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Static and Dynamic Analysis of Steel Beams with Web Openings

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Static and Dynamic Analysis of Steel Beams with Web Openings

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Abstract. The use of castellated beams has increased a lot in the past few years in all types of structures. The castellated beam is one of the several methods used to decrease the weight and cost of steel used in the construction. In castellated beams, increased depths can be achieved without increasing the self-weight of the structure. The significant advantages of castellated beams are better possessing bending moment capacity, ease of providing service pipes and wires, and aesthetic appearances. The castellated beams are made by making a zigzag cut through the web according to the desired opening shape and size, and then the two parts are welded together. In this work, static and dynamic analyses of the castellated steel beam section (ISMB 300) are performed to compare deflection, stress distribution, shear Stress, amplitude, and natural frequency. The investigation is done using ANSYS 18. The Castellated beam having a maximum opening of size 0.6h is used for the study. The castellated beams have proved to be useful under a light-uniform load.

1. Introduction

Many structures use structural steel as there major material nowadays. Use of castellated beams reduces the cost of steel as well as the self-weight of the structure [1]. The castellated beams are the beams having openings in the web portion of different sizes and spacing [2, 3, 4]. These holes are made by cutting the beam in two halves in the web area in a zig-zag manner and then putting them together in such a way that castellation is made in the web [5]. These two halves are then welded together to make a castellated beam. In castellated beams, the depth of the beam is increased without any additional steel which reduces the cost significantly [6].

The use of beams with holes has increased subsequently in the past few years as it requires the least amount of construction work compared to other alternatives. This method provides a path for passage of service provisions such as air conditioning ducts, electrical wires, pipelines, etc. which reduces the height of the floor [7]. For the present study, a solid beam and a castellated beam with the hexagonal openings of different sizes and at the various center to center distance [8, 9]. The study aims to analyze and find out the best section in terms of deflection, stress, shear, harmonic response, and natural frequency. The beam chosen for the study is 5m long, and ISMB 300 section was adopted. The opening sizes assumed were 0.2h, 0.3h, 0.4h, 0.5h, 0.6h, where h is the height of the beam, and the center to center distances chosen were 250mm, 500mm, and 1000mm.

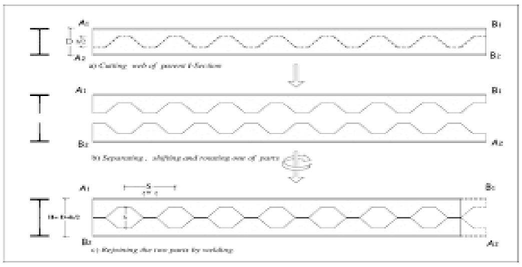

Figure 1. Castellated beam.

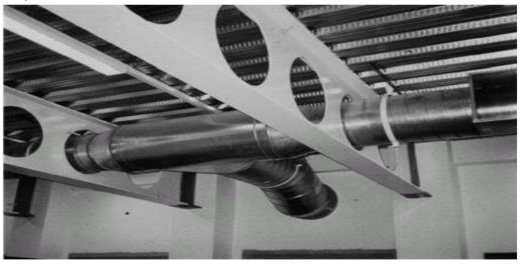

Figure 2. Beam with openings.

The section dimensions of the ISMB300 are width of the flange: 140mm, the thickness of flange: 12.4mm, height of web: 275.2 mm, and the thickness of the web: 7.5mm.

2. Procedure

2.1 Preparation of Model

A three dimensional finite element model was developed to study the behavior of the beams in Ansys 18. An ISMB 300 section was created using Ansys18 with Young's modulus = 2×10^{11} N/m^2, Poisson's ratio = 0.3, yield strength = 2.5×10^8 N/m^2, density of steel = 7850 kg/m^3. A uniformly distributed load of 0.7 MPa had been applied on top of the beam. The both ends was restrained. Static and dynamic analyses were performed to determine the deflection, stress distribution, shear stress, harmonic response and natural frequency. The length of the beam used was 5000 mm.

