

Analytical Investigation of Perforated Beams subjected to Lateral Torsional Buckling

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ABSTRACT: *BoldA Castellated beam is an I-beam that has been longitudinally cut along the web in a specific pattern. The cutting pattern will be used to split and recombine the beam to produce deeper webs. Increased strength is the main benefit of castellated beams, which is achieved by deepening the section without adding weight. To fully profit from the engineering advantages offered by castellated beams, erection stability needs to be addressed and taken into account. However, because of the greater depth of the beam, stability problems could occur during construction. Lateral Torsional Buckling (LTB) is one criterion of failure for beams in flexure. By providing beams with circular apertures, this work attempts to investigate the effects of torsion on castellated beams and the behavior of lateral torsional buckling in castellated beams using FE software. The beams in question have spans of 10, 13, and 16 meters. These castellated beams' outcomes were compared with those of regular beams. The beams with 13m span were found to produce the best outcomes.*

KEY WORDS: *Castellated beams, Lateral Torsional Buckling*

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I. INTRODUCTION

The primary advantage of castellated beams is their increased strength, which is accomplished by deepening the section without adding weight. However, stability issues during construction may arise due to the beam's larger depth. Erection stability must be addressed and taken into consideration in order to fully benefit from the engineering advantages provided by castellated beams. Castellated beams are created by cutting saw tooth-shaped grooves all the way down the web of a rolled "I" section. These cuts are then joined by welding the tips together, creating two interconnected pieces. The main advantage of this novel beam section is its deeper depth, which increases strength without requiring additional weight. The depth can be increased by as much as 50% in some circumstances. Because it increases the section modulus (S_x) and the moment of inertia (I_x), this increased depth improves the beam's bending strength and stiffness along its strong axis. Furthermore, castellations or holes make it possible for electrical conduits, plumbing pipelines, and HVAC ductwork to flow through, which reduces the thickness of the floor assembly. Castellated steel beams are of significant importance in the field of structural engineering due to various reasons, namely: effective weight-to-strength ratio, increased design flexibility, better structural performance, architectural diversity, sustainable construction practices, cost-effectiveness etc. Since a literature review offers a comprehensive synopsis and overview of the scholarship conducted from the past to the present, it is essential for any field. It helps analyze how research is different or distinct from other research and how it fits into the study's historical context. Boissonnade et. al. [1] investigated the lateral torsional buckling resistance of cellular steel beams by numerical analysis. The member slenderness, steel quality, base cross-section profile, bending moment distribution, and aperture size and position were among the significant aspects affecting the structural response that are examined. Oğuz [2] looked at the displacements brought on by bending moments and lateral torsional buckling at different locations across each of the two castellated steel beams that underwent four-point bending tests. de Carvalho et. al. [3] examined the LTB behavior of steel I-beams with sinusoidal web apertures, also known as "Angelina" beams. Kumbhar and Jamadar [4] assessed load-carrying capability of castellated beams with mild steel (MS) transverse stiffeners and

carbon fiber reinforced polymer (CFRP) under two-point loading. The study's conclusions indicate that CFRP stiffeners are superior to MS stiffeners because they can provide greater load bearing capability while lowering weight and making application easier. Zhao et. al. [5] demonstrated a comprehensive experimental and numerical evaluation of the flexural behavior of two new designs of partly encased composite (PEC) beams with H-shaped and T-shaped castellated main steel components (MSCs). Yehia et. al. [6] demonstrates how perforations on beams enhance the structural performance of cold-formed steel, which is prized for its affordability and durability. da Silva and Lubke [7] used computational optimization techniques to determine the maximum load-bearing capacity of hollow-core steel beams for two sets of different shear lines, one of which produces beams with hexagon-shaped openings and the other with elliptical ones. Zewudie et. al. [8] provided a numerical evaluation of the arched web-post shear resistance, post-buckling mode, and in-plane elastic-plastic performance of a circular arched cellular steel beam with a pinned end using the ABAQUS nonlinear finite element analysis tool. Ben et. al. [9] studied an advanced framework for predicting the lateral-torsional buckling behavior of cellular steel beams by combining hybrid intelligence models with numerical simulation. Kocher and Kulkarni [10] analyzed simply supported beams with different I-sections, namely ISLB, ISMB, and ISWB. The study discovered that differences in buckling modes had no discernible impact on the buckling load estimates in the initial set of evaluations. Khalate and Kulkarni [11] present a simple and accurate three-dimensional finite element Model (FE) capable of predicting the actual behavior of beam-to-column joints in steel frame subjected to static loads. The main parameters considered in this study were the thickness of flange & web, span and number of bolts. Kowshik and Kulkarni [12] studied the effect of castellations on beams with tapered web for various spans whereas Kulkarni and Swathi [13] studied finite element analysis of castellated beams subjected to flexure.

