INELASTIC ANALYSIS OF COLD-FORMED EHST COLUMNS UNDER ECCENTRIC LOADING

Ma Bavan[1]
Shahrizan Baharom[2]

UDK: 624.166:519.6
DOI: 10.14415/konferencijaGFS2014.022

Summary: *This paper discusses the deviancy of the ultimate axial load in the consideration of eccentric loading in terms of differing flexural rigidities by two primary axes of the Elliptical Hollow Steel Tubular (EHST) columns. A non-linear finite element (FE) model of EHST column with three dimensional solid elements and with discrete rigid ended plates was developed, and centrically loaded. The axial load and shortening responses were predicted and compared with experimental analysis. A good agreement was examined between the responses of FE model and experimental analysis found in the literature. The validated FE model was then extended with parametric studies on eccentric loadings by both axes. The failure criteria due to the stresses developed by external load is described with stress resultants in each case by considering the axial force induced by centric loading, and axial force and bending moment induced by eccentric loading in both axes. The failure criteria of the columns were determined in terms of local buckling, flexural buckling and material yielding. In addition, interaction diagram between moments induced by both axes with ultimate axial load is discussed and strengthening methods are also suggested.*

Keywords: *Elliptical hollow Steel tubular columns, Finite element analysis, Combined moment and axial load, Failure criteria, Interaction diagram*

1. INTRODUCTION

The steel tubular columns have been extensively used in bridges, offshore structures and high rise buildings due to its behaviour of high strength and high ductility. The local buckling of the columns was postponed by concrete infilling and in addition, high strength was achieved by applying carbon fibre reinforced polymer strips with postponing local and flexural buckling failures. Even there are several researches available in the determination of ultimate strength behaviour of steel tubular specifically in the sections of square, rectangular and circular, the Elliptical Hollow Steel Tubular (EHST) section is a new structural form using in the current trend, which includes

[1] Ma Bavan, Department of Civil and Structural Engineering, National University of Malaysia, Bangi, Selangoor, Malaysia tel: ++60133130643, e – mail: mmbavan@yahoo.com
[2] DR. Shahrizan Baharom, Senior Lecturer, Department of Civil and Structural Engineering, National University of Malaysia, Bangi, Selangoor, Malaysia

complicated flexural rigidities by inconsistent of major and minor axes properties as beneficiary structural forms in some cases.
At the start, the ultimate strength of concrete filled steel tubular beam-column was experimentally studied by Kloppel and Goder (1). The effects of eccentric and axial loads of concrete filled steel tubular beam-column have been experimentally studied continuously by Furlong (2) and particularly, the circular and square sections were used in his analysis. It was then constantly studied the local and global behaviours of the columns deeply in the sections of square, rectangular and circular hollow and concrete-filled steel tubular sections. In the consideration of elliptical sections, the failure criteria and ultimate strength behaviour are varied with such sections due to its stability and flexural rigidities by differing major and minor axes properties. Even there are limited researches in the section of elliptical hollow section and thus, the analysis is necessary in terms of critical failure criteria. Zhu and Young (3) have studied the design of cold-formed steel oval hollow section columns and they have extended the sections by non-linear finite element analysis to evaluate the reliability of the design rules. Moreover, the cold-formed-steel oval hollow sections under axial compression have experimentally investigated by Zhu and Young (4) and they have presented that the European and American Iron Steel Institute (AISI) are more conservative in their reliability analysis of the design rules. It was identified in this paper from the finite element analysis that the EHST columns under eccentric compression loadings were limited its ultimate strength in terms of local buckling and a detailed discussion is presented to postpone the failure criteria in terms of obtaining possible ultimate limit strength.

