4th Annual Paper Meet and 1st Civil Engineering Congress, December 22-24, 2011, Dhaka, Bangladesh ISBN: 978-984-33-4363-5
Noor, Amin, Bhuiyan, Chowdhury and Kakoli (eds) www.iebconferences.info

Behavior of partially encased slender composite columns in eccentric loading

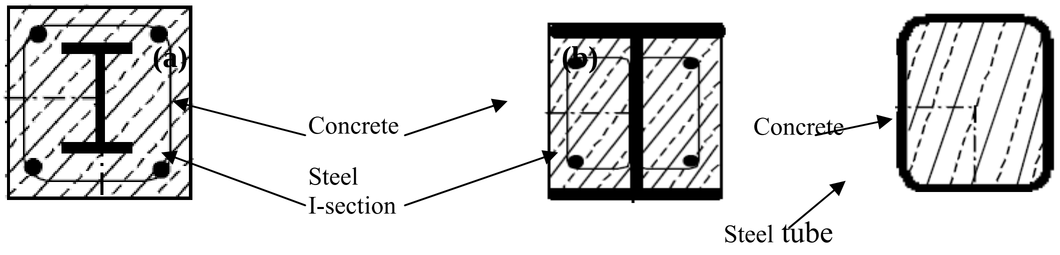
Saima Ali
Ahsanullah University of Science and Technology, Dhaka 1208, Bangladesh

Mahbuba Begum
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh

ABSTRACT: This paper presents the behavior of slender partially encased composite columns under eccentric axial load causing symmetrical single curvature bending. The load versus deflection response of slender partially encased composite column is formulated using the Newmark's iterative procedure. A parametric study is conducted using the using this method to identify the potential variables that can significantly affect the behaviour of slender partially encased composite column. The variable parameters include load eccentricity ratio (e/d) and overall column slenderness ratio (L/d). The effects of these parameters on the axial capacity and second order deflection of the slender column is studied. The axial capacity of partially encased composite columns are found to decrease significantly as the overall slenderness ratio increases, particularly for columns with slender plates. The load eccentricity ratio also has a significant impact on the capacity and deflection of these columns. The results are presented in detail in the paper.

1 INTRODUCTION

An outstanding feature of efficient, innovative structures is very often an ideal combination of various different building materials. The favourable combination of steel, with its high tensile strength and ductility, and concrete, with its high compressive strength and good resistance to corrosion, has long been recognized in structural concrete construction. With the method of composite construction, it is now possible to combine the positive features of steel construction and structural concrete, without having to accept the drawbacks. A steel concrete composite column is a compression member, comprising either a concrete encased hot-rolled steel section or a concrete filled tubular section of hot-rolled steel and is generally used as a load-bearing member in a composite framed structure. Typical cross-sections of composite columns with fully and partially encased steel sections and concrete filled tubular sections are illustrated in Figure 1. Steel-concrete composite columns are very effective in providing the required stiffness to limit the lateral drift of the building to the acceptable level as well as to resist the lateral seismic and wind loads. The introduction of steel rolled shapes and high strength concrete has made it possible to design columns of large slenderness.



(a) (b) (c)

Figure 1. Typical cross-sections of (a) Fully encased composite column (FEC), (b) Partially encased composite column (PEC) and (c) Concrete filled tubular sections (CFT)

