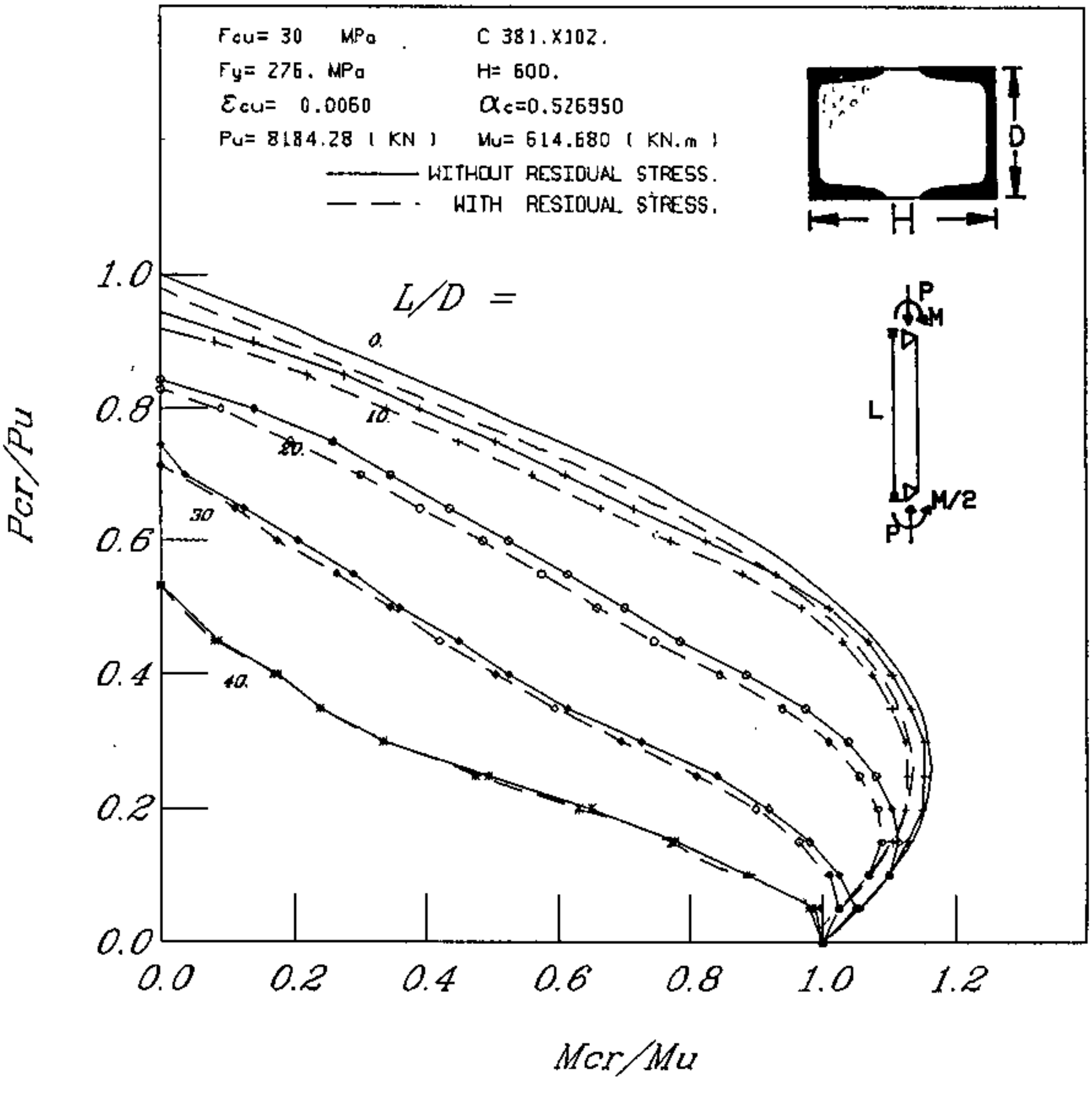

FIG. (A.27) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

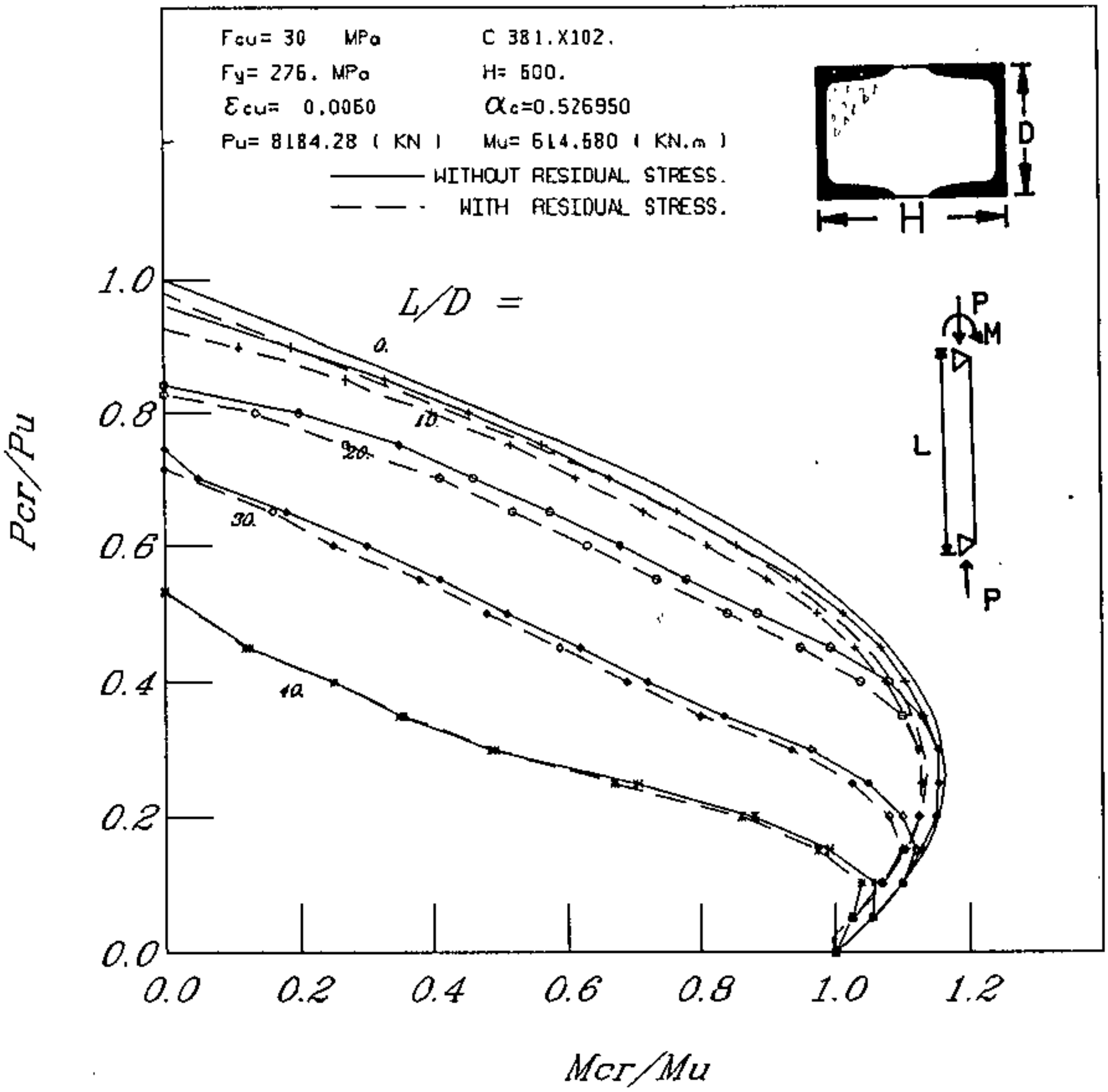

FIG. (A.28) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

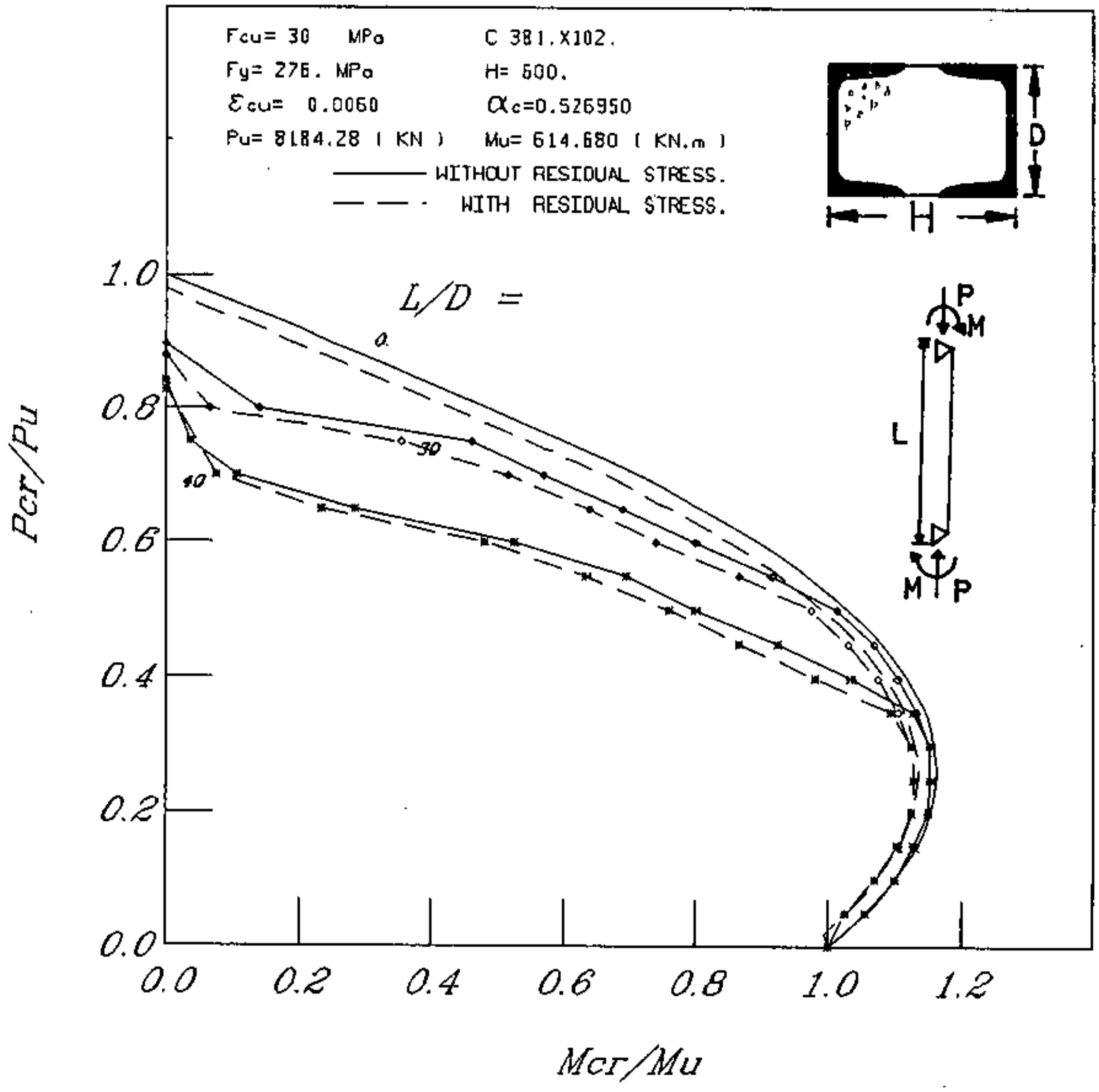

FIG. (A.29) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

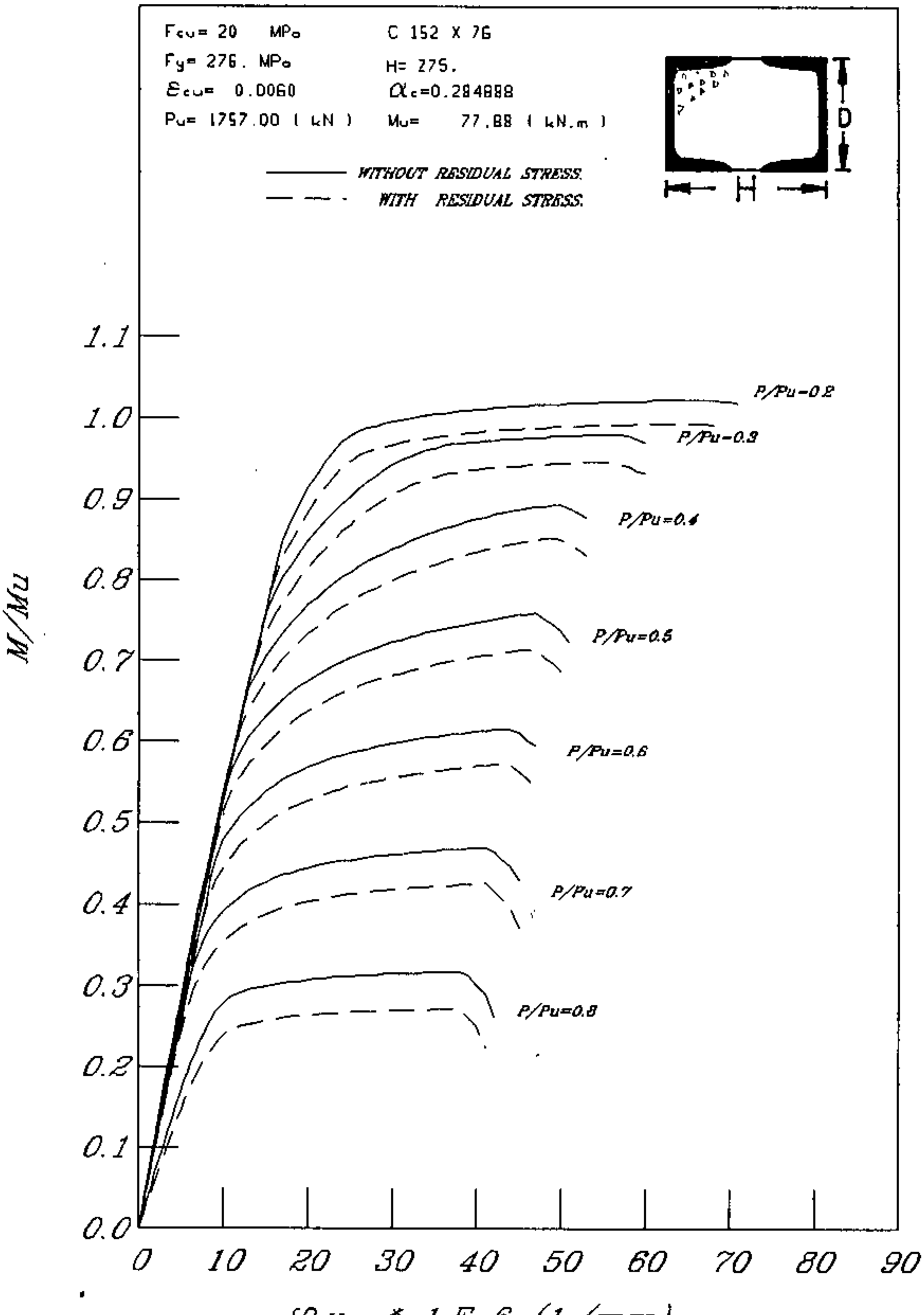

