STRUCTURAL PERFORMANCE OF DETACHABLE STEEL COLUMNS WITH BOLTED-FLANGE CONNECTIONS USING FEM

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Abstract - *The detachable bolted-flange connection is a new type of application for connecting the square hollow section (SHS) column or the circular hollow section (CHS) in prefabricated steel structures, which may carry the combination of bending moment and shear under dead loads, live loads, wind loads or even seismic loads. The performance of the detachable steel columns with bolted-flange connection used in the structural column is different from the pipelines connection. To investigate the structural performance of column with bolted-flange connection under different loading conditions, this study conducted by finite element analysis (FEA) of five column-to-column bolted-flange connections with different shapes, position of joint and inclination. The test agreed well with the FEA, which verifies the FEA. The influences of the different cross section, position of joint and inclination on the stiffness and strength of the column were studied, and the failure mode and mechanism of the connection were obtained.*

Key Words: Detachable Steel Column, Bolted-Flange Connection, Column to Column connection, Square Hollow Section, Circular Hollow Section, Finite Element Analysis, ANSYS 16.1

1. INTRODUCTION

Steel structures have an excellent degree of workability and it is very suitable for the industrial production and its connection through the high strength bolts. They are very easy to handle and transport by its standardized design. It helps to reduce the construction time by reducing the man power through its bolting up on site. The bolted connection are of two type, bearing type and non-bearing type. The bearing type the loads are transferred directly or through a division plate from the upper shaft while the non-bearing type, the loads are transferred through the bolts and splices. The column flanges are provided in high rise building on every two or three story. The connections are placed above on each floor levels. This helps a proper height for the connection (Green Book-SCI P358).

The aim of this paper is to investigate the bearing performance of bolted steel column-to-column connections under lateral loads, axial loads and eccentric loading by means of a method that takes into account the possibility of displacement of column from the bolted connection. The influences in bearing capacity of bolted-flanged steel column-to-column connection on the different cross section, position of joint, and the failure mode and mechanism of the joints were obtained under different loading conditions like lateral loads, axial loads and eccentric loads. The sizes of section is determined by maintaining the weight of the section constant. The connection parameters include flange thickness, bolt edge distance, flange edge width and bolt hole diameter. A significant prying action formed on the column flange surfaces, increased the bolt tension in the tensile region, and caused the bolt shanks to experience tension and bending moment. X.C. Liu et al. (2018) [1].

This study is to conduct an evaluation of strength behavior, ductility behavior, stress distribution and load-deflection by FEA with columns of square hollow section, circular hollow section, bolted-flange connections are placed on bottom and middle of the column and inclined square hollow section. The lateral loading, axial loading and eccentric loading are applied on all the cases. By analyzing the load-deflection, find out the performance of the different columns on their position of connection and inclination.

1.1 Objectives

The project focused on the performance study of detachable column to column bolted flange connection in prefabricated steel structures. An extensive parametric study was conducted on this finite element models to investigate the strength behavior, ductility behavior, load deflection and stress distribution of columns with bolted–flange connection under various shapes and position of joints and inclination on lateral, axial and eccentric loading conditions.

2. MODELLING AND ANALYSIS

The verification of finite element model of section size of each column is 200x10. All the specimens were made from IS961 steel. Twelve M20 high strength bolts were used. The bolt edge distance is 30mm, flange edge width is 55mm, flange thickness is 25mm and bolt hole diameter is 2mm. The finite element model is created in ANSYS using different element Types, Real Constants and Material Models and is assigned to respective elements of the model. The loads and boundary conditions are then applied. Next, the material properties are defined. The materials consist of structural steel and bolt, their engineering data are assigned. Table 1 shows the material property of connection elements.

Table -1: Material property of connection elements

Material	Modulus of elasticity (GPa)	Poisson's ratio	Yielding stress (MPa)	Ultimate stress (MPa)
ST345	200	0.3	345	460
M20 S10.9	200	0.3	1000	460

2.1 Boundary Condition, Contact Interactions and Loading

The column was considered fixed at the bottom. In reality, the connected components are related to each other frictionally. In the software as well, they are connected to each other frictionally with a friction coefficient of 0.2. Moreover, they are totally constrained by bond contact order instead of modelling the welds of sections.

2.2 Selected Parameters

The dimensions of the columns, flanges and stiffeners are the same in all connections. The first parametric study was change in shape of columns. Two different shape are selected they are square and circular.

The secondly changed parameter was the position of bolted-flange joint. The joints are placed on the square hollow section column at bottom and middle were selected.

