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Nonlinear analysis of concrete-filled steel composite columns subjected to axial loading

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Abstract. This paper investigates the nonlinear analysis of concrete-filled steel composite columns subjected to axial loading to predict the ultimate load capacity and behaviour of the columns. Finite element software LUSAS is used to conduct the nonlinear analyses. The accuracy of the finite element modelling is verified by comparing the result with the corresponding experimental result reported by other researchers. Nonlinear analyses are done to study and develop different shapes and number of cold-formed steel sheeting stiffeners with various thicknesses of cold-formed steel sheets. Effects of the parameters on the ultimate axial load capacity and ductility of the concrete-filled steel composite columns are examined. Effects of variables such as concrete compressive strength f_c and cold-formed steel sheet yield stress f_{yp} on the ultimate axial load capacity of the columns are also investigated. The results are shown in the form of axial load-normalized axial shortening plots. It is concluded from the study that the ultimate axial load capacity and behaviour of the concrete-filled steel composite columns can be accurately predicted by the proposed finite element modelling. Results in this study demonstrate that the ultimate axial load capacity and ductility of the columns are affected with various thicknesses of steel sheets and different shapes and number of stiffeners. Also, compressive strength f_c of the concrete and yield stress f_{yp} of the cold-formed steel sheet influence the performance of the columns significantly.

Keywords: nonlinear analysis; concrete-filled steel composite column; finite element; ultimate axial load capacity; cold-formed steel sheeting stiffener; ductility

1. Introduction

The use of concrete-filled steel composite columns has been increased rapidly in modern constructions, because they have demonstrated structural advantages such as better ductility, large stiffness, and high strength. The concrete core develops the critical local buckling stress of the steel sheet. On the other hand, the enhancement of the strength and ductility of the concrete is due to the confinement to the concrete provided by the steel sheet. Also, the steel sheet eliminates the need for the longitudinal and transverse reinforcement and it behaves as permanent formwork to the concrete core which results in reducing materials and labours costs.

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The stress state in concrete-filled steel columns was analysed by Brauns (1999). Shanmugam and Lakshmi (2001) presented a review of the research done on steel-concrete composite columns. Researches that included the effects of local buckling, bond strength, seismic loading, confinement of concrete, and secondary stresses on the behaviour of the columns were also considered. A series of compression and bending tests on concrete filled double skin tubes were done by Zhao and Grzebieta (2002) in order to investigate strength and ductility. A theoretical study of the local and post-local buckling of filled circular steel tubes was presented by Bradford *et al.* (2002). Tests on 35 concrete-filled steel rectangular hollow section columns were conducted by Han and Yao (2003) to study the effect of concrete compaction on strength of the columns. Liu (2004) investigated an experimental study on the behaviour of 12 high strength rectangular concrete-filled steel hollow section columns under eccentric loading. An experimental investigation of concrete-filled cold-formed high strength stainless steel tube columns was done by Young and Ellobody (2006). Experimental behaviour of concrete-filled stiffened thin-walled steel tubular columns was reported by Tao *et al.* (2007). Gupta *et al.* (2007) carried out an experimental and computational study of concrete filled steel tubular columns under axial loads in order to assess effects of diameter and D/t ratio of steel tube on the load carrying capacity of the columns and effects of concrete grade and volume of flyash in concrete. Tests on 28 thin-walled hollow structural steel columns filled with very high strength self-consolidating concrete were performed by Yu *et al.* (2008). Concrete filled steel tubular columns under static and variable repeated loadings were tested by Thayalan *et al.* (2009). Nine tests on concrete filled steel tube reinforced concrete columns under constant axial load and cyclically increasing flexural bending were reported by Han *et al.* (2009). Oliveira *et al.* (2009) tested 16 concrete-filled steel tubular columns with circular sections under axial loading to study the influence of concrete compressive strength and length/diameter ratio on the load capacity of the columns. Tests on 16 concrete-filled steel tubular columns were done by Tokgoz and Dundar (2010) to investigate an experimental study on steel tubular columns in-filled with plain and steel fibre reinforced concrete. Chitawadagi *et al.* (2010) carried out experimental studies on rectangular concrete filled steel tube columns to examine effects of change in wall thickness of steel tube, strength of in-filled concrete, cross-sectional area of the steel tube, and length of the tube on the ultimate axial load and corresponding axial shortening of the columns. Starossek *et al.* (2010) studied the force transfer by natural bond or by mechanical shear connecters and the interaction between the steel tube and concrete core of concrete-filled steel tube columns. Xu *et al.* (2010) modified the stress-strain relationship for confined concrete which introduced the influence of eccentricity on confining stress.

This paper is concerned with the nonlinear analysis of concrete-filled steel composite columns under axial loading to obtain the ultimate load capacity. In the present study, verification of the proposed finite element modelling is carried out by comparing the obtained result with the corresponding experimental study on the columns done earlier by Tao *et al.* (2007). Also, nonlinear finite element analyses are used to study different shapes and number of cold-formed steel sheeting stiffeners with various thicknesses of cold-formed steel sheets, and their effects on the ultimate axial load capacity and ductility of the columns. Furthermore, effects of the concrete compressive strength f_c and the cold-formed steel sheet yield stress f_{yp} on the ultimate axial load capacity of the columns are examined.

2. Nonlinear finite element analysis

The finite element software LUSAS Version 14 was used to carry out the nonlinear analyses in the study. Modelling, convergence study of proposed finite element modelling, and verification of the method are presented in the following sections.

2.1 Modelling

Fig. 1 shows cross-section of the concrete-filled steel composite column, UCFT2-1 (without stiffener, mild steel) which refers to unstiffened concrete filled tube 2.34 m long, tested in the past by Tao *et al.* (2007). Selection of an appropriate mesh is an important step in the finite element analysis. 6-noded thin shell element TSL6 triangle in shape and 10-noded solid element TH10 were chosen for steel sheeting and concrete, respectively. In order to obtain the ultimate axial load capacity of the column due to buckling, small transverse forces were used to create an initial geometric imperfection for the nonlinear analysis. A typical finite element mesh used for the concrete-filled steel composite column is shown in Fig. 2. Modelling of support conditions was appropriately done by restraining the nodes corresponding to the support points. Incremental displacement load with an initial increment of 1 mm was applied in the negative Y direction which acts axially to the column and simulates the load applied to the column in the experiment.

