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Original Article

Behavior of Modified Castellated Beam with Addition of Angle Profile for Building Structures on Soft Soil, Especially in South Kalimantan

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Abstract - *To increase the capacity of the WF profile, it can be modified by changing its geometry into a castellated beam. Castellated beams have several variations of opening shapes. In 2020, the author obtained the bending behavior of a hexagonal opening castellated beam, which resulted in optimum bending capacity at a hexagonal opening angle of 450. In this study, the difference in bending strength produced by the hexagonal opening castellated beam and modified opening shape will be investigated. ANSYS numeric testing was conducted to determine the behavior of the castellated beam. The test model used in this study was a modified opening castellated beam with several variations of shapes (M1 to M5). Based on the results of the ANSYS numeric testing, the optimum castellated beam from the modified opening shape was found to be a diagonal Warren-type opening (M2) with Pyield=110.8kN and Pultimate=170.5kN. The bending capacity of the modified opening shape castellated beam was then compared to the hexagonal opening castellated beam. The modified opening shape produced better results than the hexagonal opening shape. The hexagonal opening castellated beam had Pyield=61.7kN and Pultimate=95kN. The deformation experienced by the modified opening shape castellated beam was smaller than the hexagonal opening shape, indicating that the modified opening shape had a greater moment of inertia than the hexagonal opening shape.*

Keywords - *Castellated modification, Flexural beam, Steel structure, Materials, ANSYS.*

1. Introduction

In steel structures, WF profiles are commonly used as beam elements. However, WF profiles have limited capacity for supporting loads over certain long spans. If a beam element needs to support a heavy load, a larger WF profile is required, which leads to increased weight and cost of the structure. Therefore, efforts are needed to enhance the load-carrying capacity of WF beams [1]–[5]. One approach to improve their capacity is by modifying the structure's geometry. In conventional WF steel beams, the geometry can be modified by creating a castellated beam. A castellated beam is created by cutting a WF profile into two pieces with various cutting patterns and then rejoining them into a single unified beam element to support loads [6]–[11]. The height of the beam will increase, resulting in an increase in the moment of inertia of the beam [12], [13]. Castellated beams aim to increase the bending capacity of the beam element. In addition to enhancing the bending capacity, castellated beams can also produce lightweight structures. The resulting structure will be lighter, with an increased bending capacity than a conventional WF beam [14]–[20].

In 2020, the author conducted a study on the flexural capacity comparison between conventional WF beams and hexagonal opening Castellated beams. The study involved empirical and numeric ANSYS analytical testing with hexagonal opening angles of 00 (conventional WF beam) [31], 200, 300, 450, 500, and 600. The study found an increase in the flexural capacity with the addition of castellated beam geometry with hexagonal openings [22]–[24]. The larger the opening angle, the greater the increase in flexural capacity, but the optimum opening angle occurred at 450-500 degrees.

Based on the previous research results, the author wants to compare the flexural capacity between hexagonal castellated beams and a modification by adding angle profiles. In this stage, the development is carried out by cutting the conventional WF beam into two parts and adding L-angle profiles to connect the two parts to form a complete beam for carrying the load. Then, the development of the beam is compared with the castellated beam studied in the previous stage to obtain the most efficient geometry.

2. Method

2.1. Material Properties

The method used in this research is numerical testing using ANSYS software. The material used for ANSYS modeling in this research is steel sheet material from Malang City, which has been previously studied by Arya in 2017 in the research titled "Behavior of Corrugated Web Plate Girder".