2. EXPERIMENTAL REVIEWS

A series of tests were done in the studies of ultimate strength of cold-formed-steel elliptical hollow sections subjected to axial compression by Zhu and Young (3, 4). The section named as A360, consisted a length of 361.2 mm and a cross section area of 556.9 square millimetres was taken for this study. A set of 25 mm end plates were welded at both ends and the fixed ended criteria was made at both ends by bolts with bearings from restraining as of twisting, rotating and wrapping by both axes. Figure 1(a) shows the dimensions of the section of hollow section. The load was applied at the upper end of the column by hydraulic actuated as displacement control with a speed of 0.1 mm/min. The load application and support of experimental analysis done by Zhu and Young (3, 4) by using servo controlled hydraulic testing machine are shown in the Figure 1(b). The readings in the applied load and shortening of the column were recorded throughout the analysis.

3. FINITE ELEMENT MODEL GENERATION AND VALIDATION

Three dimensional finite element model was developed with non-linear material components for a steel tube oval shape column. The connections between end plate and steel tube column, and deformation of end plates have not been important in this study and thus, with considering the welding connection, two rigid end plates were fixed by tie constraint at both ends. In the concerns of post buckling effects with considering the shortening of the columns at constant deformation speed in the experimental analysis, which has been done by Zhu and Young, ABAQUS explicit solver was used to predict the reliable behaviour. The validation was done with both ABAQUS implicit solver with various types of elements, and the deformation of the structure was compared. A reference point was preferred in the rigid plate at one end of the column, and fixed support conditions were applied as shown in Figure 2. The reference point at the rigid plate of the next end was variable in the analysis according to the prediction of the required effects due to loadings. The concentrated load was applied at the reference point, and the point was allowed to move in the vertical direction, the next two directions were restricted. The quasi static solution also has been determined with the comparison of kinetic and internal energies, and kinetic energy was maintained within five percentage of internal energy throughout the analysis. The applied load and corresponding support reaction forces were compared throughout the analysis with the purpose of those impartiality to confirm the static solution in the explicit solver.

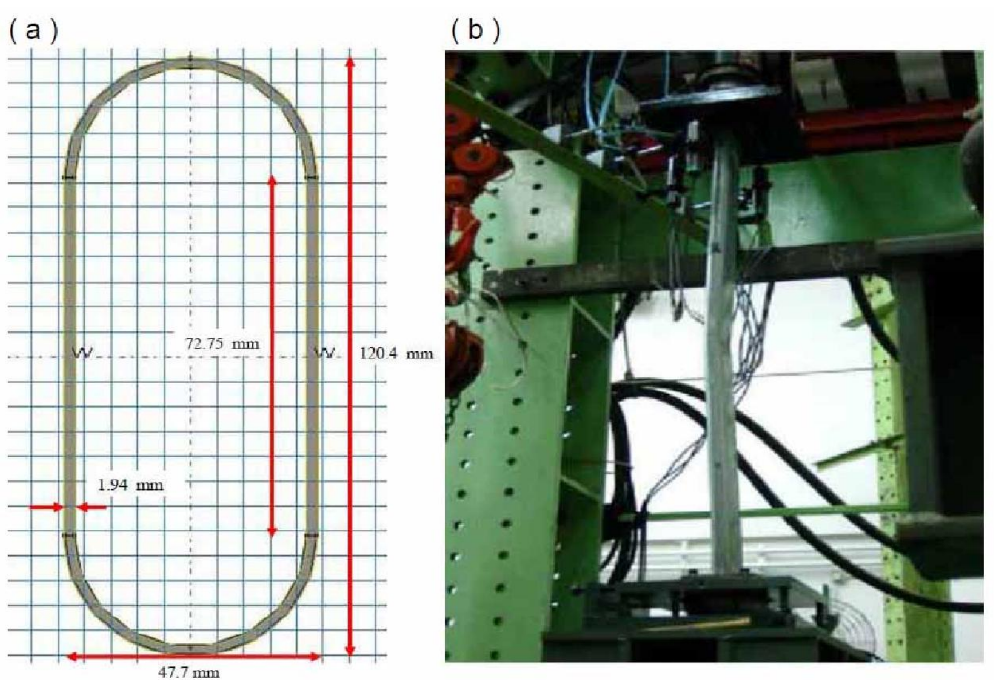

Figure 1 (a) Dimensions of the cross section of the EHST column (b) Fixed ended column test (Source: Zhu, J. and Young, B.)

