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Geometrical Optimization and Buckling Analysis of Castellated Steel Column

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Abstract – *This paper presents design and study of the buckling behavior of castellated columns members and the critical load capacity of the section at various end conditions. Different shapes of the openings are taken into account for creation of castellated column. In this paper, the critical load capacity of the section at various end conditions also studied. Linear buckling analysis has done using ANSYS Workbench for different parameters of castellated column. Hexagonal openings were provided as opening on the web post of the column. Unit load is applied at free end. Total deformation and equivalent stress was obtained at nodes, with eigenvalues buckling load multiplier were obtained. From analysis critical buckling load was obtained as 147.72 KN. This load is greater than calculated critical load 122.90 KN. On applying this load to the system, equivalent stress is obtained as 26.336 MPa.*

Key Words: **Castellated columns, Linear buckling, Hexagonal openings, stress, load multiplier**

1. INTRODUCTION

Perforated beams and columns are being used as major structural members now-a-days. These perforated elements are known as castellated beams or columns. These beams are fabricated from I-sections. Various shapes of perforation can be achieved by cutting web of I-section to two halves. Mainly hexagonal, cellular shapes are utilized in castellated columns. These two halves are rejoined together by welding across [1]. Without adding the material, it increases the depth of the beam which also increased axial bending strength as well as stiffness of the beam. These castellated beams are used for long span applications with moderate or light loading conditions. Further openings generated on the web can be utilized for services [2]. Though the welding cost increases, it reduces the cost due to height because of increased depth of the beam. Many authors have been investigated on behavior and performance of such structures [3]. Areas includes flexure buckling, torsional buckling, lateral torsional buckling, lateral buckling, shear buckling of web posts [4].

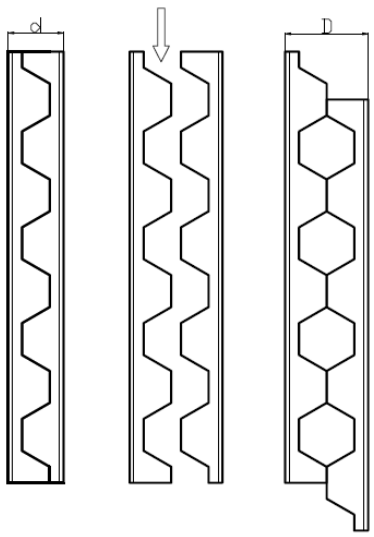
Castellated columns or beams has some limitations as less fire resistance. If they are subjected to heavy load, then needs additional reinforcement. Due to opening in web post, failure tends to different types of failures such as Vierendeel collapse mechanism, buckling of a web post, flexural failure, lateral torsional buckling and rupture at welded joints [5].

2. OBJECTIVES

The main objective of this paper is to study the buckling behavior of castellated columns members and the critical load capacity of the section at various end conditions. In this study, various shapes of the openings are taken into account for formation of castellated column. Indian Standard medium weight beams (ISMB) are to be used for the modification as castellated column.

3. CASTELLATION PROCESS

Castellation of the column or beams can be done by profile cutting the web post on its major axis. Later it is welded so that the overall beam depth gets increased by 50%. Typical process is explained in fig. 1.



(a) (b) (c)

Fig -1: Process of castellation (a) Original ISMB with profile cutting on web post, (b) Sections after profile cutting, (c) final castellation by welding the web post.

3. DESIGN APPROACH

It is very important to investigate the structural implications of the opening in the web of column. Hence single design method is highly appreciable for the columns with web

openings. Web openings have critical behavior in structural sections, such as local forces transformation, failure yield patterns, and also failure mechanisms. Various web openings are considered in this study, such as square, rectangular, hexagonal and octagonal openings.

During castellation process, overall depth was enhanced by 50%. Opening depth is maintained to 2/3 of overall section. Critical opening parameter, c, is mainly considered for analysis. All column sections are hot rolled class a ISMB sections. ISMB 100 section is mainly taken for investigation. Total length of the section after perforation is taken between 700 mm to 900mm.