Partially encased composite (PEC) columns consisting of thin walled built up steel section with concrete infill cast between the flanges, is a relatively new concept in composite construction. Transverse links are provided between the flanges at regular intervals to enhance the resistance to local instability of the thin steel plates. Typical cross-section and 3D view of the steel skeleton of a PEC column is shown in Figure 2. This innovative composite system not only reduces the cost of construction using relatively low-cost concrete by minimizing the use of higher cost steel, but also helps to overcome the complexities related to erection and design of connections of more commonly used composite columns. Several research works including both numerical and experimental works (Fillion (1998); Tremblay et al. 1998; Bouchereau & Toupin (2003); Prikett & Driver (2006); Begum et al. 2007) have been carried out for establishing the behaviour and the design provisions for this new type of composite column under various loading conditions. Most of these research works were confined in exploring the short (length-to-depth ratio of 5) column behaviour of PEC columns. However, a few long column tests (length-to-depth ratio of 20) were carried out by (Chicoine et al. 2000) under static loading. This test database is not sufficient to establish a design guideline for slender PEC columns. Therefore, extensive research work is required to fully understand the behavior of slender PEC columns under eccentric loading.

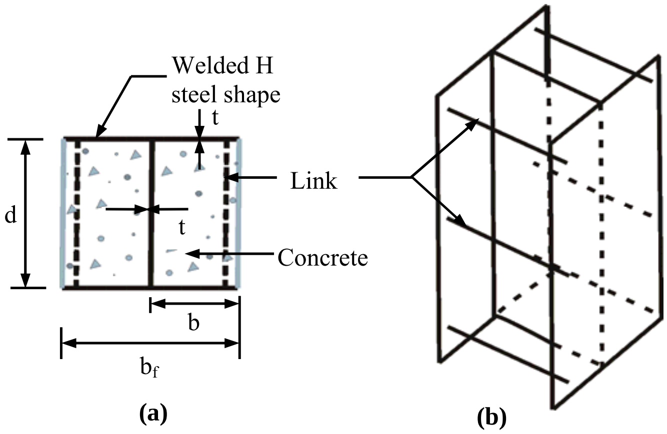


Figure 2: Partially encased composite columns, (a) cross section and (b) 3D view of the steel configuration

2 OBJECTIVES AND SCOPE

The primary objective of this study is to investigate the structural behaviour of slender partially encased composite columns subjected to eccentric axial loading. To this end, Newmark's numerical iterative procedure is used to develop the load deflection curves of partially encased composite columns subjected to symmetrical single curvature bending about major axis of the column cross-section. This procedure is then used to determine the influence the overall column slenderness ratio and load eccentricity ratio of the axial capacity and lateral deflection of the column. A parametric study is conducted on four references PEC columns with variable overall slenderness ratio and load eccentricity ratio. Five different slenderness ratios—10, 15, 20, 25 and 30—were employed in the parametric study to cover the short, intermediate and a wide range of slender columns. The load eccentricity ratios used in this study are 0.1, 0.2, 0.3, 0.4 and 0.5. The effects of these parameters were studied on 450 mm × 450 mm cross-section. The parametric columns were analyzed under monotonic loading conditions with bending about the strong axis.

3 LOAD-DEFLECTION RESPONSE OF SLENDER PEC COLUMNS

The behaviour of a slender column of length L, subjected to eccentric loading is greatly influenced by the second order bending moment at midheight resulting from the deflection due to applied eccentric loading. The resulting deflection at mid height of the column is termed as second order deflection. For columns having a small slenderness ratio this second order deflection is negligible. However for slender columns this value becomes significant and controls the maximum moment of the column. Consequently, the bending moment strength of a slender column subjected to eccentric axial load is much lower than that of its cross-section. The second order deflection therefore plays a prominent role in identifying the strength of slender PEC columns. Newmark's numerical iterative procedure is implemented to compute this second order deflection for slender PEC columns under symmetrical single curvature bending for a given axial load and applied eccentricity.

In this study a pin ended PEC column of length L, subjected to eccentric axial loading as shown in Figure 3a, is selected. The bending moment diagram of the column is shown in Figure 3b. The bending moment diagram has two parts – a constant moment (Pe) from the applied eccentricity and a variable moment (PΔ) resulting from the deflection (Δ) of the column from its original position.

