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Comparative Analysis of Regular Castellated Beam

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ABSTRACT

Castellated beam is defined as the beam in which increasing width of beam without increasing the self-weight of beam. Now a day castellated beam is a new technique. A castellated beam is fabricated from a standard steel I-shape by cutting the web on a half hexagonal line down the center of the beam. The two halves are moved across by one spacing and then rejoined by welding. This process increases the width of the beam and hence the major axis bending strength and stiffness without adding additional materials. Due to the opening in the web, castellated beams are more susceptible to lateral-torsional buckling. The main benefit of using a castellated beam is to increase its buckling resistance about the major axis. However, because of the openings in the web, castellated beam have complicated sectional properties, which make it extremely difficult to predict their buckling resistance analytically. In the Castellation process the fabrication of a section with improved section properties from virgin rolled section that is improving moment of inertia, improving depth. There by increase in moment of resistance and controlled on deflection.

KEYWORDS: *Castellated beam, hexagonal cutting, buckling resistance, web opening*

INTRODUCTION

Castellated beams have been used occasionally for many years and were initially fabricated using simple manual procedures. Although these early fabrication methods limited large-scale development, castellated beams were recognized as structurally efficient members due

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to their enhanced strength and aesthetic appearance. The openings provided in the web not only improve the visual appeal of exposed structural elements but also offer functional advantages by allowing the passage of pipes, conduits, and ductwork in modern construction systems. The most significant benefit of castellated beams is the increased load-carrying capacity and stiffness achieved without a substantial increase in material consumption, resulting in an economical structural solution.

To improve the design and production of castellated beams, the Mississippi Valley Structural Steel Company conducted extensive studies involving design analysis, production techniques, and economic evaluations. European fabrication methods and applications were thoroughly examined because castellated beams had been widely adopted in Europe due to the limited availability of rolled steel sections and the comparatively high cost of materials relative to labour. The investigation mainly focused on the Litzka process developed by Litzka Stahlbau, Bavaria, Germany. Detailed evaluation of this process demonstrated its suitability for large-scale production and automated fabrication techniques, leading to the acquisition of the equipment and manufacturing rights for its implementation.

LITERATURE SURVEY

Jamadar A. M. & Kumbhar P. D.

The use of steel as a structural material has increased significantly in modern construction due to its high strength, durability, and ease of fabrication. Among various steel construction systems, pre-engineered buildings (PEBs) are widely preferred because of their simplicity, faster construction, and economic advantages. PEB structures generally involve large spans with comparatively lower loading conditions, where conventional steel sections may satisfy strength requirements but often fail to meet serviceability criteria, particularly deflection limits. To control excessive deflection, deeper beam sections are usually required. In such cases, castellated beams provide an efficient and economical solution by increasing the depth of the beam without significantly increasing its self-weight. The enhanced depth improves the moment of inertia, stiffness, and flexural strength of the beam, thereby reducing deflection and improving overall structural performance. Consequently, castellated beams are highly suitable for long-span steel structures and PEB applications where both strength and serviceability requirements are critical.

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Although tall steel buildings constitute only a limited proportion of steel structures constructed worldwide, steel is extensively used in single-storey industrial buildings due to its strength, flexibility, and rapid construction advantages. In such structures, secondary structural members play a vital role by spanning between the primary building frames of metal building systems. These members not only support roof and wall coverings and transfer external loads to the main structural frames, but also contribute significantly to the overall stability of the structure. Secondary structural elements may function as flange bracing for primary members and can also form an integral part of the building's lateral load-resisting system. Roof secondary members, commonly known as purlins, are essential components of horizontal roof diaphragms, while wall secondary members, referred to as girts, are frequently incorporated into wall bracing systems to enhance structural stability and load distribution.

FAILURE MODE

1. Flexural Failure Mechanism

This type of failure may occur due to the action of pure bending moments on the castellated beam. When the span is subjected to pure bending, the tee-sections located above and below the web openings yield in a manner similar to that of a conventional solid web beam. However, the propagation of yielding towards the neutral axis is interrupted by the presence of the web openings. As the loading increases, the throat sections between the openings gradually reach a fully plastic state in both compression and tension. Consequently, complete plastic deformation develops in the throat region, leading to failure of the castellated beam under bending action.



Figure 1: Flexure Buckling of Castellated Beam

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2. Shear Bucking of a Web Post

In a castellated beam, one inclined edge of the web opening is subjected to tensile forces while the opposite inclined edge experiences compressive forces. Due to the presence of compressive stresses, the web post between adjacent openings becomes susceptible to buckling, which may induce a twisting effect along the height of the web post. Additionally, the horizontal shear force acting within the web post produces double-curvature bending over its height. This combined action of shear, compression, and bending results in complex stress distribution within the web post, making it one of the critical regions governing the structural behaviour and stability of castellated beams.