Three dimensional solid element C3D20 available in ABAQUS was used to steel tube column and it could be observed in the analysis with various types of element that such element, which contains 20 nodes with three degrees of freedom in each node is suitable to the steel tube column in local buckling effects. In addition, R3D4 element was applied to the rigid plates at both ends. The non-linear material behaviour of structural steel was developed by the proposed equation by Gattesco (5) with adopting the material test values of yield and ultimate stress states done by Zhu and Young (3, 4). The stress strain responses of the coupon test on the steel material from flat and curved portion are shown in the Figures 3(a) and 3(b), respectively. The beginning stage of the linear material behaviour, which is elastic state, was considered with the measured values of young modules in both curved and flat portions promptly from the test done by Zhu and Young (3, 4), and the Poision's ratio was considered as 0.3. The measures test values, which are young modules, static proof stress, ultimate tensile strength and elongation after fracture have been taken from coupon tests with both different geometric sections of curved and flat column portions.

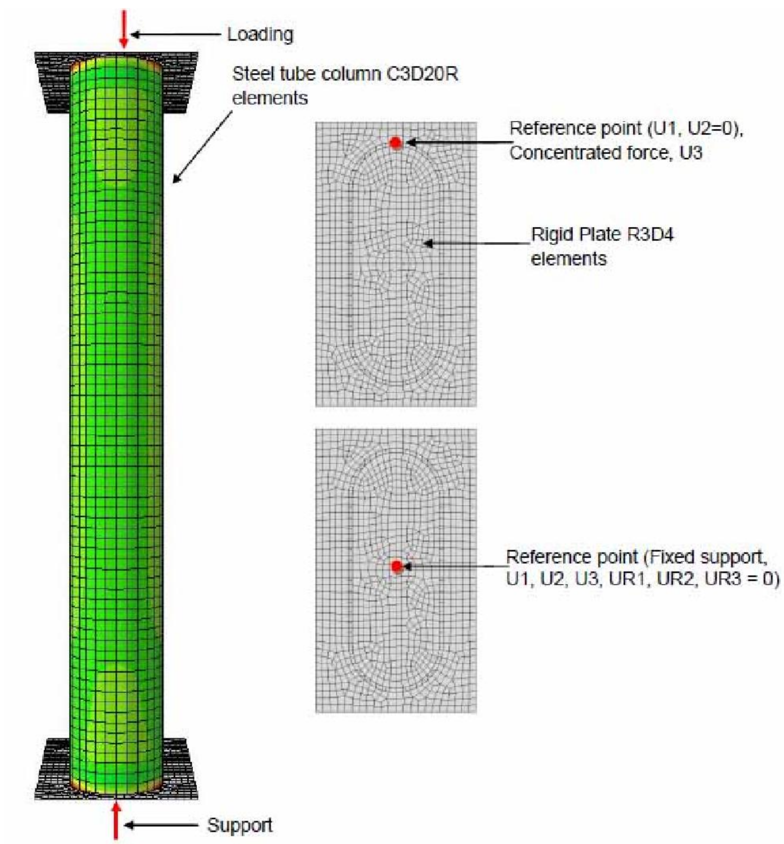

Figure 2. Elements and boundary conditions used in the FE model of the column

In the experimental analysis, the applied load at ultimate state was predicted with a value of 185.9 kN and the finite element model was shown the ultimate limit state of the applied load as 199 kN, which was a coefficient of deviation of 7%. Meanwhile, it could be observed very close applied load at ultimate limit state when the similar steel plates were used instead of rigid plates. The major concerns of the analysis were in terms of flexural and local buckling effects of EHST columns and thus, it was analysed with rigid plated end supports in an acceptable deviation of the ultimate limit state as 7% with comparing experimental analysis. The material fracture behaviour of the column was observed throughout the analysis and the first yielding point predicted in the FE model is shown in the Figure 4. In terms of the behaviour of the columns and predicted ultimate limit state in the FE model, the FE model was reliable to do the further parametric studies.

