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FEASIBILITY OF CASTELLA BEAM AS A STRUCTURAL ELEMENT TO RECEIVE EARTHQUAKE LOAD

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ABSTRACT

The purpose of this study was to determine the ability of castella beams can be used as a structural element to resist earthquake load based on earthquake resistant building regulations applicable in Indonesia. 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 results showed that in terms of the flexure capacity, beam failure at the ultimate load, partial ductility and full ductility meet the requirements of SNI 03-1726-2003 on Earthquake Planning Procedures for Building Resilience in Indonesia so castella beam (CB) can be used as a structural element to receive earthquake loads.

Keywords: steel, beam, castella, 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 WakchaureMR, Sagade AV, Auti V. (2012) and the results showed that the openings with 0.6of 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. The purpose of this study was to determine the ability of the castella possible use as a structural element in multistory buildings that receive earthquake loads.

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(a) by taking part beams and columns that are restricted to the joint [s] Figure-1(b). Due to horizontal load, the moment at mid beam and column values will be close to zero. Therefore, the position of the zero moment can be modeled as HINGED, column and beam sections tested are considered to represent part with the end as a HINGE [the moment = ZERO].

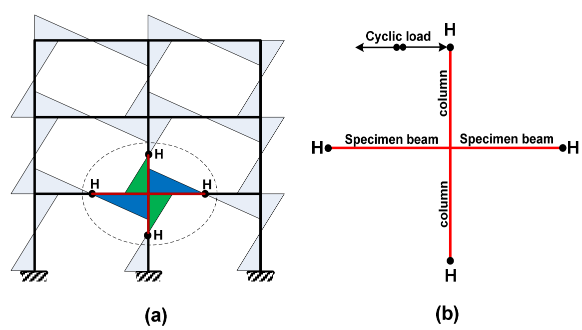

Figure-1. (a) The moment area of a frame due to earthquake loads, (b) Principle of the test beam-column element.

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

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opening angle 60^0. The cross section of the test beam as in Figure-2.

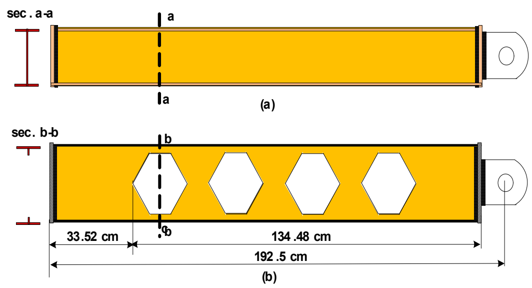
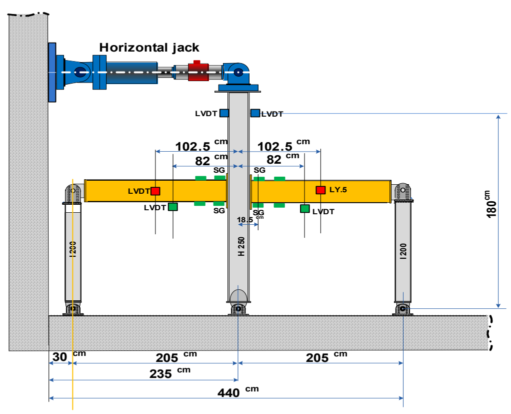


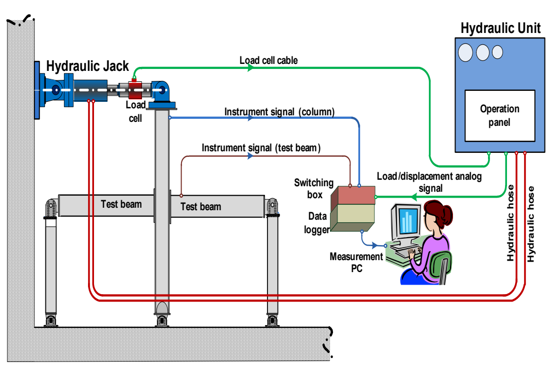
Figure-2. Beam test for the: (a) normal beam [NB], (b)castella beam [CB].

