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Parametric Study On Castellated Beam With Arch-Shape Openings

Munjalkumar H. Upadhyay[#1], Vishal B. Patel[*2], Vishal A. Arekar[#3]

[#1]PG Research Scholar, [#2,3]Assistant Professor
Structural Engineering Department, Birla Vishvakarma Mahavidyalaya Engineering College,
Vallabh Vidyanagar, Gujrat, India.

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Abstract - *Use of castellated beam for high bay span steel structures, parking structures, office buildings, health care buildings etc., increases substantially in the recent scenario because of its outweigh advantages. The objective of the castellated beam is to improve load-carrying capacity without increasing its weight to full fill loading criteria and serviceability criteria. Therefore, in this research work, non-linear numerical modelling analysis is carried out to observe the behavior of castellated beams having a newly proposed irregular shape of the opening. Curve-in-curve (Arch) type of opening shape is prepared from the parent ISMB 250 section. The finite element model was prepared using ABAQUS/CAE 6.11 version. The average load-carrying capacity of a curve-in the curve type of opening increases by 27% and 15% for circular and hexagonal shaped castellated beams respectively. Two different parameters considered for analysis of curve-in the curve type of opening castellated beam in this paper is (1) the length of its first opening provided from the end support condition of the beam and (2) load-displacement variation of a curve-in the curve type castellated beam prepared from parent ISHB 450 section for its varying web thickness. An increment in load-carrying capacity is also measured for both the models having reinforcement around the web opening.*

Keywords — *Curve-in the curve shape opening, Castellated beam with and without reinforced novel-openings, Length of 1st arch opening from the end of the beam, Castellated beam with different web thickness, ABAQUS.*

I. INTRODUCTION

Use of steel as a structural member is rapidly gaining interest nowadays because of its high strength and high ductility. Use of tapered section in the pre-engineered building has very good popularity because of its ease and simplicity to construction. PEB structures have very large spans but a comparatively low load to carry. So steel satisfies strength criteria in most cases, but they are not so good in case of deformation. So to satisfy serviceability criteria, a higher depth section is being considered, which results in higher costing. After the Second World War structural engineers tried to find many alternatives to minimize the cost of steel structures. Several methods were developed to increase the stiffness of steel without increasing its weight.

Fig. 1 High bay span castellated beam steel structure

One such improvement occurred in the mid-1930s. Formally known as "Boyd beam" was invented by an engineer working in Argentina named Geoffrey Murray Boyd (Knowles 1991). This name was later changed to castellated beam. Theinvention was described as "A line of toothed nature is a result of comprising pairs of two parts welded along with their projected extensions, which leads to improvement in built-up structural members." The primary advantage of this new section is the increase in its depth of beam without an increase in its weight. In some instance, the depth increases as much as 80 to 85% of the rolled section depth. By increasing the depth of the beam, strong axis bending strength and stiffness are improved as the strong axis moment of inertia, I_x, and section modulus, S_x, are increased. Further, the castellations or holes allow plumbing pipelines, electric wiring conduits, etc., to pass through it which ultimately reducing the thickness of floor assembly.

II. NUMERICAL PARAMETRIC STUDY

For the parametric study, the castellated beam model was prepared from the parent ISMB 250 section.

A. ISMB 250 Parent section model Configurations

Table 1 Properties of parent ISMB section

Geometric Properties	
D	250 mm
w_f	125 mm
t_f	12.5 mm
t_w	6.9 mm
I_x	5131.6 cm^4

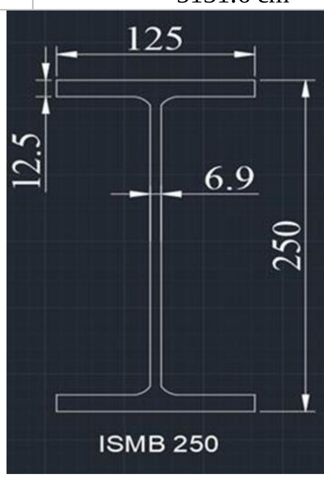


Fig. 1 Parent cross-section properties

Table 2 Properties of parent ISMB section

Material properties	
Density	7850 kg/m^3
Young's modulus	210 MPa
Poison's ratio	0.3
Yield stress	250 MPa
Ultimate stress	400 MPa

As the castellated beam sections were prepared from parent beams only, so material properties of castellated beams are considered the same as material properties (table 2) of the parent ISMB 250 section for modelling.

