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Concentric Vs. Eccentric Loading on Different Shapes of CFST Columns: A Theoretical Investigation on Axial Compressive Strength According to AISC Guidelines

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ABSTRACT

The Steel-concrete composite column can be an effective solution for any type of civil engineering construction instead of bare concrete or bare steel column because of having a good confinement effect between steel and concrete. Four types of shapes (square, rectangular, circular and elliptical) are chosen to find out their bearing capacity and axial compressive strength according to AISC (2010) guidelines. It is tried to make differences between these shapes. And it is also tried to keep the same cross-sectional dimension in the area of each shape. The main features which are found from this investigation are that circular shape has a good confinement effect and cost-effective than other shapes. Though the capacity of the square shape of CFST column is better than circular but it loses its confinement effect because of having sharp edges. And a square type of shape is suitable for easy connection. On the other hand, rectangular shape is better than elliptical shape.

***Keywords*:** Confinement effect, bearing capacity and axial compressive strength

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1. INTRODUCTION

From the beginning of the invention of concrete and steel structures, an attempt had done to combine them only to protect fire. But after a few decades, many investigations were done to know the advantages of the combination of steel and concrete structures [1]. It was found that they have a good confinement effect which could give better strength, ductility and flexure [2]. At last, at the end of the 19th century, Steel-concrete composite structures (beams, columns, deck slabs etc.) were used commercially all over the world [3]. So, steel-concrete composite structures having better fire performance and axial compressive strength, more load transferring capability and resisting property of seismic and wind load [4]. There are three types of steel-concrete composite columns. They are fully encased composite column (FEC), partially encased composite column (PEC) and concrete filled steel tubular column (CFST). The main advantages of CFST columns having the better resistivity of the excessive bending moment, vertical and lateral loads, capability of resisting the torsional effect and local buckling [5]. In CFST column concrete prohibition is separated by steel formwork which may reduce the cost of shuttering [6]. CFST column may be used in high-rise buildings, bridge piers, offshore structures, foundations in trussed bridges etc. An investigation is done on the cost-effective analysis of CFST columns [7]. It is found that if CFST construction exceeds 14th floor than it is more cost-effective than normal RCC structures [8]. Among different shapes of CFST columns, square shape is better for any type of connections. In this study, it is tried to investigate the compressive behavior of considering different shapes of CFST column according to AISC (2010) guidelines under eccentric and concentric loading. In this study, different types of shapes (square, circular, rectangular and elliptical) are tried to consider.

Investigation of the strength and failure behavior of the square shape CFST column had not conducted before under eccentric loading conditions (But for circular and rectangular shape, these had done) [9]. For many reasons such as architectural view or design parameters, the loads (slab or beam loads) may be transferred eccentrically on the columns. So, on this point of view, the study on the eccentrically loaded CFST column is very important. And the differences between interaction diagram of the steel-concrete composite column is also attached under eccentric and concentric loading. According to AISC (2010) guidelines, code predicted assumption is so limited in the case of the behavior of eccentrically loaded CFST columns. So, an effort has done to meet the conservatives of this code under eccentric loading condition. The main objective of this study is to differentiate the different shapes of CFST columns according to AISC (2010) guidelines under concentric and eccentric loading condition.

2. LITERATURE REVIEW OF THIS INVESTIGATION

A. Tailor (2017) et al. studied with the effect of the suitability of concrete filled steel tube (CFST) columns in high rise buildings. They developed different building model where the column is used square, circular CFST and only steel in STAAD pro software. After this analysis, they found that square CFST column is better for dead and live load deflection than steel column. At last, they concluded that CFST column may the economical solution for high rise construction and it can be applied in earthquake-prone areas in lieu of the bare steel column [10].

S.-H. Lee (2011) et al. investigated on the circular shape CFST column under eccentric loading. They considered high strength steel (450MPa), varying concrete and diameter to thickness ratio and the variation of eccentricity in this investigation. They found that axial stiffness increased with the decreased of diameter to thickness ratio of circular shape CFST columns with 0.5D eccentric distance. They also concluded that the ductility of 350MPa concrete is greater than the ductility of 60MPa concrete when the diameter to thickness ratio is 80 [11].

M.H. Lai and J.C.M. Ho (2017) developed a theoretical model of CFST column to analyze its axial strength. They considered two parameters. The variances of concrete strength and yield strength are two types of this parameter. They observed that the axial strength of CFST column is proportional to the yield strength of steel and the cylinder strength of concrete, but inversely proportional to the diameter to thickness ratio of steel. And at last, they concluded that the axial strength of CFST column is increased because of the confinement effect of concrete and steel instead of bare concrete or bare steel [12].

F. Ding (2017) et al. investigated on the square shape CFST stub columns by axial loading condition where a notch is attached to the steel tube. They actually observed the change of the mechanical property of steel tube with notch by axial loading condition. The load-deflection curve is totally different in the notch-steel tube because of the use of notch can hamper the confinement effect between steel and concrete. At last, they proposed a notch-steel tube mode, which satisfied the criteria of good experimental results [13].

C.-Y. Wan et al. (2017) investigated on the fire effect of slender hollow and non-hollow concrete filled double steel tube (CFDST) columns under compressive loading. They found that the slender CFDST showed better fire performance than normal concrete filled tube column. They concluded that the CFDST column satisfied better fire resistance and compressive strength and the load-bearing capacity also met the better one [14].