2.3. Testing frame

The testing requires testing framework. Testing framework is designed based on the principle of test as in Figure-1. Steel beams used are H 250 250 9 14 for themiddle column andthe IWF 200 100 5.5 8 for the other columns Figure-3. Testing framework laid out on the floor and walls of reinforced concrete. 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.



(a)

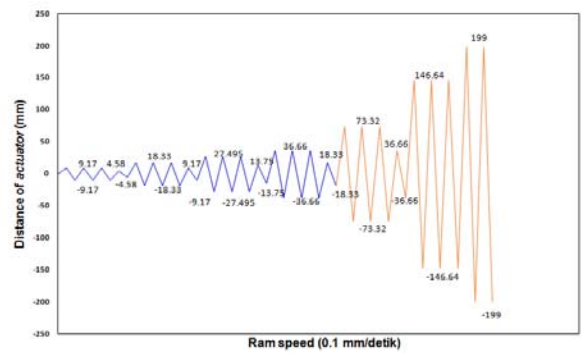


(b)

Figure-3.(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-rams speed relationship that has been done as shown in Figure-4.



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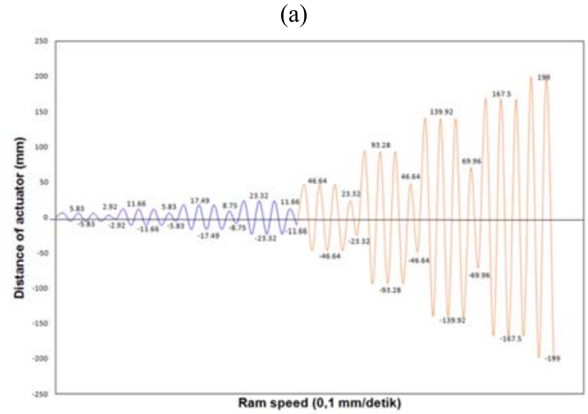

(b)

Figure-4. Displacement- ram speed relationship for the, (a) NB test beam, (b) CB test beam.

3. TEST RESULTS AND DISCUSSIONS

3.1 The maximum load at the test result

Table-1 shows the load design [P_{design}] and the maximum load [P_{actual}] achieved the maximum of each beam test in testing at the top of the middle column. The maximum load achieved smallest NB test beam is 29.45 KN, and CB beam is 54.00 KN. Design load for NB is

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31.04 KN greater than the actual load of 29.45 KN, with a deviation of 5.13%. Design load of CB test beam is 56.79KN greater than the actual load of 54.00KN with a deviation of 5.17%.

Table-1. Design load and the actual load of test beam.

Beam test	P_{design} at the top of column (KN)	$P_{actual\ min.}$ (KN)	Deviation (%)	Final Load (KN)	$P_{failure}$ = 0.80 P_{max}
NB	31.04	29.45	5.13	21.30	24.86
CB	56.79	54.00	5.17	41.23	44.00

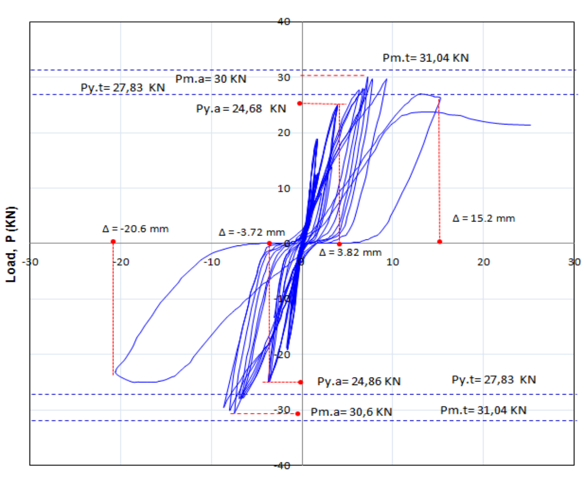
From the description above shows the beam is weakening faster due to the imposition of back and forth so that the actual load is smaller than the design load. The maximum actual load data in the Table shows, the all test beam is already in full plastic condition.

