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Behavior Of Castellated Composite Beam Subjected To Cyclic Loads

Mara. J[1], Parung. H[2], Tanijaya. J[3] and Djamaluddin R[4]
[1]*Civil Engineering Doctoral Student, Hasanuddin University, Makassar-Indonesia*
[2]*Civil Engineering Department, Hasanuddin University, Makassar-Indonesia*
[3]*Civil Engineering Department, Paulus Christian University of Indonesia, Makassar-Indonesia*
[4] *Civil Engineering Department, Hasanuddin University,Makassar-Indonesia*

Abstract:- The purpose of this study is to determine the behavior of beam-column sub-assemblages castella due to cyclic loading. Knowing these behaviors can if be analyzed the effectiveness of the concrete filler to reduce the damage and improve capacity of beam castella. Test beam consists of beam castella fabricated from normal beam (CB), castella beams with concrete filler between the flange (CCB) and normal beam (NB) as a comparison. Results showed castella beam (CB) has the advantage to increase the flexural capacity and energy absorption respectively 100.5% and 74.3%. Besides advantages, castella beam has the disadvantage that lowering partial ductility and full ductility respectively 12.6 % and 18.1%, decrease resistance ratio 29.5 % and accelerate the degradation rate of stiffness ratio 31.4%. By the concrete filler between the beam flange to improve the ability of castella beam, then the beam castella have the ability to increase the flexural capacity of 184.78 %, 217.1% increase energy absorption, increase ductility partial and full ductility respectively 27.9 % and 26 %, increases resistance ratio 52.5 % and slow the rate of degradation of the stiffness ratio 55.1 %..

Keywords: - Steel, castella, column beams, cyclic load

I. 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. To increase capacity and avoid damage that commonly occur in castella beam, then the beam castella beam reinforced with fresh concrete between the flanges The purpose of this study was to determine the ability and stiffness of the castella beam or castella beam reinforcement of concrete due to cyclic loading for possible use as a structural element in multistory buildings that receive earthquake loads.

II. TESTING PROGRAM

1. Testing Principle

The principle of the test is based on the structure of the framework that burdened earthquake load as in Fig. 1a by taking part beams and columns that are restricted to the joint (s) Fig. 1b. 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).

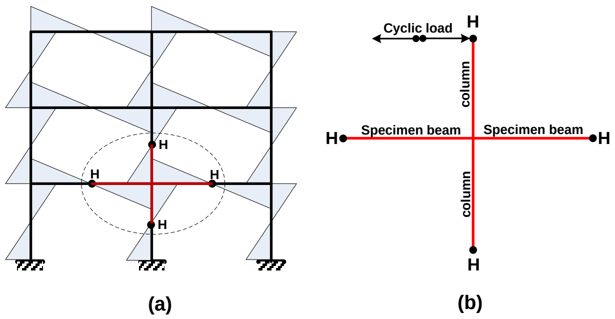


Figure 1. (a) The moment area of a frame due to earthquake loads, (b) Principle of the test Beam-column element

2. Test Beams

For 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 cross section of the test beam as in Fig. 2. Variations of the test specimen consists of a solid beam (NB) as a comparison, castella beam (CB), and castella composite beam (CCB). The placement of the holes on the castella beam based on a comparison of plastic moments between the solid section and perforated section, assuming when a solid beam section in yielding, then the hole section will also in yielding.

