PERFORMANCE STUDY ON LATERAL IMPACT REPONSE OF OCTAGONAL COLUMNS AND STRENGTHENING WITH PARTIALLY AND FULLY STIFFENED CONDITION

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Abstract - Columns are critical elements of any structure and their failure can lead to the disastrous consequences of progressive failure. The failure of these supporting structures, as a result of impact, may lead to progressive collapse. The study of impact test in the column helps to determine the parameters of the column to design properly. In this study, a comparative study has been carried out, with and without the column stiffeners, in which the number and height of stiffeners varied and are modelled and analyzed using ANSYS 16.1. All the analytical models have been subjected to impact loading. Various behaviours in terms of total deformation, load carrying capacity and stress of column were discussed. The effects of vertical and horizontal stiffeners on the performance of strengthening of hollow octagonal column were studied.

***Key Words*: Rectangular hollow steel column, Finite Element Analysis, Finite Element, Impact response study, Octagonal steel hollow column, Parametric study, partially and fully filled stiffener.**

1. INTRODUCTION

Columns are critical elements of any structure and their failure can lead to the disastrous consequences of progressive failure. In structural design, procedures to design structures to resist conventional loads are well established. Among many accidental causes that induce column failure, impact (e.g. vehicular impact, ship impact, crane impact, impact by flying debris after an explosion) has rarely been considered in the modern engineering designs of civil engineering structures such as buildings and bridges. This paper aims to develop more accurate methods of assessing steel column behaviour under impact loading. The first main objective of this study is to numerically simulate the dynamic impact response of laterally loaded steel columns under impact loading, including the prediction of failure modes, using the finite element method. The design demand for structures to withstand impact load has increased, and steel column members are expected to effectively improve structural impact resistance. The column specimens were placed vertically. The lateral impact loads were conducted at a height of 320 mm from column bottom by an Impact indentor.

1.1 RELEVANCE OF STEEL STRUCTURES

Steel is one of the most generally utilized materials of construction time. Without the use of steel, the structure doesn't make a solid while seismic vibrations like earthquakes Etc. happen. Steel structures are vulnerable to various ecological conditions. There are a few properties wherein solid structures are preferred over steel and the utilization of steel is continuously expanding everywhere throughout the world in development projects. Each steel structures have some advantages as well as disadvantages. Steel sections provide an elegant, cost-effective method of spanning long distances. Extended steel spans can provide large, open plan, column free internal spaces.

1.2 IMPACT RESPONSE STUDY

This study aims to develop more accurate methods of assessing steel column behaviour under lateral impact loads. The first main objective of this study is to numerically simulate the dynamic impact response of lateral loaded steel columns, including the prediction of failure modes, using the finite element method. To achieve this goal, a numerical model has been proposed and validated to simulate the behaviour and failure modes of laterally loaded steel columns under rigid body impact using the commercial finite element analysis and the Explicit dynamics. Afterwards, an extensive parametric study was conducted to provide a complete database of results involving different column height, impact velocities and impact locations (front impact and corner impact) in addition to different section sizes. The parametric study results have revealed that column failure was mainly dependent on the value of the kinetic energy of impact. The parametric study has also shown that strain rate has a minimum effect on the behaviour and failure of steel columns under low to medium velocity impact. The parametric study results have been used to develop an understanding of the detailed behaviour of steel columns under lateral impact in order to conform the assumptions of the proposed analytical method.