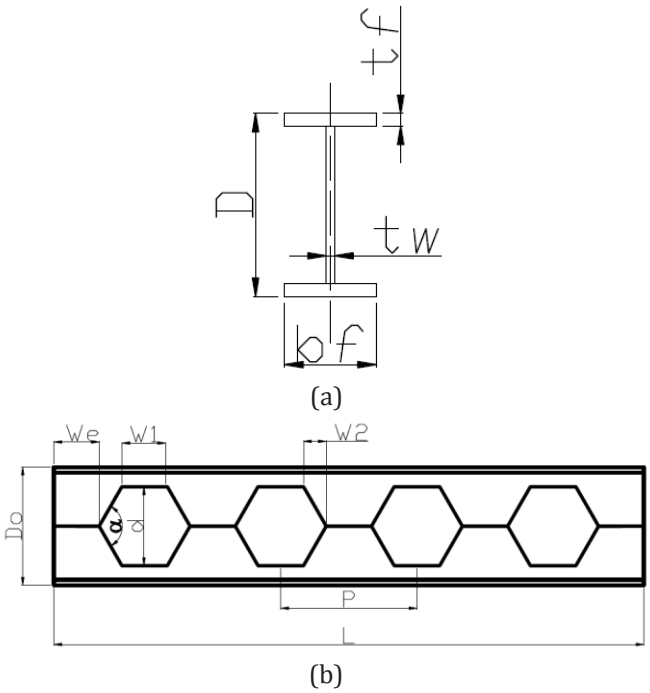


Fig -2: (a) Cross Section of ISMB, (b) nomenclature of various parameters of castellated column section

Geometrical parameters of the original section are taken as per Table 46, IS 800:2007. As shown in fig. 2(a) & (b), depth of original section is D, obtained depth of castellated section = D_0 = 1.5D, depth of the opening is kept to d = D/2, end distance of column from first opening We = 1.73d, W1 = 1.15d, W2 = 0.58d, P = 3.46d and L = length of the column which is depends on the number of openings provided within the column. Hence, geometrical parameters are derived for castellated column are shown in table 1.

Table -1: Geometrical parameters of castellated column

Geometrical parameters for the castellated column using ISMB100	
Parameter	Dimensions
D	100 mm
D_0	150 mm
d	50 mm
W_e	86.5 mm
W_1	57.5 mm
W_2	29 mm
P	173 mm
α	120°
L	750.55 mm
Number of openings	04

4. ANALYTICAL STUDY

In 1744, Euler was made the theory of buckling and explained that columns may fail by buckling as load reached at critical value. In buckling opposite faces are compressed towards one another. General formula is derived for the critical buckling load and expressed as:

$$P_{cr} = \frac{n\pi^2 EI}{L^2}$$

Where,

P_{cr}= Critical Buckling Load

n= End condition factor

E= Young's modulus of the material

I = Moment of Inertia of the c/s of the column

L = Length of column

Column end conditions are explained in IS 800:2007 and can be applied for the analysis.

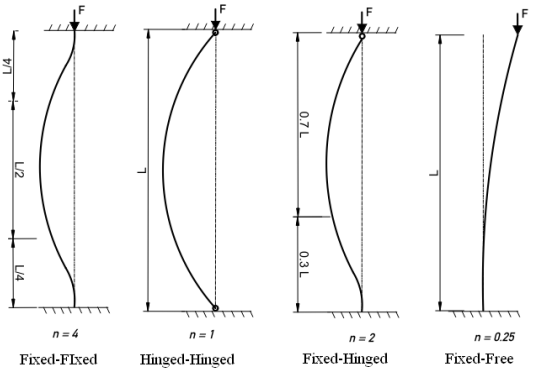


Fig -3: Different End conditions of the column

5. FINITE ELEMENT ANALYSIS

Linear buckling analysis was done using ANSYS Workbench 2020 R1 software for castellated column of the parameters given in table 1. Hexagonal openings were provided as opening on the web post of the column. End conditions are provided as

i. One end fixed and another free
ii. Both End Fixed
iii. Both end pinned
iv. One end fixed and another is pinned

Table -2: Structural & Mechanical Properties of the Material

Property	Value
Young's Modulus	$2x10^5$ MPa
Poisson's Ratio	0.3
Tensile Yield Strength	250 MPa
Compressive Yield Strength	250 MPa
Tensile Ultimate Strength	460 MPa
Cross Sectional Area of Castellated Column	9070 mm2

Analytical study was conducted using above section mentioned in table 2 with end conditions as one end is fixed and another is free. Default meshing was used to the section under test. Unit load is applied at free end. Total deformation and equivalent stress was obtained at nodes with eigenvalues buckling load multiplier were obtained. This results are presented in table 3.

