

STRESS AND DEFORMATION STUDY ON CASTELLATED STEEL BEAM WITH TAPERED SHAPE AND HEXAGONAL OPENINGS

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Abstract – *Castellated steel beam is a beam with a regular section cut into half with a particular pattern and regrouped with welding to increase its height compared to the original. This structure element has been developed in building constructions since many years ago. However, its uniform section along the span will make the modification no longer effective in cantilever structure, unless it has additional adaptation. Therefore, in this study, it is proposed to use a castellated steel beam with a tapered shape to be applied as cantilever structures. A steel beam with IWF section 150x75x5x7 is the primary sample type in this research. Some variations were made such as openings angle for 45° and 50°, openings space for 50 mm, 70 mm, and 90 mm, openings diameter for 50 mm, 75 mm, and 100 mm, and span length for 2 m, 2.5 m, 3 m, and 3.5 m. Two open-source software namely FreeCAD and LisaFEA were used to draw solid 3-dimensional samples and to conduct the numerical analysis to determine stress and deformation respectively. From the result, it is known that the smallest stresses and deformations can be achieved by a different angle of openings, openings space, and diameter for each span length.*

Keywords: *Castellated steel beam; Tapered shape; Hexagonal openings; Finite element method*

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INTRODUCTION

A beam is one of many necessary structural elements in some civil constructions. Generally, beam supports the plate in multi-story buildings. Steel is a standard material and available for a beam. It has many advantages such as the strength uniformity, its specific sections from manufactory so that people can choose provided dimension, and it has high yield strength for both compressive and tensile strength.

Designer and constructors both make the steel more useful to be used as a beam. One innovation that already exists and still developing is a castellated beam (Maulana, 2017; Maulana et al., 2018). It is a modification result by cutting a normal beam from a factory into the half with a certain pattern, then both of it is welded so that the beam's height will increase. Adding more height means the moment of inertia will rise and also enhance the flexural and shear capacity (Maulana et al., 2018). Regarding the cutting pattern, several paths generate the shape openings, one of which is hexagonal openings (Nair & Pillai, 2018).

There have been some studies about castellated beam, specifically to investigate (Frans et al., 2017), optimize holes size and space at its web (Cissé et al., 2017), use another shape as an alternative (Tudjono et al., 2017), and so on. Most of them utilize finite element

analysis as their method to obtain major parameter like stress and strain (Cissé et al., 2017).

Furthermore, the demands of the steel beam are not only as a simply supported beam structure, but also cantilever supported structure, which has one fixed support in one end and free in the other end. This castellated beam with fixed height for all span will be no longer effective if it is applied in such structure.

Some researcher tried to make innovation in steel beam like reshaping it as a tapered beam (Shao et al., 2008), that the beam will have a higher section at the support. From here, some research about tapered section has been developed to be applied as a column (Lee & Lee, 2017, 2018), incorporation between beam and column (De'nan et al., 2017; Dogariu et al., 2017), and even for a beam itself with many parameter reviewed (Akbarzade & Farshidianfar, 2017; Dennis & Jones, 2017; Ozbasaran & Yilmaz, 2018; Trahair, 2014).

Castellated beam hasn't become an option for all this time because of those reasons. To make it happen, castellated beam technology can adapt by shaping it as a tapered beam. This technology unification should be studied further to know its behavior, especially about the stress and deformation when loads are given to that cantilever structure.

In this research, linear finite element method as a representation of numerical analysis was conducted on tempered castellated beam samples to retrieve stress and deformation. Several variations on openings geometry and a span length of the structure were chosen to see the result. The purposes of this paper are to explore the most appropriate geometry dimension to get the smallest numbers of stress and deformation when all samples loaded with the same amount. It can be used for civil engineers and architects in the field as a reference to implement castellated beam as cantilever structures.

MATERIAL AND METHOD

Material

One IWF section type of steel beam was varied as a sample in this experiment. This

section had a dimension of 150x75x5x7 and modified as castellated beam so that the maximum height of examples become 225 mm. Its yield strength (f_y) refers to the steel that commonly used in building constructions, which is 400 MPa.

