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FLEXURAL CAPACITY AND DUCTILITY OF CASTELLA BEAM DUE TO CYCLIC LOAD

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ABSTRACT

The purpose of this study was to determine the flexure capacity and ductility of the castella beam due to cyclic load. This research was carried out through testing castella beams in the form of a portal with cyclic loading. Solid beams steel used is profiles IWF 200 100 5.5 8 fabricated became castella beam. Test beam consists of a solid beam (NB) as a comparison and castella beams (CB). The test results show increase 1.6 H of the high of CB beam, will affect to increase of the section modulus (S_x) and moment of inertia (I_x) respectively by 76.41% and 173.43% compared to NB beam. This increase is affect the increased flexure capacity castela beam of 82.5% compared to the beam NB Besides that, increases in the beam high will increase the slenderness cross section (H/B) and lower radius of inertia (ry) on the y-axis. This causes the transverse displacement of the CB beam is greater than NB beam. This condition causes the beam CB is less deformed in the vertical direction. This is shown by the ductility of the CB beam decreased by 46, 92 % compared to NB beams. Resistance is proportional to ductility, if the increased load will be followed by an increase in ductility. This relationship is shown by both of the beam test.

Keywords: castella, flexure, ductility, cyclic load.

1. INTRODUCTION

The need for shelter is increasingly rising day by day in Indonesia in line with population growth. Besides, the land for the construction of buildings or other buildings is more difficult to obtain and the price is higher, especially in urban areas. To save the land, then the solution is to build a multi-storey building for office buildings, dwellings or other buildings. Most of the building structure with steel material uses solid steel profiles as advantageous solution in terms of strength and material usage. Experts are trying to structure how to increase the strength of steel elements without an increase in self-weight of steel in order to obtain some new methods that beams with openings entity known as castella beam.

One form of the body opening is hexagon shape. Research on this openings has been done by Wakchaure MR, Sagade AV, Auti V. [2012] and the results showed that the openings with 0.6 of the beam height is the possible maximum openings, or in other words the maximum eligible beam height of the castella beam that can be fabricated. Research on the angle and length of exposure to a high of 0.60 to a high aperture solid beam has been carried out by Parung Herman *et al* [2013] are given monotonic load. Solid steel profiles fabricated into castella beam is IWF 200 100 5.5 8. Research results show the opening angle of 60^0 and aperture length e = 3b = 9 cm gives the best result of the angle and length of openings for openings hexagon. Mara Junus [2016] continue this research by testing Castella beams with the concrete filled between the flange and burdened with cyclic loading. The results showed flexure capacity of the castela beams with concrete filled between the flange increased by 187.34% compared to normal beam. This study aims to determine the flexure capacity and ductility of the castella beam due to cyclic loading.

2. TESTING PROGRAM

2.1 Testing principle

The principle of the test is based on the structure of the framework that burdened earthquake load as in Figure-1. The zero moment on the beams and columns are considered as the hinge (H).

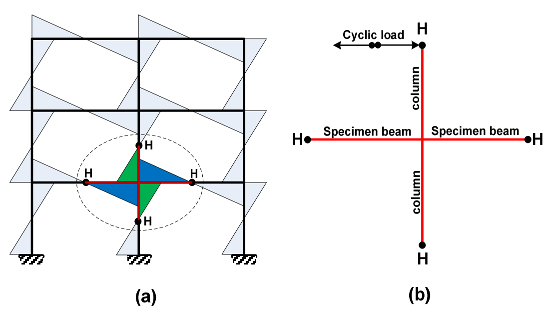

Figure-1. (a) The moment area of a frame due to earthquake loads, (b) Principle of the test beam-column element.

2.2 Test beams

Specimens, a steel beam used is a profile IWF 200 x 100 x 8 x 5.5 with hexagon shaped openings. High aperture 0.6 H, a distance of 9 cm and the aperture opening angle 60^0. The pabrication process of castella beam as in Figure-2.