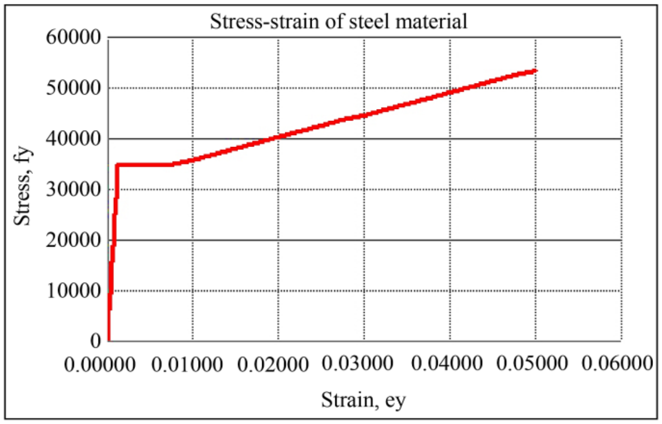


Fig. 1 Stress-strain curve of the steel material used in the study

Table 1. Material properties

Properties	Value	Units
Yield strength, f_y	240	Mpa
Ultimate Strength, f_u	370	Mpa
Modulus Elastis, E_s	200000	Mpa
Yield strain, e_y	0.0012	
Plateau strain, $e_{sh} = 6 * e_y$	0.0072	
Ultimite strain, e_{su}	0.05	

The material will be inputted into the ANSYS software using the Structural Steel Nonlinear material data with a multilinear isotropic system. The selection of the nonlinear material data is intended to achieve the fracture phase in the ANSYS numeric running results to reflect the structure's actual behavior [25]–[28]. Then, with the multilinear system, the stress-strain relationship points shown in Figure 1 can be inputted into ANSYS. Hexagonal opening Castellated beam with an optimum angle of 45 degrees, as shown in Figure 2.

In this study, a modified Castellated beam will be created from a WF 150x75x5x7 steel profile with a span of 2000mm, with the following geometric variations:

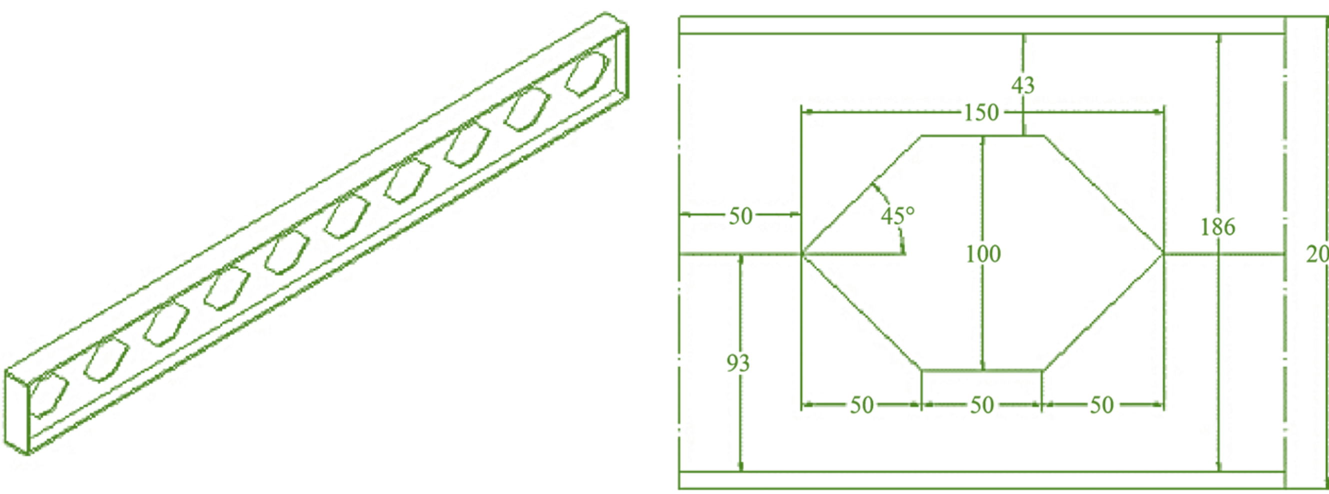


Fig. 2 Castellated beam model with 450 opening angle [29]

Table 2. List of specimens in the study

No	Model	The Total Profile Height(mm)	The L-shaped profile	The position of the angle profile	Model volume(mm3)
1	M1	300	2L 25 25 5	Vertikal	4542700
2	M2	300	2L 25 25 5	Diagonal Warren	4622294.155
3	M3	300	2L 25 25 5	Diagonal Howe	4622294.155
4	M4	300	2l 25 25 5	Diagonal Pratt	4622294.155
5	M5	300	2l 25 25 5	Diagonal Bowstring	4622294.155