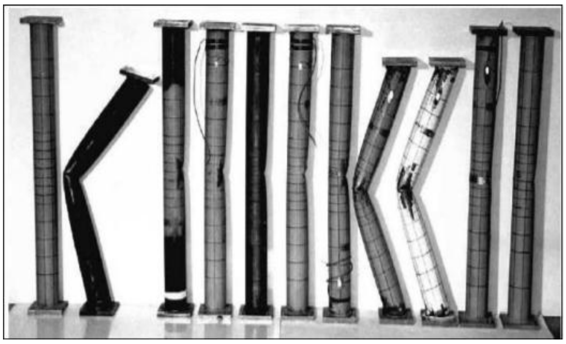

Fig-1. Examples for deformed column under different kinds of impact

2. OBJECTIVES OF THE WORK

- To study the failure modes of column when it is subjected to different kinds of impact or loading.
- To conduct parametric study on columns with variations in height and thickness of steel column
- Strengthening of columns using partially and fully stiffened condition
- To conduct comparative study on columns with and without Stiffeners

3. GEOMETRIC DETAILS

The Explicit dynamics was done in ANSYS workbench 16.1 software for the impact over the rectangular hollow steel tube columns. A column specimen of 1500mm height and stiffener size 60mm were taken for the modeling. The FE model mainly includes four components, namely column, impact indentor, stiffeners and bolts. The column, end-plate, and bolts were modeled using solid186 element.
The dimensions of member sections are shown in Table-1.

Table -1: Geometric details

Geometric details	Dimensions
C/S dimension	140x8x3
Height	1500 mm
Height of impact location	320 mm
Inner radius of cold formed steel	4.5 mm

A non linear analysis was done in ANSYS workbench 16.1 software. The column, impact indentor web stiffener, end-plate stiffener and bolts were modeled using solid186 element and the meshes used are triangular and rectangular mesh. The material properties of column are shown in Table-2.

Table -2: Material properties of model

Young's modulus	200 GPa
Yield stress	540 GPa
Poisson's Ratio	0.3
Density	7850kg/m^3

4. LOADING AND BOUNDARY CONDITION

Fixed and pinned boundary conditions were respectively applied to the lower and upper end plates of the specimen. Here into, the lower end plate was fixed to the base plate using a bolted connection. At the upper end plate of the specimen, the displacement along the front impact direction was restricted using the displacement restricting structure, as shown in Fig 2,

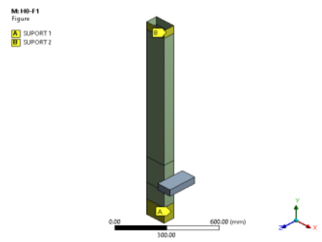

Fig-2. Boundary conditions

5. RESULTS OF FINITE ELEMENT ANALYSIS

The results obtained from the ANSYS are compared with the numerical analysis and experimental results from the reference journal. The results of simulation are represented in terms of displacement verses time curves. The obtained result is shown in Fig 3. The comparative result from journal paper and FE analysis using Ansys 16.1 are also shown in Fig 3. An indentation of the steel tube appeared on the front wall, and remarkable buckling appeared on the side walls. Given that the impact indentor had a larger width (200 mm) than the specimen (140 mm), the deformed side walls were continuously impacted by the indentor during the impact process. Thus, the original buckling expanded, causing obvious changes in the width (w) and depth (d) of the cross-section at the height of 320 mm. The width of 140 mm and depth of 80 mm changed to 182 and 48 mm for the specimen H0-F1. For the RHST specimens under front impact, the failure modes were dominated by a combination of local buckling and global flexural deformation. Given the higher initial position of the impact hammer that resulted in larger impact energy.

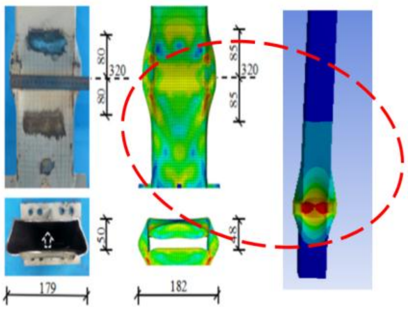

Fig-3. Deformation pattern of the model during test and FEA

The maximum load and the corresponding deformation obtained was 117kN and 38.93 mm. The validation results conducted on software obtained a maximum load of 118.8kN and corresponding deformation as 41.2mm. By comparing experimental results and finite element analysis results by means of load carrying capacity of column, a percentage variation of 5.83%and 1.53% was found.