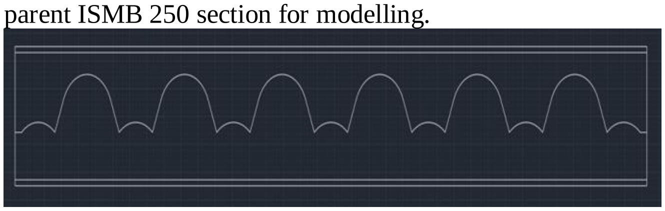


Fig. 2 Cutting pattern to make curve-in-curve (arch) shaped opening in castellated beam

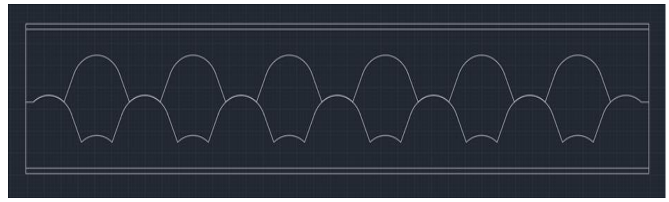


Fig. 3 Castellated beam with arch-shaped opening

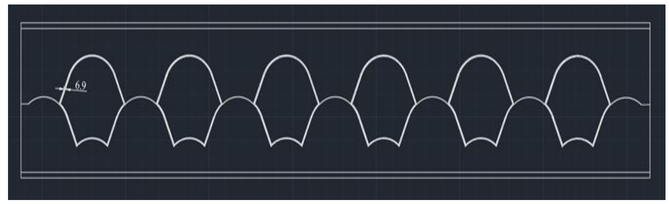
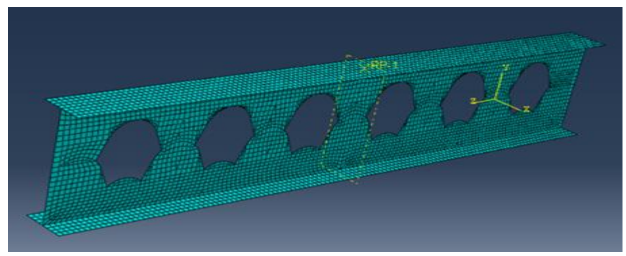


Fig. 4 Arch shaped castellated beam with reinforced web opening



The width of reinforcement is considered 55 mm, and the thickness is the same as a web of the beam having the same material properties.

All beams were prepared using ABAQUS as a 3D shell element, and for mashing purposes, quad-dominated S4R was used, as shown in fig 5. Beams having a total length of 1.85 m and hinge supports at both ends with the line load at the center of a beam, as shown in fig 6.

Fig. 5 Mashing of arch-shaped castellated beam

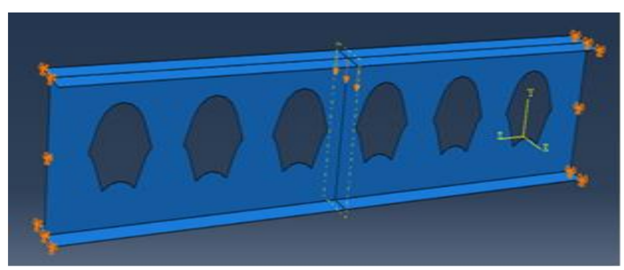


Fig. 6 Loading pattern and support condition of arch-shaped

Another model is also prepared for the parametric study with different web thickness.

B. ISHB 450 Parent section model Configurations

Fig 7 and 8 shows the geometric properties of ISHB 450 section with different web thickness.

