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EFFECT OF STIFFENER VARIATION ON THE FLEXURAL CAPACITYOF CASTELLATED BEAM HEXAGONAL OPENING

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ABSTRACT

One of the innovations that could be done is to change the WF steel profile into a castellated beam with hexagonal openings. This research examines the effect of adding stiffener variations on castellated beams with hexagonal openings on flexural capacity. The steel profile used is a WF 150x75x5x7 steel profile with BJ 37 which is made into a castellated beam with hexagonal openings with an opening angle of 45° and a profile cut width of 50 mm with a beam length of 2000 mm with variations of stiffeners are plate 35x6, reinforcement Ø-16, and elbows. 25.25.4 with variations in distance of 200 mm and 400 mm. The analysis in this study uses manual analysis and numerical testing using the software. From the results obtained from the analysis, the flexural capacity, deformation, stress, and failure patterns that occur with each model will be compared. Based on the research results, it was found that the capacity of all models using stiffeners was greater than that of castellated steel beams without stiffeners. The reinforcement with a distance of 200 mm is the largest stiffener that can withstand the load with an increase of 6.25%.

Keywords: Flexural capacity, Castellated beams hexagonal, Stiffener

1. INTRODUCTION

Nowadays, steel structures are often encountered in the construction of buildings or other structures. Some conventional steel profiles that are often found include WF steel profiles. To increase the strength of steel, it is necessary to make innovations with more efficient planning. One of the innovations that can be done is to change the WF steel profiles into a castellated beam with a hexagonal opening. The advantage of castellated steel beams is that it increases the height of the steel profile so that the profile inertia increases. Castellated steel beams hexagonal opening increase the flexural capacity by 8-19% and the maximum flexural strength occurs at an opening angle of 45°-50° (Barkiah and Darmawan, 2020). Research (Permadi, 2021) shows that castellated beams hexagonal opening with a profile cut width of 30-70 mm produce the same value of flexural capacity.

This means that the variation in the width of the profile does not significantly affect the flexural capacity at yielding conditions of the castellated beams opening hexagonal. In addition, based on research (Putra and Sabariman, 2014) by adding a stiffener plate to the load distribution body be decreased equitably down to every one of the test objects. Test object 5 (t=8 mm) is the best of the other test objects. In this study, what will be investigated is the effect of flexural capacity if additional stiffeners are added to the castellated beam. The research conducted compared the flexural capacity of castellated beams hexagonal opening with various variations of stiffeners.

1. THEORETICAL STUDY

Castellated Beam

A castellated beam is a profile detail whose part strength is expanded by reaching out toward one another and welded along with the pattern. This castellated beam has a height (h) practically half higher than the initial profile, thereby expanding the benefit of bending axial, a moment of inertia (Ix), and section modulus (Sx). (Knowles PR, 1991).

Flexural Capacity of Castellated Beam

The nominal flexural moment of castellated beam based on ASCE journal page 3327 is

$$Mn = Mp - fy \, . \, \Delta As \left(\frac{h_o}{4} + e \right)$$

Where:

Mn	= Nominal Flexural Moment Beam (N.mm)
Mp	= Plastic Moment = Zx . fy (N.mm)
ΔAs	= h0 . tw (mm2)
ho	= Hole height (mm)
tw	= Web thickness (mm)
e	= Width of profile cut/hole eccentricity (mm)
fy	= Steel yield strength (MPa)

2. METHOD

The tested specimens planned and analyzed in this study were steel profiles formed into castellated beams hexagonal opening with a profile cutting width of 50 mm and an angle of 45º. This research is an experiment on stiffeners in castellated beams by varying the distance and type of stiffeners used. With variations of stiffener plate 35x6, reinforcement Ø-16, and elbow 25.25.4 with a variation of distance of 200 mm and 400 mm.

