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PARAMETRIC STUDY OF STEEL BEAM WITH OPENING

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Abstract - Height limitations are not uncommon in multi-storey buildings due to economic requirements and esthetical considerations. Substantial spaces are normally required to enable the passage of large pipes and ducts beneath steel beams leading to uneconomic floor heights. The most adopted solution for this issue is the use of steel beam web openings to provide the required space for services. . Parametric study is performed for various shapes of openings, various lengths of beam, various ISMB sections of beam. The parameters considered were deflection maximum principal stress, minimum principal stress, von mises stress and maximum shear stress. The objective of this work is to investigate and compare, through an analytical study, the behavior of perforated steel beams with circular and square shape configurations of web openings. In this investigation design tables were obtained with gives minimum safe ISMB section for given length and given loading conditions.

Keywords: Steel beam with web opening, circular web opening, square web opening, Vierendeel analysis, ANSYS,

I. Steel beam with web opening

Modern multi-storeyed buildings requires maximum space utilization and cost effectiveness, demands the use of long spanned, shallow, light weight beams in steel and composite structures. Construction spans are becoming longer for multi-storeyed building and industrial building, one way of achieving this is to use perforated beam. Traditional structural steel framing consists of beams and girder with solid web. After structural erection has been completed, there may be need sof service engineer to fix air conditioning ducts, increasing the floor height at design stage to accommodate services lead to additional cost. A common solution to minimize floor height is to cut openings into steel beam webs. Openings can also accommodate building services within constructional depth of floor.

Figure 1 Steel beam with web opening

a) T section approach:

In this approach, the perforated section is considered to be built up of two T sections which are separated by certain distance according to the height of opening, and all the global actions are taken as local forces and moments. The structural adequacy of beam depends on T section capacity under existing axial forces, shear forces and local moments. Design according to T section approach is difficult and need much calculation efforts. Approximate design expressions are presented to reduce the calculation effort in case of complex problems, leading to conservative results.

b) Perforated section approach:

In this approach, perforated section is considered as critical section for design. The structural adequacy of beam depends on T section capacity under existing global shear forces and global moments. Moment shear interaction curves are used sometimes. So the design method is considered to be simple and suitable for engineers for practical design. However method may leads to conservative results. The perforated section approach is used for current study.

