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# EXPERIMENTAL STUDY ON BUCKLING ANALYSIS & STRESS BEHAVIOR OF CASTELLATED COLUMN

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## ABSTRACT

An experimental study of the complex dynamics of castellated columns is presented in the abstract, with a focus on the analysis of stress behavior and buckling events. Castellated columns provide a distinctive structural design with possible benefits including weight savings and architectural versatility. They are distinguished by carefully positioned apertures. The study makes use of exact experimental methods to examine the buckling behavior of castellated columns under various stress conditions. By thoroughly investigating patterns of stress distribution, the main goal is to clarify the structural consequences and performance characteristics of these columns. An improved knowledge that may greatly aid in the optimization of castellated column designs, enhancing their load-bearing capacity and structural resilience across a range of engineering applications, is the study's expected conclusion.

**Keywords:** Castellated Column, Buckling Analysis, Stress Behavior, Structural Performance, Experimental Study, Load-Bearing Capacity, Stress Distribution.

## I. INTRODUCTION

The field of structural engineering has seen an ongoing search for cutting-edge concepts and materials to satisfy the changing needs of contemporary building. With their well-planned apertures, castellated columns are a unique architectural solution that strikes a compromise between weight savings, structural effectiveness, and aesthetic flexibility. A detailed grasp of the buckling behavior and stress distribution of these columns is essential to guaranteeing optimum performance and safety as they become more common in modern building projects. In order to understand the intricate dynamics controlling castellated columns' structural reaction, this thesis sets out on an experimental investigation of them. The main emphasis is on a thorough examination of stress behavior and buckling events, exploring the ramifications of the special design elements. This work aims to provide important insights into the mechanical performance of castellated columns under different stress circumstances by using strict experimental procedures. As we explore the complexities of the experiment, our main objective is to add to the body of knowledge in structural engineering. The research endeavor is expected to provide insights into design optimizations, construction practices, and standards that will eventually improve the structural robustness, load-bearing capacity, and efficiency of castellated columns in a variety of engineering applications. We hope that our investigation will close current knowledge gaps and open the door to a more creative and educated approach to the use of castellated columns in modern structural architecture.

### 1.1 BACKGROUND OF THE STUDY

The development of structural design in contemporary building has been characterized by an unwavering search for novel approaches that combine economy, efficiency, and aesthetic concerns. Castellated columns are one such invention that has drawn interest in the field of structural engineering. They are characterized by well-placed apertures throughout their length. Since of its unique shape, castellated columns are a popular option for modern building projects since it not only increases architectural variety but also has the ability to save weight.

Although castellated columns are becoming more and more common, there is still a significant knowledge vacuum about their structural behavior, especially with regard to stress distribution and buckling analysis. To assure the structural integrity and performance of these columns under varying loading circumstances, a

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thorough research is necessary due to the unusual geometry created by the apertures. The necessity to close this information gap and provide a methodical investigation of the buckling phenomena and stress behavior shown by castellated columns is what drives this work.

**1.2 TERMINOLOGIES OF CASTELLATED COLUMNS**

In the context of castellated columns, several key terminologies play a crucial role in describing their design, behavior, and construction. A castellated column is a structural element characterized by regularly spaced openings or cut-outs along its length, resembling the battlements of a castle. These openings, referred to as cut-outs, are intentionally incorporated to reduce the column's weight while preserving its load-bearing capacity. Axial load, the vertical force acting along the column's axis, induces either compression or tension. Bending moment, a measure of the tendency to bend, and shear force, a lateral force parallel to the column's surface, are critical considerations in structural analysis. The slenderness ratio, comparing the effective length to the least radius of gyration, is vital for assessing buckling tendencies. Engineers must also account for material properties like yield strength, determining the stress at which plastic deformation occurs. Structural analysis involves evaluating the behavior of the castellated column under various loads, while connection details refer to the specific design features influencing load transfer and stability at joints. Compliance with local building codes and standards ensures the safe and effective implementation of castellated columns in construction projects.

