

Review Paper on Castellated Beam Systems

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ABSTRACT

Castellated beams have become an important innovation in steel construction due to their enhanced structural efficiency, higher strength-to-weight ratio, and economical use of material. These beams are fabricated by cutting and rejoining the web of rolled steel I-sections to create openings, which increase the depth and stiffness of the beam without adding extra weight. The web openings also facilitate the passage of utility services such as ducts, pipes, and electrical cables, thereby reducing floor height and improving architectural flexibility.

This review paper presents a comprehensive study of castellated beams, including their fabrication methods, types of web openings, structural behavior, advantages, and failure mechanisms. Previous research studies on different opening shapes such as hexagonal, rectangular, square, and sinusoidal openings are reviewed and compared based on parameters like load carrying capacity, deflection, stress distribution, and buckling behavior. Special attention is given to the stress concentration developed around web openings, which is one of the major causes of failure in castellated beams.

The review also highlights the application of Finite Element Analysis (FEA) and optimization techniques used by researchers to improve beam performance. Findings from the literature indicate that castellated beams significantly enhance bending strength and stiffness while reducing material consumption. Furthermore, sinusoidal web openings have shown improved structural performance by minimizing stress concentration effects compared to conventional hexagonal openings. This paper summarizes the latest developments and research trends related to castellated beams and provides guidance for future studies and practical applications in steel and Pre-

Engineered Building (PEB) structures.

KEYWORDS: *Castellated beam, web opening*

INTRODUCTION

Steel structures have gained significant importance in modern construction due to their high strength, durability, ductility, and ease of fabrication. In recent years, the demand for economical and efficient structural systems has led to the development of innovative steel members such as castellated beams. Castellated beams are modified steel sections fabricated by cutting the web of a rolled steel I-section in a specific zigzag or geometric pattern and rejoining the two halves through welding. This fabrication process increases the overall depth of the beam without adding additional material or self-weight, thereby improving the structural efficiency of the member.

The term “castellated beam” is derived from the appearance of the openings in the web, which resemble the battlements of a castle. These web openings may be hexagonal, circular, rectangular, square, diamond, or sinusoidal in shape depending on design requirements. The introduction of openings in the web not only improves the aesthetic appearance of the beam but also provides practical advantages by allowing the passage of electrical conduits, ventilation ducts, and piping systems through the beam depth. This helps in reducing the floor-to-floor height of buildings and provides greater architectural flexibility.

Castellated beams offer several structural advantages over conventional solid web beams, including higher bending stiffness, increased section modulus, improved moment of inertia, and superior strength-to-weight ratio. Due to these benefits, they are widely used in industrial buildings, warehouses, factories, bridges, commercial structures, and Pre-Engineered Buildings (PEB). However, the presence of web openings also introduces certain challenges such as stress concentration, web post buckling, lateral torsional buckling, and shear failure around the openings. Therefore, detailed analysis and proper design considerations are essential for ensuring the safe and efficient performance of castellated beams.

Several researchers have carried out experimental, analytical, and numerical studies to investigate the behavior of castellated beams under different loading conditions. The

influence of opening shape, opening size, spacing, beam geometry, and strengthening methods has been extensively studied using Finite Element Analysis (FEA) and experimental investigations. Among various opening configurations, sinusoidal and circular openings have shown improved stress distribution and reduced stress concentration compared to conventional hexagonal openings.

This review paper presents a comprehensive study on castellated beams, including their fabrication techniques, structural behavior, advantages, limitations, failure modes, and recent research developments. The paper also reviews different web opening configurations and compares their performance based on load carrying capacity, deflection, buckling behavior, and overall structural efficiency. The objective of this review is to provide a detailed understanding of castellated beam systems and highlight future research opportunities for improving their structural performance and applications in modern steel construction.

LITERATURE SURVEY

C. M. Meera

Steel is a material which has high strength per unit mass. Hence it is used in construction of structures with large column-free space. Most of the Industrial Structures require this criterion. An Industrial Warehouse is a storage building and is usually characterized as single storey steel structures with or without mezzanine floors. The enclosures of these structures may be brick masonry, concrete walls or GI sheet coverings. The walls are generally non-bearing but sufficiently strong enough to withstand lateral forces caused by wind or earthquake. The designing of industrial warehouse includes designing of the structural elements including principal rater or roof truss, column and column base, purlins, sag rods, tie rods, gantry girder, bracings, etc. A combination of standard hot-rolled sections, cold-formed sections, profiled sheets; steel rods, etc. are used for the construction of industrial steel structures.