c) Analysis of steel beam with web opening

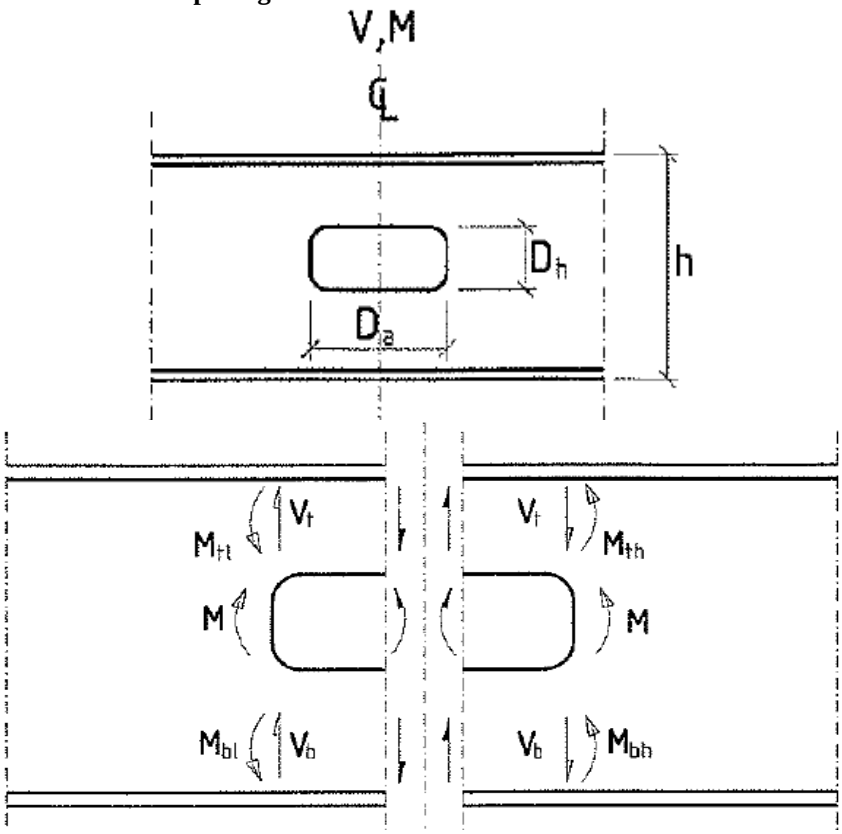

Figure 2 Forces acting at web opening

The forces at an opening are depicted in figure. Figure contains an opening with Da length and Dh height. The global shear and moment acting at the centre line of the opening is denoted as V and M respectively. Global moment is also called as primary moment. The part above an opening known as top tee is subjected to shear Vt and secondary bending moments Mtl and Mth. The part below an opening known as top tee is subjected to shear Vb and secondary bending moments Mbl and Mbh. The acting forces on the tee's at centre of opening are shown as filled arrows. The reaction forces at tee's end are shown as open arrows. The subscripts t and b stands for top and bottom section. Subscripts l and h stands for low and high moment end of the opening.

d) **Major failure mode**

Formation of Vierendeel Mechanism

This type of failure is associated with high shear forces acting on the beam. Formation of plastic hinges at the reentrant corners of web opening tends to deform the T section above the web opening to a stretched shape. Beams with shorter span and larger length of web opening are liable to this mode of failure. When the perforated beam is subjected to shear, T section above and below the opening must carry applied shear as well as the primary and secondary bending moment. The primary moment is conventional moment and secondary moment is the moment due to shear forces on the T section above and below the opening. Usually increasing the height of the opening reduces shear and bending capacity. However increasing the length of the opening do not significantly affect the shear and bending capacity but increases the local bending moment occurring and reduces the vierendeel collapse capacity of the perforated section.

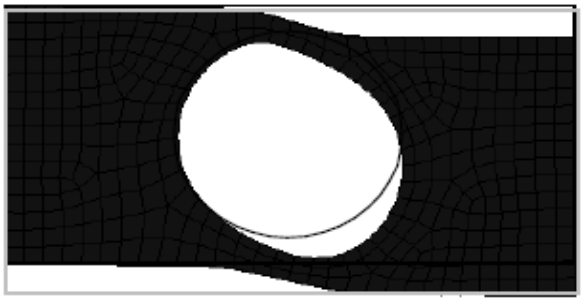

Figure 3 Vierendeel failure

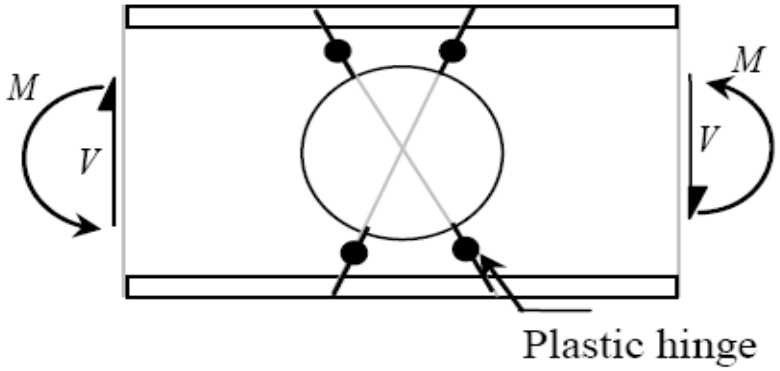

Figure 4 Plastic hinge formation

II. NUMERICAL STUDY

a) Analysis of beam

In the present investigation, all steel beams are hot rolled I-beams (compact section). All web openings are concentric to the mid-height of the sections and symmetric about the mid span of the beam. For beams with multiple web openings, buckling of web posts may be critical when the openings are closely spaced. In this study for multiple openings, the distances between the edges of the openings are kept 0.1L, where L is span of the beam and even number of openings are placed such that it divides beam in equal parts. For perforated sections with these geometrical dimensions, it is generally considered that local buckling in the tee sections at the perforated sections is not critical, in agreement with Liu and Chung. A large number of finite element models were constructed to generalize the results. When investigating the effect of web openings on the behavior of steel beam, both square and rectangular web openings are considered.

b) Beam with circular web opening

A steel beams with fixed end supports having spans 2.5m was considered to be loaded with uniformly distributed load of 30KN/m. Different number of circular web openings were considered; 2, 4 and 6 of size 0.5D, where D is depth of the beams. Different sections of beam like, ISMB 175, ISMB 200, ISMB 225, ISMB 250 were considered for analysis. The parameters of the beam studied were deflection, maximum principal stress, minimum principal stress, von mises stress, and maximum shear stress. Following are the graphs showing the comparison of these beams for various parameters individually with various numbers of openings.

