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Experimental and Numerical Investigation on the Behavior of Composite Cold Formed Steel Columns under Axial and Lateral Loads

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Abstract:- Steel-concrete composite structures are used widely in the current construction of bridges and multi-story buildings. Experimental and numerical studies were conducted to investigate the behavior of composite cold formed steel columns under axial load only with lack of experimental investigation on composite cold formed steel columns under lateral loads. This paper conducted to investigate experimentally and numerically the behavior of composite cold formed steel columns under axial and lateral loads. Five specimens were tested to evaluate the failure modes, strains development and load-deformation histories in the steel tube. Finite element (FE) models using ANSYS Workbench were developed and verified against experimental results. The verified FE will be used in future by the authors to study the influence of key parameters that control the behavior of composite cold forms steel columns, including cross sections, fastener spacing, fastener length, yield strength of steel, on the load carrying capacity. It was observed from the obtained results that composite column with sigma section show better behavior than C section because of the web and flange for the sigma section are both stiffened. The embedded fasteners length of 50mm enhanced load carrying by 13% compared to 30mm length.

Keywords:- *Composite Columns, Finite Element Model, Cold Formed Steel, Axial Loads, Lateral Loads.*

I. INTRODUCTION

Concrete filled steel tube (CFST) columns are favored for many earthquake resistant structures, columns in high rise buildings, bridge piers subject to high strain rate from traffic and railways decks[1]. The main advantage of composite construction is to enhance the properties of concrete and steel[2]. The use of the composite action between steel and concrete provides better properties if compared to their individual responses, such as structural strength, durability and ductility[3]. Anis Saggaff et.al[4], studied the composite action of a cold-formed steel section with bolted shear connectors of 16mm diameter, which yielded better strength and moment carrying capacity. Increasing the number of shear connectors increase the load carrying capacity of the columns and the failure mode is affected obviously by both the number and width of the stiffeners[5]. However, research on CFST columns under cyclic lateral loading is still missing, which demonstrates a requirement for additional exploration in this area[6].

Cold-formed sections are produced at encompassing temperature and thus experience plastic deformations causing strain hardening of the material[7]. CFS section expands the solidarity to weight proportion which expanded the interest of applying CFS section in constructions with higher load[8,9]. One of the principle impediments of the CFS section is its high slenderness (Width to thickness ratio) which exposed the CFS section to be buckled mainly by one or a blend of three primary modes: local, distortional and Global buckling[10]. Closed sections such as box-shaped sections made by interfacing two channel areas tip to tip are regularly found in use in cold-formed steel structures due to their relatively large torsional rigidity[11].

There are a few sorts of stiffening methods available for use in CFT. For instance, welding longitudinal stiffeners on the inner surfaces of the steel tube[12], inserting shear studs in the steel tube and what's more by utilizing either tie bars or restraining rods to fortify the plastic zones of the CFTs[13]. The effect of longitudinal stiffeners on the behavior of square CFT stub columns experimentally had been studied by Ge and Usami[14]. The test results demonstrated that the longitudinal stiffeners effectively delay the local buckling of the tube, increase the sectional capacity and improve the lateral confinement of the concrete core.

In the past several decades, CFST have been broadly utilized in seismic regions, because of their incredible quake opposing properties[15].

In this study, a series of lateral load tests was conducted to investigate the behavior of composite cold formed steel columns with relatively thick wall of 4 mm. Three different column sections were considered, with different shear connectors spacing. A model was also developed by finite element program ANSYS[16] and utilized to give a numerical viewpoint of the behavior of the Composite cold formed steel columns. The comparison

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shows that the finite element program has a good agreement with the experimental results.

II. EXPERIMENTAL PROGRAM

Test Specimens

Five composite cold formed steel columns. Two had sigma cold formed section and three had C section. All columns were built up by assembling the steel sections and connecting together using cover plates and fasteners bolts as shown in Fig.1 to create a tube to fill with normal strength concrete, which had a compressive strength (f_{cu}) of 25 MPa after 28 days. The considered parameters were the column cross section, the vertical spacing between fasteners, the horizontal spacing between fasteners, the length of fasteners were used. The details of the tested columns are shown in Fig.1 and table 1.

Geometry of Specimens

The columns are classified into two groups; A and B, first group A consists of two columns with sigma section and the second one B consists of three columns with C section. All columns had a height of 1600mm, column A-1 with cross section of 2 sigma covered by 2 plates and connected together using fasteners bolts with a vertical fastener spacing of 100mm, clear fastener length of 30mm. and horizontal spacing between fastener of 160mm Fig.1. Column A-2 with cross section of 2 sigma covered by 2 plates and connected together using fasteners bolts with a vertical fastener spacing of 100mm, embedded fastener length of 30mm. and horizontal spacing between fastener of 200mm. column B-1 with cross section of 2 C covered by 2 plates and connected together using fastener bolts with a vertical fastener spacing of 200mm and horizontal fastener spacing of 100mm, embedded fastener length of 30 mm. column B-2 with cross section of 2 C covered by 2 plates and connected together using fastener bolts with a vertical fastener spacing of 200mm and horizontal fastener spacing of 50mm, clear fastener length of 30mm. column B-3 with cross section of 2 C covered by 2 plates and connected together using fastener bolts with a vertical fastener spacing of 200mm and horizontal fastener spacing of 100mm, embedded fastener length of 50mm.

Material Properties

The concrete cube dimensions and test procedures according to the Egyptian Code of Practice for Concrete Design ECP 203-2017[17]. Three cubes with dimensions of 150x150x150mm were used to calculate the average compressive strength of the concrete used for the composite columns. The average results of the compressive strength are (f_{cu}) of 25 MPa after 28 days.

Steel used is st37 with yield and ultimate strength of 240 and 360 MPa respectively according to the manufacturer's specifications.