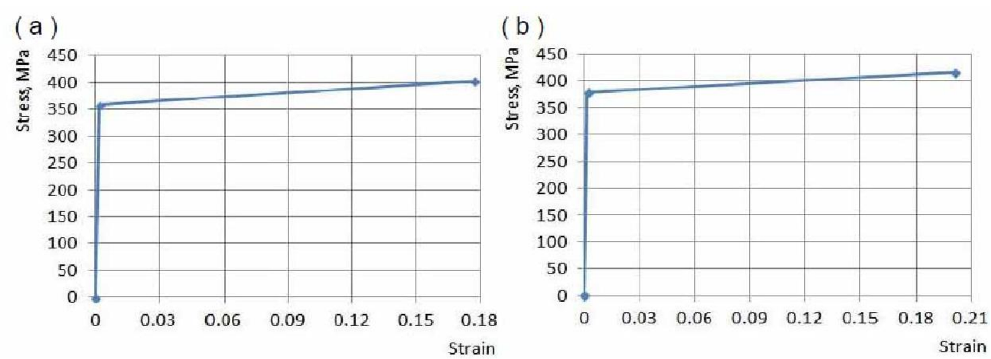

Figure 3. Stress strain curves of steel from experiment (a) at flat portion (b) at curved portion. Source: Source: Zhu, J. and Young, B.

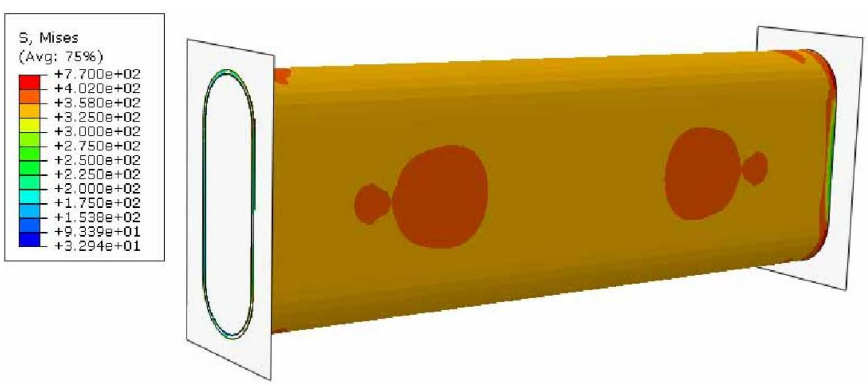

Figure 4. Initial yielding point of column

4. RESULTS AND DISCUSSIONS

The validated finite element model was then included in the analyses of parametric studies such that the loading points were shifted in the directions of both x and y axes. The concentrated load was applied in the similar way of an experiment at the selected points, and the applied load and shortening responses were predicted throughout the analysis of each model. The Figures 5(a) and 5(b) show the cross section of the EHST section and the obtained interaction diagram of ultimate applied load with induced moments due to the eccentric loadings. Table 1 shows the detailed loading points, applied loads and induced moments at ultimate limit state. Mostly, local buckling was the effect in limiting the ultimate strength of the EHST columns, and the early initial buckling was occurred according to the characteristic point of eccentric loadings. The results commonly showed that the ultimate strength reduces with increasing the eccentricity of loadings. The yielding point at various levels of axial load was observed in the models with eccentric loadings. Meanwhile, the failure modes were predicted in terms of buckling effects. The yielding regions of the model which was applied the load at maximum distance from the X axis, applied the load at maximum distance from the Y axis, and applied the load at maximum distance from the X and Y axis are shown in the Figures 6(a), 6(b) and 6(c), respectively. It was reached the ultimate stress as early when the load was applied with induced moments in both axes. A maximum of 76 % deviation was predicted and an amount of deviation was mostly observed in all FE models. It could be concluded that the ultimate limit state of axial load limits when the EHST columns subjected to combined applied load with induced moments from the involved verification studies of EHST columns.