The elastic modulus, yield stress, and Poisson's ratio of steel and also the elastic modulus, compressive strength, and Poisson's ratio of concrete were considered in LUSAS. Fig. 3 shows the assumed uniaxial stress-strain curves for steel and concrete. Material properties for the concrete-filled steel composite column (UCFT2-1, without stiffener, mild steel) are presented in Table 1. The yield stress, f_{yp}, of cold-formed steel sheeting used in this study is 550 MPa.

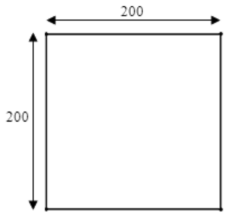


Fig. 1 Cross section of the concrete-filled steel composite column (UCFT2-1, without stiffener, mild steel sheet of 2.5 mm, used by Tao *et al.* 2007) (All dimensions are in mm)

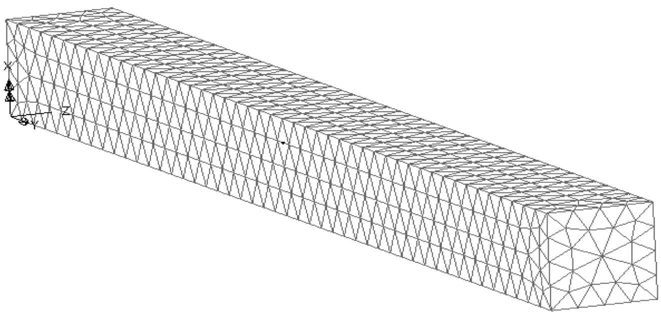


Fig. 2 Typical finite element mesh of the column used in the current study

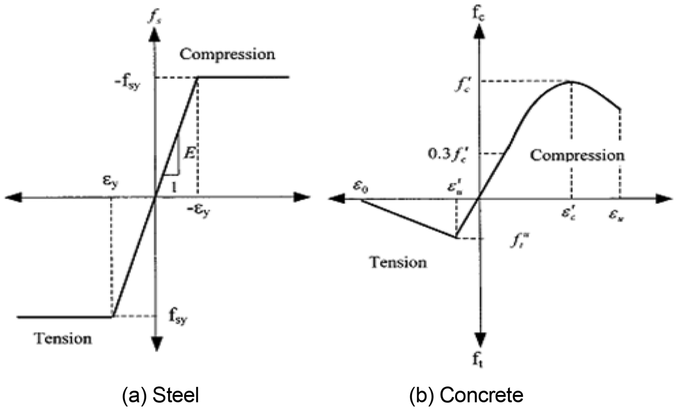


Fig. 3 Typical stress-strain curves for steel and concrete

Table 1 Material properties for the concrete-filled steel composite column (UCFT2-1, without stiffener, mild steel) (Tao *et al.* 2007)

Material	Poisson's ratio υ	Elastic modulus (MPa), E_s	Yield stress (MPa), f_y	Compressive strength (MPa), f_c
Mild Steel	0.303	203000	270	-
Concrete	0.2	30600	-	58.3

2.2 Finite element discretization

In order to determine a suitable finite element model for the nonlinear analysis, convergence studies were carried out on the concrete-filled steel composite columns. In the current study, the results corresponding to seven different meshes are shown in Fig. 4. It can be understood from the figure that there is not much difference between the models with 7962 and 13455 elements. Consequently, nonlinear finite element analysis based on 7962 elements is found sufficient to predict the ultimate axial load capacity and behaviour of the columns examined in the present study.

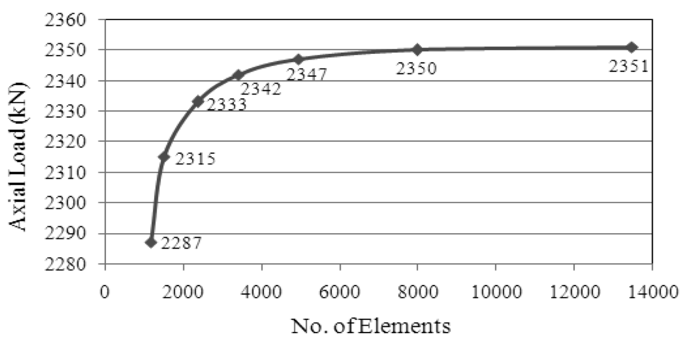


Fig. 4 Results from the convergence study

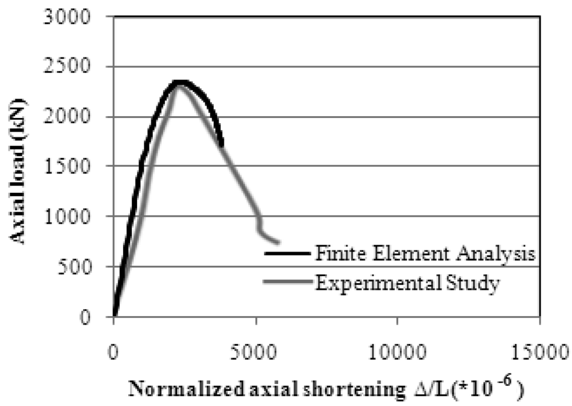


Fig. 5 Axial load-normalized axial shortening curves of the concrete-filled steel composite column (without stiffener, mild steel)

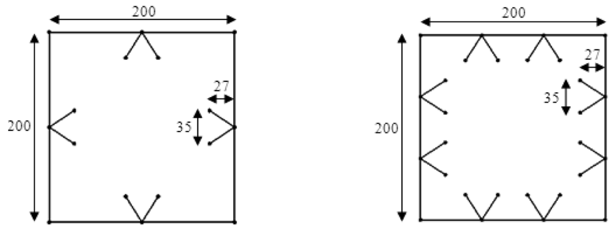
2.3 Verification of the finite element model

Accuracy of the finite element modelling of the concrete-filled steel composite columns was done in this study by comparing the result of the modelling with the corresponding experimental result, (UCFT2-1, without stiffener, mild steel), reported by Tao *et al.* (2007). Fig. 5 shows that the result obtained from the finite element analysis is very close to the one from the experiment. In accordance with the figure, the ultimate axial load capacity from the finite element analysis of the concrete-filled steel composite column (UCFT2-1, without stiffener, mild steel) is 2350 kN compared to 2305 kN from the experimental study which has 2% overestimation by the finite element analysis. This approximation is absolutely acceptable and it is concluded from the verification study that the proposed finite element modelling is perfectly capable of predicting the nonlinear behaviour of the columns in this study.