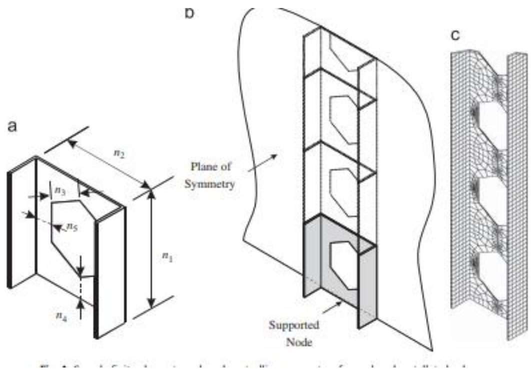


**Figure 1:** Sample finite element mesh and controlling parameters for analyzed castellated

Use of steel as structural member in structure is rapidly gaining interest now a day. In steel structures, the concept of pre-engineered building (PEB) is most popular because of ease and simplicity in construction. Such pre-engineered buildings have very large spans but comparatively subjected to less loading. Thus, steel sections are safe for strength requirement; but, sections don't satisfy serviceability requirements. So it becomes essential to use column with more depths to satisfy this requirement. Use of perforated web or open web column is the best solution in order to overcome this difficulty. Perforated web column are also called as castellated column when perforations are made of hexagonal or square shapes and those provided with circular openings are called cellular column. Reduction in total weight of the structure is the main advantage of using castellated column. So, lesser quantity of steel is required.

## II. LITERATURE REVIEW

**Tianhua Zhouet al (2017)** in this paper studied standard design practice for distortional buckling considers a lower bound solution as the real buckling load. In reality, this practice is inconsistent with factual case since the attained buckling load is a constant value no matter how long the column is and whatever the end condition is. According to available literature, the study dealt with such a problem is set up quite rare. A logical approach for establishing a new distortional buckling formula is presented, which is taking both the effects of column length and end condition in consideration. The model was assumed to be pin-ended and fix-ended so as to research their effects. The Galerkin approach was employed to decide the distortional buckling formula. Further, simplifications to the rigorous formula were made to allow them to be fluently used. The results obtained from the derived formula were compared with the numerical results obtained from the computer software GBTUL in order to validate the accuracy of the derived formula. In addition, the performance of the derived formula was more verified by comparing the corresponding ultimate strength based on Shafer's DSM expressions with numerical result from the literature. The comparison and confirmation result shows that the derived formula (i) can be used successfully in estimating the distortional buckling load for both pin-ended and fix-ended columns with practical length and (ii) can general more rational buckling strength estimation due to the consideration of column length and end condition effect. **Radek Pichaletal (2017)** this paper studied pre-stressed stayed compression members are frequently needed as very slender load- bearing structural elements by both investors and architects. Behavior of these members is depending on their geometrical and material parcels, pre-stressing and boundary conditions. Respective critical buckling loads and post-buckling paths with respects to 2D and 3D GMNIA (geometrically and materially nonlinear analysis with defects) are discussed in the paper. Former tests and recent detailed analyses of other authors are reflected with respect to the 3D analysis, degree of defects, boundary conditions at central cross arm (fixed or sliding stays) and nonlinear stainless steel material. **Delphine Soncket al (2016)** in this paper the Cellular and castellated members are produced by performing slice and re-welding operations on a hot rolled I- section member. As illustrated in former work, these operations will impact the residual stresses present in the members in a manner which is mischievous for the flexural buckling resistance. Up to now, this has not been considered in the limited quantity of literature concerning the flexural buckling resistance of these members. The weak- axis flexural buckling resistance is examined, taking into account the influence of the modified residual stress pattern and the modified geometry of cellular and castellated members. Hence, the critical buckling load and the buckling resistance of simply supported cellular and castellated members were delved numerically. A modified residual stress pattern was introduced, based on earlier measures in the numerical model. As the quantum of measurements was fairly limited, the results of these simulations should be considered as primary results, in attendance of an evidence of the applied residual stress pattern. The results of the simulations are illustrating that the detrimental influence of the anticipated residual stress pattern modification on the buckling resistance. Preliminary best fit curves could be tagged by comparing the results with the European buckling curves. This comparison was executed with a 2T approach, in which all cross-sectional parcels are calculated for the 2T section at the center of the opening. **Jian- zu Guet al (2016)** this paper presents a logical result for calculating the critical buckling load of simply supported cellular columns when they buckle about the major axis. The result takes in to regard the influence of web shear deformation on the buckling of cellular columns and is derived using the stationary principle of potential energy. The formula derived for calculating the critical buckling load is validated using finite element analysis results. The web shear deformation can significantly reduce the buckling resistance of cellular columns. The influence of the shear deformation on the critical buckling load increases with the cross-section area of the tee section and the radius of circular holes but decrease with the length and the web thickness of the cellular column. **Yu- Chen Song et al( 2016)** this paper presents a theoretical study on both local and post-local buckling behavior of partly boxed composite( PEC) columns, made with thin- walled, welded H- shapes and concrete encasement between flanges; transverse links that are welded between flange tips for supporting the section. Nonlinear finite element analysis (FEA) was conducted to prognosticate buckling actions and strengths of steel shapes. Finite element models were verified through a comparison of FEA results with experimental results. A parametric study was then performed using validated FEA models to probe the effect of several parameters on the buckling behavior of PEC columns. The residual stress of steel shapes introduced through welding process, is also discussed in detail.