Table 1 Dimensions of columns specimen

Column	Height (L), mm	Cross Section	Cross Section Area, mm^2	Plate Dimensions, (mm)	Vertical Spacing between fasteners, (mm)	Horizontal Spacing between fasteners, (mm)		Fasteners length, (mm)	Width, (mm)
						Spacing (a)	Edge (b)		
A1	1600	2∑250×80×4	5036	2 pl 184×4	100	120	40	30	200
A2	1600	2∑250×80×4	5356	2 pl 224×4	100	160	40	30	240
B1	1600	2[300×90×4	5220	2 pl 284×4	200	100	50	30	300
B2	1600	2[300×90×4	5220	2 pl 284×4	200	50	50	30	300
B3	1600	2[300×90×4	5220	2 pl 284×4	200	100	50	50	300

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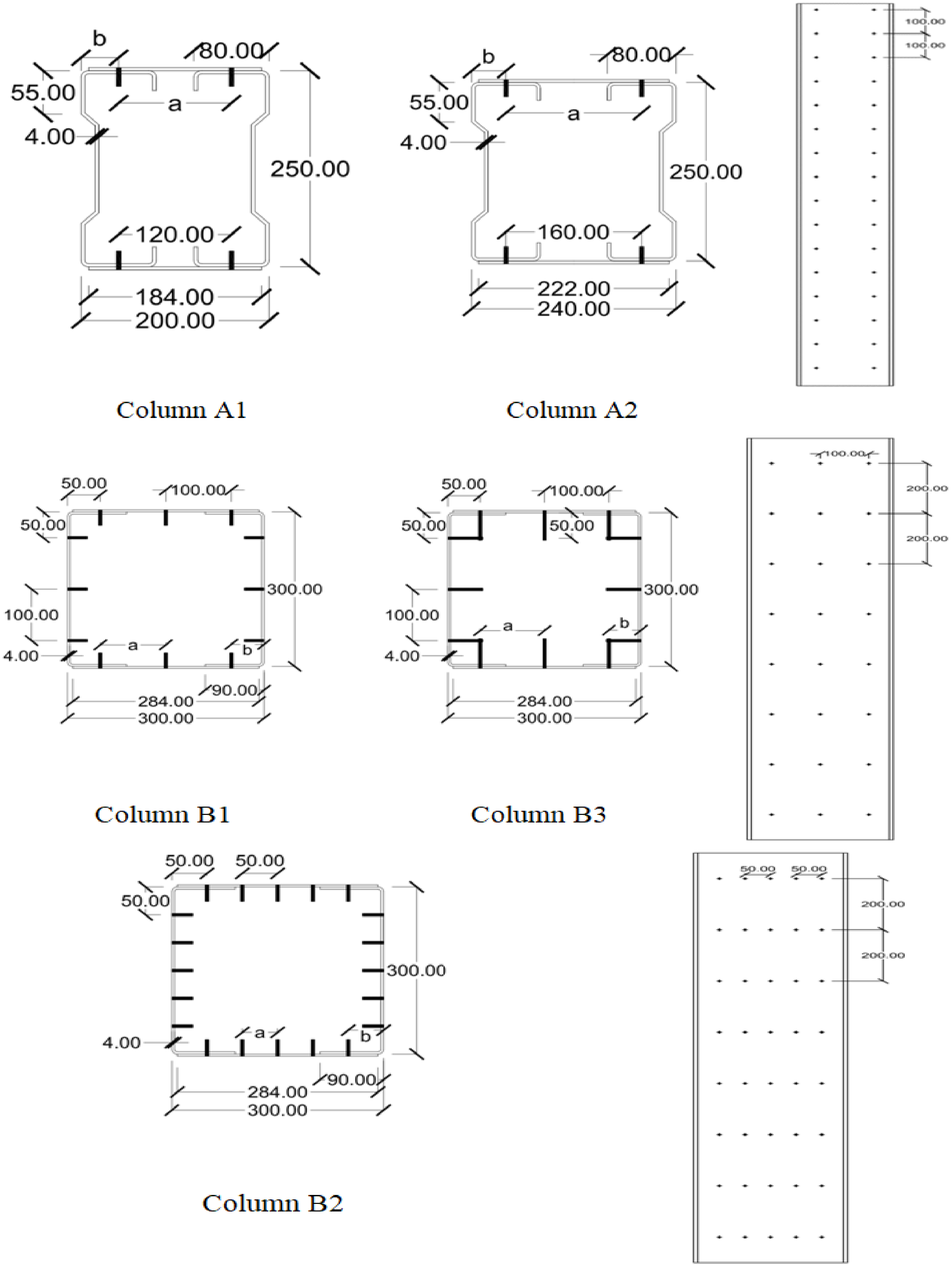


Fig. 1 Details of tested Columns

Experimental Setup

The experimental work of this study was conducted at University of Mansoura in the Heavy Structures Lab using the steel frame shown in Fig. 2. the axial and lateral loads test procedures start with fixing column specimens at the machine frame base and tested under axial compression and lateral cyclic load. The cyclic load was applied by using Two-way digital hydraulic jack of 1000kN capacity at the top of the composite column. The column base was fixed and the column top was loaded. The strain gauges, the strain indicator shown in Fig. 3. Electrical resistance of 6 mm length strain was used to measure the strains at the critical locations of the composite columns. Linear Variable Differential Transformer (LVDT) and dial gauges were used to measure the displacement at the top and mid-height of the column as shown in Fig. 3.