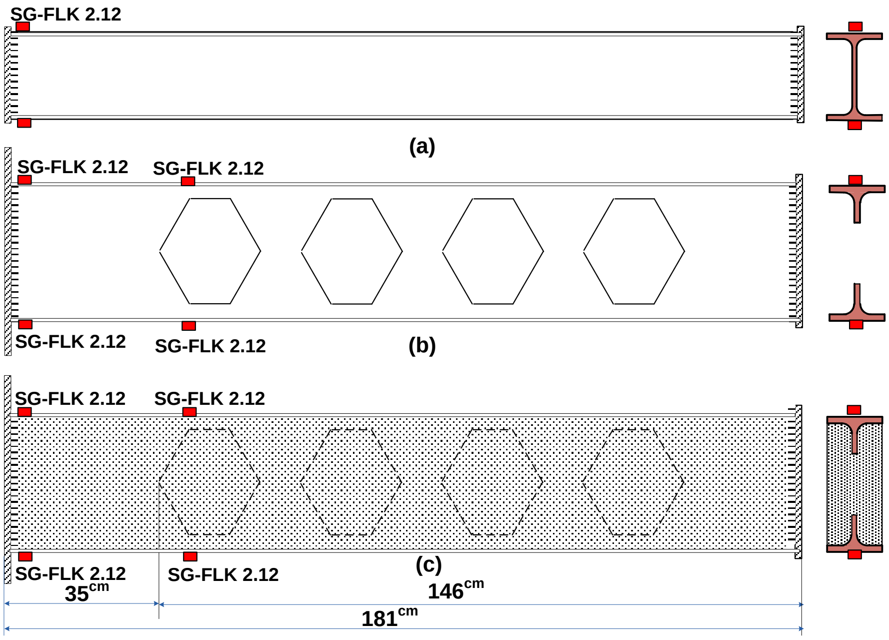


Fig. 2. Beam test for the: (a) NB, (b) castella CB, and (c) CCB

3. Testing Framework

The testing requires testing framework. Testing framework is designed based on the principle of test as in Fig. 1. Steel beams used are H 250 250 9 14 for the middle column and the IWF 200 100 5.5 8 for the other columns Fig. 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, data logger and switching box.

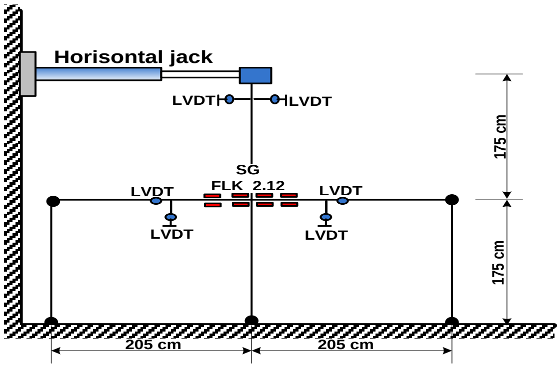


Fig. 3. Framework for testing and placement of testing instruments

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 and additional cycle for the specimen fails could not be continued due to displacement is limited by the maximum displacement of the actuator (horizontal jack).

(a) (b) (c)

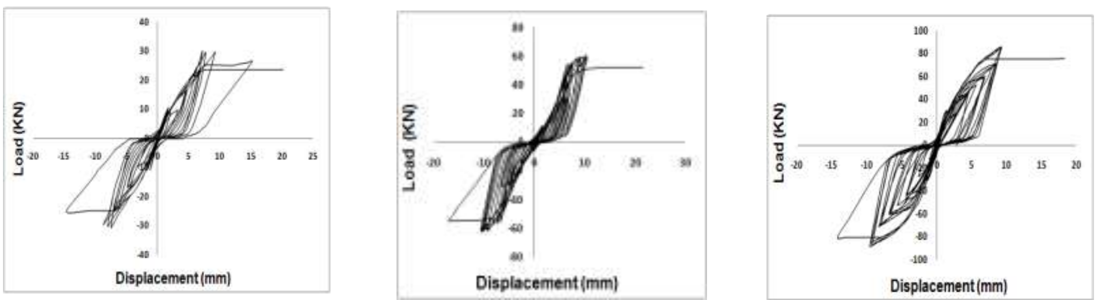
Fig. 4. Testing implementation for the, (a) NB, (b) CB and (c) CCB