Table 1 Detailed loading point, applied load and induced moments at ultimate limit state

Models	Load applied from (0,0)		Applied Load	Moment, M_x	Moment, M_y	Load deviation	Moment, M_x	Moment, M_y
	X (mm)	Y (mm)	kN	kNm	kNm	With respect to validated model	With respect to induced highest moment	
Validated Model	0.0000	0.0000	180.10	0.0000	0.0000	0%	0.00	0.00
1	6.0000	0.0000	124.32	0.00	0.75	31%	0.00	0.40
2	0.0000	15.0000	141.37	2.12	0.00	22%	0.43	0.00
3	6.0000	15.0000	66.30	0.99	0.40	63%	0.20	0.21
4	6.0000	7.5000	71.83	0.54	0.43	60%	0.11	0.23
5	11.4400	0.0000	105.20	0.00	1.20	42%	0.00	0.65
6	0.0000	29.6150	102.40	3.03	0.00	43%	0.61	0.00
7	11.4400	29.6150	49.90	1.48	0.57	72%	0.30	0.31
8	11.4400	14.8075	60.44	0.89	0.69	66%	0.18	0.37
9	18.9800	0.0000	81.83	0.00	1.55	55%	0.00	0.83
10	0.0000	44.4225	88.40	3.93	0.00	51%	0.79	0.00
11	18.9800	44.4225	42.62	1.89	0.81	76%	0.38	0.43
12	18.9800	22.2113	53.29	1.18	1.01	70%	0.24	0.54
13	22.8800	0.0000	81.34	0.00	1.86	55%	0.00	1.00
14	0.0000	59.2300	83.46	4.94	0.00	54%	1.00	0.00
15	22.8800	59.2300	43.81	2.60	1.00	76%	0.52	0.54
16	22.8800	29.6200	75.74	2.24	1.73	58%	0.45	0.93

5. CONCLUSIONS AND SUGGESTION FOR FUTURE RESEARCH

The behaviour of the EHST column section was studied with non-linear finite element analysis in the subjection of eccentric loadings.

It was found that the ultimate limit axial strength reduces when the axial load was applied in a combination of bending moments and axial compressive load. When load reference point was in a high distance from centric point, the axial strength was highly reduced. It was hugely dropped by 76% of deviation when the applied load was applied in maximum distances along both axes. The failure criteria of the column were observed as local buckling in all cases, and the yielding point and reaching an ultimate limit state were shifted as early due to the induced moment by eccentric applied axial loads. It has to be implemented the analysis in terms of postponing the failure criteria with an increase of ultimate limit state axial loads. It was not considered the behaviour of the EHST columns in this study with column geometric and material properties such as steel yield strength, slenderness ratio and depth-to thickness ratio, which will be more influenced in the ultimate limit state behaviour. Thus, this study can be extended to analyse a proper strengthening method with various properties of the column.

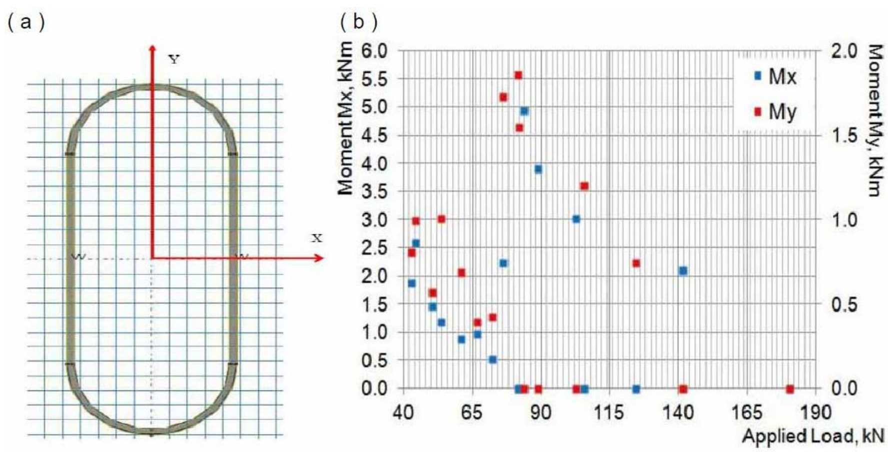

Figure 5. (a) Cross section of the EHST section (b) Interaction diagram of ultimate applied load with induced moments due to the eccentric loadings

