International Journal of Scientific & Engineering Research Volume 10, Issue 5, May-2019
ISSN 2229-5518

Finite element analysis of innovative single skin strengthened corrugated column subjected to axial and eccentric loading

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Abstract— Recent days it has been a growing trend of replacing conventional structural elements by innovative components to achieve more strengthen infrastructure. For example lighter steel structures are used to the heavier ones as alternative material. With the development of steel as a construction material, the varieties of steel sections were also increased. Among these sections, the Hollow Structural Sections (HSS) were the most reliable one to make lighter. Many researches have been carried out of corrugated web beam and girders, but fewer amounts of research for corrugated column. In this project, the analysis of corrugated hollow steel column by using ANSYS software was done by evaluating the effect of corrugation angle under weight constant ,effect of corrugation angle under section constant and effect of column height subjected to axial and eccentric loading condition and also checks its ductility and load carrying capacity by strengthening the corrugated hollow column.

Index Terms Axial loading ,Conventional column, Corrugated hollow steel column, Eccentric loading, FEA, High strength steel tubes, Strengthening .

1 INTRODUCTION

Recent days, lighter steel structures are widely used in building and construction industry. The main advantages of steel structures over reinforced concrete structures are its high strength, prefabrication and quicker transportability to the site and faster erection. With increased use of steel, the varieties of steel sections are used.

Among these sections, the Hollow structural sections (HSS) are most reliable one. A hollow structural section is a type of metal profile with a hollow cross section. HSS members can be circular, square, or rectangular sections. The extensive use of thin-walled steel structural systems in the construction industry is mostly indebted for their high strength to weight ratio attributes and remarkable fabrication versatility. Corrugated plates fall in this category and also have a wide range of application in various engineering fields. They are lightweight, economical, and have higher load carrying capacities than flat plates, which ensure their popularity and have attracted research interest since they were introduced. The corrugation shape provides continuous stiffening property which permits the use of thinner plates. A corrugated plate can easily be bent in one direction, whereas it retains its rigidity in the other direction. Corrugated steel is a building material composed of sheets of hot-dip galvanized mild steel, cold-rolled to produce a linear corrugated pattern. The corrugations can increase the bending strength of the sheet in the direction perpendicular to the corrugations, but not parallel to them. Normally each sheet is manufactured longer in its strong direction. Corrugated steel is lightweight and easily transported. It was and still is widely used especially in rural and military buildings such as sheds and water tanks.

Fabrication costs for elements with corrugated panels are normally lower than those with stiffened plates. It is also worth noting that limited research has been conducted on the structures consisting of corrugated shells. From the other side, although corrugated plates have been studied either individually or implemented in girders web, they have never been used in fabricating of hollow columns. Therefore, for better understanding of performance of the proposed innovative corrugated columns, numerical study was done.

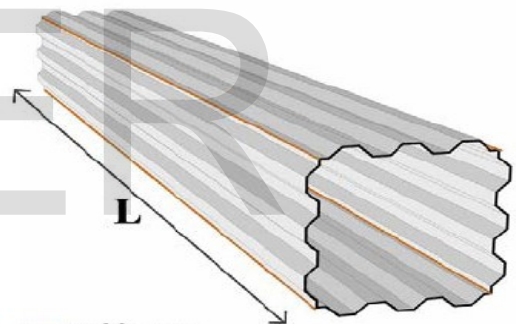

Fig 1: Corrugated column

2 ANALYTICAL STUDY

2.1 Material properties

The material used for the analysis of corrugated column is steel of yield strength 250MPa. The properties are given below:

Table 1:Material properties

Material	Steel
Density	7860 kg/m^3
Modulus of elasticity	2x10^5 MPa
Poisson's ratio	0.3
Yield strength	250MPa
Bulk modulus	1.66677x10^{11} Pa
Shear modulus	7.6923x10^{10} Pa

2.2 Section properties

The types of corrugation profiles are sinusoidal, triangular, trapezoidal, rectangular and square. In this study trapezoidal corrugation profile is selected. The thickness of corrugated sheet is 3mm, four different corrugation angles taken as 75^0,60^0,45^0,30^0 and corrugation depth of 15mm is considered. The innovative column is a square column of size 210x210mm and height of 1m.

