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BEHAVIOUR OF ECCENTRICALLY LOADED SLENDER CONCRETE FILLED STEEL TUBES COLUMNS

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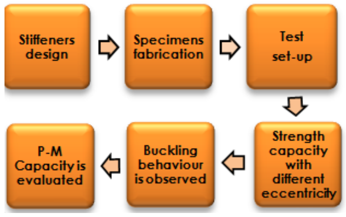
Graphical abstract



Abstract

This paper presents an experimental investigation into the structural behaviour of eccentrically loaded concrete filled, thin walled, steel tubular slender column with tab stiffeners (CFST). The primary parameters studied through the experimental work are load eccentricity and type of stiffeners. Three different types of stiffeners used in this study are longitudinal stiffeners of 10mm height, longitudinal and tab stiffeners of 25mm height and longitudinal and extended tab stiffeners at 40mm. The effects of the stiffeners on the structural behavior were investigated experimentally using 26 specimens of slender CFST, loaded with eccentricity ranging from 0 mm to 60 mm. It was observed that all specimens failed mainly by overall buckling and, the compressive strength and bending strength of the specimens decreases as the applied load eccentricity increases.

Keywords: Concrete filled tubes, Thin walled column, Slender column, Stiffeners, Eccentricity

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1.0 INTRODUCTION

A Concrete filled steel tube (CFST) column is a structural system with excellent structural characteristics, which is the result of combining the advantages of a steel tube and those of concrete. A CFST column is constructed by filling a hollow rectangular or circular structural steel tube with concrete. As a structural system, a CFST column has a high load bearing capacity, excellent earthquake-resistance, good ductility, high fire resistance and its higher stiffness which delays the onset of local buckling [1]. Besides that, the steel tube can function as a permanent formwork as well as reinforcement, thus more economical to be utilised.

Studies on slender columns have been quite intensive in recent years [2]-[11], [19]. Researchers agree that the ultimate strength of slender CFST column is governed by stability rather than strength. Hence, for overall buckling failures, there is little confinement of the concrete to occur and thus little additional strength gained. It has been agreed by many authors that a slenderness ratio (L/D) equal to 15 roughly marks a boundary between short and long column behaviour. The method of failure of long concrete filled steel tube columns is characterized by overall elastic buckling of the member [12]. The overall buckling occurs way before the normal stress reaches the strength of column material. This failure mode described by Hibbeler, as failure due to elastic instability [13]. The actual compressive stress at the point of failure is less than the ultimate compressive stress that the material is capable of withstanding.

A long column is sensitive to eccentric loading effects and initial out-of-straightness. The failure mechanism of long columns due to eccentric loading will be similar to the concentric case, except that failure will occur at a smaller load and the failure load will decrease with an increase in eccentricity [2], [3], [9], [11], [18]. However, the axial load and bending capacities of CFST could be improved by providing sufficient internal stiffening method.

This paper presents the study the structural behaviour of concrete filled thin-walled steel tube columns with tab stiffening system as discussed in details by Petrus *et al*. [15], [16].

2.0 EXPERIMENTAL PROGRAM

The behaviour of CFST slender column with a new stiffening system under eccentric load is investigated experimentally. The new stiffening system was attained by welding together four pieces of lipped angle, whereupon two parts of the lips were notched and folded vertically in order to form the tab stiffeners. Prior to real casting work being done to prepare the CFST columns specimens, a trial casting using a transparent acrylic tube as shown in Figure 1(a) was carried out. The wet concrete mix is poured into the acrylic tube from the height of 3m, to determine the most suitable concrete mix with the designed concrete strength used and to ensure that the flow-ability of the concrete to the steel tubes does require a minimum compaction. During the concrete casting, the concrete mix is poured in layers and compacted by a poker vibrator as shown in Figure 1(b). Extra care is required during the compaction process as to ensure there is a minimum segregation and that homogeneous concrete in-filled is obtained for each specimens.


(a) (b)

Figure 1 Samples preparations

After concrete casting, the specimens are left in an upright position with the top part covered by wet gunnysack at least for 28 days for curing. During the curing process, a very small amount of longitudinal shrinkage occurs at the top of the columns. A high-strength epoxy is used to level the column top surface. Prior to testing, both column ends are smoothly grind and a 250mm x 250mm x 8mm thick plate are welded at both ends.