FIG.(A.30) : MOMENT - THRUST - CURVATURE CURVES UNDER UNIAXIAL BENDING ABOUT MINOR AXIS

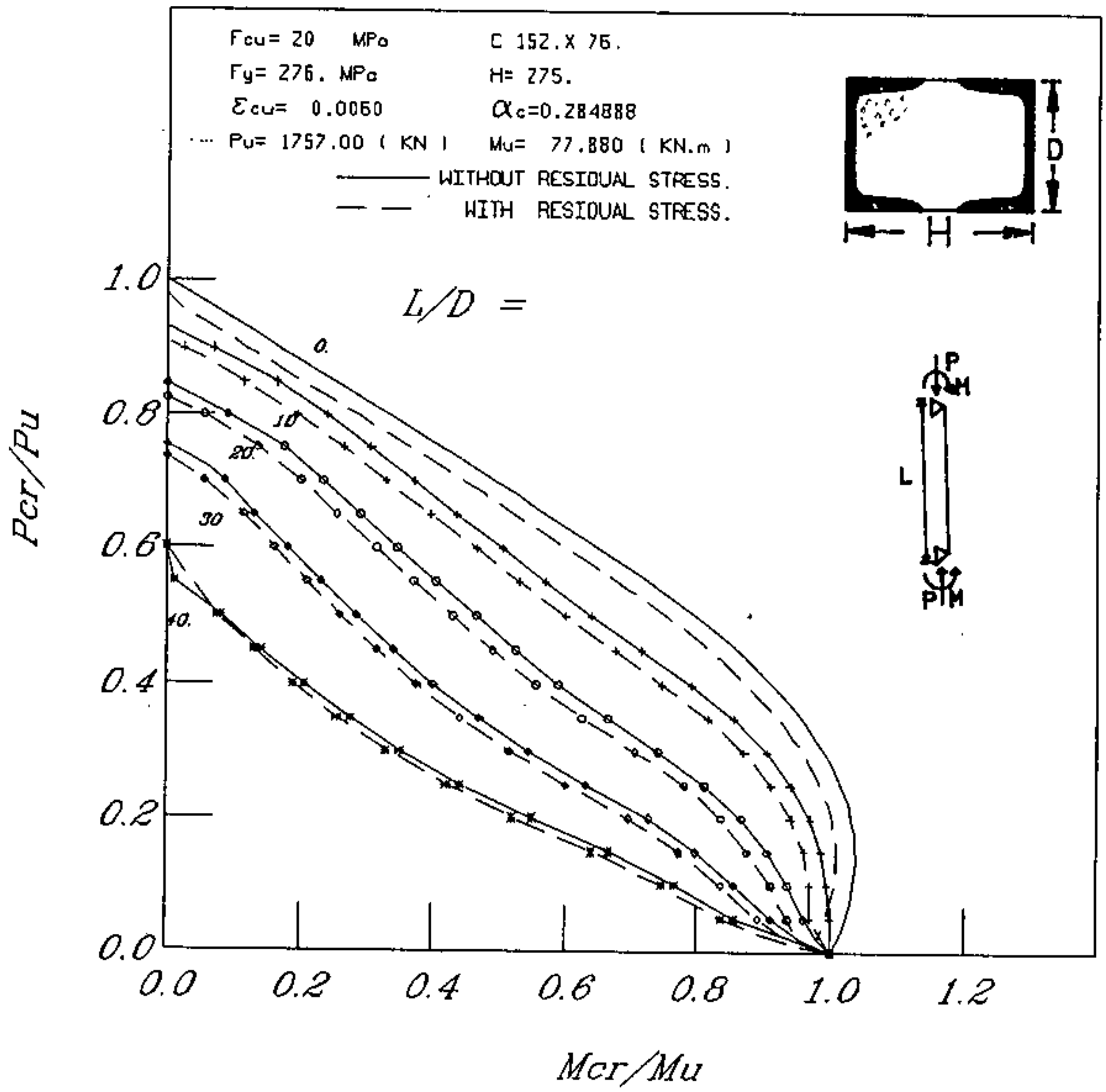

FIG. (A.31) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

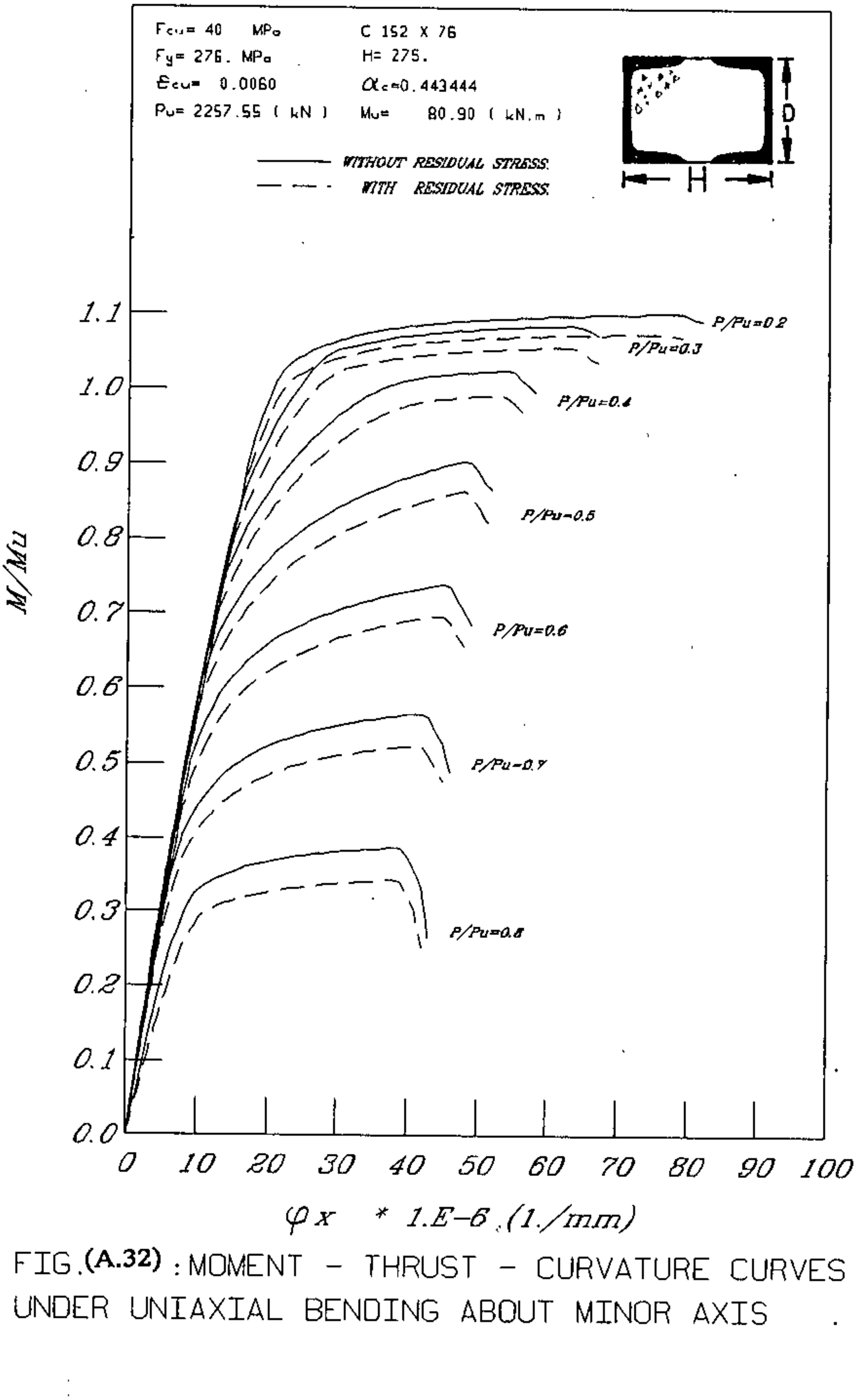

FIG.(A.32) : MOMENT - THRUST - CURVATURE CURVES UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