Fig.2 Main Test machine

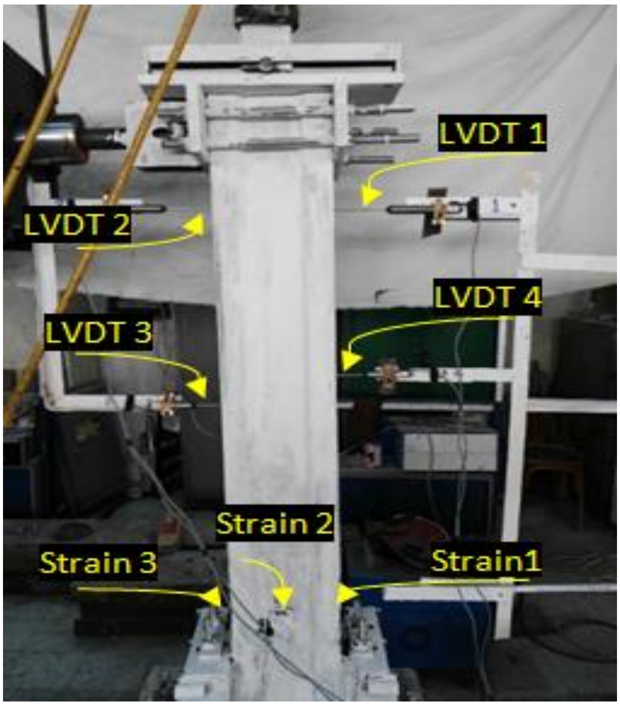
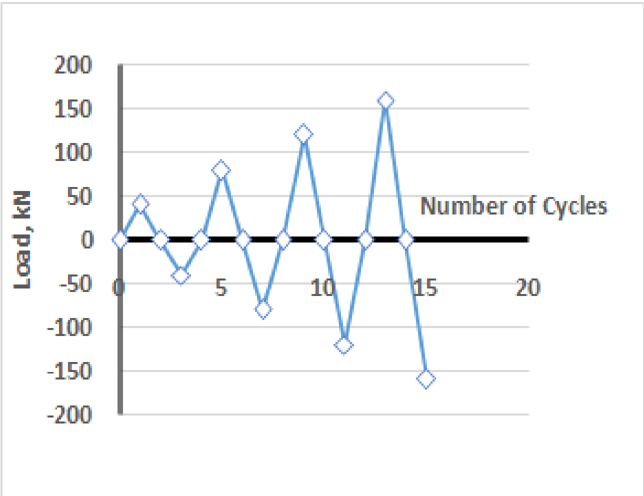


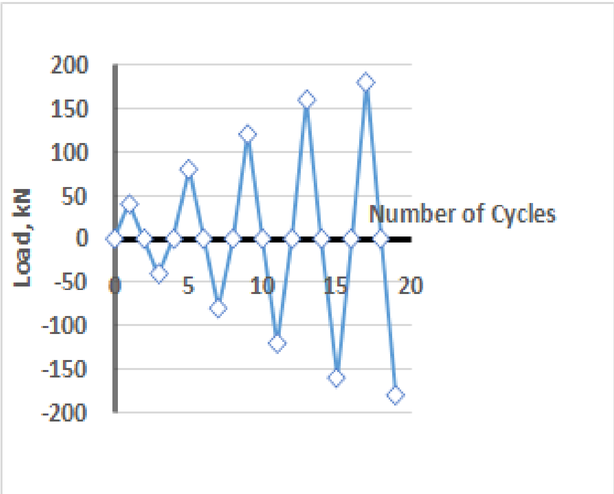
Fig.3 LVDT and strain gauges

Test Procedure

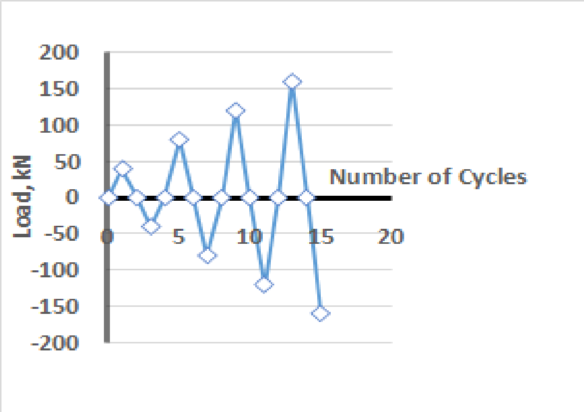
Each composite column tested under axial compression of 20kN and lateral cyclic load. The cyclic load was applied by using Two-way digital hydraulic jack of 1000kN capacity at the top of the composite column. Fig.4 shows the lateral load applied to the composite columns.



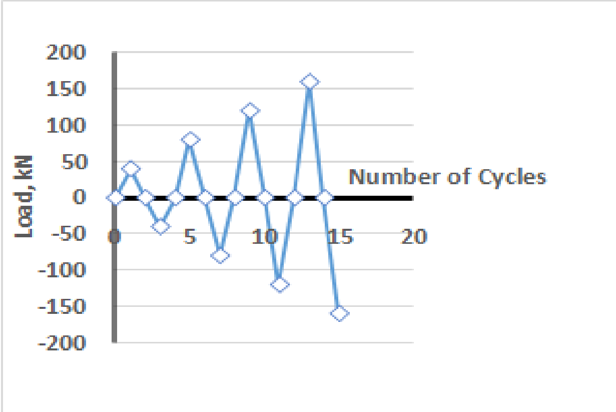
Load sequence for column A1



Load sequence for column A2



Load sequence for column B1



Load sequence for column B2

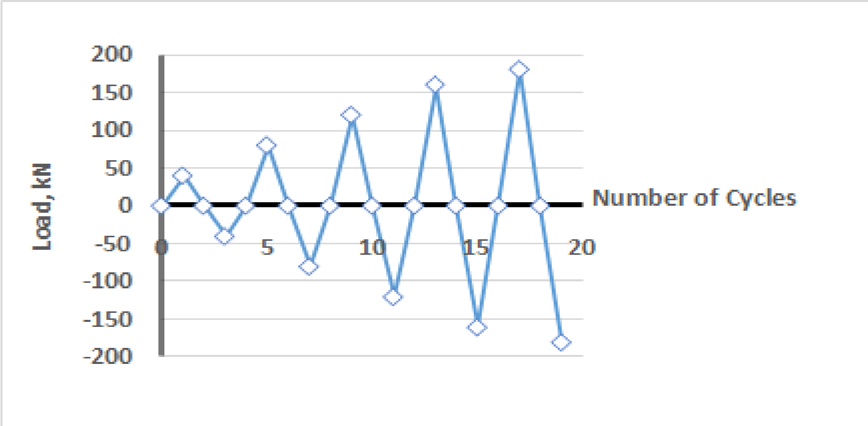


Fig.4 lateral load applied to the tested composite columns

III. Test Results and Discussion

Experimental Results

Max Top Displacement

- For composite columns group A

The maximum top displacement (MTD), of composite columns with two cross sections are represented in table 2, The MTD of column A2 is greater than column A1 by about 15% at yield. At failure, The MTD of column A2 is greater than column A1 by about 10% and column. As shown in Fig.5.