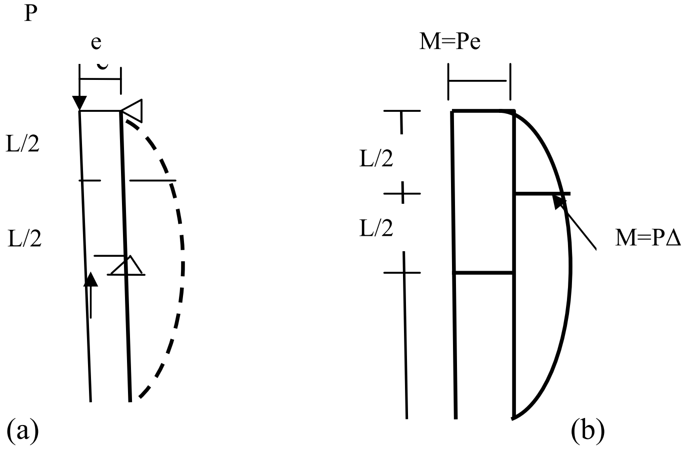


Figure 3. (a) Column subjected to eccentric loading (b) Bending moment diagram of the column

Newmark's method (Newmarks (1943)) is used to determine the equilibrium configuration for a given combination of axial load and end moments that were applied to column. The column is subdivided into segments or stations of equal length for which initial deflections have been assumed based on the applied end moments. The first-order moments and the second-order moments due to slenderness effects are computed and summed at each station. The curvature corresponding to the total moment at each station are retrieved from the cross section moment-curvature curve for the given axial load level in order to define the distribution of curvature along the column length. Then the conjugate beam method is used to compute the deflection at each of the stations. If the computed deflections and the initial deflections are within prescribed limits of 0.05%, an equilibrium solution is obtained. If not, the computed deflections are substituted for the assumed deflections and the process is repeated until the deflections converged. For each value of axial load, similar procedure is adopted. Thus for a specific eccentricity, the load deflection curve is plotted. Using the value from load deflection curve, moment at mid height of composite slender column is determined by multiplying the axial load to the summation of assumed eccentricity and second order deflection at mid height of column. In case of drawing load deflection curve at different slenderness ratios, eccentricity of column has been fixed and length of column has been varied and the above procedure has been followed.

From the load deflection curve, the ultimate capacity of column is determined by calculating the moment from deflection. In connection with it, for the specific cross-section, interaction diagram of the column is drawn using the strain compatibility relationship as applied for reinforced concrete columns. From the load moment interaction diagram, for a specific eccentricity, angle of straight line intersecting the interaction diagram, is determined. The corresponding point represents the axial load capacity of the column at a specific moment and eccentricity. The value of moment is noted. To determine the axial load capacity of a composite slender column, this value of moment is considered as the moment capacity of the column. Both values of axial load and mid height deflection are assumed and trial was done using Newmark's formula for several times to obtain the desired moment. The trial from which the required value of the cross-sectional moment is achieved has been noted. This axial load is the ultimate axial load capacity of the composite slender column at the specific eccentricity. Similar procedure is followed for determining the axial load capacity at other eccentricities. The load eccentricity of the column is then fixed and length of column has been varied and the procedure described above has been followed to determine capacity of column at different slenderness ratios.

4 DESIGN OF PARAMETRIC STUDY

The potential variables that can significantly affect the behaviour of slender partially encased composite columns are the overall column slenderness ratio, flange plate slenderness ratio, load eccentricity ratio and link spacing. This paper demonstrates the effect of the overall column slenderness ratio and load eccentricity ratio in combination with flange plate slenderness ratio and link spacing. The column cross-section was fixed at 450mmx450mm. Four reference columns were designed with variable plate thickness and link spacing. The properties of these columns are shown in Table 1.

Table 1. Geometric properties of the reference columns.