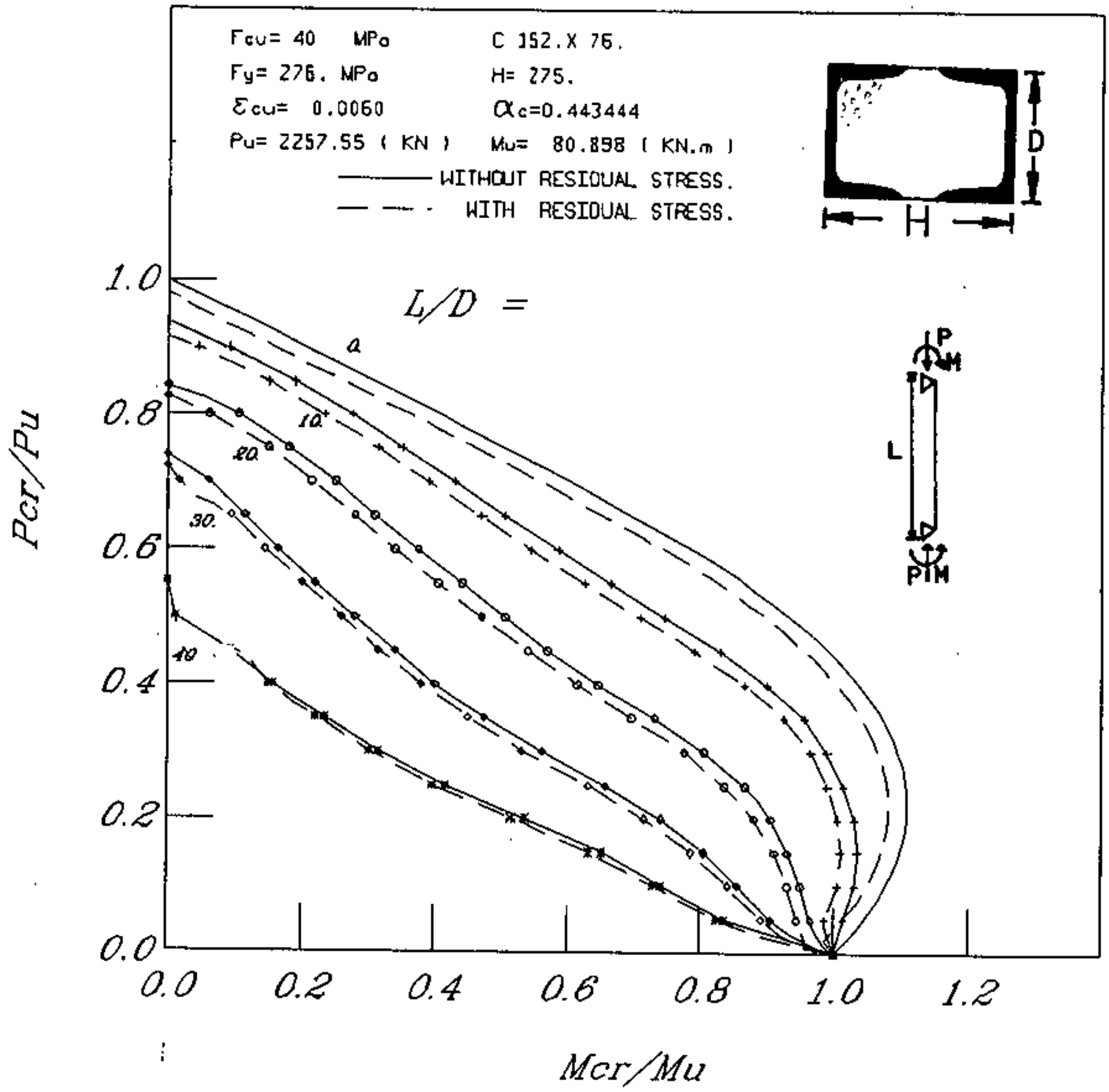

FIG. **(A.33)** : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

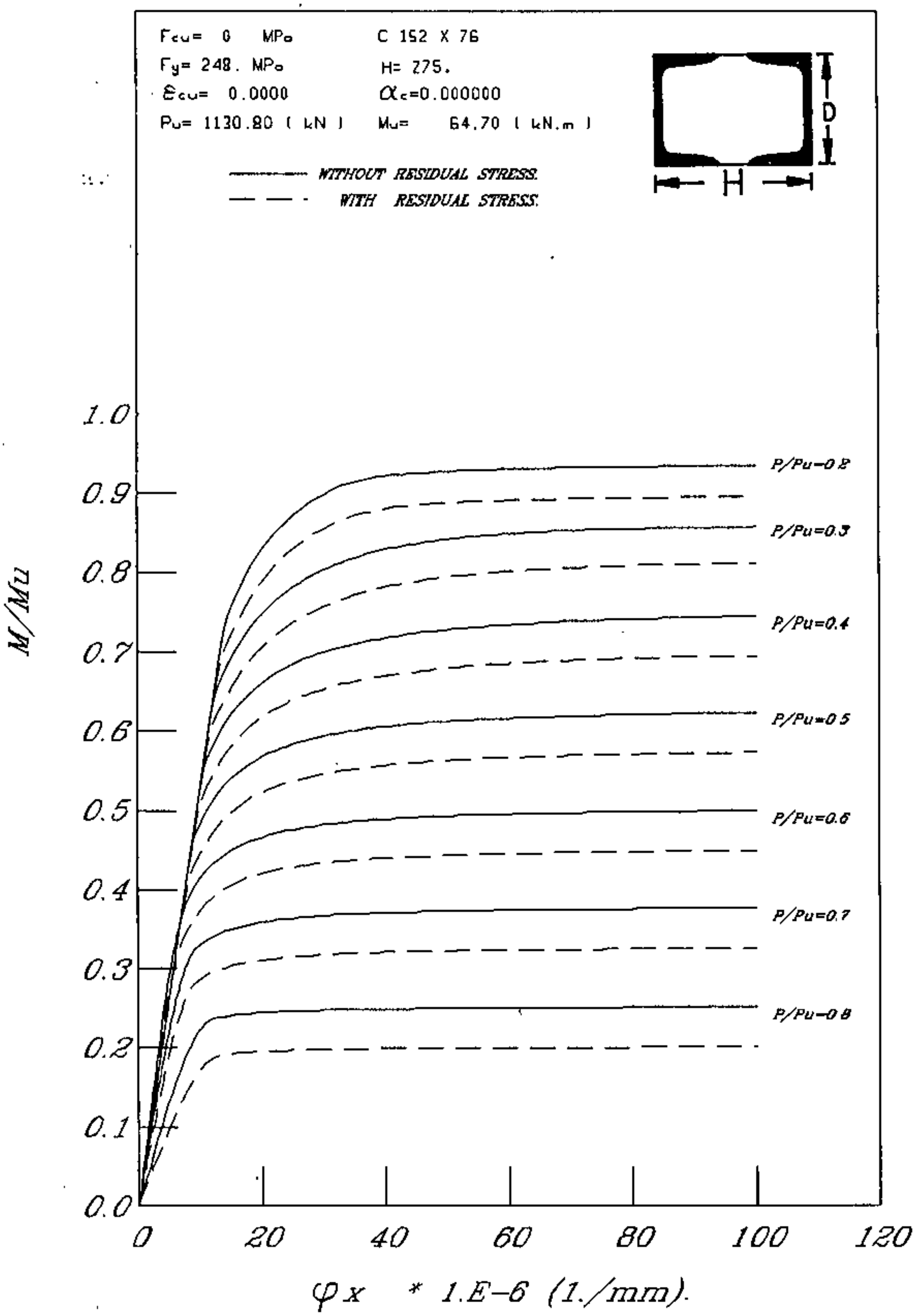

FIG. (A.34): MOMENT - THRUST - CURVATURE CURVES UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

