Assessment of the Web-to-Flange Ratio to the I-Beam Stress Accuracy

V. Y. Raj[1], M. S. Yob[1,2,*], M. J. Ab Latif[1,2], M. S. Kasim[2] and O. Kurdi[3]

[1]Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2]Advanced Manufacturing Centre, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[3]Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia

[*]Corresponding e-mail: mshukriy@utem.edu.my

Keywords: I-beam section; four-point bending; finite element analysis

ABSTRACT – The correlation between the I-beam web-to-flange ratio to the accuracy of stress is investigated. The beam's theory is used to validate the Finite Element Analysis (FEA) result. The accuracy percentage is evaluated based on the validation result. Finally, the new web-to-flange ratio was established to limit the height, h of the I-beam section which has promisingly improved the accuracy of stress. The web-to-flange ratio of 0.8, 1.95, and 5.2 are recommended to use for I-beam base, b of 100 mm, 200 mm, and 300 mm to ensure the stress accuracy is maintained above 95%.

1. INTRODUCTION

I-beam section has been widely used in the construction of civil infrastructure, automobile structures, and oil and gas installations. It is due to the I-beam section's characteristics of small size, their strength to weight ratio, and the ensuing price that demonstrated capability to withstand various types of loads [1]. Generally, Euler Bernoulli's beam theory is used to evaluate the stress on the beam caused by the applied load. The previous research by Helene Xue and Hassan Khawaja's used the Bernoulli beam equation to solve a four-point bending problem [2].

Mostly, rapid engineering analysis such as finite elements is used to solve the following structural properties known as static displacement and static stress [3]. An important step in finite element modeling (FEM) is the selection of the mesh density. When there is an increase in mesh density, it has a negligible effect on the results. Normally, a convergence study is carried out to determine an appropriate mesh density [4].

Next, the boundary conditions play a crucial role in capturing the true response of the structure. Generally, the predictions obtained from the analysis are compared with test results. Displacement boundary conditions are needed to constrain the model where the supports exist to ensure that the model acts the same way as the experimental beams [4]. For four-point bending, the boundary condition is given by applying total force to two points at equal distances from the supports, while the fixed support is placed at two ends of the beam [5].

In this research, the FEA is performed to validate the stress result obtained from the Euler Bernoulli bending equation for the I-beam section. It is done to investigate the correlation between the web-to-flange to the accuracy of analytical and numerical analysis. The acceptance rate of accuracy percentage is set at 95%. The acceptance rate is set based on the previous study by Farzampour et al. on the accuracy of the analytical and FE analysis for corrugated steel plates [6]. Finally, a web-to-flange ratio was established to limit the height, h of the I-beam section that has affected the accuracy.

2. METHODOLOGY

2.1. *Model simple I-beam*

The I-beam's web and flange thickness parameters are set for 8 mm and 5.5 mm respectively. At the same time, the length of the I-beam section is set at 6000 mm. It is because the steels are usually delivered in standard size of 6000 mm by industrial suppliers.

2.2. *Euler Bernoulli beams theory*

The Euler Bernoulli bending equation is used to evaluate the Von Misses stress caused by the applied force. The yield stress for mild steel of 250 Mpa is used as the limit state to determine the force for the analysis.

2.3. *Boundary condition*

The boundary condition of the I-beam model was proposed for this study based on the four-point bending condition as shown in Figure 1. It is based on the American Society for Testing and Materials, ASTM which allows overhanging on each flange end should be less than 10% of the support span [7]. Therefore, the remote displacement was placed at each support. The value of the Y-axis was set as default-free 0. It is to fix the movement at the support of the Y-axis. Next, two force points were located at 1600 mm from the supports. Two edges of the web are selected to place the boundary condition.

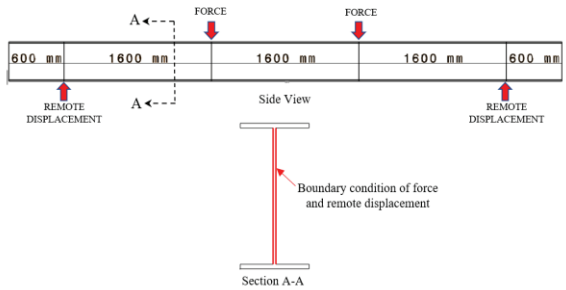

Figure 1 Boundary condition for four-point bending of the beam.

2.4. *Convergence meshing study*

A convergence study is carried out to determine an appropriate mesh density. Nine types of mesh are used to find the best mesh size for FEA. The meshing quality of fine is used to determine the maximum stress value for the study. The number of elements from 486 to 4560 is used to obtain the maximum stress.

3. RESULT AND DISCUSSION

3.1. Convergence mesh study

I-beam size of 400 mm X 200 mm X 6000 mm is used to evaluate the maximum stress. A constant force of 310000 N is used to evaluate the maximum stress of the simple I-beam model for the following number of elements. The result shows that a 2000 to 4560 number of elements is appropriate to use for the FEA as shown in Figure 2.