3. Numerical analysis

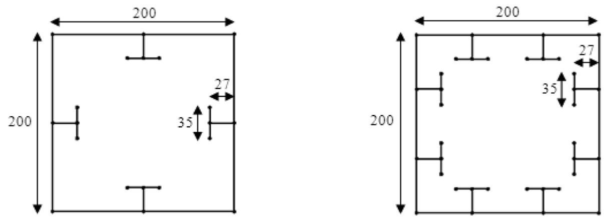
In view of the accuracy of the finite element model proposed, the method was used for the analysis of concrete-filled steel composite columns of same size and cross-section as the column (UCFT2-1, without stiffener, mild steel) tested by Tao *et al.* (2007) but with different thicknesses of cold-formed steel sheets and various shapes of the stiffeners namely V, T, L, Line, and Triangular stiffeners. Also, different number of the stiffeners was analysed. Moreover, effects of thickness of steel sheet, and shape and number of the stiffeners on the ultimate axial load capacity and ductility of the columns were studied. Modelling of each of these columns was done as per the mesh mentioned previously, appropriate restraints considered at the boundaries, and loading conditions incorporated. Following cross sections of the concrete-filled steel composite columns were analysed by the use of the finite element method. These can be divided into 5 categories and 10 subcategories. Cross sections of the concrete-filled steel composite columns with different number and shapes of the stiffeners are shown in Figs. 6 to 10.

All the above concrete-filled steel composite columns were modelled and detailed nonlinear analyses carried out by the use of the finite element software LUSAS. Results obtained from the



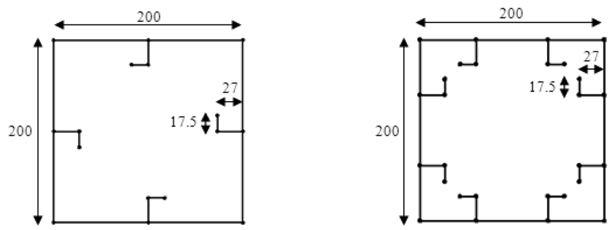
1 on side 2 on side

Fig. 6 Cross sections of the concrete-filled steel composite columns (V stiffeners & cold-formed steel sheets of 1.5, 1.75 & 2 mm) (All dimensions are in mm)



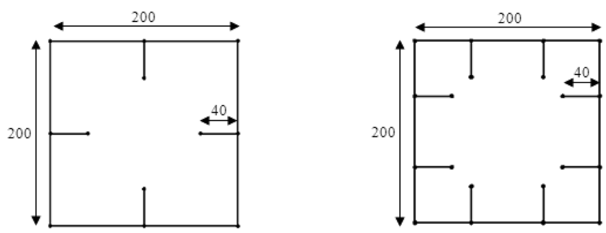
1 on side 2 on side

Fig. 7 Cross sections of the concrete-filled steel composite columns (T stiffeners & cold-formed steel sheets of 1.5, 1.75 & 2 mm)



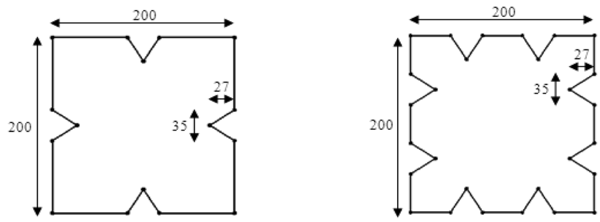
1 on side 2 on side

Fig. 8 Cross sections of the concrete-filled steel composite columns (L stiffeners & cold-formed steel sheets of 1.5, 1.75 & 2 mm)



1 on side 2 on side

Fig. 9 Cross sections of the concrete-filled steel composite columns (Line stiffeners & cold-formed steel sheets of 1.5, 1.75 & 2 mm)



1 on side 2 on side

Fig. 10 Cross sections of the concrete-filled steel composite columns (Triangular stiffeners & cold-formed steel sheets of 1.5, 1.75 & 2 mm)

study are presented in the form of axial load-normalized axial shortening plots in the following sections.

4. Results and discussion

The detailed specifications and obtained ultimate axial load capacities of the analysed columns with various thicknesses of steel sheets, and different number and shapes of steel sheeting stiffeners are summarized in Table 2 and their corresponding axial load-normalized axial shortening plots are shown in Figs. 11 to 25. Also, plots of the analysed columns with different concrete compressive strengths f_c and various cold-formed steel sheet yield stresses f_{yp} are presented in Figs. 29 & 30 and Figs. 31 & 32, respectively. Effects of different parameters on the ultimate axial load capacity and ductility of the columns are also discussed in the following sections.

Table 2 Specifications and ultimate axial load capacities of the concrete-filled steel composite columns

No.	Column	Thickness of steel sheet (mm)	Area of steel sheeting (A_S) (mm^2)	Area of concrete (A_c) (mm^2)	Ultimate axial load capacity (N_u) (kN)
1	Without Stiffener, Mild Steel	2.5	1975	38025	2350
2	V Stiffener (2 on side)	1.5	1963	38037	2864
3	V Stiffener (2 on side)	1.75	2289	37711	3045
4	V Stiffener (2 on side)	2	2614	37386	3225
5	T Stiffener (2 on side)	1.5	1917	38083	2590
6	T Stiffener (2 on side)	1.75	2231	37769	2776
7	T Stiffener (2 on side)	2	2544	37456	2962
8	L Stiffener (2 on side)	1.5	1707	38293	2474
9	L Stiffener (2 on side)	1.75	1986	38014	2642
10	L Stiffener (2 on side)	2	2264	37736	2807
11	Line Stiffener (2 on side)	1.5	1671	38329	2263
12	Line Stiffener (2 on side)	1.75	1948	38052	2361
13	Line Stiffener (2 on side)	2	2224	37776	2516
14	Triangular Stiffener (2 on side)	1.5	1219	35092	2237
15	Triangular Stiffener (2 on side)	1.75	1421	34832	2341