The ultimate load of NB test beam is 21.3 KN already past the deadline for testing requirements are $P_{failure}$ = 0.80 P_{max}. or equal 24.86 KN. The ultimate load of CB test beam is 41.23KN already past the deadline for testing requirements are $P_{failure}$ = 0.80 P_{max}. or equal 44KN

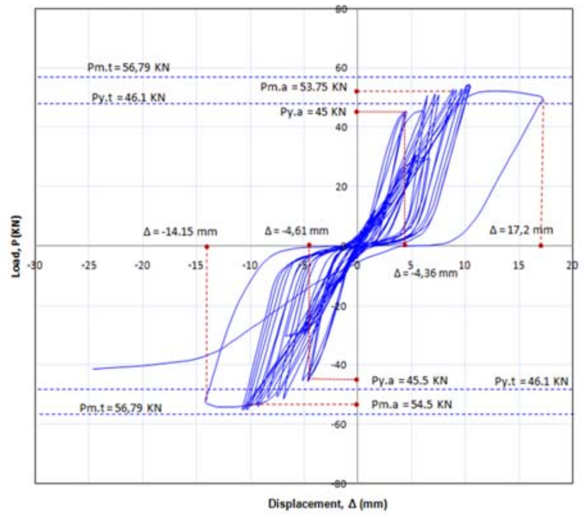
3.2. Load-displacement [P-Δ]

Figure-5, curve (P-Δ) with data from the load and displacement of yield condition and final load. NB test beam began yielding in the fourth cycle with load and displacement respectively 24, 68 KN and 3, 82 mm at the positive region, and 24, 86 KN, -3, 72 mm at the negative region. CB test beam began yielding in the cycle to VI with load and displacement respectively 45KN, 4, 36 mm at the positive region and 45,5KN, 4, 61 mm at the negative region. The maximum displacement of NB and CB at the ultimate load respectively 20, 6 mm and 17, 20 mm.

Displacement at the yield conditions and at the ultimate load conditions determine the partial ductility and full ductility value that can be achieved both test beam.



(a)



(b)

Figure-5. The load-displacement curve relationship (P-Δ) for, (a) NB test beam, (b) CB test beam.

3.3 Flexural capacity

Table-2, the list of resistance ratio ($\varepsilon = P_i/P_y$) for the test beams at yielding and maximum condition. Based on the minimal of P_{max} at maximum load conditions (cycle 6 and 8), the P_{max} minimal of NB and CB test beam respectively 29,45 KN and 54,00 KN.

Based on these data, flexural capacity of CB test beam increased by 83,36% compared to the test beam NB. So, with the addition of the heightcastella beam without adding steel weight can improve the flexure capacity of the beam.

Table-2. Resistance ratio of the test beam.