## III. METHODOLOGY

### 3.1 General

Columns are almost exclusively subjected to compressive axial forces. As such, for slender members, the buckling behavior will often be the critical design factor. As castellated members have been in use since the fifties and cellular members since the eighties, several design guidelines exist for those members that are applied as beams.

### 3.2 Assumption for castellated column

The main assumptions used in this investigation are summarized below:

- All columns are assumed to have a linear elastic material with a modulus of Elasticity E= 2 X 105 MPa and Poisson's ratio v = 0.3.

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- Length L, flange width bf, flange thickness tf, web width hw and web thickness tw define I-shaped column.
- The dominant failure mode is in plane buckling of the column accompanied by major-axis bending.
- The column is axially loaded with concentrated loads that are applied to its ends.

### 3.3 Geometry of a typical castellated column

- **Section properties**

ISMB100

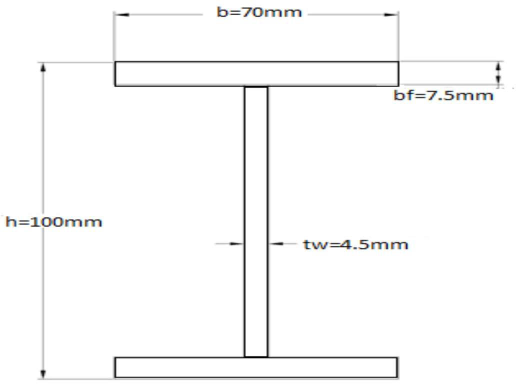


**Figure 2:** Dimension of original section

According to the above geometry modified section is presented below

**The diameter of a circle that encloses the hexagonal perforation**

**d =** 0.443h= 0.443 x 100 = 44.3mm

**Centre-to-Centre spacing between castellation**

**s=** 1.5d=1.5 x 44.3= 66.45mm

**End distance of the hexagonal opening =** 0.75d= 0.75 x 44.3=33.25mm

**Inclined side height of hexagonal opening =** 0.25d= 0.25 x 44.3=11.07mm

**Vertical side height=**0.50d= 0.50 x 44.3= 22.15mm

In case of cellular column and square shape castellated column length and section properties are same.

For Cellular Column values of all parameters are same i.e. d and s

For Square castellated Column also values for d and s are same but side length is 31.325 mm.

