Steel Castella as Steel Beams Construction for Optimization

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Abstract. Beam castella (castellated beam) is formed by beams of profile H-beam, I-beam, or wide flange beam used for construction of long spans greater than 8 meters by raising the "web" of her. The web part is cut with a castella pattern and then rejoined with the way las. The result of the merged profile pieces will be holes of 3 shapes: hexagon (honeycomb), rhombi, and circles (circular). These profiles are perforated to minimize the weight of their own profiles. Castellated beam profiles can be used on the roof or in the walls for beams at the eastern limit of the block length. The angle (Ø), high (h) and width (e) profile-pieces of steel beams on elastic behavior of castellated beam was conducted to determine the influence by this research. Castellated beam horizontal zig-zag profile applies the model for this study and test objects with WF 200.100.5.5.8. The cutting profile is different for each test object WF intact then formed steel castella with angle, height and width. Objects test to cutting corners the profile treatment namely Ø1 = 0˚(whole), Ø2 = 45 ,˚ Ø3= 50 ,˚ Ø4 = 60 ,˚Ø5 = 65 ,˚ Ø6= 70˚and Ø7=75 .˚ cutting treatment for The test objects high profile i.e., h1 = 0 mm (whole), h2 = 26 mm wide, h3=50 mm, h4=76mm, h5=102, 5 mm, and h6 = 150 mm. width of the treatment to test objects are pieces of profile (e) i.e. estd = 51, 25 mm, e0 = 0 (intact), e1 = 177 mm, e2 = 150 mm, e3 = 125 mm, e4= 50 mm, and e5 = 75 mm. Provides a concentrated load around the mid-span steel beam, then in the test region the behavior of the steel beam when receiving a concentrated load is studied using a hydraulic jack, it is a castellated steel beam testing system carried out in the laboratory. The stress that occurs before it starts to melt is the stress of the quality steel. then a tensile test will be carried out, namely by taking a sample of profile steel to test the quality of the steel in order to determine the quality of the steel (fy). The results showed that at the melting condition and collapsed, cutting the corner profile (Ø) is not too influential to the strength of flexure, there was a rise in the value of this banding if large corner profile is getting bigger but accession was not significant. A trend of buckling that occurs is getting smaller cause, When are reviewed from the angle of the cutting profile buckling condition (Ø) affects to the buckling, the greater the angle of the cutting profile (Ø) showed. The results showed on the conditions of yield and collapsing, cutting height profile (h) affect the strength of the flexure, the greater the strength of the flexure then the more high profile. The greater buckling When are reviewed from a high profile cutting of buckling condition (h) affect to the buckling, the more high profile cutting (h) there is a tendency that happens.Whereas in terms of the width of the cutting profile (e), affects the value of buckling, the width of the cutting profile (e) then the greater the value of buckling. The range between the angle 45 60˚or angle must not exceed 60 ˚Based on the results of the study treatment angle profile pieces (Ø) on the most optimal castella steel when are reviewed from the moment, shear strength, buckling and deflection. For high-profile pieces (h) on the most optimal castella steel recommended height pieces (h) may not exceed 50% of the high-profile intact. Is the width of the profile pieces (e) on steel the most optimal castella is e should not be in excess of 2 1⁄2 times the height profile intact.

Keywords: Castellated beam, cutting angle profile, width of profile pieces.

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1 Introduction

Web Expanded Beams and Girders open are beams that have a perforated web plate element splitting the middle part of the web plate, then the lower part of the cleavage is reversed and put back together between the parts. top and bottom by sliding a little and then welded (HE Horton, Chicago, 1910), now better known as the Castella method. The shape of the castella steel profile body depends on the cleavage technique of the profile body plate which is tailored to its needs. Steel can be used for the construction of columns, beams and roof trusses. With the increasing use of steel in the community as building construction, there are also many choices of types and forms offered by the market. One of them is a castella beam (castellated beam).

