ISBN 978-93-84422-57-8
Proceedings of 2015 International Conference on Disaster Management in Civil Engineering (ICDMCE'2015)
Phuket, Thailand, October 1-3, 2015, pp. 1-7

Seismic Performance of Interior Beam-Column Joint With Fuse-Bar Designed Using Ec8 Under In-Plane Lateral Cyclic Loading

S.Y. Muhammad[1], N.H. Hamid [2] and N.F. Hadi[3]
[1]Lecturer, Faculty of Civil Engineering, Universiti Teknologi MARA, Pasir Gudang Campus,
81750 Johor Bahru, Johor, Malaysia
[2]Associate Professor, Dr., Faculty of Civil Engineering, Universiti Teknologi MARA,
40450 Shah Alam, Selangor, Malaysia
[3]Postgraduate Student, Faculty of Civil Engineering, Universiti Teknologi MARA,
40450, Shah Alam, Selangor, Malaysia

Abstract: *The paper focuses on the seismic performance of interior beam-column joint with fuse-bar subjected to in-plane lateral cyclic loading through experimental work. Sub-assemblage of interior beam-column joint of moment resisting frame was designed in accordance to Eurocode 8, constructed and tested in laboratory. Three beams were connected to the column and equipped with eight numbers of fuse-bars acting as energy dissipators which were located at centre of the joint. The specimen was tested under in-plane lateral cyclic loading by applying the lateral load at top of the column and tested up to ±2.50% drift. The seismic performance of the joint was analyzed and examined in terms of damage visual observation after testing, the behaviour of hysteresis loops, ultimate load carrying capacity, stiffness, ductility and equivalent viscous damping. By placing fuse-bars at the interior joint and designed the structures in accordance with Eurocode 8 under Ductility Class Medium (DCM) for strong column-weak beam condition, it is expected that the specimen will survive under moderate or strong earthquake. From visual observation more cracks were observed at the in-plane beam and less cracks were observed on the column. Experimental result shows that the beam-column joint has higher lateral strength capacity, stiffness, equivalent viscous damping and displacement ductility of 3.7 which can be classified under moderate ductility. Therefore, this building which are designed using Eurocode 8 will survive under moderate or strong earthquake.*

Keywords: *Ductility Class Medium (DCM), energy dissipators, Eurocode 8, fuse bars, interior beam-column joint, lateral cyclic loading*

1. Introduction

Nowadays, are many earthquake events occurred in Asean region especially within Pacific Ring of Fire which include Sumatera, Indonesia, Philippines and other countries. Earthquakes with magnitude between 2.4 to 3.6 on the Richter scale occurred in Peninsular Malaysia and magnitude between 3.6 to 5.6 on the Richter scale in East Malaysia. During the 2004 Banda Acheh Earthquake, the residents who live in high rise buildings in West Coast of Peninsular Malaysia felt the tremor and vibrations. Most of the reinforced concrete structures in Malaysia were designed using BS 8110 to cater for gravity/vertical loads and omitting the earthquake load. Subsequently, the structures will not be able to resist the lateral load due to seismic load and performed poorly under moderate and strong earthquake. This phenomenon obviously warned the engineers and researchers the importance of designing beam-column joint using the current seismic code of practice. In most cases, damages in RC buildings mostly occurred due to poor detailing of reinforcement bars, poor workmanship and low percentage of reinforcement bars in the concrete. In order to avoid severe damage in the future due to moderate or major earthquake, the construction industries in Malaysia should adopt Eurocode 8 for the design and construction of high rise buildings. Most of existing RC buildings in Malaysia were designed in accordance to British Standard (BS 8110) which did not have any provision and guidelines for earthquake loading at all. Experimental works had been conducted for tunnel form building [1], non-seismic precast RC beam-column joint [2], wall-slab joints of Industrialized Building System (IBS) [3] and precast shear-key wall panel [4] which designed according to BS8110. The experimental results showed that the structural components performed poorly under in-plane and out-of-plane loading with low ductility. Therefore, an appropriate seismic code of practice should be adapted by Malaysia authority in the future for the construction of RC buildings to cater for lateral load which comes from earthquake loading and some mitigations action will be prepared from any damages and after an earthquake event.