Table 1. Variation of data for each model

Model	L (mm)	tw (mm)	tf (mm)	hw (mm)	bf (mm)	Distance between stiffeners (mm)	Type of stiffener	Number of holes	Number of Stiffeners
TP	2000	5	7	186	75	-	-	10	-
PP200	2000	5	7	186	75	200	Plates 35x6	10	18
PS200	2000	5	7	186	75	200	Elbow 25.25.4	10	18
PT200	2000	5	7	186	75	200	Ø 16	10	18
PP400	2000	5	7	186	75	400	Plates 35x6	10	10
PS400	2000	5	7	186	75	400	Elbow 25.25.4	10	10
PT400	2000	5	7	186	75	400	Ø 16	10	10

Where :

TP = Castellated beam without stiffener

PP200 = Castellated beam with plates 35x6 at distance of 200 mm

PT200 = Castellated beam with elbow 25.25.4 at distance of 200 mm

PS200 = Castellated beam with reinforcement Ø-16 at distance of 200 mm

PP400 = Castellated beam with plates 35x6 at distance of 400 mm

PT400 = Castellated beam with elbow 25.25.4 at distance of 400 mm

PS400 = Castellated beam with reinforcement Ø-16 at distance of 400 mm

Each model made will be analyzed as a steel beam element simple structure on two supports ,which subjected to two static two-point loads such as the seen in the following Figure.

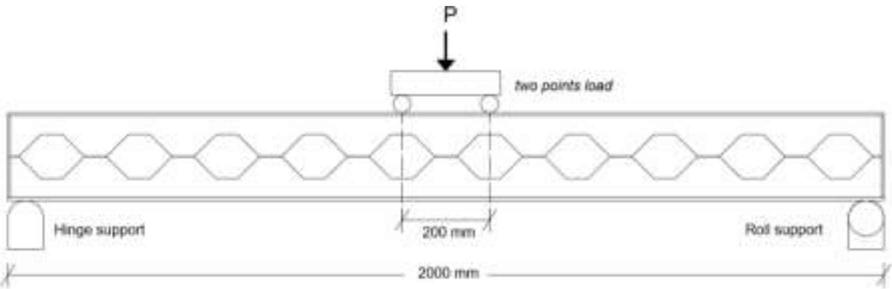


Figure 1. Loading configuration for each model variation

The tes e supports, specifically joints and rollers. The loaded given is in the form of a load static two-point in the range with a distance between the heap focuses similar to 200 mm. The utilization of this two-point load is planned so the inside powers that happen in the bar length are pure flexure, without shear forces. This can happen on the grounds that the greatness of the shear forces between the two burden focuses is zero. So the perusing is simply because of the power around then. This test is intended to acquire the flexural capacity of the bar example.

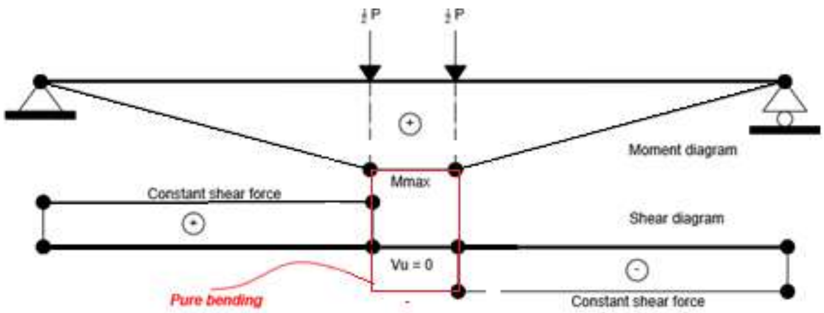


Figure 2. Illustration of moment and shear diagram for beams

Loads are applied progressively to the beams, until the beams come up short. The accident given by the numerical test is an indication of a blunder at run. This blunder demonstrates that the applied burden has surpassed a definitive restriction of the beam. The quantity of stacking stages is 20 load steps. For deflection readings, the course of the nodal deformation is given at the lower part of the bar at the focal point of the range. Similarly for the perusing of the flexural strain esteem, the nodal strain is given at the upper flange, center body, and base flange at the focal point of the range. The perusing of the strain esteem was completed at 5 places. The numerical test settings for each model are as per the following.