Table 2 Continued

No.	Column	Thickness of steel sheet (mm)	Area of steel sheeting (A_S) (mm^2)	Area of concrete (A_c) (mm^2)	Ultimate axial load capacity (N_u) (kN)
16	Triangular Stiffener (2 on side)	2	1622	34636	2496
17	V Stiffener (1 on side)	1.5	1577	38423	2636
18	V Stiffener (1 on side)	1.75	1838	38162	2807
19	V Stiffener (1 on side)	2	2099	37901	2957
20	T Stiffener (1 on side)	1.5	1554	38446	2253
21	T Stiffener (1 on side)	1.75	1810	38191	2415
22	T Stiffener (1 on side)	2	2064	37936	2564
23	L Stiffener (1 on side)	1.5	1449	38551	2209
24	L Stiffener (1 on side)	1.75	1687	38313	2350
25	L Stiffener (1 on side)	2	1924	38076	2487
26	Line Stiffener (1 on side)	1.5	1431	38569	1880
27	Line Stiffener (1 on side)	1.75	1668	38332	2009
28	Line Stiffener (1 on side)	2	1904	38096	2141
29	Triangular Stiffener (1 on side)	1.5	1205	36919	1855
30	Triangular Stiffener (1 on side)	1.75	1404	36722	1976
31	Triangular Stiffener (1 on side)	2	1603	36526	2094

4.1 Effect of number of stiffeners on ultimate axial load capacity

As can be seen from Table 2 and Figs. 11 to 25, the use of the stiffeners can affect the ultimate axial load capacity of the columns. For example, by the use of V stiffener (2 mm) the ultimate axial load capacity which is 3225 kN (2 on side) is higher than, 2350 kN, the ultimate axial load capacity of the column without stiffener-mild steel, an optimization of 37%. Also, according to the figures, the ultimate axial load capacity is enhanced by the increase of the number of steel sheeting stiffeners. For example, in the case of T stiffener (1.75 mm) the ultimate axial load is 2415 kN (1 on side) which is increased to 2776 kN by the use of 2 on side stiffener, an increase of around 15%.

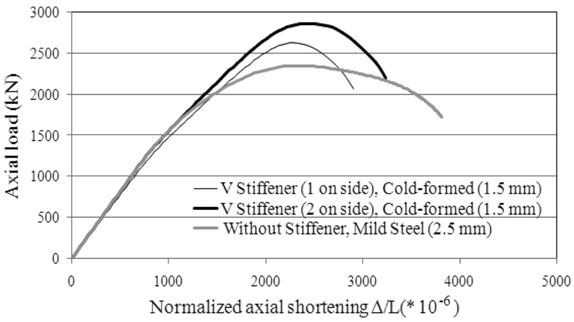


Fig. 11 Axial load-normalized axial shortening plots for columns with different number of V stiffeners (cold-formed 1.5 mm) and without stiffener (mild steel 2.5 mm)

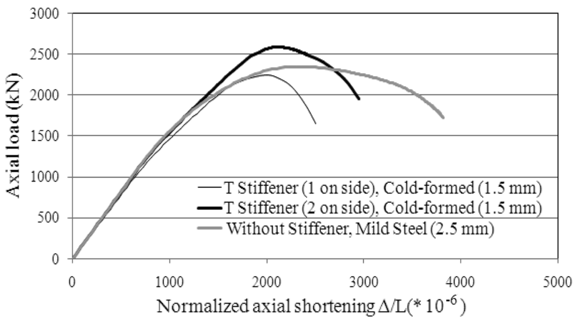


Fig. 12 Axial load-normalized axial shortening plots for columns with different number of T stiffeners (cold-formed 1.5 mm) and without stiffener (mild steel 2.5 mm)

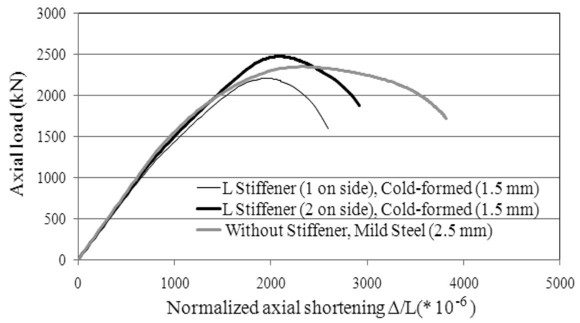


Fig. 13 Axial load-normalized axial shortening plots for columns with different number of L stiffeners (cold-formed 1.5 mm) and without stiffener (mild steel 2.5 mm)

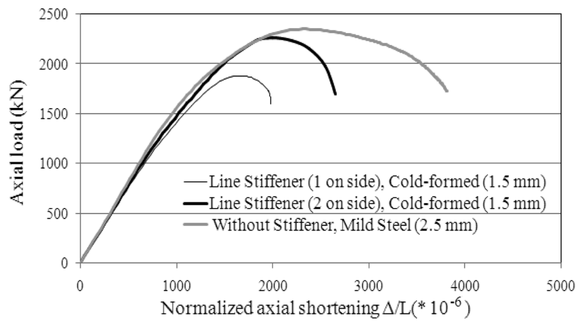


Fig. 14 Axial load-normalized axial shortening plots for columns with different number of Line stiffeners (cold-formed 1.5 mm) and without stiffener (mild steel 2.5 mm)

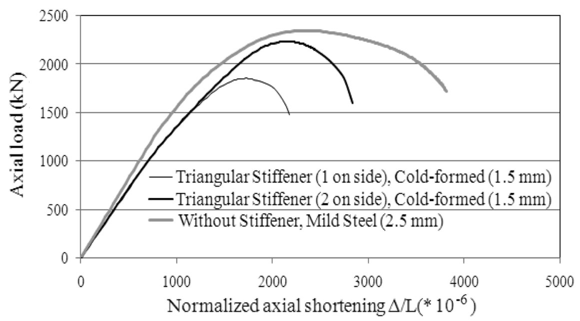


Fig. 15 Axial load-normalized axial shortening plots for columns with different number of Triangular stiffeners (cold-formed 1.5 mm) and without stiffener (mild steel 2.5 mm)