6. PARAMETRIC STUDY ON HOLLOW STEEL COLUMN

The main advantage of the circular cross-section is the high structural efficiency which can resist the local buckling while the rectangular cross-section has a better constructability as the flat sides can provide more design options for the beam-column connections such as bolted connection with end plate. Octagonal hollow section which is somewhere between circular and square hollow section can achieve both advantages in circular and rectangular steel tubes especially in large-scale columns. Octagonal steel tubes have already shown its high constructability in transmission poles and telegraph towers. Octagonal columns provide extreme versatile combination of mounting heights, base types and outreach options making it the most widely used range of columns. The parametric study was conducted on the octagonal column by varying its height, external diameter and the thickness and analyses the influence on load carrying capacity and deformation of the selected specimens.

- More resistant to buckling when compared to rectangular and circular cross sections.
- No weak corners no stress concentration.
- The resistance of bending or deflection of an octagonal cross section is higher than a circular and rectangular cross section.
- The peculiarities of octagonal cross section are above the rectangular and circular cross section.

An important objective of this study is to develop a thorough understanding of the effects of different parameters on the response and failure modes of axially compressed steel columns under lateral impact. This can then enable simple methods of analysis to be developed so that complicated numerical analyses such as the ones employed in this study may be dispensed with within the practical design procedure. On the other hand, simplifying assumptions will be necessary when developing any design calculation method, and it is evident that such assumptions are based on a complete understanding of the effects of different parameters on column behavior and failure modes This particular chapter presents the results of a parametric study to investigate the effects of several parameters on the response of laterally loaded steel columns under transverse impact by a rigid mass. The following three important parameters have been identified for investigation in the parametric study presented in this chapter.

1) The column slenderness ratio (section size and column length).

2) The Thickness of the column

6.1 SUDY OF PARAMETERS BY VARYING HEIGHT OF COLUMN

A total of six specimens were modeled by changing the height of the steel tube. The thickness and external diameter of the steel tube is kept constant in all the models. The models are shown in Fig 4 and the size details are given in Table 3.

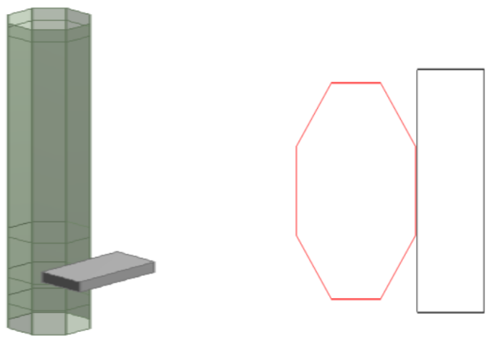

Fig-4: Model of octagonal column and the impact indentor

6.2. FINITE ELEMENT ANALYSIS RESULT OF THE STUDY

A column is generally designed as a compressive member. Compression members are structural elements that are pushed together or carry a load more technically they are subjected only to axial compressive forces. That is, the loads are applied on the longitudinal axis through the centroid of the member cross section, and the load over the cross sectional area gives the stress on the compressed member. Lateral load capacity is one of the major factors that are considered while designing a column. During Lateral loading long columns undergo lateral deflection and buckling. The failure modes of both the columns are global buckling with smooth residual bending deformation. The deformation from lateral loading is shown in chart 2

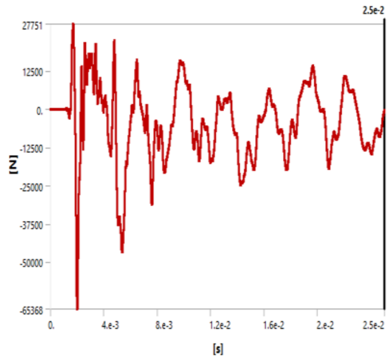

Chart 2-Impact Force Impact Time Curve (3000 mm)