Column	Width (b_f) (mm)	Depth (d) (mm)	Thickness(t) (mm)	Link Spacing (s) (mm)
P_a	450	450	9	
				225
P_b	450	450	9	
P_c	450	450	7.5	315
P_d	450	450	7.5	
				225
				315

In each of these columns the overall slenderness ratio and load eccentricity ratio was varied. The global stability of the column is controlled by the overall slenderness ratio, which is defined as the ratio of the length of the column, L, to the depth of the column cross-section, d. Five different slenderness ratios— 10, 15, 20, 25 and 30—were employed in the parametric study to cover the range of short, intermediate and a wide range of slender columns. The load eccentricity ratios which can be obtained by dividing the initial eccentricity, e, of the applied axial load by the depth of the column cross-section, d, used in this study are 0.1, 0.2 0.3, 0.4 and 0.5. The effects of the selected parameters on the load deflection response, axial capacity and deflection of PEC columns under single curvature bending about major axis are presented in the subsequent sections.

4.1 *Effect of Load Eccentricity (e/d) ratio*

The behaviour of a PEC column under bending induced by an eccentrically applied axial load is found to be greatly affected by the initial load eccentricity ratio. Table 2 to 5 shows the effect of column load eccentricity (e/d) ratio on the axial capacity and mid-height deflection of the column. For column P_b with L/d ratio of 15, increasing in the e/d ratio from 0.1 to 0.2, 0.3, 0.4 and 0.5 reduces the ultimate load capacity by 13%, 24%, 33% and 41% respectively and increases the lateral deflection by 43%, 66%, 75% and 76% respectively with respect to the column with e/d ratio of 0.1. Again, for column P_b with L/d ratio of 25, increasing the e/d ratio from 0.1 to 0.2, 0.3, 0.4 and 0.5 decreases the ultimate load capacity by 7%, 14%, 20% and 27% and increases the deflection by 42%, 64%, 72% and 73% respectively. Both of the analysis results show that reduction in ultimate load capacity and increase in lateral deflection accelerated with the increase in load eccentricity ratio. For column P_d with L/d ratio of 15 and 25, for the previous increment, the ultimate load capacity was reduced by 14%, 24%, 34%, 42% and 7%, 13%, 20%, 27% respectively. At the same time, deflection was increased by 37%, 60%, 66%, 67% and 42%, 65%, 70%, 71% respectively. Similar to column P_b, ultimate load capacity was reduced and deflection was increased significantly with increasing the load eccentricity ratio.

Figures 4-7 presents the relation between axial and mid-height deflections obtained by the proposed analytical method for the columns subjected to different initial load eccentricities and the eccentricity varies for e/d = 0.1 to 0.5 about the major axis. These columns have slenderness ratio of 15 and 25 and pinned at the ends were subjected to single curvature bending. It is clear that column capacity is strongly affected by the amount of eccentricity. As the eccentricity increases, the load-carrying capacity drops significantly with an increase in the mid height deflection.

Table 2. Effect of Load Eccentricity (e/d) Ratio of Column P_b at Slenderness Ratio 15.

Column	e/d	L/d	b/t	s/d	Pu (kN)	Δu (mm)	% Variation in Pu	% Variation in Δu
P_b	0.1	15	25	0.7	3850	103	_	_
	0.2				3340	148	13	43
	0.3				2945	172	24	66
	0.4				2580	181	33	75
	0.5				2260	182	41	76

Table 3. Effect of Load Eccentricity (e/d) Ratio of Column P_b at Slenderness Ratio 25.

Column	e/d	L/d	b/t	s/d	Pu (kN)	Δu (mm)	% Variation in Pu	% Variation in Δu
P_b	0.1	25	25	0.7	1815	271	_	_
	0.2				1680	384	7	42
	0.3				1565	445	14	64
	0.4				1450	466	20	72
	0.5				1330	469	27	73

Table 4. Effect of Load Eccentricity (e/d) Ratio of Column P_d at Slenderness Ratio 15.

