

Stress and deformation analysis of tapered cantilever castellated beam using numerical method

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Abstract. The castellated beam is often used in buildings because of its lighter weight compared with a normal steel beam. There are many types of an opening in the castellated beam, one of which is hexagonal openings. This paper will discuss the analysis of stress and deformation on castellated beam with a variation of openings diameter, space between holes, and angle of hexagonal openings. Furthermore, stress distribution on specimen will be seen under static loading. This study used IWF section 150x75x5x7 with 4 variations of the span with one fixed support, and yield strength is 400 MPa. Linear finite element analysis is used with 10-node tetrahedron solid element, by observing von Misses stress. The software used in this study are freeware, which is LISAFE 8.0 for analyzing and FreeCAD for drawing. The result shows that value of stress and deformation for each sample is quite volatile, but it can be concluded that stress distribution around the opening is larger than in web and flange.

1. Introduction

The beam is a structural element that supports shear force and bending moment more dominant than axial load. Many materials are utilized as a beam, one of which is steel materials. Steel has many advantages of usage, for example, tensile and compressive strength steel is higher than concrete, and its strength is more uniform than concrete because it is fabricated in the factory. But on some occasion, steel is still considered expensive rather than concrete. To reduce its cost, there are a lot of innovations, one of them is to create steel beam as a castellated beam. The castellated beam is a normal steel beam modified by cutting into the half with specific pattern and united by welding so that its height increases significantly with holes in its web [1]. Experimental and numerical tests were done in previous research such as looking for elastic-plastic behavior [2], optimizing by size and distance of hole [3], and improving analysis of castellated beam using finite element analysis[4], but all of those studies used simply-supported so that implementation of prismatic steel beam is still relevant.

There are many kinds of supports, one of which is fixed support in cantilever beam structure. Cantilever beam internal forces are concentrated in the supported area so that practicing prismatic section steel beam in the field would cost much. Some studies already conducted about the usage of the structural member in cantilever support for example steel-concrete composite[5], high steel reinforced concrete[6], and checked by the crack with modeling [7], but so far the further research of castellated beam as cantilever structure has not been conducted yet.

Furthermore, non-uniform section steels are usually used for reducing the cost of construction and increasing strength purposes. This innovation already tried to be applied for many applications, for example in dome-like structures [8]. Also, there is already research about numerical modeling based



on an experimental test for buckling behavior of tapered steel section [9], but the application in castellated beam have been done before.

This paper discusses stress and deformation that happened in castellated cantilever beam with hexagonal openings which is used in cantilever beam and also applying non-prismatic section as tapered steel member to optimize steel beam usage. It also shows stress distribution surround body of the structure. Numerical test was conducted using linear finite element method.

2. Samples and Analysis Method

2.1. Samples

Steel material that used in this research refers to ANSI/AISC 360-10 [10] with yield strength 400 MPa, Modulus of Young 200 GPa and Poisson's ratio 0.3. All of the samples have its final height 255 mm at fixed support. The number of samples is 72 with 4 variations which are span length, the angle of openings, openings space and the hole diameter of openings. The detailed of variations are written in table 1.

Table 1. Detailed variations of samples that are used in this study

Span Length (m)	Angle ($^{\circ}$)	Openings space (mm)	Hole diameter (mm)
2	55	60	50
2.5	60	80	75
3		100	100
3.5			

Samples are drawn in 2 dimensions using AutoCAD program to get the final length nearest its span length requirement. For example, in figure 1, it is shown how to cut the steel section from prismatic with hexagonal pattern and reunited to be a non-prismatic section. The cutting of steel section is done diagonally and only takes 120 mm from the total height of 150 mm (IWF 150x75x5x7) because the other 30 mm were not cut to keep the flange part and corner part as original. Each sample is given a code name, for example, D100-S60-JA100 which means this sample has openings diameter 100 mm, angle of opening 60° and space between holes 100 mm.

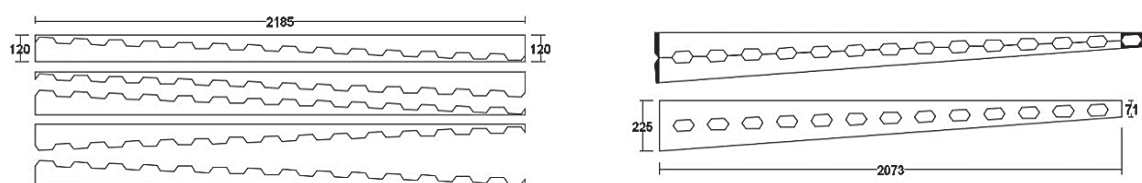


Figure 1. Creating non-prismatic castellated beam section sample from regular steel beam

