FLEXURAL BEHAVIOUR OF ROLLED STEEL I- BEAM AND CASTELLATED STEEL BEAMS

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ABSTRACT

Economy, ease and speed of construction are the main factors for using steel as a building material. In this paper castellated beams with hexagonal openings and standard hot rolled I-sections are considered as the main flexural member of industrial buildings. The main goal of manufacturing castellated beams is to increase the moment of inertia, section modulus, depth of section without any additional weight. The initiative was to identify the maximum load behaviour and deflection of steel beams with openings in the web. The performance of such beams has been considered only for vertical loads. Hot rolled steel beam of ISMB 150 with openings in the web were tested to failure. The beams were simply supported at the ends and subjected to a concentrated load applied at the mid-span. The openings considered in the experimental study are standard and non-standard hexagonal shapes. The deflection at centre of beam and various failure patterns are studied. All the beams were analyzed by the finite element method by using general finite element analysis software ANSYS and the results were compared with those obtained experimentally. The finite element results for deformation and ultimate strength shows good agreement with the corresponding values observed in the experiments. At last, a comparative study was carried out using finite element method to examine that which type of beam gives best performance during loading. The numerical results indicate that the use of Castellated beam sections is an economical and advantageous choice.

Key words: Rolled steel I- beam section, castellated steel beam sections, Load – Deflection behavior, ANSYS, Finite element method

INTRODUCTION

GENERAL

Steel offers much better compressive and tensile strength than concrete and enables lighter constructions. Also, unlike masonry or reinforced concrete, steel can be easily recycled. Beams are flexural members that support loads which are applied transverse to their longitudinal axes. Beams have a far more complex load-carrying action than other structural elements such as trusses and cables. The load transfer by a beam is primarily by bending and shear.

Rolled steel I -Beam

I-beams are commonly made of structural steel but may also be formed from aluminium or other materials. An I-beam, also known as H-beam, W-beam (for "wide flange"), Universal Beam (UB), Rolled Steel Joist (RSJ), or double-T is a beam with an I- or H-shaped cross-section. The horizontal

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elements of the "I" are known as flanges, while the vertical element is termed the "web".

The web resists shear forces, while the flanges resist most of the bending moment experienced by the beam. Beam theory shows that the I-shaped section is a very efficient form for carrying both bending and shear loads in the plane of the web.

Castellated steel beams

A beam with a number of regular openings in its web is called a castellated beam. Castellated beams have been used in a wide variety of applications, such as roof beams and rafters in both simple span and cantilever construction, floor beams and girders for heavy as well as light floor loads, tier buildings, rafter portions of rigid frames, pipe bridges, girts and other special applications.

They also demonstrate the interesting appearance and the functional use of the web holes. Even the increased depth is at times advantageous as in the case of spandrels or other special architectural features. The economy of castellated beams is one of their most important advantages.

However, the efficiency and economy of castellated beams has been well established and, for beams on most spans carrying medium to heavy loads, their use merits consideration.

OBJECTIVE OF THE STUDY

The aim of the research is to determine the most suitable castellated beam section that can produce of desirable strength without compromising engineering performance and minimum possible self weight.

- To investigate and compare, through an experimental programme of work, the flexural behaviour of castellated steel beams with hexagonal web opening shape configurations with universe beams (I- section).
- To examine both the load carrying capacities and the failure modes of castellated sections and positions of high stress concentration points in the vicinity of the web openings.
- To correlate the experimental results with FE models, and thoroughly investigate their complex structural behaviour in terms of buckling load, stress distribution and failure mode.

LITERATURE REVIEW

General

This chapter describes the literature review on behavior of steel beams with web openings

T.C.H.Liu and K.F. Chung, (2003) conducted a study of "Steel beams with large web opening of various shape and size: finite element investigation". Authors suggested that not only an empirical shear–moment interaction curve at the perforated section but also suggested a method for practical design of steel beams with circular web opening against Vierendeel mechanism. Vierendeel mechanism is always critical in steel beams with single large web openings. While the depth of web openings controls both the shear and the flexural failures of the perforated sections, it is the length of the web openings that governs the 'Vierendeel' mechanism which in turn depends on the local shear and moment capacities of the tee sections above and below the web opening. A comprehensive finite element investigation on steel beams with web openings of various shapes and sizes was reported, and the primary structural characteristics of those steel beams were presented.