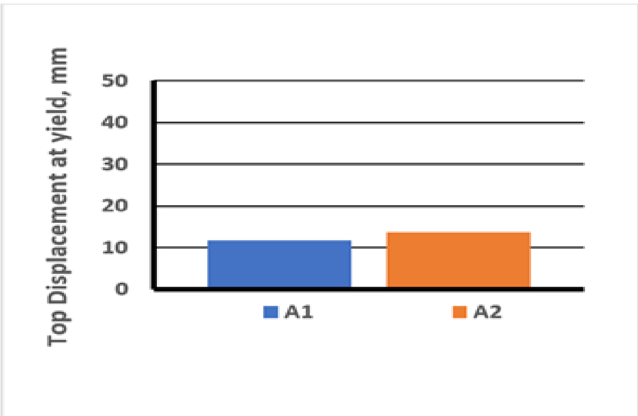


Fig.5 Recorded horizontal maximum top displacement at yield and failure for group A

- For composite columns group B

The maximum top displacement (MTD), of composite columns with one cross section represented in table 2, The MTD of column B2 is greater than column B1 by about 68% and 13% greater than B3 at yield. At failure The MTD of column B3 is greater than column B2 by about 12% and 25% than column B1. As shown in Fig. 6

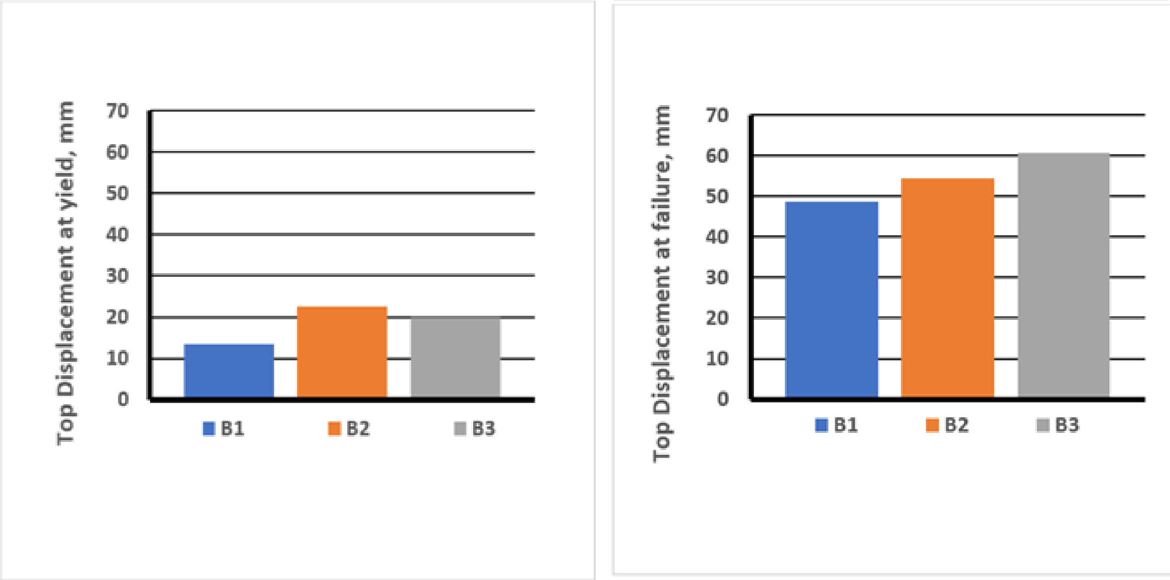


Fig. 6 Recorded horizontal maximum top displacement at yield and failure for group B

Table 2 Recorded horizontal maximum top and mid displacement at failure and yield for group A, B.

Column	**Top Displacement, mm**		**Mid Displacement, mm**	
	Failure	**Yield**	**Failure**	**Yield**
A1	39.52	11.765	18.184	5.612
A2	43.53	13.599	21.265	6.487
B1	48.7	13.43	25.45	7.048
B2	54.54	22.55	28.363	10.841
B3	60.71	19.99	31.868	9.458

Hysteretic Curves of Lateral Load Versus Column Displacement

Fig. 7 to 11 show the hysteretic curves of lateral load versus top displacement of the composite column for all tested specimens. For the group A, the maximum lateral loads carried by the composite columns A1 and A2 were 160 and 180 kN respectively, these loads were at the MTD of 39.52 and 43.53 mm. For the group B, the maximum lateral loads carried by the composite columns B1, B2 and B3 were 160, 160 and 180 kN, respectively, at MTD of 48.7, 54.54, and 60.71 mm, respectively. Group A showed a large value of lateral displacements compared to column group B, this may be as a result of large column width of group B.