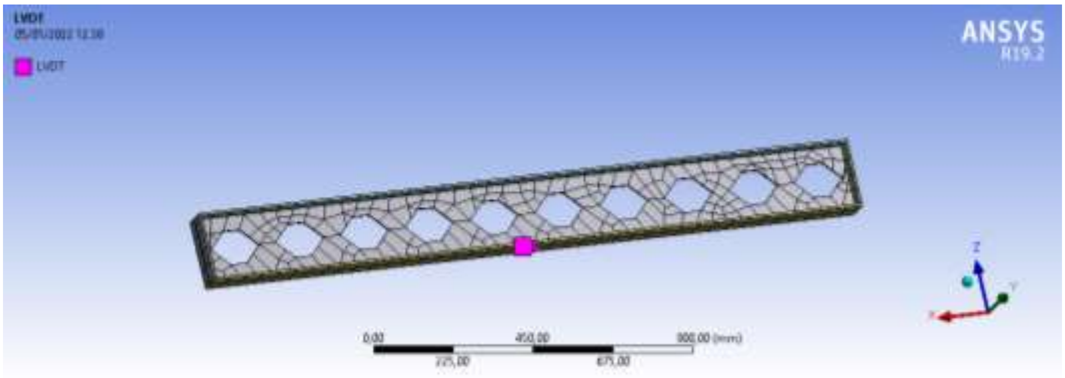


Figure 3. Deflection measurement point using software

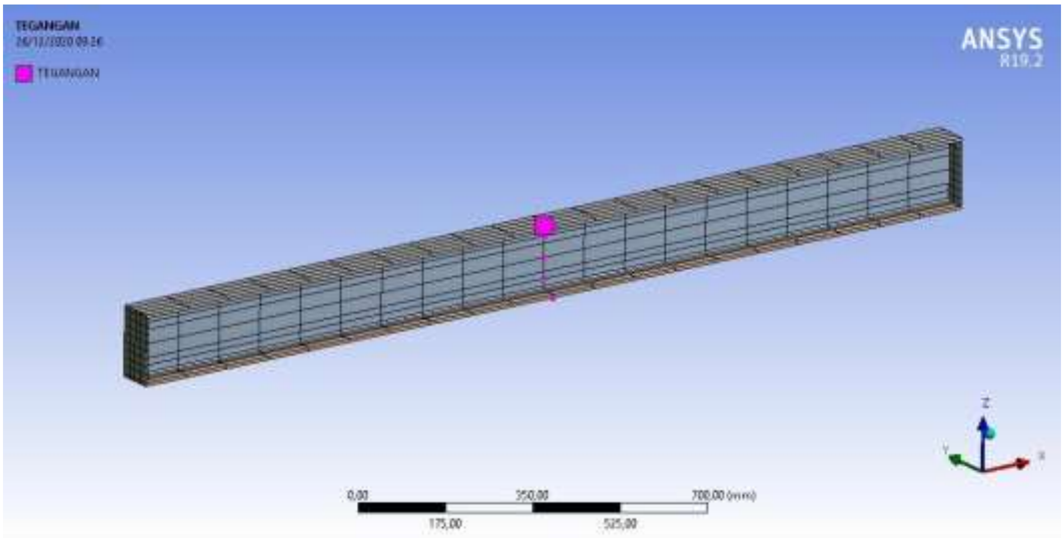


Figure 4. Flexural stress measurement point with software

3. RESULT AND DISCUSSION

Calculation Results Based on Manual Analysis

Dependent on the ASCE journal page 3327 in calculating the flexural capacity of castellated beams an equation is utilized. The cross-sectional inertia

(Ix), plastic modulus (Zx) and flexural capacity (Mn) are separately each test object.