Hexagonal openings were made in the web with sizes of 0.2h (60 mm), 0.3h (90 mm), 0.4h (120 mm), 0.5h (150 mm), and 0.6h (180 mm). The center to center distances were kept as 250mm, 500mm, and 1000mm. A total of 16 models were generated and analyzed. Meshing was also done using Ansys18 and default size of element was kept and no changes were made to circumvent errors.

2.2 *Static Analysis*

After modelling, analysis was carried out in Ansys 18 software and results were obtained for deformation, stress distribution and shear stress. Graphs were prepared from the results and comparison was done.

2.3 Dynamic Analysis

The same models were also subjected to dynamic loadings and the natural frequency, amplitudes and mode shapes were obtained and compared with a solid beam.

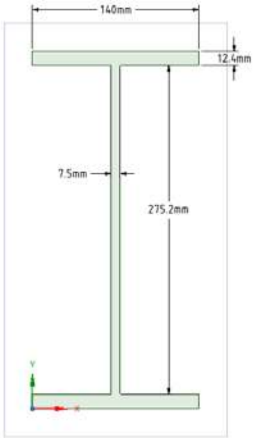

Figure 3. Typical beam section details.

3 Results & Discussion

3.1 Static Analysis

The following Table 1 shows the results of the beam deflection, stress and shear obtained in static analysis. The deflection of the beams is shown in fig. 3 to 13. The deflection of the castellated beam with 0.2h and 1 m spacing was close (1.54%) to the deflection of the solid beam. The comparison of the deflections is shown in fig. 14 to 21. The stress results are shown in fig. 22 and the shear results are shown in fig. 23.

Table 1. Static Analysis Results.

Specimen	Deflection (mm)	Stress (MPa)	Shear (MPa)
0.2h-0.25m	16.731	270.31	270.31
0.2h-0.5m	15.462	263	102.3
0.2h-1m	14.551	253.76	98.872
0.3h-0.25m	19.223	274.26	119.3
0.3h-0.5m	16.174	274.54	104.14
0.3h-1m	14.826	271.74	98.176
0.4h-0.25m	34.504	319.94	124.77
0.4h-0.5m	18.928	278.27	113.25
0.4h-1m	14.721	268.01	103.22
0.5h-0.25m	115.26	440.37	142.83
0.5h-0.5m	22.599	280.6	114.31
0.5h-1m	14.985	282.92	106.91
0.6h-0.25m	396.72	754.79	143.82
0.6h-0.5m	40.29	320.46	130.76
0.6h-1m	15.576	268.1	100.57
solid	14.33	261.77	24.927

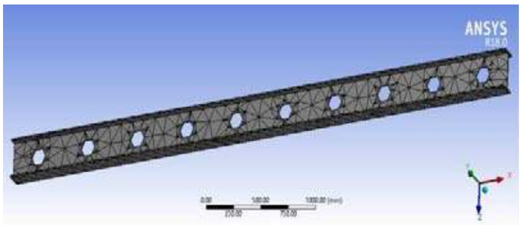

Figure 4. Typical Meshed beam.

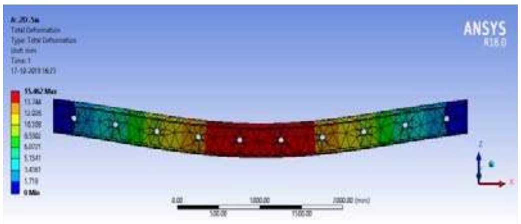

Figure 5. Deformation 0.2h 0.5m.

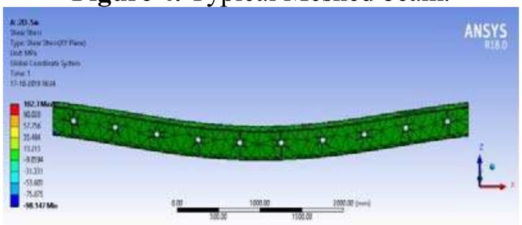

Figure 6. Shear 0.2h 0.5m.