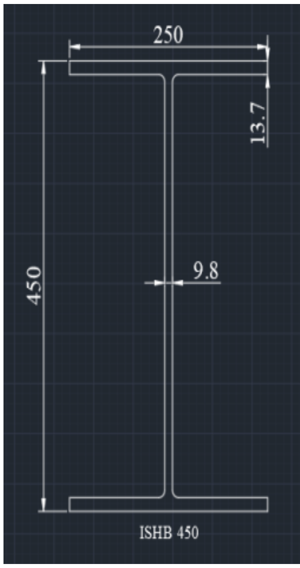


Fig. 7 ISHB 450 section having a thickness of web 9.8 mm

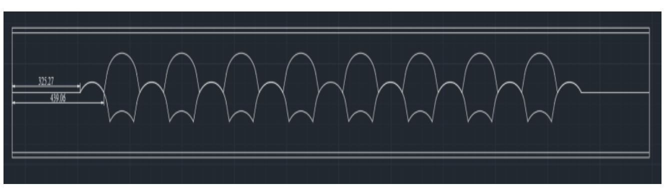
Fig. 8 ISHB 450 section having a thickness of web 11.3 mm

III. RESULTS AND DISCUSSION

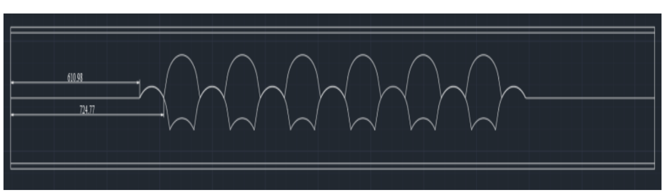
After confirmation of the correctness of the results obtained from a validation study in numerical analysis, wide-ranging extensive work is carried out for all arch-shaped castellated beams. The research reveals that arch-shaped castellated beams' load-carrying capacity is higher than other regular shapes castellated beams.

As per the above-shown data, a numerical model was prepared to analyze the effect of increasing the length of beam from the first opening (TL) by consequently decreasing the numbers of openings provided in the castellated beam.

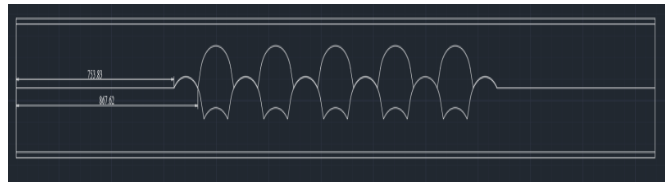
Four different geometric shapes were prepared to get results for the load variation curve, which are shown in fig 9 with the modelling meshes and stress concentration as shown in fig 10.



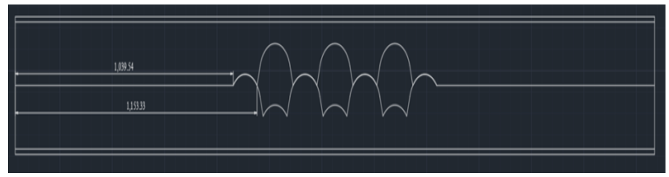
(a)



(b)



(c)



(d)

Fig. 9 Geometric properties of an arch-shaped castellated beam with different length from the first opening provided (a) 439.06, (b) 724.77, (c) 867.62, and (d) 1153.33

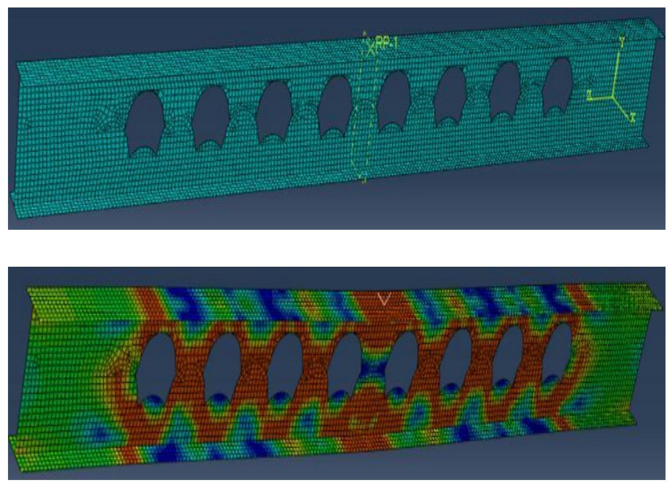


Fig. 10 Mashing and stress concentration in the un-reinforced beam

The parametric study reveals that castellated steel beams were very effective as a structural solution compared to conventional solid beams. But on contrary, the use of an unreinforced or unstiffened castellated beam is not always an economical or easy solution.