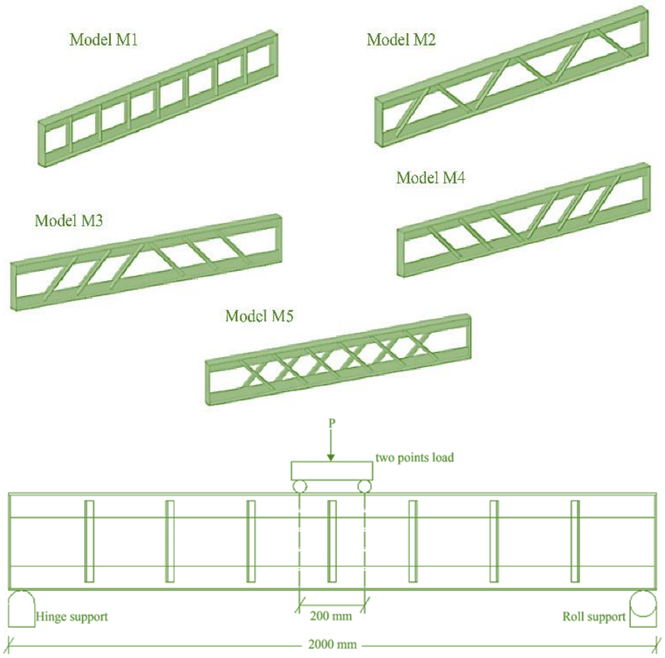


Fig. 3 Illustration of test setup

2.2. The Test Setup

This research was conducted through computer numerical testing using ANSYS. The test object is a beam with a span length of 2000mm, supported on two simple supports, namely a hinge and a roller. The load given is in the form of two-point loads at the center of the span with a distance of 200mm between the load points. The load is gradually applied to the beam until it reaches failure. To measure deflection, a nodal deformation direction is given on the bottom side of the beam, precisely in the middle of the span. Moreover, nodal strain is given on the top flens side, middle web side, and bottom flens side in the middle of the span for measuring the value of bending strain.

3. Result

3.1. The Flexural Capacity of Castellated Beam with 45° Hexagonal Opening

In 2020, the author conducted research on the bending behavior of castellated beams with hexagonal openings. In the study, both manual mathematical analytical and numerical analytical tests were performed on several models with varying hexagonal opening angles.