Cycle Number	NB P_i (KN)		NB P_y (KN)		NB Resistance		CB P_i (KN)		CB P_y (KN)		CB Resistance	
	P_i^+	P_i^-	P_y^+	P_y^-	ϵ_i^+	ϵ_i^-	P_i^+	P_i^-	P_y^+	P_y^-	ϵ_i^+	ϵ_i^-
4.1	24.68	24.86	24.68	24.86	1	1						
4.2	24.87	24.92	24.68	24.86	1.01	1.00						
4.3	24.89	24.96	24.68	24.86	1.01	1.00						
5.1	27.71	27.89	24.68	24.86	1.12	1.12	45.00	45.25	45.00	45.25	1.00	1.00
5.2	27.86	27.96	24.68	24.86	1.13	1.12	45.25	45.00	45.00	45.25	1.01	0.99
5.3	27.88	27.92	24.68	24.86	1.13	1.12	45.50	45.00	45.00	45.25	1.01	0.99
6.1	30.00	30.6	24.68	24.86	1.22	1.23	50.75	51.25	45.00	45.25	1.13	1.13
6.2	29.54	30.12	24.68	24.86	1.20	1.21	51.25	50.50	45.00	45.25	1.14	1.12
6.3	29.66	29.45	24.68	24.86	1.20	1.18	50.75	50.75	45.00	45.25	1.13	1.12
7.1							52.85	53.85	45.00	45.25	1.17	1.19
7.2							52.65	53.25	45.00	45.25	1.17	1.18
7.3							53.00	53.75	45.00	45.25	1.18	1.19
8.1							54.25	55.00	45.00	45.25	1.21	1.22
8.2							54.65	54.75	45.00	45.25	1.21	1.21
8.3							54.00	55.00	45.00	45.25	1.20	1.22

3.4 Ductility

Table-3 list of partial ductility from yield condition to final load. At the final load ($P_{failure}$ = 0.80 P_{max}) partial ductility (μ_o) of NB and CCB test beam respectively 6, 6 and 5, 34. These data indicate partial ductility of CB test beam smaller 23, 6% compared with test beam NB. This is caused by the increased rigidity of

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the beam due to the addition heightof the beams so that minimize displacement value.

Table-3. Partial ductility of test beam.

Cycle number	NB Δ^+ (mm)	NB Δ^- (mm)	NB Δ^+y (mm)	NB Δ^-y (mm)	NB μ_{oi}^+	NB μ_{oi}^-	NB μ_{oi} min	CB Δ^+ (mm)	CB Δ^- (mm)	CB Δ^+y (mm)	CB Δ^-y (mm)	CB μ_{oi}^+	CB μ_{oi}^-	CB μ_{oi} min
4.1	3.81	3.65	3.82	3.73	0.997	0.979	1							
4.2	3.82	3.73	3.82	3.73	1	1.00								
4.3	3.86	3.77	3.82	3.73	1.01	1.01								
5.1	6.28	6.52	3.82	3.73	1.644	1.75	1.64	4.36	4.61	4.36	4.61	1	1	1
5.2	6.73	6.72	3.82	3.73	1.762	1.80		4.56	4.63	4.36	4.61	1.0459	1.00	
5.3	6.92	6.95	3.82	3.73	1.812	1.86		4.61	5.12	4.36	4.61	1.0573	1.11	
6.1	7.2	7.49	3.82	3.73	1.885	2.01	1.88	6.5	6.87	4.36	4.61	1.4908	1.49	1.49
6.2	7.75	8.01	3.82	3.73	2.029	2.15		7.23	7.5	4.36	4.61	1.6583	1.63	
6.3	9.25	8.69	3.82	3.73	2.421	2.33		7.56	8.35	4.36	4.61	1.7339	1.81	
7.1	15.2	20.6	3.82	3.73	3.98	5.52		8.92	9.26	4.36	4.61	2.0459	2.01	2.01
7.2	25.2		3.82	3.73	6.60		6.6	9.21	9.46	4.36	4.61	2.1124	2.05	
7.3								9.71	9.92	4.36	4.61	2.2271	2.15	
8.1								10.21	10.28	4.36	4.61	2.3417	2.23	2.23
8.2								10.4	10.52	4.36	4.61	2.3853	2.28	
8.3								10.5	10.7	4.36	4.61	2.4083	2.32	
9.1								17.2	14.15	4.36	4.61	3.945	3.07	
9.2									24.6	4.36	4.61		5.34	5.34

Table-4 list of full ductility from yield condition to final load. At the ultimate load ($P_{failure} = 0.80\ P_{max}$), full ductility ($\mu$) of NB and CB test beam respectively 7.17 and 5,8. These data indicate full ductility of CB test beam smaller 23, 62 % compared with test beam NB. This is caused by the increased rigidity of the beam due to the additionheightof the beams so that minimize displacement value.