As can be seen in Fig. 1, the IWF normal section is cut into half with a specific pattern. After that, those two parts were re-joined by welding. This action results in increasing the section height near the support and decreasing the section height on free support. All variations made in these experiments are also presented in Table 1.

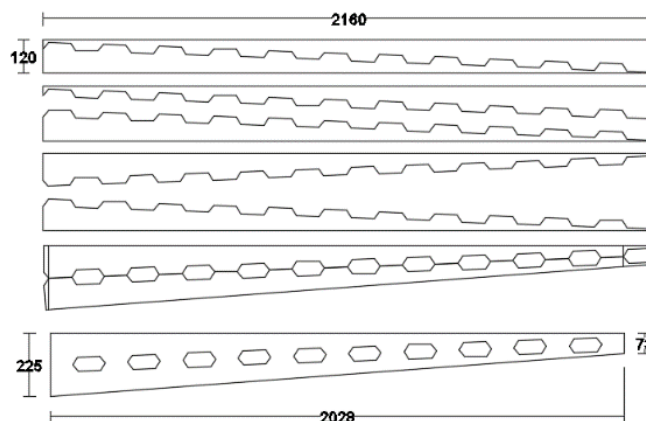


Figure 1. Example of sample creation from steel beam with a uniform section

Table 1. Variations in this study

Span length (m)	Angle (°)	Openings space (mm)	Hole Diameter (mm)
2	45	50	50
2.5		70	75
3		90	100
3.5	50	-	-

Method

Generally, the finite element method will be run as an analysis to generate stress and deformation from all samples. However, to create the samples easier, other open-source software involved to draw the solid element. Some utilized programs are mentioned as follows.

FreeCAD

FreeCAD has been developed to draw either 2-D or 3-D object and it can be used freely as it is an open-source program. All samples in this study were made in this software as a 3-D solid element, and after the drawings were ready,

all of it was imported to the finite element analysis (FEA) software.

LisaFEA

LisaFEA is FEA software that has enough capability to analyze and generate all static parametric needed although the analysis only limited to linear analysis. After all, samples are drawn as a 3D solid element in FreeCAD, those geometries were imported into LisaFEA and in this software, loads, support, and type of analysis were defined. The analysis was run using 10-tetrahedron solid and the geometries meshed into a smaller size. Before deciding the result, some trials were conducted to analyze the convergence between the number of elements involved and the deformation. This attempt is to make the result more accurate. All the stages of this study are depicted as a flowchart in Fig. 2. Example of the drawing 3-Dimensional element process was shown in Fig. 3 with the example of running the analysis was illustrated in Fig. 4.