The contemporary research has taken into account hypothetical data and research gaps were identified. It was determined to use fictitious data from the conventional literature review to analyze and construct steel castellated beams.

II. METHODOLOGY

2.1 Design as per IS:800-2007 [15]

The design of Castellated Steel beam for a span of 13m was carried out with design data [14] as under. The summary of the design [15] of castellated beam with circular openings is in Table I below:

Table I. Summary of castellated beam design

Particular	Value	Particular	Value
Span	13m	Spacing	450mm
Load	8 kN/m	No. of openings	24
Original section	ISMB400	Max moment	169 kNm
Castellated depth	600mm	Moment capacity	351.4 kNm
Opening type	Circular	Max shear	52 kN
Opening diameter	300mm	Shear capacity	401.7 kNm
Clear gap	262.5mm	Max deflection	43.3mm
Steel grade	Fe 410 ($f_y = 250 \text{ N/mm}^2$)		

2.2 Model of beam with circular openings

The main aim of this study is to compare the load carrying capacity of normal steel beam as against castellated beam. Finite element (FE) solution is an approximation to find out how much closer is the representation of ideal calculation in terms of deflection, stresses, strains etc. FE based software was used to carry out a analysis in order to compare the behavior of a castellated steel beam. Two-dimensional shell element Shell63 was employed to generate the models. The castellated beam's geometric characteristics, including beam length, web height, and flange width, were considered. The beam model under consideration was with following dimensions: Overall span 13m, Effective span 12.5m, Depth of beam 600mm, Flange width 150mm, Web thickness 9.4mm and Flange thickness 17.4mm. The FE model of 13m span beam with castellations is shown in Fig. 1 and Fig. 2.

Fig.2 shows model with Young's modulus of $E = 2.1 \times 10^5 \text{ N/mm}^2$, Poisson's ration $\mu = 0.3$ and mesh size of 25mm. The mesh size was so selected that it does not violate the element shape. The simply supported boundary conditions are maintained at both the supports by allowing translation in z, rotations about x, y and z axes. In order to create the buckling effect, the translation along x at the top of the flange is allowed. A unit load is applied at mid-span on the top of the flange and five buckling modes were studied.