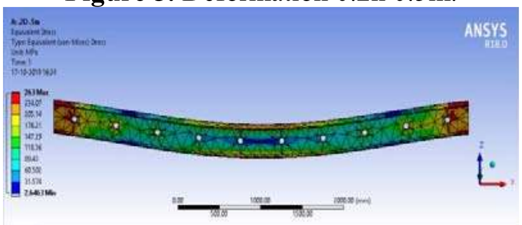

Figure 7. Stress 0.2h 0.5m.

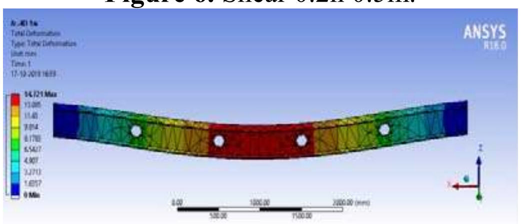

Figure 8. Deformation 0.4h 1m.

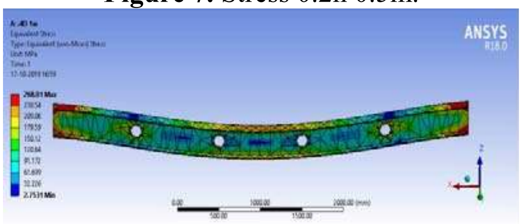

Figure 9. Stress 0.4h 1m.

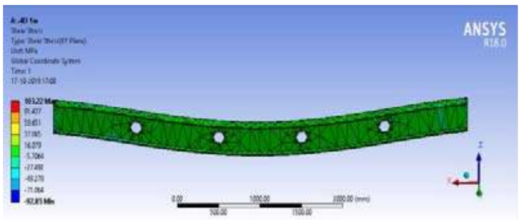

Figure 10. Shear 0.4h 1m.

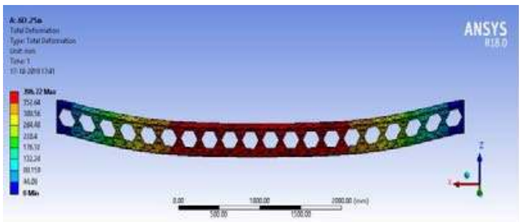

Figure 11. Deformation 0.6h 0.25m.

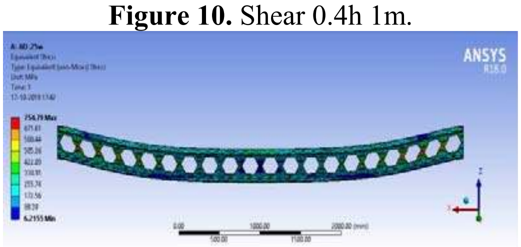

Figure 12. Stress 0.6h 0.25m.

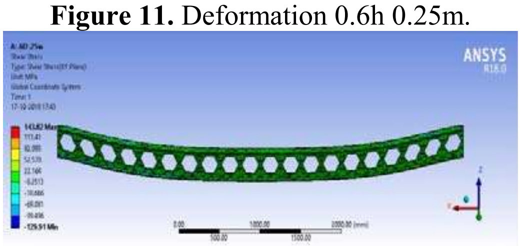

Figure 13. Shear 0.6h 0.25m.

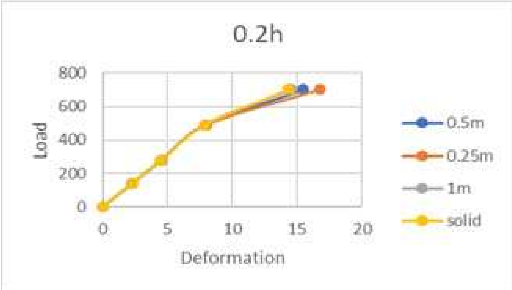

Figure 14. Opening of 0.2h.