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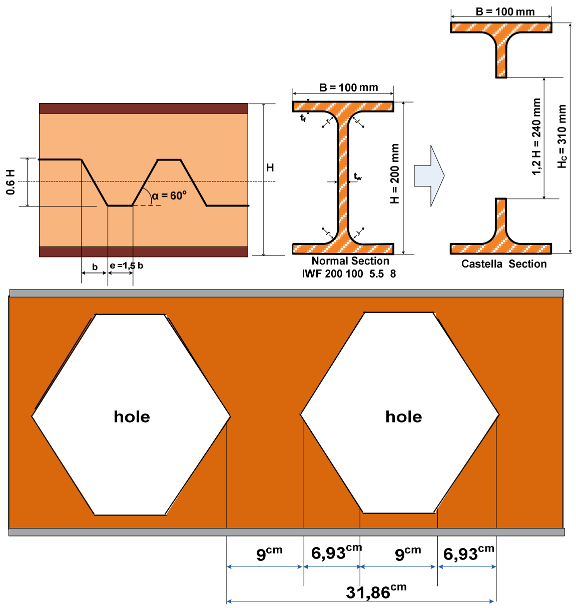


Figure-2. Pabrication process of castellan beam.

Test beam consists of a normal beam (NB) as the comparison and castella beam (CB).

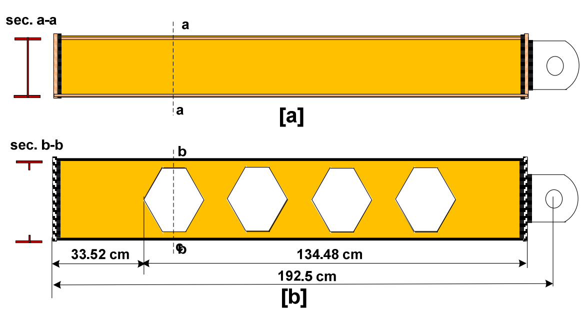
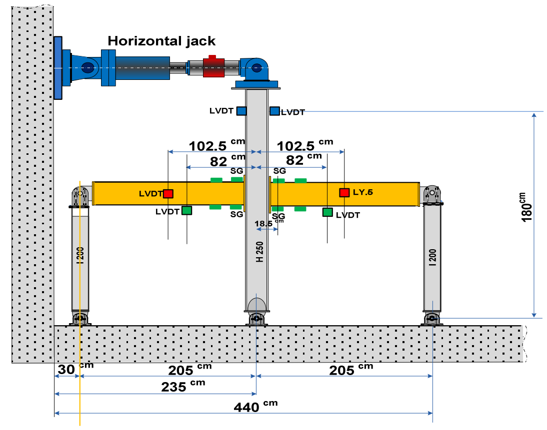


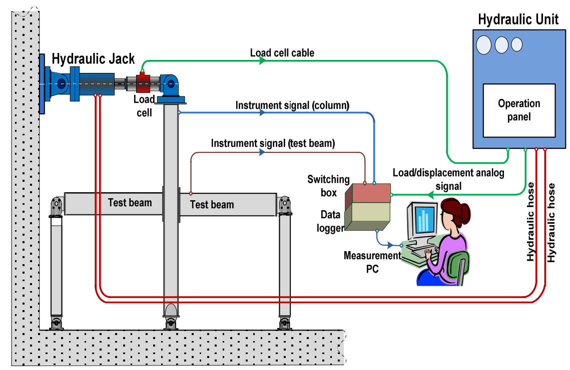
Figure-3. Beam test for the: (a) normal beam [NB], (b) castella beam [CB].

2.3. Testing frame

The testing requires testing framework. Testing framework is designed based on the principle of test as in Figure-1. Equipment and testing instruments required are: crane, strain gauge FLK 2.12, LVDT (Linear Variable Displacement Transducer) with a precision of 0.005 and 0.01, actuator (horizontal jack) with a capacity of 1200 KN, logger data and switching box. Testing framework, instrument placement and installation of the test are presented in Figure-4.



Source: Mara Junus (2016)
(a)



Source: Mara Junus (2016)
(b)

Figure-4. (a) Framework for testing and placement of testing instruments, (b) testing installation.