K.D.Tsavdaridisa and Cedric D'Mellob (2011) conducted a study on "FE modelling techniques for web-post buckling response - perforated steel beams with closely spaced web openings of various shapes" Authors uinvestigated that the effective 'strut' action of the web-post buckling and proposed an empirical formula which predicts the ultimate vertical shear load strength of web posts formed from the particular web opening shapes. The predicted mode of buckling includes some flange rotation, which is also observed in the test beam. In most of the FE analyses, an early out-of-plane web movement is observed due to the applied lateral force. The latter can be a trigger load, an imperfection or the eigen-vectors. As the load is increased the web starts to return to its original position. At higher load levels the web starts becoming unstable which is the onset of buckling. Increasing the load results in the web deforming plastically (buckling), while in some cases a jump in the opposite direction is observed.

Pattamad Panedpojaman and Teerawat Rongram (2013) conducted a investigation of "Design equations for vierendeel bending of steel beams with circular web openings" to evaluate the load carrying capacity of steel beams with circular openings based on Vierendeel failures. The computations are derived based on the shear area according to BS EN 993-1-1 and they are compared with fininte element analysis of various steel models with opening ratios of 0.5 and 0.8. Also carried out a detailed study investigates Vierendeel's effect on overall behaviour of the perforated beams in terms of the normalized moment- shear interaction curve. The theoretical moment and shear capacities in this study agree well with those predicted by the FE Analysis. Through the analytical results, the stress distributions and Vierendeel failure behaviour of all models are similar.

N. Boissonnade and H. Somja (2014) performed the experimental and numerical study of "Influence of imperfections in fem modeling of lateral torsional buckling". Authors suggested a design procedure of cellular beam against lateral torsional buckling. They were investigated towards the influence of imperfections on the FEM modeling of the Lateral Torsional buckling phenomenon have been led. Typical influences of the constitutive law definition, of the residual stresses adopted distributions and of geometrical initial imperfections (both local and global) have been studied, through adequate shell models. More than 700 results of FEM simulations show that i) an adequate and reasonably realistic set of residual stresses, initial lateral imperfection and torsional twist lead to consistent results, and that ii) such "standard" definitions may be used in FEM-led parametric studies. Detailed recommendations for FE modeling (type and amplitudes) are also finally given.

R. R. Jichkar, et al., (2014) conducted the experimental and analytical study of "Analysis of steel beam with web openings subjected to buckling load". Authors analyzed that the Buckling load Analysis and deflection calculation of different section of beams with different support condition and different loadings with circular, square and hexagonal web openings. As a result several new methods have been aimed at increasing the stiffness of the steel members without any increase in weight of the steel required. Beam with web opening have proved to be efficient for moderately loaded longer span where the design is controlled by moment capacity or deflection. A steel beam is selected and is analyzed for different loading and support condition by using Ansys Software. The deflection pattern at the Center distance of the beam is studied for different parametric condition by same depth of web opening to the depth of beam ratio and also for various combinations of shapes of opening.

METHODOLOGY

Introduction

This chapter describes the methodology of this project, the main topics included in this chapter are study of material, selection of suitable section, section properties, fabrication of test specimens, testing of specimens, observation for both rolled steel I-beams and castellated steel beams and the last thing is the results and discussions.

Study of material

Study of material is about the gaining of general ideas and knowledge about the materials using in the project. It also includes study of the terms involved in the project. It consists of the general study about steel, properties, advantages, applications and castellation techniques details etc.

Selection of suitable section

The suitable section selection is nothing but identifying the most suitable section of beam required for the project from literature reviewed. The section is designed and analyzed by the limit state method.

Section properties

From the Indian standard recommendations the selected section properties are considered for further design checks.

Table 1: comparison of section modulus of Beams

S.No	Name of the Beam	Elastic modulus, Z_{ez} (mm^3)	Plastic modulus, Z_{pz} (mm^3)
1	I – Section	95.7×10^3 mm^3	110.48×10^3 mm^3
2	Castellated beam	152.51×10^3 mm^3	183.01×10^3 mm^3

Fabrication of test specimens

ISMB150 is selected as a parent section for fabricating castellated beam. Following guidelines are followed for fabrication-

- The hole should be centrally placed in the web and eccentricity of the opening is avoided as far as possible.
- Stiffened openings are not always appropriate, unless they are located in low shear and low bending moment regions.
- Web opening should be away from the support by at least twice

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the beam depth, D or 10% of the span, whichever is greater.