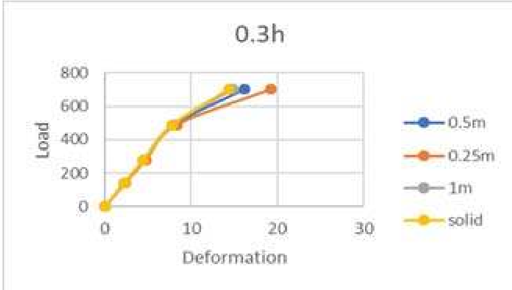

Figure 15. Opening of 0.3h.

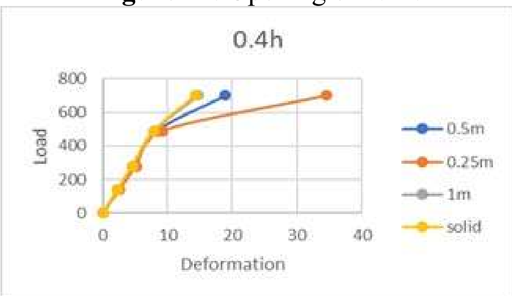

Figure 16. Opening of 0.4h.

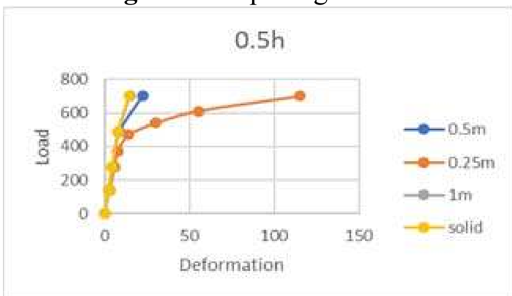

Figure 17. Opening of 0.5h.

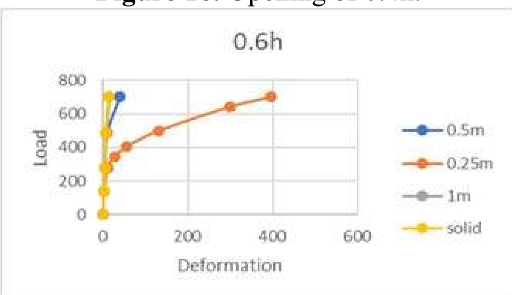

Figure 18. Opening of 0.6h.

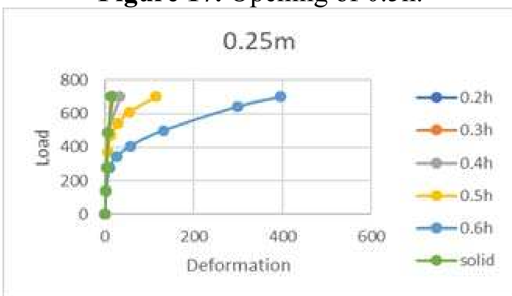

Figure 19. Spacing of 0.25m.

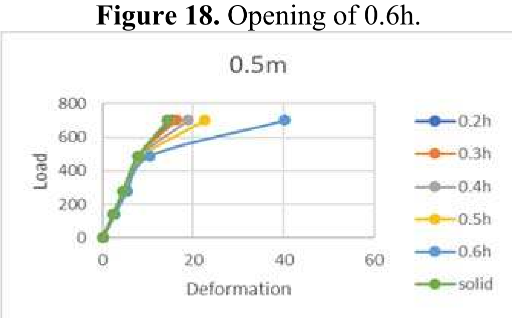

Figure 20. Spacing of 0.5m.