X. Qu et al. (2013) studied the parametric behavior of the rectangular shape CFST column under eccentric loading condition. They analyzed the vertical and horizontal load deflection results and the strain at a definite point. They found that the eccentricity ratio and the strength index were inversely proportional to each other. They also added that the effect of eccentricity ratio on the ductile behavior of CFST column was not up to the mark [15].

Y. Ouyang et al. (2017) investigated on the confinement effect of circular shape CFST under eccentric loading condition. They found that after the eccentric loading condition the confinement of circular shape CFST column turns into uniform to non-uniform. So, they developed a new finite element method to solve this such complicated problem and tried to match the strength and failure behavior of experimental and numerical results [16].

3. CODE RELATED CALCULATION

All the equations which are attached below are taken from the AISC specification (2010).

Table 1 gives the condition for compact, noncompact and slender composite member subjected to axial compression.

Table 1. The condition for compact, noncompact and slender composite member subjected to axial compression (AISC-2010).

Description of Element	Width to thickness Ratio	λ_p	λ_r	Maximum Permitted
Walls of Rectangular HSS and Boxes of uniform Thickness	b/t	$2.26\sqrt{\frac{E}{F_y}}$	$3.00\sqrt{\frac{E}{F_y}}$	$5.00\sqrt{\frac{E}{F_y}}$
Round HSS	D/t	$\frac{0.15\,E}{F_y}$	$\frac{0.19\,E}{F_y}$	$\frac{0.31\,E}{F_y}$

So, the equation of the axial compressive strength of CFST column is given below (without considering the length effect).

A) For compact section:

$$P_p = F_y A_s + C_2 f_c^{/} \left(A_c + A_{sr}\frac{E_s}{E_c}\right)$$

where: F_y = Yield strength of steel.

A_s = Area of steel section

A_c = Area of concrete

$f_c^{/}$ **=** Concrete compressive strength

A_{sr} = Area of continuous reinforcing bars

E_s = Modulus of steel

E_c = modulus of concrete

C_2 = 0.85 for rectangular sections and 0.95 for round sections

B) For noncompact sections

$$P_{no} = P_p - \frac{P_p - P_y}{(\lambda_r - \lambda_p)^2}(\lambda_r - \lambda_p)^2$$

where: $P_y = F_y A_s + 0.7\, f_c^{/} \left(A_c + A_{sr}\frac{E_s}{E_c}\right)$

C) For slender section

$$P_{no} = F_{cr} A_s + 0.7 f_c^{/} (A_c + A_{sr} \frac{E_s}{E_c})$$

For rectangular fillet section:

$$F_{cr} = \frac{9E_s}{(\frac{b}{t})^2}$$

Now the equations of the axial compressive strength of the CFST column with considering the length effect are given below.

$$P_{no} = P_p = F_y A_s + C_2 f_c^{/} (A_c + A_{sr} \frac{E_s}{E_c})$$

where: C_2 = 0.85 for rectangular sections

$$C_3 = 0.6 + 2 \left(\frac{A_s}{A_c + A_s} \right) \leq 0.9$$

$$E_c = W_c^{1.5} \sqrt{f_c^{/}}$$

$$EI_{eff} = E_s I_{sy} + E_s I_{sr} + C_3 E_c I_{cy}$$

where: E_s = modulus of steel

E_c = modulus of concrete

I_s = moment of inertia steel section

I_{sr} = moment of inertia reinforcement

I_c = moment of inertia concrete

EI_{eff} = effective rigidity

$$P_e = \pi^2 (EIeff) / (KL)^2$$

So, the axial compressive strength with consider the length effect of CFST column,

$$P_n = P_{no} [\, 0.659^{\frac{Pno}{Pe}} \,]$$

4. THEORETICAL ANALYSIS & DISCUSSION

Theoretical analysis is developed on the basis of AISC (2010) guidelines. There are four types of shapes are considered. They are square, circular, rectangular and elliptical. The comparison between these shapes is attached to the last portion of this analysis. And an attempt has done to calculate these different shapes of the column for both eccentric and concentric loading conditions. Table 2 shows the axial compressive strength of the square size CFST column under concentric and eccentric loading.

Table 2. The axial compressive strength of the square size CFST column under concentric and eccentric loading.

No.	Designation	Size (mm)	Length (mm)	fc' (MPa)	f_y (MPa)	Thickness, t (mm)	e (mm)	Bearing Capacity of CFST column (kip)	Axial Compressive strength of CFST column (MPa)
1	SST-130-25-3-0	130×130	1200	25	413	3	0	202.15	90
2	SST-130-25-3-28	130×130	1200	25	413	3	28	133	60