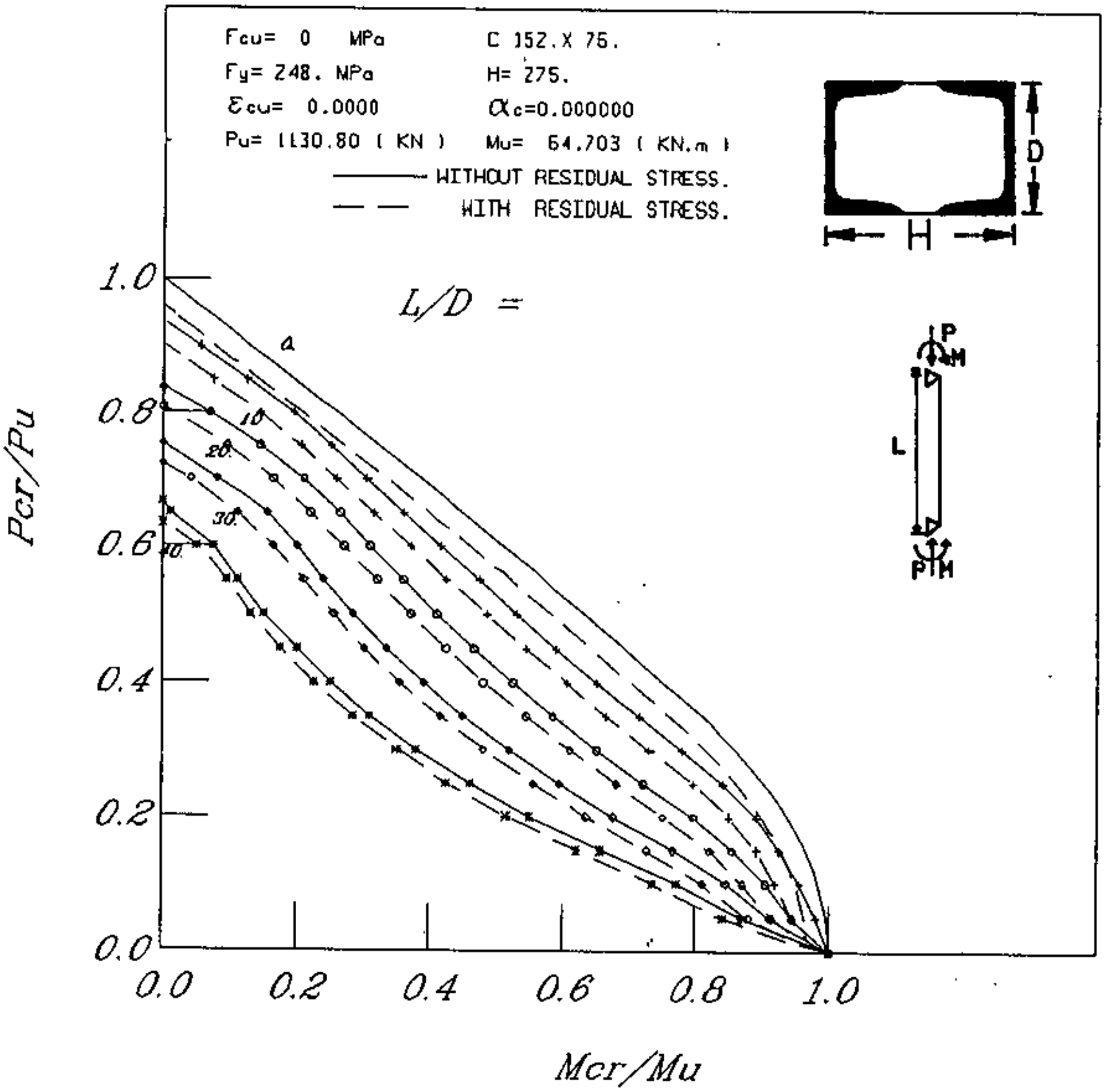

FIG. (A.35) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

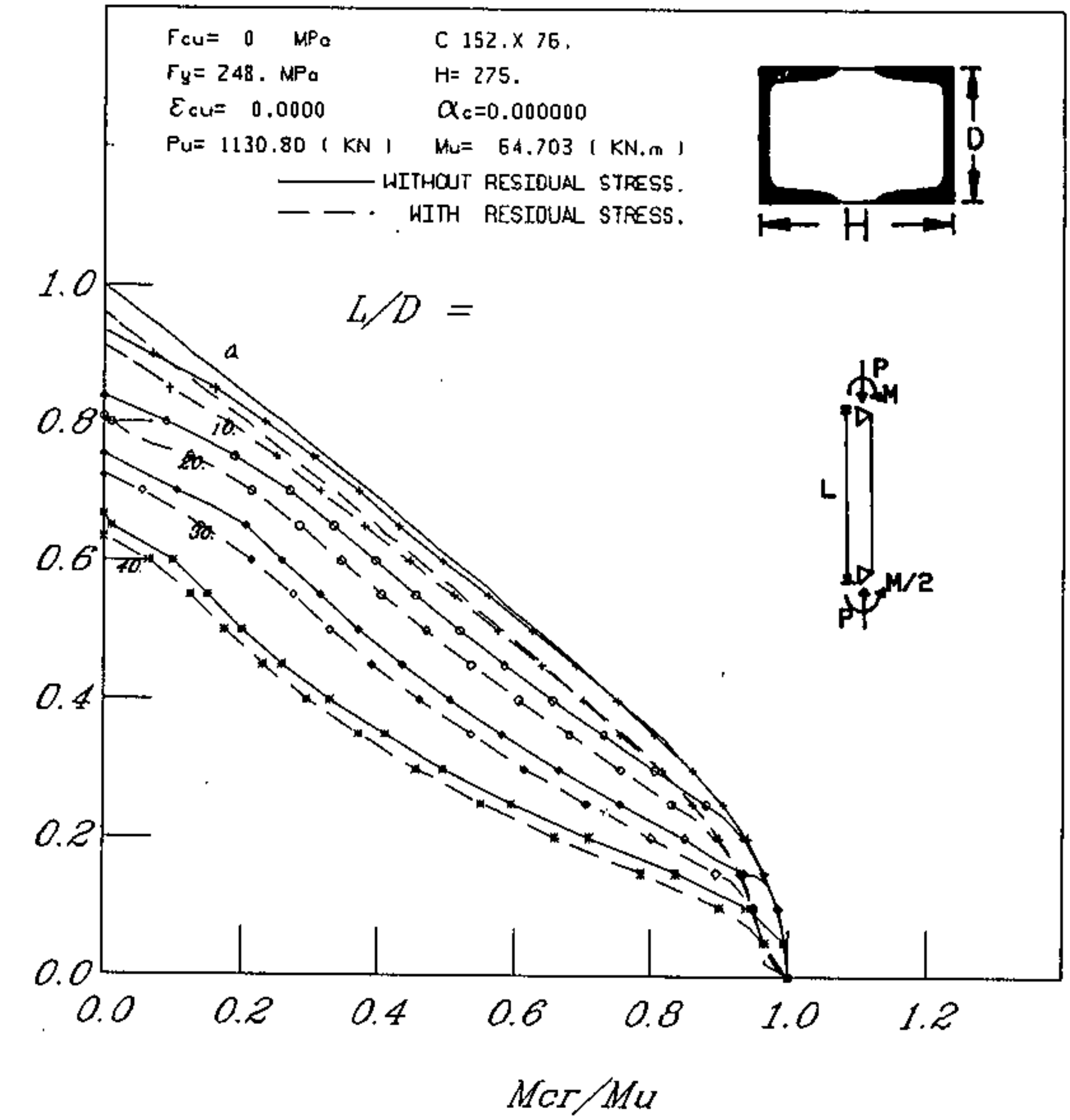

FIG. (A.36) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

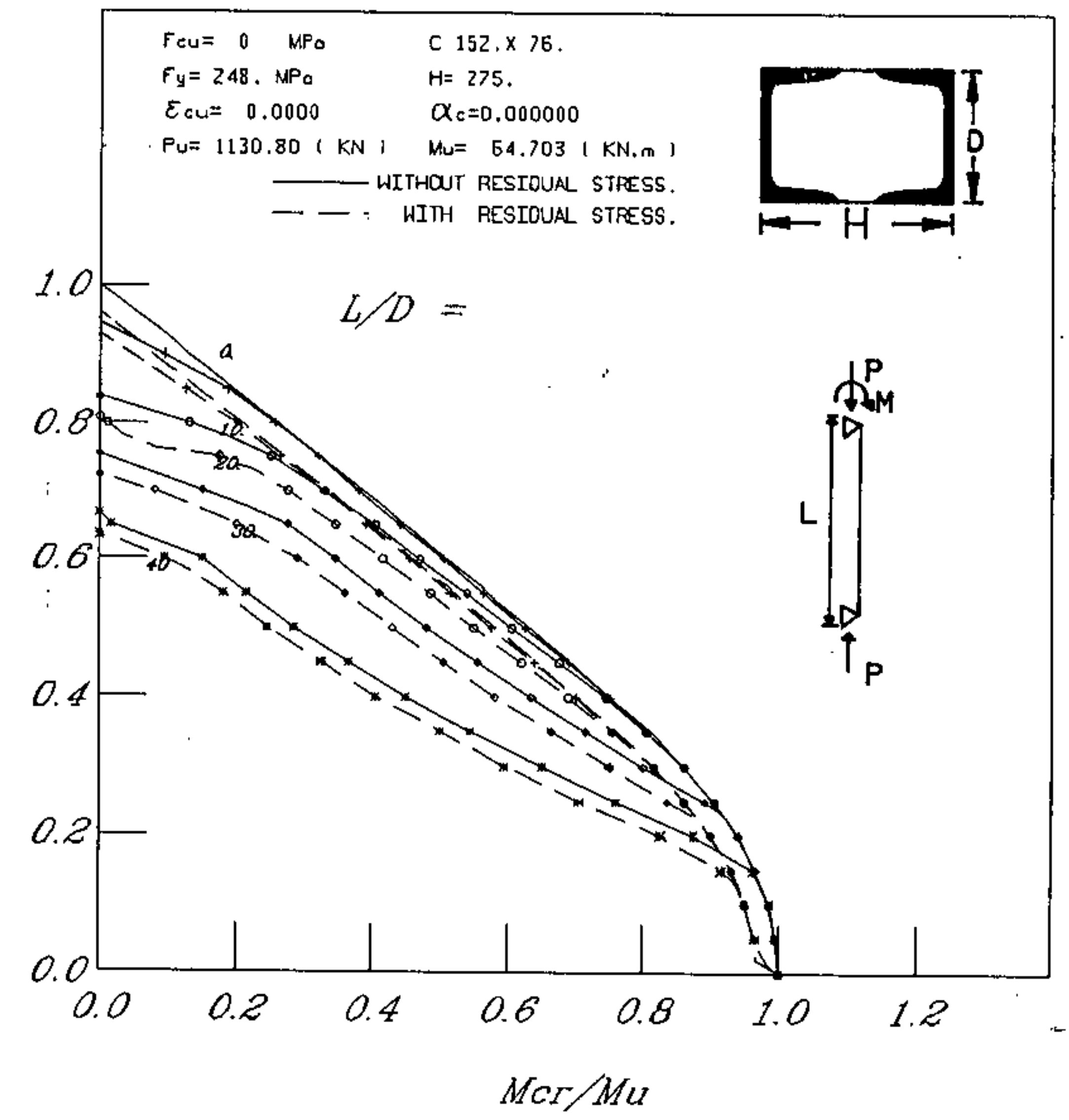

FIG. (A.37) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

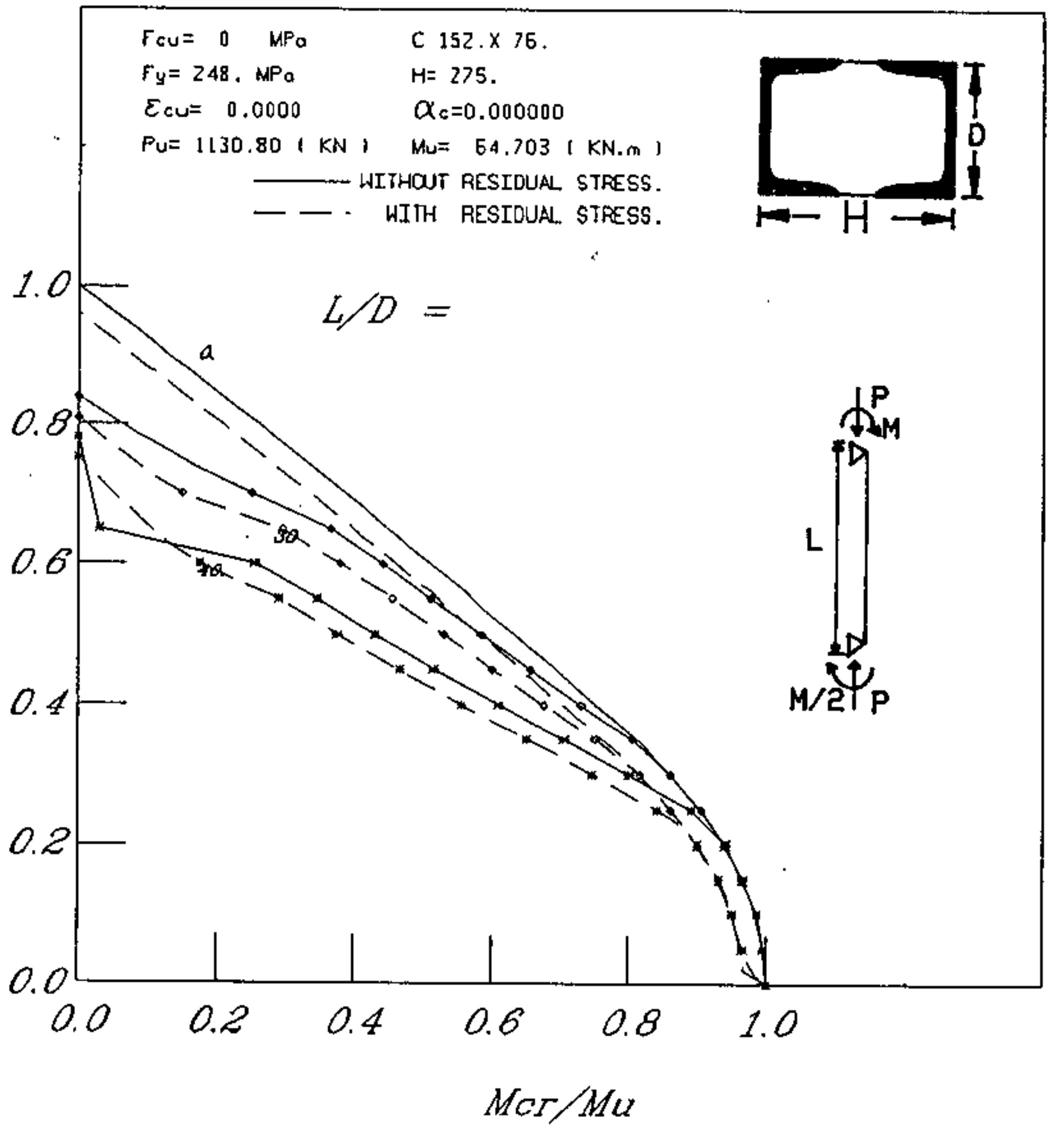