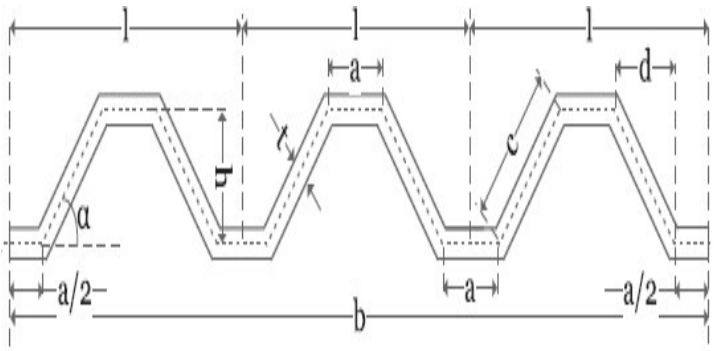

Fig 2: Trapezoidal corrugated sheet cross-section and dimension notations [3]

Table 2 : Corrugation dimension parameters (mm)

	α (^{0})	a	h	t	l	d	c	b
Type I	75	43.59	15	3	70	4.02	15.53	210
Type II	60	32.67	15	3	70	8.66	17.32	210
Type III	45	21.63	15	3	70	15	21.21	210
Type IV	30	8.04	15	3	70	25.98	30	210

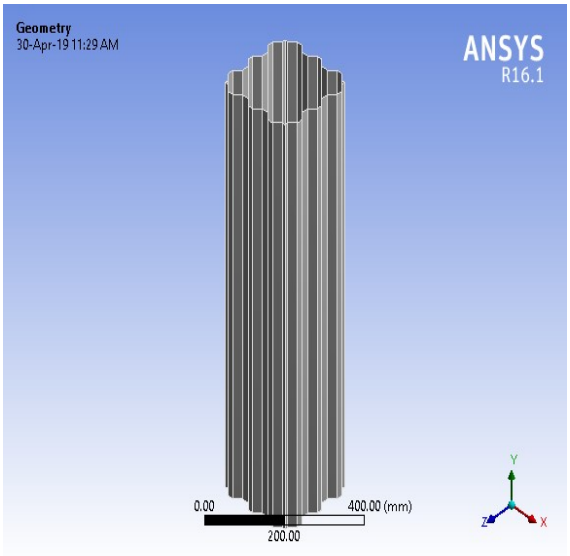

Fig 3: Model of corrugated column from software

2.3 Loading Condition

There is two types of loading condition are used .They are axial and eccentric loading.

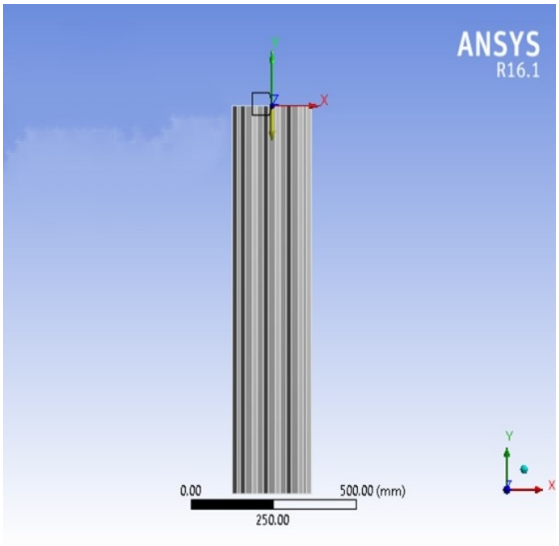

Fig 4: Model of axial loading condition

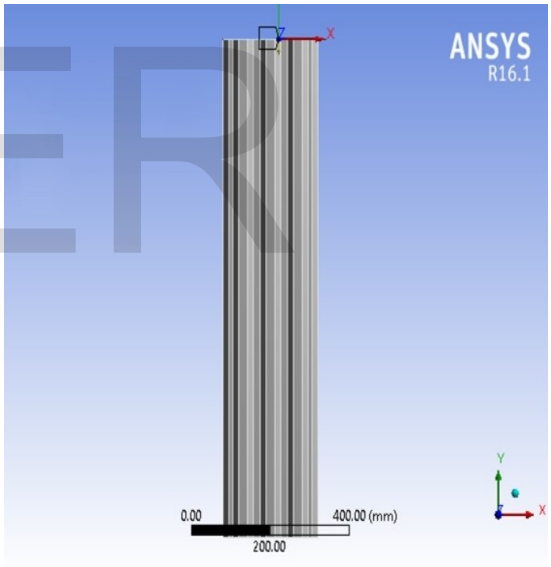

Fig 5: Model of eccentric loading condition

3 RESULT AND DISCUSSIONS

3.1 Parametric Study –Axial Loading

In this work numerical study is done to know the performance of innovative corrugated column subjected to axial and eccentric loading. The finite element models are created using ANSYS software. SHELL 181 element is used to mesh the corrugated column. The grade of steel is kept constant in all models. The load carrying capacity is obtained from ANSYS.