2.1 Test Specimens

There are 26 specimens prepared for the slender column which includes 5 hollow tubes and 21 CFBST columns. The details of the specimens are given in Table 1.

For column specimens' identification purpose, a label system is adopted. For the specimens tabulated in Table 1, the first letter L refers to long column followed by S indicating square cross-section shape. Next, the letter F or U represents concrete filled or unfilled built-up steel tubes respectively. The fourth letter, L, T or ET indicates the type of stiffeners that is with longitudinal stiffeners, tab stiffeners or extended tab stiffeners respectively. The subsequent number is the height of stiffeners. The value of the load eccentricity is indicated by e20, e40 or e60 (i.e e20 - 20mm eccentricity.

Table 1 Slender CFST column specimens

No	*Specimens label*	*L(mm)*	*$e_{x\text{-}x}$ (mm)*	*e/r*	*f_{cu} (N/mm²)*	*f_y (MPa)*	*N_{Ue} (kN)*	*M_{Ue} (kNm)*
1	LSUL25(1)	3000	0	-	-	309	476.6	0
2	LSUL25(2)	3000	0	-	-	309	506.4	0
3	LSUT25(2)	3000	0	-	-	309	365.6	0
4	LSUETe0 (1)	3000	0	-	-	309	382.7	0
5	LSUETe20(3)	3000	20	0.2			287	5.74
6	LSFL25-b1	3000	20	0.2	40	309	1716.3	34.33
7	LSFL25-b2	3000	0	-	40	309	NA*	NA*
8	LSFL25-b3	3000	20	0.2	40	309	1700	34
9	LSFL10-b1	3000	20	0.2	40	309	1469.5	29.39
10	LSFL10-b2	3000	20	0.2	40	309	1530.7	30.61
11	LSFL10-b3	3000	20	0.2	40	309	1551.8	31.04
12	LSFT25-b1	3000	20	0.2	40	309	1602.2	32.04
13	LSFT25-b2	3000	20	0.2	40	309	1604.1	32.08
14	LSFT25-b3	3000	20	0.2	40	309	1708	34.16
15	LSFTe20-c1	3000	20	0.2	44	309	1657.5	33.15
16	LSFTe20-c2	3000	20	0.2	44	309	1679.8	33.60
17	LSFTe40-c1	3000	40	0.4	44	309	1278	51.12
18	LSFTe40-c2	3000	40	0.4	44	309	1314.6	52.59
19	LSFTe60-c1	3000	60	0.6	44	309	1103.4	66.20
20	LSFTe60-c2	3000	60	0.6	44	309	1054.7	63.29
21	LSFETe20-c1	3000	20	0.2	44	309	1741.3	34.83
22	LSFETe20-c2	3000	20	0.2	44	309	1731.6	34.63
23	LSFETe40-c1	3000	40	0.4	44	309	1327.4	53.10
24	LSFETe40-c2	3000	40	0.4	44	309	1302.8	52.11
25	LSFETe60-c1	3000	60	0.6	44	309	1130.5	67.83
26	LSFETe60-c2	3000	60	0.6	44	309	1068.4	64.10

L-long column; S-square cross-section shape; F or U-concrete filled or unfilled tubes; L, T or ET-longitudinal, tab or extended tab stiffeners respectively; 10 or 25-height of stiffeners; e0 or e20-eccentricity (i.e e20-20mm eccentricity) (1-3)-number of identical specimens.

2.2 Test Set-up and Instrumentation

The schematic view of the test set-up and instrumentation for eccentrically loaded slender column is shown in Figure 2.