FIG. **(A.38)** : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

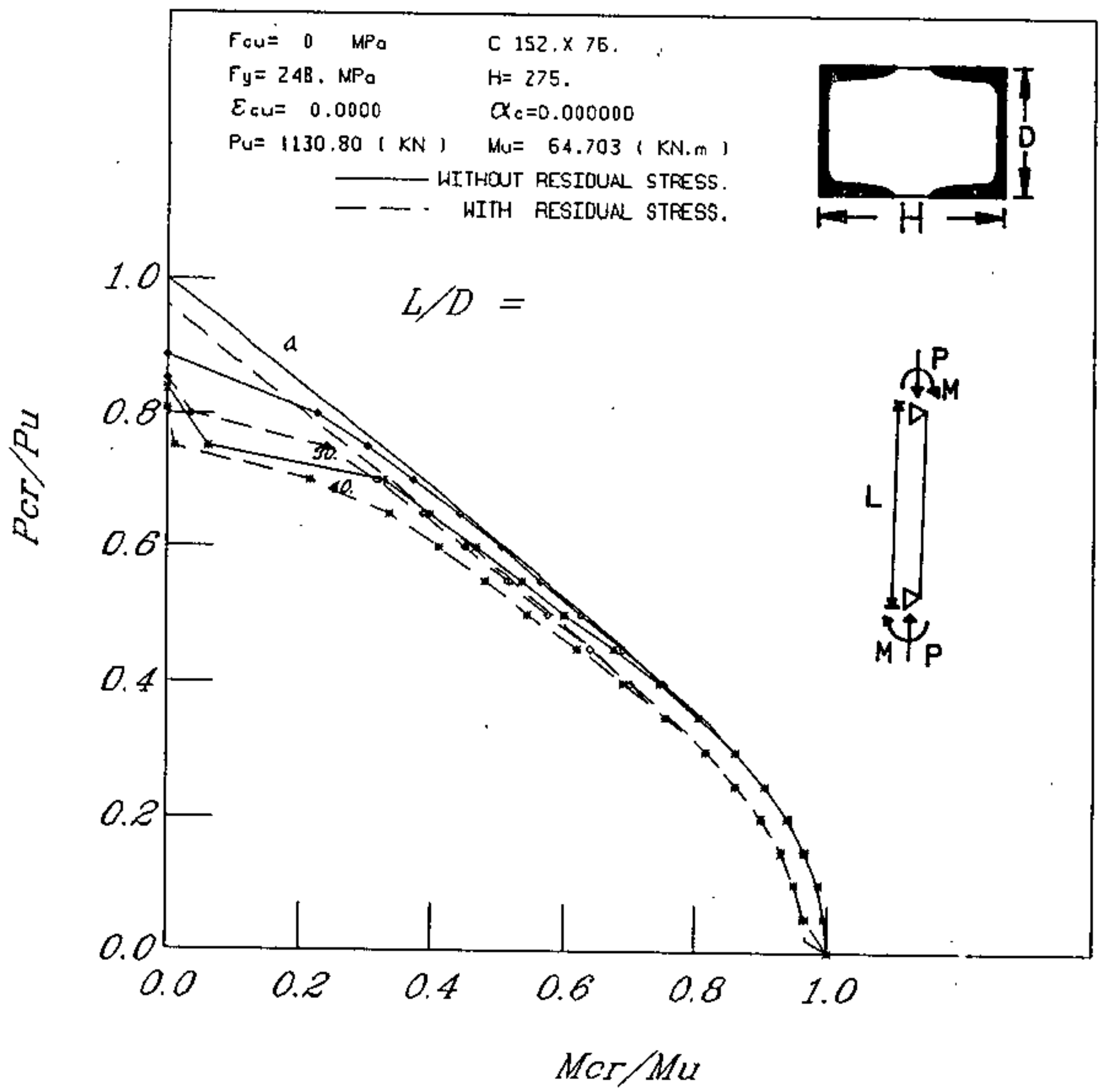

FIG. (A.39) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

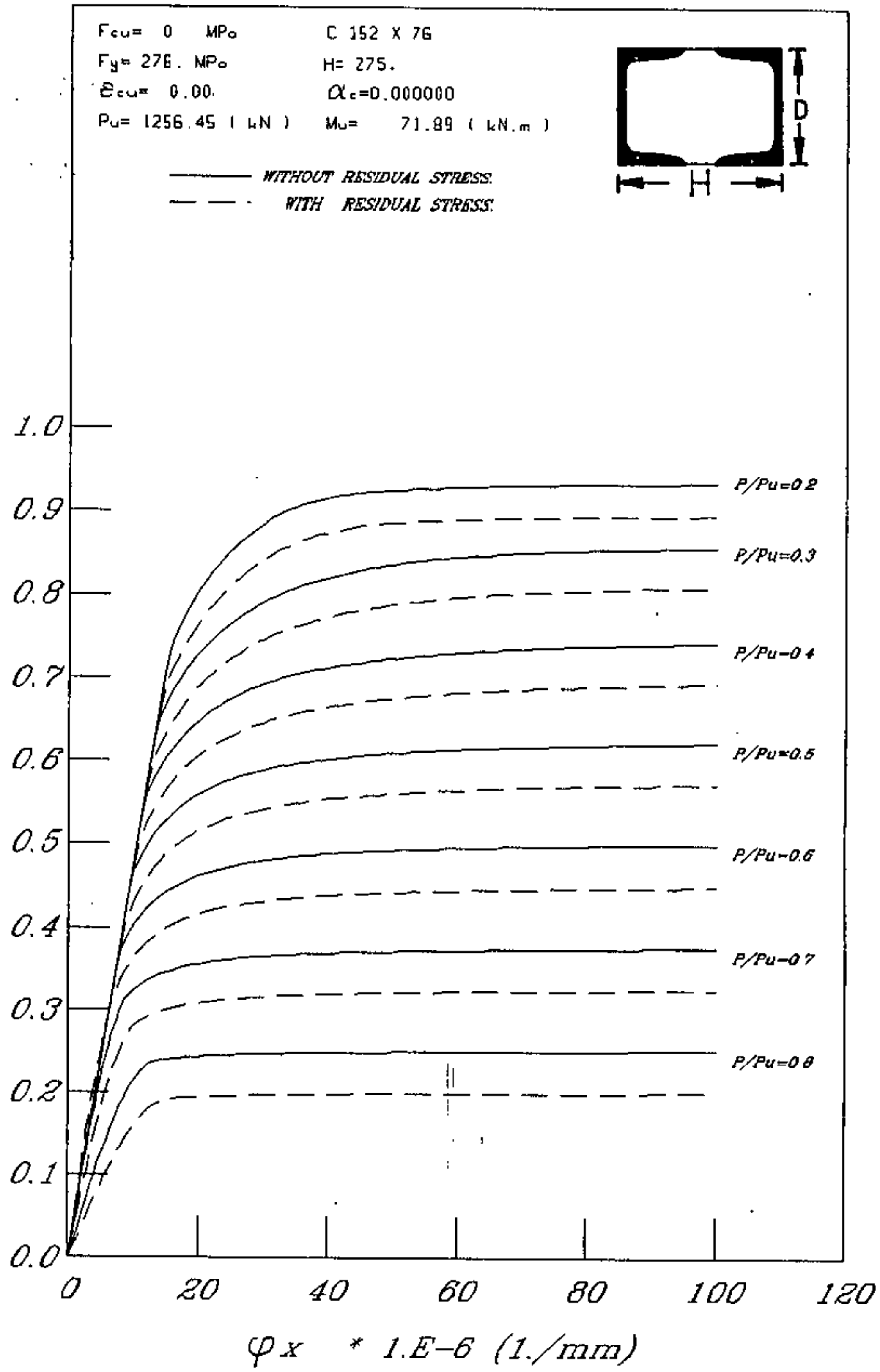

FIG. (A.40): MOMENT - THRUST - CURVATURE CURVES UNDER UNIAXIAL BENDING ABOUT MINOR AXIS

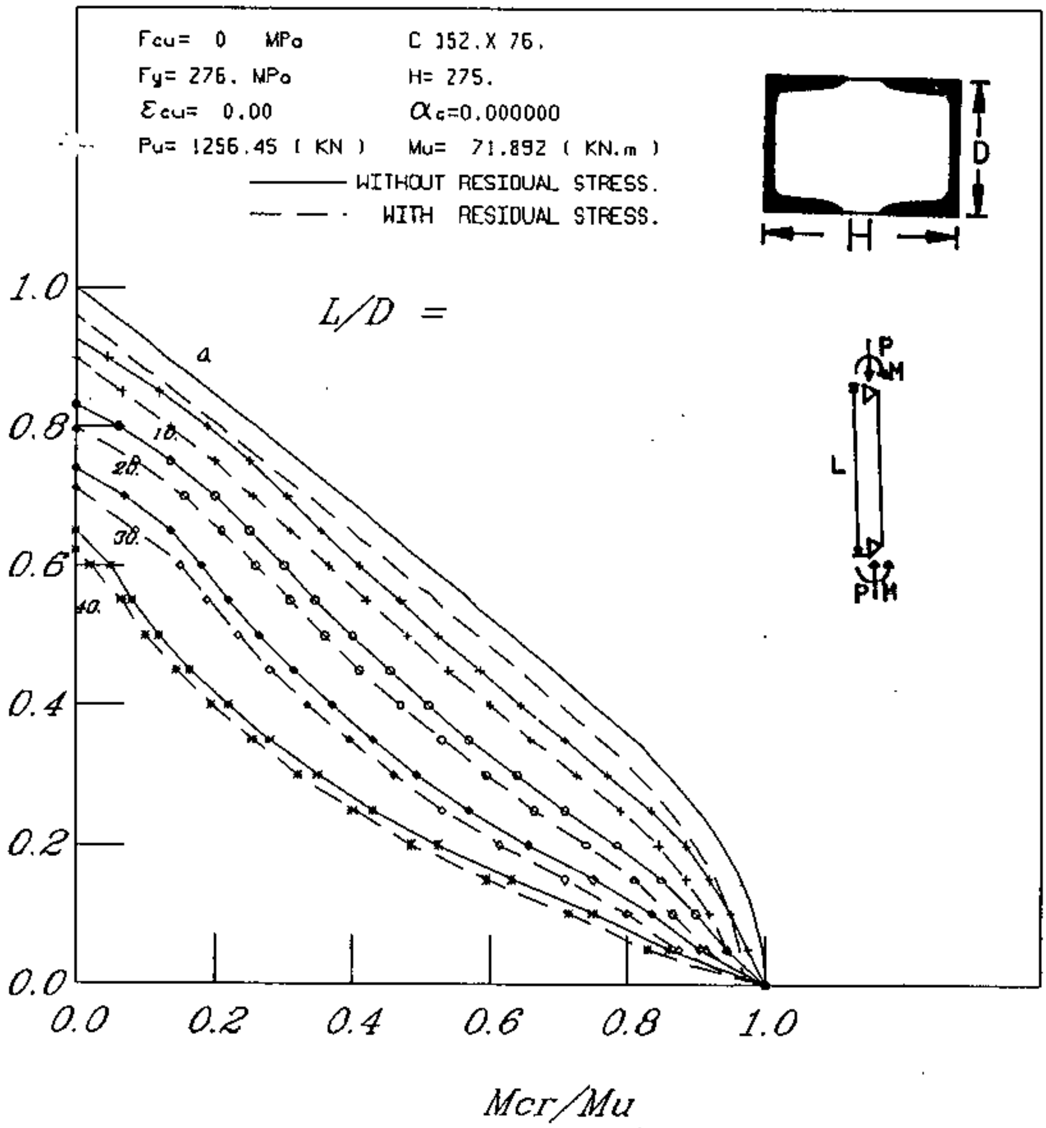

FIG. (A.41): ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

