Finite Element Analysis of Elliptical Hollow and Concrete Filled Tube Columns

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Abstract

Concrete filled tube (CFT) columns have been used as primary axial load-carrying members in high-rise building especially in seismic zones. The structural member has become popular as it has a number of distinct advantages over an equivalent steel, reinforced concrete, or steel-reinforce concrete structural member. This paper is intended to presents numerical modeling of elliptical concrete-filled steel tube columns. Elliptical steel tube is relatively a new shape used as composite columns structure and currently the data for the column is insufficient with very limited understanding therefore it deserve further investigation. This project will investigate the behaviour, capacity and failure pattern up to and beyond the ultimate load of this cross-sectional shape of composite column. Finite element program, ABAQUS also has been used as this method allows the analyses of complex structures and structural phenomena. In order to study the nonlinear response, three dimensional finite element model is develop by considering material non-linearity of the structure.

Keywords: composite CFT columns, finite element modeling.

1. INTRODUCTION

Technology of composite structure has been started when concrete encasement was used initially to protect steel section against fire. At the beginning, the composite action that lies in the structure, which can increase the structure performance, was not taken into consideration. However, it has been recognized in the middle of 20th century due to the increased in stiffness and strength in the structure thus, the composite action utilization was identified since then [1]. Composite structures are available in various forms. The steel sections can be placed externally to the concrete element instead of encased in the concrete material. Concrete filled steel tube column is simply constructed by filling a hollow section with concrete. Its elements orientation significantly leads to an optimization in strength and stiffness of the structure. This is due to the steel section at the outer perimeter performs effectively in tension and bending moment, meanwhile the stiffness is enhanced by the greater modulus of elasticity and its location that situated farthest from the centroid. In addition, concrete core that acts as an inner structure [2] is ideal in withstanding the compression loading and often found delaying or preventing local buckling of the steel section particularly in rectangular CFTs [3].

Researches on concrete-filled steel tubes as a composite member have been on-going for many decades [4, 5]. The earliest of complete test on concrete-filled steel tubes hereafter referred to as CFT as reported by [6] was done in 1957 by Kloppel and Goder. Since then many effort has been put on to develop a better understanding for this type of structural and most of the development has been made in studying the CFT columns with variety cross-section such as; circular, square and rectangular section. Currently, there are only a few numbers of investigations that had been undertaken involving elliptical shape in the application of column structure. Moreover most of the research involving elliptical tube as hollow columns structure and only one research of elliptical composite column had been found. However, all of them are just considered as stub elliptical columns. Thus more investigations and experimental data are needed for elliptical CFT columns particularly for slender columns.

Confinement that arises in this type of structure is significant to the structure ductility as well as providing a significant advantage in ultimate strength of the column. Concrete confinement is provided by the steel tube depends on many factors such as the dimension of the steel tube, concrete strength, steel thicknesses, yield stress of steel tube and shape of the column cross section [7, 8]. At the steel-concrete interface, a radial pressure is developed and setting up a hoop tension in the tube and at this stage, the steel shell provides confining pressure to the concrete expansion of concrete core in CFT columns, which puts the concrete under tri-axial stress the concrete core is stressed tri-axially. Thus, it is expected that the steel tube in CFT enhances the concrete core in axial compressive strength by its lateral confinement. Section shape effect on confinement was investigated by Tomii [9] and results demonstrated that concrete confinement does have an effect in circular and octagonal CFT columns but not in square columns. Confinement was found higher in circular section. It is expected because of the uniform lateral pressure arise in this particular shape however, in square column only at the centre and the corner of the section have higher confining pressure compare to its sides [10]. The condition for rectangular section is similar to square CFT column where the tension hoop developed along the side of rectangular tube is not constant seem to be the reason why confinement effect was not present except in the corner of the steel tube. Thus, it is expected that elliptical columns does has confinement contribution to its strength as elliptical shape can be considered as in between of rectangular and circular. It should be noted that the confining effect enhances considerably the strength of a short column but less significant to slender columns [11].

2. FINITE ELEMENT ANALYSIS

The general purpose nonlinear finite element package program ABAQUS Version 6.7 is employed to perform the numerical simulation of the elliptical CFT columns subjected to axial compressive forces. In order to analyze the non-linear response of elliptical CFT columns a reliable finite element model subjected to axial load is carefully modelled by taking into account the nonlinear material models of concrete core and steel tube. Analysis was performed using STATIC, RIKS procedure. The incremental plasticity model was provided within a range of the true stress-strain curve from the point corresponding to the last value of the linear range of the static engineering stress-strain curve, the ultimate point and also the fracture stress for steel and softening branch for concrete.