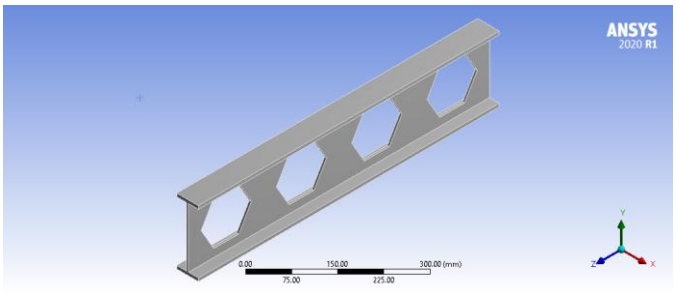


Fig -4: Model of castellated column

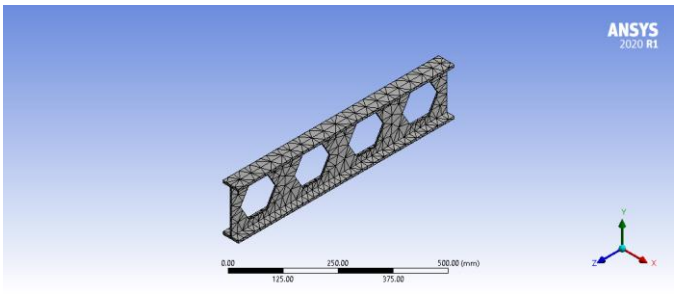
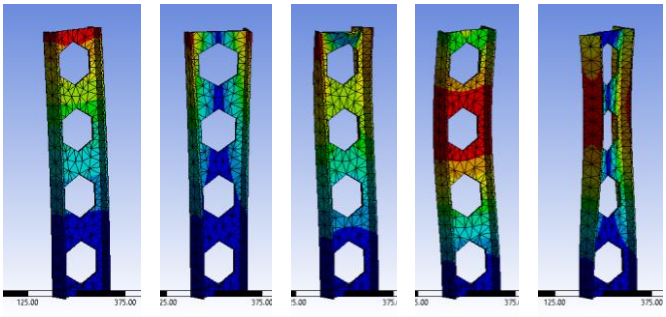


Fig -5: Meshing of Model



(a) (b) (c) (d) (e)

Fig -6: Deflection of the column at node 1-5 respectively

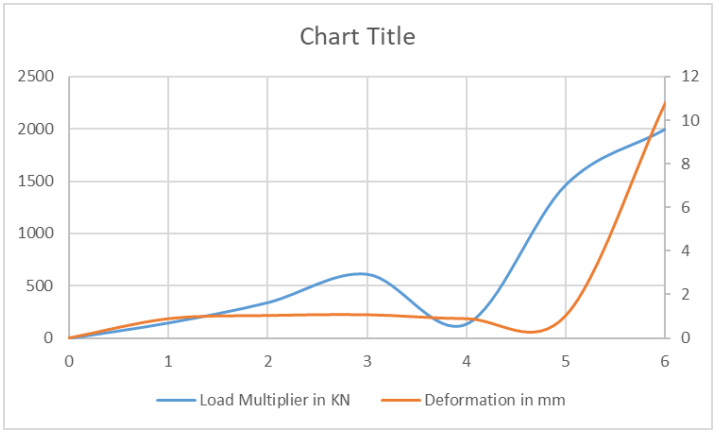


Chart -1: Load multiplier and deformation at 1-6 nodes

Using the load multiplier obtained in the analysis critical buckling load was obtained as 147.72 KN which greater than calculated critical load 122.90 KN. Applying this load to the system equivalent stress obtained as 26.336 MPa.

6. CONCLUSIONS

The buckling analysis of the castellated columns ISMB100 in one end fixed and another end is free conditions are completed. The critical buckling loads of designed column made with same material are calculated by using Euler's equation. Calculated critical buckling load and obtained from ANSYS Workbench are nearby with difference of 18 KN approximately. Hence analysis done by both the ways is completed and validated.

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