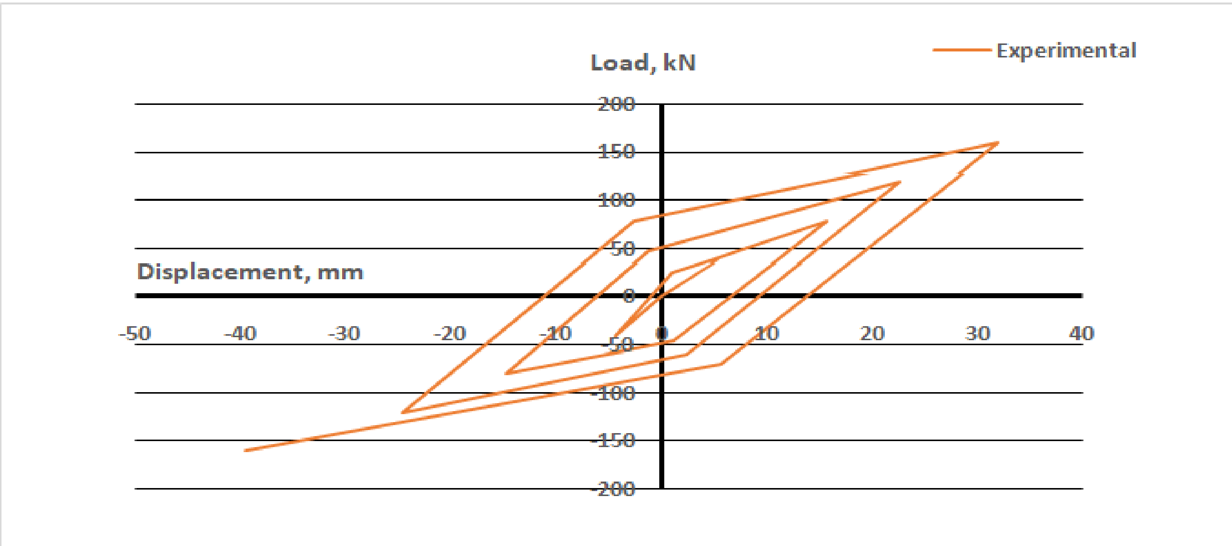


Fig. 7 Hysteretic loop of column A1

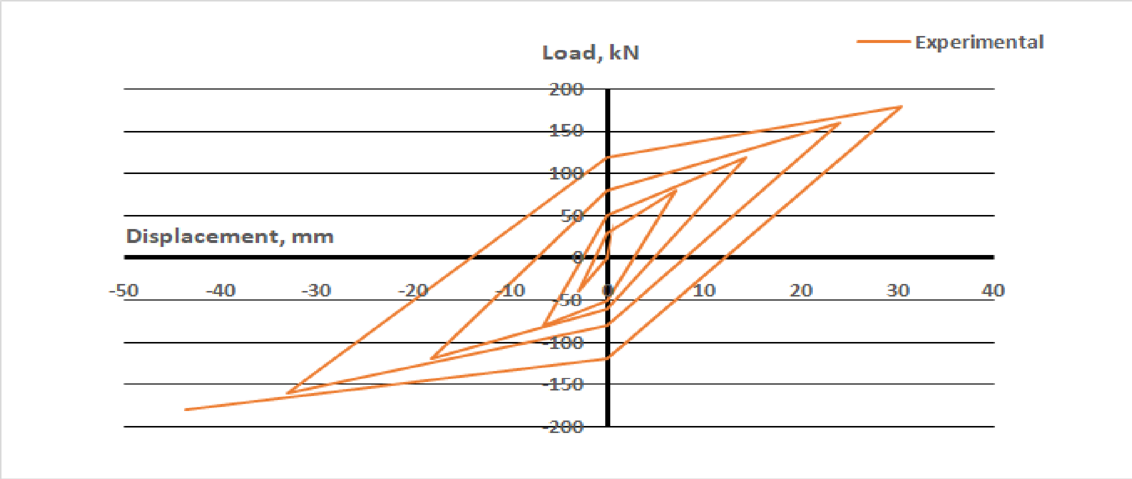


Fig. 8 Hysteretic loop of column A2

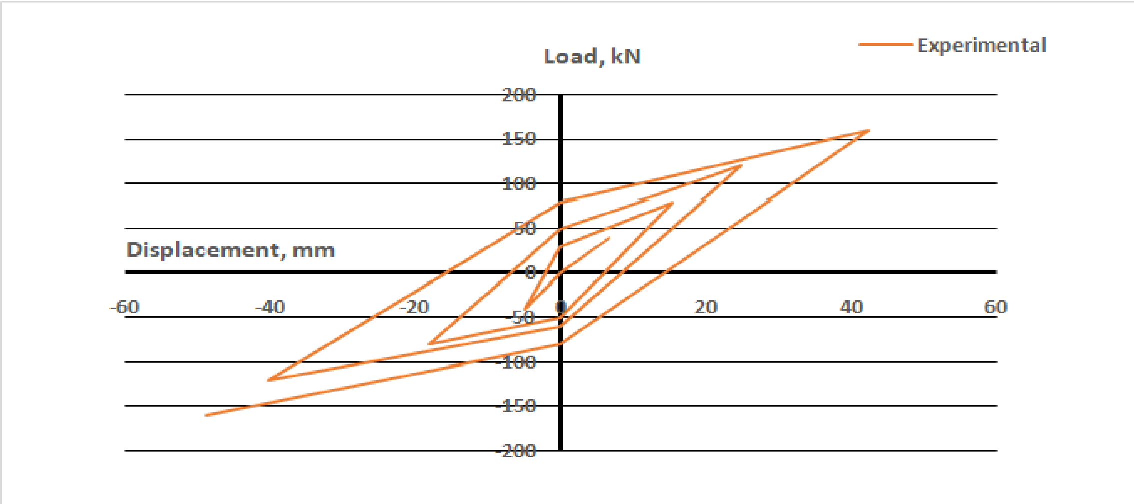


Fig. 9 Hysteretic loop of column B1

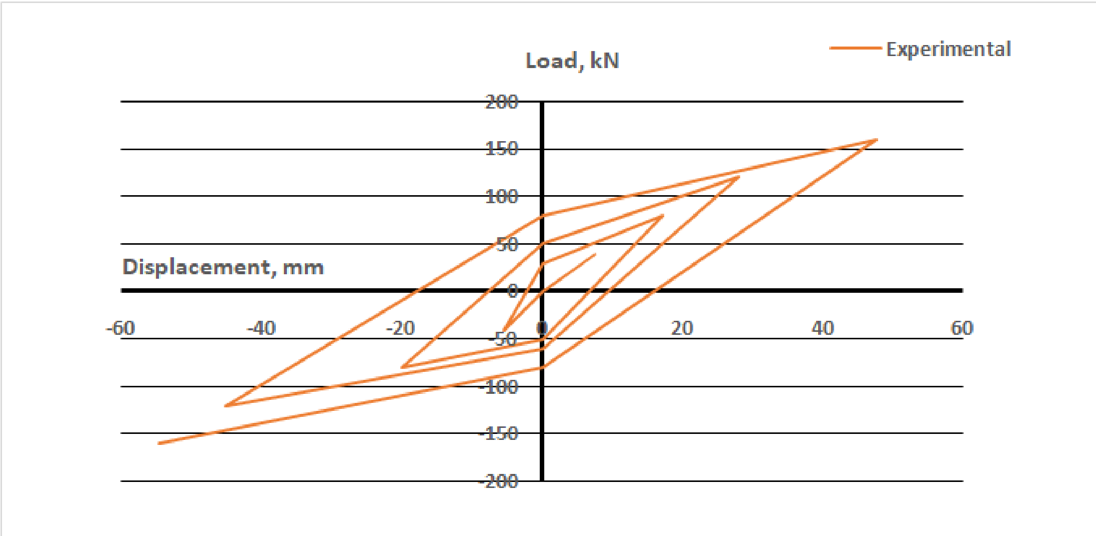


Fig. 10 Hysteretic loop of column B2

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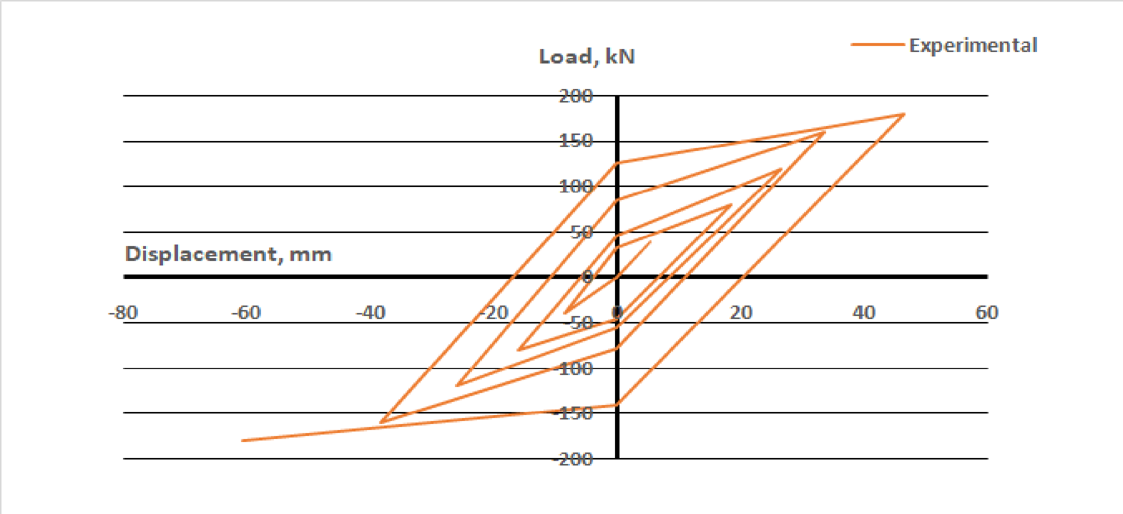

Fig.11 Hysteretic loop of column B3

Failure Mode

All tested composite columns representing plate buckling failure. Local buckling was observed in all tested columns at the column base as shown in Fig. 12

A1

A2

B1

B2

B3

Fig. 12 (A1,A2,B1,B2,B3) Failure shape of tested columns

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Finite Element Modelling

This section gives a description of the finite element modelling which were used to understand the behavior of the composite cold-formed steel columns under axial and lateral loads. Finite Element modelling is getting significant and mainstream in structural analysis regards to the precise outcomes and less time and cash expending that can be acquired from FE modelling. A finite element analysis was conducted using ANSYS Workbench. The cross-section dimensions shown in Fig. 1 were used to setup the finite element models. The structural steel and concrete were added in the engineering data and the material properties was assigned as follow; For steel, yield strength f_y = 240 MPa, Poisson's ratio v = 0.3, elastic modulus E = 20 × 10^5 MPa. And for concrete, f_{cu}= 25 MPa, Poisson's ratio v = 0.2, elastic modulus E = 2.35 × 10^4 MPa. The contact between steel and concrete was indicated as frictional connection with frictional coefficient of 0.2[18], and the contact between fastener and surrounding elements such as steel section, steel plates and concrete were indicated as bonded connection. Solid 186 element