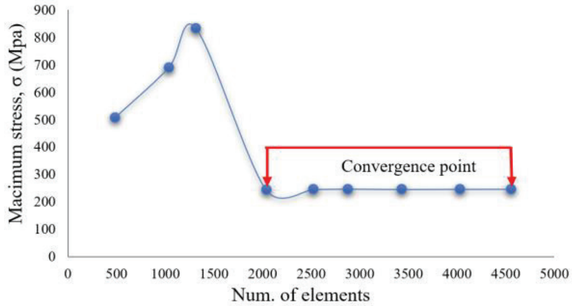

Figure 2 convergence meshing study

3.2. Comparison between Euler Bernoulli bending equation and FEA

The analytical result and numerical analysis results are compared. The error between both results is evaluated. The error percentage result is used to evaluate the accuracy percentage.

3.3. Correlation of web-to-flange ratio to the accuracy

Figure 3 shows Correlation of the web-to-flange ratio to the accuracy based on the validation result. The graph shows a certain limit of height, h is exceptional to use for the base, b size of 100 mm, 200 mm, and 300 mm. A ratio is established to represent the limit state of height, h for the following base, b.

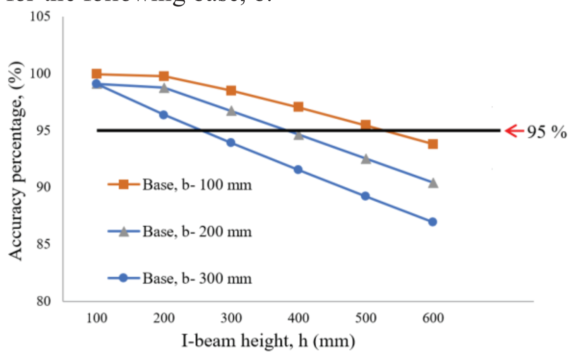

Figure 3 Correlation of web-to-flange ratio to the accuracy

3.4. Establish I-beam size ratio for accuracy

Figure 4 shows the web-to-flange ratio for 100 mm, 200 mm, and 300 mm base, b of variable height, h I-beam section. The height of the I-beam section has a significant effect on the accuracy percentage of the following I-beam section. When the height increases, the accuracy percentage decreases. The I-beam web-to-flange ratio of 0.8, 1.95, and 5.2 is recommended to use for FEA.

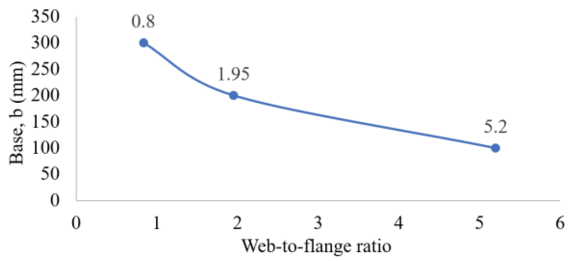

Figure 4 I-beam size ratio for accuracy

4. CONCLUSIONS

From the study, accuracy percentage between analytical and numerical analysis for the I-beam section of variable size is obtained based on validation. The results show that the accuracy reduces as the I-beam height increases. Therefore, the I-beam web to flange ratio of 0.8, 1.95, and 5.2 was established to limit the I-beam height to use for FEA.

ACKNOWLEDGEMENT

Author are grateful to Faculty of Mechanical Engineering of University Teknikal Malaysia Melaka and the industrial partner for financial support through INDUSTRI (MTUN) HRSB/ 2021FKM/I100052.

REFERENCES

[1] J. M. D. Gąska, T. Haniszewski, 'I-beam girders dimensioning with numerical modelling of local stresses in wheel-supporting flanges', MECHANIKA, vol. 23, no. 3, pp. 347–352, 2017.
[2] H. K. Hui Xue, 'Analytical and case studies of a sandwich structure using Euler−Bernoulli beam equation', Math. Eng. Sci. Aerosp., vol. 7, 2016.
[3] N. F. Rieger, 'Relationship Between Finite Element Analysis and Modal Analysis.', S V Sound Vib., vol. 20, no. 1, pp. 16–18, 23, 1986.
[4] A. Y. Ali and M. Hameed, 'Analysis for Behavior of Reinforcement Lap Splices in Deep Beams Analysis for Behavior of Reinforcement Lap Splices in Deep Beams', J. Univ. Babylon, Eng. Sci., vol. 26, no. 5, pp. 347–361, 2018.
[5] M. S. Yob, S. Mansor, and R. Sulaiman, 'Finite Element Modelling to Predict Equivalent Stiffness of 3D Space Frame Structural Joint Using Circular Beam Element', Appl. Mech. Mater., vol. 431, pp. 104–109, 2013.
[6] A. Farzampour, I. Mansouri, C. H. Lee, H. B. Sim, and J. W. Hu, 'Analysis and design recommendations for corrugated steel plate shear walls with a reduced beam section', Thin-Walled Struct., vol. 132, pp. 658–666, 2018.
[7] ASTM D790, 'D790: Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials', Annual Book of ASTM Standards. pp. 1–12, 2002.