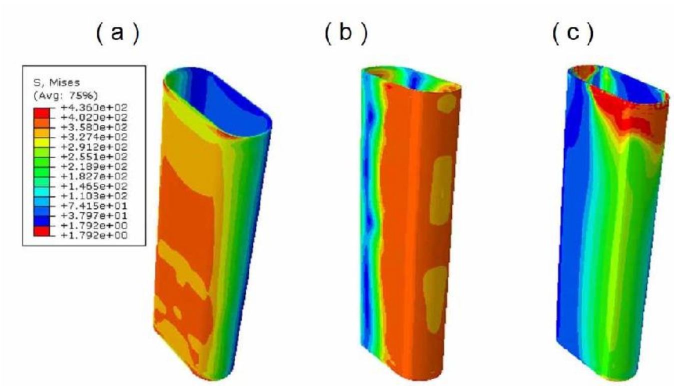

Figure 6. The yielding regions where applied the load was at maximum distance from the axis (a) From the X axis (b) From the Y axis (c) From the X and Y axis

REFERENCES

[1] Kloppel, V.K., Goder, W. (1957). Strength of concrete filled steel tubular columns. Journal of Structural Division, ASCE, 95(12), 2565-2587.

[2] Furlong, R.W. (1967). Strength of steel encased concrete beam columns. Journal of Structural Division, ASCE, 93(5), 113-124.

[3] Zhu, Ji-Hua., Young, B. (2012). Design of cold-formed steel oval hollow section columns. J Constr Steel Res 71, 26-37.

[4] Zhu, Ji-Hua., Young, B. (2011). Cold-formed steel oval hollow sections under axial compression. J Journal of Structural Engineering, ASCE, 137(7), 719-727.

[5] Gattesco, N. (1999). Analytical modelling of nonlinear behavior of composite beams with deformable connection. J Constr Steel Res 52. pp 195-218.

[6] British Standard Institution. 2005. Eurocode 4: Design of composite steel and composite structures. DDENV 1994-1-1. European Committee for standardisation.

[7] ABAQUS user's manual: version 6.11, Dassault Systèmes Simulia Corp., Providence, RI, USA.

НЕЛИНЕАРНА АНАЛИЗА ХЛАДНО ОБЛИКОВАНИХ "EHST" СТУБОВА ПОД УТИЦАЈЕМ ЕКСЦЕНТРИЧНОГ ОПТЕРЕЋЕЊА

Резиме: *Овај рад приказује анализу одступања граничне носивости на центрични притисак у односу на ексцентрични притисак у смислу различите крутости на савијање око две главне осе челилних стубова са елиптичним шупљим попречним пресеком (EHST стубови). Нелинеарни модел EHST стубова сачињен од 3Д запреминских коначних елемената (МКЕ) и крутих плоча на крајевима је анализиран под утицајем центричног оптерећења. Срачунато центрично оптерећење и деформација скраћења су поређени са експериментално добијеним подацима. Утврђено је добро слагање резултата добијених помоћу МКЕ и експерименталних резултата из литературе. Потврђени МКЕ модел је након тога проширен и спроведена је параметарска анализа ексцентричног оптерећења за обе главне осе савијања. Критеријум лома услед напона који су настали као последица спољашњег оптерећења је дефинисан помоћу резултанти напона које су код сваког случаја оптерећења узимали у обзир чист центрични притисак и центрични притисак заједно са моментом савијања насталих као последица ексцентричног оптерећења у односу на обе осе. Критеријум лома је описан на основу појаве локалног и глобалног избочавања и гњечења материјала. Такође, дијаграм интеракције између момената око обе осе и центричног притиска је анализиран и предложене су методе за ојачање оваквих стубова.*

Кључне речи: *Челични стубови са шупљим елиптичним пресеком, метод коначних елемената, комбиновано оптерећење момент-нормална сила, критеријум лома, дијаграм интеракције*