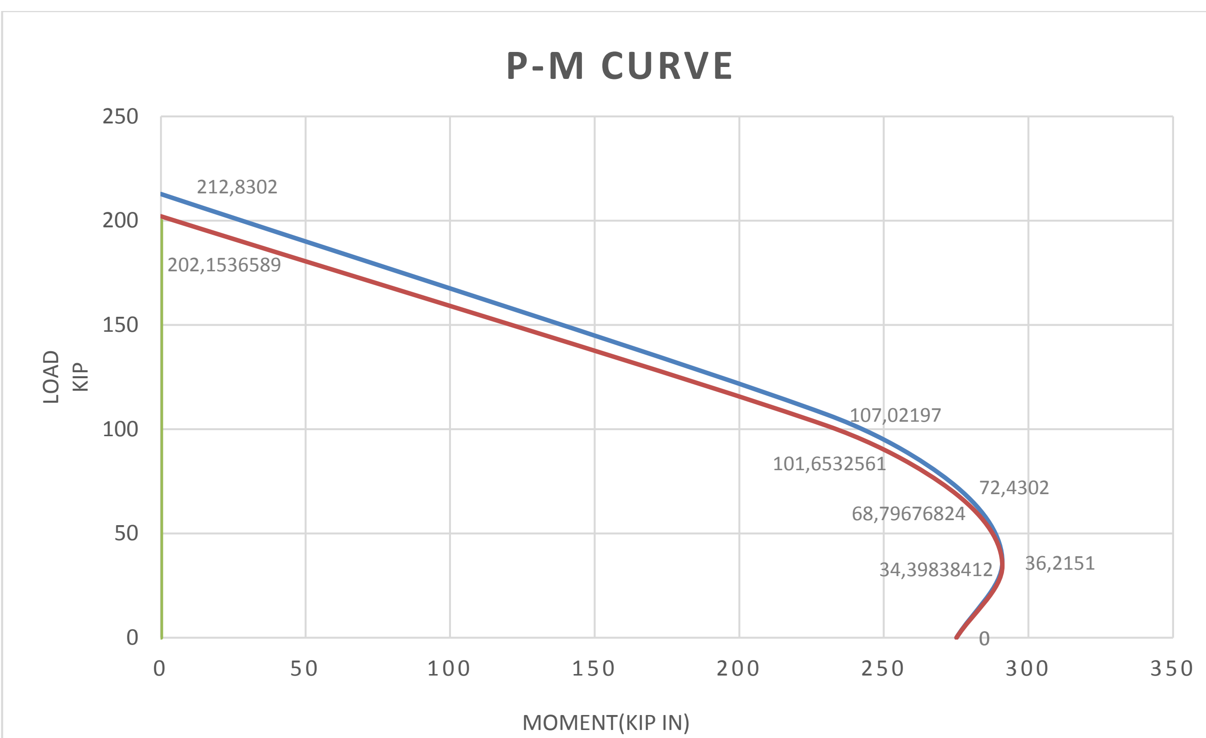

Figure 1. Interaction diagram of specimen 1.

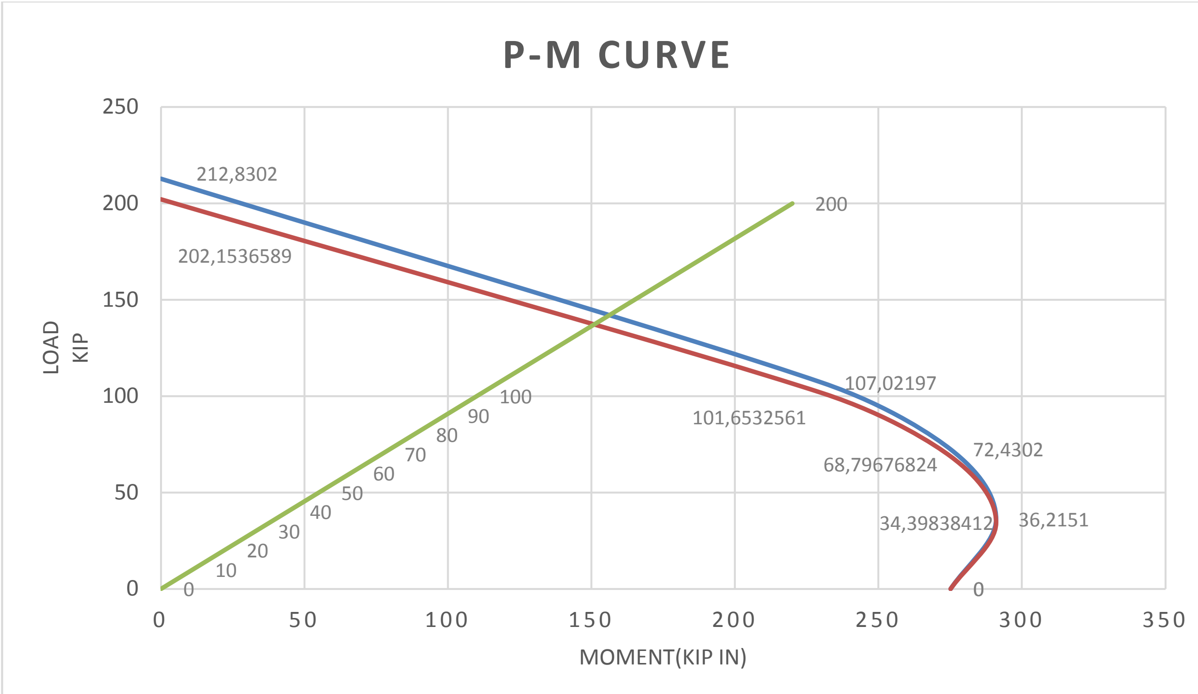

Figure 2. Interaction diagram of specimen 2.