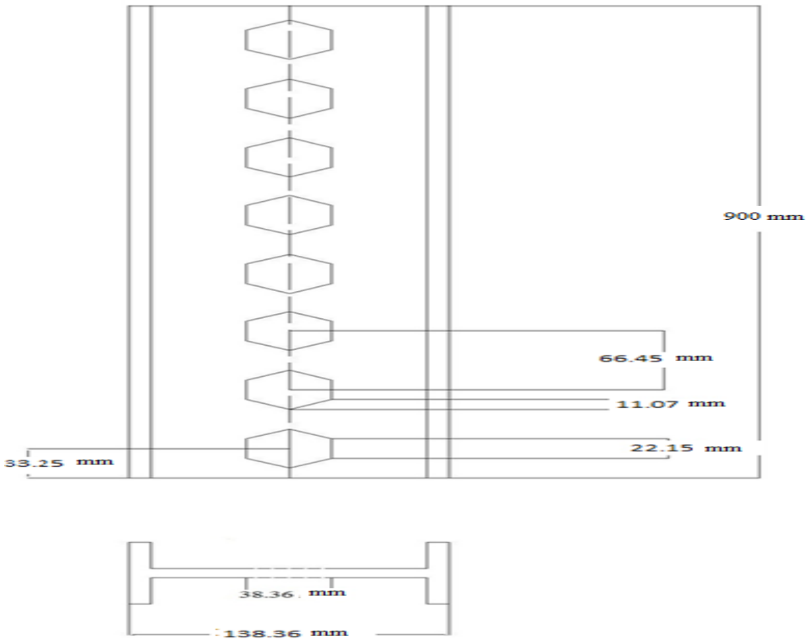


**Figure 3:** Dimension of Modified section

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## IV. MODELING AND ANALYSIS

### 4.1 Ansys 2019 R3 Workbench:

ANSYS is known for its capabilities in engineering simulation, allowing engineers and scientists to simulate, analyze, and optimize the behavior of physical systems.

### 4.2 Geometry

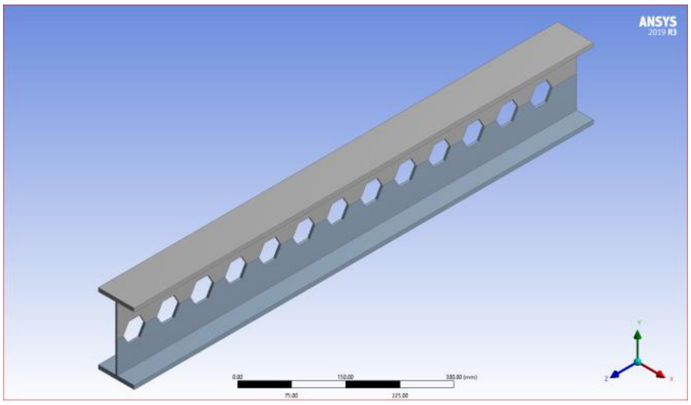


**Figure 4:** Geometry of a model

### 4.3 Analysis:

#### 4.3.1 Loading Conditions:

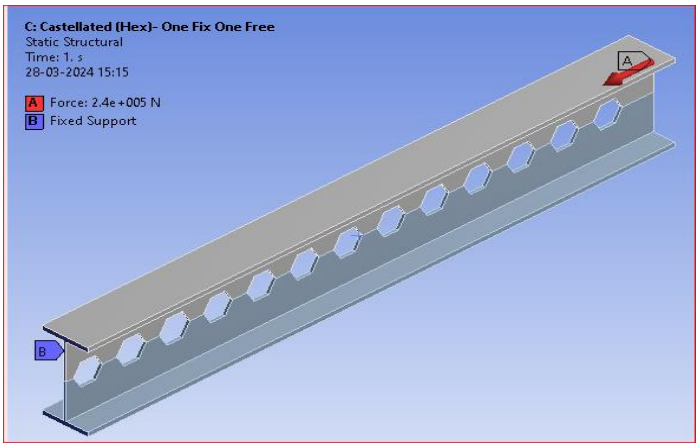


**Figure 5:** Loading on Column

#### 4.3.2 Total deformation:

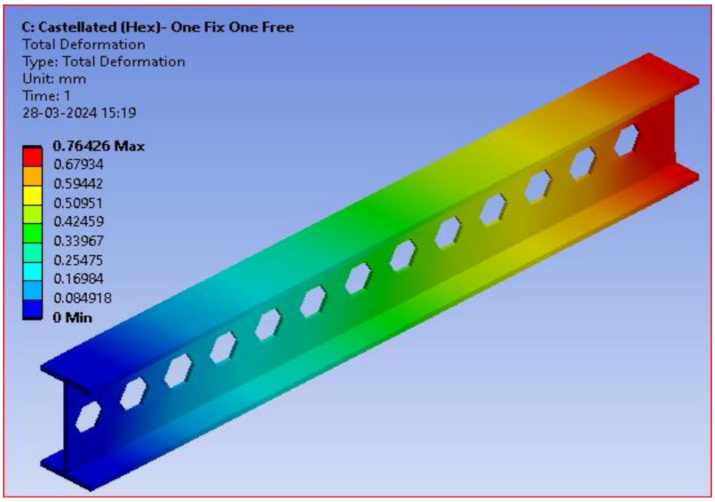


**Figure 6:** Total deformation

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**4.3.3 Equivalent Stress:**