Castella beam (Castellated Beam) is a beam formed from the profile of H-beam, I-beam or wide flange beam which is used for long span construction of more than 8 meters by modifying the 'web' section to be higher than the original profile. The web is cut with a castella pattern and then reconnected by welding. The web parts cut with the Castella pattern are joined by welding. The results of the profile pieces that are put together will form a hole with 3 shapes, namely a hexagon (honey comb), a rhombus, and a circle (circular). The profile is perforated to reduce the profile's own weight. Castella beam (castellated beam) is an I WF profile whose web parts are cut in a certain way and model, thus forming two profile sections which are then joined to obtain a certain profile height. So that the cross section of the beam obtained becomes higher and stronger. The two cutting profiles are joined by welding, so as to form 1.5 D from the I WF profile which one is formed.

There are several failures in the manufacture of castellated beams, including: (1) Lateral – Torsional – Buckling, Nethercot and Kerdal stated that the web opening had a negligible effect on lateral torsional buckling of the beams they had tested [1]; (2) Rupture of Welded Joint, Weld at a distance between one hole to another (e) can rupture (break) when the horizontal shear stress exceeds the yield strength of the weld (welded joint) [2]**.** The horizontal length of the hole (horizontal length of the opening) is directly proportional to the length of the weld, and when the horizontal length is reduced to increase the secondary moment (Vierendeel truss). Then the weld along the profile body becomes more prone to failure (failure). The Vierendeed mechanism usually occurs in beams that have a fairly long horizontal hole spacing (therefore having a longer weld length) [3].

With the price of building materials, especially steel, which is relatively increasing in price, using castellated beams in the construction process will result in significant cost savings in terms of the use of steel materials, while also being more labor-intensive. The shape of the castella steel profile body depends on the cleavage technique of the profile body plate which is tailored to its needs. There are several kinds of shapes that are often used in the field, one of which is a horizontal zig-zag split [4].

2 Research Methods

The research was carried out using laboratory tests, by making a horizontal zigzag beam castella model with WF steel profile specimens. The author plans to investigate the optimization of the flexural stress strength of the castella beam when different angles (Ø), height (h) and width (e) of profile cutting are applied to each specimen. The specimens for the treatment of profile cutting angles are 45˚, 50˚, 55˚, 60˚, 65˚ and 70˚. For the treatment specimens, the profile cutting height is h1=0mm (whole), h2=26mm, h3=50mm, h4=76mm, h5=102.5mm, and h6=150mm. For treatment specimens, the width of the profile cut is e1=51.25mm, e2=0 (whole), e3=177mm, e4=150mm, e5=125mm, e6=75mm and e7=50mm. The stages of making the test object are as shown in the image below.