Column	e/d	L/d	b/t	s/d	Pu (kN)	Δu (mm)	% Variation in Pu	% Variationin Δu
P_d	0.1	15	30	0.7	3360	110	_	_
	0.2				2880	151	14	37
	0.3				2555	177	24	60
	0.4				2215	183	34	66
	0.5				1940	184	42	67

Table 5. Effect of Load Eccentricity (e/d) Ratio of Column P_d at Slenderness Ratio 25.

Column	e/d	L/d	b/t	s/d	Pu (kN)	Δu (mm)	% Variation in Pu	% Variation in Δu
P_d	0.1	25	30	0.7	1555	277	_	_
	0.2				1445	392	7	42
	0.3				1350	456	13	65
	0.4				1240	470	20	70
	0.5				1145	473	27	71

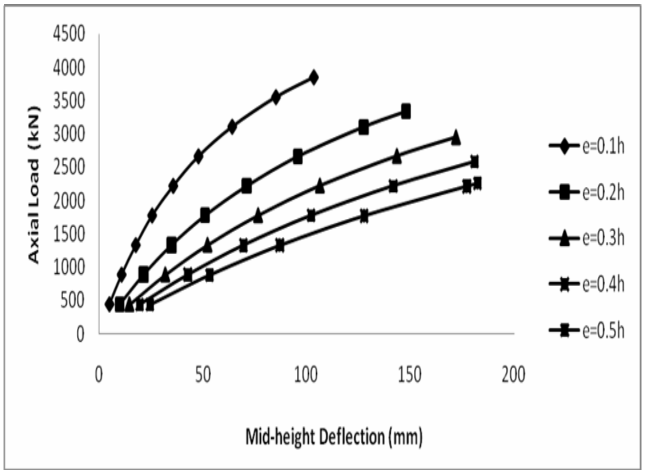


Figure 4. Load Deflection curve of P_b column with L/d ratio 15

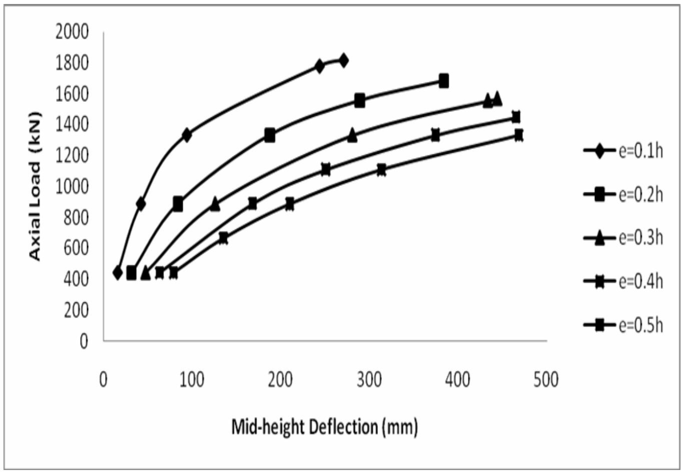


Figure 5. Load Deflection curve of P_b column with L/d ratio 25

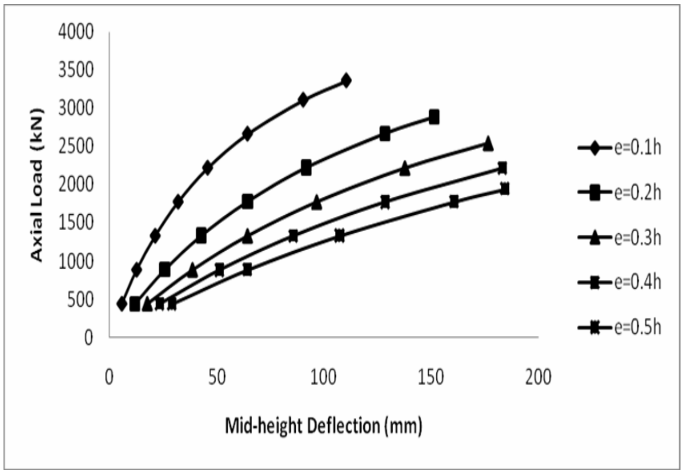


Figure 6. Load Deflection curve of P_d column with L/d ratio 15

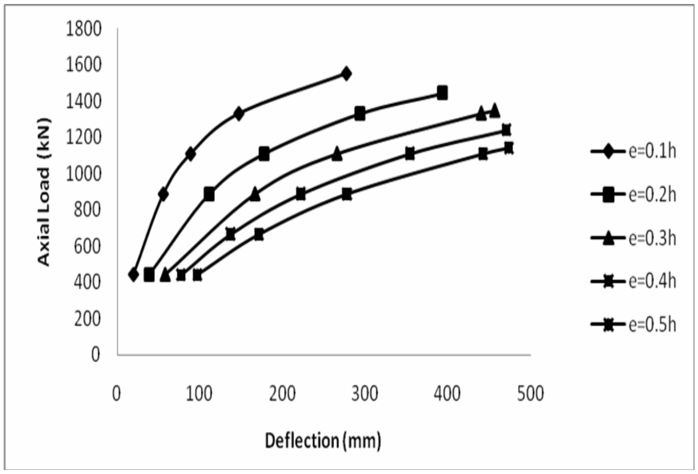


Figure 7. Load Deflection curve of P_d column with L/d ratio 25

4.2 Effect of Overall Column Slenderness (L/d) ratio

The global stability of the column is controlled by the overall slenderness ratio, which is defined as the ratio of the length of the column, L, to the depth of column cross-section, d. In the parametric study five different slenderness ratios- 10,15,20,25 and 30- were employed. Tables 6 to 8 show the effect of overall column slenderness (L/d) ratio on the selected output parameters at the peak load point. For column P_a, if L/d ratio is increased by 5, 10, 15 and 20 the ultimate load capacity is reduced by 33%, 54%, 67% and 75% respectively and the lateral deflection is increased by 112%, 261%, 450% and 680% respectively. Again, for column P_b, an