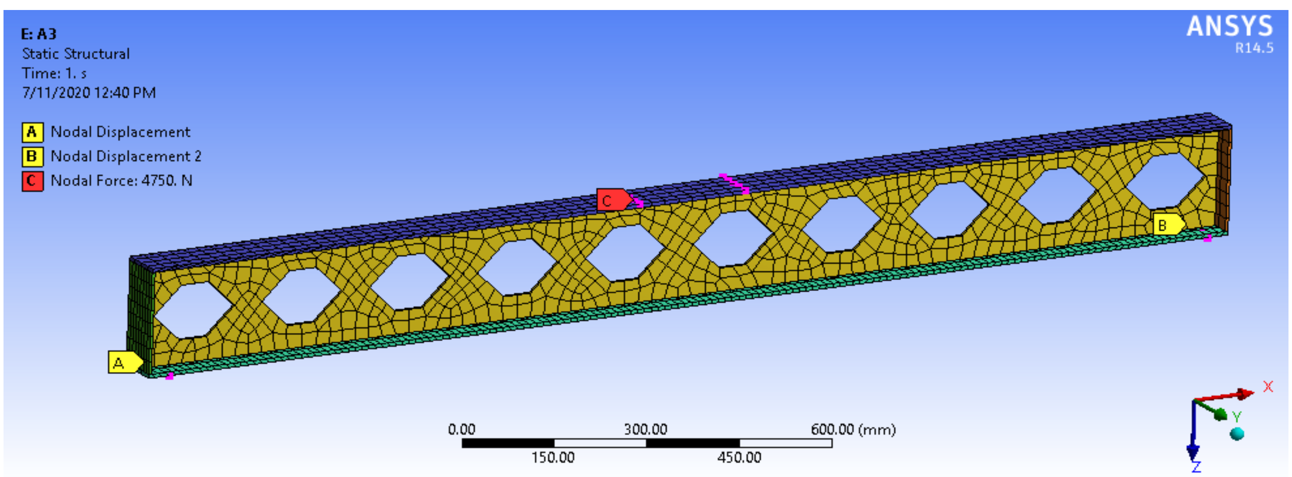


Fig. 4 Testing setup for hexagonal castellated beam

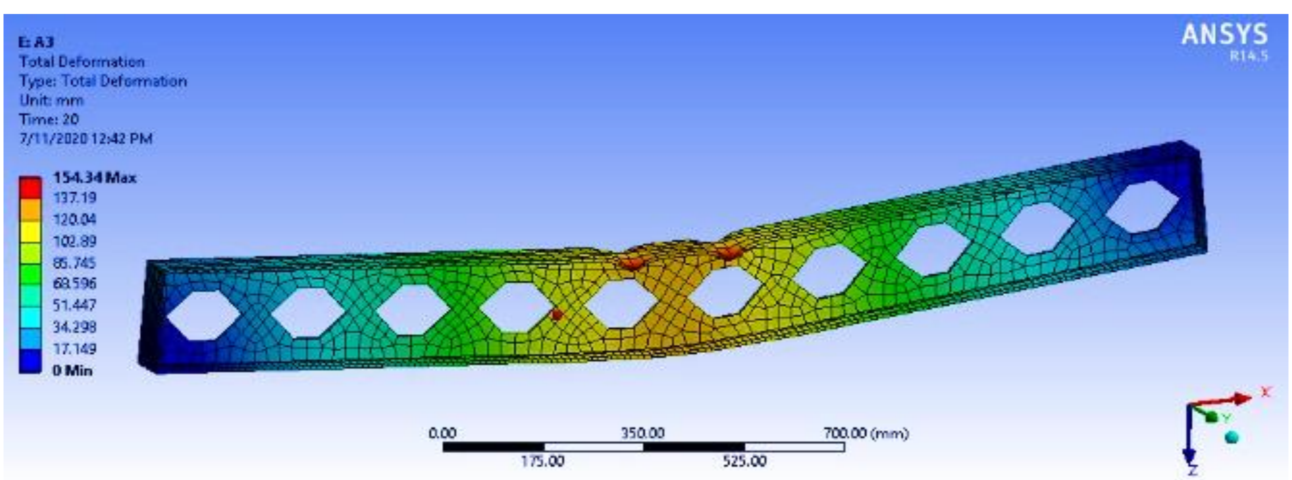


Fig. 5 Deformation shape of castellated beam with 450 hexagonal opening angle

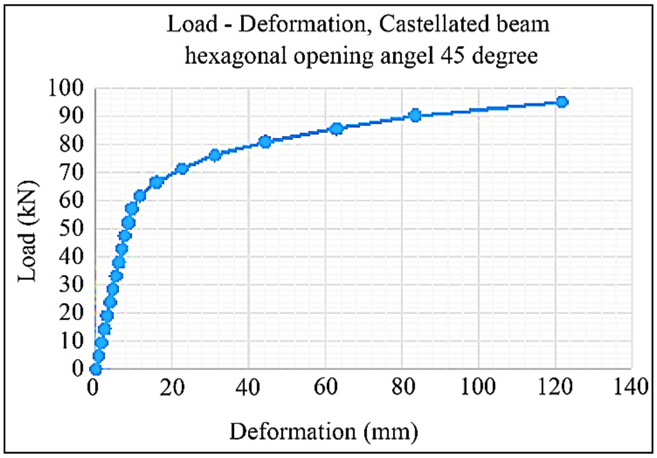


Fig. 6 Load-deformation curve of castellated beam with 450 hexagonal opening angle

The opening angle variations included 0 degrees (conventional beam), 20, 30, 45, 50, and 60 degrees. Among the various angles tested, the optimal opening angle was found to be 45 degrees, with a yield load (Py) of 61.7 kN and an ultimate load (Pu) capacity of 95 kN.

The Castellated beam with a 450 hexagonal opening angle obtained the highest bending capacity compared to several other opening angle variations. It can be said that converting the conventional WF beam into a Castellated beam with a 450 hexagonal opening angle can provide an increase in bending capacity. The increase in moment of inertia of the hexagonal opening Castellated beam makes the bending capacity higher than that of the conventional WF beam. According to Hayder Wafi, the Castellated beam can increase ultimate strength by about 50% compared to the original conventional profile. Based on these results, the Castellated beam with a 450 hexagonal opening angle will be compared to the modified Castellated beam in terms of bending capacity.

