NUMERICAL STUDY ON COLD-FORMED CASTELLATED STEEL BEAMS

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Abstract - This study presents a comprehensive numerical investigation into the structural performance of cold-formed castellated steel beams. Castellated beams, characterized by web openings that improve their strength-to-weight ratio, are increasingly utilized in modern construction. However, their structural behavior when fabricated from cold-formed steel—distinct from hot-rolled steel in terms of material properties and failure mechanisms—remains insufficiently explored. To address this, Finite Element Analysis (FEA) was conducted using ABAQUS to simulate the response of various beam configurations under applied loading. Key parameters, including web opening geometry, web thickness, and span length, were systematically varied to evaluate their effects on stress distribution, deformation behavior, and failure modes. The numerical results were validated against available experimental data and analytical solutions to ensure accuracy. Findings reveal that cold-formed castellated beams offer considerable benefits in terms of material efficiency and design adaptability. However, they are particularly susceptible to local buckling and stress concentrations around the openings, which must be carefully considered in design. This research provides valuable insights to support the optimized and safe application of cold-formed castellated steel beams in structural engineering practice.

INTRODUCTION

Using steel structures in construction of pre-engineered building (PEB) is becoming widespread due to simplicity and speed of erection in addition to other advantages, such as durability, and strength to weight ratio. However, this type of building has very long spans compare with less loading. In some cases, the standard steel section satisfies the requirement of strength, but does not attain serviceability i.e. deflection criteria. In order to satisfy deflections requirement, it is necessary to increase the depth to span length ratio of beams. Using castellated beams results in increasing in the depth of beams without any increasing in the weight.

The castellated beams are made by separating a standard hot rolled wide flange I-section into two equal parts by cutting the web in a regular alternating zigzag pattern, and then both halves are shifted and rejoined by welding as shown in Fig. 1. The increasing in depth of beam that is obtained due to construction process leads to modify the stiffness and strength of the castellated beam compared to the original I-section beams. In the recent years with the development mechanisms of cutting and welding tools, the castellated beams are manufactured almost in an unlimited number of depths and spans.

The major advantage of the castellated beam is increasing the stiffness and strength of standard I-section beam by increasing its depth without adding any weight. Another advantage of castellated beam which is easing use of functional requirement like ductwork, service pipe, electrical cable, etc. which can be extended into the hexagonal holes, so that the height of floors can be reduced. Also, when used in buildings with exposed members, the hexagonal hole in web gives aesthetic advantage

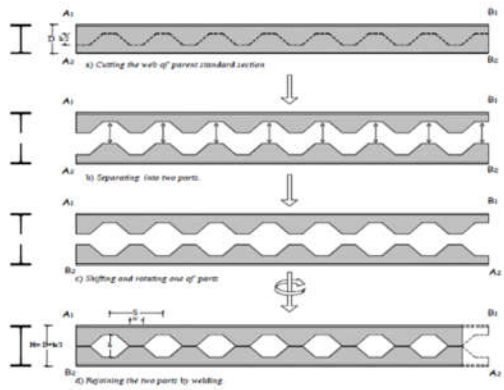

Fig-1 fabrication process of castellated steel beam

LITERATURE REVIEW

1. In 1973, Hosain and Speirs (1973) analyzed experimental results of twelve samples of castellated steel beam to study effect of change numbers of hole on the behavior of beams that have same length of span and ratio of expansion. Also, the effect of hole size on failure mode and ultimate load carried was investigated. The results of experimental test indicated that the best hole size requires a minimum distance of the throat which made the beam less subjected to failure because of Vierendeel mechanism.

2. Galambos, et al. in (1975) tested five castellated steel beams fabricated from standard section (W10x15) to verify a numerical approach to study the optimum expansion ratio by using elastic and plastic analysis methods. All experimental specimens of castellated beams were subjected to mid-span concentrated loads. The span length of beams was kept constant, but the beam depths were differenced based on variation expansion ratios. The ultimate load capacity was presented but no further discussion about the failure modes was given.

3. In (2011), Ehab Ello body (2011) investigated the interaction of buckling modes in castellated steel beams with hexagonal hole experimentally as well as analytically. The author developed 3D finite element model and nonlinear material properties to ninety-six model of castellated steel beams by using (ABAQUS) software program. By using nonlinear finite element modeling, the parametric study was carried out to investigate the effects of the variation in geometries of cross-section, span length of beams and steel strength on behavior of castellated steel beam. This study noted that the presence of web distortional buckling causes a significant decrease in the ultimate strength of castellated steel beams. The ultimate load capacity is directly proportional to the steel strength hence offers significantly increase in load failure.