The parametric study is conducted to know the influence of different parameters on load carrying behavior of innovative column. There are four parameters are taken into consideration. They are effect of corrugation shape constant, effect of corrugation depth constant, effect of length to depth ratio, effect of column height. And the specimens tested under axial and eccentric loading conditions. Then the conventional corrugated column strengthened by two ways. They are by using high strength steel pipes at the corners and by increasing the thickness of sheet.

3.1.1 Corrugation Shape Constant

The angle of corrugations selected as 75^0,60^0,45^0 and 30^0 .The weight of section and corrugation depth is also varying. From this study 75^0 corrugation angle got better load carrying capacity. But it may be due to the high weight of 75^0 section.

Table 3 : Corrugation shape constant

Description	Deflection (mm)	Load (kN)
CSC 75	10.649	1596.40
CSC 60	7.8843	994.53
CSC 45	8.025	808.75
CSC 30	3.9625	687.26

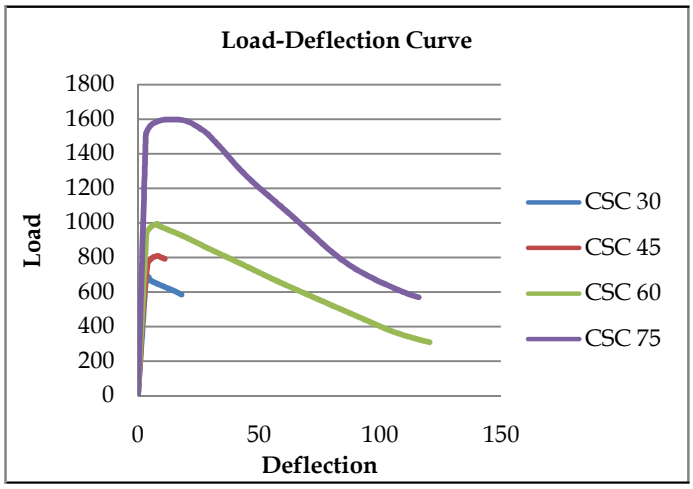

Fig 6 : Load Vs deflection curve of corrugation shape constant study

3.1.2 Corrugation Depth Constant

The angles of corrugations selected are 75^0,60^0,45^0 and 30^0 .The weight of section and corrugation depth is kept constant in this study. From this study 45^0 corrugation angle shows better performance than 75^0, 60^0 and 30^0. When the inclination increases the performance decreases.

Table 4 : Corrugation depth constant

Description	Deflection (mm)	Load (kN)
CDC 75	6.4884	766.26
CDC 60	13.894	953.29
CDC 45	17.788	960.6
CDC 30	6.2673	746.21

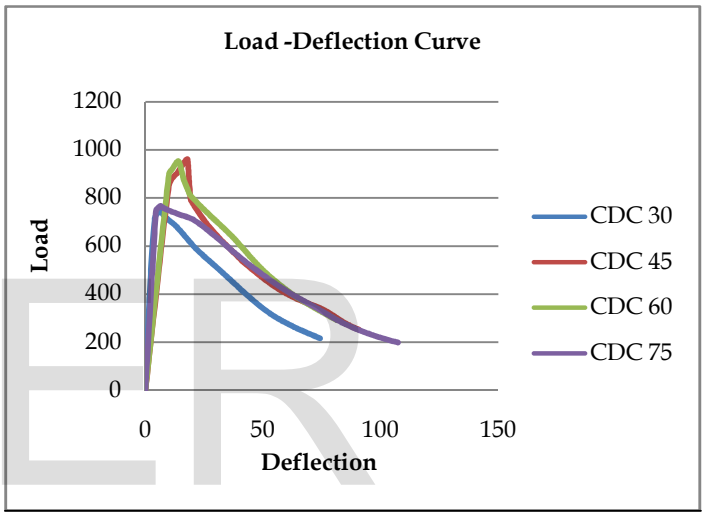

Fig 7 : Load Vs deflection curve of corrugation depth constant study

3.1.3 Length to depth ratio

This study is carried out by changing the L/D ratio. In each model the height of model is also changed. The height changed up to maximum 2.52m. L/D ratio of 4.76 has higher strength than others. i.e., column with height of 1m.