Third parameter was the change in inclination on columns of square hollow section. There are two models, which one top inclined column and one bottom inclined column. For this analysis the best position of joint is taken from the above analysis.

Finally three different loadings such as lateral loading, axial loading and eccentric loading were selected for the performance evaluation like strength behavior, ductility behavior and stress distribution of different column models. The analysis was done in ANSYS software.

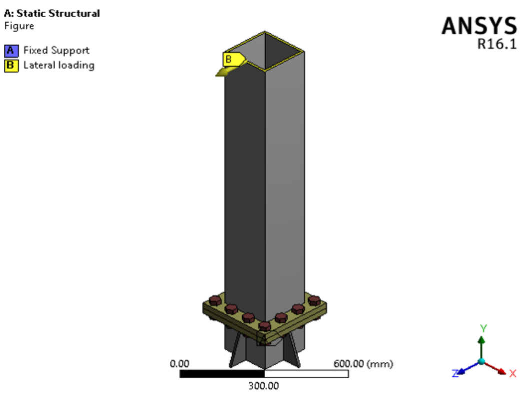


Fig -1: Boundary conditions and lateral loading

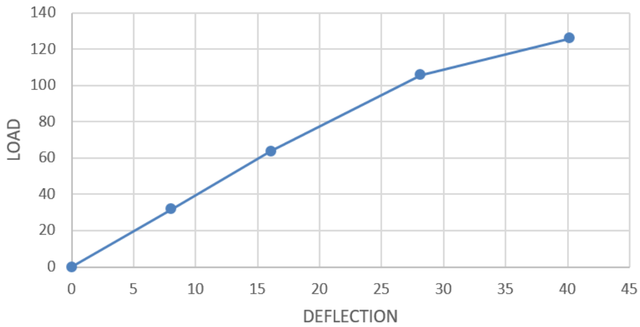


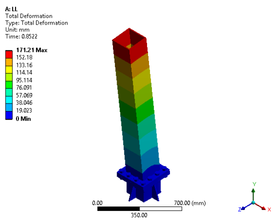
Chart -1: Load deflection curve

In the finite element software, loading was applied statically which a displacement control loading is to the top of the column up to the final loading step. Fig 2 shows the curve of the load at the bolted flanged column vs. the horizontal displacement at the top of the specimen. Then analyse the model in ANSYS Workbench 16.1.

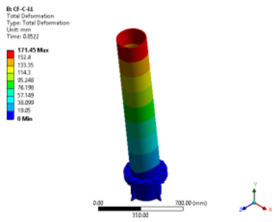
3. RESULTS AND DISCUSSION

3.1 The Performance of Change in Shape of Columns

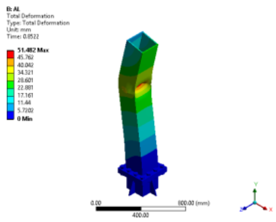
In this study, there are two models. In each model have same overall weight. The dimensions of the flange connection and stiffeners are the same in all connections. The models are different just in the shape of columns.



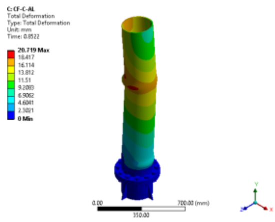
SHS - LL



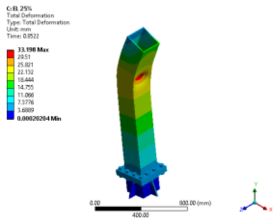
CHS - LL



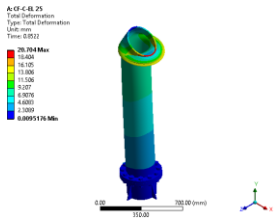
SHS - AL



CHS - AL



SHS – EL – 25%



CHS - EL – 25%

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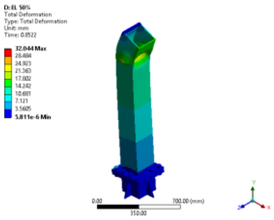