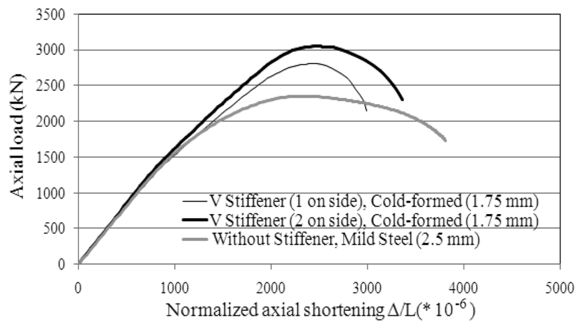


Fig. 16 Axial load-normalized axial shortening plots for columns with different number of V stiffeners (cold-formed 1.75 mm) and without stiffener (mild steel 2.5 mm)

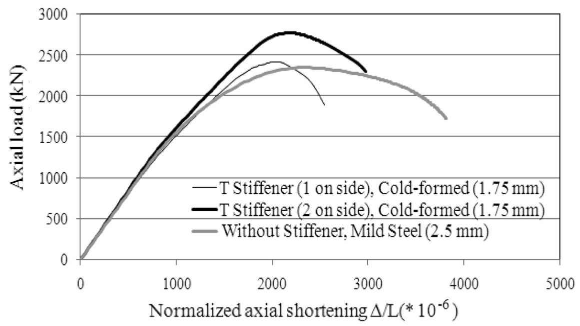


Fig. 17 Axial load-normalized axial shortening plots for columns with different number of T stiffeners (cold-formed 1.75 mm) and without stiffener (mild steel 2.5 mm)

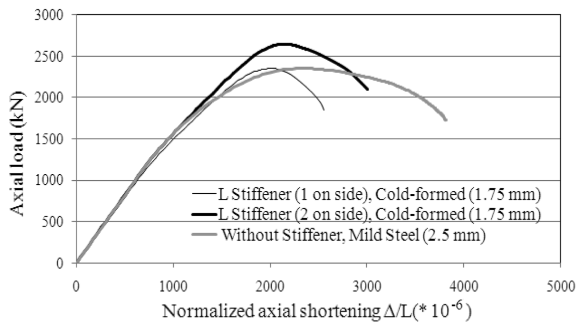


Fig. 18 Axial load-normalized axial shortening plots for columns with different number of L stiffeners (cold-formed 1.75 mm) and without stiffener (mild steel 2.5 mm)

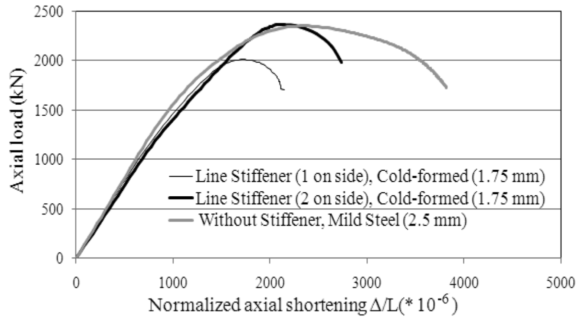


Fig. 19 Axial load-normalized axial shortening plots for columns with different number of Line stiffeners (cold-formed 1.75 mm) and without stiffener (mild steel 2.5 mm)

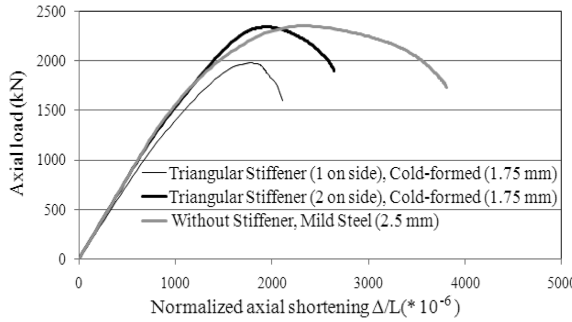


Fig. 20 Axial load-normalized axial shortening plots for columns with different number of Triangular stiffeners (cold-formed 1.75 mm) and without stiffener (mild steel 2.5 mm)

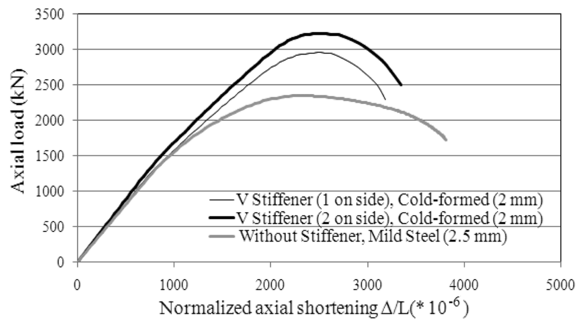


Fig. 21 Axial load-normalized axial shortening plots for columns with different number of V stiffeners (cold-formed 2 mm) and without stiffener (mild steel 2.5 mm)

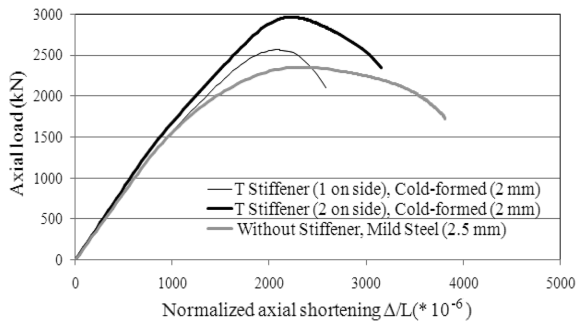


Fig. 22 Axial load-normalized axial shortening plots for columns with different number of T stiffeners (cold-formed 2 mm) and without stiffener (mild steel 2.5 mm)

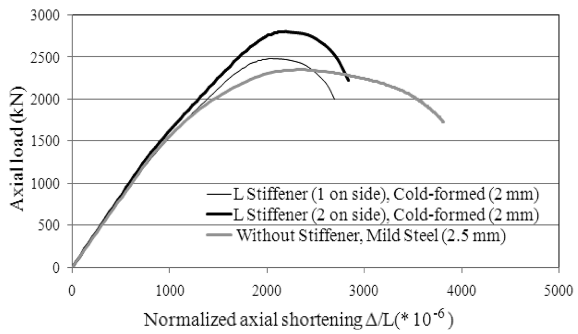


Fig. 23 Axial load-normalized axial shortening plots for columns with different number of L stiffeners (cold-formed 2 mm) and without stiffener (mild steel 2.5 mm)