2.2. Analysis method

In this study, an analysis is conducted using finite element method with 10-node tetrahedron solid element. Before all samples are analyzed, those were modelled as 3D solid steel beam in FreeCAD as shown in figure 2 and after that solid samples are imported to finite element analysis program which is LisaFEA and in that program, several actions were done such as defining material, determining number of element that is used by determining size element, running the program, and resuming the result of stress and deformation that happened. The process of modeling samples in LisaFEA is depicted in figure 3. The stress of samples is calculated using Von-mises criterion [11] as stated in Equation 1. After all those steps are done, the number of elements used for each length is determined by calculating convergence method to seek an optimum number of the element. This method is comparing between the number of element and displacement under the same load and chooses the

smallest number of element that is resulting from the best displacement which approaches real value with small error (< 5%).

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2 = 2\sigma_y^2 \quad (1)$$

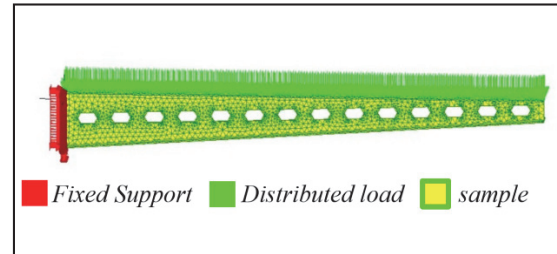
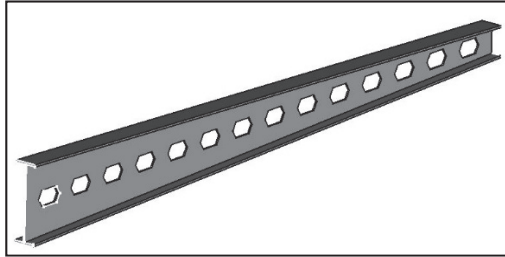


Figure 2. Solid 3-dimensional drawing in FreeCad **Figure 3.** Analyzing samples in LisaFEA

3. Result and Discussion

Convergence tests are done for each length variation. For example, in figure 4, the convergence test is done for length variation 2 meters, and the number of an element is chosen 10,000 because the displacement of samples does not change much after modeled with more elements. The load is given to samples based on the result of stress which approaches yield stress for every length variation. Those are resumed in table 2. Stress and deformation result from the test are fluctuating for each sample, which is shown in figure 5. From figure 6, it can be seen that stress is concentrated at corner of hexagonal openings nearby support which is the weakest and vulnerable area.

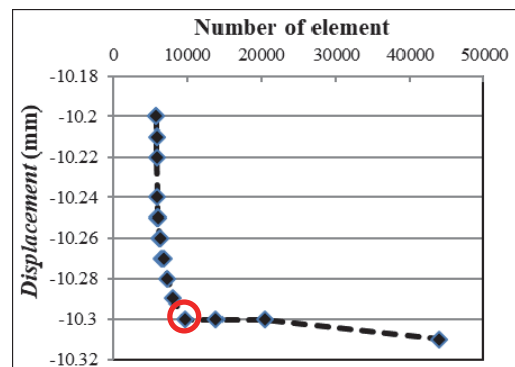


Figure 4. Convergence test result and choosing number of element

Table 2. Resume of load given in every sample in the same span length

Span length (m)	Code name	Optimum load for analyzing (ton)	Stress reached (MPa)
2	D100-S60-JA100	2.5	385.4
2.5	D100-S60-JA100	2.3	385.2
3	D100-S60-JA100	2.1	378.1
3.5	D100-S55-JA100	1.9	398.3