was used to model the steel sections, fasteners and fixation plates; the element is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior.The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. While for the concrete, the solid element Solid 65 which has eight nodes with three degrees of freedom at each node: translations in the nodal x, y, and z directions[19]. The final model is shown in Fig. 13.

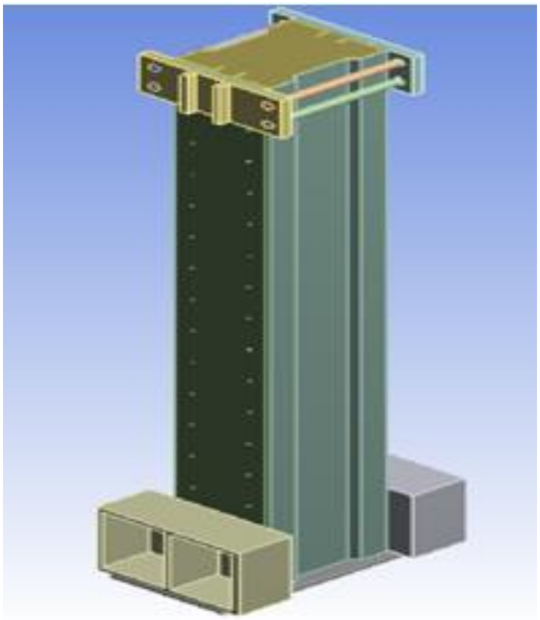

Fig. 13 ANSYS Geometry model column A1

Comparison with Finite Element Model Results

This section compares the outcomes between the finite element model (FEM) and experimental (EXP) data which were collected from laboratory tests of the composite columns. The comparison is made for lateral load capacity of all composite column table 3 presents the acquired outcomes from the experimental data and were compared with outcomes from the finite element model.

Table 3 Experimental vs Analysis results

Column	Failure load, kN		Exp./Analysis
	Experimental	Analysis	
A1	160	190.9	0.84
A2	180	216.4	0.83
B1	160	166.8	0.96
B2	160	170.2	0.94
B3	180	216.1	0.83
Mean			0.88

Hysteretic Curves of Lateral Load Versus Column Displacement

The load-displacement of the investigation of the composite cold formed steel columns are plotted in Figs. 14 to 18 respectively. Illustrate a comparison between the hysteretic loop of composite cold formed columns tests and that calculated from the finite element program ANSYS. Results shows that finite element has a good agreement with the experimental results of load-displacement at the top of the column, but at the end of loading, the experimental curve shows some differences, it is noticed that there are a small differences between finite element and experimental results due to the difference between test setup procedure and FE model and due to the geometrical imperfection which was not included in the FE model.