Table 2. Recapitulation of the calculation of the of each model

No.	Model	Number of stiffener	Volume (x 10^6 mm^3)	Mass (kg)	Cross-sectional Inertia,Ix (x 10^6 mm^4)		Plastic Modulus, Zx (x 10^4 mm^4)		flexural capacity (Nominal Moment, x 10^6 N.mm)
					Without Hole	With Hole	Without Hole	With Hole	
1	TP	-	3,747	29,227	12,463	12,198	14,457	13,207	31,697
2	PP200	18	4,450	34,711	50,000	49,735	75,000	73,750	45,000
3	PT200	18	4,420	34,478	29,623	29,358	42,134	40,884	34,521
4	PS200	18	4,366	34,058	39,275	39,010	57,702	56,452	39,485
5	PP400	10	4,138	32,274	50,000	49,735	75,000	73,750	45,000
6	PT400	10	4,121	32,144	29,623	29,358	42,134	40,884	34,521
7	PS400	10	4,091	31,911	39,275	39,010	57,702	56,452	39,485

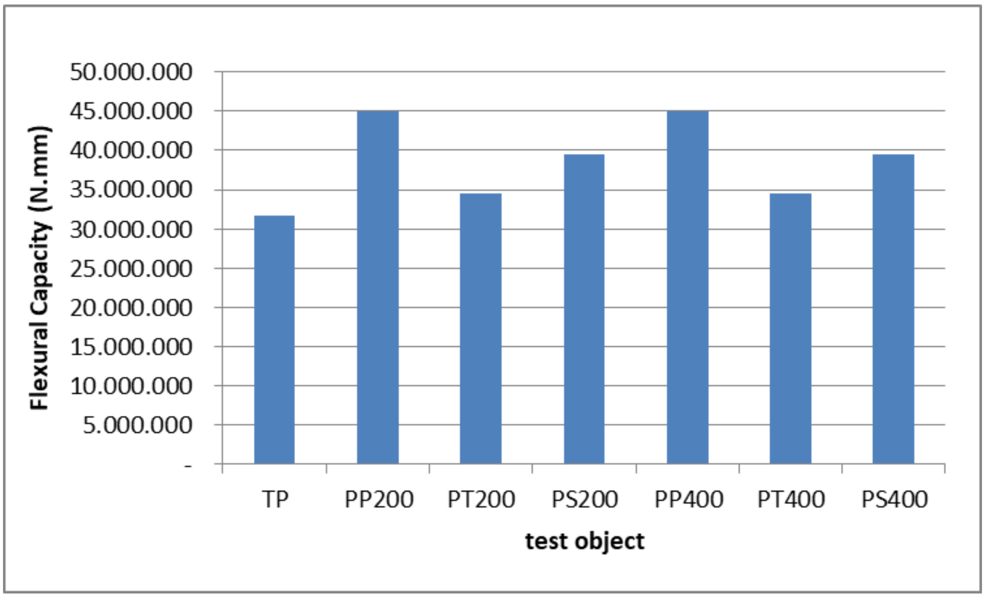
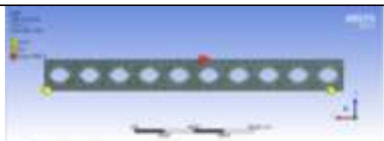


Figure 5. The relationship between flexural capacity (Mn) of hexagonal openings with stiffeners based on Manual Calculations