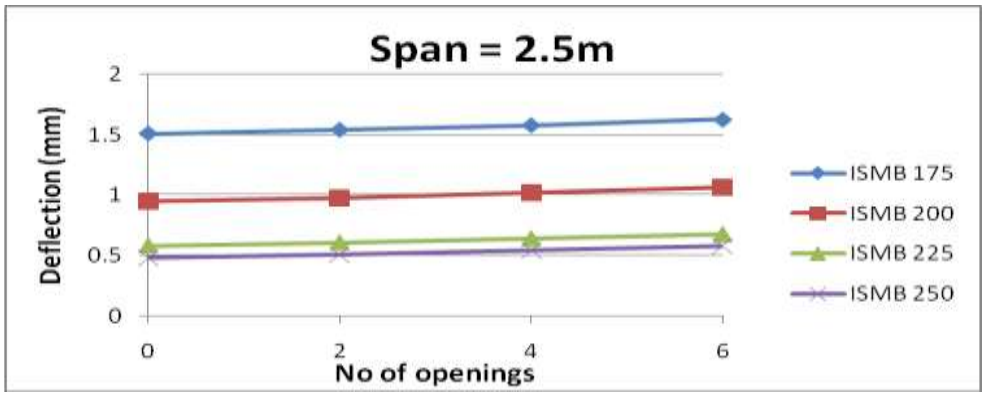

Figure 5 Effect of circular opening on deflection at mid span of beam

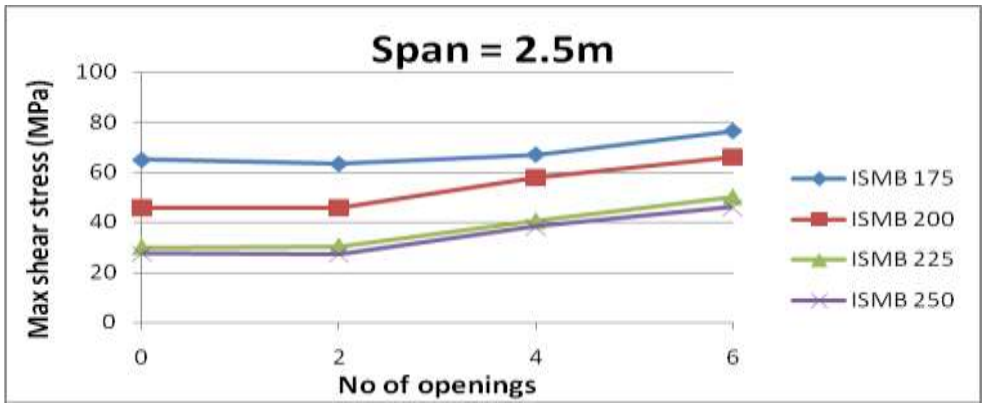

Figure 6 Effect of circular opening on max shear stress of beam

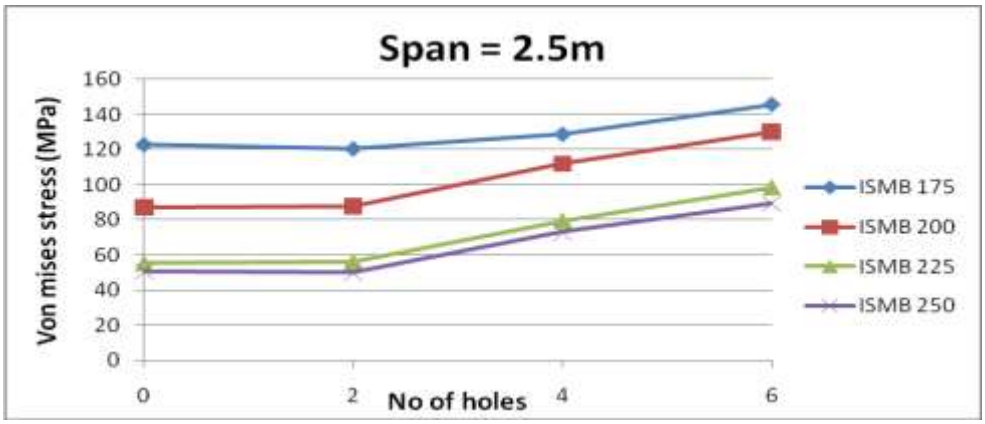

Figure 7 Effect of circular opening on von mises stress of beam

The graphs for number of openings and deflection for various beams of ISMB sections have shown linear variation. Maximum shear stress variation for various beams gives nearly same trend, and variation in the value of maximum shear stress was very less for beam without opening and beam with two opening. Further increasing no of openings the value of maximum shear stress keeps on increasing. Von mises stress variation for various beams gives nearly same trend, and variation in the value of von mises stress was very less for beam without opening and beam with two opening. Further increasing no of openings the value of von mises stress keeps on increasing.

c) Beam with square web opening

A steel beam having span 2.5m, 5m, and fixed end support is loaded with uniformly distributed load of 30KN/m. different number of web openings were considered; 2, 4 and 6 of size equivalent to the circular web opening ,ISMB 175, ISMB 200, ISMB 225, ISMB 250 sections of beam were taken for analysis. The parameters of the beam studied were deflection, maximum principal stress, minimum principal stress, von mises stress, and maximum shear stress. Following are the graphs showing the relation of various parameters with various numbers of openings.