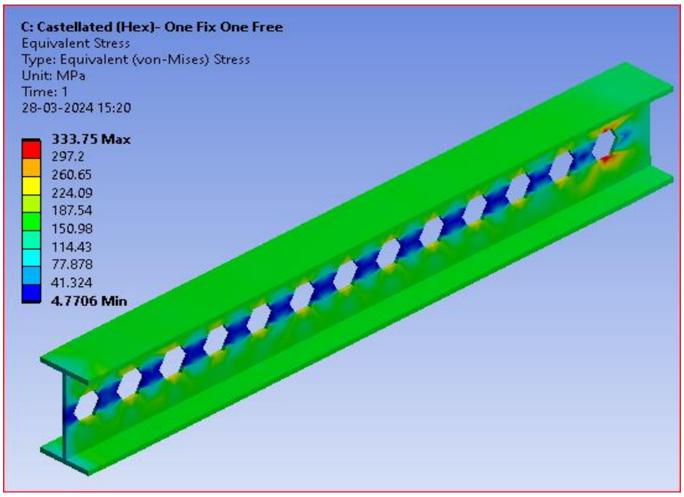


**Figure 7:** Equivalent Stress

**4.4 Buckling Analysis**

**4.4.1 Total deformation 1:**

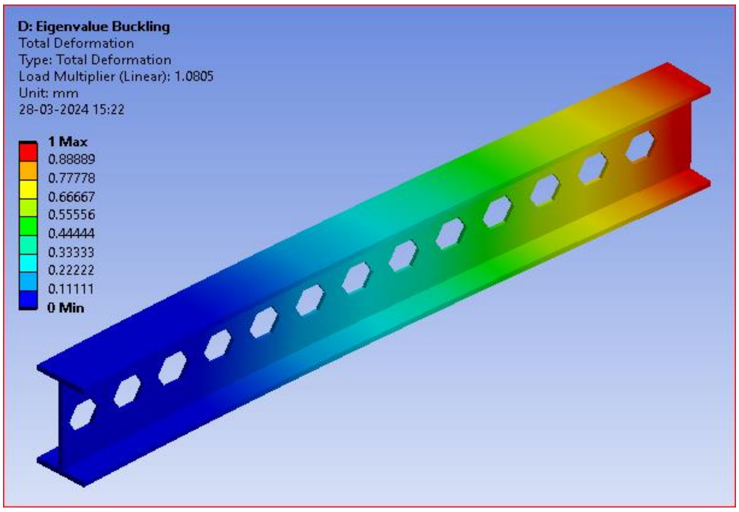


**Figure 8:** Buckling Total Deformation 1

**4.4.2 Total deformation 2:**

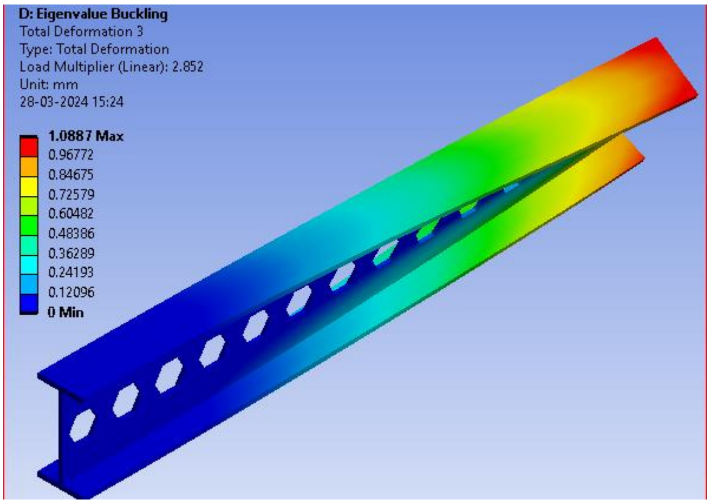


**Figure 9:** Buckling Total Deformation 2

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## V. EXPERIMENT ANALYSIS

### 5.1. EXPERIMENTAL INVESTIGATION

For the column's experimental setup, locally accessible 10 mm steel sheets are used to fabricate specimens for the connecting plates and channels. A Universal Testing Machine (UTM) is used to test the column, which has a length of three meters.