Table -3: Load and Deformation of columns with varying height

specimen	Height(mm)	Max load (Kn)	Max deformation(mm)
1	1500	64.85	56.194
2	2000	62.62	54.694
3	2500	29.75	55.457
4	3000	27.75	53.472
5	3500	41.3	53.729
6	4000	45	53.766

6.3 STUDY OF PARAMETERS BY VARYING THICKNESS

From the above chapter, it is found that the columns with variation in height does not show much change in properties of load carrying capacity and resistance to deformation so, there done the next parametric study by changing thickness of the steel and analyzing the properties. Different models are studied with varying thickness of steel tube. Its structural and impact response studies are investigated. The columns are provided with the thickness of 3 mm and 6 mm and the impact load was applied in the column with the geometric characters given in the table. The Influence of diameter to thickness ratio is found out. The geometrical specifications are given in Table 4 given below.

Table -4: Load and Deformation of column

Column height	thickness	diameter	D/t ratio
1500	3	153	20
1500	6	153	10
4000	3	178	20
4000	6	178	10

6.4. RESULTS OF FINITE ELEMENT ANALYSIS

The columns were studied with various thicknesses. Its Load carrying capacity and deformation behavior is examined, by using the D/t ratio. The columns were subjected to lateral loading. The load carrying capacity of column under impact load and structural conditions are studied. The table 5.2 given below shows the values obtained and its graphical representation is given below in fig.5. As we can analyses that the columns with diameter to thickness ratio lesser shows high load carrying capacity and less deformation when compared to other columns.

Table -5: Load and Deformation of column with varying thickness

Column height	D/t ratio	Max load(kN)	Max deformation(mm)
1500	51.25	54.58	59.284
1500	25.5	99	25.963
4000	59.33	45	53.766
4000	29.66	116	21.658

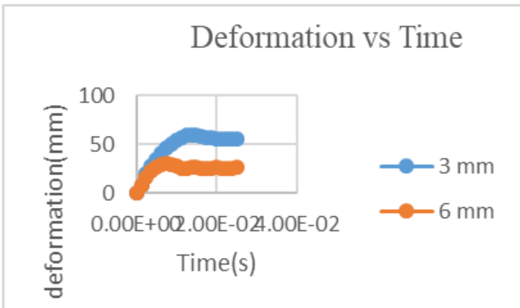

Fig 5: Deformation time graph of 1500 mm height Column with 3 mm and 6 mm thickness

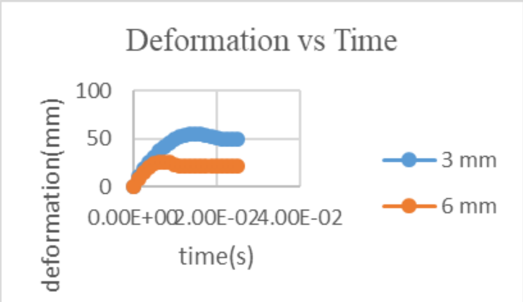

Fig 6: Deformation time graph of 4000mm height column with 3mm and 6 mm thickness.

The ultimate strength increases when diameter to thickness ratio decreases. Load carrying capacity and displacement is also enhanced by the D/t ratio. In the structure performances carried out for both columns, column 2 has increase in strength of 44.86% whereas column 4 has increase in strength of 61.20%.

7. STRENGTHENING OF COLUMNS WITH PARTIALLY AND FULLY FILLED STIFFENERS

From the above chapters it is inferred that, strengthening of column should be done in order to withstand the impact load and thereby increasing the ultimate strength and for that, here introducing the condition of filling stiffeners in the column in two different condition that is partially filling and fully filling. The provision of providing stiffeners in the hollow steel columns has proven to be an effective way to increase the lateral load carrying capacity and also to reduce the local buckling of the steel tube. The involved methods include increasing stiffener height, increasing stiffener number on each tube face, using vertical and horizontal octagonal shaped stiffeners, welding binding or anchor bars on stiffeners. It has been found that adding stiffeners to the hollow steel column is the most effective method in enhancing the ductility capacity.