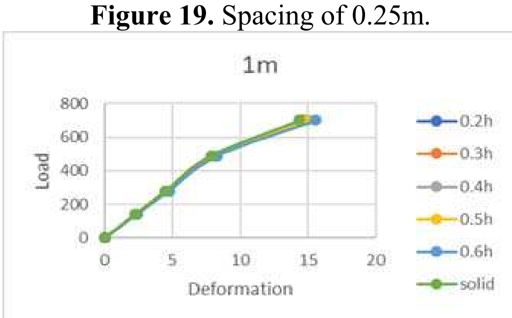

Figure 21. Spacing of 1m.

Figure 22. Maximum stress.

Figure 23. Maximum shear.

From the static analysis results, the maximum deflection was 396.72 mm obtained in 0.6h-0.25m beam and the minimum deflection was 14.33 mm in the solid beam. The maximum shear was 270.31 MPa found in 0.2h-0.25m beam and minimum shear was 24.927 MPa found in the solid beam. The maximum stress was 754.79 MPa obtained in 0.6h-0.25m beam and minimum stress was 253.76 MPa obtained in 0.2h-1m beam.The Ansys results indicated that the increase in size of the holes increased the deflection, stress and shear stress. Similarly, the decrease in distance between the holes, increased the deflection, stress and shear stress.From this analysis, the beam with 0.4h and spacing of 1 meter can be recommended as it behaves similar or equivalent to the solid beam.

3.2 Dynamic Analysis

The Analytical model was investigated and the harmonic response and natural frequency (table 2, fig. 38), and the mode shapes (fig. 24 – 29) are tabulated below. The amplitude values are shown in fig. 30 – 37. The mode shapes of castellated beams from different models are represented below.

Table 2. Natural Frequency.

Specimen	Frequency (Hz)
0.2h-0.25m	121.91
0.2h-0.5m	122.13
0.2h-1m	123.51
0.3h-0.25m	121.95
0.3h-0.5m	122.51
0.3h-1m	123.75
0.4h-0.25m	123.77
0.4h-0.5m	122.81
0.4h-1m	124.84
0.5h-0.25m	126.95
0.5h-0.5m	124.7
0.5h-1m	124.7
0.6h-0.25m	129.99
0.6h-0.5m	125.74
0.6h-1m	125.91
solid	117.8

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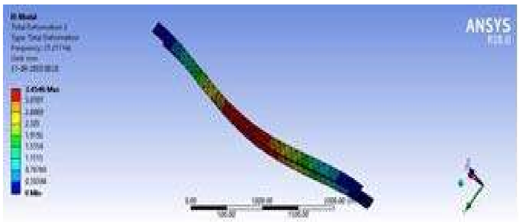

Figure 24. Mode shape 1 of 0.2h 0.25m.

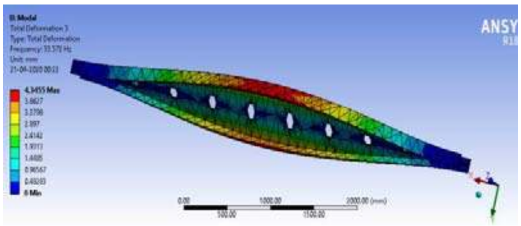

Figure 25. Mode shape 2 of 0.3h 0.5m.

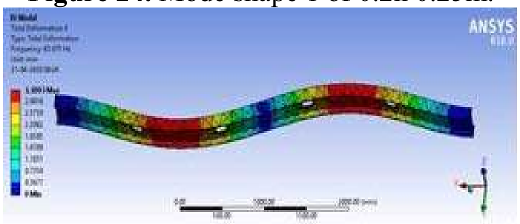

Figure 26. Mode shape 3 of 0.4h 1m.

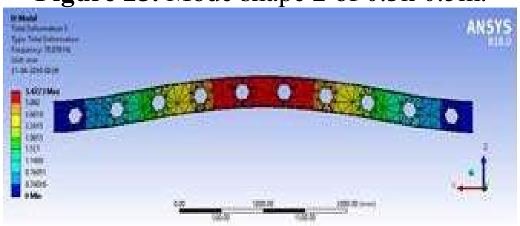

Figure 27. Mode shape 4 of 0.5h 0.5m.