4. In (2012), Wakchaure et al. (2012) used finite element models to study flexural behavior of hexagonal castellated steel beams. The investigation is carried out on castellated beams with two concentrated load and simply boundary condition by using ANSYS software package. From the results of nonlinear finite element model, they are concluded that castellated steel beams were agreeable of serviceability criteria up to a maximum hexagonal opening height in web (60 %) of beam height. Also, since design of longer spans with moderately loaded is controlled by limitation of deflection, the castellated steel beam has demonstrated to be efficient for these cases.

5. In (2015), Jamadar and Kumbhar (2015) tested experimentally and analytically castellated steel beams using package program ABAQUS ver. 6.13. The castellated steel beams were provided with two types of opening shaped (circular and diamond) by following the recommendation given EUR-Code 3. The analytical results which obtained by using software were validated it by comparing with experimental results. In their paper, it can be seen that the castellated steel beams with diamond opening suffers least amount of local failure as more shear transfer area is available as compared to the castellated steel beams with circular.

SECTION AND ITS PROPERTIES

Cold-rolled steel sheet of Grade IS 513CR2 of 3 mm thickness having yield stress, ultimate tensile strength, and elongation percentage as 220, 280MPa and35%respectively. According to the dimensions of flange and web, machine cutting, i.e., straight cutting is done on the cold-rolled sheet are Laser cutting is done on web for the zig zag pattern for castellated beam.

PARAMETERS CONSIDERED FOR THE STUDY
Material Properties:
Poisson's Ratio is 0.3
Material model – Elastic-Perfectly plastic.
Member Properties:
Thickness of section (t) is 3mm.
Length of the specimen varies with 1500 mm and 1300 mm.
End condition is simply-supported.

NUMERICAL MODELING USING ABAQUS SOFTWARE

Abaqus is a software suitable for finite element analysis. It can be used for both static and dynamic problems. Abaqus CAE is a software application used for both the modelling and analysis of components and assembling and visualizing the finite element analysis result. Abaqus CFD denotes computational fluid dynamics software application which provides advanced computational fluid dynamic capabilities with extensive support.

Specimen	UNITS	Build up i section beam	Castellated built up I section beam		
		CRB	CRCB-1	CRCB-2	CRCB-3
Depth	mm	200	250	250	250
Breadth	mm	100	100	100	100
Span	mm	1300	1300	1300	1300
Web and flange thickness	mm	3	3	3	3
Spacing(s)	mm	_	150	100	75
End pitch(e)	mm	_	125	100	62.5
Number of openings		–	3	4	5

Table-1 specimen dimension

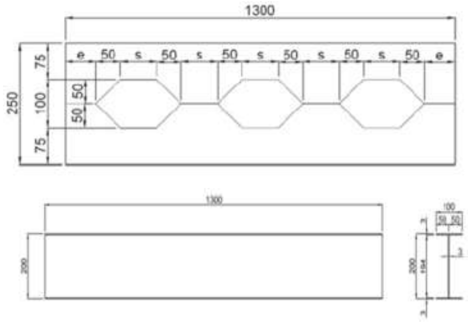

Fig-2 Details of castellated beam

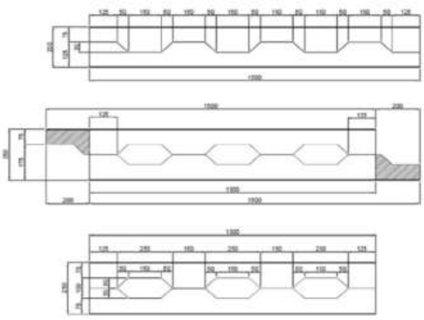

Fig-3 castellation for CRCB-1

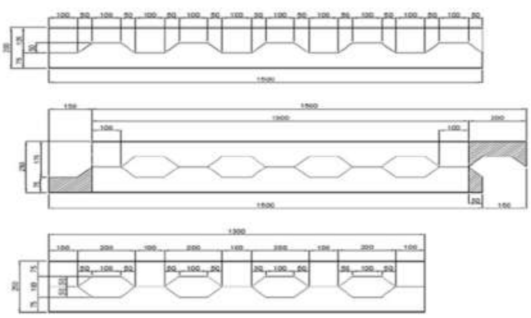

Fig-4 castellation for CRCB-2

Non-linear analysis:
A non-linear geometric parameter (nlgeom=on) was enabled to deal with the geometric imperfections. The parameters used in the non-linear Static General analyses were:
Maximum number of load increments = 100
Initial increment size = 0.01
Minimum increment size = 1E-015
Maximum increment size = 1
Displacement control was enabled.
Automatic increment reduction was enabled, and large displacements were allowed.

