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Study of Hollow Corrugated Columns with Perforations

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Abstract - *Thin walled steel structural members are nowadays used as effective alternatives for heavier reinforced concrete members or pre-stressed concrete members in many situations. Here, the mechanical behavior of 2 side plane and two side corrugated cold-formed square hollow sections, with and without perforations on two opposite plane sides is focused. For overcoming the effects of perforations, trapezoidal stiffeners are used. Experimental and analytical models were developed to examine the behavior of three different types of columns. The results obtained were compared and identified the advantages of innovative column over conventional steel columns.*

Key Words: Hollow sections, cold-formed, perforations, stiffeners, corrugations.

1.INTRODUCTION

Nowadays steel structures are more popular than concrete structures. Light weight steel or cold-formed steel seeks more attention from researchers as it is easy to handle, economic and have higher load carrying capacity. Holes are to be provided in structural members to accommodate services like electrical wirings, pipes etc. so far, many researches have been conducted on cold formed steel columns with 4 sides plane or corrugated. Most of the existing experimental and analytical data are based on stub column with holes where the strength depends on the buckling behavior and yielding of column [1-8]. The effects of certain shapes of holes like circle and rectangle on ultimate strength have also been reported [2-4]. But the use of cold-formed steel structures is limited where high ductility is required. Therefore, it has been seen that sections with high performance is needed to expand its application in various fields [9-10]. Innovative columns consisting four corrugated plates have been investigated and concluded that they have higher load carrying capacity compared to conventional columns [11].

It is important to note that very few researches have been done on the structures with cold-formed steel corrugated plates. On the other side, several investigations have been conducted on individual corrugated plates but never been used to get the behavior of structural members like beam, column etc.

Here the cold formed steel column consisting both plane and corrugated plates under compression is focused.

2. INNOVATIVE COLUMNS

In this study, innovative cold formed steel columns are those square hollow columns having two sides plane and two sides corrugated whose corners are welded to give an integrated column. The configuration of corrugation used is trapezoidal as it offers more ductility and higher load carrying capacity compared to sinusoidal profile. The length and thickness of all columns are assumed to be 1.6 mm and 700 mm respectively. Butt weld was used for the fabrication of columns at corners. Trapezoidal corrugated plates used in this current study is shown in Fig 1. Trapezoidal stiffeners are taken as a single module of the corrugated plate. The geometry dimension of corrugated plate is given in Table 1.

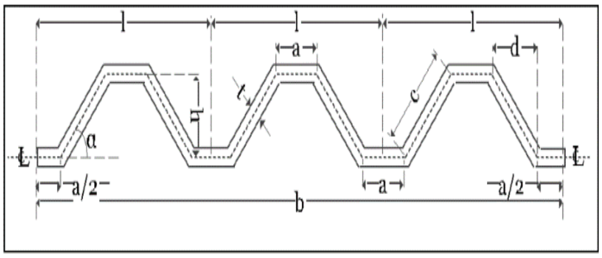


Fig -1: Cross-section of corrugated plate and its dimension

Table -1: Dimension Parameters of Corrugation Used (mm)

α (º)	a	h	t	c	l	b	d
45	20	15	1.6	21.21	70	210	15

3. EXPERIMENTS

In the experimental study, a total of three column specimens are fabricated as shown in Fig. 2. In Type-I column two plane and two corrugated plates are butt welded at corners to get an integrated column. Type-II column is similar to that of Type-I column but the two plane opposite sides are provided with three circular shaped perforations with diameter 82mm and spacing 175 mm i.e., equally spaced. Then, Type-II column is strengthened with four trapezoidal stiffeners with dimension same as that of single module of trapezoidal corrugation and it is named as Type-III column.

The complete mechanical behavior and load-deflection graph of column specimens are determined from the study. The cold-formed steel used for the fabrication of proposed specimens is of CR2 Grade. Also, in this study the behavior of innovative column is compared with that of conventional steel column having same cross-section.