III. TEST RESULTS AND DISCUSSION

1. Load-Displacement (P-Δ)

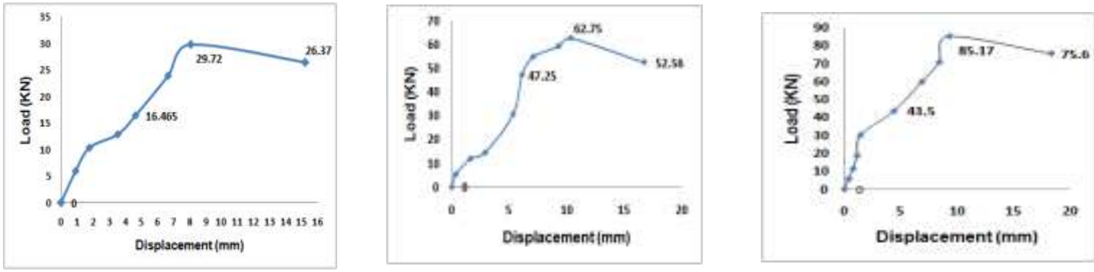
Fig. 5, curve (P-Δ) for maximum load (P_{max}) and maximum displacement (Δ_{max}) of the test beam. The load and maximum displacement for positive moment (P^+, Δ^-) and negative moments (P^-, Δ^+) of the test beam; the NB test beam, (P^+) is 30 KN, (Δ^-) is 9.25 mm, (P^-) is 30.60 KN, and (Δ^+) is 8.69 mm. The CB test beam, (P^+) is 60.75 KN, (Δ^-) is 10.4 mm, (P^-) is 61.5 KN, and (Δ^+) is 10.7 mm. The CCB test beam, (P^+) is 85.75 KN, (Δ^-) is 9.32 mm (P^-) is 88.25 KN and (Δ^+) is 9.65 mm. Average percentage of the maximum load of the test beam CB and CCB to control beam NB respectively 202.15% and 287.95%.

Fig. 6, curve (P-Δ) with average data from the load and displacement of each cycle in the negative moment area. NB test beam began yielding in the fourth cycle with an average load 16.66KN, CB test beam began yielding in the sixth cycle with an average load of 47.25 KN and CCB test beam began yielding in the sixth cycle with an average load of 43.5 KN. At the end of the loading cycle plans, test beams are given additional cycles with a maximum displacement of the tool that is up to 20 cm. The percentage of the cycle addition load to the maximum load of the test beam NB, CB and CCB respectively 87.9%, 86.52% and 88.16%.



(a) (b) (c)

Figure 5. The load-displacement curve relationship (P-Δ) for, (a) NB, (b) CB and (c) CCB



(a) (b) (c)

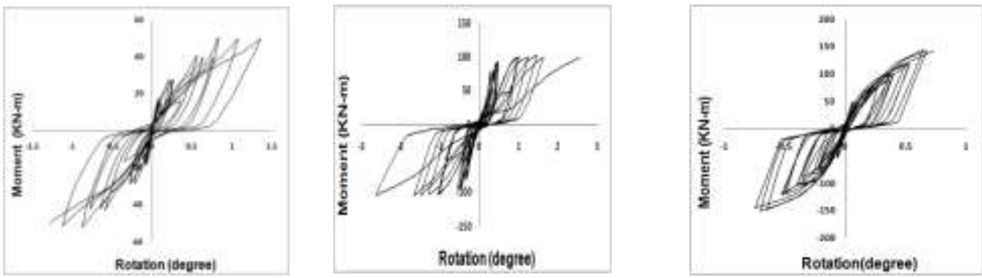
Fig. 6. The load-displacement curve relationship in negative moment regions for, (a) NB, (b) CB and (c) CCB

2. Moment – Rotation

Fig. 7, the moment - rotation relationship curves (M-φ) at the one end of the test beams. This curve is identical with load-displacement curve relationship (P-Δ). The magnitude of rotation angle due to positive moment (ϕ^-) and negative moments (ϕ^+) at the yielding conditions and the maximum condition on each test beam as follows :

At the yielding conditions, rotation angle for : NB test beam, (ϕ^-) is 0.22^0 , (ϕ^+) is 0.22^0. For CB test beam, (ϕ^-) is 0.30^0 , (ϕ^+) is 0.28^0. And for the CCB test beam, (φ-) is 021^0 and (ϕ^+) is 0.21^0

At the maximum conditions, rotation angle for; NB test beam, (ϕ^-) is 1.28^0 and (ϕ^+) is 1.37^0 . CB test beam, (ϕ^-) is 2.61^0 and (ϕ^+) is 2.50^0. and CCB test beam, (ϕ^-) is 074^0 and (ϕ^+) is 073^0. Average percentage of the rotation progress from the yielding conditions to maximum conditions for the test beam NB is 502.27%, CB test beam is 781.03%, and the test beam CCB is 250%. These conditions indicate the NB and CB test beam already unstable at the maximum load condition compared with CCB test beam. This condition is shown in Fig. 7.