Numerical Validation Test and Results of Program Software

<table>
<tr><td colspan="2">Model TP</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Model PP200</td><td>Model PP40</td></tr>
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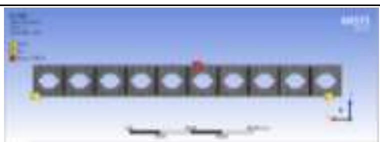
<tr><td>Model PT200</td><td>Model PT400</td></tr>
<tr><td></td><td></td></tr>
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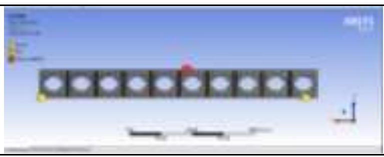
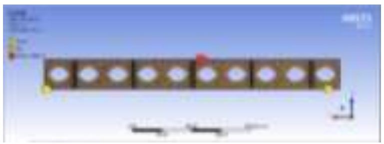
<tr><td></td><td></td></tr>
</table>

Figure 6. Numerical testing model with software

Figure 6 shows the modeling conditions of the test object with only assistance software. The definition of bearings and loads is applied to predetermined nodes. The laying nodes have 3 nodes each, while the load nodes have a total of 6 nodes. This number of nodes is made so that the solution of the force is not concentrated at one point, so that the force can be evenly distributed on the beam flange. Giving the number of load steps when modeling with software is 20 stages of loading, so that later a curve or graph that is not so rough will be obtained. The deformation pattern of each test object can be seen in Figure 7 below.

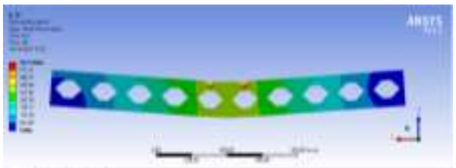
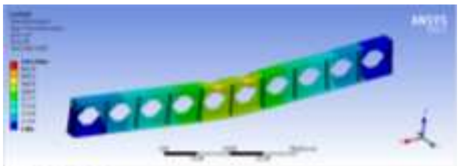
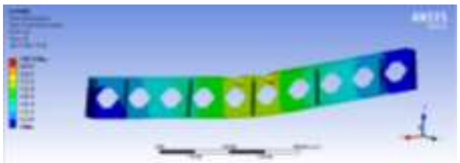
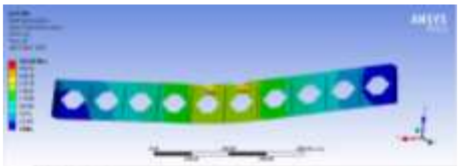
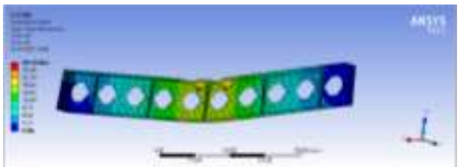
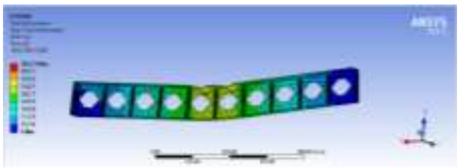
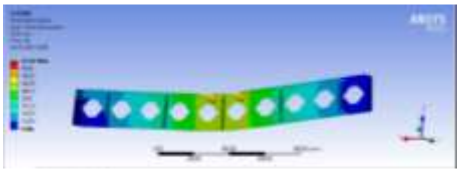
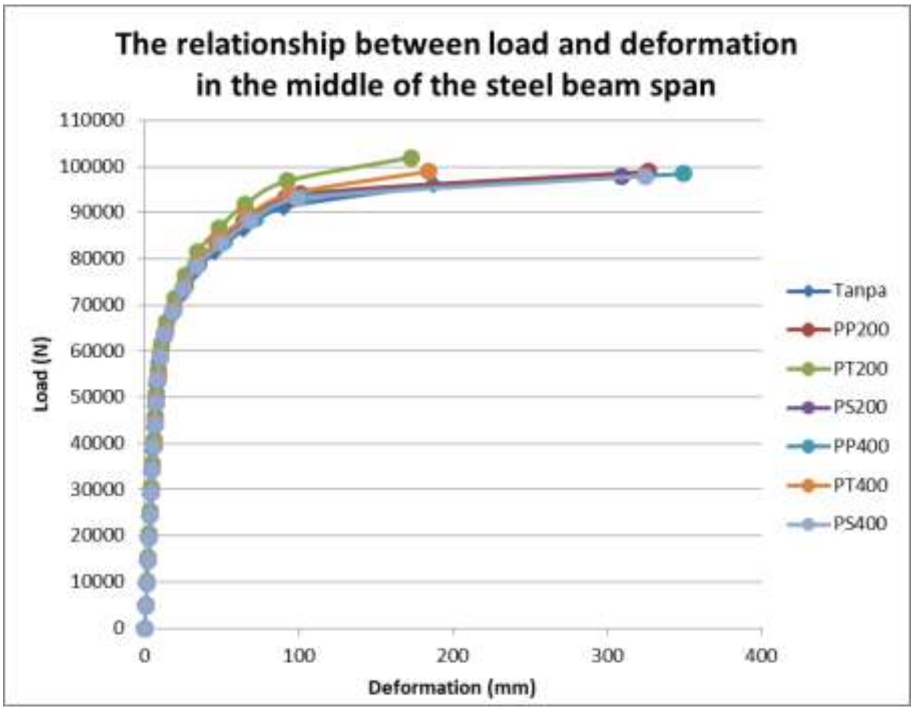
Model TP	
	