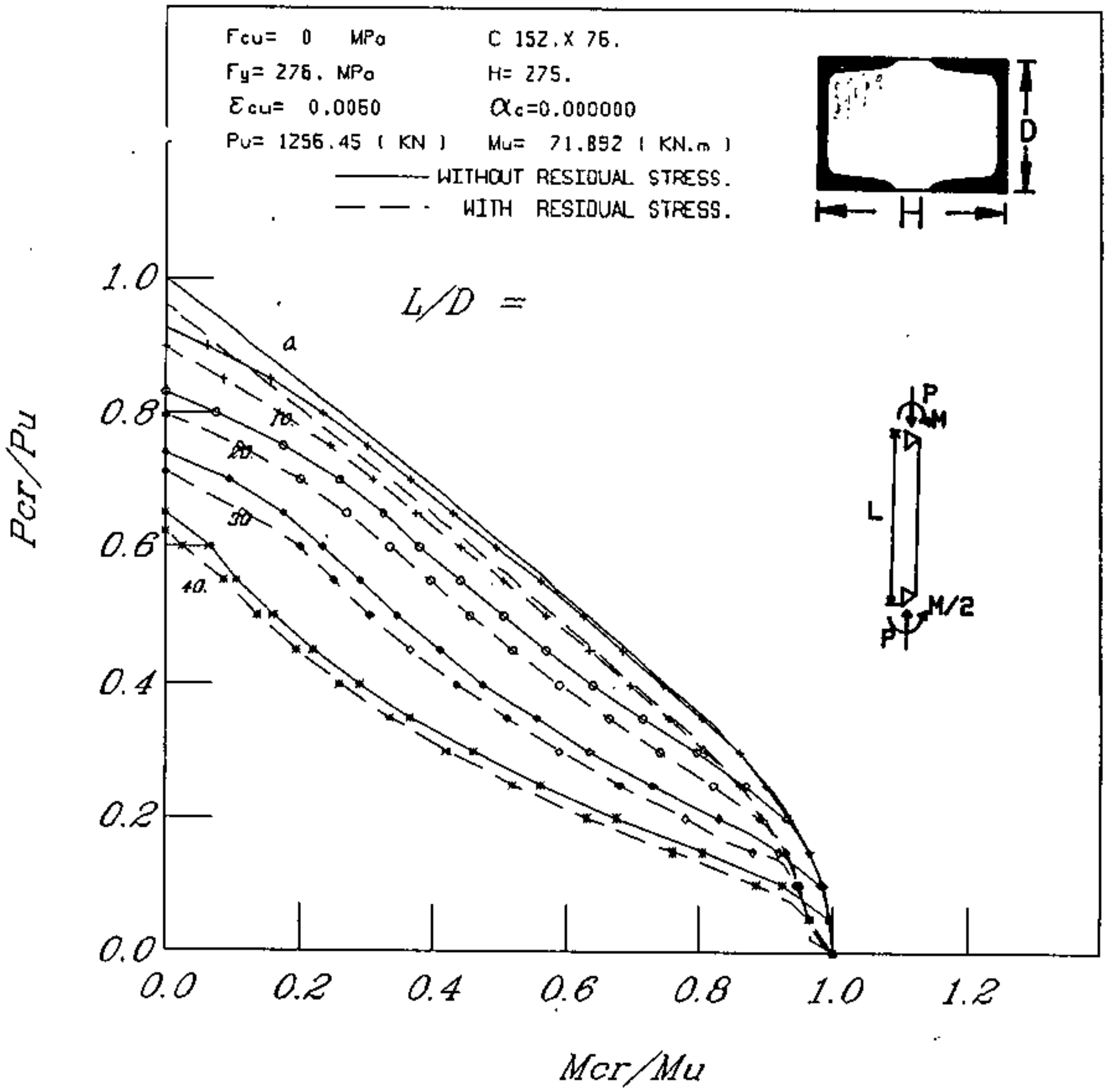

FIG. (A.42) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

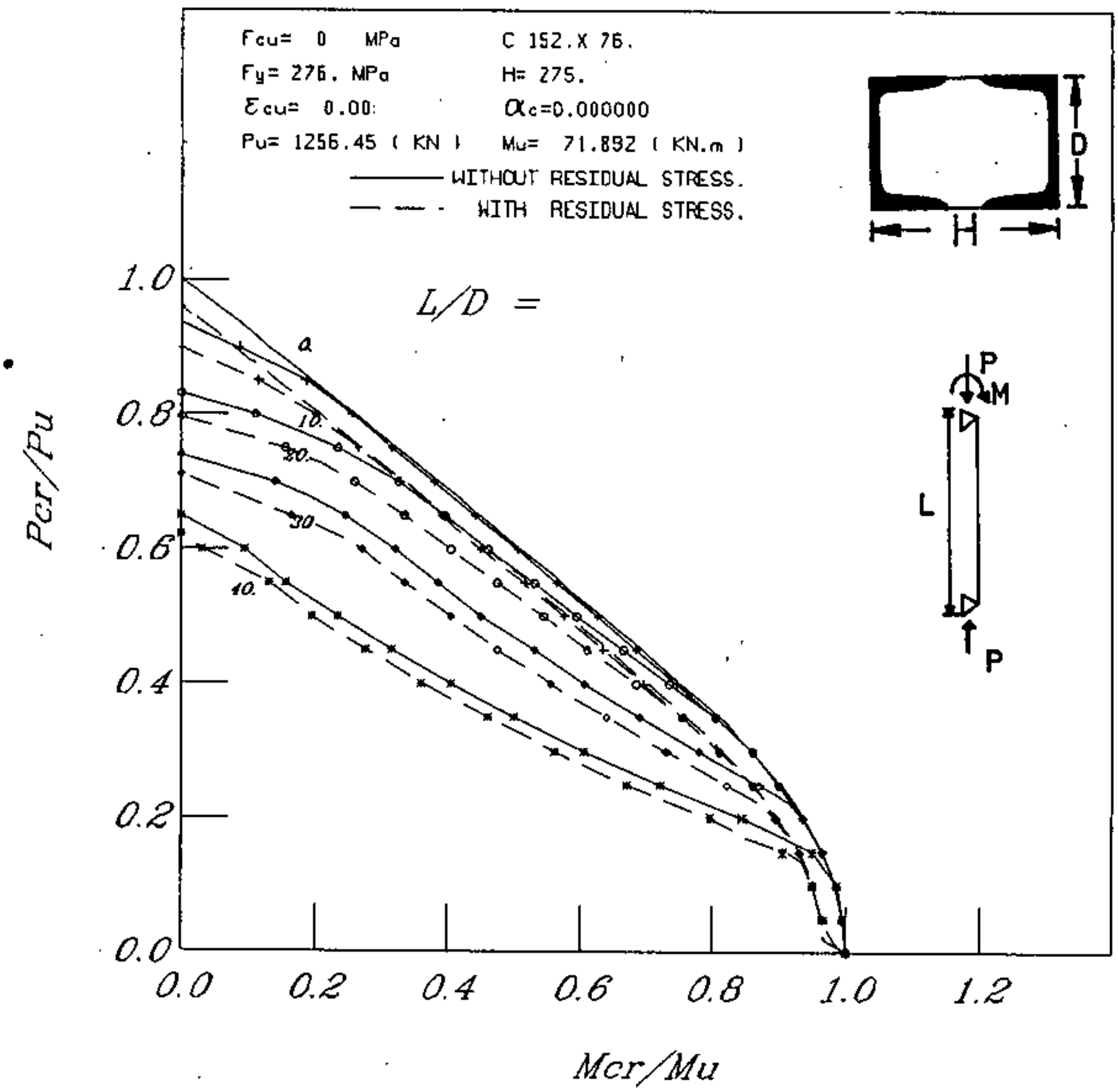

FIG. **(A.43)** : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

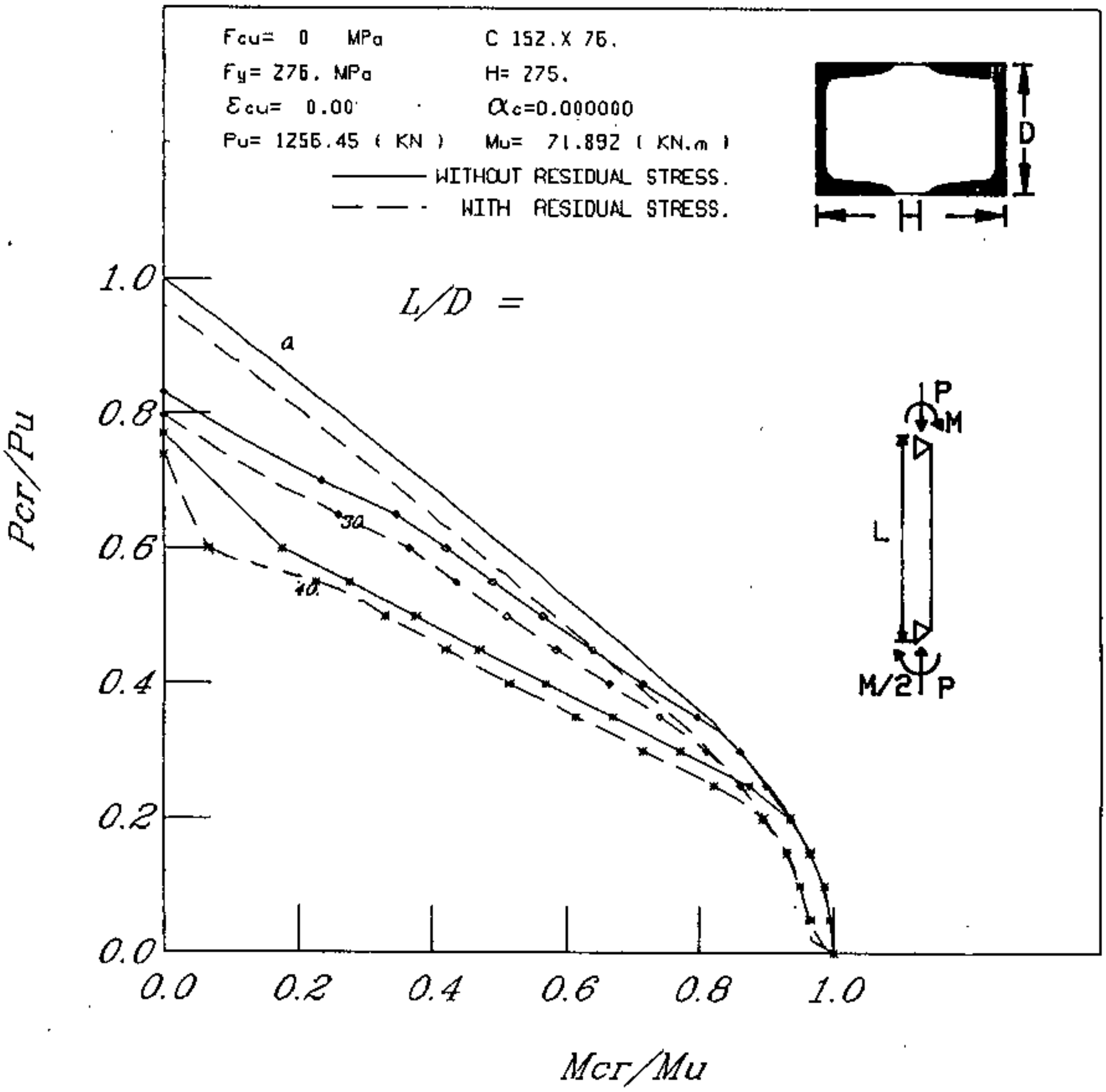

FIG. (A.44) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

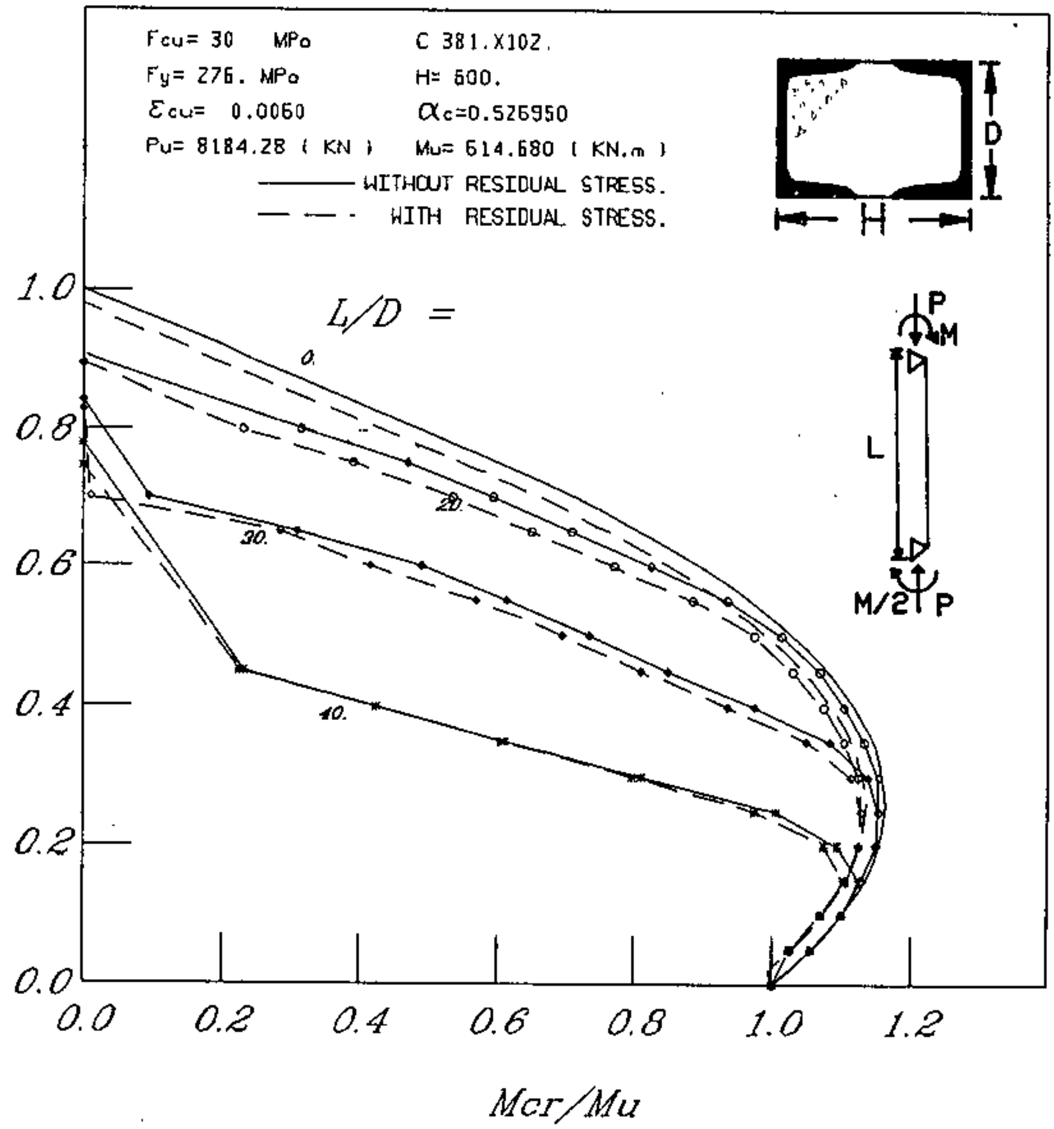