2.4. Testing implementation

The cyclic loading is given in the form of displacement-controlled at the upper end of the column. Method of loading each cycle based on the "Recommended Testing Procedure for Assessing the Behavior of Structural Elements under Cyclic Loads issued by the European Convention for Constructional steelwork (ECCS)". The testing stopped when loading cycles plans reached $P_{failure} = 0.80\ P_{max}$. (Recommendation by ASTM international, designation: E 2126-02a year 2002). Displacement load-ram speed relationship that has been done as shown in Figure-5.

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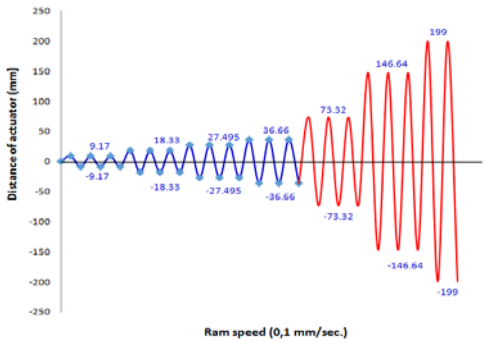

Source: Mara Junus (2016)
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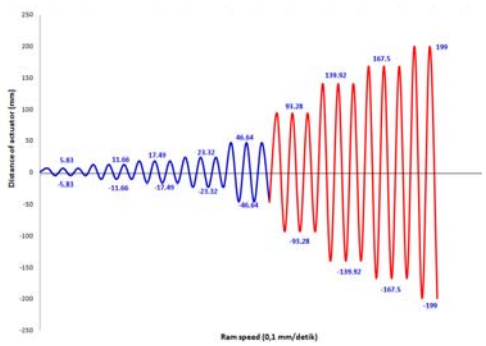

(b)

Figure-5. Displacement-ram speed relationship for the, (a) NB test beam, (b) CB test beam.

Termination of loading of each beam test after the ability of each beam decreases ± 20%, expressed as the limit load termination in accordance ASTM *international, designation*: E 2126-02a year 2002. On termination of loading, the final load for NB and CB respectively of 21.3 KN and 41.23 KN. Documentation pictures of the testing are presented in Figure-6.

Source : Mara Junus (2016)

(a) (b)

Figure-6. Testing documentation for the, (a) NB test beam, (b) CCB test beam.

3. TEST RESULTS AND DISCUSSIONS

3.1 Section properties

Table-1 shows the section modulus and inertia moment data of the NB and CB test beam. Cross section data of the CB test beam calculated on a solid cross-section close to the column as a section that receives the greatest moment.

Table-1. Section properties of the test beam.

Test beam	Sx x10^3(mm^3)	Ix x10^3 (mm^4)	Enhancement Sx against NB (%)	Enhancement Ix against NB (%)
NB	184	18,400		
CB	324,59	50,311,55	76,41	173,43

Based on the data above, section modulus (S_X) and the moment of inertia (I_x) CB beam test increased respectively 76.41% and 173.43% when compared to the NB beam. This is caused by the addition of CB test beam high of 1.6 H. The magnitude of the increase in section modulus (S_x) will affect the increased the bending moment capability of the CB beam.

When compared to normal profile, the CB beam test similar to the IWF 250 125 5 8 with the section modulus is 285,000 mm3 and profiles weight 25.70 kg/m'. When compared to the NB test beam with profile weight is 21.3 kg/m', then there is efficiency in the steel use by 20.66%