To date, no study had been done for stress-strain concrete core relationship nor mathematic expressions were developed for material properties of confined concrete in elliptical steel tube. Therefore in this analysis, concrete modelling was performed by considering condition of confined uni-axial stress-strain curve of concrete. To consider this, an equivalent uni-axial stress-strain curve for confined concrete has to be obtained followed by approach as taken in [7], the relationship between unconfined concrete and confined concrete was determined.

In the model of this study, an elastic perfectly plastic model based on Drucker-Prager yield criterion has been used. In the analysis, the constant K and β are set to 0.8 and 20o respectively. This material model has been considered associated to an elastic-perfectly plastic behaviour as it had been used by many CFT columns' researcher. The Poisson's ratio of concrete under uniaxial compressive stress was taken as 0.2. Elliptical steel tube is formed using shell element and the material properties were from the stress-strain curve of the coupon tests. The types of element of SR4 and C3D8R were chosen to represent steel tube and concrete core respectively. Steel caps that were placed on top and bottom of the CFT were represented as rigid element body in the analysis.

2.1 Boundary conditions, loading and contact

Fixed ends were achieved by restraining displacement and rotation against all degrees of freedom except in direction of the applied load. To simulate the contact between the inner surface of steel tube and concrete core, contact elements were used in the analysis. In this analysis, frictional force which resists the relative sliding of the surfaces is taken into account and a common friction model, Coulomb friction, was used. Penalty function was employed and coefficient of friction, μ between these faces was taken as 0.25. The friction is maintained as long as the surfaces remain in contact. Through the interface elements, the contact surfaces between the concrete and steel tube are allowed to separate although not penetration between each other was allowed.

3. VALIDATION WITH THE EXPERIMENTAL STUDY

The FE model was established according to experimental specimen in [12]. However for oval hollow column the experimental and results were conducted and supplied by Imperial College. The stress-strain relationship for steel tube used in this model was taken from coupon test and shown in Fig. 1.

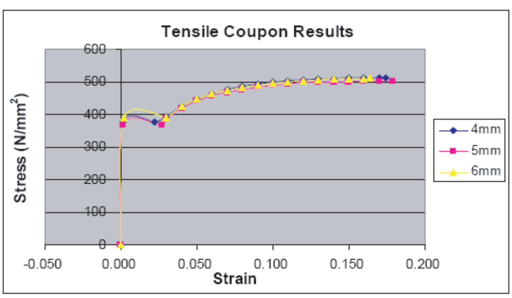


Fig.1 Stress-strain curve from coupon test

Imperfection was not considered in the analysis as the measurement for imperfection was not taken during the experiment. In addition to it as the element is quite stocky and it buckles after yielding, they are not so sensitive to geometric imperfection which is proved in Report R874 [13] where the buckling load for various imperfection sizes were found to be very similar. From finite element simulation, the load-deformation curves of axially loaded elliptical CFT columns were obtained and shown in Fig. 2(a) and Fig. 2(b), (c) and (d) show the experiment results for columns with thickness 4, 5 and 6.3 mm respectively. It is clearly observed that a good agreement was achieved in FE analysis for both the elastic and plastic regions. Even though from Table 1 the finite element model was closely predicted the ultimate load however, generally FE results gave a slightly overestimate the load capacity compared to the experiments. Column with 4 mm thickness was found to have the ultimate strength at 569.3 kN. Meanwhile, 546 kN ultimate strength was observed from the experiment. The ultimate strength of oval hollow column with 5 mm and 6.3 mm thicknesses from finite element analysis are 718.1 kN and 1110.7 kN respectively where as from experiment the ultimate strengths for these two different thicknesses are 694 kN and 927 kN. The possible reason for this may be due to the consideration of specimen as a perfect model where zero imperfection was assumed. Besides that, inaccurate material modelling consideration such as the use of tensile tests results to represent compressive stress-strain properties. Furthermore the yield stress spikes in the curves were not considered in the modelling. Nevertheless the FEA results apparently show the ultimate capacities of elliptical CFT column were considerably affected by the wall thickness of the steel tube as shown in Table 1.

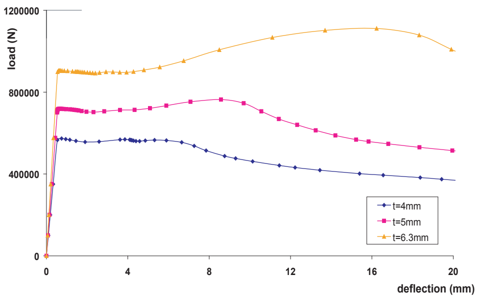


Fig. 2(a) Graph obtained from FE in this study

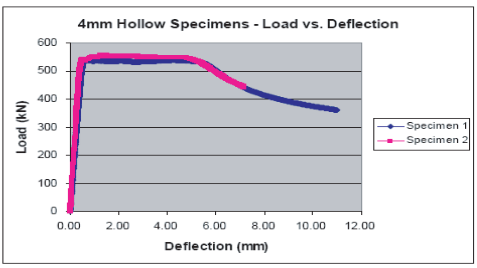


Fig. 2(b): Experimental results for 4 mm specimen thickness [12]