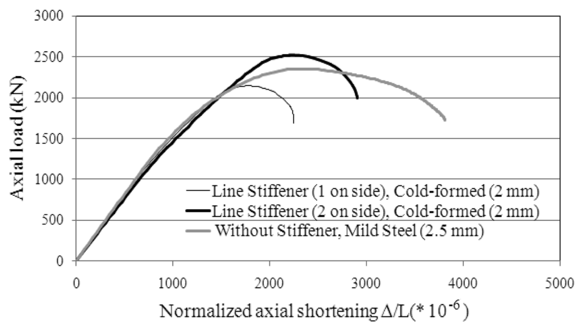


Fig. 24 Axial load-normalized axial shortening plots for columns with different number of Line stiffeners (cold-formed 2 mm) and without stiffener (mild steel 2.5 mm)

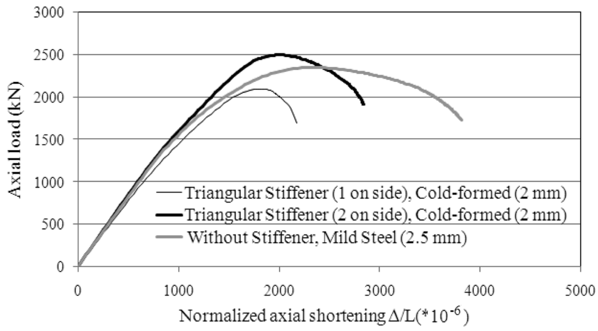


Fig. 25 Axial load-normalized axial shortening plots for columns with different number of Triangular stiffeners (cold-formed 2 mm) and without stiffener (mild steel 2.5 mm)

4.2 Effect of thickness of steel sheet on ultimate axial load capacity

It can be realized from Table 2 and Figs. 11 to 25 that the use of different thicknesses of cold-formed steel sheets is effective on the ultimate axial load capacity of the columns. According to them, as the thickness of cold-formed steel sheet is increased from 1.5 mm to 2 mm the ultimate axial load capacity of the columns is enhanced which in most cases results into obtaining higher ultimate axial load capacity than that of the column without stiffener-mild steel. For example, in the case of T stiffener (2 on side) the ultimate axial load capacity which is 2590 kN for the thickness of 1.5 mm, increases to 2962 kN for the same column with the thickness of 2 mm, an enhancement of 14%.

4.3 Effect of shape of stiffeners on ultimate axial load capacity

According to Figs. 11 to 25, different shapes of the stiffeners influence the ultimate axial load capacity of the columns. This effect is shown in Figs. 26 and 27. In accordance with the figures, the hierarchy of the different shapes of the stiffeners with same thickness of cold-formed steel sheet and

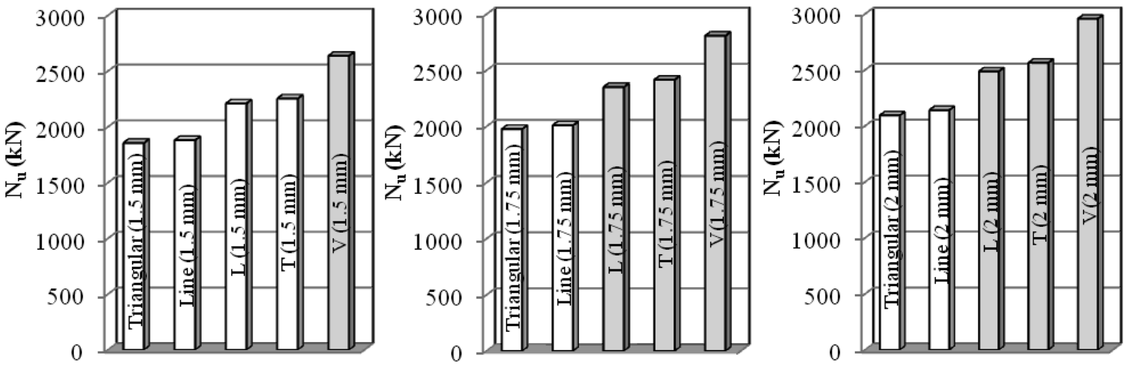


Fig. 26 Effect of shape of steel sheeting stiffeners on ultimate axial load capacity of the columns (1 on side stiffeners)

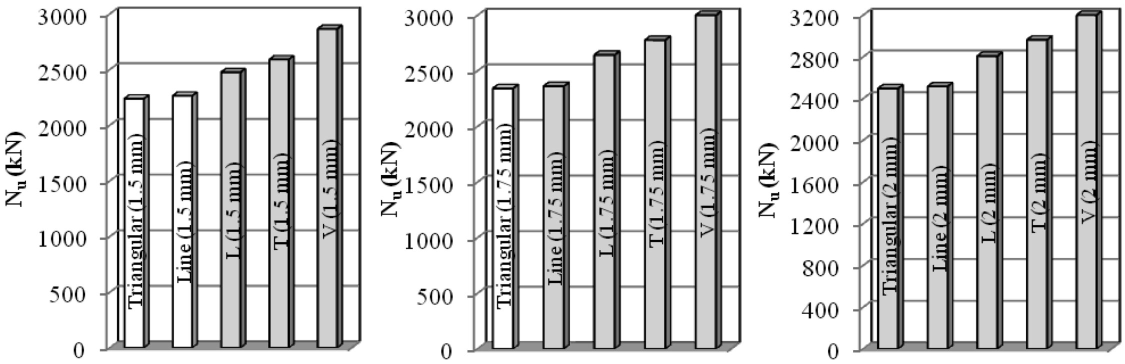


Fig. 27 Effect of shape of steel sheeting stiffeners on ultimate axial load capacity of the columns (2 on side stiffeners)

same number of the stiffeners from the ultimate axial load capacity view is V, T, L, Line, and Triangular stiffeners. For instance, the ultimate axial load capacity of the columns with V stiffener (2 on side) and the thickness of 2 mm is 3225 kN compared to the other forms of the stiffeners for which the corresponding axial load capacities are 2962 kN, 2807 kN, 2516 kN, and 2496 kN, respectively for T, L, Line, and Triangular stiffeners.