3.2. Bending Capacity of Modified Castellated Beam

To obtain a comparison of the flexural capacity between the hexagonal castellated beam and the modified castellated beam, a similar testing setup was conducted with the same beam span and load position for the hexagonal castellated beam. There were 5 variations of modified models tested, and the deformation contour for each model is shown in Table 3.

This study determined the ultimate load capacity achieved by each model. The variation in these models was only in the placement direction of the angle bars, with uniform steel volume. The most optimal variation was Model M2 with diagonal Warren angle bars, as the angle bars can serve as both tension and compression members.

Table 3. Deformation Pattern of Modified Castellated Beam

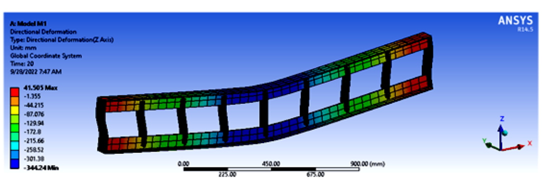
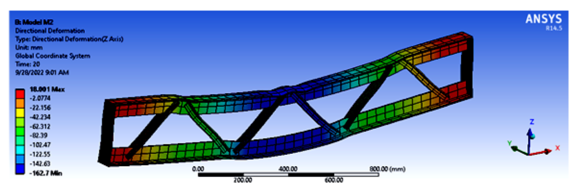
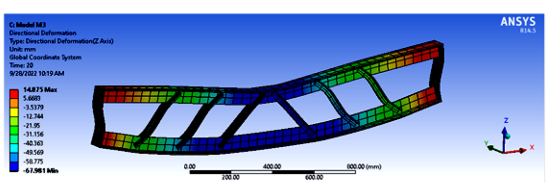
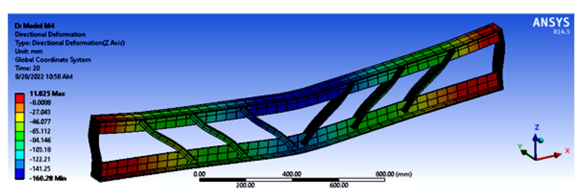
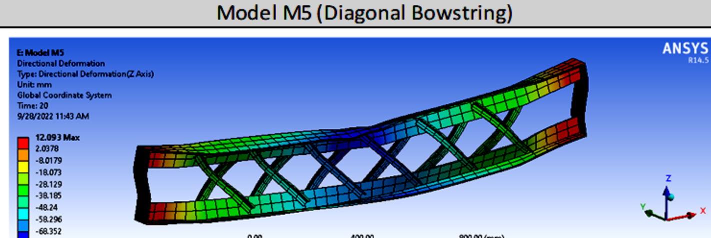
Model M1 (Vertikal)	Model M2 (Diagonal Warren)
	
Model M3 (Diagonal Howe)	Model M4 (Diagonal Pratt)
	
Model M5 (Diagonal Bowstring)	
	

Table 4. Comparison of Capacity/Volume Ratio

	Yield Load(py), kN	Ultimate Load(Pu), kN	Volume(mm3)	Ratio (Capacity / Volume)	
Castellated Hexagonal Opening 45deg	61.7	95	3590200	1.00	Note: Ratio to Hexagonal Opening
Castellated Modification M2	110.8	170.5	4622294	1.39	