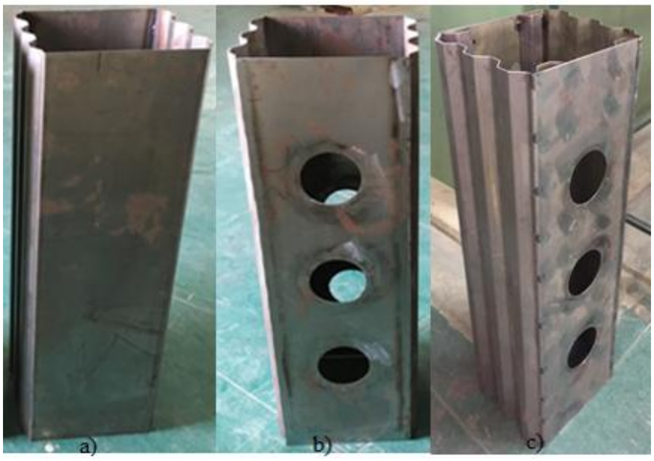


Fig -2: a) Type-I column, b) Type-II column and c) Type-III column

3.1 Test Procedure

All the specimens were tested in UTM having load capacity of 1000 kN. Proposed columns were placed between two rigid blocks, in which the bottom was fixed and the top part was moving downward during testing. Deflection meters were placed and the deflection corresponding to each axial load increment was noted. Every specimen was loaded up to failure and the load- deflection graph was plotted. Fig. 2 shows the test setup of Type-I innovative column. In order to determine the material properties of the fabricated columns, tensile coupons were taken and conducted tensile test.

Fig -1: Test-setup of column

4. ANALYTICAL APPROACH

Sudden inelastic failure or loss of stability of the structure is a phenomenon called collapse. From analytical point of view, computation of relationship between loads acting on the column and deformations in response to these loads can be referred as collapse analysis.

In this study, along with experimental tests analytical models were created using ANSYS Workbench. The element type used was SHELL181 which is a four-node element with six degrees of freedom. In order to introduce plasticity for the elements, isotropic hardening behavior is defined for the material as material property. The results obtained from analytical approach is then validated with that of experimental results. Once it is validated, then it can be used for further investigations by varying geometric parameters or shapes of holes etc. This method would be less time consuming, more convenient and economic. In addition to this, model of commonly used conventional steel column is developed and compared with innovative corrugated columns to determine the advantages of innovative columns over conventional columns.

5. RESULTS AND DISCUSSIONS

In the following sections, behavior of the innovative columns under compression and the comparison of experimental results with those of analytical results are discussed.

5.1 Material Properties

From the extracted stress- strain graph (Fig. 4) for the tested tensile coupons, the Modulus of elasticity (E) and the yield stress obtained was 204 GPa and 295 MPa respectively.

5.2 Verification of Numerical Model

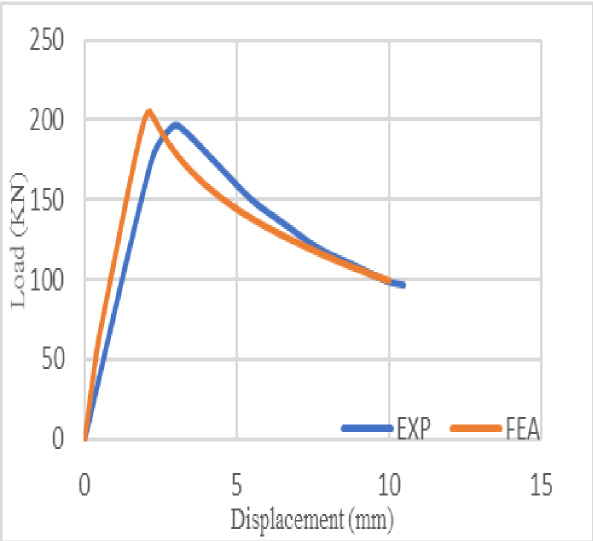
The numerical load-displacement curves obtained for proposed columns are compared with that of experimental results in Fig. 4. There is only a marginal variation in results. This reveals that the Finite Element Model could project the actual behavior of the test specimen.

5.3 Performance of Innovative Columns

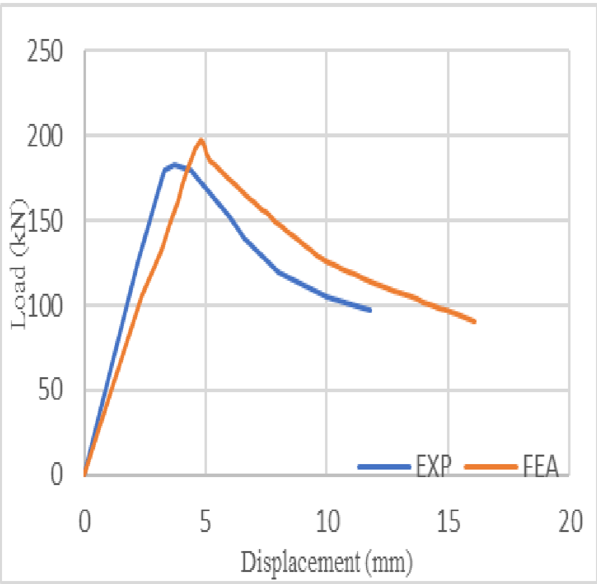
Fig.5 shows the experimental load versus displacement curves obtained during compression tests of innovative corrugated columns.