The examples, which have a fixed support at the bottom, are made to resemble column behavior under stress. To examine the column's structural reaction, a 360 KN load is applied. With materials easily obtained for on-site testing, this configuration enables the investigation of the column's load-bearing capability, deformation characteristics, and overall structural performance under realistic circumstances.

**Figure 10:** End condition arrangement

**Figure 11:** Pattern marking on the section

**Figure 12:** Fabricated section

**Figure 13:** Testing of catellated section

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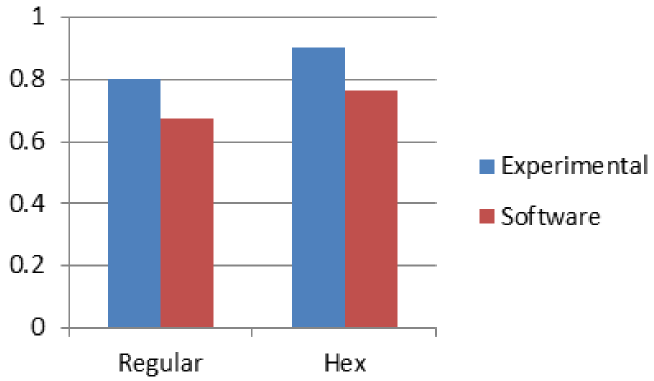
## VI. RESULT

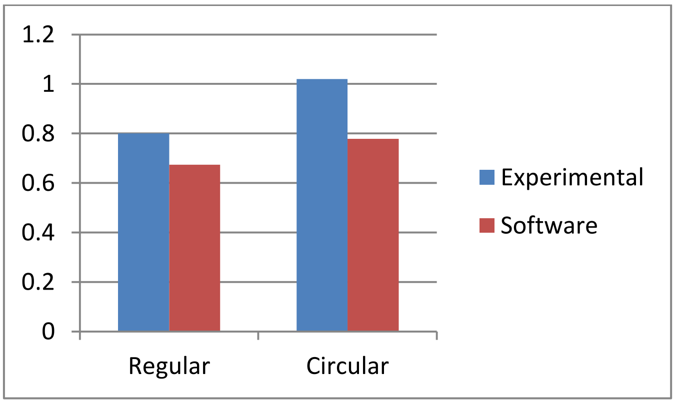
### 6.1 Comparison between Experimental & software design results

**Table 1:** Total Deformation- Experimental and Software results comparison

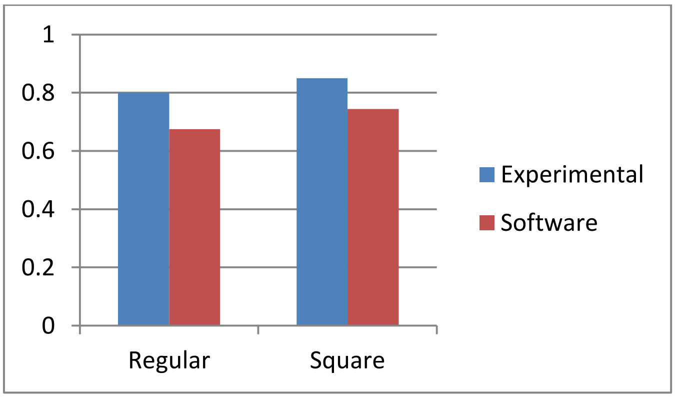
| | Experiment | | | |
|---|---|---|---|---|
| **Load (KN)** | **Regular** | **Hex** | **Circular** | **Square** |
| 240 | 0.8 | 0.9 | 1.02 | 0.85 |
| | **Software** | | | |
| **Load (KN)** | **Regular** | **Hex** | **Circular** | **Square** |
| 240 | 0.6743 | 0.764 | 0.7785 | 0.7445 |