Table 3. The axial compressive strength of the circular size CFST column under concentric and eccentric loading.

No.	Designation	Diameter (mm)	Length (mm)	fc' (MPa)	f_y (MPa)	Thickness, t (mm)	e (mm)	Bearing Capacity of CFST column (kip)	Axial Compressive strength of CFST column (MPa)
3	SST-130-25-3-0	130	1200	25	413	3	0	160.68	71.34
4	SST-130-25-3-28	130	1200	25	413	3	28	145	64.3

From the analysis of the above table, the square shape CFST column is considered for this analysis. Capacity and axial compressive strength are determined according to the equation of the considering length effect (AISC 2010). And it is clearly seen that the capacity and compressive strength are decreased under eccentric loading conditions. Figure 1 and Figure 2 indicate the interaction diagram of the above specimen.

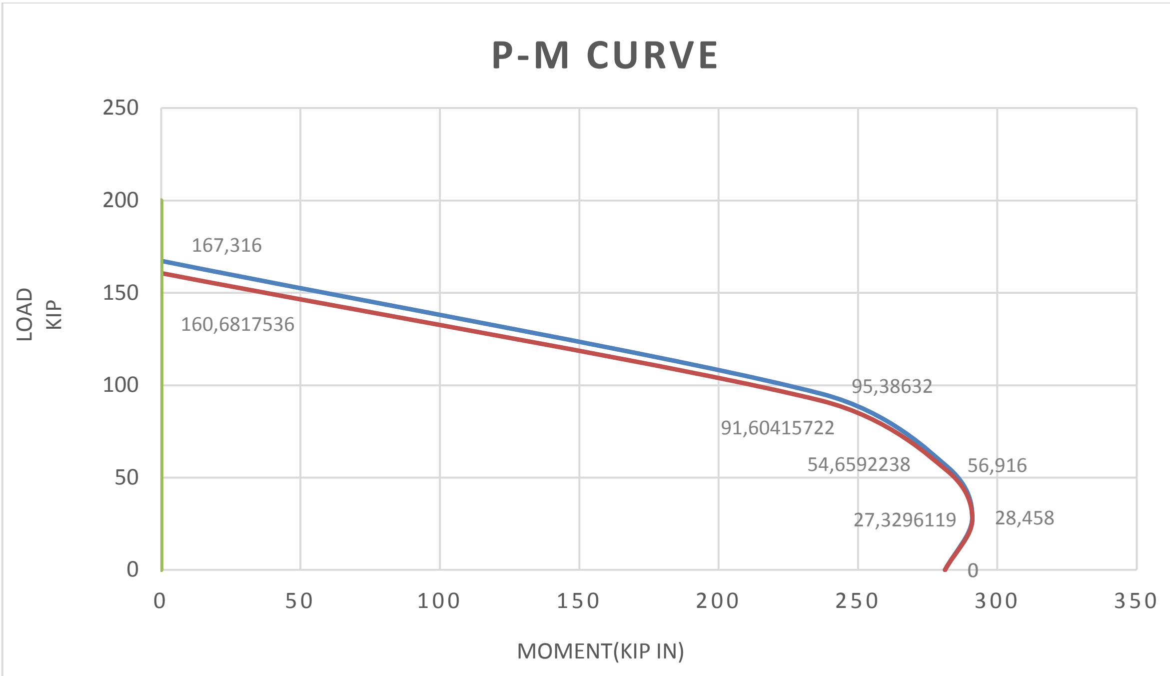

Figure 3. Interaction diagram of specimen 3.