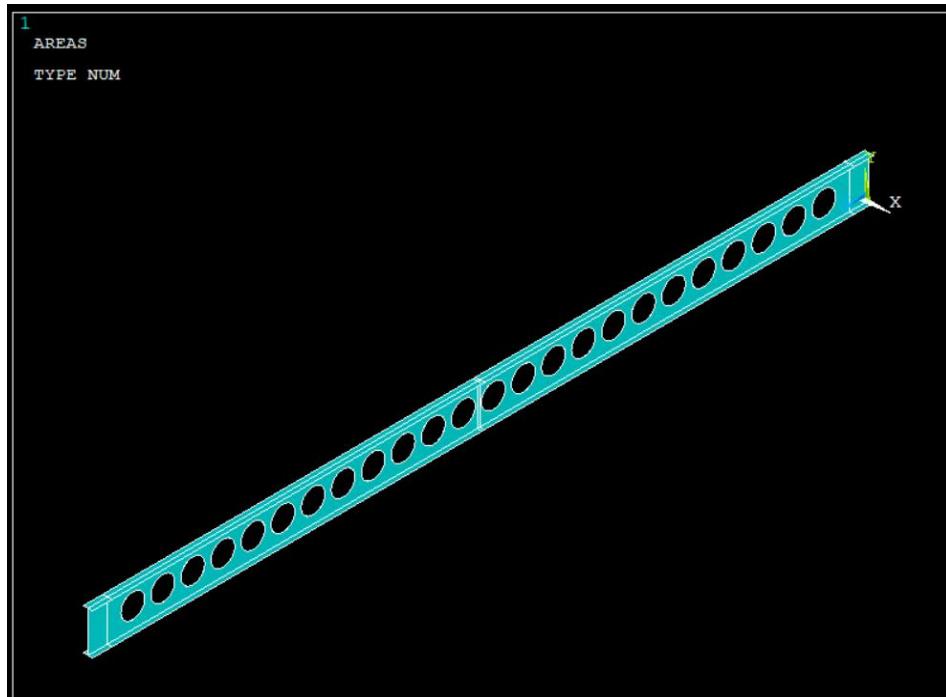


Figure 1: FE Model of a 13m normal castellated steel beam

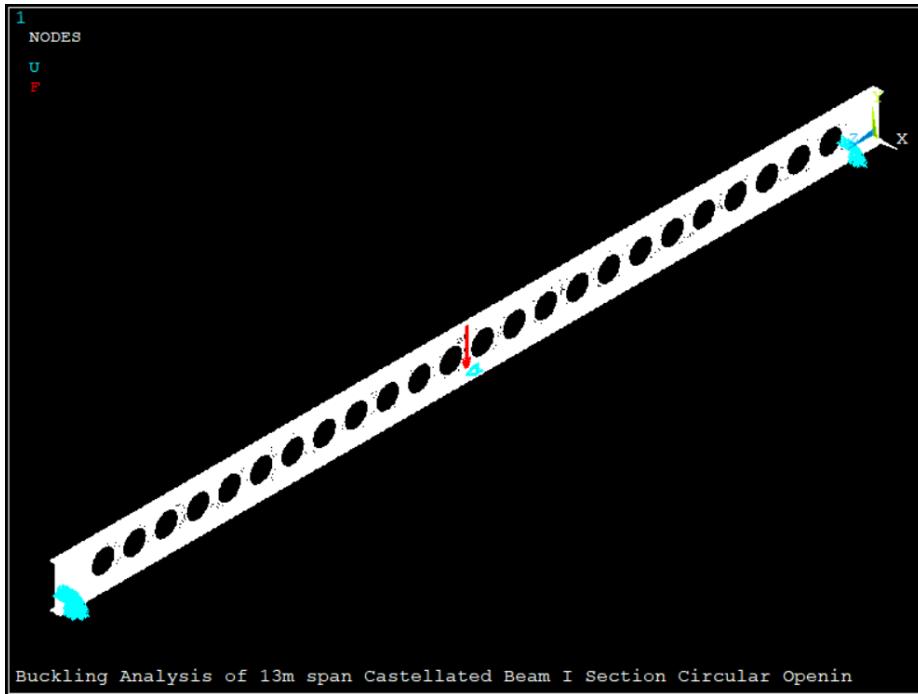


Figure 2: Loading and boundary conditions on 13m span castellated steel beam

III. RESULTS AND DISCUSSIONS

Table II and Figures 3 to 7 display the results of the FE software's lateral torsional buckling study of the 13-meter-span castellated beams. The comparison between a standard ISMB 450 beam and a castellated beam for a 13 m span highlights the structural and economic advantages of using castellated sections. The normal beam exhibits a torsional buckling moment of 69.68 kN-mm and weighs approximately 941.2 kg. In contrast, the castellated beam demonstrates a higher torsional buckling moment of 81.51 kN-mm while weighing only 752.37 kg. This reflects a significant weight reduction of around 20.06%.

The improved torsional buckling performance of the castellated beam is primarily due to the increased overall depth and enhanced stiffness resulting from the opening configuration. Despite having a lighter section,

it offers better resistance to lateral-torsional instability, which is critical in long-span applications. The reduction in self-weight not only minimizes dead load but also contributes to cost savings in material, transportation, and foundation design.

