A Parametric Study of castellated column of mild steel with Analytical and Experimental Methods: A Review

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Abstract

In recent years, due to numerous benefits, such as reduced weight, ease of handling, and cost effectiveness, castellated steel columns (CSC) are widely used in steel constructions. castellated columns are created by flame cutting a steel I-section along the centerline, welding the two halves back together, and increasing the overall column width by 50% to improve the performance of the column. The stiffeners of mild steel material are used for strengthening castellated column section. However, in recent years the use of stiffeners has become popular in repair and rehabilitation of structures due to their excellent tensile strength. The studies are also carried out on the steel and castellated column using the stiffeners in the form of strips/laminates. In this paper, an attempt has been done to rigorously carry out the literature review to understand the behavior of castellated column. From the study of literature review, it is concluded that castellated column are the efficient structural members and their behavior needs to be studied for different shapes of openings with stiffeners as a mild steel.

Keywords: *Castellated column; Web openings; castellation process; Stiffeners; Load carrying capacity.*

1. Introduction

The cost of steel structures has been a major concern for structural engineers since World War II. In order to reduce the cost and increase the load carrying capacity of steel members, efforts have been taken to implement a variety of new techniques. For this reason, the development of castellated members has been considered as one of the best, popular and most widely used techniques. Now a days Perforated beams and columns are being used as major structural members. These perforated members are known as castellated beams or columns. These members are fabricated from I-sections. I-section web can be split in two halves to create a variety of perforation shapes. In castellated columns, cellular shapes mainly hexagonal are utilized. Without adding the material, these two sides are re-joined together by welding across. Though the welding cost increases, it reduces the cost due to height because of increased width of the column. Many authors have been investigated on behavior and performance of such structures. In recent years, castellated members have also been widely used as building columns. Increased buckling resistance about the principal axis is the main advantage of utilizing a castellated column. Castellated columns, however, have complicated sectional characteristics due of the openings in the web, making it very challenging to predict their buckling resistance analytically.

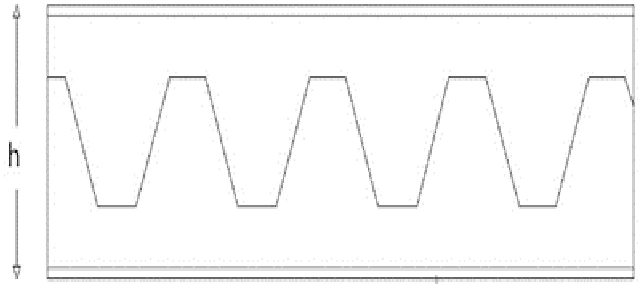

Figure 1. Creating a zigzag pattern out of the parent I-section

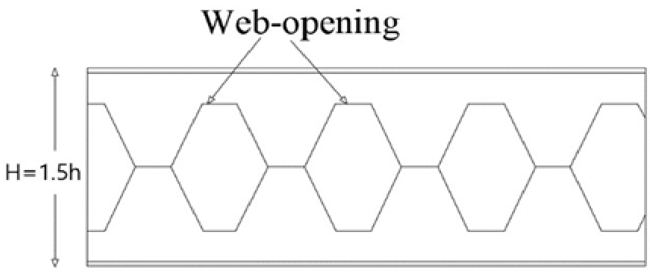

Figure 2. After cutting and re-uniting, a castellated column was obtained with a 1.5-hour depth.

1.1 Castellated columns

A castellated column is one in which the column's width is increased without the column's self-weight increasing. A new technique adopted nowadays is the castellated column. Castellated columns are more susceptible to lateral-torsional buckling because of the opening in the web. Using a castellated column increases its buckling resistance about the major axis, which is the main advantage. Analytical predictions of the buckling resistance of castellated columns are extremely difficult due to the complex sectional properties of these columns caused by the openings in the web. Castellated elements provide better strength, weight-to-size ratios, attractive architectural appearances, etc. than traditional I-section elements. Because of this, castellated elements can be used in big span structures like stadiums, bridges, and multistorey buildings. Castellated columns or beams have some limitations, such as less fire resistance. Additional strengthening is required if they are subjected to heavy loads. Due to the opening in the web post, failure is more likely to be of several types, including the Vierendeel collapse mechanism, web post buckling, flexural failure, lateral torsional buckling, and rupture at welded joints. The fabrication process creates opening on the web that can be used to accommodate services.

Experimental investigation was carried out and methods using finite elements were used to predict the buckling. By increasing the width, the column section that is generated in this manner might be as much as 50% larger than the parent section.

Advantages: -

1. The column section obtained can be even 1.5 times the width of the original section.

2. Load carrying capacity of the column is increased considerably without increasing the weight of column.
3. Economical and aesthetic.

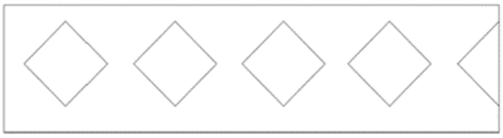

Figure 3. Castellated column with diamond opening.