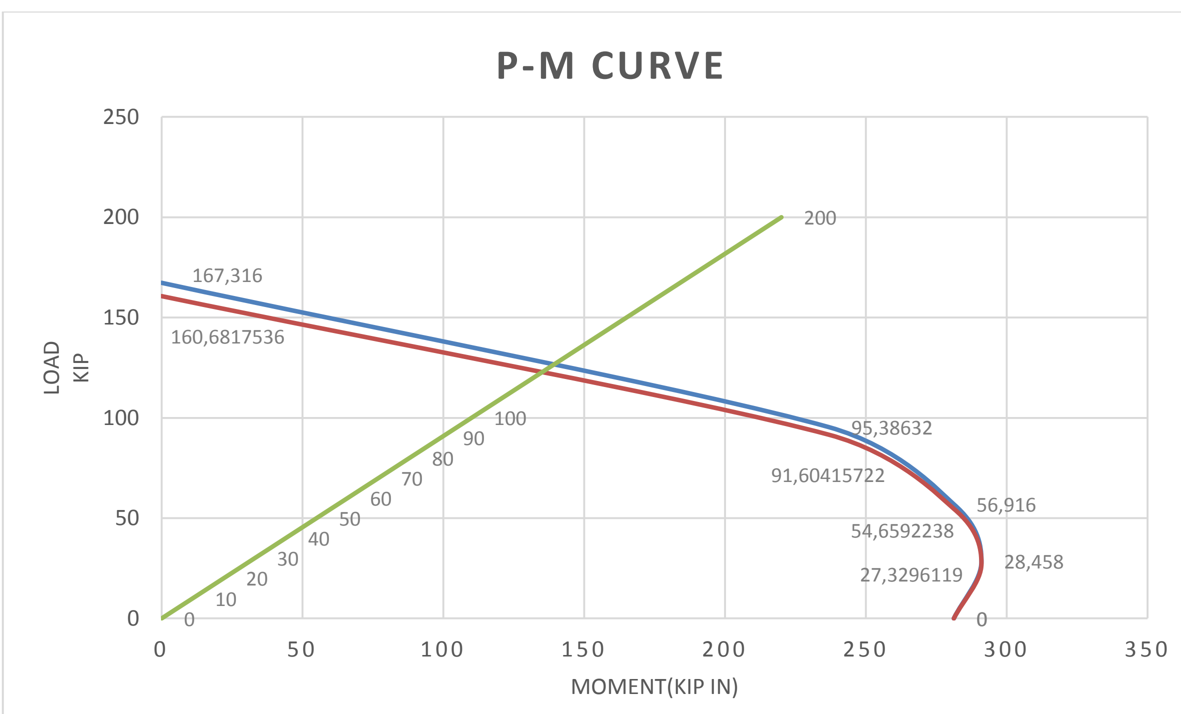

Figure 4. Interaction diagram of specimen 4.

From the analysis of above Figure 1 and Figure 2, blue line denotes the capacity of the square shape CFST column, which is found from without length effect considering equation. And the red line is found from the equation by considering the length effect. From the analysis of two specimens, it is clearly understood that the eccentric position (28 mm) of loading reduces the capacity and strength of a square shape CFST column than concentric position.

Table 3 shows the axial compressive strength of the circular size CFST column under concentric and eccentric loading.

From the analysis of the above table, the circular shape CFST column is considered for this analysis. Capacity and axial compressive strength are determined according to the equation of the considering length effect (AISC 2010). And it is clearly seen that the capacity and compressive strength are decreased under eccentric loading conditions. Figure 3 and Figure 4 indicate the interaction diagram of the above specimen.

From the analysis of above Figure 3 and Figure 4, blue line denotes the capacity of the square shape CFST column, which is found from without length effect considering equation. And the red line is found from the equation by considering the length effect. From the analysis of two specimens, it is clearly understood that the eccentric position (28 mm) of loading reduces the capacity and strength of a square shape CFST column than concentric position.

Table 4 shows the axial compressive strength of the rectangular size CFST column under concentric and eccentric loading.

Table 4. The axial compressive strength of the rectangular size CFST column under concentric and eccentric loading.

No.	Designation	Size (mm)	Length (mm)	fc' (MPa)	f_y (MPa)	Thickness, t (mm)	e (mm)	Bearing Capacity of CFST column (kip)	Axial Compressive strength of CFST column (MPa)
5	SST-(130×135)-25-3-0	130×135	1200	25	413	3	0	207.83	93
6	SST-(130×135)-25-3-28	130×135	1200	25	413	3	28	138	61.2

From the analysis of the above table, the rectangular shape CFST column is considered for this analysis. Capacity and axial compressive strength are determined according to the equation of the considering length effect (AISC 2010). And it is clearly seen that the capacity and compressive strength are decreased under eccentric loading conditions. Figure 5 and Figure 6 indicate the interaction diagram of the above specimen.

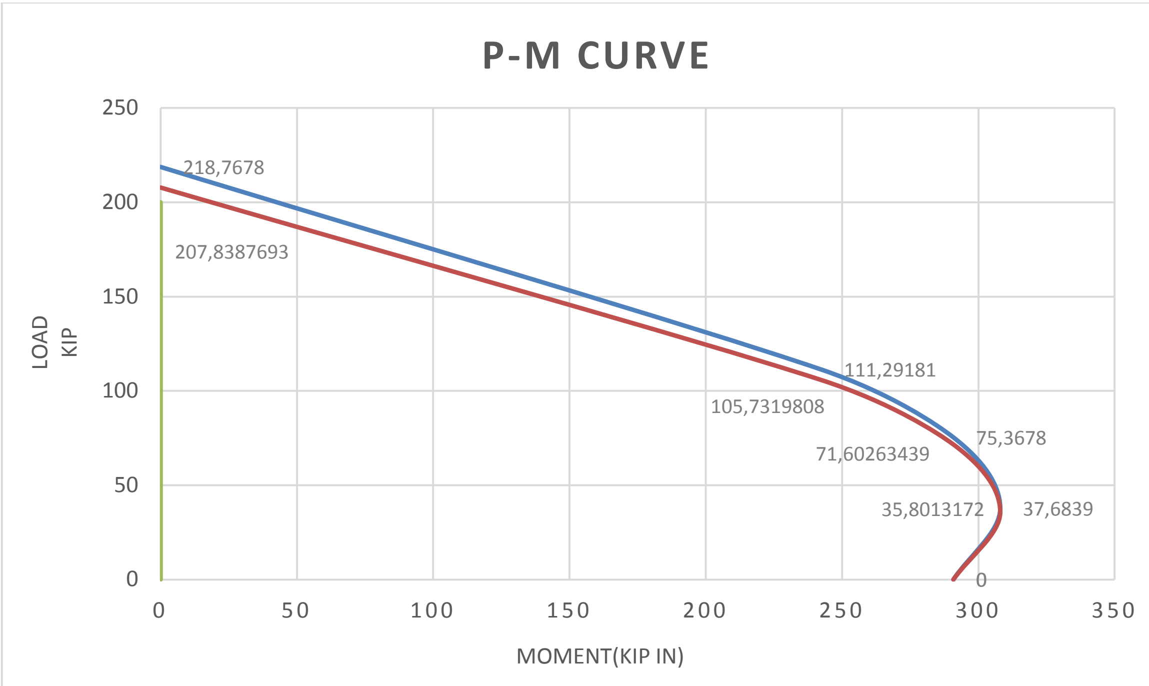

Figure 5. Interaction diagram of specimen 5.