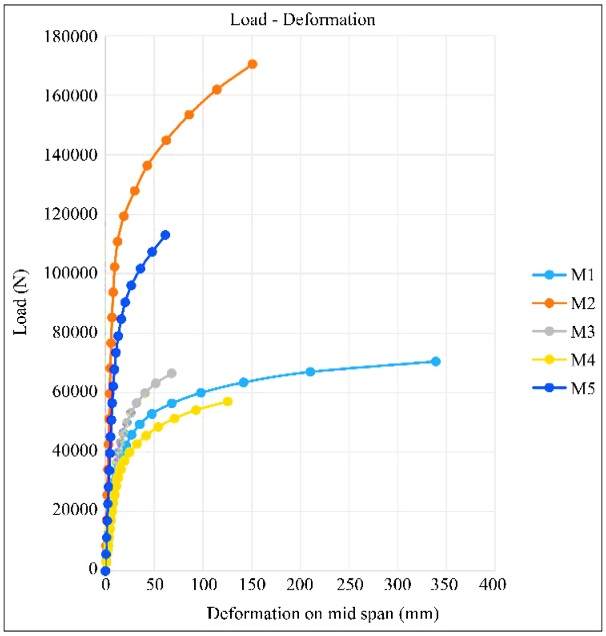


Fig. 7 Load-deflection curve of modified Castellated Beam model

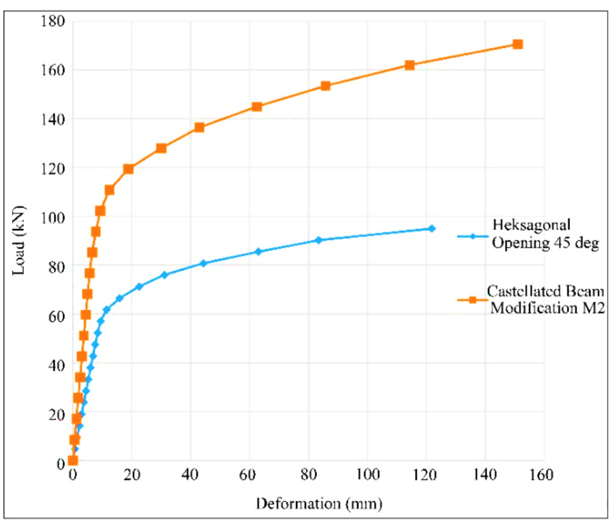


Fig. 8 The load-deflection curve comparison between the hexagonal Castellated beam and the modified Castellated beam model M2

Meanwhile, the least optimal was Model M4, where the angle bars were placed in a state of tension only, causing no bracing member to support the load at the load-bearing point. This weakness caused Model M4 to have the lowest load capacity and the largest deflection at the load-bearing point, where there was no plate or angle bar support.

3.3. Comparison of Flexural Capacity between Hexagonal Castellated Beam and Modified Versions

To obtain the most optimum opening geometry for the castellated beam in terms of increased flexural capacity, a comparison was made between the results of the castellated beam with 450 hexagonal opening angle and the modified castellated beam M2. The comparison results can be seen in the following figure.

The bending capacity value of the modified Castellated beam can provide Py=110kN and Pu=170kN, while the bending capacity that can be provided by the hexagonal Castellated beam is only Py=61.7kN and Pu=95kN. Although the modified Castellated beam requires more steel volume, it can provide a much higher capacity than the hexagonal Castellated beam. Therefore, if the ratio of capacity/volume is considered, the modified Castellated beam is far superior. Thus, if the modified Castellated beam is designed to have the same capacity as the hexagonal Castellated beam, it only requires a lighter weight.

4. Conclusion

Based on the results of the testing and discussion, several conclusions can be drawn:

- Based on the test results and discussions, it can be concluded that the Castellated Beam with modification has the most optimum bending capacity compared to the hexagonal opening. The bending capacity of the modified Castellated Beam can reach Py=110kN and Pu=170kN, while the bending capacity of the Castellated Beam with a hexagonal opening only reaches Py=61.7kN and Pu=95kN. Although the modified Castellated Beam requires more volume of steel, it can provide much higher capacity than the hexagonal opening. Therefore, based on the ratio of capacity to volume, the modified Castellated Beam is superior. Thus, if the modified Castellated Beam is designed to have the same capacity as the hexagonal opening, it will only require a lighter weight.
- The M2 model with a diagonal Warren angle section is the most optimal variation. This is because the angle section can serve as both tension and compression members. Meanwhile, the least optimal variation is the M4 model, where the angle section is placed in a state of tension only, so there is no supporting member at the point where the load is applied. This causes the M4 model to be the weakest in carrying loads, with the weakest condition being at the point where the load is not supported by the plate or the section (the largest deflection occurs at the load point).

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