increase in the L/d ratio by 5, 10, 15 and 20 decreases the ultimate load capacity by 33%, 53%, 66% and 75% and increases the deflection by 112%, 261%, 449% and 677% respectively which are almost similar to column P_a. Both of the analysis results show that reduction in ultimate load capacity and increase in deflection accelerated with the increase in slenderness ratio. For column P_a and P_b, main distinguishing feature is the spacing of transverse links. The ultimate load capacity variation rate is observed to be similar for these columns with the applied variation in the overall slenderness ratio. Therefore, the effect of the spacing of the transverse links can be taken as insignificant for slender columns. For column P_d, an increase in the L/d ratio by 5, 10, 15 and 20 reduces the ultimate load capacity by 26%, 46%, 59% and 68% respectively. Again, lateral deflections increased by 113%, 262%, 446% and 669% respectively. The ultimate load capacity reduction rate is higher for column P_d as compared to columns P_a or P_b. This is due to the presence of slender flange plates of column P_d.

Table 6. Effect of Slenderness (L/d) Ratio of Column P_a

Column	L/d	e/d	b/t	s/d	Pu (kN)	Δu (mm)	% Variationin Pu	% Variation in Δu
P_a	10	0.2	25	0.5	5130	74	_	_
	15				3425	156	33	112
	20				2370	267	54	261
	25				1705	406	67	450
	30				1275	577	75	680

Table 7. Effect of Slenderness (L/d) Ratio of Column P_b

Column	L/d	e/d	b/t	s/d	Pu (kN)	Δu (mm)	% Variation in Pu	% Varia-tionin Δu
P_b	10	0.2	25	0.7	4950	70	_	_
	15				3340	148	33	112
	20				2330	253	53	261
	25				1680	384	66	449
	30				1260	543	75	677