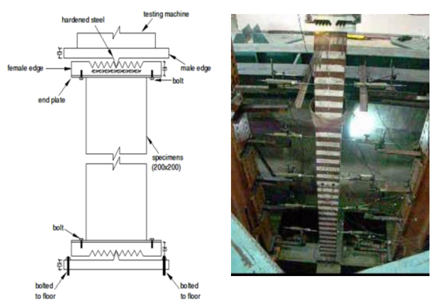

Figure 2 schematic views of the test set-up and instrumentation

All specimens are tested under eccentric loading about the major axis in a 2000 kN capacity universal testing machine. Since the standard accessories of the testing machine are unable to produce eccentric loading, knife edges are constructed which allow the load from the testing machine to be applied at designed eccentricities to the specimens similar to end assemblage used by Liu [17], with slight modification. The knife edges are employed at both the bottom and the top of the specimens to simulate pin-pin boundary conditions and subjected to single curvature bending. The knife edges consist of a male edge and female counterpart. The male edge consists of a 250 x 250mm x 25mm thick hardened steel block with 50mm width x 50m long V-shaped male edge. It is bolted to the top platen of the testing machine. The female edge consists of 250 x 250mm x 35mm thick hardened steel block with female V-shaped grooves of 10mm depth at every 20mm interval. It is positioned to the top end plate of the specimen with four numbers of bolts in order to align and to prevent the slippage between the female edges and the specimens. Axial loading is applied through the V-shaped female edges at each specimen so that the load eccentricity (e) could be precisely controlled.

3.0 RESULTS AND DISCUSSION

Based on the experimental result from the test of the slender columns with the new stiffening system, several observations on the buckling behaviour and the section strength capacities were evaluated.

3.1 Buckling Behaviour

There are two types of failure mode observed during the test namely, local buckling and overall buckling. In general, local buckling failure occurs in slender empty tubes loaded without eccentricity. Local buckling normally starts at one third from the top end of column specimens and eventually fails by overall buckling about the axis where the load is applied. Meanwhile the failure mode in concrete filled built-up steel tubes specimens is governed by global buckling. The schematic view of the buckling modes observed for respective specimens are as illustrated in Figure 3.

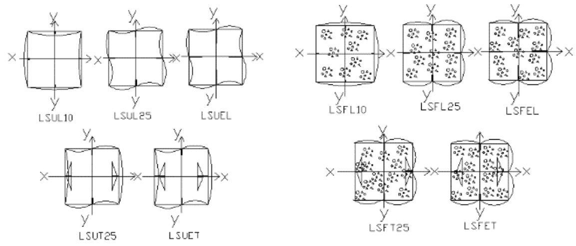

Figure 3 Buckling modes

The failure mode of concrete filled built-up steel tubes columns is also influenced by the applied loading eccentricity. The deflection shapes observed during the test for all specimens with eccentricity are approximately in the shape of half sine wave. A lateral deflection curve of the composite columns during the loading process is plotted in order to demonstrate the buckling curves development. Figure 4 shows the deflection curves development for specimens LSFT with 20mm, 40mm and 60mm eccentricity. At peak load the columns maximum deflections at mid-height are recorded as 20.82mm, 24.57mm and 33.53 for eccentricity 20mm. 40mm and 60mm respectively. From the deflections curves for all the specimens, it can be seen that the magnitude of the mid-height deflections is further increased as the eccentricity increases. As can be seen, the agreement between the test curves and the half-sine waves is better for specimens with higher eccentricity. It is also observed that the deflection magnitude increases rapidly after the peak load is exceeded.

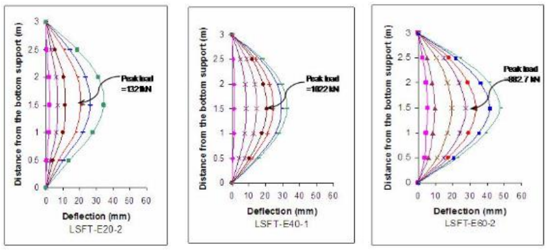

Figure 4 Buckling modes

3.2 Ultimate Strength Capacity

The ultimate strength capacity of slender columns in terms of their maximum axial load and maximum bending moment are as detailed in Table 1. The highest ultimate axial load capacity is observed in LSFL25, which is about 1708 kN in average. It is higher than LSFL10 and LSFT25 in averages which are approximately 11.17% and 4.1% respectively. The corresponding ultimate bending moment capacity for LSFL25 is 34.16kNm, which is about 12.5% and 4.6% higher in average than LSFL10 and LSFT25 respectively. On the other hand, the specimens with extended tab stiffeners LSFET show higher ultimate axial load and bending moment compared to specimens LSFL25 and LSFT25 on average of about 1.65% and 5% respectively. These results show that the tab stiffeners become beneficial when they are introduced at a certain length of longitudinal stiffeners. In this case, since the extended tab is introduced at extended longitudinal stiffeners of 20mm from the steel tube, both the longitudinal stiffeners and tab stiffeners contributed to the ultimate strengths capacities of slender column.