3.2 The determination of the yield point and yield load

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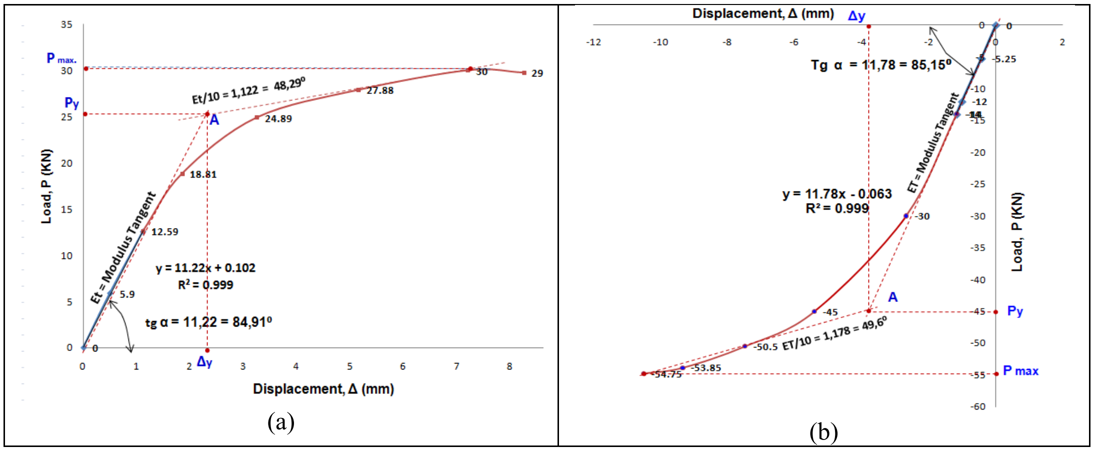

Figure-7. The determining of yield point, yield load and yield displacement for, (a) NB test beam, (b) CB test beam.

Determination of yield point and yield load of the beam NB and CB test beam based on Recommended Testing Procedure for Assessing the Behavior of Structural Elements under Cyclic Loads issued by the European Convention for Constructional steelwork (ECCS). The process of determining the yield point, yield load (P_y) and the yield displacement (Δy) are presented in Figure-7.

NB test beam:

Modulus tangent (ET): $y = 11.22 x + 0.102$

Tg $\alpha = y' = 11.22 = 84.91^o$, $ET/10 = 1.122 = 48.29^o$

CB test beam:

Modulus tangent (ET): $y = 11.78 x - 0.063$

Tg $\alpha = y' = 11.78 = 85.15^o$, $ET/10 = 1.178 = 49.60^o$

The results of the calculation are presented in Table-2.

Table-2. Yield load and yield displacement of the test beam.

Test beam	P_y (KN)	Δy (mm)
NB	25.02	2.12
CB	-46.00	-3.90

3.3 Flexural Capacity

Flexure capability data of the test beam are presented in Table-3.

Table-3. Flexural capacity of the test beam.

Test beam	P_y (KN)	$P_{max.}$ (KN)	e (m)	M_y (KN-m)	$M_{max.}$ (KN-m)	$\epsilon = M_{max}/M_y$
NB	25.02	30.00	1.65	41.283	49.500	1.199
CB	-46.00	-54.75	1.65	-75.900	-90.338	1.190

The table data above shows that the flexure capacity of the CB beam test until the yielding occurrence increased 83.85% compared to the NB beam. Resistance of the NB and CB beam test to reach maximum load after the yield condition respectively 1.199 and 1.190. This data shows the resistance of the both test beam after the yielding are almost same with a very small deviation is 0.75%. From the maximum load that can be achieved by both the beam test shows the CB test beam capacity increased 82.5% compared to the test beam NB.

The conditions above are caused by the increased section modulus (S_x) and the inertia moment (I_x) of the CB test beam respectively by 76.41% and 173.43% compared to beam NB.

3.4. Ductility

a. Vertical displacement

Determination Process of the ultimate displacement vertical test beam are presented in Figure-8.