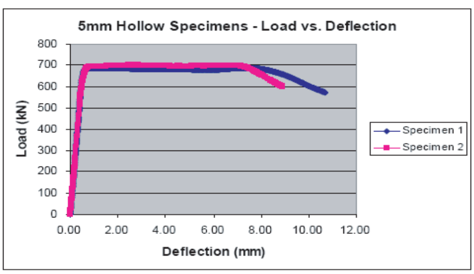


Fig. 2(c): FE results for 5 mm specimen thickness [12]

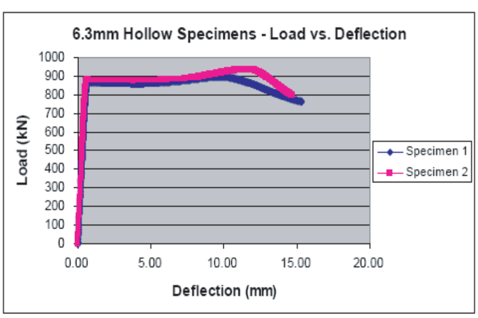


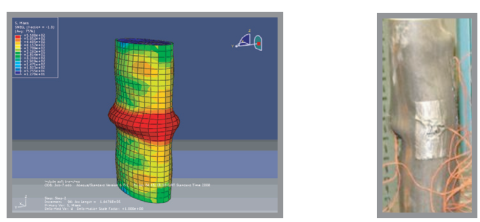
Fig. 2(d): FE results for 6.3 mm specimen thickness [12]

Fig. 2 Load-deflection curve comparison for elliptical hollow columns

Table 1: Results for elliptical hollow columns

Specimens	Exp. Failure load	FEA ultimate load	Different %
4 mm	546	569.3	0.04
5 mm	694	763.5	0.09
6.3 mm	927	1110.75	0.17

For specimen with 4 mm thickness the mode of failure was shown in Fig. 2(a) and Fig. 2(b) from both FE analysis and experimental result. According to Testo [12] the specimen showed a sign of local buckling due to steel yielding during testing with more concentration around the capped end of the specimen. This was suggested due to the weaker of plaster of Paris which was applied to the top of specimen in order to ensure the smooth level of loading. Shown in Fig. 3 is a comparison of deformation from both FEA and experimental. Even though from the Fig., simulation result shows no obvious sign of local buckling concentrated at the end of the specimen but it still shown that the deformation was occurred at three parts; top, middle and bottom specimen with the middle experienced more bulging. It worth to note there was no consideration for plaster of Paris material and only concrete and steel material were involved in this analysis.



(a) FEA (b) Exp.

Fig. 3 Deformation shape from FEA and experimental

The load-deflection for both experiment and FEA is shown in Fig. 4. From the graph, FE result shows the column is stiffer and underestimates the ultimate load in which from experiment 838.6 kN ultimate load was achieved while from FEA the load was 747.21 kN. Results for all elliptical CFT columns are detailed in Table 2. In should be noted that for CFT columns, each specimen has difference concrete strength. Specimen labeled as C1, C2 and C3 has concrete grade of C30, C60 and C100 respectively.

Table 2: Results for elliptical CFT columns

Ref.	P_{test} (kN)	P_{FEA} (kN)	Ptest / P_{FEA}
C1	838.6	764.38	1.1
C2	971.6	900.44	1.08
C3	1264.6	1128.39	1.12
		Mean	**1.1**

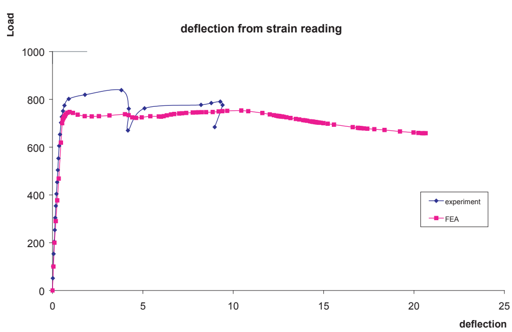


Fig. 4 Load-deflection curve for elliptical CFT column with 4mm thickness.

4. CONCLUSION

From FE results, confined concrete properties were used and prove to be occurred to model the elliptical CFT columns. Furthermore the present of confinement proved to enhances the strength and capacity of the structure compared to hollow column. However, refined techniques for modelling the structure should be considered as the FE analysis under predicted the actual strength of CFT column and overestimate the strengths for hollow columns. More refine models can be useful in the attempt to understand and study the behaviour of elliptical CFT column. To develop a reliable finite element model is always one of the desires in order to study the linear and non-linear response of elliptical CFT under axial load.

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