Overall, the castellated beam proves to be more efficient in both strength and weight optimization. It is particularly advantageous in structures where weight reduction and buckling resistance are essential design considerations. This analysis supports the use of castellated beams as a superior alternative to conventional I-sections in modern structural engineering.

Table II.Buckling behaviour of 13m normal and castellated beams

Sr. No.	Beam type	Torsional Buckling Moment (kN-mm)
1	Normal beam ISMB450	69.68
2	Castellated beam	81.51

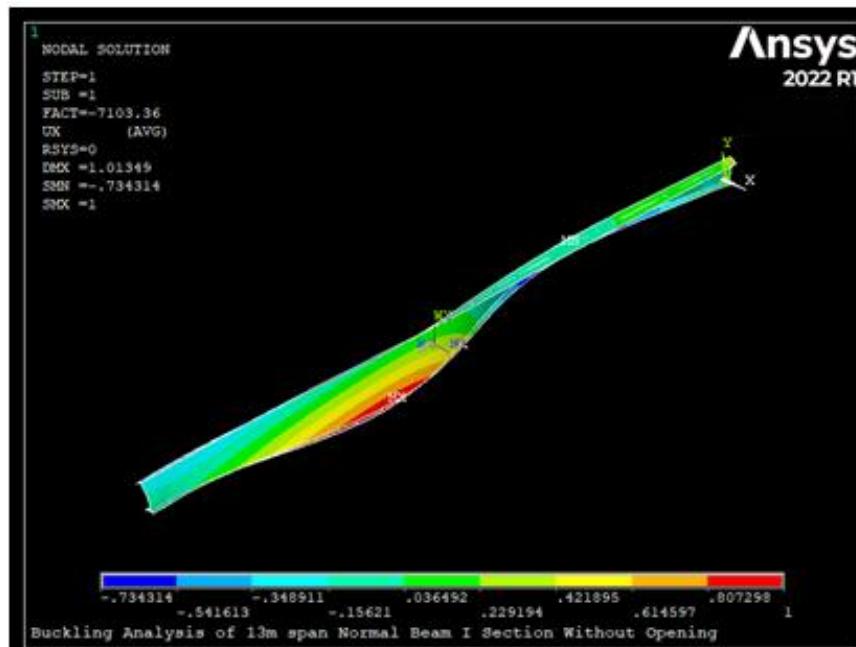


Figure 3: Buckling mode 1 of 13m span normal steel I beam

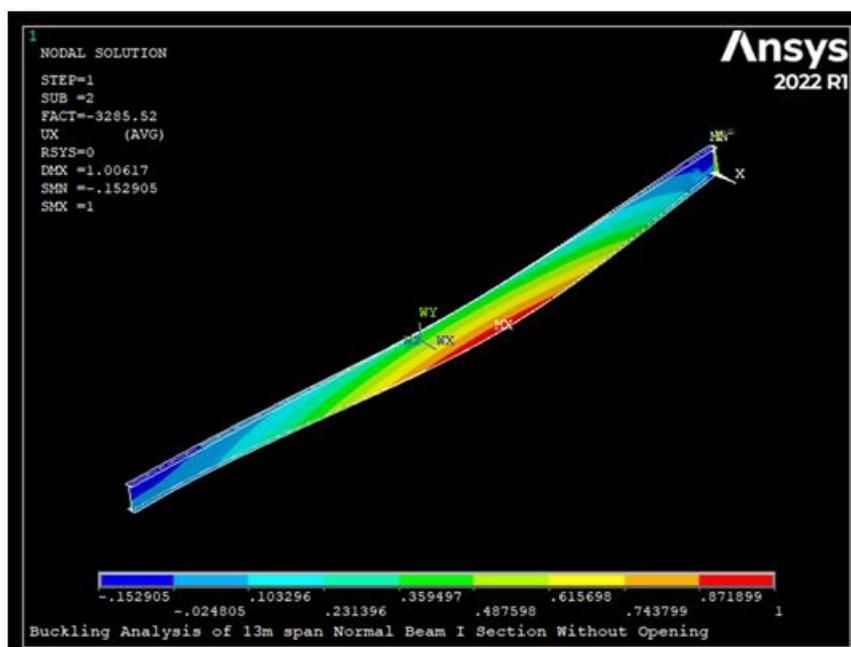


Figure 4: Buckling mode 2 of 13m span normal steel I beam

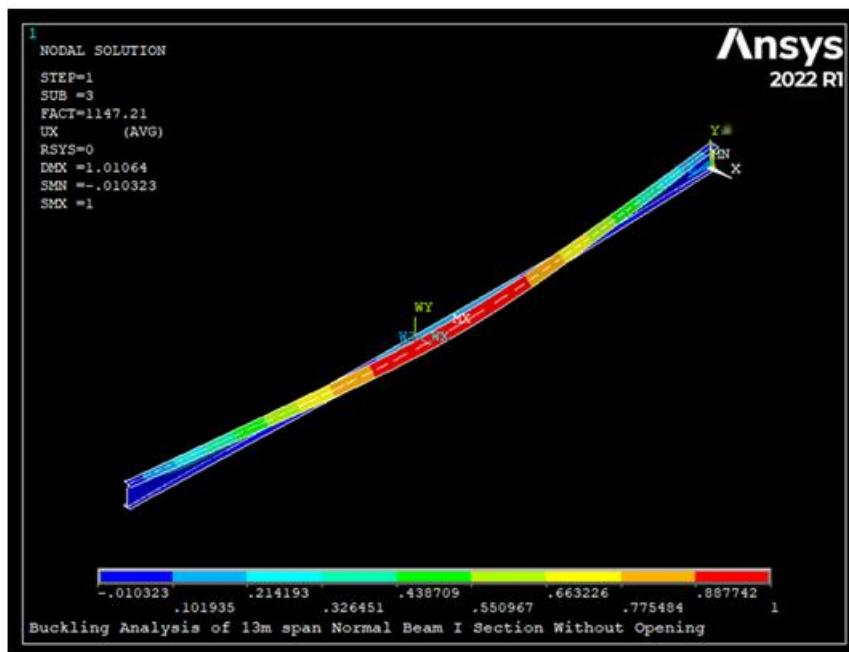


Figure 5: Buckling mode 3 of 13m span normal steel I beam

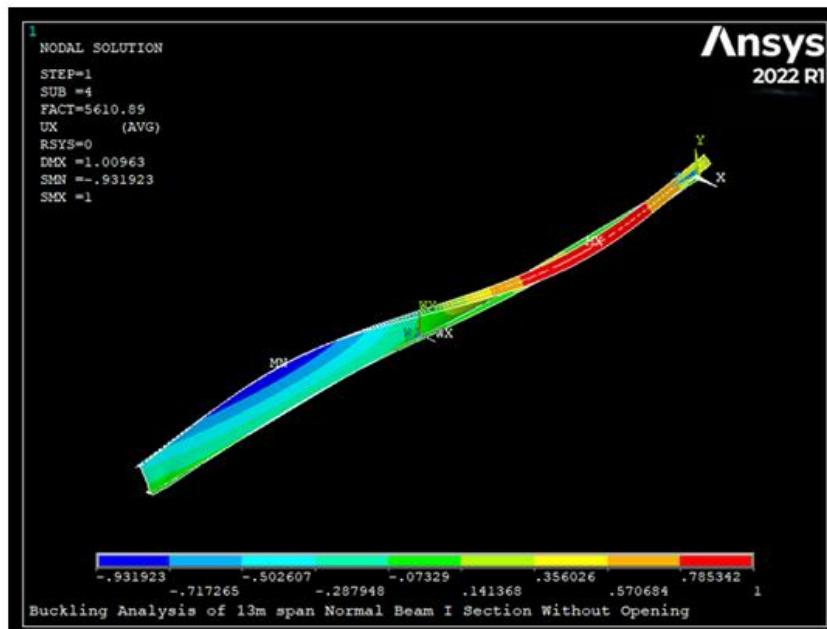


Figure 6: Buckling mode 4 of 13m span normal steel I beam

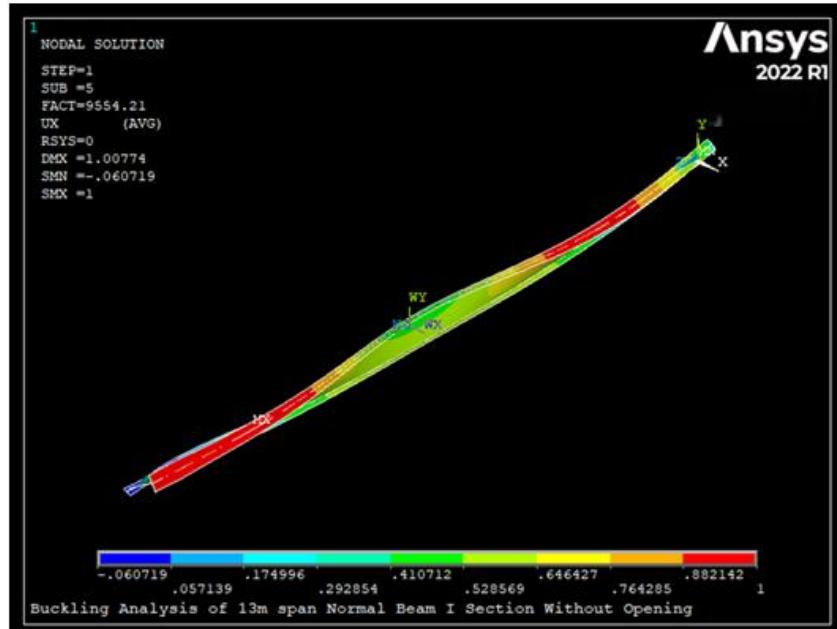


Figure 7: Buckling mode 5 of 13m span normal steel I beam

Table III. Buckling behaviour of 13m normal and castellated beams

Beam Span (m)	Shape 1	Shape 2	Shape 3	Shape 4	Shape 5
10	-49.4614	-23.1485	6.980796	34.43192	51.55214
13	-81.5111	-37.8682	9.926641	47.50286	75.83454
16	-74.0838	15.46635	63.47678	82.09165	109.6837