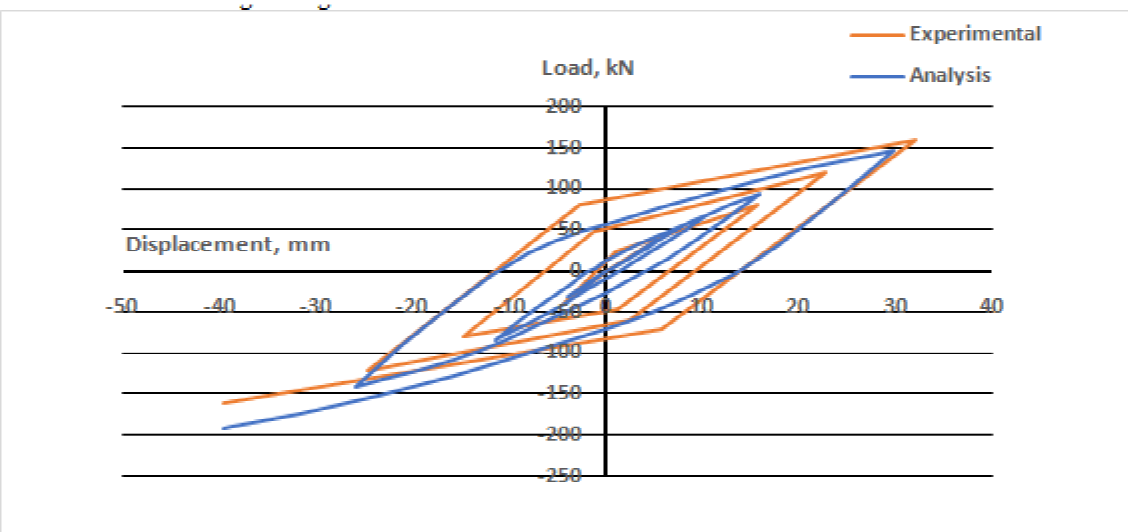

Fig. 14 Comparison between experimental hysteretic loop of column A1 and the calculated from ANSYS

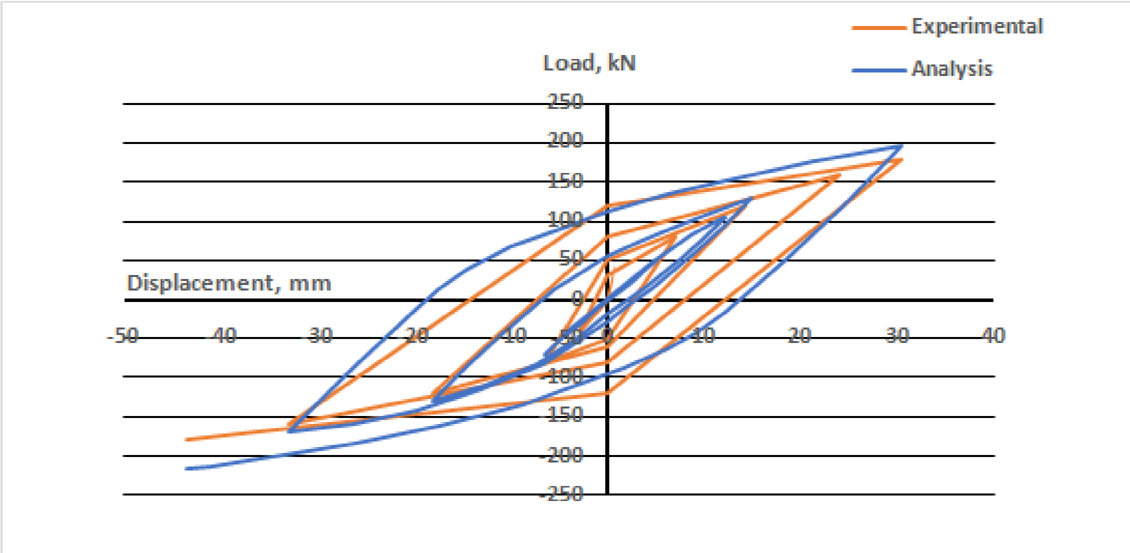

Fig. 15 Comparison between experimental hysteretic loop of column A2 and the calculated from ANSYS

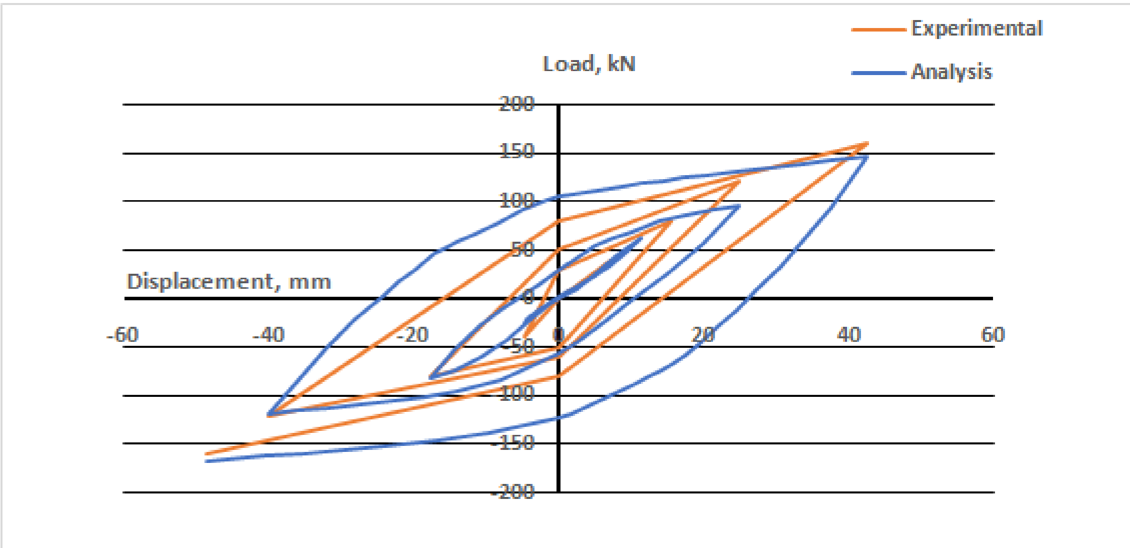

Fig. 16 Comparison between experimental hysteretic loop of column B1 and the calculated from ANSYS