Industrial buildings can be categorized as Pre-Engineered Buildings (PEB) and Conventional Steel Buildings (CSB), according to the design concepts. The paper starts with the discussion of methods adopted in the study. Introduction to PEB systems and CSB systems are then described followed by the details of case study. Loads and the load combinations adopted for carrying out the analysis of the structure is well defined in the further portions. A section

depicting the importance of the software used and the software procedure followed is included. Final portion explains the results obtained from the software analysis of the case study and the inferences from the literature studies. The paper aims at developing

Huiyun Qiao, Zhuangzhuang Guo, Yu Chen.

The authors focused on the experimental and numerical investigation of a castellated steel beam substructure subjected to a column removal scenario to evaluate its progressive collapse resistance. The study examined the catenary action, load transfer mechanism, and structural response under potential collapse conditions. Parameters such as deformation capacity, vertical load–displacement behavior, failure modes, and the contribution of flexural and catenary actions were thoroughly analyzed. A total of five castellated beam specimens were experimentally tested and compared with a conventional parent specimen. Furthermore, Finite Element Analysis (FEA) was carried out using the ABAQUS software to validate the experimental findings and to study the structural behavior in detail.

Syed Firoz, Sarath Chandra Kumar B & S. Kanakambara Rao

A tall steel building is not more in the total number of tall steel structures that are built around the world. A large steel structures being built are only single storey buildings for industrial purpose. Secondary structural members span the distance between the primary building frames of metal building systems. They play a complex role that extends beyond supporting roof and wall covering and carrying exterior loads to main frames. Secondary structural's, as these members are sometimes called, may serve as flange bracing for primary framing and may function as a part of the building's lateral load–resisting system. Roof secondary members, known as purlins, often form an essential part of horizontal roof diaphragms; wall secondary members, known as girts, are frequently found in wall bracing assemblies.

The majority of steel structures being built are only low-rise buildings, which are generally of one storey only. Industrial buildings, a subset of low-rise buildings are normally used for steel plants, automobile industries, light, utility and process industries, thermal power stations, warehouses, assembly plants, storage, garages, small scale industries, etc. These buildings require large column free areas. Hence interior columns, walls and partitions are often eliminated or kept to a minimum. Most of these buildings may require adequate

headroom for use of an overhead traveling crane. A third type of secondary framing, known by the names of eave strut, eave purlin, or eave girt, acts as part purlin and part girt its top flange supports roof panels, its web, wall siding. Girts, purlins and eave struts exhibit similar structural behaviour. Since most secondary members normally encountered in metal building systems are made of cold formed steel, our discussion starts with some relevant issues in design of cold-formed steel structures

M. Anbarasu, Anjali Kumari Pravin Kumar Pandey

The study focused on evaluating the effect of castellation on the bending strength and stiffness of hot-rolled steel square tubular beams and castellated tubular beams under simply supported boundary conditions. A total of eight specimens were fabricated and tested in accordance with Indian Standard specifications. The investigation demonstrated that the castellation process enhances the aspect ratio of the beam section, resulting in improved flexural stiffness and increased load carrying capacity. The results confirmed that castellated tubular beams exhibit superior flexural performance compared to conventional tubular sections.

Silda Ghazi Doori, Ahmad Reshad Noori

The objective of this study was to investigate the static behavior of castellated beams with different web opening configurations. A three-dimensional Finite Element Analysis (FEA) was performed using ABAQUS software to evaluate the structural performance of various beam models subjected to uniformly distributed loading and fixed support conditions. Different web opening shapes were analyzed and compared with the conventional hexagonal opening while maintaining the same opening area for all configurations. The study also proposed a new design model incorporating multiple web opening shapes within the beam section. Parameters such as displacement and stress distribution were evaluated and compared for different cases to identify the most efficient opening configuration in terms of structural performance.