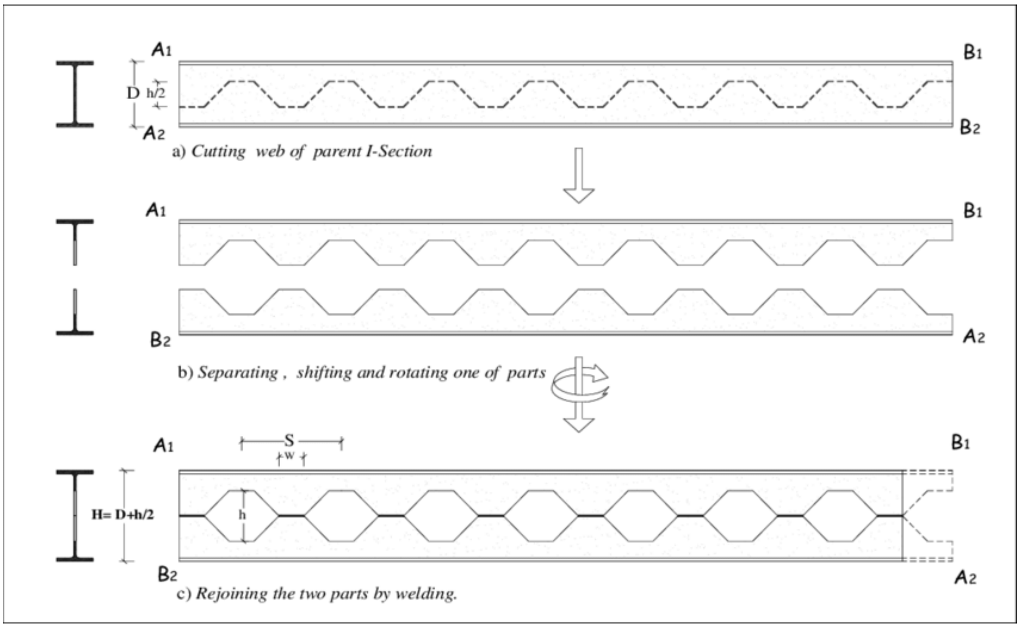

Figure 1. Making Castellated Beam Hexagon Shape

Testing of castellated steel beams carried out in the laboratory by giving a concentrated load around the middle of the steel beam span, then in the test region the behavior of the steel beams when receiving the concentrated load is studied. The details of the exam picture are as below.

3 Research Results And Discussion

3.1 Presentation of Tensile Tests

From the results of tensile testing of steel WF 200.100,5,5.8 on the body, upper and lower wings, the quality of the steel can be known. Steel quality is expressed in the form of a graph between stress and strain.quality of the steel is indicated by the first yield stress of the test object, the first yield stress can be seen in the graphic image as follows:

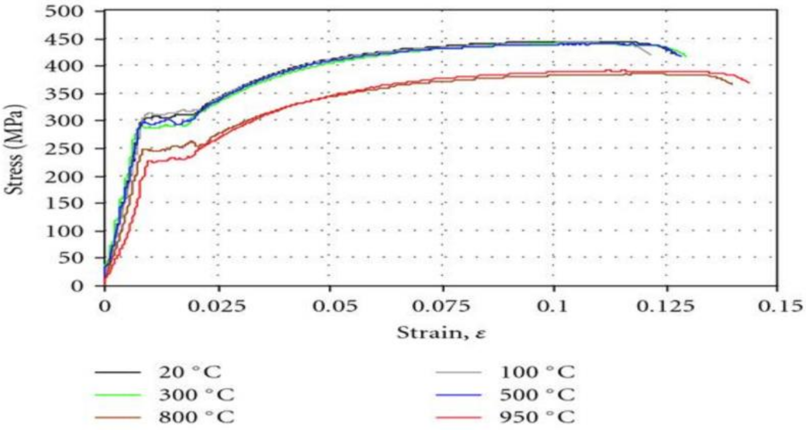

Figure 2. Graph of the Stress and Strain Relationship

From Figure 2 the results of the tensile test above obtained the average quality of steel as detailed in the table 1 .

Table 1. Characteristics of steel

No	Description	a Melt	a Collapse
1	body	372.73	527.27
2	lower wing	384.26	572.30
3	top wing	356.40	566.32
	average Fy body melting	372.73	
	average Fy melting wings	370.33	
	average Fy collapsing		527.27
	average Fy collapsed wings		569.31

3.2 Effect of Angle on Flexural Strength of Castella Beams

In this study, there were seven test specimens of castella steel beams with profile cutting angle (Ø) used, namely 1= 0˚ (intact), 2= 45˚, Ø3= 50˚, 4= 60˚, 5= 65˚, 6= 70˚, 7= 75˚ and each specimen has a different span. After testing the flexural strength with a concentrated load on a steel cross section that is not perforated, the maximum load of the beam is also different.

Theoretically, the larger the profile cutting angle (Ø), the smaller the hole in the cross section of the steel body, so that the castella steel beam is stiffer [5]. Referring to this, the moment of inertia is also getting bigger, because the value of the moment of inertia is directly proportional to the level of stiffness. The height of the test object also affects the magnitude of the moment of inertia, where the higher the test object, the greater the moment of inertia. This can be proven from the specimen 1 (intact) which has a smaller moment of inertia compared to other specimens which are already in the form of castella steel beams. So the larger the profile cutting angle (Ø), the greater the moment of inertia and the stiffer the beam, so the ability to withstand the moment is also greater so that the beam is stronger [6].