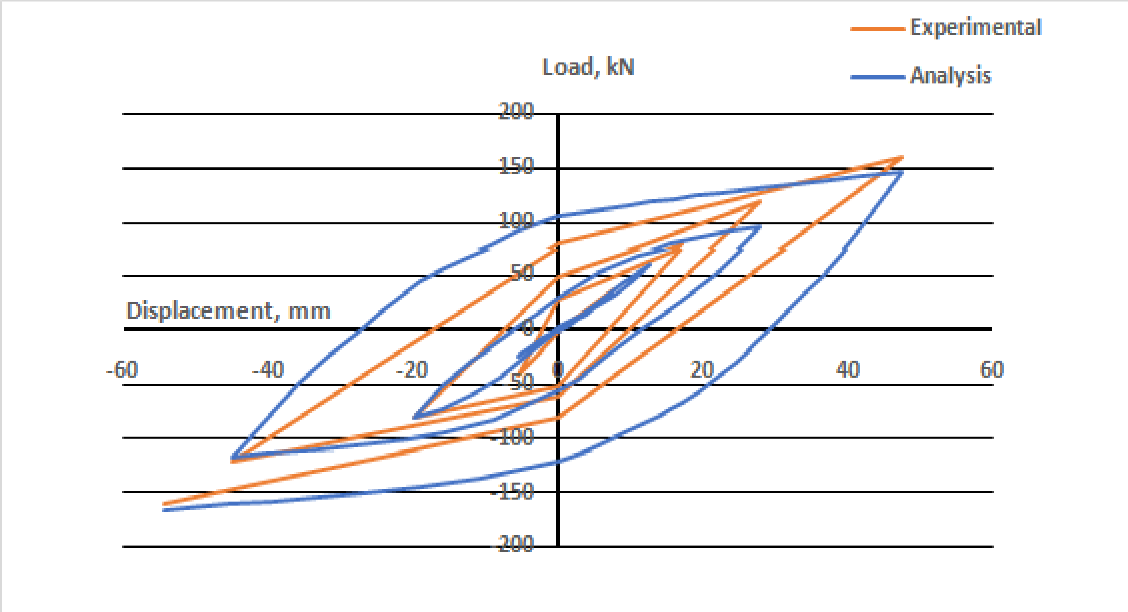

Fig. 17 Comparison between experimental hysteretic loop of column B2 and the calculated from ANSYS

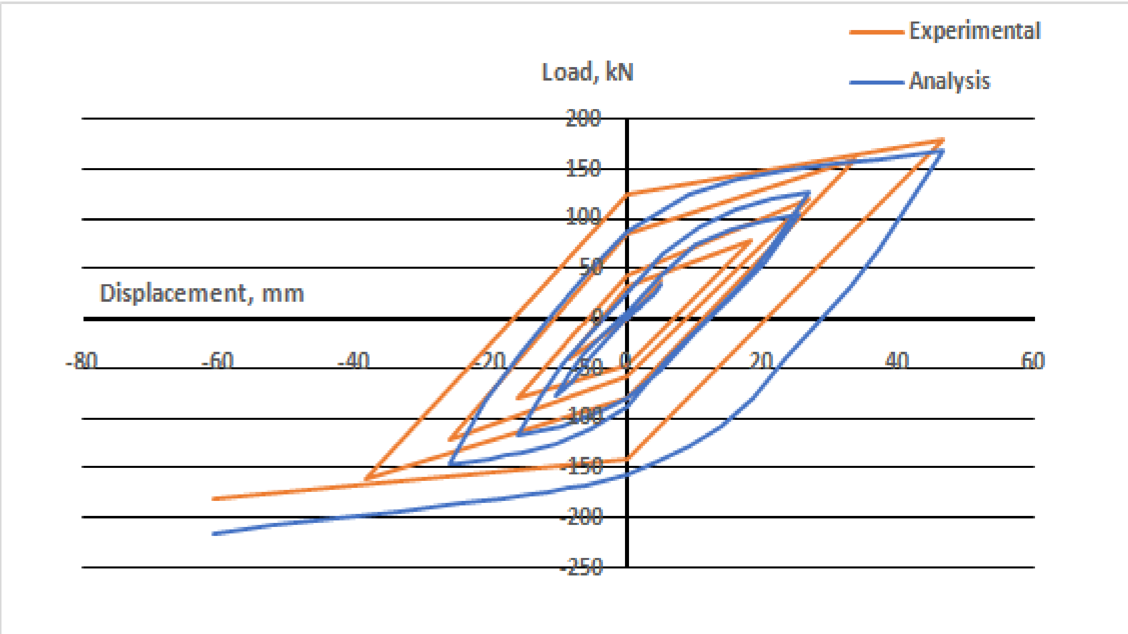

Fig. 18 Comparison between experimental hysteretic loop of column B3 and the calculated from ANSYS

IV. CONCLUSION

The behavior of composite cold formed steel columns under axial and lateral loads has been investigated in this study. Series of laboratory tests has been led to assess the adequacy of the column cross section, fastener spacing and fastener length on column behavior. In view of the test information got, the following conclusion are drawn:

- The comparison values between ANSYS Workbench and the experimental lateral cyclic load tests was in great understanding. It tends to be inferred that the behavior of composite columns can be anticipated from the FEM programs.
- The specimen consists of 2 sigma section covered with plate with 100 mm vertical spacing between fasteners showed more lateral load capacity than specimen with 2 C, this indicated that the use of sigma section much better than ordinary section because of the web and flange for the sigma section are both stiffened.
- The specimen with embedded fasteners length of 50 mm showed more load carrying than specimen with 30 mm embedded fastener length by 13% due to the embedded fastener length increases the bond between steel section and concrete.
- The highest capacity in carrying the lateral load is found in column A2 consists of 2 sigma cold formed section covered by 2 plates connected together using 2 fasteners with length 30 mm in row each side and vertical spacing of 100 mm.

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