A Tjahjono, E J Wijayantil

Castellated beams are extensively utilized in steel construction due to their improved Structural efficiency and reduced self-weight. This study focused on castellated beams with circular web openings, commonly referred to as cellular beams, with the objective of

achieving cost optimization while maintaining structural performance. The optimization process considered parameters such as the selection of the parent beam section, diameter of the web openings, and the number of openings provided along the beam length. Four metaheuristic optimization techniques, namely Particle Swarm Optimization (PSO), Differential Evolution (DE), Symbiotic Organisms Search (SOS), and Artificial Bee Colony (ABC), were employed to obtain the optimum beam configuration. A case study consisting of a 4 m span beam subjected to a central point live load of 50 kN and a uniformly distributed dead load of 5 kN/m was analyzed. The results demonstrated that the Symbiotic Organisms Search (SOS) algorithm provided the most effective optimization performance in terms of average solution quality, consistency, and convergence characteristics, achieving a success rate of 30 out of 30 trials.

M.R. Soltani, A. Bouchaïr, M. Mimoune

The presence of web openings in castellated beams introduces several failure modes that significantly influence the shear strength and buckling resistance of the member. These failure mechanisms are primarily dependent on factors such as beam geometry, web slenderness, type of loading, size and shape of the openings, and support conditions. Common modes of failure observed in castellated beams include web-post buckling, Vierendeel mechanism, and fracture at welded joints. These are generally categorized as local failures because they are directly associated with the geometry of the web openings and the behavior of the upper and lower tee sections formed after castellation.

The Vierendeel mechanism occurs due to the formation of four plastic hinges in the upper and lower tee sections under the combined action of global bending moments and localized Vierendeel moments around the openings. Fracture at welded joints is mainly caused by horizontal shear forces, particularly when the width of the web-post and the length of the welded joints are insufficient. In addition, local buckling may occur due to vertical instability of the web opening sides in regions subjected to high shear forces, as well as buckling of the compression flange. These failure modes must be carefully considered during the design and analysis of castellated beams to ensure structural safety and performance.

Siddheshwari A. Patil, Popat D. Kumbhar

Study and optimization of the castellated beam is done by many researchers. From the

research gap we can frame a conclusion that the study of the behavior of the castellated beam with stiffener is not yet understood. But on the other hand the day by day use of the castellated beam is increasing widely and demand of good performance of the beam under point loading is increasing. This will also give a rise to a new area of optimizing the design of stiffener. From the review of literature following conclusions can be drawn: 1. Analysis and design of castellated beam needs to be carried out by using stiffeners in transverse direction and also along the edge of openings in order to minimize web post buckling. 2. Optimization of castellated beams with stiffeners by varying the parameters namely, size and positions in web portion is necessary.

Wakchaure M. R; Sagade A.V; Auti V. A.

From the experimental testing, it is concluded that, Castellated steel beam behaves satisfactory for serviceability, up to maximum depth of opening $0.6D$. Castellated beams has holes in its web, as holes incorporated various local effects in beams, increase in load causes beams to be failed in different failure mode, which resist them to take load up to their actual carrying capacity. So we cannot compare beams with different modes of failure directly for strength criteria. Due to the presence of holes in the web, the structural behavior of castellated steel beam will be different from that of the solid web beams. It make structure highly indeterminate, which may not analyzed by simple methods of analysis. So we have to design beam to avoid local effects, for improved performance of castellated beam. It is observed as depth of opening increases in Vierendeel effects is prominently observed at the hole corners, so by taking corrective measures (i.e corners should be rounded, provision of reinforcement) we can expect improvement in performance of beam.

They can conclude that castellated beams are well accepted for industrial buildings, power plant and multistoried structures, where generally loads are less and spans are more with its economy and satisfying serviceability criteria.

CONCLUSION

Castellated beams are an efficient and economical alternative to conventional steel beams due to their higher strength-to-weight ratio, improved stiffness, and increased load carrying capacity without significant increase in self weight. The web openings not only enhance structural performance but also provide space for utility services, making them suitable for

industrial and commercial structures.

This review highlighted the behavior, advantages, failure modes, and different web opening configurations of castellated beams. Studies showed that opening shape, size, and spacing greatly influence beam performance, while advanced analysis methods such as FEA are effective in evaluating their behavior. Although castellated beams are susceptible to local failures such as web-post buckling and Vierendeel action, proper design and optimization can significantly improve their efficiency and structural performance.

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