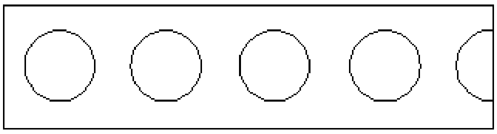

Figure 4. Castellated column with circular opening.

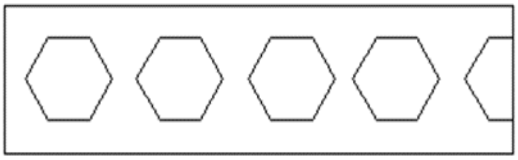

Figure 5. Castellated column with hexagonal opening.

1.2 Castellation process

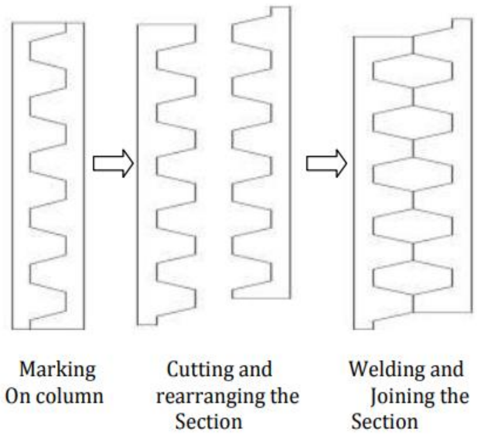

Figure 6. Castellation process

1.3 Stiffeners

Stiffeners are the structural components used to increase the shear and moment resistance of steel elements. Stiffeners can be used placed longitudinally, transversally, or around the edge of openings. The CSC need to be strengthened because the column performs inadequate when subjected to axial loads, so stiffeners can be used for this. The studies show that there are insufficient details on the behaviors of CSC using stiffeners in the web parts. This aspect makes it necessary to conduct research on the behaviors of CSC by supplying them with stiffeners made of various materials for the CSC with various web openings.

The different types of stiffeners used for the steel I-Beam/CSC depending upon the direction and location include:

- Load carrying stiffener
- Bearing stiffener
- Intermediate transverse web stiffener
- Transverse stiffener
- Torsion stiffener
- Stiffeners along the web openings

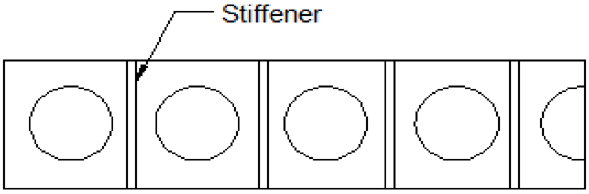

Figure 7. Castellated column with transverse stiffeners

1.4 Steel Stiffener

The use of steel stiffener is most common in practice for strengthening the castellated columns. The use of steel stiffeners not only increases the weight but also limits one of the benefits of the castellated column i.e., total weight reduction.

2. Literature Review

The research works published by several researchers in the various journals have been reviewed and are presented in the following section:

Wei-bin Yuan, Boksun Kim, Long-yuan Li [1] the energy approach was used to carry out an analytical solution to determine the buckling capacity of castellated columns. Castellated columns are difficult to predict in terms of their buckling resistance due to their complex sectional characteristics. The amount of analytical work that can be used to predict the buckling capacity of the castellated columns is limited. The critical buckling loads of castellated columns are shown to be most strongly influenced by the cross-sectional area of a tee section and the depth of the web opening, while the column's length and web thickness have the least impact.

Delphine Sonck , Jan Belis [2] research analyses the weak-axis flexural buckling resistance while considering the impact of the modified geometry of cellular and castellated sections as well as a modified residual stress pattern. This resulted in an investigation of the critical buckling load and buckling resistance of simply supported cellular and castellated components numerically. Based on prior data, the numerical model included a modified residual stress pattern. The results of these simulations should be regarded as preliminary results in expectation of verification of the used residual stress pattern because the number of measurements was rather a small amount. The outcomes of the simulations demonstrate the negative impact on buckling resistance of the planned modification to the residual stress pattern.

Jeppe Jönsson , Tudor-Cristian Stan [3] carried out advanced non-linear finite element analysis (GMNIA) to analyse flexural column buckling using plane shell elements in an effort to restore the European buckling curves. Assumptions used in determined modelling of column buckling are also reviewed historically, as well as the evolution of European buckling curves. The value of performing current numerical deterministic analysis based on the typical yield stress, the typical stress-strain relationship of the material, and the typical values of errors and residual stresses. Additionally, they propose that similar column bend defects generated directly from the Ayrton-Perry formulation can be used for finite element or frame analysis. Results indicate that it offers understanding into deterministic modelling of flexural column buckling and advises adjustments to enhance the use of modern steel grades in European buckling.