According to SNI 03-1726-2003 on Earthquake Resilience Planning Procedures for Building Article 3.1.2.3 states structure should achieve full ductility (μ) of 5.20. Full ductility CB test beam at 5.8 greater than the regulatory requirements that apply in Indonesia. Under the provisions above, CB beams can be used as a structural element for receiving seismic load.

Table-4. Full ductility of test beam.

Cycle number	NB Δd_i^+ (mm)	NB Δd_i^- (mm)	NB Δ^+y (mm)	NB Δ^-y (mm)	NB μ_i^+	NB μ_i^-	NB μ_i min	CB Δd_i^+ (mm)	CB Δd_i^- (mm)	CB Δ^+y (mm)	CB Δ^-y (mm)	CB μ_i^+	CB μ_i^-	CB μ_i min
4.1	3.9	4	3.82	3.73	1.02	1.07	1.02							
4.2	4.07	4.33	3.82	3.73	1.07	1.16								
4.3	4.11	4.37	3.82	3.73	1.08	1.17								
5.1	6.6	7.02	3.82	3.73	1.73	1.88	1.73	4.81	4.91	4.36	4.61	1.1	1.065	1.07
5.2	7.71	7.34	3.82	3.73	2.02	1.97		4.81	4.95	4.36	4.61	1.1	1.074	
5.3	7.91	7.57	3.82	3.73	2.07	2.03		5.06	5.44	4.36	4.61	1.16	1.18	
6.1	7.65	9.19	3.82	3.73	2	2.46	2.00	7.27	7.09	4.36	4.61	1.67	1.538	1.54
6.2	9.55	9.72	3.82	3.73	2.5	2.61		7.99	8.26	4.36	4.61	1.83	1.792	
6.3	11.44	10.4	3.82	3.73	2.99	2.79		8.24	8.90	4.36	4.61	1.89	1.931	
7.1	17.105	22.3	3.82	3.73	4.48	5.98		9.92	10.01	4.36	4.61	2.28	2.171	2.17
7.2	27.39		3.82	3.73	7.17	0	7.17	10.4	10.56	4.36	4.61	2.37	2.291	
7.3								10.8	11.02	4.36	4.61	2.48	2.39	
8.1								11.6	11.85	4.36	4.61	2.67	2.57	2.57
8.2								11.8	12.08	4.36	4.61	2.71	2.62	
8.3								11.9	12.26	4.36	4.61	2.73	2.659	
9.1								18.6	15.11	4.36	4.61	4.27	3.28	
9.2									26.76	4.36	4.61	0	5.80	5.80

3.5. The failure of the test beam

Based on a local failure of the beam theory which states that; if $\lambda_G \leq \lambda_p$ then the beam will failure due to yielding. From data of the NB beam, and CB with λ_G of 6.25 is smaller than λ_p at 10.97. This shows flange beams NB, and CB will fail due to yielding. Evaluation is based on ASTM international , designation: E 2126-02a year 2002, at $P_{failure} = 0.80\ P_{max}$

a) The failure of NB test beam

Flange buckling occurs early on in the cycle to V with the flexure moment ($M_{t.a}$) of 41.82 KN-m and strain ($\varepsilon_{t.a}$) -8, 936 for micro strain greater than the yielding strain (ε_y) of 1200 micro-strain. Buckling process goes on until the ultimate loading with maximum strain value ($\varepsilon_{m.a}$) of -15,082 micro strain and steel stress (f_s) of 281.05 MPa.NB beam flange buckling at the ultimate loading is already a permanent buckling. Figure-6 shows the maximum strain values obtained from the test data and stress value calculated theoretically based on the maximum load test results. Shear stress occurs (Ƭ) of 25 MPa less than the yield stress (fy) of 240 MPa. This shows the beam does not fail due to shear.