FIG. (A.45) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

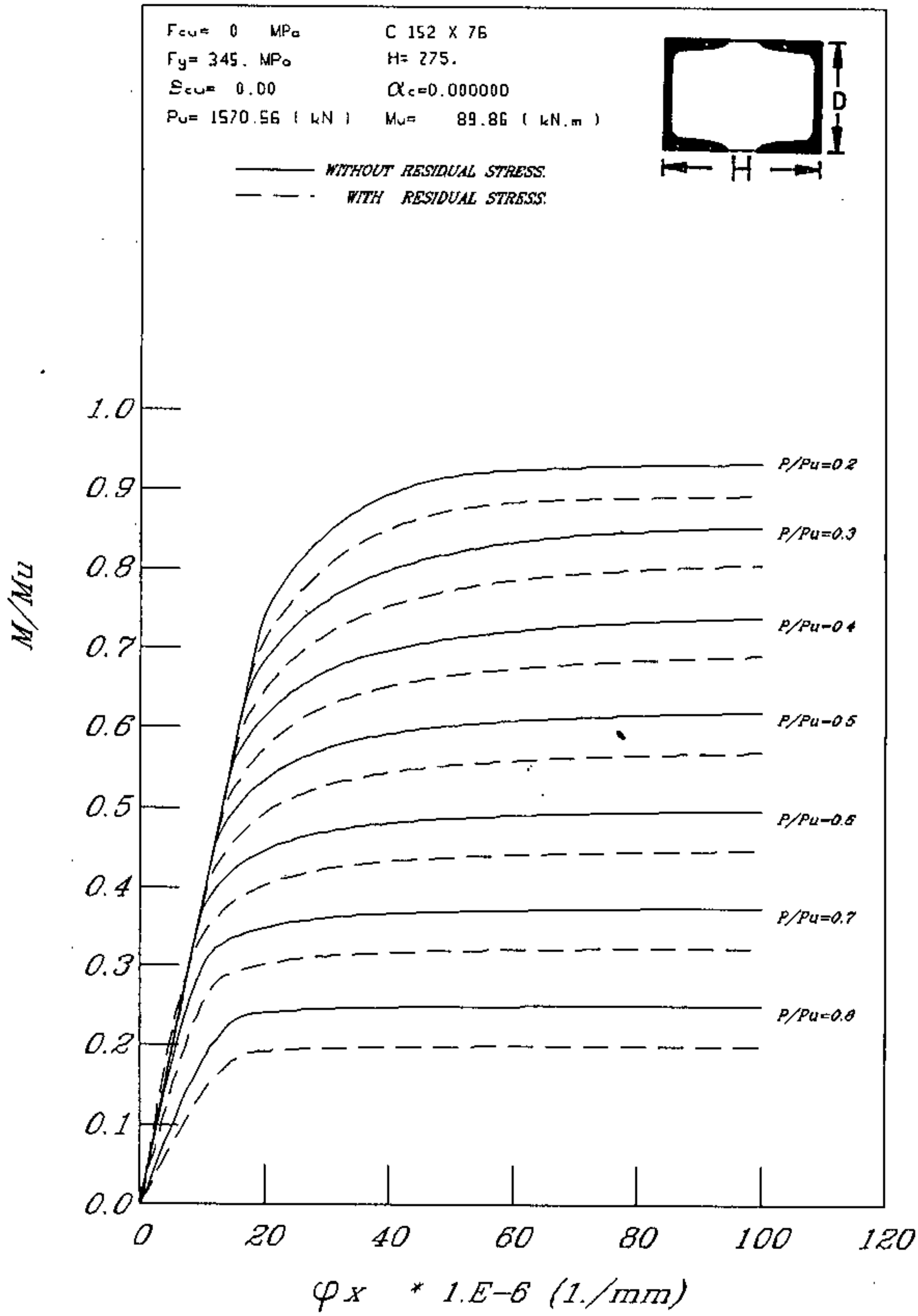

FIG. **(A.46)**: MOMENT - THRUST - CURVATURE CURVES UNDER UNIAXIAL BENDING ABOUT MINOR AXIS

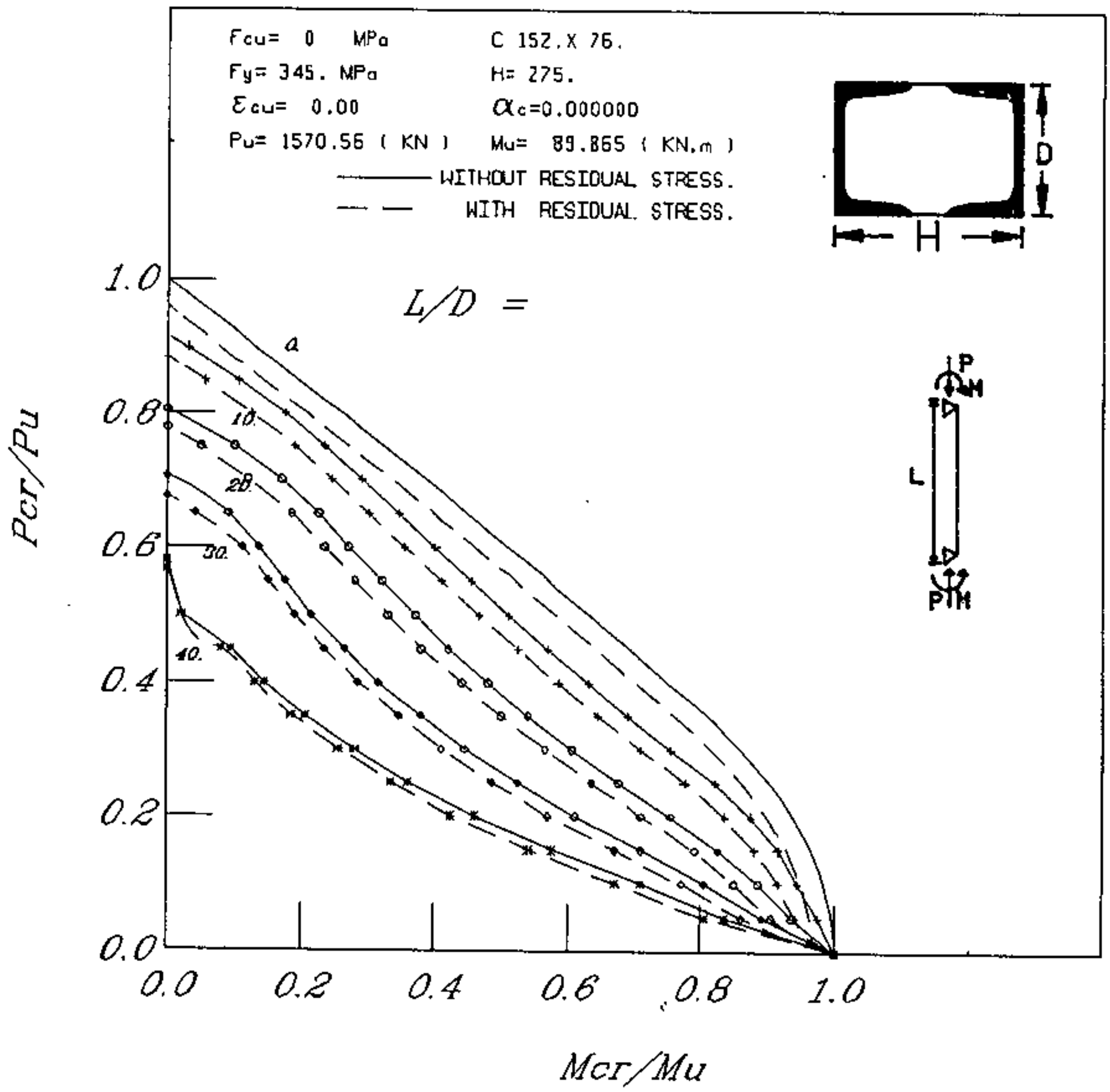

FIG. (A.47) : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

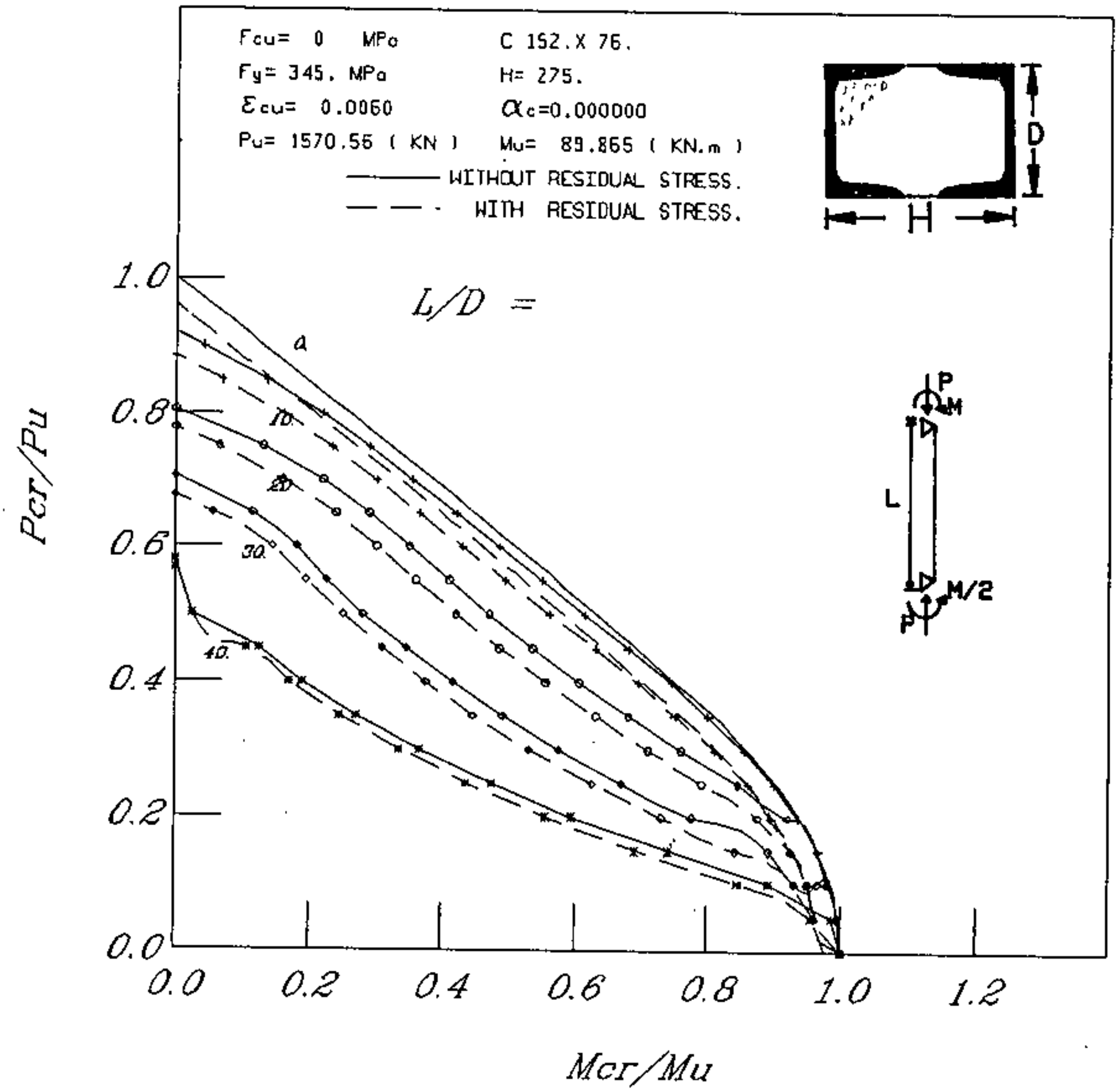