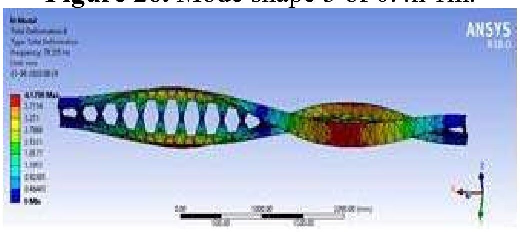

Figure 28. Mode shape 5 of 0.6h 0.25m.

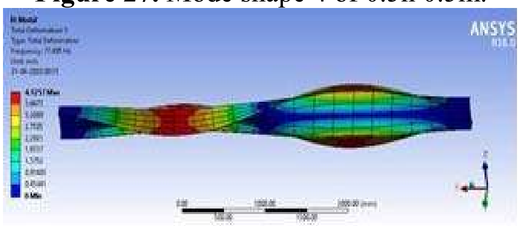

Figure 29. Mode shape 4 of solid beam.

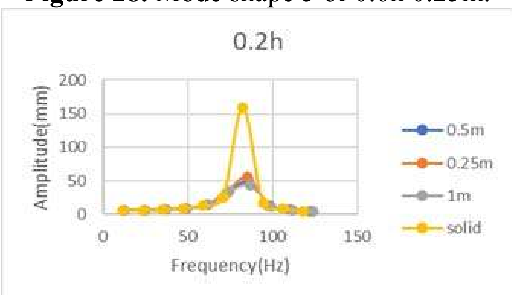

Figure 30. Opening of 0.2h.

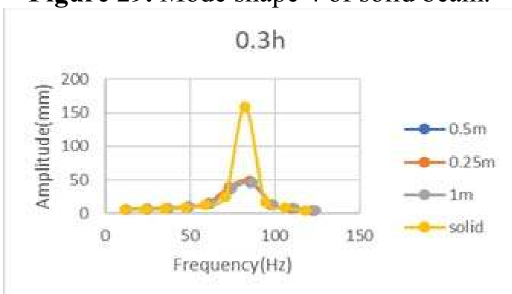

Figure 31. Opening of 0.3h.

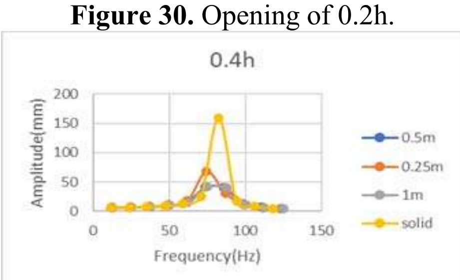

Figure 32. Opening of 0.4h.

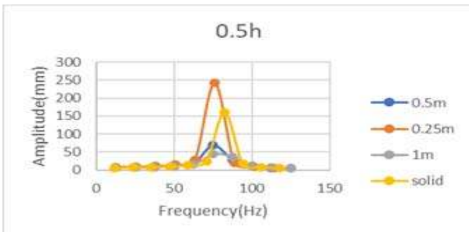

Figure 33. Opening of 0.5h.

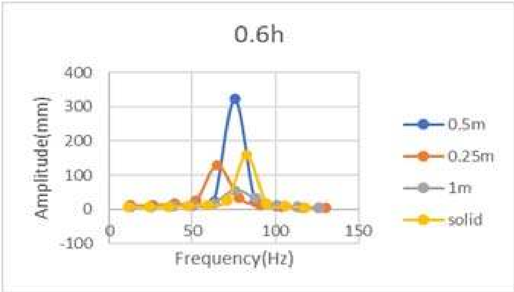

Figure 34. Opening of 0.6h.