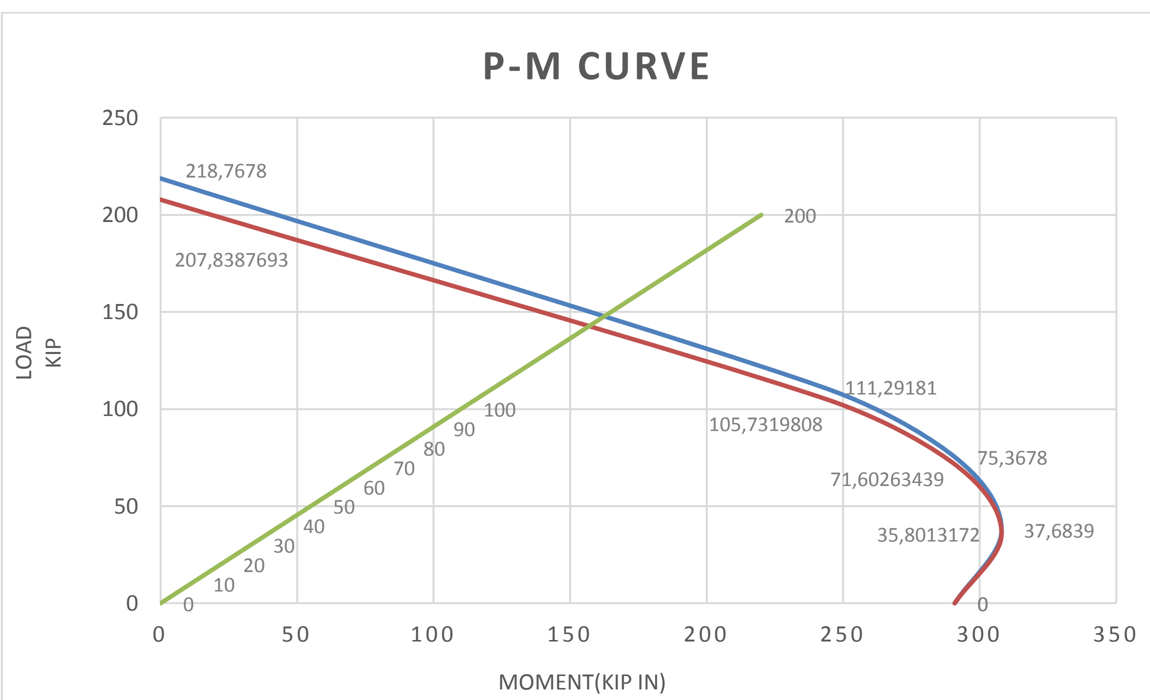

Figure 6. Interaction diagram of specimen 6.

From the analysis of above Figure 5 and Figure 6, blue line denotes the capacity of the rectangular shape CFST column, which is found from without length effect considering equation. And the red line is found from the equation by considering the length effect. From the analysis of two specimens, it is clearly understood that the eccentric position (2 8mm) of loading reduces the capacity and strength of a rectangular shape CFST column than concentric position. Table 5 shows the axial compressive strength of the elliptical size CFST column under concentric and eccentric loading.

Table 5. The axial compressive strength of the elliptical size CFST column under concentric and eccentric loading.

No.	Designation	a	b	Length (mm)	fc' (MPa)	f_y (MPa)	Thickness, t (mm)	e (mm)	Bearing Capacity of CFST column (kip)	Axial Compressive strength of CFST column (MPa)
5	SST-(130×135)-25-3-0	65	67.5	1200	25	413	3	0	164.63	57
6	SST-(130×135)-25-3-28	65	67.5	1200	25	413	3	28	129	43.66

From the analysis of the above table, the elliptical shape CFST column is considered for this analysis. Capacity and axial compressive strength are determined according to the equation of the considering length effect (AISC 2010). And it is clearly seen that the capacity and compressive strength are decreased under eccentric loading conditions. Figure 7 and Figure 8 indicate the interaction diagram of the above specimen.