Table 5 : Length to depth ratio

Description	Deflection (mm)	Load (kN)
L/D 12	11.75	763.15
L/D 10	15.137	791.24
L/D 8	12.465	794.65
L/D 6	22.238	951.21
L/D 4.76	17.788	960.6
L/D 2	7.381	954.26

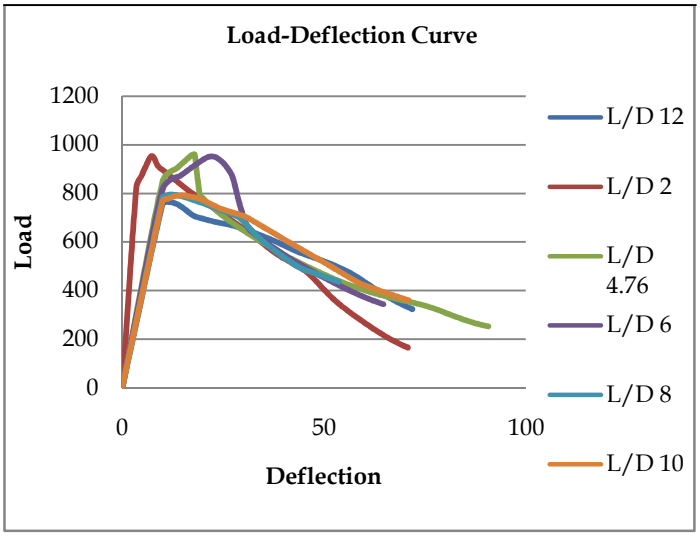

Fig 8 : Load Vs deflection curve of L/D ratio study

3.1.4 Effect of column height

This study is done by changing the column height from 1000mm to 8000mm. The height chooses are 1000mm, 2520mm, 4000mm, 6000mm and 8000mm. The load carrying capacity decreases with increasing column height.

Table 6: Effect of column height

Description	Deflection (mm)	Load (kN)
L 1000	17.788	960.60
L 2520	11.75	763.15
L 4000	17.788	756.90
L 6000	35.604	779.81
L 8000	44.091	761.70

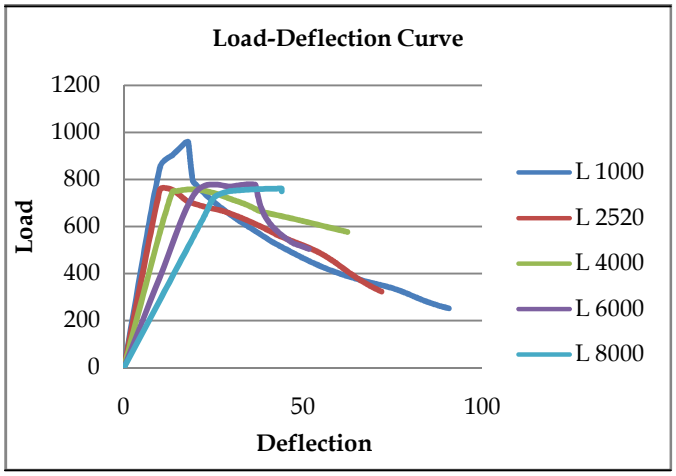

Fig 9 : Load Vs deflection curve of column height study

3.2 Strengthening of corrugated column

Strengthened the corrugated column by two ways;

- By using high strength steel pipes of yield strength 345 MPa, diameter 76.1mm and thickness 3.2mm .
- By increasing corrugation thickness to 5.35mm from 3mm.

The weights of both sections are made constant.