**Graph 1:** Total Deformation for regular and Hex- Experimental and Software results comparison



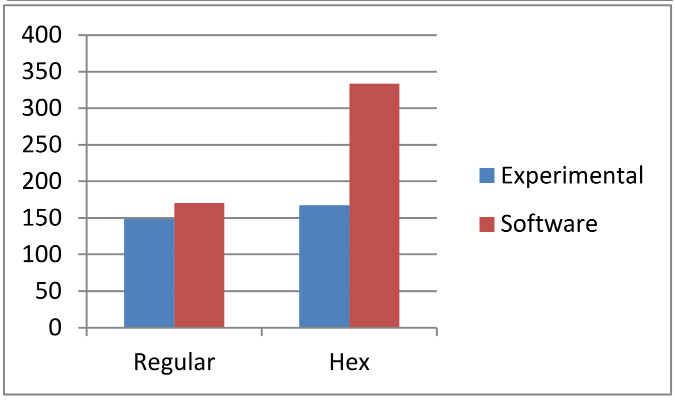

**Graph 2:** Total Deformation for regular and Circular- Experimental and Software results comparison



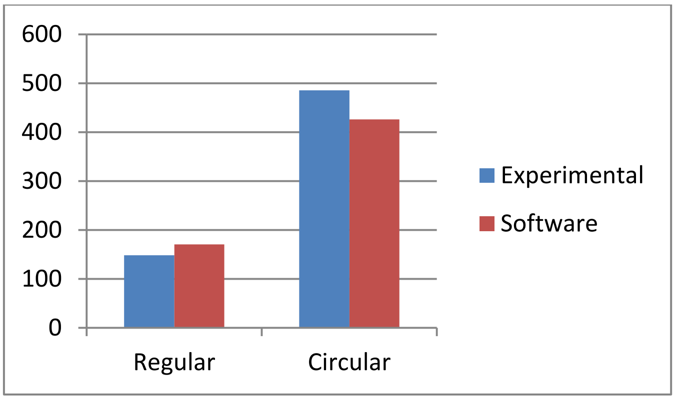

**Graph 3:** Total Deformation for regular and Square- Experimental and Software results comparison

**Table 2:** Equivalent Stress- Experimental and Software results comparison

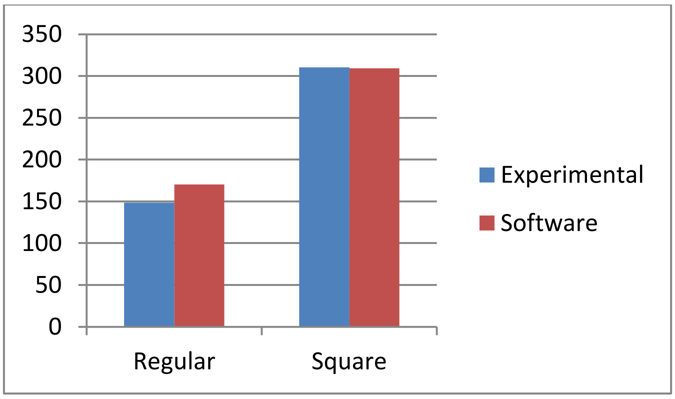
| | Experiment | | | |
|---|---|---|---|---|
| **Load (KN)** | **Regular** | **Hex** | **Circular** | **Square** |
| 240 | 148 | 167.14 | 485.5 | 310.2 |
| | **Software** | | | |
| **Load (KN)** | **Regular** | **Hex** | **Circular** | **Square** |
| 240 | 170.35 | 333.75 | 425.75 | 309.4 |




**Graph 4:** Equivalent Stress for regular and Hex- Experimental and Software results comparison




**Graph 5:** Equivalent Stress for regular and Circular- Experimental and Software results comparison




**Graph 6:** Equivalent Stress for regular and Square- Experimental and Software results comparison

## VII. CONCLUSION

1. Equivalent Stress for regular section is 170.35 MPa, for Hexagonal 333.75 MPa, for cellular 425.75 MPa and 309.4 MPa for square castellated column.
2. Studying all sections it is clear that cellular section is more likely to fail while hexagonal section is mostly suitable for buckling conditions.
3. Stresses developed in castellated column are more than the regular column.
4. The stiffness of regular column for both end fixed is 32.68 kN/mm and for castellated column is 26.31 kN/mm, so castellated section is more effective than regular section.

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