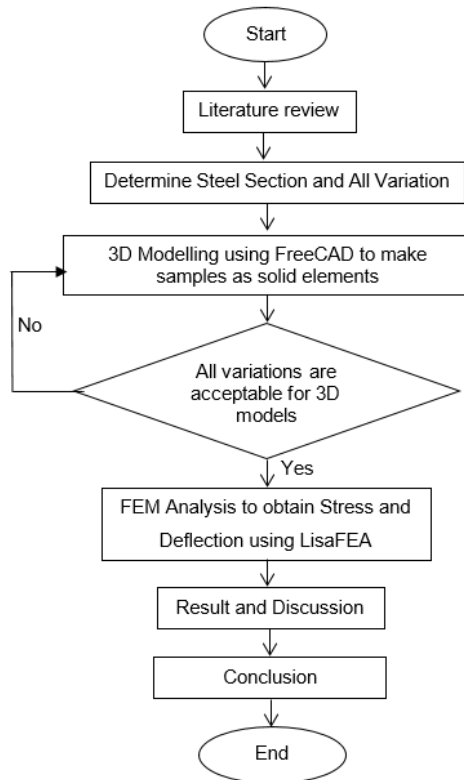


Figure 2. Research flowchart

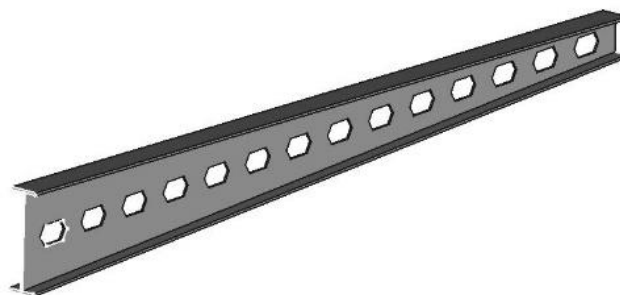


Figure 3. 3-Dimensional drawing of samples using FreeCAD

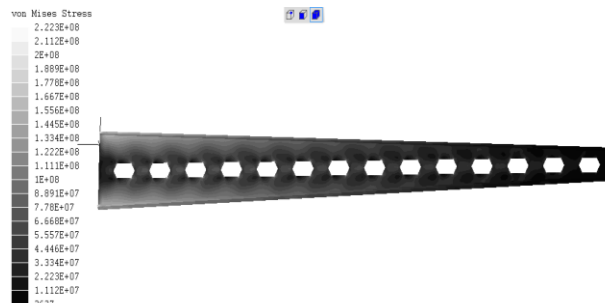


Figure 4. Finite element analysis of samples to obtain stress and deformation by LisaFEA

In addition, all samples were given a code name to make the result reading more obvious. The name was based on its variations. For

instance, a sample with name "B2-D50-S45-JA50" has a meaning of tempered cantilever steel beam with a span length of 2 m, openings

diameter of 50 mm, openings angle of 45 °, and openings space of 50 mm.

RESULT AND DISCUSSION

Convergence analysis was conducted in the beginning to obtain stress and deformation that can be accepted and tolerated. This should be done before all the samples were analyzed to make sure the size of the element that can handle the calculation precisely as well as the number of elements involved. The bigger size of element used, a total number of elements in the same sample's size should decrease, and the

analysis will run faster but the result may not exact, whereas the smaller size of element used will give the result nearer the absolute, but the running process will take more time.

In Fig. 5, it is shown about an example of convergence analysis conducted for a sample with a span length of 2 m. The trial chose a varying number of elements compared to the result of deformation. From that investigation, it is known that meshing resulted in 10,000 elements should be reliable enough to conduct the test, with the volume element size of 24 to 40 mm³.

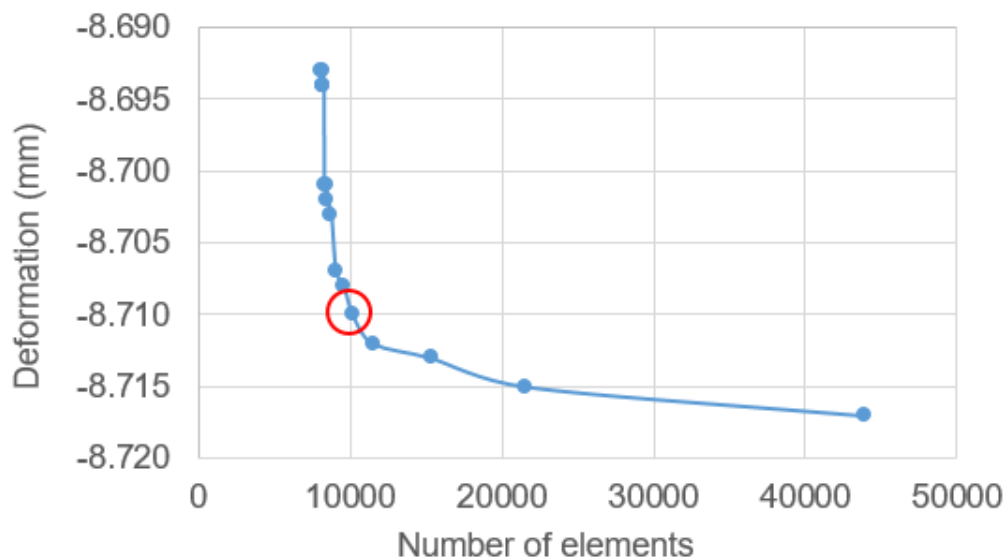


Figure 5. Convergence test for samples with a span length of 2 m

Afterward, all loads given to the sample will result in stress in every element that must not exceed than 400 MPa to keep the analysis run below the non-linear condition. Table 2 shows the optimum load that can be received for every sample regarding the span length.