Fig 7: Arrangement of stiffners in the column

The columns were modeled using the explicit dynamics and the impact load were applied at a height of 320 mm from the bottom with a velocity of 6.5 m/s. The stiffeners with 5 mm thickness also analyzed by using the same procedure then the impact force and deformation were found out.

7.1 RESULTS OF FINITE ELEMENT ANALYSIS

By using partially filled stiffener with varying in height infer that 25% filling of stiffener is appropriate and there is no large variation when the stiffener is filled in a height of 50% and 75 % of the column height. When comparing with the conventional column with column height 3000mm the column with partially filled stiffener placed vertically shows 50.49% increase in load carrying capacity and shows deformation resistance or local buckling resistance of 48% than the column without the stiffener. When comparing with the conventional column with column height 3000mm the column with partially filled stiffener placed horizontally shows 51.04% increase in load carrying capacity and shows deformation resistance or local buckling resistance of 50.12% than the column without the stiffener. Horizontal placement of stiffener shows more peculiar characteristics than vertically placed stiffener.

Load carrying capacity and deformation resistance of the octagonal column increases while using the fully filled stiffened condition. When comparing with the conventional column with column height 3000mm the column with partially filled stiffener placed vertically shows 71.3% increase in load carrying capacity and shows deformation resistance or local buckling resistance of 60.44% than the column without the stiffener. When comparing with the conventional column with column height 3000mm the column with partially filled stiffener placed horizontally shows 72.15% increase in load carrying capacity and shows deformation resistance or local buckling resistance of 60.44% than the column without the stiffener. Horizontal placement of stiffener shows more peculiar characteristics than vertically placed stiffener. The condition of stiffener which is fully filled in the column shows an increase in load carrying capacity by 30% and decrease the deformation by 20% than the partially filling method and it shows that fully filling of stiffeners is more appropriate to increase the load carrying capacity and thus the strength of the column.

8. CONCLUSIONS

In the study conducted on octagonal hollow steel column subjected to impact load its dynamic and structural analysis is conducted. Then in order to enhance the behavior of columns parametric studies are conducted with different shape study, variation in thickness of the column and changing the external diameter of the column. Then the column is strengthened by involving the stiffened condition. Then comparative studies were conducted between columns with and without stiffeners, at last all the modelled columns are compared with respect to its load carrying capacity and deformation of columns. From the studies conducted it is concluded that:

Octagonal columns have the strength to carry huge head-loads, so they are perfect for multi-fitting applications or for sports, where multiple brackets and fittings can create a challenge for traditional column types

On increasing the height of the column there shows the slenderness of the column and local buckling increases with height so that the load carrying capacity decreases and as a result deformation increases

The load carrying capacity of column increases when the thickness of column changes from 3mm to 6mm and there is 61% increase of load carrying capacity and 59% decrease in the deformation of the column when 6 mm thick column were used. So it is preferable to use 6 mm thick column for better performance. The ultimate strength increases when diameter to thickness ratio decreases. Load carrying capacity and displacement is also enhanced by the diameter to thickness ratio. In the structure performances carried out for both columns, Column 1 has decrease in strength of 44.86% whereas column 3 has decrease in strength of 61.20%.

The strengthening methods of column using stiffeners really enhance the strength and load carrying capacity of the column. Here use both conditions of stiffener filling that is partially filling and fully filled stiffened condition Load carrying capacity and deformation resistance of the octagonal column increases while using the fully filled stiffened condition

When comparing with the conventional column with column height 3000mm the column with partially filled stiffener placed vertically shows 71.3% increase in load carrying capacity and shows deformation resistance or local buckling resistance of 60.44% than the column without the stiffener

When comparing with the conventional column with column height 3000mm the column with partially filled stiffener placed horizontally shows 72.15% increase in load carrying capacity and shows deformation resistance or local buckling resistance of 60.44% than the column without the stiffener

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