Model PP200	Model PP40
	
Model PT200	Model PT400
	
Model PS200	Model PS400
	

Figure 7. Pattern of Deformation on Test Objects



Graph 1. The relationship between load and deformation in the middle of the steel beam span based on the results of numerical analysis with the help of software

From graph 1 it can be seen that castellated beams with stiffener variations will increase the flexural capacity. If viewed from the flexural capacity produced, it can be seen that castellated beams with various stiffeners will produce a higher flexural capacity value than castellated beams without stiffeners. And based on the model that is able to carry the biggest load, the PT200 model is followed by the PT400, PP200, PP400, PS200, PS400, and the last one is the TP.

Table 3. Comparison of load at yielding (Py) between manual analysis and numerical analysis results with the help of software

No.	Model	Number of stiffener	Volume (mm^3)	Mass (kg)	Load at yielding, Py (N)		Manual and Numeric Difference (%)
					Analysis Manual Py= 2*(Mn/a)	Numeric test with Software	
1	TP	-	3747071	29,23	70437	72000	-2,22%
2	PP200	18	4450151	34,71	100000	74250	25,75%
3	PT200	18	4420226	34,48	76714	76500	0,28%
4	PS200	18	4366451	34,06	87744	73500	16,23%
5	PP400	10	4137671	32,27	100000	73875	26,13%
6	PT400	10	4121046	32,14	76714	74250	3,21%
7	PS400	10	4091171	31,91	87744	73500	16,23%

Table 5 shows the correlation of the load values that cause the steel beam to yield (elastic limit) from the aftereffects of manual investigation computations and numerical testing with the assistance of programming. Based on table 5, the greatest contrast between the aftereffects of the yielding load (Py) between the consequences of manual investigation estimations and numerical testing with the assistance of programming isn't over 26%.

Failure Pattern

The following is the lateral buckling that occurs in the model due to the applied load.

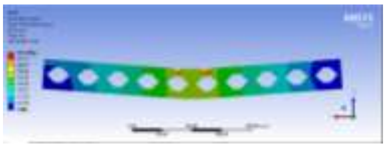
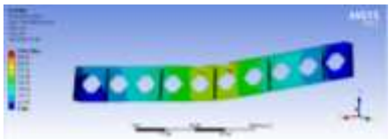
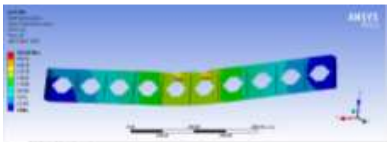
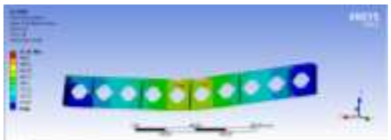
<table>
<tr><td colspan="2">Model TP</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Model PP200</td><td>Model PP40</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Model PT200</td><td>Model PT400</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Model PS200</td><td>Model PS400</td></tr>
<tr><td></td><td></td></tr>
</table>

Figure 8. Lateral buckling

The following is a web buckling that occurs in the model due to a given load.