From Fig. 5, it can be observed that the load carrying capacity of Type-II column is reduced up to 7% when compared to Type-I column and the Type-III column has 28% higher the load carrying capacity compared to Type-I column. As the hole is introduced in Type-II column, the stiffness reduced and hence the load carrying capacity. In Type-III column, the trapezoidal stiffeners overcome the reduction in stiffness due to perforations and hence giving a strengthened column with high load carrying capacity. In situations where hollow section with perforations having high loading carrying capacity is required, the innovative column would be a better choice.

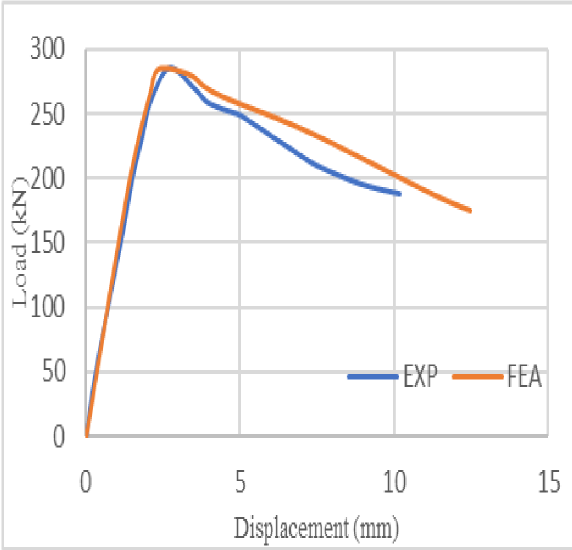
Also, the post-peak behavior of the proposed columns is clearly understood from Fig. 5. The load carrying capacity of Type-I and Type-II column drops suddenly, once the peak load is reached. However, Type-III column shows much more ductile behavior and has higher load carrying capacity than Type-I and Type-II columns. In case of conventional steel column, even though it has a prominent ductile post-peak behavior the load carrying capacity is very low compared to innovative columns. It is observed that, Type-III column has almost thrice the load carrying capacity of conventional steel column and shows a reasonable ductile post-peak behavior.



(a)



(b)



(c)

Fig -4: a) Type-I column, b) Type-II column and c) Type-III column

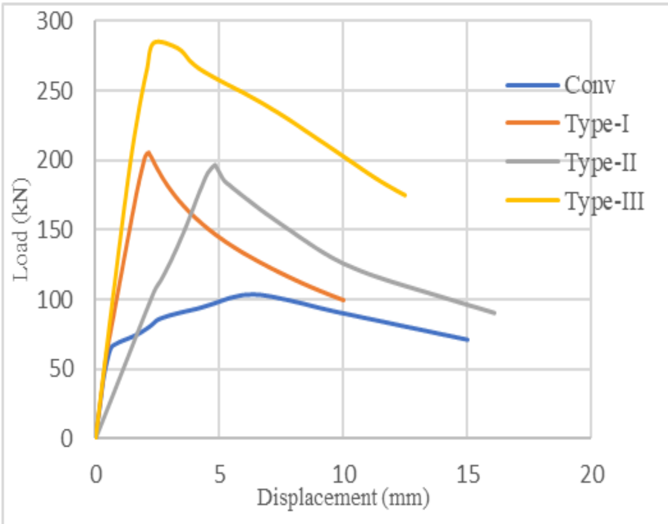
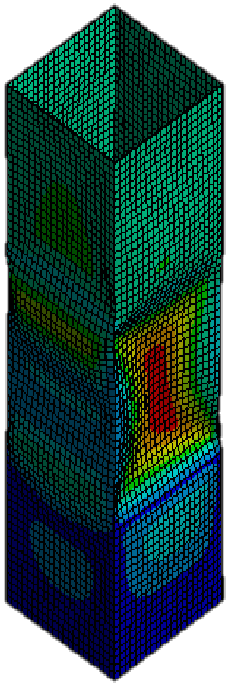