Table 8. Effect of Slenderness (L/d) Ratio of Column P_d

Column	L/d	e/d	b/t	s/d	Pu (kN)	Δu (mm)	% Variation in Pu	% Variation in Δu
P_d	10	0.4	30	0.7	3020	86	_	_
	15				2220	183	26	113
	20				1650	311	46	262
	25				1240	470	59	446
	30				960	662	68	669

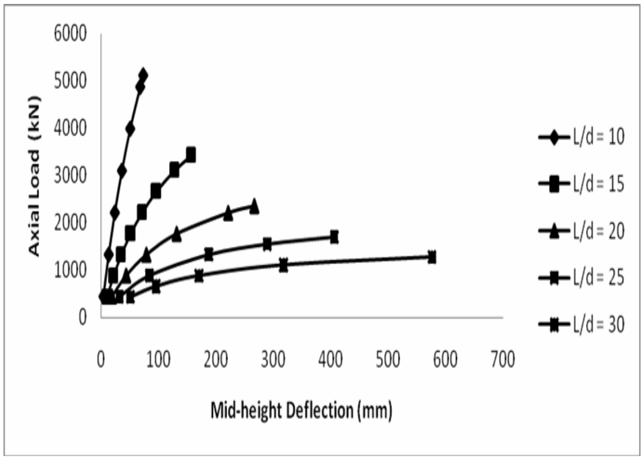


Figure 8. Load Deflection curve of P_a column with e/h ratio 0.2

The effects of overall column slenderness ratio on PEC columns at a fixed load eccentricity ratio are presented in Figures 8-10. The load versus deflection responses for the columns with five different slenderness ratios 10 to 30, subjected to an initial load eccentricity ratio of 0.2 and 0.4 is shown. From these figures it is clear that increase in the slenderness ratio increases the lateral deflection at mid height with a significant reduction in the load bearing capacity. It also shows that for L/d ratio 10, curve shows linear pattern. It implies that, at this length of column, initial deflection is more dominant than secondary deflection. At other slenderness ratios, nonlinear curves have been found and deflection at mid-height of column increases exponentially with the increase in the slenderness ratios.