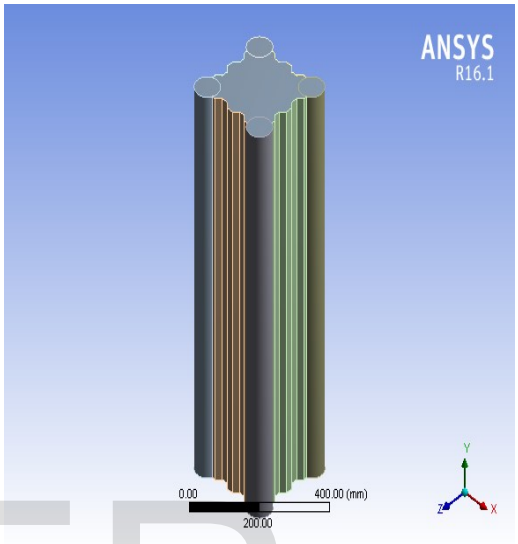

Fig 10: Model of corrugated column with HSP

Table 7 : Strengthening of corrugated column

Description	Deflection (mm)	Load (kN)
S HSP	16.096	1474.70
S CT	16.233	1210.70

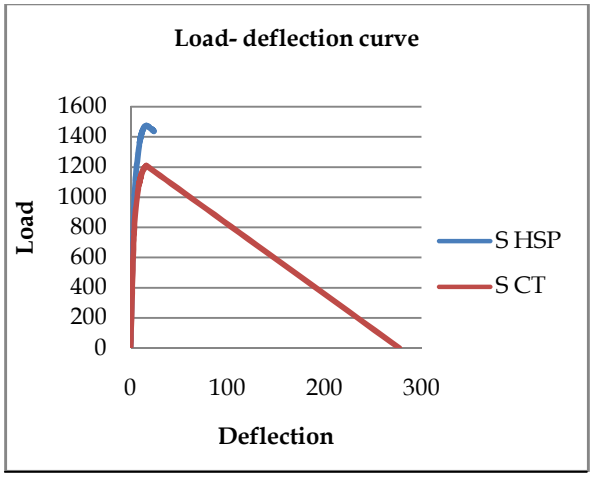

Fig 11: Load Vs deflection curve of strengthened columns

3.3 Eccentric loading

When the load acting on the column is away from the centroid , then it makes bending of column. This is called eccentric loading. The loading is done in the model of corrugation angle 45^0, corrugation depth 15mm, L/D ratio 4.76 and column height 1m. Three different percentages of eccentricities are applied, they are 0%, 10% and 20%.

Table 8: Percentage of eccentricity

Description	Deflection (mm)	Load (kN)
EL 0	6.1057	718.60
EL 10	6.0352	640.58
EL 20	8.4227	543.40

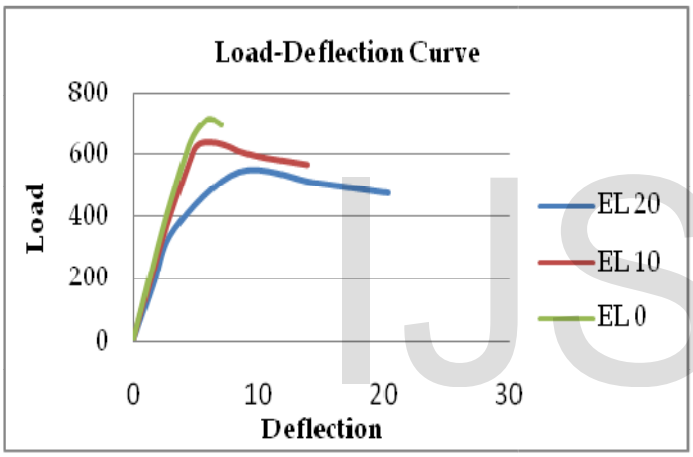

Fig 12 : Load Vs deflection curve of eccentric loading

3.4 Strengthening –effect of percentage of eccentricity

3.4.1 Strengthening using High strength steel pipes – effect of percentage of eccentricity

When the percentage of eccentricity increases the load carrying capacity decreases. The column with high strength steel pipes under zero percentage eccentricity have good strength than conventional corrugated column.