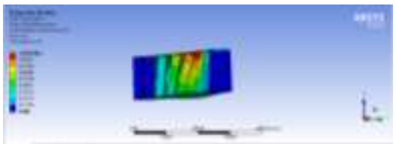
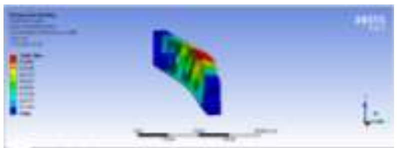
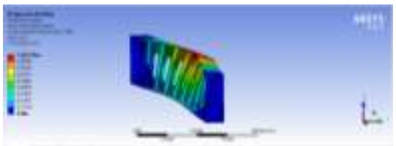
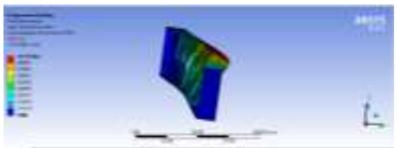
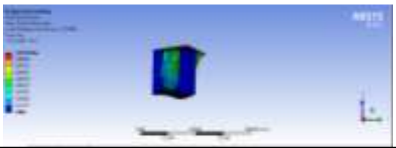
Model TP	
	
Model PP200	Model PP40
	
Model PT200	Model PT400
	
Model PS200	Model PS400
	

Figure 9. Web buckling

Cross-Sectional Flexural Stress in the Middle of the Span

The measurement points for each test specimen model are as follows:

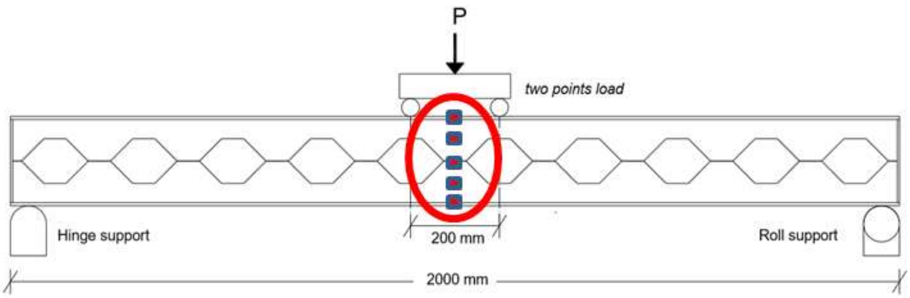
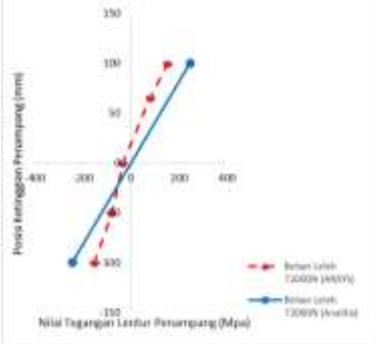
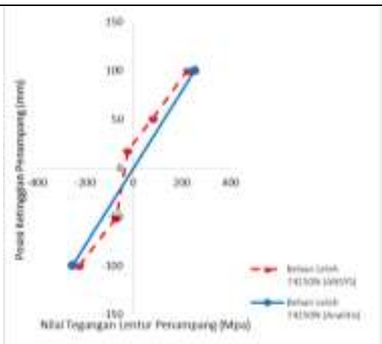
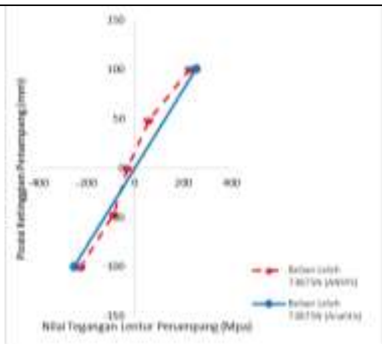
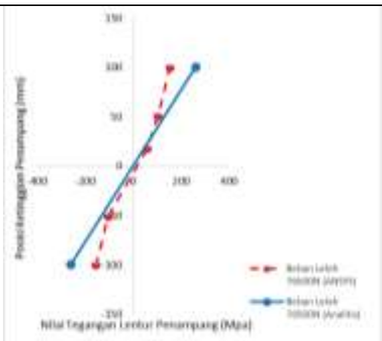
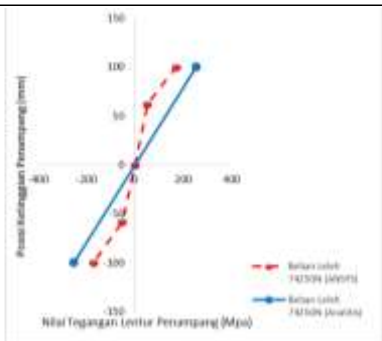