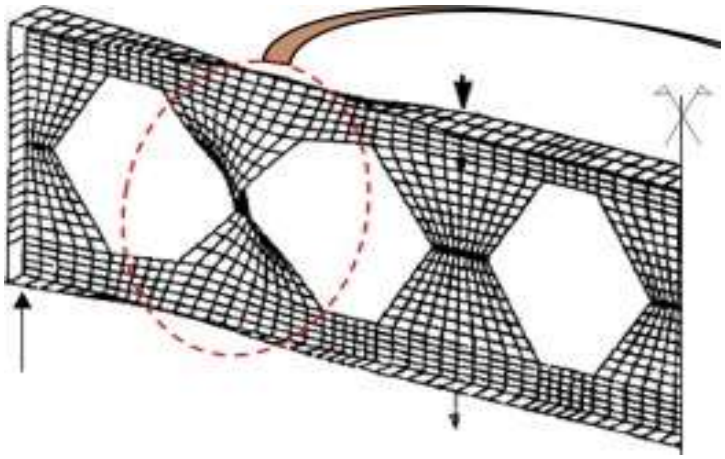


Figure 2: Shear Bucking of a Web Post

3. Lateral-Torsional Buckling

Non-composite castellated beams are more vulnerable to lateral-torsional buckling due to the absence of adequate lateral support to the compression flange. The lateral-torsional buckling behavior of castellated beams is generally similar to that of conventional solid web beams; however, the presence of web openings significantly influences their overall stability and buckling response. These openings reduce the torsional rigidity and alter the stress distribution within the section, thereby increasing the susceptibility of the beam to lateral displacement and twisting under loading. Consequently, the geometry and size of the openings play a critical role in determining the lateral-torsional buckling resistance of castellated beams.

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Figure 3: Lateral-Torsional Buckling of Castellated Beam

SECTION PROPERTIES USED FOR CASTELLATION

The structural section used in the study is ISMB 150. The beam section has a unit weight of 14.99 kg/m and a cross-sectional area of 19.10 cm^2. The overall depth of the section is 150 mm, while the flange width is 75 mm. The thickness of the flange and web are 8 mm and 5 mm respectively, indicating adequate sectional stability and strength for structural applications.

The moment of inertia of the section about the major axis (Ixx) is 717.6 cm^4, whereas about the minor axis (Iyy) it is 46.8 cm^4. The corresponding radii of gyration are 6.13 cm and 1.57 cm respectively. The section modulus values are 95.7 cm^3 about the major axis and 12.5 cm^3 about the minor axis, which represent the bending resistance capacity of the section. Additionally, the maximum flange rivet size specified for the section is 12 mm.

COMPONENT OF PEB

A typical assembly of a simple metal building system is shown below to illustrate the Synergy between the various building components as described below:

The major components of a Pre-Engineered Building (PEB) are classified into primary members, secondary members, roofing systems, and accessory components. Primary structural members mainly include columns, rafters, and rigid frames, which carry the major structural loads and transfer them safely to the foundation. These members are generally fabricated using built-up steel sections to achieve high strength and economy for large-span structures.

Secondary structural members consist of purlins, girts, eave struts, bracings, and sag rods.

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Purlins support the roof sheeting, while girts support wall cladding systems. Bracing members provide stability against lateral loads such as wind and seismic forces. Roofing and cladding systems include roof sheets, wall panels, insulation materials, skylights, turbo ventilators, and gutters, which protect the structure from environmental effects and improve functional performance. Other accessory components of PEB include doors, windows, mezzanine floors, crane systems, flashing, trims, and fasteners, all of which contribute to the overall efficiency, durability, and usability of the building system.

1. Primary Components

Primary components are the main load-carrying members of the structure. These elements transfer the loads safely to the foundation.

- **Columns** – Vertical members that support the entire building load.
- **Rafters** – Inclined or horizontal members supporting the roof system.
- **Rigid Frames** – Combination of columns and rafters forming the main structural frame.
- **End Wall Frames** – Structural members provided at the ends of the building.

2. Secondary Components

Secondary components support the sheeting system and improve structural stability.

- **Purlins**– Roof secondary members supporting roof sheets.
- **Girts**– Wall secondary members supporting wall cladding.
- **Eave Struts**– Members located at the junction of roof and wall.
- **Bracing Systems**– Members resisting wind and seismic forces.
- **Sag Rods**– Elements used to align and strengthen purlins and girts.

3. Sheeting or Cladding Components

These components provide enclosure and protection against environmental conditions.

- **Roof Sheeting**– Metal sheets covering the roof area.
- **Wall Cladding**– External wall covering panels.
- **Insulation Materials**– Materials used for thermal and sound insulation.
- **Liner Sheets**– Internal sheets used for better appearance and protection.
- **Skylights**– Transparent sheets allowing natural light inside the building.