- The best location for the opening is within the middle third of the span.
- Clear Spacing between the openings should not be less than beam depth D.
- The best location for opening is where the shear force is the lowest.
- The diameter of circular openings is generally restricted to 0.5D.
- Depth of rectangular openings should not be greater than 0.5D and the length not greater than 1.5D for un-stiffened openings.
- The clear spacing between such openings should be at least equal the longer dimension of the opening.
- The depth of the rectangular openings should not be greater than 0.6D and the length not greater than 2D for stiffened openings. The above rule regarding spacing applies.
- Corners of rectangular openings should be rounded.
- Point loads should not be applied at less than D from side of the adjacent opening.
- If stiffeners are provided at the openings, the length of the welds should be sufficient to develop the full strength of the stiffener.
- If the above rules are followed, the additional deflection due to each opening may be taken as 3% of the mid-span deflection of the beam without the opening.

Experimental Testing of specimens

The experimental investigations carried out on the test specimen to study the flexural behavior of Hot rolled I-sections and castellated beam sections. Test specimen's span (*l*) = 1.9 m. The beams were simply supported at the ends and subjected to a concentrated load applied at the mid-span. The deflection at centre of beam and various failure patterns are studied.

Flexural behaviour of I-section

The following figures show that flexural behavior of Rolled steel I-Beams

Fig.1: Testing Arrangement For Solid Web Beam ISMB 150

Fig.2: Local Failure- Failure of Compression Flange ISMB 150

Fig.3: Lateral Torsional Buckling of ISMB 150

Flexural behaviour of castellated steel beam

Fig.4: Beam NCB 150 Mounted for Testing

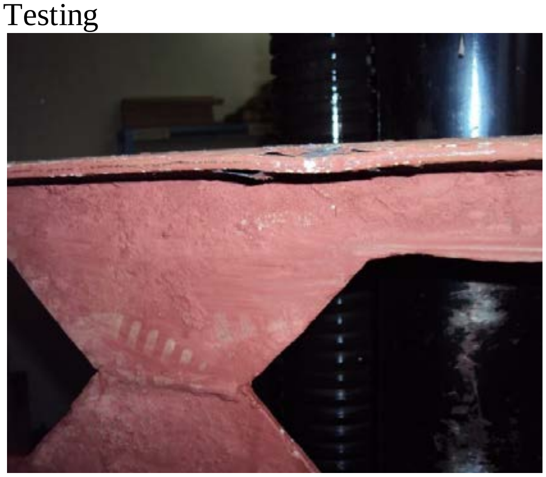

Fig.5: Local Failure Mode –Buckling of Compression Flange

Fig.6: Flexural Buckling of Beam NCB 150

RESULTS AND DISCUSSIONS

Experimental test results of Load – Deflection behavior of beams are obtained for both Rolled steel I-sections and castellated steel beams.

Serviceability limit for beam= L / 325 = 1900 / 325 = 5.846 mm

Table.2: Comparison of test results for serviceability limit

S. No	Beam	Deflection (mm)	Max load (kN)	Global Mode of failure
1	ISMB 150	5.86	78	Lateral torsional buckling
2	NCB 150		68	Flexural buckling of Web

This indicates that up to the serviceability limit castellated beams has nearly same stiffness of its parent beam.

After this load increased continuously, due to presence of holes in the web opening it starts introducing some local effect, due to which its deflection increases rapidly and moment carrying capacity decreases. For carrying maximum moment we have to follow following conditions while designing:

- To avoid local failure of beam. (i.e. provision of plate below concentrated load).
- To provide reinforcement at the weak sections of the beam.
- To avoid Vierendeel effect (to avoid stress concentration) corners of the holes are to be rounded.

SUMMARY

From this research work of experimental and theoretical investigation, Castellated beam 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 is studied. 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 behaviour 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.

On-going process

- ➢ Finite element modeling of beams
- ➢ Comparative study of standard rolled steel I-beam and Castellated steel beam sections

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