Span of beam = 2.5m

Figure 8 Effect of square opening on deflection at mid span of beam

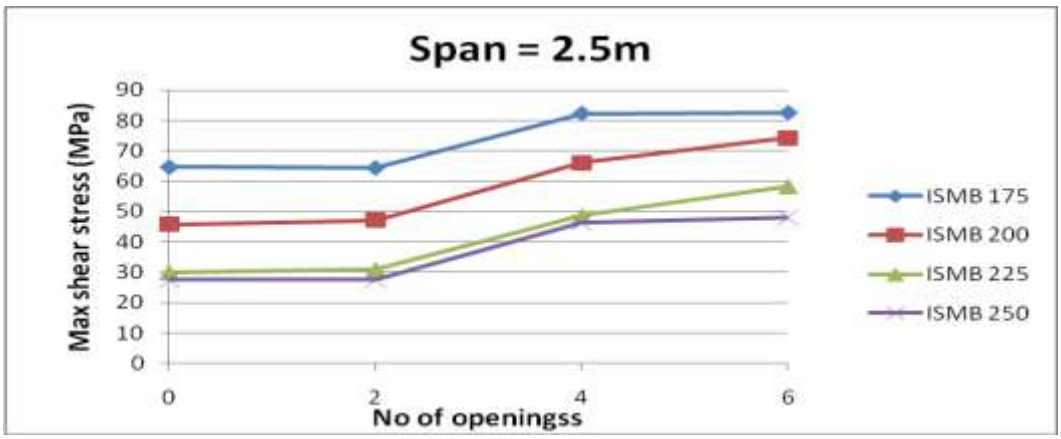

Figure 9 Effect of square opening on max shear stress of beam

Figure 10 Effect of square opening on von mises stress of beam

The graphs for number of openings and deflection for various beams of ISMB sections have shown linear variation. Maximum shear stress variation for various beams gives nearly same trend, and variation in the value of maximum shear stress was very less for beam without opening and beam with two opening. Further increasing no of openings the value of maximum shear stress keeps on increasing. Von mises stress variation for various beams gives nearly same trend, and variation in the value of von mises stress was very less for beam without opening and beam with two opening. Further increasing no of openings the value of von mises stress keeps on increasing.

d) **Design tables for steel beam with web opening**

By analyzing steel beam for length of 2.5m for various loading condition following are the ISMB sections which satisfies all criteria.

e) For circular web opening

	No of openings		
Load carrying capacity (KN/m)	2 openings	4 openings	6 openings
10	ISMB 100	ISMB 100	ISMB 100
20	ISMB 125	ISMB 125	ISMB 125
30	ISMB 150	ISMB 175	ISMB 175
40	ISMB 175	ISMB 175	ISMB 175
50	ISMB 200	ISMB 200	ISMB 200
60	ISMB 200	ISMB 225	ISMB 225
70	ISMB 225	ISMB 225	ISMB 225
80	ISMB 225	ISMB 225	ISMB 250
90	ISMB 250	ISMB 250	-

f) For square web opening

	No of openings		
Load carrying capacity (KN/m)	2 openings	4 openings	6 openings
10	ISMB 100	ISMB 100	ISMB 100
20	ISMB 125	ISMB 125	ISMB 125
30	ISMB 150	ISMB 175	ISMB 175
40	ISMB 175	ISMB 175	ISMB 175
50	ISMB 200	ISMB 200	ISMB 200
60	ISMB 200	ISMB 225	ISMB 225
70	ISMB 225	ISMB 225	ISMB 225
80	ISMB 225	ISMB 225	ISMB 250
90	ISMB 250	ISMB 250	-

III. CONCLUSION

- For all steel beam with web opening Equivalent (VON-MISES) stress is predominant stress.
- The major reduction in shear capacity arises from reduced shear area in the opening compared to beam with circular opening, further reduction in shear capacity for beam with square opening is due to secondary moments.
- Deflection in square openings found to be higher than that of circular openings for same area of both the openings.
- This study proposes design tables, the results are more conservative as it is specified by considering steel material behavior up to elastic limit.

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