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4. Accessories

Accessories improve the functionality, ventilation, drainage, and appearance of the building.

- **Doors and Windows**– Openings for entry, exit, lighting, and ventilation.
- **Turbo Ventilators**– Devices used for air circulation and ventilation.
- **Gutters and Downpipes**– Components used for rainwater drainage.
- **Louvers**– Ventilation devices allowing airflow.
- **Fasteners and Bolts**– Used for connecting structural members and sheets.
- **Crane Systems**– Installed for material handling in industrial buildings.

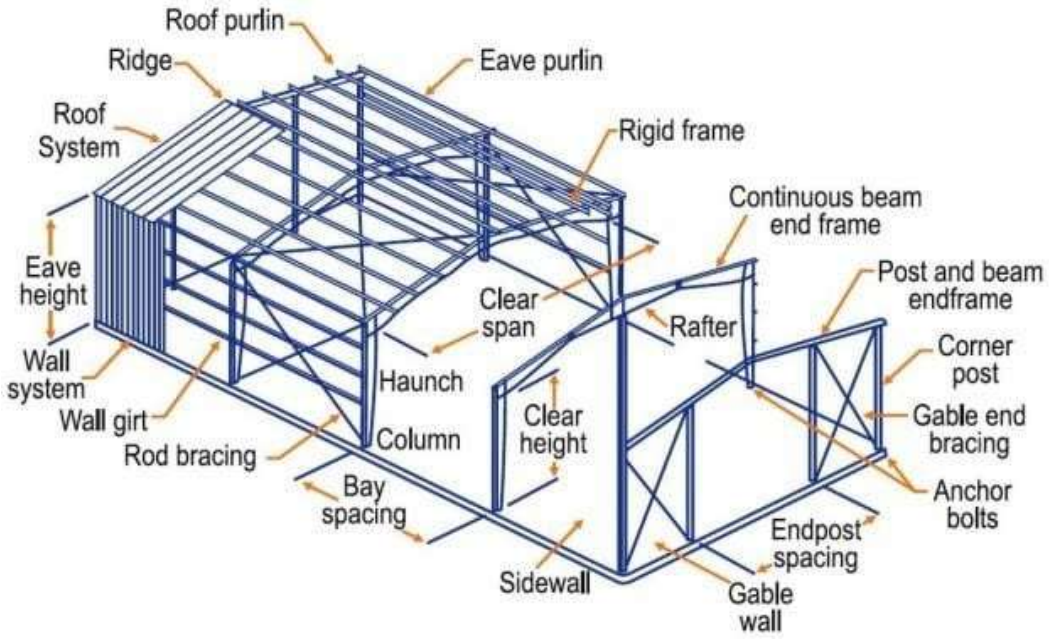


Figure: 4

EXPERIMENTAL INVESTIGATION

Experimental investigation is a systematic process carried out to study the behaviour, strength, stability, and performance of structural elements under different loading conditions through laboratory testing. In structural engineering, experimental investigations are conducted to validate theoretical analysis, numerical models, and design assumptions. The testing procedure generally includes specimen preparation, material selection, instrumentation, loading arrangement, observation of behaviour, and recording of results such as deflection, strain, stress, and failure pattern.

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In the case of castellated beams, experimental investigation is mainly performed to evaluate parameters such as load-carrying capacity, deflection behaviour, stiffness, buckling resistance, web post performance, and failure mechanisms under static or dynamic loading. The beam specimens are fabricated using standard steel sections and tested under controlled loading conditions using testing machines. During the experiment, observations related to lateral-torsional buckling, web post buckling, shear failure, and flexural behaviour are carefully recorded. The results obtained from experimental studies help in understanding the actual structural performance of castellated beams and provide guidance for safe and economical design in practical applications.