Table 2. Optimum load for every span length variation with stress less than 400 MPa (yield)

Span Length (m)	Optimum load (ton)	Stress (MPa)
2.0	2.8	395.0
2.5	2.7	399.2
3.0	2.35	395.3
3.5	2.15	393.9

After each load is applied and the analysis is run, the Von-misses stress (in MPa) and deformation (in mm) are retrieved for all samples. All results are depicted in Fig. 6 to Fig. 13 for every span length variation.

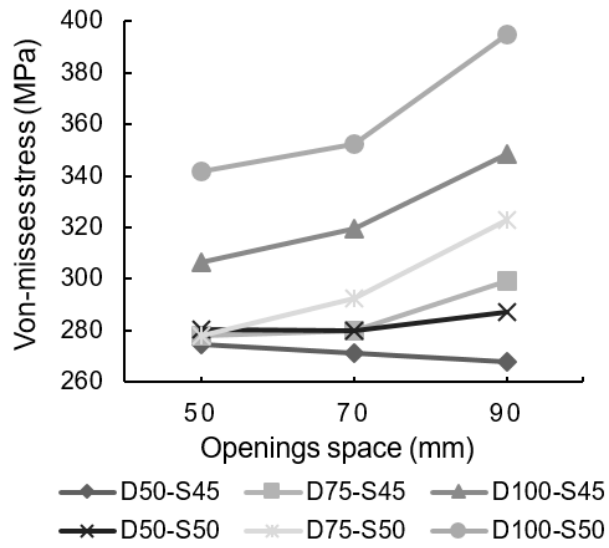


Figure 6. Stress for samples with 2 m span length

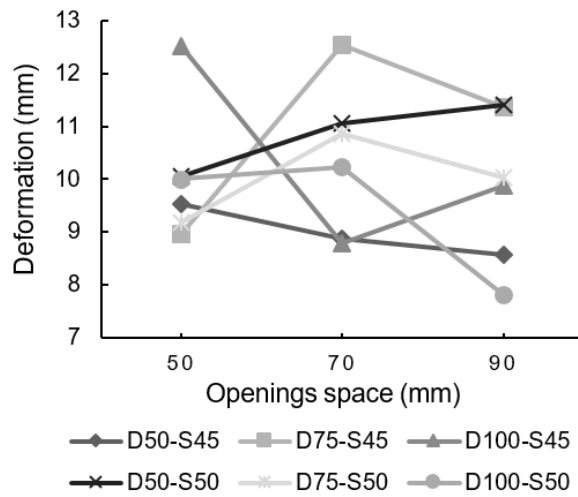


Figure 7. Deformation for samples with 2 m span length

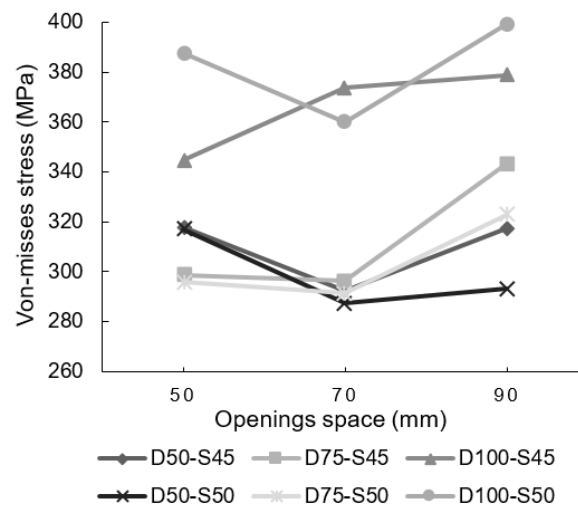


Figure 8. Stress for samples with 2.5 m span length

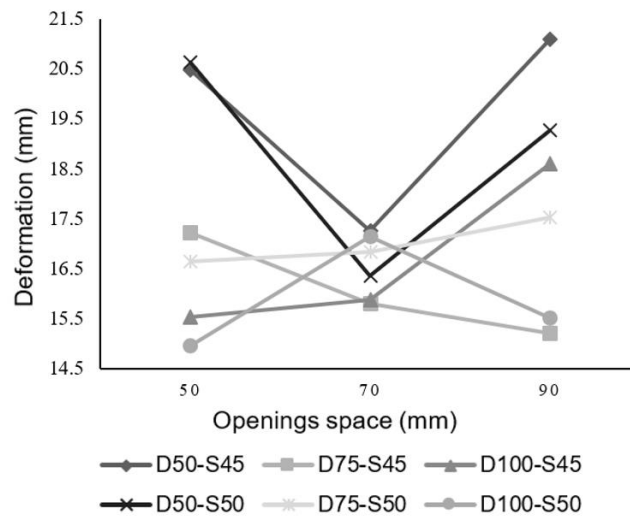


Figure 9. Deformation for samples with 2.5 m span length

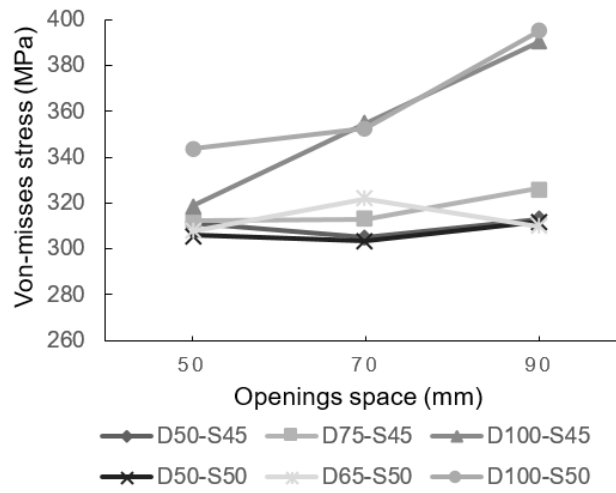


Figure 10. Stress for samples with 3 m span length

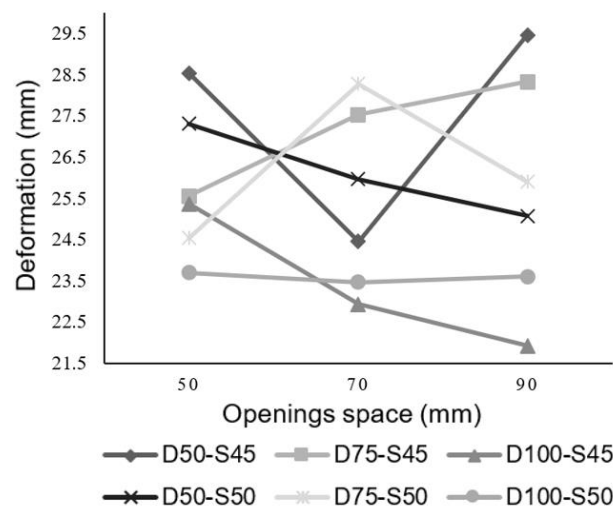


Figure 11. Deformation for samples with 3 m span length

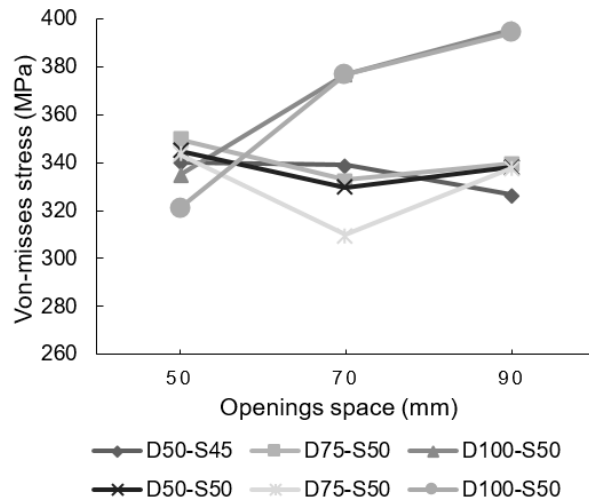


Figure 12. Stress for samples with 3.5 m span length

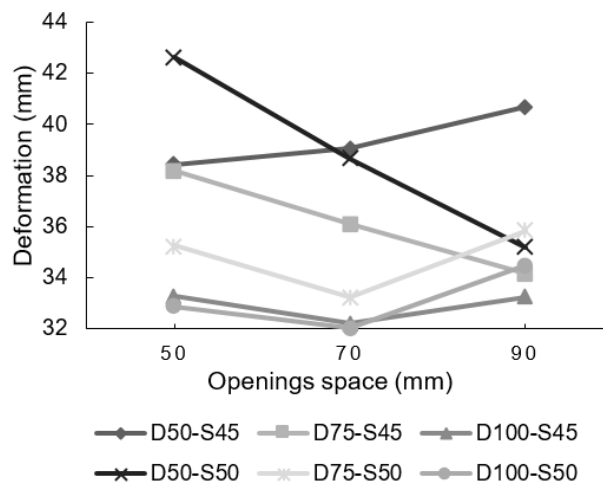


Figure 13. Deformation for samples with 3.5 m span length

All specimens were analyzed by measuring two important aspects, namely displacement and maximum stress that occurred in castellated beams. Cantilever with a span of 2 m to 3.5 m was chosen because it is often used in buildings for exterior rooms. Fig. 6 to Fig. 13 are illustrations that coupling