4.4 Effects of stiffeners and thickness of steel sheet on ductility (DI)

A ductility index (DI) which was defined by Lin and Tsai (2001) and used by Tao *et al.* (2007) has been also utilized in this paper in order to investigate the effect of different parameters on the ductility. The ductility index is

$$DI = \varepsilon_{85\%} / \varepsilon_y$$

where $\varepsilon_{85\%}$ is the nominal axial shortening (Δ/L) corresponding to the load which falls to its 85% of the ultimate axial load capacity and ε_y is $\varepsilon_{75\%} / 0.75$ in which $\varepsilon_{75\%}$ is the nominal axial shortening corresponding to the load that obtains 75% of the ultimate axial load capacity. The values of $\varepsilon_{85\%}$ and ε_y can be taken from Figs. 11 to 25. Effects of stiffeners and thickness of steel sheet on the ductility have been shown in Fig. 28.

According to the figure, increase of the number of the stiffeners enhances the ductility of the columns. As the number of the stiffeners increases from 1 on side to 2 on side for the same shape of the stiffener and the same thickness of steel sheet, the ductility improves from 1% to 11%, with its average improvement of 5%. For example, the ductility of the column with Triangular stiffener (1 on side) and steel sheet thickness of 1.75 mm is 1.498 which enhances to 1.644 by the use of Triangular stiffener (2 on side) and same steel sheet thickness of 1.75 mm, an enhancement of about 10%. Also, it can be seen that different shapes of the stiffeners influence the columns ductility. For instance, the ductility of the column with L stiffener (2 on side) and steel sheet thickness of 2 mm is 1.562 which is increased to 1.673 by the use of Triangular stiffener (2 on side) and same steel sheet thickness of 2 mm, an increase of 7%. Meanwhile, increasing the thickness of steel sheet

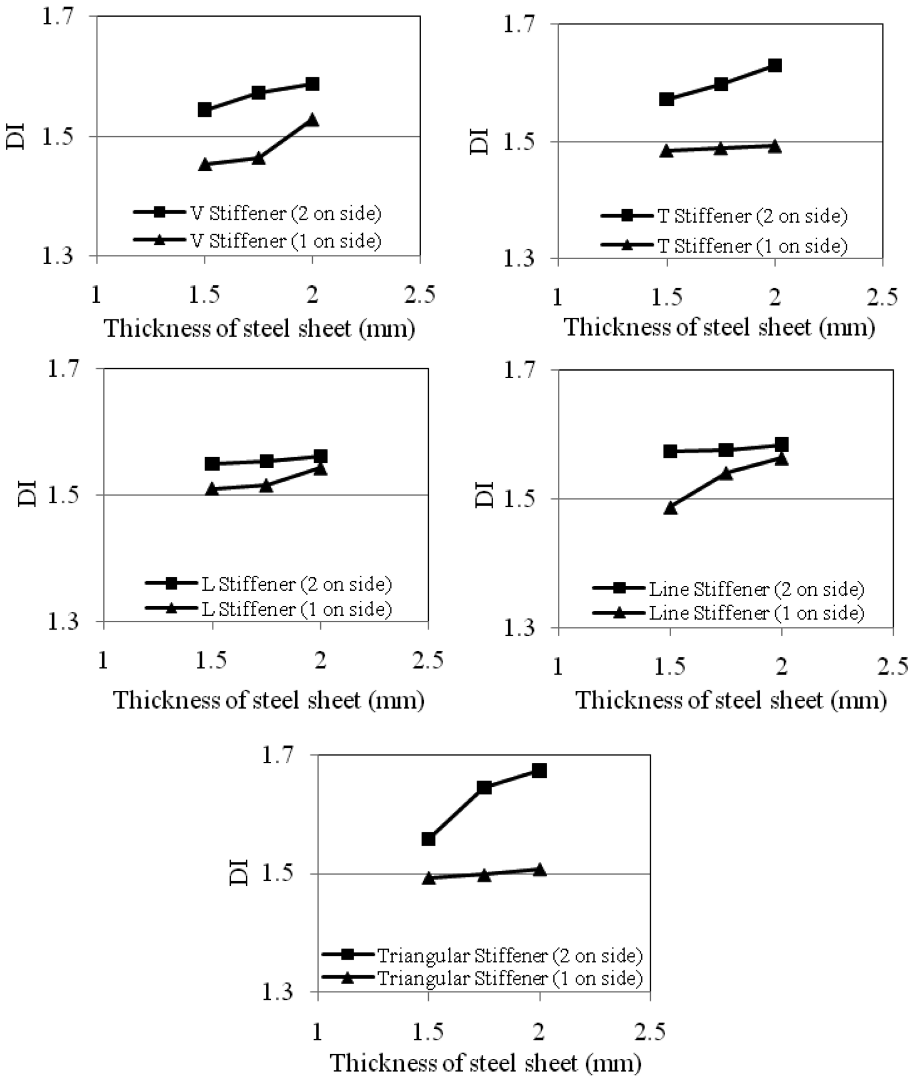


Fig. 28 Effects of stiffeners and thickness of steel sheet on ductility of the columns

improves the ductility. As the thickness of steel sheet increases from 1.5 mm to 2 mm for the same shape and number of the stiffeners the range of the ductility enhances from 1% to 7% which its average enhancement is around 3% and not appreciable. For example, the ductility of the column with Line stiffener (1 on side) and steel sheet thickness of 1.5 mm is 1.487 which is improved to 1.563 for the column with Line stiffener (1 on side) and steel sheet thickness of 2 mm, an improvement of 5%.