SHS - EL – 50%

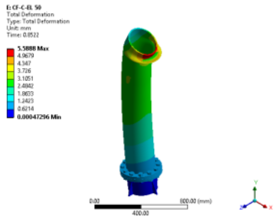
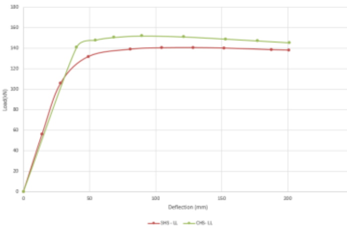
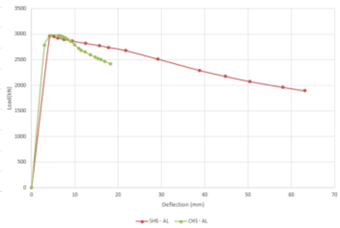
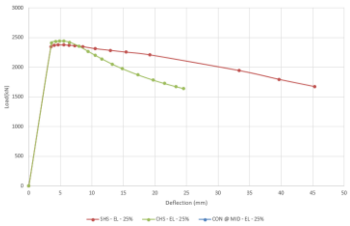

CHS - EL – 50%

Fig -2: Total deformation of SHS and CHS columns


(a) LL


(b) AL


(c) EL 25%

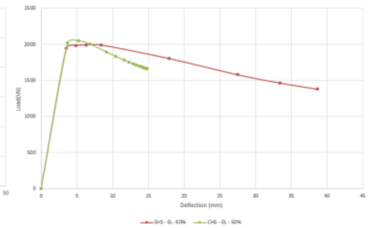

(d) EL 50%

Chart -2: Load deflection curve

Chart. 2(a) shows the load-deflection graph of the SHS and CHS column with bolted-flange connection. According to this graph the circular hollow section column with bolted-flange connection have the maximum lateral load carrying than the square hollow section column. The CHS column can carry 8% of additional lateral load than the SHS column.

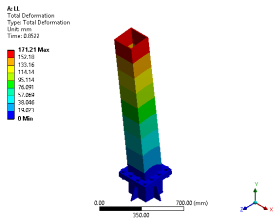
Chart. 2(b) shows the load-deflection graph of the SHS and CHS column with bolted-flange connection. According to this graph the circular hollow section column with bolted-flange connection have a slightly larger axial load carrying capacity than the square hollow section column. The CHS column can carry 0.14% of additional axial load than the SHS column.

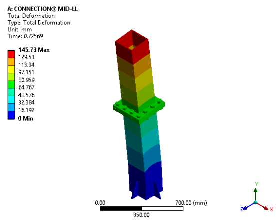
The eccentric loading is act on 25mm from the axis of the SHS column and 29mm in CHS column. According to this figure, in the bolted-flange connections is in its safe region. The column failure is happened before the connection failure. The connection is strong enough to hold both SHS and CHS column. Thus the load deflection graph (chart 2(c)) shows only a small increase (2.4%) in load carrying capacity in CHS than SHS.

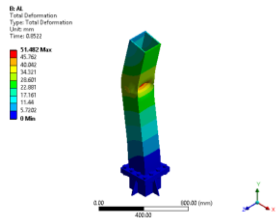
The eccentric loading is act on 50mm from the axis of the SHS column and 58mm in CHS column. According to this figure, in the bolted-flange connections is in its safe region. The column failure is happened before the connection failure. The connection is strong enough to hold both SHS and CHS column. Thus the load deflection graph (chart 2(d)) shows only a small increase (2.8%) in load carrying capacity in CHS than SHS.

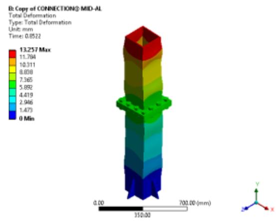
3.2 The Performance of Change in Position of Bolted-Flange Connection

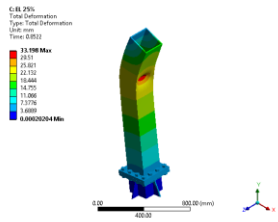
In this study, there are two models and each model have same dimensions according to their shapes. The dimensions of the flange connection and stiffeners are the same in all connections. The models are different just in the position of connections, one is on the bottom and next is on the middle. The joint is placed on 200mm and 825mm from the bottom. The overall weight of the column, dimensions of the bolted-flange connections are kept constant.