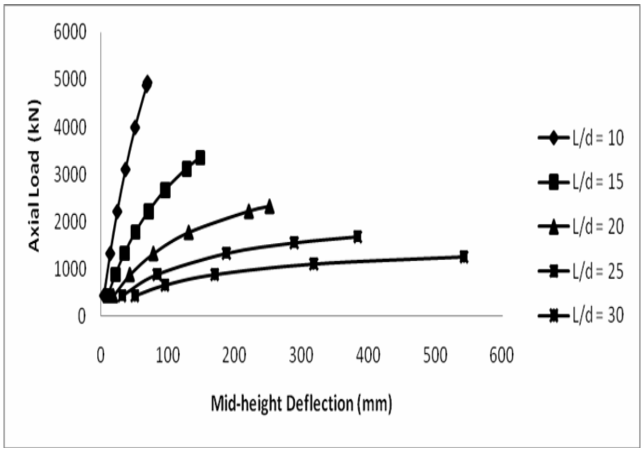


Figure 9. Load Deflection curve of P_b column with e/h ratio 0.2

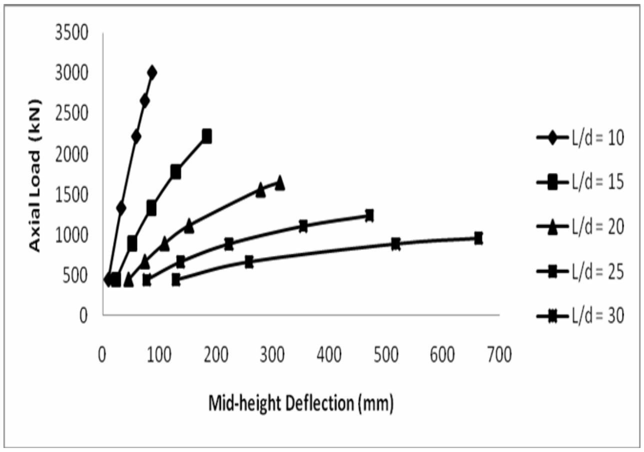


Figure 10. Load Deflection curve of P_d column with e/h ratio 0.4

5 CONCLUSIONS

The behaviour of slender partially encased composite column has been studied using Newmark's iterative procedure. A parametric study is conducted using this method to identify the potential variables that can significantly affect the behaviour of slender partially encased composite column. The variable parameters include load eccentricity ratio (e/d) and slenderness ratio (L/d). The effects of overall slenderness ratio and load eccentricity ratio have been studied by formulating the load deflection response of the parametric column. The effects of these parameters on the axial capacity and second order deflection of the slender column has been demonstrated. The axial capacity of a partially encased composite column has been reduced prominently as the overall slenderness ratio increases, particularly for columns with slender plates. This reduction is more prominent in columns with larger link spacing. Besides, exponential increase in lateral deflection has been observed with the increase in the slenderness ratio. Effect of second order deflection on total deflection has been found to be insignificant when L/d ratio is 10. For the eccentrically loaded columns, load carrying capacity has been found to drop significantly with an increase of eccentricity. The effect of the ratio of initial load eccentricity to the overall depth of the column cross-section has been observed to increase the lateral displacement of columns significantly and has been found more pronounced for columns with higher L/d ratio.

REFERENCES

Begum, M., Driver, R.G. and Elwi, A.E. 2007. Background. *Finite-Element Modelling of Partially Encased Composite Columns Using the Dynamic Explicit Method;* ASCE Structural Journal 133, 326-334.

Begum, M. 2007. Short column constructed with normal strength concrete. *Partially Encased Composite Columns: an Innovative Composite Structural System*; Proceedings of New Technologies for Urban Safety of Mega Cities in Asia.

Bouchereau, R., and Toupin, J.-D. 2003. *Étude du Comportement en Compression-Flexion des Poteaux Mixtes Partiellement En-*

robés; Report EPM/GCS-2003-03, Dept. of Civil, Geological and Mining Engineering, Ecole Polytechnique, Montreal, Canada.

Chicoine, T., Tremblay, R., Massicotte, B., Ricles, J., and Lu, L.-W. 2002. *Behavior and Strength of Partially-Encased Composite Columns with Built Up Shapes*; Journal of Structural Engineering, ASCE, 128 (3), 279-288.

Filion, I. 1998. *Étude Expérimentale des Poteaux Mixtes Avec Section d'acier de classe 4*; Report n^o. EPM/GCS-1998-06, Dept. of Civil, Geological and Mining Engineering, Ecole Polytechnique, Montreal, Canada.

Mirza, S.A., and Tikka, T.K. 1999. Introduction. *Flexural Stiffness of Composite Columns Subjected to Major Axis Bending;* ACI Structural Journal 96, 19-28.

Mirza, S.A., and Tikka, T.K. 2005. Computations of theoretical cross section and slender column bending moment resistances. *Equivalent Uniform Moment Diagram Factor for Composite Columns in Major Axis Bending;* ASCE Structural Journal 131, 569-581.

Newmark, N. M. 1943. *Numerical Procedures for computing deflections, moments, and buckling loads*; Trans. ASCE, 108, 1161-1234.

Prickett, B. S. and Driver, R. G. 2006. *Behaviour of Partially Encased Composite Columns Made with High Performance Concrete*. Structural Engineering Report No 262, Dept. of Civil and Environmental Engineering, University of Alberta, AB, Canada.

Tremblay, R., Massicotte, B., Filion, I., and Maranda, R. 1998 *Experimental Study on the Behaviour of Partially Encased Composite Columns Made with Light Welded H Steel Shapes under Compressive Axial Loads*; Proc., SSRC Annual Technical Session & Meeting, Atlanta, 195-204.