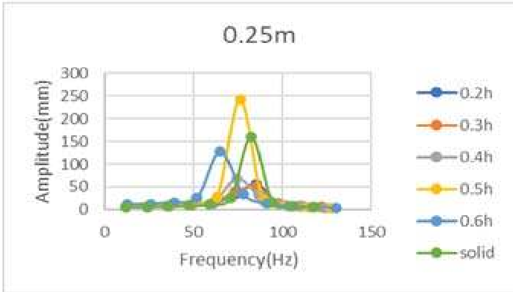

Figure 35. Spacing of 0.25m.

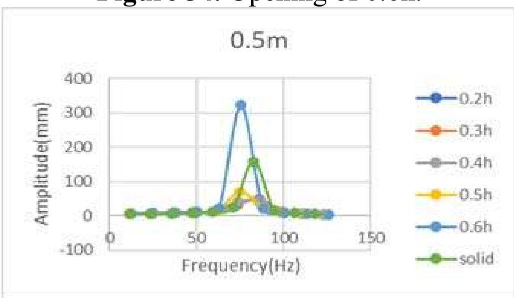

Figure 36. Spacing of 0.5m.

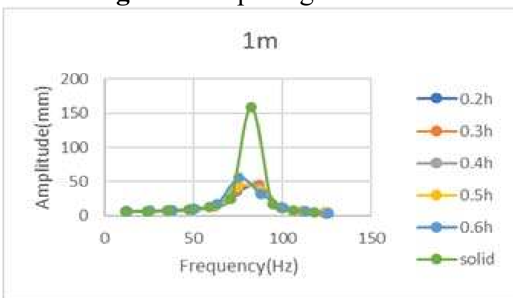

Figure 37. Spacing of 1m.

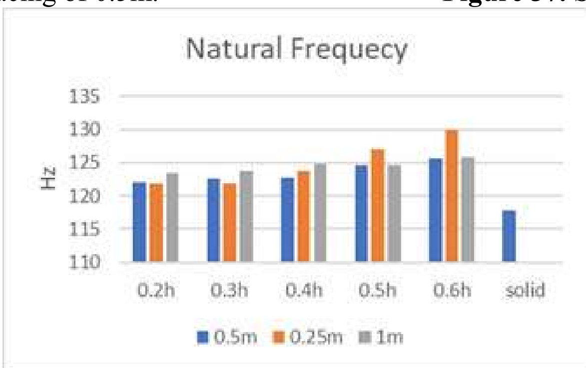

Figure 38. Maximum Natural Frequency

From the dyanmic analysis results, the highest frequency was 129.99 Hz was obtained in 0.6h-0.25m beam and lowest frequency was 117.8 Hz in solid beam. The maximum amplitude was 322.99 mm in 0.6h-0.5m beam and minimum amplitude was 41.478 mm 0.4h-0.5m beam. The Ansys harmonic result indicates that decrease in spacing increases the frequency. Also increase in height of the beam increase the frequency.

4. Conclusion

The analysis of the castellated steel beams for deflection, stresses, shear, Harmonic Response, and natural frequency was done using Ansys18 software, including the modeling. The purpose of the study was to achieve the best beam section by using different sizes of hexagonal web openings and spacing's. Therefore, many analyses were carried out to find the same, and the followings findings and conclusion can be drawn,

- The analyses have shown that barring bigger holes of sizes 0.5h and 0.6h, no significant change in deflection was observed
- It was seen that the bigger holes tend to generate more stresses between the holes.
- Shear increased as the distance between holes was reduced
- Keeping holes at a considerable distance gave the best results.
- The analyses shown that with an increase in hole size maximum natural frequency increases.
- It is seen that for smaller holes, natural frequency increases with increase in center to center distance, but as the hole sizes increase it becomes the other way around
- For smaller holes, peak amplitude was achieved at the almost same frequency for the different center to center distances but for bigger holes, peak was achieved at different frequencies
- Beams with the higher spacing were consistently performing better
- Keeping holes at a similar center to center distance, beam with 0.4h hole size performed best.

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