4.5 Effect of concrete compressive strength f_c on ultimate axial load capacity

More analyses were done on 2 typical concrete-filled steel composite columns with V stiffener (1 on side) and V stiffener (2 on side) both with cold-formed steel sheet of 2 mm in order to study the

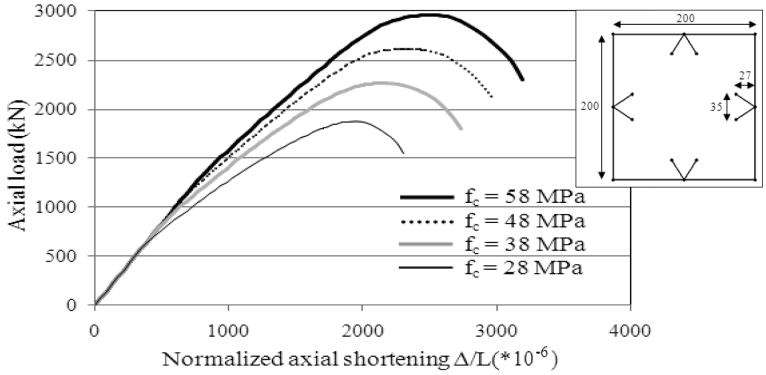


Fig. 29 Effect of concrete compressive strength f_c

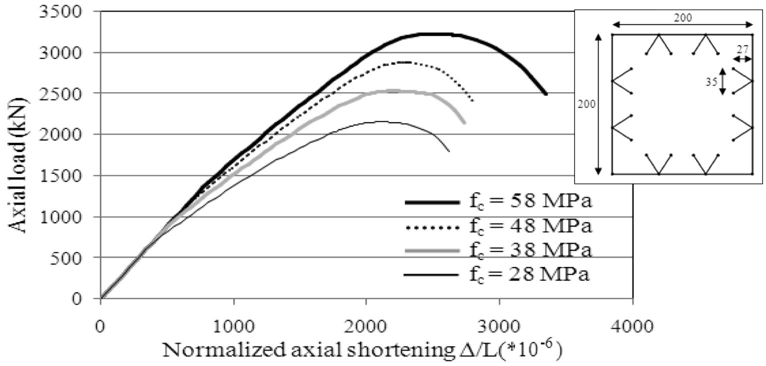


Fig. 30 Effect of concrete compressive strength f_c

effect of concrete compressive strengths f_c (28 MPa, 38 MPa, 48 MPa, and 58 MPa) on the ultimate axial load capacity of the columns. Figs. 29 & 30 show the result of the analyses. It can be seen from the figures that the ultimate axial load capacity of the columns is improved by the increase of the concrete compressive strength. For instance, increase of the concrete compressive strength for the column with V stiffener (1 on side) from 28 MPa to 58 MPa enhances the ultimate axial load capacity from 1871 kN to 2957 kN, an enhancement of 58%.

4.6 Effect of yield stress f_{yp} of cold-formed steel sheet on ultimate axial load capacity

Same columns were analysed to investigate the effect of four different yield stresses f_{yp} (250 MPa, 350 MPa, 450 MPa, and 550 MPa) of cold-formed steel sheet on the ultimate axial load capacity. As it is obvious from Figs. 31 & 32, the higher yield stress of cold-formed steel sheet leads to higher ultimate axial load capacity of the columns. For example, as the yield stress of cold-formed steel sheet for the column with V stiffener (2 on side) increases from 250 MPa to 550 MPa the ultimate axial load capacity improves from 2442 kN to 3225 kN, an improvement of 32%.

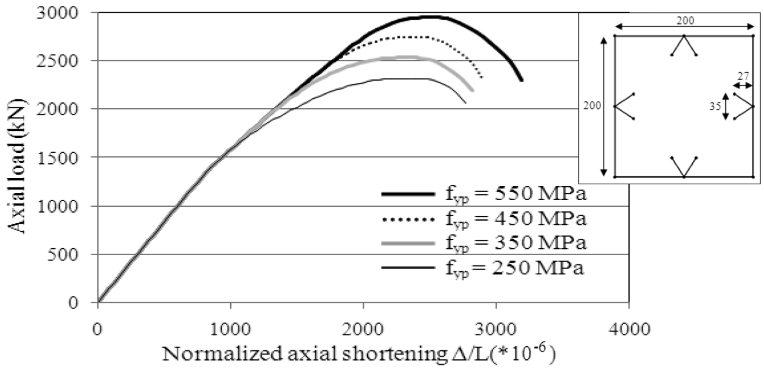


Fig. 31 Effect of yield stress f_{yp} of cold-formed steel sheet

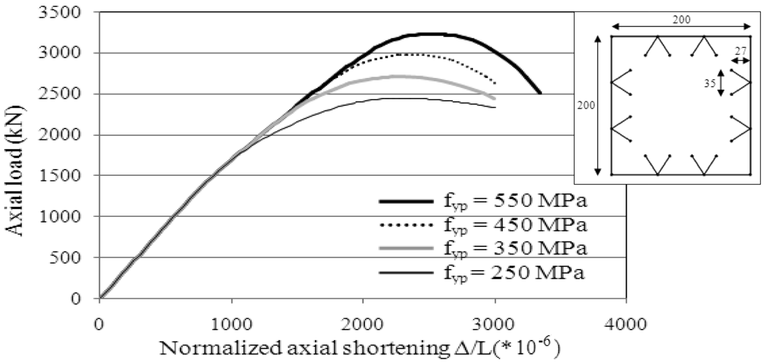


Fig. 32 Effect of yield stress f_{yp} of cold-formed steel sheet

5. Conclusions

Nonlinear finite element analyses of the behaviour and ultimate axial load capacity of the concrete-filled steel composite columns have been presented in this paper. Verification of the finite element analyses of the columns was carried out and compared with the existing experimental result of the columns. According to the results, it can be concluded that the proposed three dimensional finite element modelling using LUSAS software is sufficiently accurate to predict the ultimate axial load capacity and behaviour of the columns. It is demonstrated from the finite element analyses of the columns with different shapes and number of cold-formed steel sheeting stiffeners in various thicknesses of cold-formed steel sheets that these parameters influence the ultimate axial load capacity and ductility of the columns. Also, as the number of the stiffeners and/or thicknesses of steel sheets are increased the ultimate axial load capacity and ductility of the columns are enhanced. But, these parameters are more effective on the ultimate axial load capacity than ductility of the columns. The hierarchy of different shapes of the stiffeners with same thickness of steel sheet and same number of the stiffeners from the ultimate axial load capacity view is V, T, L, Line, and Triangular stiffeners. According to the finite element analyses of the columns with different concrete compressive strengths f_c and cold-formed steel sheeting yield stresses f_{yp}, it is also concluded that increasing these variables improves the ultimate axial load capacities of the columns.

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