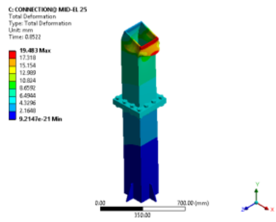

CON @ BOT - LL

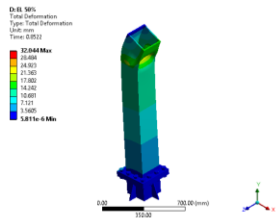

CON @ MID - LL


CON @ BOT - AL


CON @ MID - AL


CON @ BOT – EL – 25%


CON @ MID – EL – 25%


CON @ BOT – EL – 50%

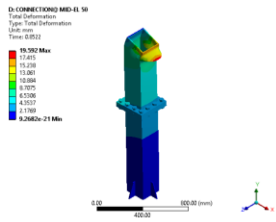
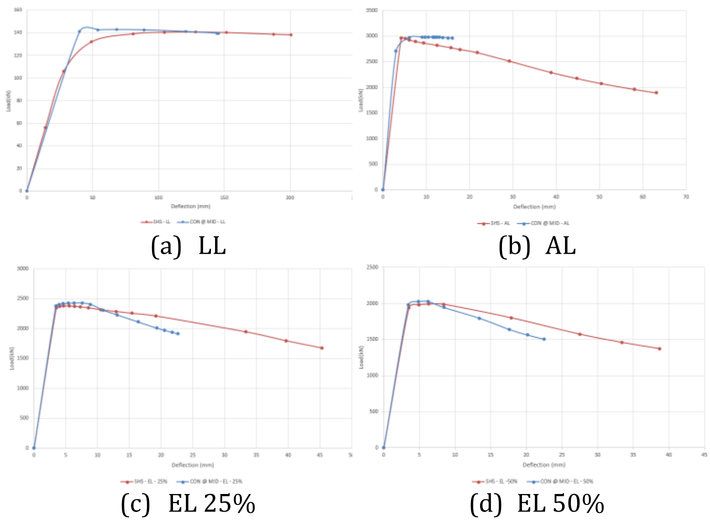

CON @ MID – EL – 50%

Fig -3: Total deformation of columns with connection at bottom and middle



(a) LL (b) AL

(c) EL 25% (d) EL 50%

Chart -3: Load deflection curve

Chart. 3(a) shows the load- deflection of bolted-flange connection at bottom and middle under lateral loading. According to this figure the connection at middle have a small increase (1.5%) in load carrying capacity than the connection at bottom.

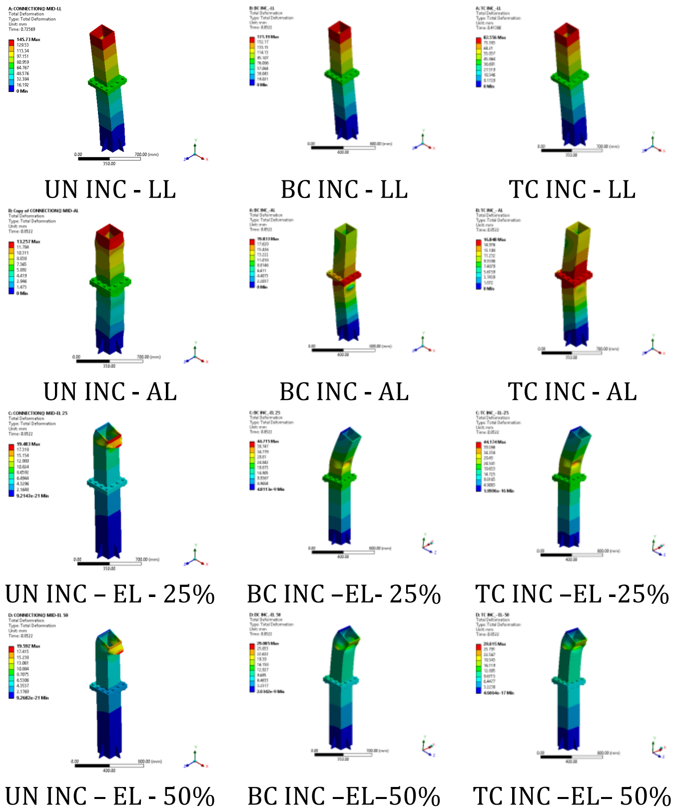
Chart. 3(b) shows the load- deflection of bolted-flange connection at bottom and middle under axial loading. According to this figure the connection at middle have almost same load carrying capacity than the connection at bottom.

On eccentric loading, the load is placed 25mm the axis of in-plane. Chart. 3(c) shows the load- deflection of bolted-flange connection at bottom and middle. According to this figure the connection at middle have a small increase (2%) in load carrying capacity than the connection at bottom.

On eccentric loading, the load is placed 50mm the axis of in-plane. Chart. 3(d) shows the load- deflection of bolted-flange connection at bottom and middle. According to this figure the connection at middle have a small increase (1.8%) in load carrying capacity than the connection at bottom.