The graph shows that all test objects have experimental yield moments greater than theoretical yield moments. At the melting moment, the experiment showed that there was a greater tendency from test object 1 (intact) to test object 4 (Ø4= 60˚), then decreased in test object 5 (Ø5= 65˚) and test object 7 (Ø7= 75˚) . While the test object 6 (Ø6 = 70˚) experienced a spike because it has a long span and a large load. This shows that from the point of view of the yield moment, the optimal angle lies in the test object 4 (Ø4= 60˚) or it should not exceed the angle of 60˚. The theoretical moment calculation for each castella steel beam test object has almost the same value (the difference in value is not too large). The theoretical moment is closely related to the height of the steel profile, the higher the steel profile, the greater the value of the theoretical moment [7]. Referring to this, in this study specimen 1 (Ø1 = intact) has the lowest profile height compared to other test objects, so that test object 1 has the smallest theoretical moment value. Then for specimens 2 (Ø2= 45˚) to test objects 7 (Ø7= 75˚) which have been converted into castella steel beam profiles with almost the same height, the theoretical moment values are almost the same. So based on the analysis of the yield and collapse moments above, for the safety of the flexural moment strength of the castel steel beam, the optimal profile cutting angle (Ø) ranges from an angle of 45˚-60˚ or should not exceed an angle of 60˚.

3.3 Effect of Profile Cutting Height (h) on Flexural Strength of Castella Beams

Theoretically, the higher the cutting profile (h), the greater the moment of inertia, so that the ability to withstand the moment of the castella steel beam is greater which in turn will make the beam stronger and stiffer. Then after narrating the research data on the yielding condition of the test object, it is seen that the higher the profile cutting (h), the test object, the greater the moment of inertia that is produced. -6. Where the moment of inertia will be directly proportional In this case, when viewed theoretically, the higher the profile cutting (h), the greater the moment of inertia, so that the ability to withstand the moment of the castella steel beam is greater which in turn will make the beam stronger and stiffer. Then after narrating the research data on the collapsing condition of the test object, it is seen that the higher the profile cut (h), the test object, the greater the moment of inertia that is produced. -6. Where the moment of inertia will be directly proportional to the magnitude of the experimental moment and also the level of strength and stiffness of the steel beam. So the higher the cutting profile (h), the greater the moment will be. However, what distinguishes the yield and collapse conditions is the presence of buckling symptoms. So with the profile cutting height (h), the higher the cut, the more buckling symptoms occur. However, under certain conditions, optimal buckling must be taken so that no large buckling occurs, so that castella steel beams still have the expected strength and stiffness [9].

Judging from the residual strength in the collapse condition produced between the experimental moment and the theoretical moment, it is above 20%. Then to generalize the flexural strength shown by the moment of the entire test object, the ratio of the moment to the span is calculated using the formula for the moment/span (M/L), because the magnitude of the moment is also affected by the span of the specimen. So it can be concluded that based on some of the analysis above, that for the safety of its flexural strength, it is recommended that the profile cut height (h) of the castella steel beam does not exceed 50% of the profile cut height (h) before making the castella [10].

3.4 Effect of Profile Cut Width (e) on Flexural Strength of Castella Beams.

The results of the calculation of the bending moment show that the experimental moment on the test object 6 (e=5.125cm) has the greatest moment value compared to the other test objects. The experimental collapse moment value of test object 1 is 178.09 KNm. For the to the magnitude of the experimental moment and also the level of strength and stiffness of the steel beam. So the higher the profile cutting (h), the greater the moment will be [8].

Based on the results of the calculation of the theoretical moment, each castella beam test object has almost the same value (the value is not too big). This is because the test objects have the same dimensions. So the large change in the width of the profile cut (e) is not very influential, in this case the most influential on the strength of the castella beam is the height of the profile. Based on table 4.12, the flexural strength of the beam (residual strength) produced between the experimental yielding moment and the experimental moment of collapse is also calculated. The average value of the flexural strength of the beam is 53.75%. When seen in Tables 4.10 and 4.12 it is proven that the strength of the castel steel withstanding the moment is greater than that of the intact steel, this condition is shown in the table of the percentage of the moment column.

Based on several analyzes above, that for the safety of its flexural strength, the optimal indication of the width of the steel profile section (e) is recommended not to exceed 2 h cm (e=12.5cm).