The use of reinforcement around the opening proves an excellent solution to increase its stiffness and subsequently results in high strength. Finite element modelling of all arch-shaped novel castellated steel beams having reinforced opening thickness of 6.9 mm and width of 55 mm has shown in fig. 11.

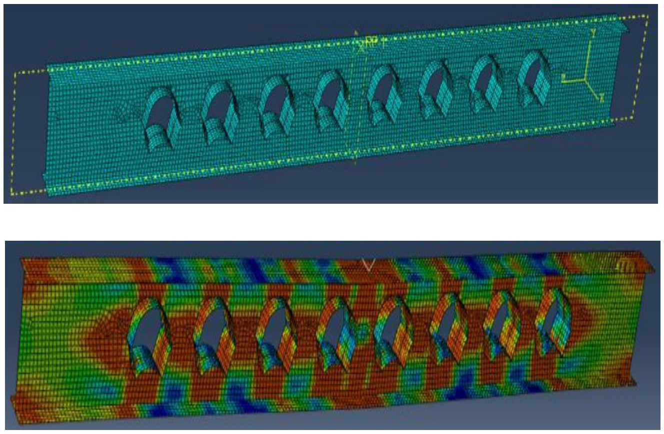


Fig. 11 Mashing and stress concentration in the reinforced beam

Graph representing load vs. displacement variation curve for all unreinforced (fig. 12) and reinforced (fig. 13) arch-shaped castellated beams.

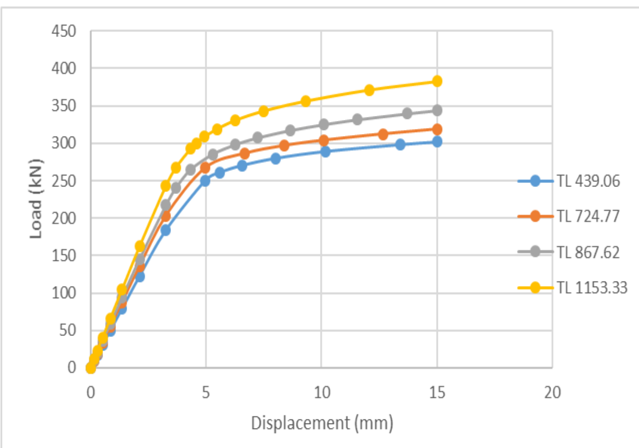


Fig. 12 Load vs. displacement curve for all different TL lengths in arch-shaped unreinforced castellated steel beams

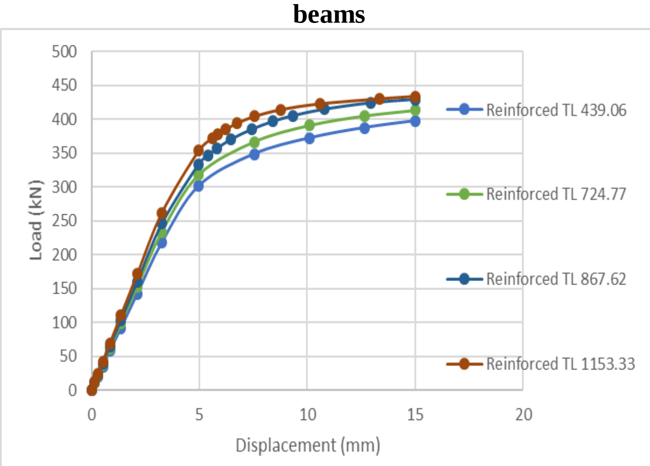


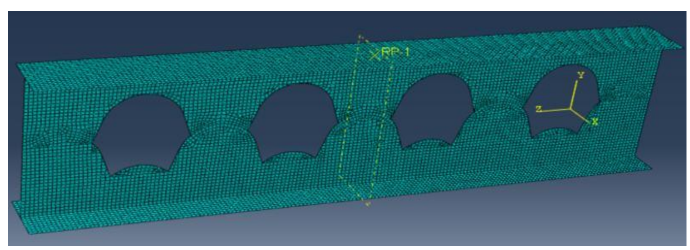
Fig. 13 Load vs. displacement curve for all different TL lengths in arch-shaped reinforced castellated steel beams

Table 3 shows the increment in load-carrying capacity of an arch-shaped castellated beam by reinforcing the opening.