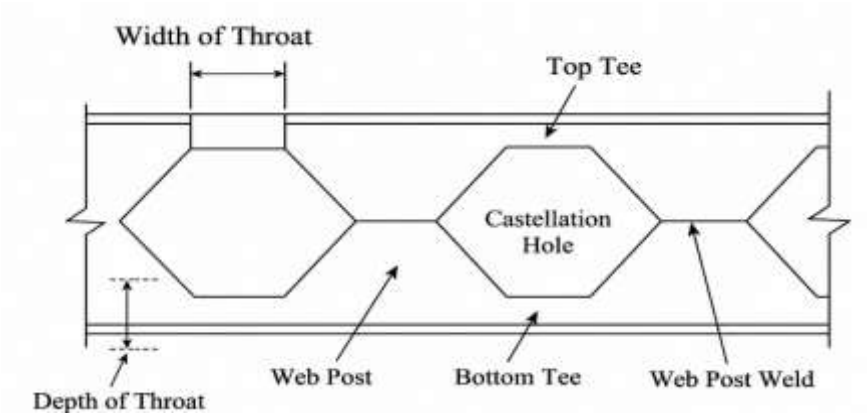


Figure: 5

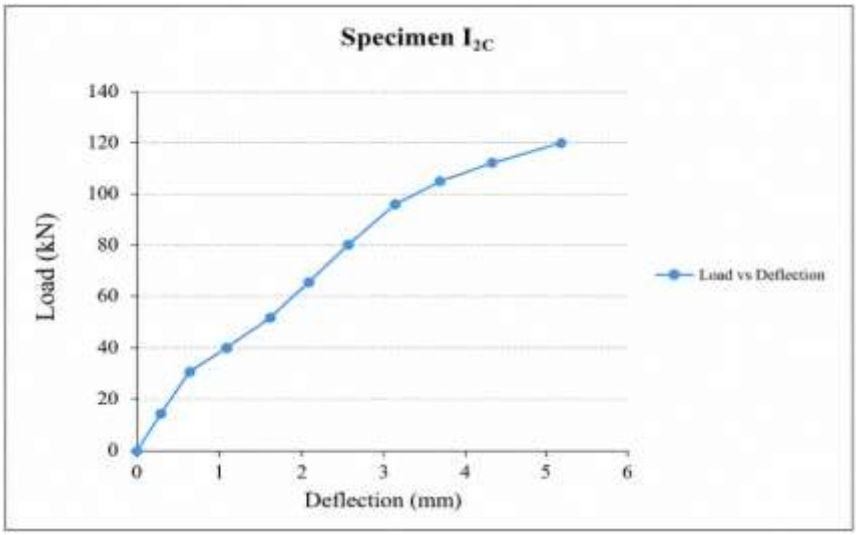


Figure 6: Load vs. Deflection for Sinusoidal Section IH2

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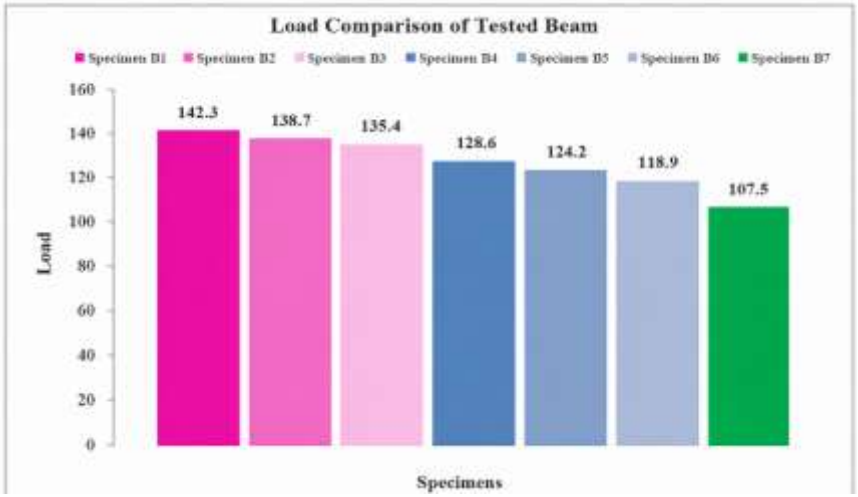


Figure 7: Comparison of Deflection of Tested Beam Specimens

CONCLUSION

1. The load-carrying capacity of castellated beams with sinusoidal web openings is higher compared to castellated beams with hexagonal web openings.
2. The load-carrying capacity of specimen IS1 is 18.55% higher than the parent beam (IP), while IS2 and IS3 show increases of 16.66% and 17.79% respectively compared to IP.
3. Castellated beams with sinusoidal web openings exhibit structural performance comparable to beams with hexagonal openings in terms of stress distribution, shear behaviour, and failure modes.
4. The sinusoidal web opening castellated beam demonstrates greater shear capacity than the castellated beam with hexagonal web openings.
5. Castellated beams with sinusoidal web openings show lower deflection compared to beams with hexagonal web openings.
6. The deflection of specimen IS1 is 14.59% lower than IP, whereas IS2 and IS3 exhibit reductions in deflection of 12.5% and 5.66% respectively.
7. Experimental analysis indicates that shear stresses are more effectively redistributed around the fillet corners in sinusoidal web opening castellated beams.
8. The load-to-deflection ratios obtained for the specimens are 1.27 for IS1, 1.33 for IS2, and 3.14 for IS3.
9. Among all sinusoidal web opening castellated beams, the beam with a fillet radius equal to one-fourth of the opening size exhibited superior performance compared to beams with fillet radii equal to one-sixth and one-eighth of the opening size, based on the load-to-deflection ratio.

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