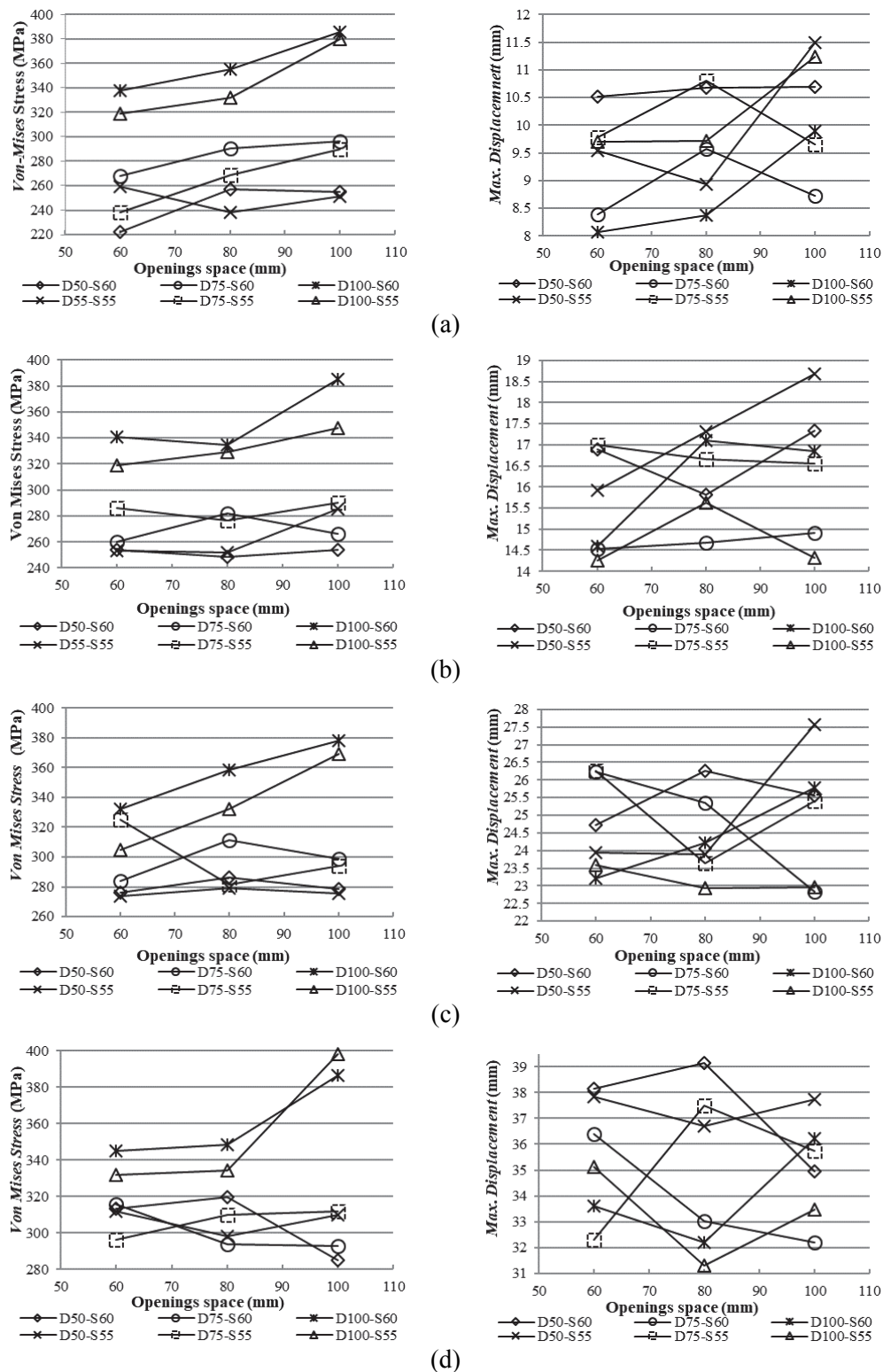


Figure 5. Stress and displacement resulted from the test with span length of (a) 2 m; (b) 2.5 m (c) 3 m; (d) 3.5 m

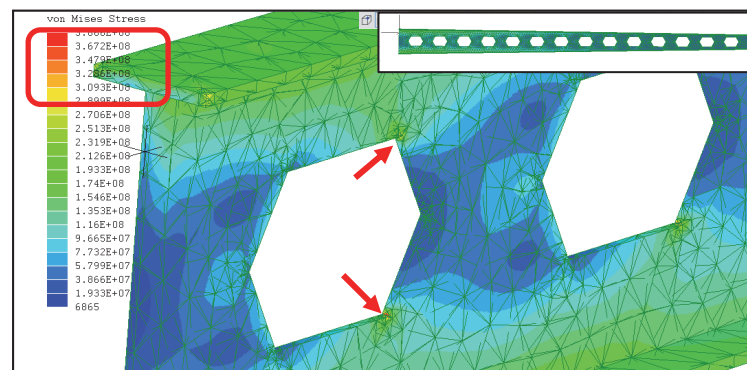


Figure 6. Stress distribution in body of castellated beam

4. Conclusion

To sum up, the value of stress and distribution for each sample are fluctuating. Those samples do not have any pattern because several factors namely different result openings amount in every sample, the different distance between support and the first hole for each sample and different height of the beam near free support resulted from the cutting method. Further study should be conducted to predict the value of stress and distribution based on the result. Nevertheless, it can be known that stress distribution in every sample is concentrated to the corner of hexagonal openings which is the nearest from the fixed support.

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