(a) (b) (c)

Figure 7. Moment-rotation relationship curve for the, (a) the NB, (b) CB and (c) CCB

3. Flexural Capacity

Tab. 1, The list of moment resistance for the test beams at yielding and maximum condition. At the yielding conditions, the ability of each specimen beams to receive positive moment and negative moment ; the ability of CB test beam increased respectively by 184.6 % and 183.5%, or an average 184.1 %, and the ability of CCB test beam increased by 165.1% and 161%, or an average 163% when compared to the NB test beam. At the maximum conditions, the ability of each test beam to receive moment positive and negative ; the capability of CB test beam increased respectively by 98.85% and 101.3% or an average is 100.08%, the ability of CCB test beam increased respectively increased by 180.69% and 188.87 %, or an average 184.78% when compared to the NB test beam, and the ability of CCB test beam increased respectively by 41.15% and 43.5%, or an average 42.32% when compared to the CB test beam.

Table 1. MOMENT, DISPLACEMENT, AND DUCTILITY

Beam number	Yield moment (My) (KN-m)		M max (KN-m)		Yield displacement (Δy)(mm)		Partial displ. max (Δmax) (mm)		Full displ. (Δ_i max) (mm)		Partial ductility (u_{oi})		Full ductility (u_i)	
	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)
NB	27.91	28.16	51.63	51.63	4.56	4.45	9.25	8.69	11	10.9	2.03	1.95	2.41	2.44
CB	79.43	79.85	102.67	103.94	5.94	6.24	10.5	10.7	12.1	12.1	1.77	1.71	2.03	1.94
CCB	73.52	73.52	144.92	149.14	4.36	4.36	9.77	9.65	10.6	11.2	2.24	2.21	2.43	2.57

4. Ductility

Tab. 1, the list of partial ductility (Δ_{max} / Δ_y) and full ductility (Δi_{max} / Δ_y) for the test beams. The partial ductility of each test beam at the positive moment and negative moment; the partial ductility of CB test beam decreased respectively by 12.95 % and 12.19 %, or an average is 12.6 % and the partial ductility of CCB test beam increased respectively by 10.35% and 13.34%, or an average is 11.84 % when compared to the NB test beam. The partial ductility of CCB test beam increased respectively by 26.77 % and 29.1 %, or an average is 27.9 % when compared to the CB test beam. The full ductility (ui) for each test beam at the positive moment and negative moment; the full ductility of CB test beam decreased respectively by 15.62 % and 20.56 %, or an average 18.1 %, and the full ductility of the CCB test beam increased respectively by 1.13% and 4.97 %, or an average is 3.05 % when compared to the NB test beam. The full ductility of CCB test beam increased respectively by 19.86 % and 32.14 % or an average 26% when compared to the CB test beam.

5. Energy

Tab. 2, the list of energy absorption (P-Δ) for the test beams at yielding and maximum conditions. At the yielding conditions, the absorption energy of each test beam at the positive moment and negative moment: the energy absorption of CB test beam increased respectively by 98.1% and 50.5% or an average 74.3%, the energy absorption of CCB test beam increased respectively by 108.6% and 92.23% or an average 105.4% when compared with NB test beam, and absorption energy of the CCB test beam increased respectively by 5.3% and 27.7% or an average is 16.5% when compared to the CB test beam. At the maximum conditions, absorption energy for the beam test on the positive moment and negative moment: The absorption energy of CB test beam increased respectively by 36.5% and 22%, or an average 29.3%, the energy absorption of CCB test beam increased respectively by 253.2% and 181% or an average 217.1% when compared to the NB test beam, and energy absorption of CCB test beam increased respectively by 158.8% and 130.3% or an average 144.6% when compared to the CB test beam.