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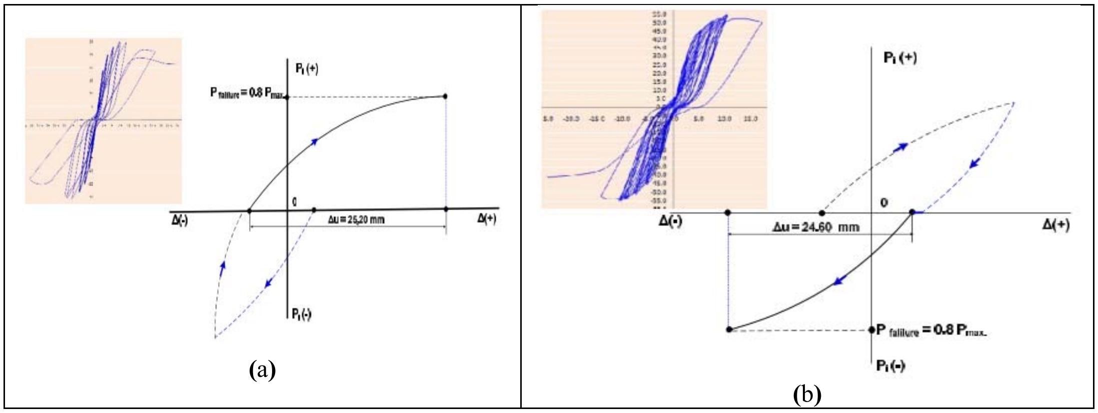
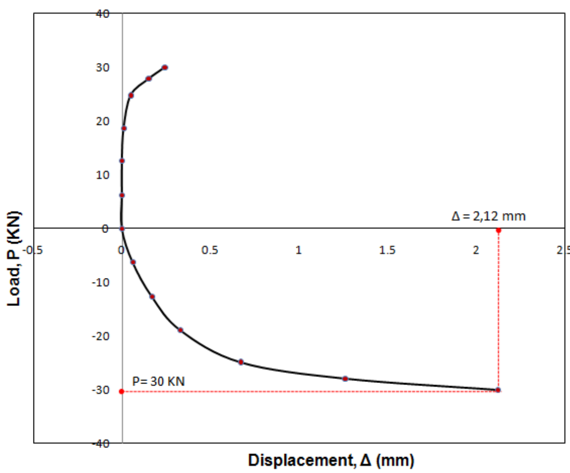


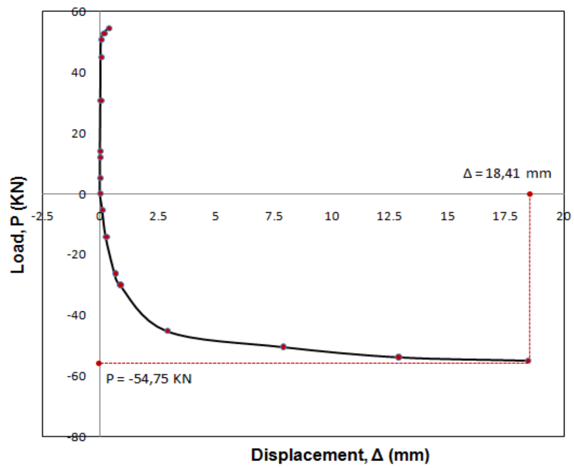
Figure-8. The determining of ultimate displacement for, (a) NB test beam, (b) CB test beam.

b. The transverse displacement

The transverse displacement data for the PB and CB beams test are presented in the chart of Figure-9.



(a)



(b)

Figure-9. Transverse displacement of the, (a) NB test beam, (b) CB test beam.

The transverse displacement obtained from Figure-9 and section properties related to the transverse displacement are presented in Table-4 below.

Table-4. Section properties and transverse displacement of the test beam.

Test beam	**H** (mm)	**B** (mm)	**H/B**	r_y (mm)	**Transverse displacement** (mm)
NB	200	100	2.00	22.2	2.12
CB	310	100	3.1	20.09	18.41

From Table-4 shows ductility (μ) of NB and CB test beam respectively 10.72 and 6.31. This data shows the ductility of the beam CB decreased by 46.92% against the NB beam. This is influenced by large transverse displacement of the CB beam that affect to the vertical deformation ability of the beams.

The transverse displacement of the CB beam test greater than the NB beam. This is caused by the addition of CB beam high is causing increasing slenderness (H/B) and the declining value of the radius of inertia (r_y) for the y-axis which is the weakest of the beam axis

3.5. Moment-curvature relationship

The moment(M)-curvature (M/EI) relationship of the test beams area presented in Figure-10.