From the analysis of above Figure 7 and Figure 8, blue line denotes the capacity of the elliptical shape CFST column, which is found from without length effect considering equation. And the red line is found from the equation by considering the length effect. From the analysis of two specimens, it is clearly understood that the eccentric position (28 mm) of loading reduces the capacity and strength of an elliptical shape CFST column than concentric position. From the analysis of the above data, the capacity of square shape is larger than the circular shape of CFST column. Here, same dimensions (width, diameter and height) are tried to consider such investigation. But the circular shape of the column has many positive sides. It attains good confinement effect than square shape and having the cost-effective capability. So, this type of shape (circular CFST column) can be used in large piers or large load bearing construction with a large diameter. And the square type of shape CFST column can be used in a medium type of construction where connection type is very complex. And the rectangular type of shape is better than elliptical shape. The construction procedure of the elliptical type of shape of CFST column is complex. And it is not suitable for a complex type of connection. Both square and rectangular shapes of CFST column may lose their confinement effect because of their sharp edge. The round shape can be a good solution for them.

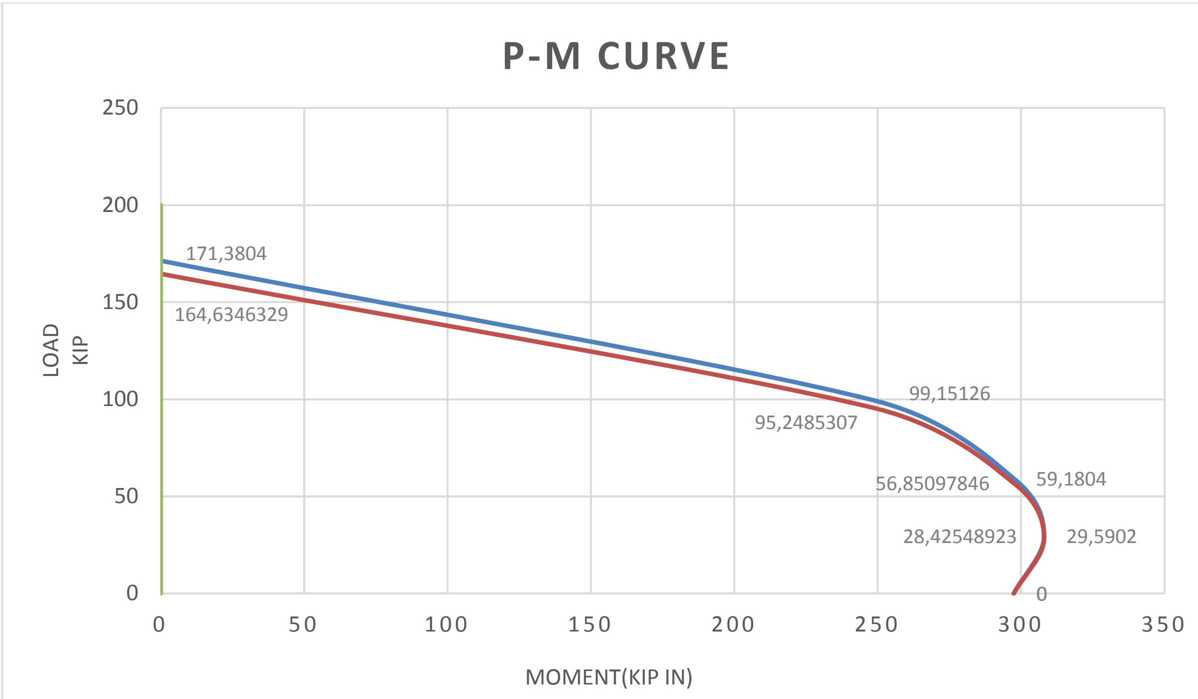

Figure 7. Interaction diagram of specimen 7.