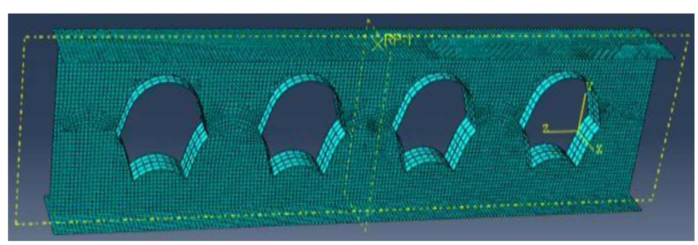
Table 3 Comparison of numerical analysis results for a reinforced and unreinforced curve-in-curve castellated beam with different TL length

Sr. No	CSB beam	Span (mm)	Shape of opening	Load (kN) for 15 mm deflection (Un-reinforced)	Load (kN) for 15 mm deflection (Reinforced)	% Increase in load
1	TL 439.06	3050	Curve-in-curve (Arch) shaped	301.96	397.64	31.69
2	TL 724.77	3050		318.66	413.67	29.82
3	TL 867.62	3050		344.11	429.55	24.83
4	TL 1153.33	3050		382.76	434.04	13.39

Numerical modelling for a model having different web thickness is also prepared. Fig 14 shows the mashing provided in both reinforced and unreinforced beams having a web thickness of 9.8 mm.



(a)



(b)

Fig. 14 Mashing provide in an arch-shaped castellated beam having web thickness 9.8 mm (a) unreinforced beam, (b) reinforced beam

Graphs are also prepared for both different web thickness beams having reinforced and unreinforced web openings.

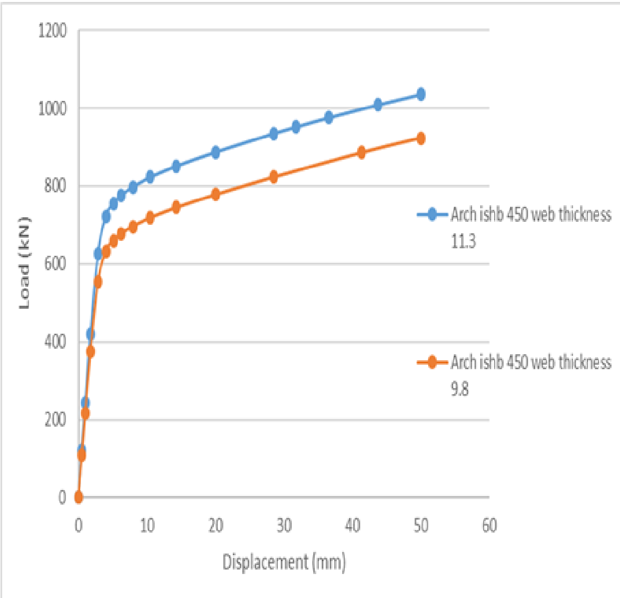


Fig. 15 Load vs. displacement variation graph for both castellated beam sections having un-reinforced web-openings

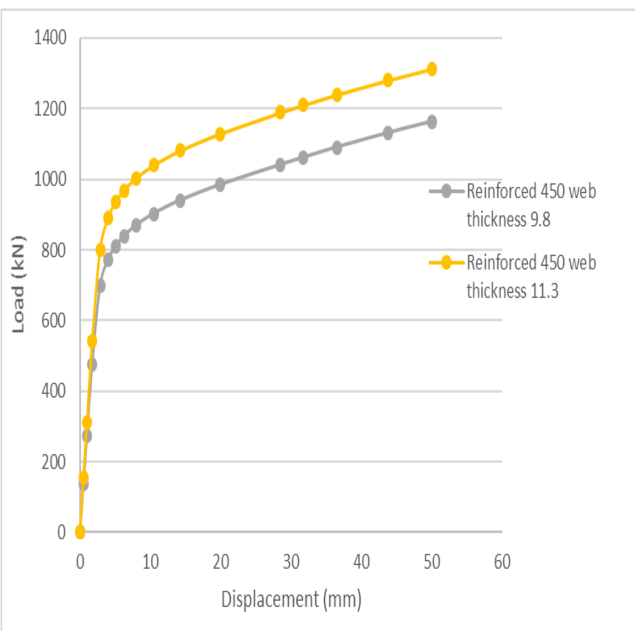


Fig. 16 Load vs. displacement variation graph for both castellated beam sections having reinforced web-openings

It has been seen that from analysis load-carrying capacity of the beam increases as the thickness of the web increases from 9.8 mm to 11.3 mm.