3.3 The Performance of Change in Inclination of Columns

In this study, there are two different inclined columns are taken. In each model have same dimensions according to their shapes. The dimensions of the flange connection and stiffeners are the same in all connections. The bottom column is fixed on its base. The inclined columns are placed on different positions, they are at top and bottom of the connection respectively. Three degree of inclination is taken on columns for safe inclination.



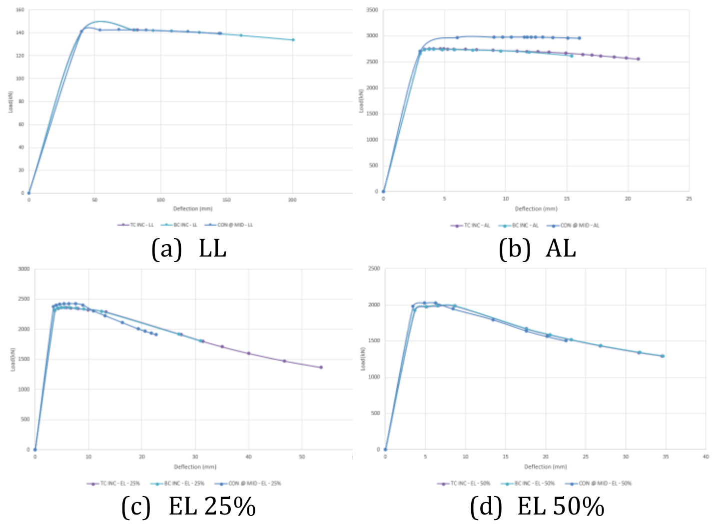
UN INC - LL BC INC - LL TC INC - LL

UN INC - AL BC INC - AL TC INC - AL

UN INC – EL - 25% BC INC –EL- 25% TC INC –EL -25%

UN INC – EL - 50% BC INC –EL–50% TC INC –EL– 50%

Fig -4: Total deformation of inclined and un-inclined columns



(a) LL (b) AL

(c) EL 25% (d) EL 50%

Chart -4: Load deflection curve

Chart. 3(a) Fig.4.20 shows the load-deflection of bolted connection of inclined and un-inclined columns under lateral loading. Only a negligible difference in load carrying capacity of columns with inclination.

Chart. 3(b) shows the load-deflection of bolted connection of inclined and un-inclined columns. Only a small difference (2%) in load carrying capacity of columns with inclination.

The eccentric load is applied on 25mm from the axis of in-plane and the inclination is taken only three degree. Chart. 3(c) shows the load-deflection of bolted connection of inclined and un-inclined columns. Only a small difference (2.5%) in load carrying capacity of columns with inclination.

The eccentric load is applied on 50mm from the axis of in-plane and the inclination is taken only three degree. Chart. 3(d) shows the load-deflection of bolted connection of inclined and un-inclined columns. Only a small difference (2.5%) in load carrying capacity of columns with inclination.

4. COMPARISON OF RESULTS

A total of five models were analyzed under different loading conditions such as lateral loading, axial and eccentric loading. In each model have same dimensions according to their shapes. The dimensions of the flange connection and stiffeners are the same in all connections.

4.1 The Effect of Columns in Lateral Load

Chart-5 presents the comparison of lateral load on all five models. According to these figure, the circular hollow section (CHS) column have the larger load bearing capacity than all other four models. The SHS column with connection at middle have larger load carrying capacity than the bottom connection. The top inclined column and the bottom inclined column have almost same load carrying capacity, it can take a small more amount of lateral load than the uninclined column.