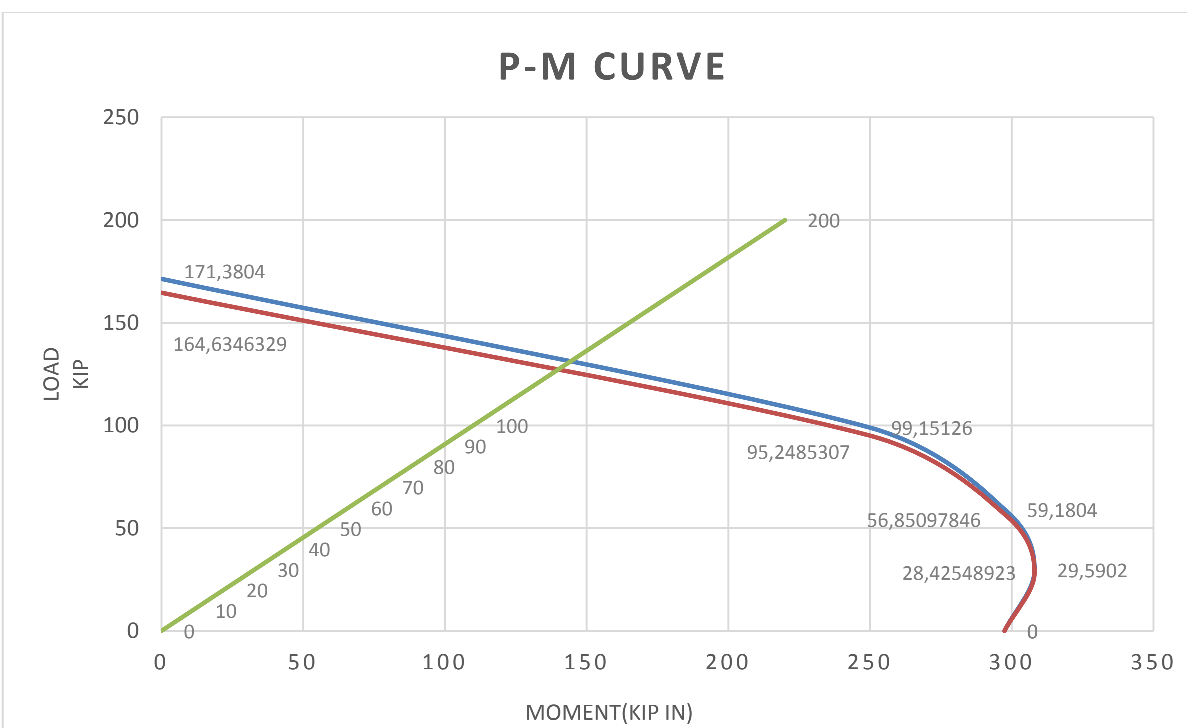

Figure 8. Interaction diagram of specimen 8.

5. FUTURE RECOMMENDATION

1) A Large-scale experimental study should be needed on different shapes of CFST columns.
2) The More numerical study should be needed to match the experimental data of different shapes of CFST columns by ABAQUS.
3) Suitability of good connection for the square shape CFST column should be studied.
4) The confinement effect of the circular shape CFST column should be studied.

6. CONCLUDING REMARKS

In this type of investigation, it is tried to find out the advantages and disadvantages of different shapes of CFST columns. There are four types of shapes are considered. Among these, the rectangular and square shape can carry more load, but having a less confinement effect than other shapes because of having sharp edges. But they show better performance in case of a complex joint. On the other hand, circular shape is preferred because of having a good confinement effect and cost-effective capability. And the elliptical shape of CFST column is rarely used in construction. So, more investigations should be required, particularly in the elliptical shape of CFST column.

References

[1] S.H. Lee, S.H. Kim, J.S. Bang, Y.A. Won and S.M. Choia, Structural Characteristics of Welded Built-up Square Concrete Filled Tubular Stub Columns Associated with Concrete Strength, *Procedia Engineering* 14 (2011) 1140–1148.

[2] G.T. Zhao, M.X. Zhang and Y.H. Li, Behavior of Slender Steel Concrete Composite Columns In Eccentric Loading, *Journal of Shanghai University (English Edition)* 13 (2009) 481–488.

[3] M.A. Bradford, H.Y. Loh and B. Uy, Slenderness limits for filled circular steel tubes, *Journal of Constructional Steel Research*, 58 (2002) 243-252.

[4] G. Giakoumelis and D. Lam, Axial capacity of circular concrete-filled tube columns, *Journal of Constructional Steel Research* 60 (2004) 1049-1068.

[5] J. Cai and Z.Q. He, Axial Load Behavior of Square CFT Stub Column With Binding Bars, *Journal of Constructional Steel Research* 62 (2006) 472–483.

[6] M.D. O'Shea and R.Q. Bridge, Design of Circular Thin-Walled Concrete Filled Steel Tubes, *Journal of the Structural Engineering* 26 (2000) 1295-303.

[7] A.L. Krishan, E.A. Troshkina and E.P. Chernyshova, Efficient Design of Concrete Filled Steel Tube Columns, *Procedia Engineering* 150 (2016) 1709-1714.

[8] M. Begum, Md. S. Salekin, N.M. TB. Khan and W. Ahmed, Cost Analysis of Steel Concrete Composite Structures in Bangladesh, *Asian Journal of Civil Engineering (BHRC)* 14 (2013) 935- 944.

[9] E. Ellobody, B. Young and D. Lam, Eccentrically Loaded Concrete Encased Steel Composite Columns, *Thin-Walled Structures* 49 (2011) 53–65.

[10] Tailor, S.P. Dalal and A.K. Desai, Comparative Performance Evaluation of Steel Column Building & Concrete Filled Tube Column Building under Static and Dynamic Loading, *Procedia Engineering* 173 (2017) 1847–1853.

[11] S.H. Lee, B. Uy, S.H. Kim, YH Choi and SM Choi, Behavior of high-strength circular concrete-filled steel tubular (CFST) column under eccentric loading, *Journal of Constructional Steel Research* 67 (2011) 1-13.

[12] M.H. Lai and J.C. M. Ho, An analysis-based model for axially loaded circular CFST columns, *Thin-Walled Structures* 119 (2017) 770–781.

[13] F.X. Ding, L. Fu and Z.W. Yua, Behaviors of axially loaded square concrete-filled steel tube (CFST) Stub columns with notch in steel tube, *Thin–Walled Structures* 115 (2017) 196–204.

[14] C.Y. Wan, X.X. Zha and J.B. M. Dassekpo, Analysis of axially loaded concrete filled circular hollow double steel tubular columns exposed to fire, *Fire Safety Journal* 88 (2017) 1–12.

[15] X. Qu, Z. Chen and G. Sun, Experimental study of rectangular CFST columns subjected to eccentric loading, *Thin-Walled Structures* 64 (2013) 83–93.

[16] Y. Ouyang, A.K. H. Kwan, S.H. Lo and J.C. M. Ho, Finite element analysis of concrete-filled steel tube (CFST) columns with circular sections under eccentric load, *Engineering Structures* 148 (2017) 387–398.