Table 9 : Strengthening using HSP – effect of percentage of eccentricity

Description	Deflection (mm)	Load (kN)
S HSP EL 0	16.096	1474.70
S HSP EL 10	27.378	1412.90
S HSP EL 20	34.419	1332.30

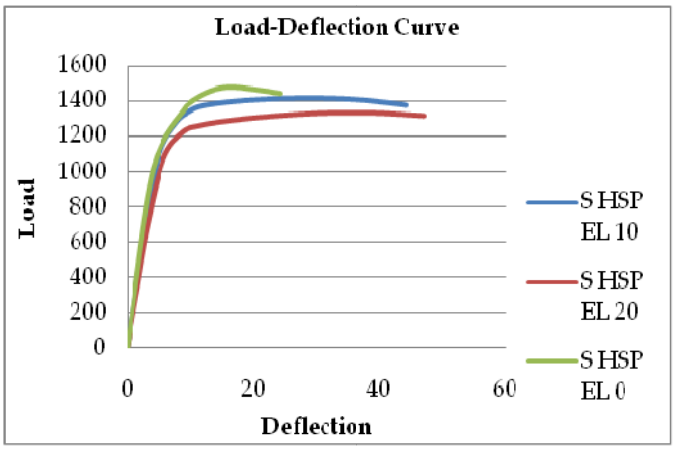

Fig 13 : Load Vs deflection curve of HSP column under eccentricity

3.4.2 Strengthening using corrugation thickness – effect of percentage of eccentricity

The strength or load carrying capacity decreases with increase in percentage of eccentricity. By increasing the corrugation thickness to 5.35mm ;the load carrying capacity increases than conventional corrugated column. But in the case of strengthening ; column with high strength steel pipes have higher strength than column with increase in thickness.

Table 10 : Strengthening using corrugation thickness – effect of percentage of eccentricity

Description	Deflection (mm)	Load (kN)
S CT EL 0	16.233	1210.70
S CT EL 10	16.63	1162.10
S CT EL 20	9.0301	1020.60

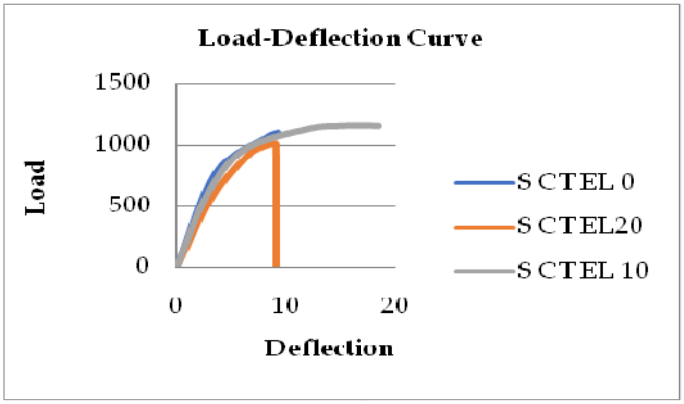

Fig 14 : Load Vs deflection curve of thickness increased column under eccentricity

4 Conclusion

From this work it is understood that the corrugated column have good load carrying capacity and better ductility.

On the parametric study of section constant under axial loading by varying the angles 75^0 shows better load carrying capacity than 60^0,45^0,30^0. But in this case the weight of section and corrugation depth is varying .So, in this case the influence of weight may be come. The next study conducted with depth constant by varying angles .From this 45^0 got better performance .In this case the weight made constant. In the study of changing L/D ratio , height of section is varying. When height increases the load carrying capacity decreases. L/D ratio 4.76 shows better performance. When studying the effect of column height ,when height increases the load carrying capacity decreases like 20.55%, 21.21%, 18.82%, 20.70% for 2.52m, 4m, 6m and 8m respectively.1m have best performance.

Then strengthened the corrugated column for improving ductility and load carrying capacity by two ways, i.e., using high strength steel pipes and using corrugation thickness. From that analysis using high strength pipes gives effective performance rather than using corrugation thickness under axial loading.

By comparing conventional corrugated column and strengthened columns, corrugated column with high strength steel pipes have 34.86% and column strengthened using corrugation thickness have 15.61% higher load carrying capacity than conventional column under axial loading .

On the eccentricity study of 45^0 angle , it is understood that when eccentricity increases like 10%, 20% the load carrying capacity decreases like 20.55%, 21.20% respectively. 0% eccentricity shows better performance. In the case of corrugated column with high strength steel pipes for eccentricities 10% and 20% , performance decreases like 4.19% and 9.65% respectively. Eccentric performance on column which is strengthened with corrugation thickness ,it is found that for 10% and 20% load carrying capacity decreases like 4.01% and 15.70% respectively.

By overall study it is found that rather than increasing thickness of the model alternatively changing the design by implementing the corner strengthening of the structure which gives the best result in the axial as well as eccentric performance.

ACKNOWLEDGEMENT

I wishes to express my sincere thanks & gratitude to all people who have helped directly or indirectly for the completion of this project work.

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