Table 4 Comparison of numerical analysis results for a reinforced and unreinforced curve-in-curve castellated beam with different web thickness

Sr. No	CSB beam	Span (mm)	Shape of opening	Load (kN) for 50 mm deflection (Un-reinforced)	Load (kN) for 50 mm deflection (Reinforced)	% Increase in load
1	CSB 608	1850	Curve-in-curve shaped	923.43	1162.63	25.9
2	CSB 608	1850		1034.66	1312.39	26.84

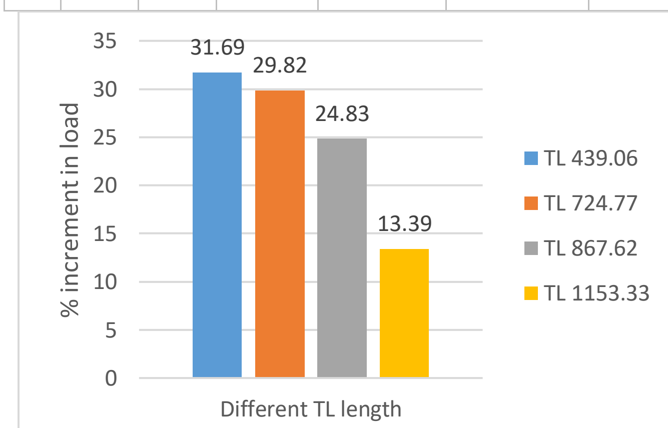


Chart 1 %ge increment in the load-carrying capacity of arch-shaped CSB for different TL length because of web-reinforcement

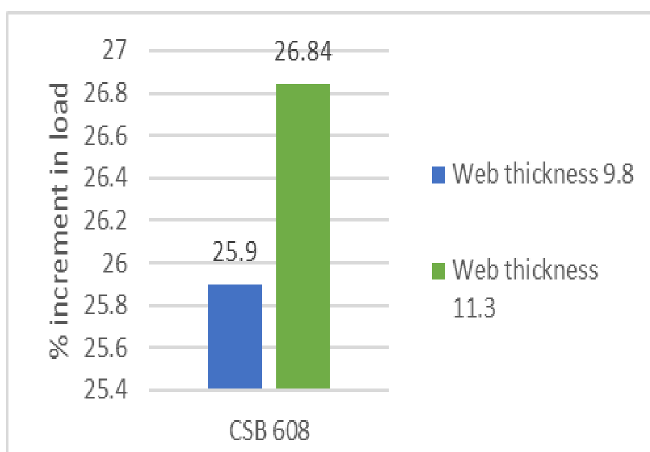


Chart 2 %ge increment in the load-carrying capacity of arch-shaped CSB having different web thickness because of web-reinforcement

IV. CONCLUSION

This research work analyzes the castellated beam with a novel (arch) web opening, with stiffeners and without stiffeners around web openings, is studied numerically using finite element analysis software ABAQUS.

- As the length from the first opening (TL) increases and the number of the opening decrease, the load-carrying capacity of the beam increases. Stress concentration also increases.
- From analysis, it is observed that the load-carrying capacity of the beam with TL 439.06 having 31.69% more load carrying capacity for reinforced web openings than the normal web openings with a total 8 number of openings in it.
- Same for a beam with TL 724.77, 867.62, and 1153.33 load-carrying capacity increased by 29.82%, 24.83%, and 13.39% for reinforced web openings. As the number of openings varying 6, 5, and 3 respectively.
- From analysis, it is observed that load-carrying capacity of CSB 608 section prepared from parent ISHB 450 section, a width of web 11.3 mm having load-carrying capacity as 12.05 % higher than CSB 608 prepared from parent ISHB 450 section with a web of width 9.8 mm.
- The load-carrying capacity of CSB 608 having 9.8 mm web thickness increases by 25.9% by providing reinforced web openings.
- Same as for CSB 608 having 11.6 mm web thickness load-carrying capacity increases by 26.84% by providing reinforced web openings.

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