Fig -5: Experimental load vs Displacement

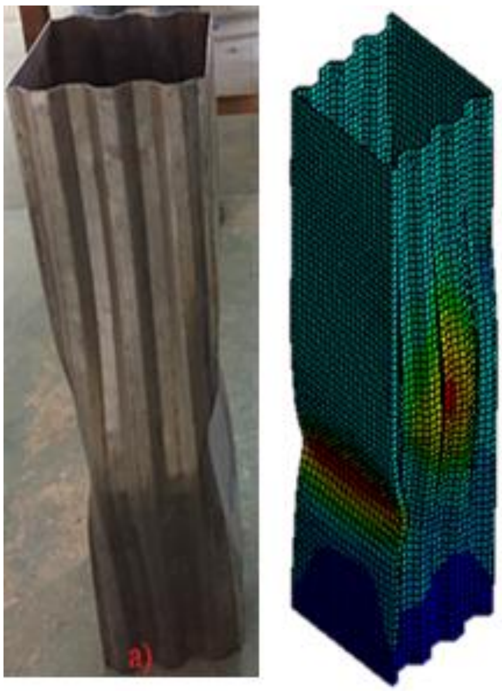
5.4 Material Properties

During the compression testing of specimens, the load increases from zero to the maximum load and then the load decreases with an increase in displacement as shown in Fig. 4. Usually, cold-formed steel structural members develop both local buckling and global buckling which are essential factors determining the behavior of column. The failure mechanisms of both innovative columns and conventional column is depicted in Fig. 6. As the load is increased, area surrounding the perforation undergo local buckling followed by global buckling. Overall, the sides of the specimen having higher stiffness i.e., corrugated sides buckled outward and the sides with lesser stiffness (plane sides) buckled inward.

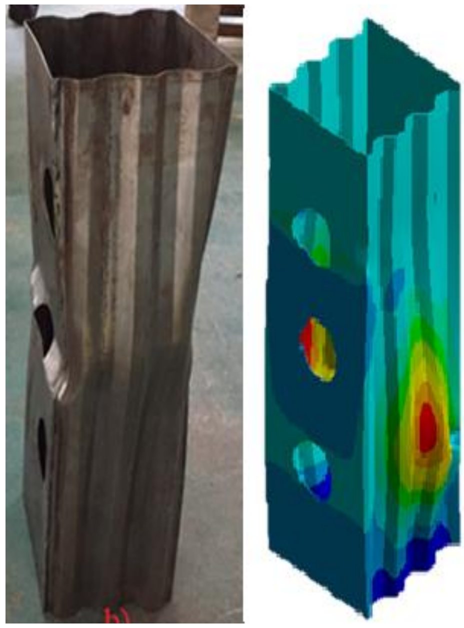
This type failure mode named as roof-shaped mechanism. While for the conventional column the failure mode is flip-disk mechanism.



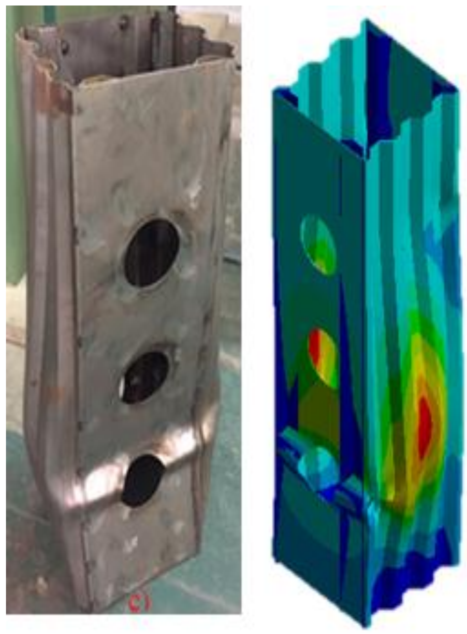
(a) Conventional column



(b) Type-I column



(c) Type-II column



(d) Type-III column

5.5 Cost Analysis

In order to determine the acceptance of innovative column from cost point of view, cost analysis has also been conducted. Based on the cost and the load carrying capacity of each specimen, calculations are made. The total cost includes, cost of raw material and fabrication cost. The maximum load carried by each specimen, deflection at peak load and the ratio of cost to load is given in Table-II. After determining the cost to load ratio, the specimen having the least value is considered as the most efficient one since it carries higher load and is economical.

Table -2: Results of Different Types of Columns

Specimen	Peak Load (kN)	Maximum Displacement (mm)	$\frac{\text{Cost}}{\text{Load}}$
Conventional steel column	103.52	6.6	5.25
Type I	205	2.15	3.14
Type II	196	4.8	3.79
Type III	284.98	2.3	2.82

6. CONCLUSIONS

The behavior of the innovative hollow cold-formed steel columns with two sides plane and two sides corrugated is discussed in this paper.

Here the performance of Innovative column with and without openings under compressive load is observed both experimentally and analytically. From the results obtained, it can be inferred that the percentage reduction in strength will be less than 7% for columns with holes compared to columns without holes. In order to compensate the reduction in strength due to provisions of openings, trapezoidal stiffeners were incorporated with Type-II column, named as Type-III column. The results surprisingly revealed that; stiffeners not only enhance the load capacity by 1.5 times but also the ductile behavior of column. To recapitulate, the cold-formed steel column with stiffeners ensure high load carrying capacity with considerable ductile behavior and would be a competitive column in terms of cost and weight to those conventional columns having same strength and cross-section.

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