TABLE 2. ENERGY, STIFFNESS, AND RESISTANCE

Beam number	Energy (J)				Stiffness ratios (ξ)				Resistance ratios (ϵ)			
	Yield		Max.		Yield		max		Yield		Max.	
	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)
NB	1069.20	1096.92	5141.55	6112.83	1.00	1.00	0.37	0.42	1.00	1.00	1.85	1.83
CB	2230.82	2108.63	18158.34	17176.87	1.00	1.00	0.26	0.28	1.00	1.00	1.29	1.30
CCB	2230.82	2108.63	18158.34	17176.87	1.00	1.00	0.66	0.56	1.00	1.00	1.97	2.00

6. Stiffness

Tab. 2 , the list of stiffness ratio ($\xi = tg\alpha i / tg\alpha y$) for the test beam. The stiffness ratio of each test beam at the positive moment and the negative moment: The stiffness ratio of CB test beam decreased faster is respectively 30.3% and 32.5% or an average 31.4%, the stiffness ratio of CCB test beam decreased more slowly is respectively 76.6 % and 33.3 %, or an average is 55 % when compared to the NB test beam, and the stiffness ratio of CCB test beam also experienced a slower decline respectively by 52.5% and 53.66 % or an average is 55.1% when compared to the CB test beam.

7. Resistance

Tab. 2, the list of resistance ratio ($\varepsilon = P/P_y$) for the test beams at the time of maximum load. The resistance ratio of each test beam at the positive moments and negative moments: the resistance ratio of CB test beam decreased respectively by 30 % and 28.5%, or an average of 29.5 % and the resistance ratio of CCB test beam increased respectively by 6.7% and 9.2%, or an average is 7.9% when compared to the NB test beam. The resistance ratio of CCB test beam increased respectively by 52.51% and 53.66 %, or an average 52.5 % when compared to the CB test beam.

8. The Failure of the Test Specimen

The failure of the specimen at cyclic loading different than failure of the test specimen due to monotonic loading. In the monotonic loading, failures caused by the greater deflection due to the addition of the applied load. In the cyclic loading to the frame, the deflection that occurs is much smaller than the monotonic loading. The failure of cyclic loading is fatigue failure due to cyclic loading from a given number of loading cycles.

The failure of NB test beam is flange buckling at cycle VI and reducing capacity of the beam after the application of an additional cycle. Likewise, the failure of CB test beam is flange buckling at cycle VII and reducing capacity after application additional cycles. The failure of the CCB test beam seems at cycle VII with the onset of cracks in the concrete and reducing the capacity of the beam after the application of additional cycles.

IV. CONCLUSIONS

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

1. Fabrication normal beam (NB) into castella beam (CB) will increase the flexural capacity of 100.5%, increase an energy absorption of 74.3%, lower the ductility partial and the full ductility respectively by 12.6 % and 18.1%, decrease the resistance ratio 29.5% and accelerate of degradation rate of the stiffness ratio 31.4%
2. Fabrication normal beam (NB) into castella composite beam (CCB) will increase the flexural capacity 184.78 %, increase an energy absorption 217.1%, increase the ductility partial and the full ductility respectively 24.45% and 26.2%, increases the resistance ratio 7.9 % and slows the rate of degradation of the stiffness ratio 55 %.
3. Function concrete filler between the flange of the castella beam will increase the flexural capacity 42.32 %, increase an energy absorption 144.6%, increase the ductility partial and the full ductility respectively 27.9 % and 26 %, increase the resistance ratio 52.5 % and slows the rate of degradation of the stiffness ratio 55.1 %.

REFERENCES

[1]. Anonymous, Recommended Testing Procedure for Assessing the Behavior of Structural Elements under Cyclic Loads , European Convention for Constructional steelwork (ECCS)

[2]. Wakchaure M.R, Sagade A.V and Auti V.A, Parametric Study of Castellated Beam with Varying Depth of Web Opening. International Journal of Scientific and Research Publications, Volume 2, Issue 8, August 2012.

[3]. Parung et al, Experimental Study on Castellated Steel Beam Using Monotonic Loading, ITB Bandung, KNPTS, 2013.