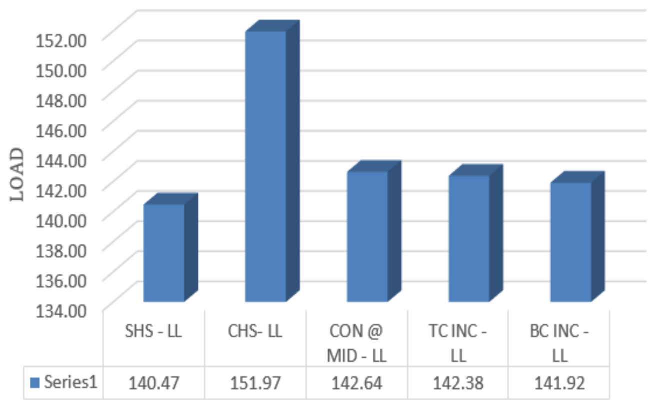


Chart -5: Comparison of load - lateral loading case

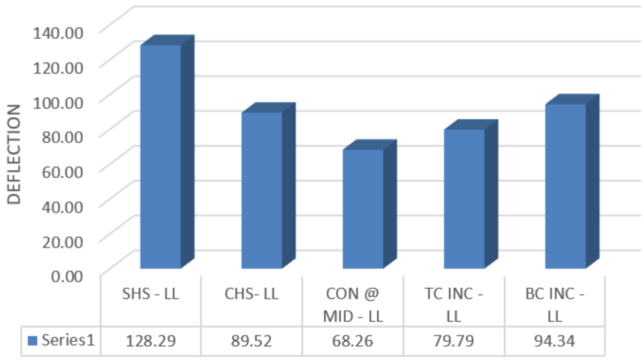


Chart -6: Comparison of deflection - lateral loading case

Chart-6 shows the comparison of deflection under lateral loading. According to this figure the SHS have a larger deflection than all other columns, so it has more ductile behavior than other columns. The CHS has a 43% of drop in deflection than the SHS. The SHS column with connection at bottom has 80% of more deflection than the column with connection at middle. The bottom inclined column has larger deflection than the top inclined column and uninclined columns.

4.2 The Effect of columns in Axial Load and Eccentric Load

Axial loading is the loading with eccentricity zero. Chart-7 presents the comparison of axial and eccentric load on all five models. According to these figure, the axial load in SHS and CHS have almost same value, the column with inclination have a 7% decrease in loading capacity. All columns have almost same load carrying capacity with eccentric loadings at 25% and 50%.the load carrying capacity of inclined columns may be decreases with the increase in inclination of top and bottom columns.

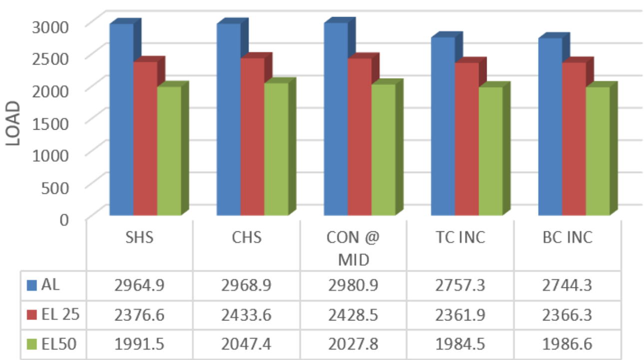
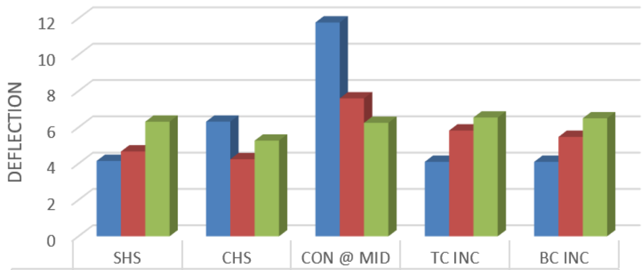


Chart -7: Comparison of load - axial and eccentric



	SHS	CHS	CON @ MID	TC INC	BC INC
AL	4.1553	6.3155	11.778	4.1031	4.1026
EL25	4.6732	4.2474	7.5977	5.8273	5.4765
EL50	6.3146	5.2695	6.2487	6.5427	6.4995

Chart -8: Comparison of deflection - axial and eccentric

Chart-8 shows the comparison of deflection under axial and eccentric loading. According to this figure the SHS with connection at middle have a larger deflection than all other columns, so it has more ductile behavior than other columns. The inclined and uninclined column has almost same deflection.

5. CONCLUSIONS

The following conclusions may be drawn from the Finite Element Analysis (FEA) performed on five columns with flange connections, the following conclusions were obtained by using finite element analysis software ANSYS Workbench 16.1.

• On the performance evaluation of five different columns lead to a conclusion that circular hollow section have the maximum strength than the square hollow section.
• The location of bolted flange connection joint of square hollow section column on the middle have larger load bearing capacity than in bottom.
• The load carrying capacity decreases with inclination of columns.
• The inclined top column is safe than the inclined bottom column.
• The inclination of columns lead to the failure of columns.
• The square hollow section column has taken more deflection than the circular hollow section column.
• The square hollow section column with connection at bottom take double the deflection than the connection at middle.
• There may be a performance change will happen, when the application of load may be on out-plane side or variation in angle of inclination from 4 degree to above.
• The column is failure in all the conditions, the joint is not at all intact.

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