FIG. **(A.48)** : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

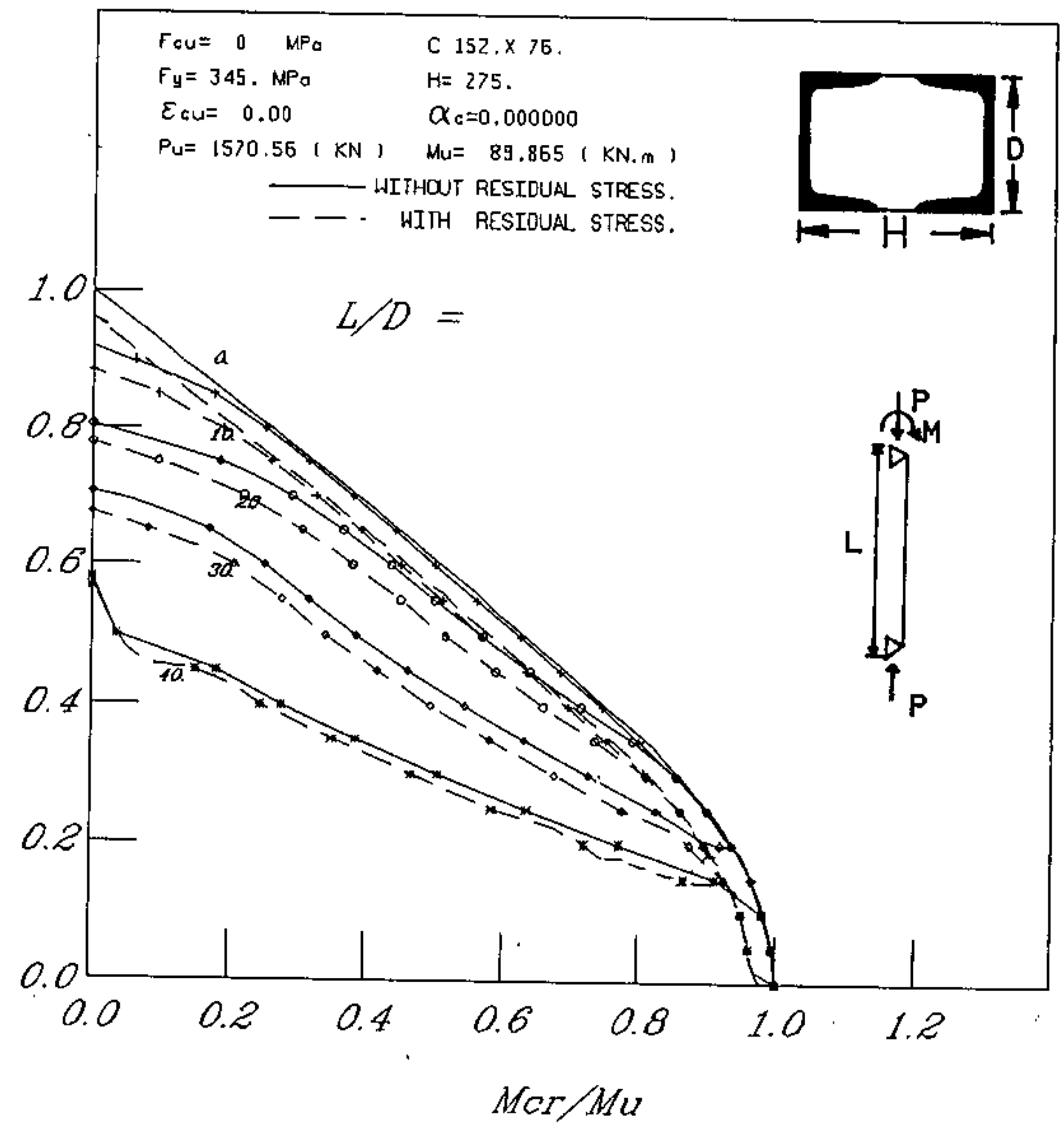

FIG. **(A.49)** : ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

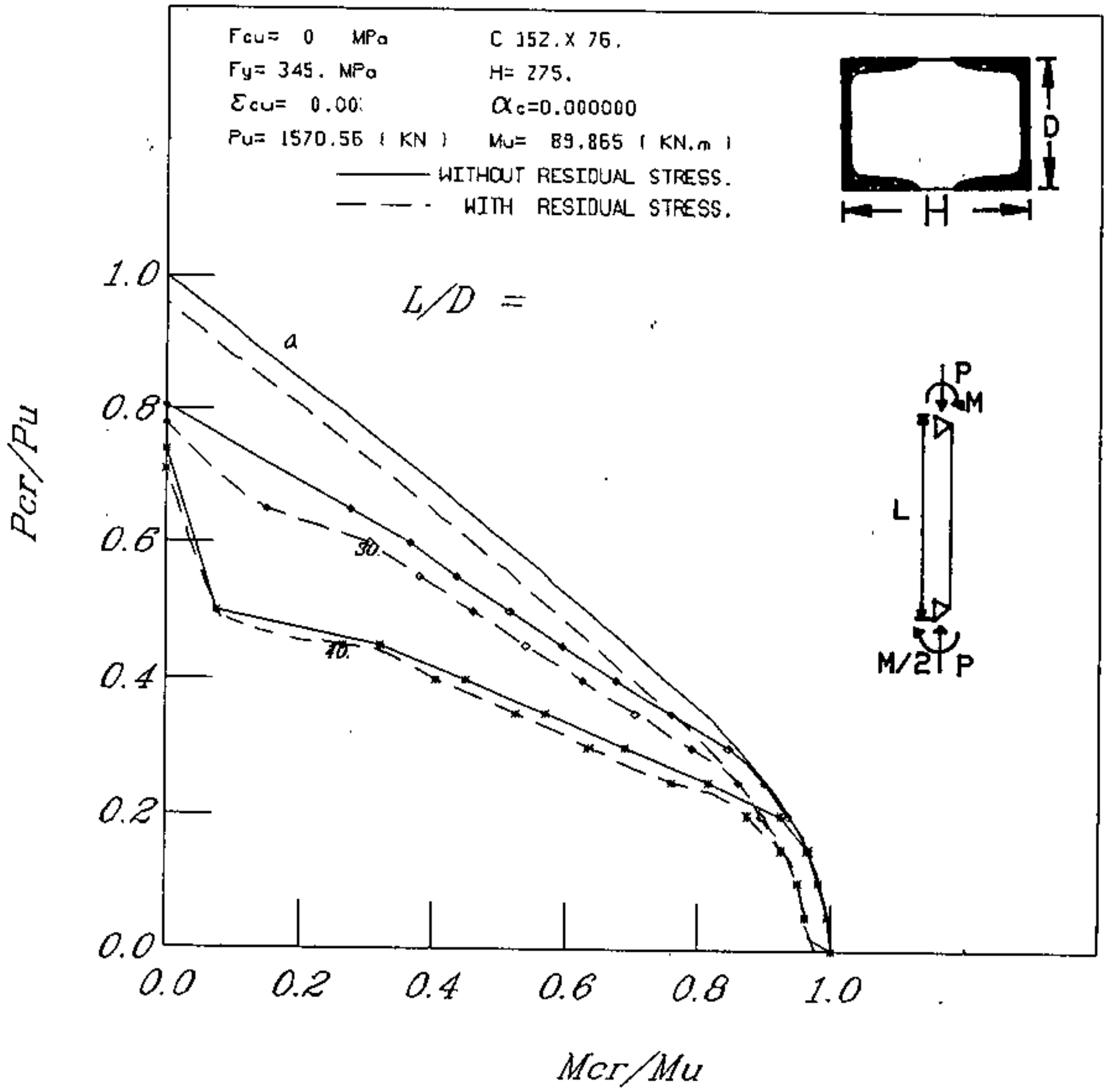

FIG.( ) :ULTIMATE STRENGTH INTERACTION CURVES FOR SLENDER BATTENED COMPOSITE COLUMN UNDER UNIAXIAL BENDING ABOUT MINOR AXIS .

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