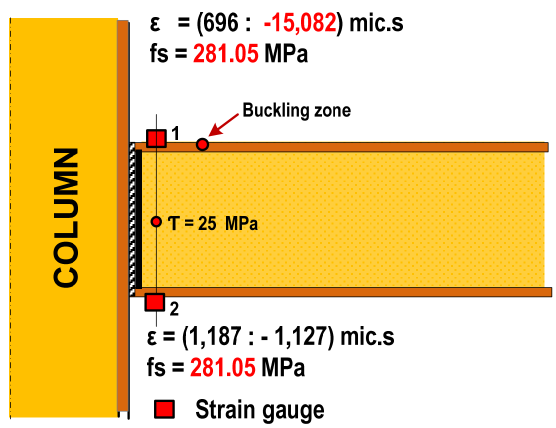

Figure-6. Stress and strain maximum at NB test beam.

b) The failure of the CB test beam

The first Buckling occurs at the topflange in the cycle VII with the buckling moment (Mt.a) 80.28 KN-m and strain (εt.a) -6,674 micro strain. Buckling process goes on until the end of the loading with maximum strain value (εm.a) -7,315 micro strains with steel stress (fs) of 320.21 MPa at the upper flange near the joint.And the maximum strain ($\varepsilon_{m.a}$) -8,848 micro strain with steel stress (f_s) of 483.68 MPa at the bottom flange of the T sections in the first hole of castella. The flange buckling of the CB beam at the ultimate loading it is a permanent buckling.

Figure-7 shows the maximum strain obtained from the test data and the and maximum stress is calculated based on the maximum load test. Shear stress (T) at cross section near the joint is 24.16 MPa, vertical shear stress (Tv) and horizontal shear stress (Th) on a solid web between two holes castella respectively is 116.86 MPa and 111.59 MPa, and web buckling stresses (FTK) of 174.1 MPa. Third stresses is still less than the yield stress fy = 240 MPa.

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This condition indicates the failure of the beam CB is not caused by the three types of stresses. Ultimate load of 41.23 KN already reached the limit of the testing requirements are $P_{failure} = 0.80\ P_{max}$. or equal to 44 KN.

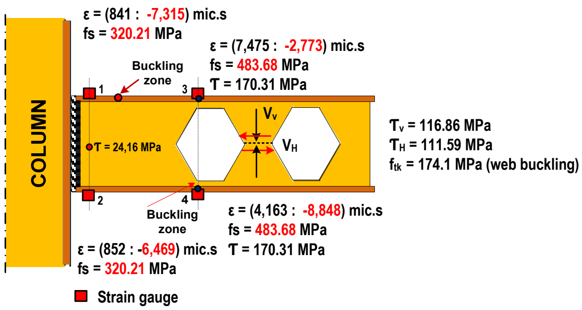

Figure-7. Stress and strain maximum at CB test beam.

From the description above indicate that, NB and CB beams failed due to yielding. Stress and strain that occurs already exceeded steel yield stress and strain of steel. Stress and strain of steel will increase continuously along with the addition of each load cycle. Both of these conditions will cause the elastic modulus of the steel progressively decreases so that the flanges are buckled at each change of direction of the load is not able to return to its original position so that the beam flange buckled permanently. Until the ultimate loading, the second beams do not show the failures models like at the beam due to monotonic loading and beam damage is not significant until the loading limit.

4. CONCLUSIONS

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

a) Fabrication normal beam into a castella beam does not add to the weight of steel and can increase the flexure capacity of 83.36% when compared with the normal beam (NB).

b) Partial ductility and full ductility value of the CB beam eligible in accordance with SNI 03-1726-2003 on Earthquake Planning Procedures for Building Resilience in Indonesia.

c) Until the end of the ulimate load, CB beam damage is not significant and the damage can be repaired.

d) Based on the conclusions 1, 2 and 3 showed CB beam can be used as a structural element due to receiving seismic load.

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