3.5 Effect of Profile Cutting Angle (Ø) on Shear Strength

The results of the calculation of the shear strength in the hollow section of the castella steel beam test object are as follows for an indication of the safety of the shear strength on the cross section of the castella steel beam, the profile cutting angle (Ø) is recommended to range from an angle of 45˚ - 60˚ or should not exceed an angle of 60.

3.6 Effect of Profile Cutting Height (h) on Shear Strength.

To prove the existence of shear damage in this study, the shear strength will be carried out to prove the truth. In the hollow section, there is a tendency for the difference to decrease in Vu < Vn consistently, where the value of the difference in decrease in Vu < Vn is inversely proportional to the cutting height of the steel profile (h). This is in line with expectations so that the entire test object is subject to flexural damage, not shear damage or fracture. However, at the condition of the 6th test object, it began to show a decrease in the shear strength. Meanwhile, the shear strength in the non-perforated part has a relatively the same tendency for damage that occurs in the entire test object. So that the average thing that occurs in this non-perforated steel cross section is flexural damage.

So for an indication of the safety of shear strength in the cross section of the castella beam, the recommended profile cutting height is h<102.5mm or it can be said that the cutting height (h) should not be more than 50% of the profile height before making the castella beam.

3.7 Effect of Profile Cut Width (e)

Strength versus Shear Strength. The shear strength in the hollow section and in the non-perforated section shows that in the overall caste steel beam test object the magnitude of the transverse force from the loading is smaller than the nominal shear strength, or in other words the Vu Vn equation as a shear strength plan has been fulfilled. This means that the test object can be said to have flexural damage because for the shear planning all the test objects have been fulfilled.

Based on Table 6 and Table 7 also shows that the shear strength in the hollow and non-perforated sections has a different tendency for each VuVn test object to be almost the same, because when viewed from the calculation of the profile cutting width formula (e) it does not affect the shear value. However, when viewed logically, the larger the cutting width of the profile, the smaller the hole or in other words, the larger the complete cross section, so the shear value is also greater. This shows that during the flexural test, the load applied to the steel cross section of the castellated steel beam test object is channeled to the bottom or the transverse force of the loading is evenly distributed throughout the steel cross section, so that shear collapse does not occur but flexural damage occurs.

3.8 Effect of Profile Cutting Angle (Ø) on Deflection

Theoretically, the larger the profile cutting angle (Ø), the smaller the hole in the cross section of the steel body and the greater the number of holes, so that the castella steel beam becomes stiffer because the area of the intact cross section on the body is getting bigger. . Referring to this, the moment of inertia is also getting bigger, because the value of the moment of inertia is directly proportional to the level of stiffness. So the greater the angle of profile cutting (Ø), the greater the moment of inertia and the stiffer the beam, so that the resulting deflection is smaller and the ability to withstand the moment is greater so that the beam is stronger. Besides, the amount of deflection produced during the test is also influenced by the occurrence of buckling.

In Table 8, the experimental deflection test results at P before melting have not shown a tendency for the resulting deflection to decrease. This can be caused by several factors including the occurrence of buckling on the test object during testing because the greater the buckling that occurs, the greater the deflection produced, then the less effective process of welding joints on the steel body which can affect the strength of the test object, and less accurate readings. dial gauge during a pressure test in the laboratory. The smallest deflection occurs in test object 4

(Ø4= 60˚), because the span is not too long and the cross-sectional area of the whole body is also large, so the resulting deflection is small. Then for test object 2 (Ø2= 45˚) until test object 3 (Ø3= 50˚) or before test object 4 the deflection is still relatively low, while for test object 5 (Ø5= 65˚) until test object 7 (Ø7= 75) or after the test object 4 the deflection tends to be greater. This shows that in terms of deflection at the load before yielding, the optimal angle is located on the test object 4 (Ø4= 60˚) or should not exceed the angle of 60˚.