respectively. In Fig. 6 and Fig. 7, it is shown that the value of deformation and maximum stress achieved for the distance between openings is 50 mm, 70 mm and 90 mm. The selection of the use of element dimensions can be considered with these two parameters so that application in the field is faster.

It is known from Fig. 6, under the same load, the lowest stress is achieved by a beam with a diameter of 50 mm, a hexagonal angle of 45° , with a distance between spaces is 90 mm. Conversely, the lowest displacement is achieved in specimens with a diameter of 100 mm openings, with an angle of 50° , and with the

same spacing between 90 mm. This shows that for a span of 2 m, the stress will be low if the small diameter with the angle is relatively the same, while the displacement is low when the opening hole is getting bigger.

The other pair shows results for a span of 2.5 m, as in Fig. 8 which shows the von Mises stress and Fig. 9 for displacement. From Figure 8, it is known that the lowest stress is in a specimen that has a diameter of 50 mm, an angle of 50° with an opening space of 70 mm while the minimum displacement in Fig. 9 is in a sample with a diameter of 100 mm, an angle of 50° , and an opening space of 50 mm.

Similar to a 3 m span, the lowest stress was achieved by specimens with a diameter of 50 mm with an angle of 50° and an opening space of 70 mm, with differences between specimens relatively low. Furthermore, in Figure 11, it is known that the lowest deformation value is a hexagonal hole with a diameter of 100 mm,

angle 45° with an opening space of 90 mm. Furthermore, the results for the 3.5 m span are shown in Fig. 12, the lowest displacement results achieved by beams with a hole diameter of 75 mm, angle 50° with a spacing of 70 mm. Besides, Fig. 13 gives the illustration that the minimum information reached by specimen with D75-S50 is a space of 70 mm. Nonetheless, everything is still below the permit limit of 400 MPa so that all are still safe to use. For this study, openings angle with 50° is relatively more effective compared to 45° .

CONCLUSION

Based on all results presented above, it can be concluded that the castellated steel beam can be applied as a cantilever beam with a tapered shape under certain load limit value for each span length. Also, the stress and deformation for each span length will fluctuate due to numbers of holes resulted from the variations. Each span has a different variation that will be resulting smallest stressor smallest deformation as well.

It is suggested to do further research using machine learning for determining all parameter faster like Artificial Neural Network or else. Also, the cost for fabricating and implementing the specimen in the real world should be included in the study in the future. It is hoped that from this study, it can be a reference for engineers in the field as a reference for application in real building construction.

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