Khaled M. El-Sawy, AmrM.I.Sweedan MohamedI.Martini [4] the primary objective work is to carry out research on the major-axis buckling characteristics and buckling capacity of axially loaded I-shaped steel columns with perforated web sections. The study investigates how shear and flexural deformations impact the castellated columns capacity to buckle. The results are used to find a dimensionless buckling modification factor, Z, and associated equivalent section characteristics. The study's findings demonstrate a correlation between greater columns' castellation sizes, as measured by the depth to web thickness ratio (d/hw), and higher values of the buckling modification factor Z. This indicates that because of the loss in shear stiffness, these columns' buckling capability is reduced more drastically. Conversely, columns with lower (d/hw) ratios are more susceptible to buckling modifications factor Z close to unity, which is the typical value for plain-webbed long columns with minimal shear deformations.

Supekar Gorakshanath, Prof. P. B. Autade [5] experimentally studied the behavior of castellated columns under different loading conditions and compare them with regular columns. It provides experimental and analytical results to evaluate the buckling resistance and stresses in castellated columns. The the fabricated sections and the testing setup for both regular and castellated columns under different end conditions. Load versus deflection data and corresponding graphs are presented for each test case. Ansys results, including maximum and minimum stresses, are also provided for comparison. Results indicate that the corners of the castellated section have developed the maximumn stresses. Compared to other end conditions, the fixed column at both ends carries more load. In comparison to normal columns, castellated columns create more stresses. It is evident from analysing every end condition that the two end fixed conditions are better suited for the column.

Tadeh Zirakian [6] analysed the complexity of lateral-torsional and lateral-distortional buckling modes, which involve interactions between different types of displacements and distortions. Lateral-distortional buckling is characterized by local changes in cross-section geometry along with lateral displacement and twist. The paper presents experimental results

of four full-scale I-beams undergoing inelastic lateral-distortional buckling, comparing the predicted critical loads. The results show that the extrapolated loads obtained from the Southwell, Modified, and Massey Plots, separately applied to measurements of δ and ε, were in good agreement with the maximum test loads. The study provides valuable insights into the application of extrapolation techniques for analysing lateral-distortional buckling behaviour in steel beams.

Nikos D. Lagaros∗, Lemonis D. Psarras, Manolis Papadrakakis, Giannis Panagiotou [7] research focuses on optimizing 3D steel structures with perforated I-section beams. The study formulates the optimization problem considering sizing, shape, and topology design variables and compares two formulations based on different finite element discretization approaches. The findings illustrate the potential for reducing the weight of the structure by incorporating web openings in the beams while maintaining structural strength and serviceability requirements. Results shows that the improvement in weight reduction reaches up to 20% when web openings are considered in the structure's beams and also, this study demonstrates the effectiveness of a mixed-discrete evolutionary algorithm for optimizing the design of steel structures with perforated web sections.

Hanan Hussien El-Tobgy, Anwar Badawy Badawy Abu-Sena, Mohamed Wahied Fares [8] determined experimental analysis of the castellated beam-column steel elements' structural behaviour. Twelve short and long castellated beams, columns, and beam-column elements conducted an experimental evaluation. To verify that FEA may be used as a numerical tool, the outcomes of the experimental work were compared to the findings of FEA. Verified finite element modelling was used in this study to examine the behaviour and strength of the castellated beam, columns, and beam-column elements. The research's numerous parameters included in that order, the load eccentricity, element length, and castellation ratio. Results indicate that as the castellation ratio (e/d) is increased, the linear buckling moment of the beam-column members increases while the linear buckling load decreases. Additionally, the element's length influences both the linear buckling load and moment due to the effects of lateral-torsional buckling.

Mangesh Dhede, Prof. Mohan Shirsat [9] carried out design and study of the buckling behaviour of castellated column members, specifically focusing on the critical load capacity of the section under various end conditions. Different shapes of openings, such as square, rectangular, hexagonal, and octagonal, are considered in the study. The design approach involves maintaining the opening depth at 2/3 of the overall section depth and analyzing the critical opening parameter. ANSYS Workbench software is utilized for finite element analysis, considering the geometric parameters of the castellated column. The results obtained from both analytical and numerical analyses are compared and found to be in close agreement. The analysis methods used are validated and can be applied to design castellated columns with different opening shapes and end conditions.

3. Conclusions

From the study of literature review following conclusions can be drawn:

1. The castellated column sections are effectively used for construction of steel buildings due to their increased width by castellation process, weight reduction, cost-effectiveness, easy to handle, flexibility in service providing, and aesthetically.

2. The castellated section failure mechanisms including flexural failure, shear failure, lateral-torsional buckling, Vierendeel mechanism, web post buckling, and welded joint rupture occur when it is loaded, requiring their strengthening with stiffeners made of various materials.
3. There is a good scope for studying the structural behaviors of castellated column section by providing the mild steel as a transverse stiffener and have shown the improvements in the load carrying capacity of section.

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