In Table 9. the results of the calculation of the theoretical deflection at P before yielding have shown a tendency to reduce the resulting deflection. In specimen 3 (Ø3= 50˚) to test object 7 (Ø7= 75˚) it can be seen that the deflection that occurs is getting smaller. In specimen 6 (Ø6= 70˚) the amount of deflection experienced a spike because it has a long span. Similarly, the test object 3 also has the largest theoretical deflection because it has the longest span compared to other test objects.

So based on the experimental deflection analysis and theoretical deflection at the load before yielding, the maximum load and the same load above, for the safety of the flexural strength of the castella steel beam in terms of deflection, the optimal profile cutting angle (Ø) ranges from an angle of 45˚ - 60˚ or should not exceed the angle of 60˚.

4 Conclusions And Recommendations

From the results and data analysis, it can be concluded as follows:

1) Based on the data from the research, it can be concluded that in terms of indications of yield moment, collapse moment, deflection and buckling in castella steel. The profile cut angle (Ø) in the most optimal castella hole ranges from an angle of 45˚ - 60˚ or should not exceed an angle of 60˚.
2) Based on the data from the research, it can be concluded that in terms of indications of yield moment, collapse moment, deflection and buckling of castella steel. The height of the profile cut (h) in the most optimal castella hole should not exceed 50% (dg) of the profile height before making the castella beam (0.5 dg).
3) Based on the data from the research, it can be concluded that in terms of indications of yielding moment, collapse moment, deflection and buckling of castella steel. the profile cut height (h) in the most optimal castella hole is not allowed to exceed Ds or not to be more than 150mm.

Based on the conclusions above, it can be suggested that:

1) Based on the data from the research, when viewed from the height of the profile cutting with h 50% of the profile height before making the castel beam the strength of the castel steel continues to increase, it is advisable for further research to test the material. with a height (h) of more than 50% of the profile height before the castella beam was made.
2) Based on the research data, the damage that occurs to the castella steel is the collapse in the buckling condition so that a stiffener is needed on the castella steel, so further research is needed on the optimization of the stiffener for the castella steel.
3) Based on the research data that the lower flange of the castella steel beam does not work optimally, so that in future research it is necessary to carry out further studies on the distribution of the load on each part of the castel steel beam so that all parts of the upper flange, body and lower flange can be used. work optimally.
4) In the next research, the shape of the hollow cross section should be made different from this research, for example a rectangular or circular shape.

References

[1] Nethercot.. D.A., and Kerdal. (1982). O. Laterai-torsional buckling of castellated beams Struct. *Engr~ 60B:* 3, 53-61

[2] Hosain.. M.U., and Spiers. W.G. (1971). Experiments on castellated steel beams. *J. American Welding Society, Welding Research Supplement,* 52(8), 329S-342S

[3] Dougherty, B.K. (1993). Castellated beams: Astate of the art report. Journal of the South African lnstitution of Optimalisasi Baja Kastel. *Civil Engineers,* 35(2), pp 12-20

[4] Megharief, Jihad Dokali. (1997). *Behavior of Composite Castellated Beam*. Canada : McGILL UNIVERSITY Montreal

[5] Anonim. (2011). Cara Membuat Balok Castella *(Castella Beam)*. Retrived from *http://mikhamarthen.wordpress.com/*

[6] Davis, H.E., Troxel. G.E., Wiskocil, C.T.. (1955). *The Testing and Inspection of Engineering Materials*. New York, USA : *McGraw-Hill Book Company*

[7] Griinbauer, Johann. (2001). Engineering Theories of Software Intensive Systems. Retrived from *http://www.springerlink.com/openurl.asp?genre=book&isbn=978-1-4020- 3530-2*

[8] Knowles, P.R. (1991). Castellated beams. *Proc. Institution of Civil Engineers,* Part l, Vol. 90, pp 521-536

[9] L. Amayreh and M. P. Saka. (2005). *Failure load prediction of castellated beamsUsing artificial neural networks.* Bahrain : Department of Civil Engineering, University of Bahrain.

[10] Sudarmadi. (2008). Evaluasi Kekuatan dan Lendutan Struktur Balok Baja Pada Gedung Dengan Uji Beban Lapangan. Retrieved from *http:// www.scribd.com/doc/84649774/2308241249*