The typical effects of different type of stiffeners on axial load-mid-height deflections are shown in Figure 5. The axial load decreases slowly after the failure load has been reached, indicating the favorable ductility performance in the post yield behaviour of the specimens. The specimens LSFET with extended stiffeners shows highest strength as the stiffness of the tab stiffeners is not lost while the bond strength between the steel tube and concrete interfaces is maintained. This result indicates that the proposed stiffening system has a great potential to be used as a stiffeners in CFST.

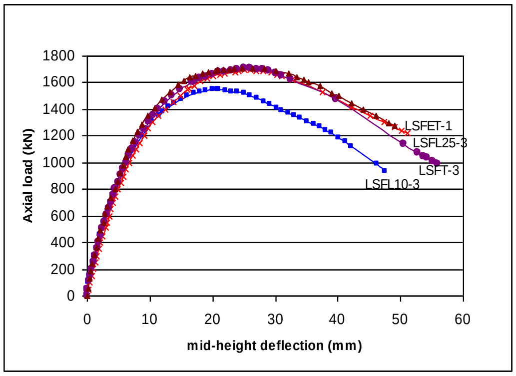

Figure 5 Effect of different type of stiffeners on load-mid-height deflections response

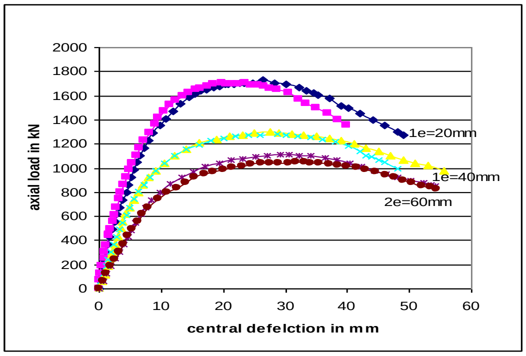

Figure 6 Effect of eccentricity on load-deformation response

The effect of eccentricity on load-deformation response for the specimens is shown in Figure 6. In general, the axial load strength in both specimen types decreases as the applied load eccentricity increases. Meanwhile the bending strength increases with increasing eccentricity. However, it is observed that LSFET shows slightly higher axial and bending strengths capacity in every applied load eccentricity. The axial load and bending strength capacity in LSFET are higher compared to LSFT25 in an average about 4.1%, 1.4% and 1.8% for 20mm, 40mm and 60mm eccentricity respectively. The strength capacity of LSFET is higher compared to LSFT25 because the stiffness I_{xx} in LSFET is slightly higher as compared to I_{xx} in LSFT25. It is also noticed that the strength capacity difference is smaller with a higher eccentricity. This behaviour is observed in all specimens. These behaviours are evidence that the tab stiffeners effects on the strengths capacities decreases with increasing eccentricity.

4.0 CONCLUSION

The behaviour of CFST is evaluated from the experimental result of the slender column with the new stiffening system when subjected to eccentric load. From the test results of 26 slender CFST specimens which include nine (5) un-filled slender tubes and twenty-one (21) slender CFST columns, several observations and conclusion as follows can be drawn;

1. Un-filled slender tubes loaded without eccentricity failed by local buckling. It is also noted that buckling mode is improved as the height of the stiffeners is increased which is observed both in specimens with 25mm stiffeners height (LSUL25) and in specimens with extended stiffeners height to 40mm (LSUEL).

2. Specimens loaded with eccentricity are observed to fail mainly by overall buckling with slight local buckling along the compression sides. The magnitude of the mid-height displacement increases with increasing eccentricity.

3. For the concrete filled built-up steel tubes, the highest ultimate axial load and bending moment capacity is observed in LSFL25, which is higher than LSFL10 and LSFT25 on average about 11.17% and 4.1% for axial load and 12.5% and 4.6% for bending moment respectively.

4. In general, the axial load strength in both specimen types decreases as the applied load eccentricity increases. These behaviours are evidence that the tab stiffeners affect on

the strengths capacities decreases with increasing eccentricity.

In overall, providing stiffeners with sufficient stiffness onto the un-filled built-up steel tubes slender column is beneficial to increase the ductility and strength capacity of CFST.