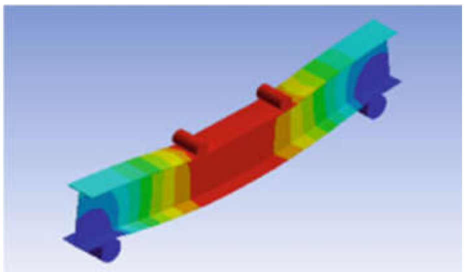

Fig-5 Nonlinear representation of I section

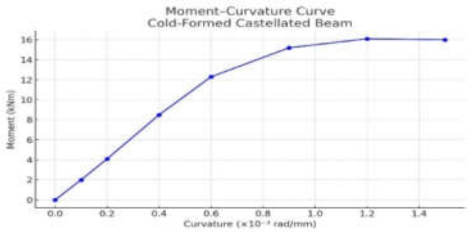

Fig-6 moment vs curvature of CRB

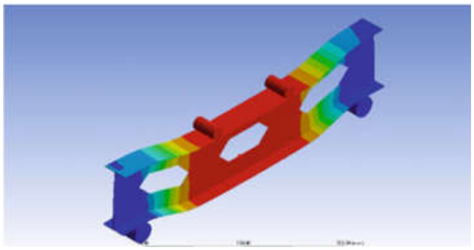

Fig-7 Nonlinear representation of CRCB-1

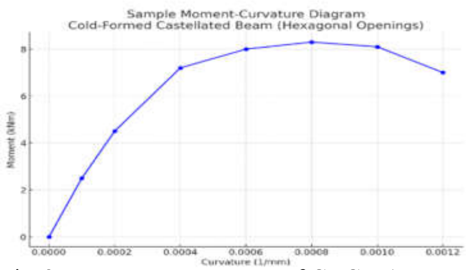

Fig-8 moment vs curvature of CRCB-1

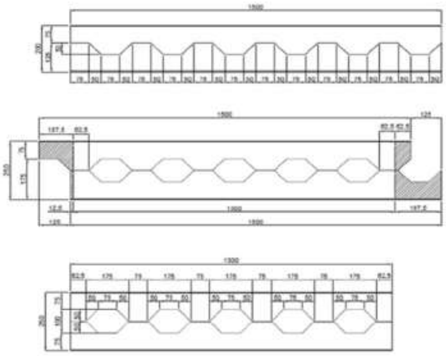

Fig-9 castellation for CRCB-3

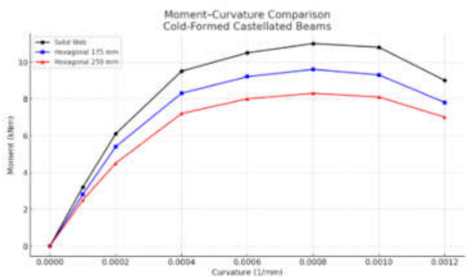

Fig-9 comparison moment curvature

Curvature (1/mm)	Solid Web (kNm)	Hex 175 mm (kNm)	Hex 250 mm (kNm)
0.0000	0.0	0.0	0.0
0.0001	3.2	2.8	2.5
0.0002	6.1	5.4	4.5
0.0004	9.5	8.3	7.2
0.0006	10.5	9.2	8.0
0.0008	11.0	9.6	8.3
0.0010	10.8	9.3	8.1
0.0012	9.0	7.8	7.0

Table-2 comparison moment curvature

CONCLUSION

The structural performance of castellated beam is studied, and it is more evident that without an increase in self-weight of the structure, the depth is increased. This castellated beam can be even more effectively designed considering the factors like span, loading and depth required.

From this analysis, it was observed that as the depth of opening increases, stress concentrations increase at the hole corners and at load application point. The results also confirm that the flexural stiffness of the castellated beams decreases as the depth of opening increases. Finally, the performance and benefits of castellated beam are understood by numerically, and this can be used in general construction practice as secondary beams to reduce the self-weight for structure.

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