Five buckling mode forms of various beam configurations are represented by each of the three sets of buckling data in Table III. The load multiplier shows the amount that must be added to the applied load in order to cause buckling in the mode of deformation that each shape number represents.

First Positive Multiplier Critical Buckling Mode: 10m 13m Span: Shape 3 – 9.926641 16m Span: Shape 2 – 15.46635 Span: Shape 3 – 6.980796. The lowest load at which any beam configuration becomes unstable is shown by these values. When figuring out design capacity, they are essential. Two negative values are seen in the 10 and 13 m spans, suggesting theoretically sound but physically meaningless modes under unidirectional compression. There is only one negative mode for span 16m, indicating a better or more stable setup. From a 10m span to a 16m span, the critical load rises by 10m. Span: 13m/6.980796 Span: 15.46635 Span: 9.926641 16m. This suggests that the 16-meter-span beam is the most stable, whether as a result of better boundary conditions, material modifications, or geometric optimization. Following the crucial mode, all sets display multipliers that increase gradually. These higher modes, which frequently involve more intricate deformations such lateral-torsional buckling, are secondary or global failures that only happen after the initial instability. In conclusion, the first positive multiplier—the lowest of these—is the most crucial buckling mode for any beam. According to critical buckling loads, a beam with a span of 16 meters is the most stable, whereas one with a span of 10 meters is the least stable. Although higher modes aid in the comprehension of post-buckling behavior, the lowest positive multiplier should be the primary emphasis of the original design.

IV. CONCLUSIONS AND RECOMMENDATIONS

To ascertain the economy of castellated steel beams and the reaction of normal and castellated beams under buckling, finite element analysis is used. ANSYS software has been used to analyze the various instances. A castellated steel beam is then used to compare the outcomes of the normal beam. The research yields the following findings.

- 1- This study found that buckling resistance is not significantly impacted for a 13-meter span when castellations are incorporated into the beam's web in accordance with the configuration of web apertures.
- 2- The beam's self-weight is decreased by 20.06% in comparison to a regular beam by adding castellations to the web.

3- For a 13-meter span, the web's castellations provide self-weight economy without causing undesired effects under buckling.

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