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References

[1] Baig, M. N., Fan, J. and Nie, J. 2006. Strength of Concrete Filled Steel Tubular Columns. *Tsinghua Science & Technology*. 11(6): 657-666.
[2] Gardner, N. J., Godse, R. G. and Wong, T.-F. 1992. Laterally Prestressed Eccentrically Loaded Slender Columns. *ACI Structural Journal*. 89(S51): 547-555.
[3] Rangan and Joyce. 1992. Strength of eccentrically Loaded Slender Steel Tubular Columns Filled with High-Strength Concrete. *ACI Structural Journal*. 89(6): 676-681.
[4] Wang, Y. C. 1999. Tests On Slender Composite Columns. *Journal of Constructional Steel Research*. 49(1): 25-41.
[5] Vrcelj, Z. and Uy, B. 2002. Strength Of Slender Concrete-Filled Steel Box Columns Incorporating Local Buckling. *Journal of Constructional Steel Research*. 58(2): 275-300.
[6] Liu, D. 2004. Behaviour Of High Strength Rectangular Concrete-Filled Steel Hollow Section Columns Under Eccentric Loading. *Thin-Walled Structures*. 42(12): 1631-1644.
[7] Lu, F. W., Li, S. P. and Sun, G. 2007. A Study On The Behaviour Of Eccentrically Compressed Square Concrete-Filled Steel Tube Columns. *Journal of Constructional Steel Research*. 63(7): 941-948.
[8] Mohanad Mursi and Brian Uy. 2004. Strength Of Slender Concrete Filled High Strength Steel Box Columns. *Journal of Constructional Steel Research*. 60: 1825-1848.
[9] Gopal, S. R. and Manoharan, P. D. 2006. Experimental Behaviour Of Eccentrically Loaded Slender Circular Hollow Steel Columns In-Filled With Fibre Reinforced Concrete. *Journal of Constructional Steel Research*. 62(5): 513-520.
[10] Ellobody, E. 2007. Nonlinear Behaviour Of Concrete-Filled Stainless Steel Stiffened Slender Tube Columns. *Thin-Walled Structures*. 45(3): 259-273.
[11] Luciano Galano and Andrea Vignoli. 2008. Strength And Ductility Of HSC And SCC Slender Columns Subjected To Short-Term Eccentric Load. *ACI Structural Journal*. 105(3): 259-270.
[12] Shakir-Khalil, H. and Zeghiche, Z. 1989. Experimental Behaviour of Concrete-Filled Rolled Rectangular Hollow-section Columns. The Structural Engineer 67(19): 345-353.
[13] Hibbeler, R. C. 2004. *Mechanics of Materials*. Singapore, Pearson Prentice Hall.
[14] Gadner, N. J. and Jacobson, R. 1967. Structural Behaviour Of Concrete Filled Steel Tubes. *ACI Structural Journal*. 64(38): 404-414.
[15] C. Petrus, H. A. Hamid, A. Ibrahim, G Parke. 2010. Experimental Behaviour Of Concrete Filled Thin Walled Steel Tubes With Tab Stiffeners. *Journal of Constructional Steel Research*. 66(7): 915-922.
[16] C. Petrus, H. A. Hamid, A. Ibrahim, J. D. Nyuin. 2011. Bond Strength In Concrete Filled Built-Up Steel Tubes Columns With Tab Stiffeners. *Canadian Journal of Civil Engineering*. 38(6): 627-637.
[17] Liu, D. 2006. Behaviour Of Eccentrically Loaded High-Strength Rectangular Concrete-Filled Steel Tubular Columns. *Journal of Constructional Steel Research*. 62(8): 839-846.
[18] K. Chithira and K. Baskar, 2012. Experimental and Numerical Investigation on Circular CFT Columns under Eccentric Load Condition with and without Shear Connectors. *International Journal of Earth Sciences and Engineering*. 05(01): 169-179.
[19] Patel, V., Liang, Q., and Hadi, M. 2014. Behavior Of Biaxially-Loaded Rectangular Concrete-Filled Steel Tubular Slender Beam-Columns With Preload Effects. *Thin-Walled Structure*. 10.1016/j.tws.2014.02.013. 166-177.