Figure 10. Measurement points for each model

Model TP	
	
Model PP200	Model PP40
	
Model PT200	Model PT400
	
Model PS200	Model PS400

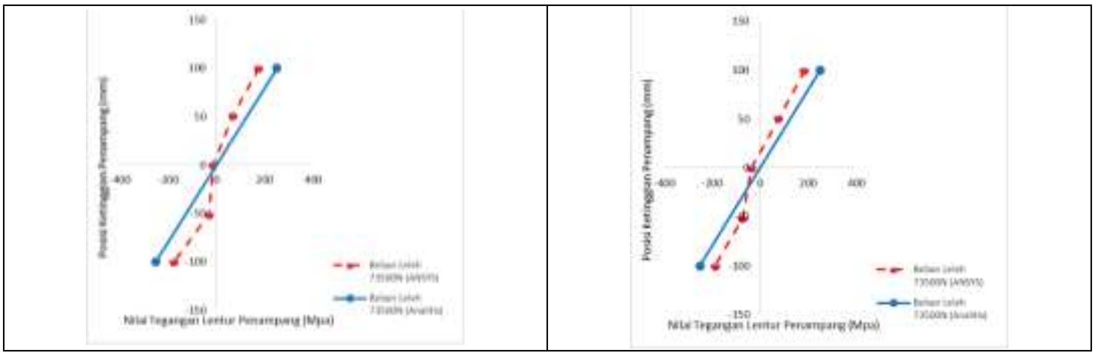


Figure 11. Comparison of cross-sectional flexural stress at mid-span based on results software and manual methods on yield load

4. CONCLUSION

The conclusions that can be drawn from this study are as follows.

1. Based on the results of numerical analysis using software, the use of stiffeners on castellated steel beams with hexagonal opening affects the flexural capacity, where the capacity of all models using stiffeners is greater than that of castellated steel beams without stiffeners. Reinforcement is the largest that can withstand the load with an increase of 6.25% against the castellated steel beam without stiffeners, followed by plate stiffeners and finally elbow stiffeners.
2. Based on numerical analysis with the help of software, the comparison of the flexural capacity of castellated steel beam hexagonal opening with variations in the location of the stiffeners was obtained at a distance of 200 mm. The flexural capacity was greater than that of stiffeners with a distance of 400 mm with an increase of 3.03%.
3. Based on numerical analysis with the help of software, there are two types of failure patterns that occur in each model in this study, namely buckling on the wings (lateral buckling) and buckling on the body (web buckling). This shows the occurrence of flexural failure that occurs due to buckling in each of the steel beam models which is expected in this study.

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