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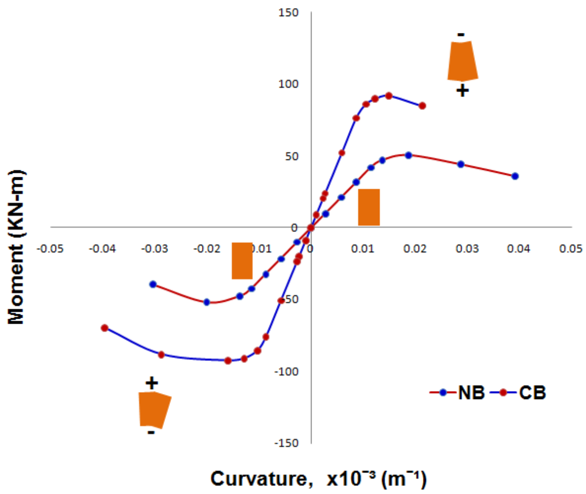

Figure-10. Moment-curvature relationship curve of the test beam.

The curve of the figure shows several things as follows:

a) NB test beam ; moment with the curvature linear relationship until the cycle IV. Starting from cycle V to ultimate load, moment-curvature relationship is not linear anymore. This is affected by the stiffness degradation (ξ) that occur from cycle V which gradually decreases until the ultimate load.

b) b. CB test beam : moment with the curvature linear relationship until the cycle V. Starting from cycle VI to ultimate load, moment-curvature relationship is not linear anymore. This is affected by the stiffness degradation (ξ) that occur from cycle VI which gradually decreases until the ultimate load.

3.6 The resistance-ductility relationship

Increased loading after yield conditions will be followed by an increase of displacement and rotation. Displacement and rotation directly influence the increase in ductility and a decrease of stiffness. Resistance (ε) - ductility (μ) relationship of NB and CB beams test are presented in the form of curves in Figure-11.

Resistance-ductility relationship of the NB test beam expressed in the equation: $\mu = 12.24\ \epsilon^2 - 13.8\ \epsilon + 2.562$. [1]

$1 \le \epsilon \le 1.199$

Resistance-ductility relationship of the CB test beam expressed in the equation: $\mu = 10.04\ \epsilon^2 - 26.79\ \epsilon + 11.74$. [2]

$1 \le \epsilon \le 1.190$

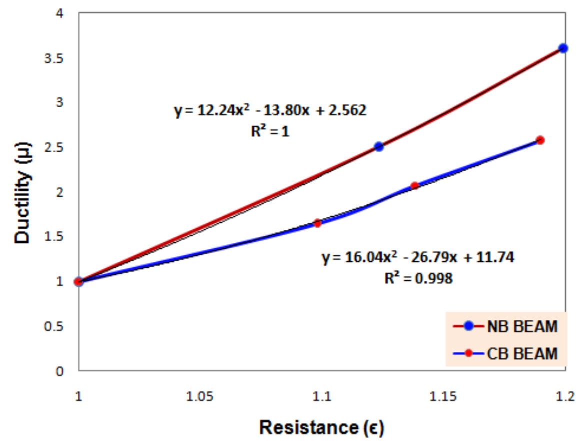

Figure-11. Resistance-ductility relationship curve of the test beam.

The chart of Figure-11 and equations [1] [2] indicates that resistance is proportional to ductility. Any increase in load will be followed by an increase in ductility.

4. CONCLUSIONS

From the discussion above, a number of conclusions as follow:

a) Fabrication normal beam (NB) into castells beam (CB) can increase the section modulus (S_x) and moment of inertia (I_x) respectively by 76.41 % and 173.43 %. It becomes the cause of increasing the flexure capacity of the CB beam by 82.5 % compared to NB beam.

b) High-profile additions of the CB beam, causes increased in cross-section slenderness (H / B) and lower the value of the radius of inertia (iy) on the y-axis. This condition causes the beam CB is not stable in the loading and reduce the ability of the beam deforms. Transverse displacement that occurred so large that affect the ductility of the beam. This is evident from the decrease in CB beam ductility by 46.92 % against the NB beam.

c) Resistance is proportional to ductility, if the increased load will be followed by an increase in ductility. This is shown by the equation: $\mu = 12.24\ \epsilon^2 - 13.8\ \epsilon + 2.562$ for NB beam, $\mu = 10.04\ \epsilon^2 - 26.79\ \epsilon + 11.74$ for CB beam.

d) Flexural capacity of castella beam is greatly increased compared with the normal beam, but need reinforcement or support at the web when it is used as a structural element for receiving seismic load

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