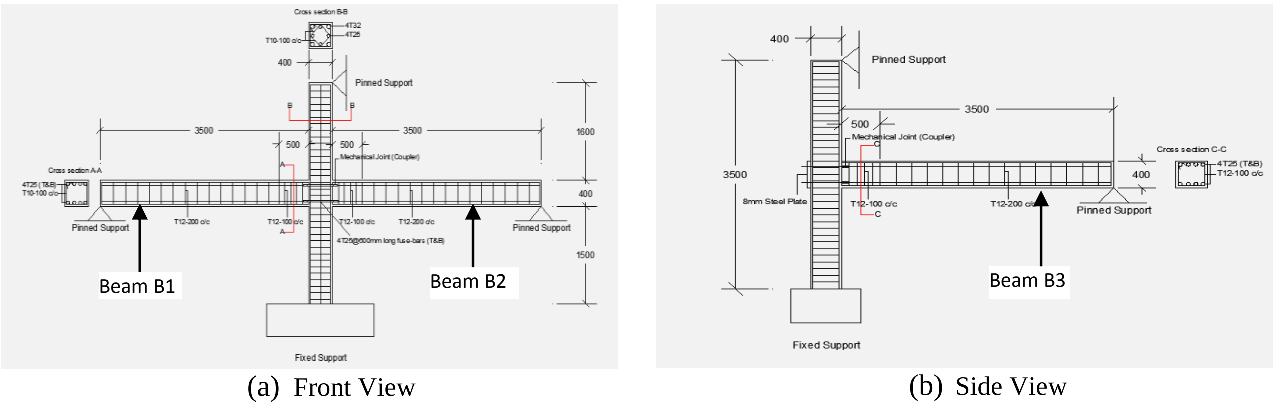
2. Findings from Previous Research

Several studies had been conducted to evaluate the seismic performance of precast beam-column moment resisting frames under in-plane lateral cyclic loading. The moment-resisting frames together with their connections were performed very well under earthquake loading when designed using the concepts of strong column-weak beam. All the connections performed adequately well in seismic conditions with respect to strength, ductility and energy dissipation capability [5]. Contradictorily, Ghani and Hamid [6] conducted an experimental work on a full-scale precast concrete beam-column interior joint with corbels designed according to BS 8110 and tested under in-plane lateral cyclic loading. The experimental results showed that the cracks started at +0.5% drifts with spalling of concrete and major cracks were observed at the cast-in-place of the joint. Further study was carried out on seismic behaviour of interior RC beam-column joints with additional bars under in-plane lateral cyclic loading [7]. Experimental results showed additional bars can improve in term of cracking, confined concrete, lateral strength, stiffness and ductility.

Previous research had highlighted that most of the RC structures components which have been designed such as beam-column joint with corbel, wall-slab connection, tunnel form building and precast shear-key wall performed poorly under in-plane lateral cyclic loading [1,2,3,4]. In order to improve the performance of beam-column joint in RC moment-resisting frames, fuse-bars which acting as energy dissipater will be installed inside the beam-column joint. Some previous research showed that installation of fuse-bars at the joint [8], fuse-bars at the bottom of wall-foundation interface [9], external fuse-bars out-side beam-column joint [10], fuse-bar at two-third of precast hollow core wall[11] and self-centering BRB supplemented with fuse-bar superelastic NiTi SMA [12] can improve the performance of the structures components under seismic load. Therefore, the interior beam-column joint in this study will equipped with fuse-bar and designed for Ductility Class Medium (DCM) in accordance to Eurocode 8 (EC8). Fuse-bars acting as energy dissipator designed to absorb energy when the specimen is subjected to in-plane lateral cyclic loading, reduce damages to the structure and increasing the ductility (3<μ<6) for the structure to survive under moderate earthquake excitations.

3. Construction of Interior Beam-Column Joint

The sub-assemblage of full-scale interior beam column joint was designed as a moment resisting frame for seismic load according to Eurocode 8 (Part 1 BS EN1998-1:2004). Figure 1 (a) and (b) shows the detailing of interior beam-column joint for front view and side view, respectively. The specimen consists of three beams with dimensions of 3500mm x 400mm x 400mm framing at mid height into 3 sides of one column. The dimension of column is 3500mm x 400mm x 400mm was constructed vertically on the foundation beam.



(a) Front View (b) Side View

Fig. 1: Detailing of sub-assemblage of interior beam-column joint using fuse-bars

Eight numbers of fuse-bars with 25mm diameter and 600mm long were installed at the joint between beam B1 and beam B2 as shown in Figure 1(a). Strain gauge was glues cautiously to reinforcement bars to prevent from damages an malfunction during concreting process. Figure 2(a) shows actual size of the fuse-bars made from high yield reinforcement bars and Figure 2(b) shows the installation of fuse-bars at the beam-column joint. Steel plate with fuse-bars were welded together at the end of Beam B3 and full welded was performed along the perimeter of main bars. The specimen is ready for instrumentation and experimental set-up when the compressive strength achieved 45 MPa after 28 days. This specimen was configured as strong column-weak beam capacity as indicated in Eurocode 8. End condition of column support is designated as fully fixed where the column is cast-in-situ concrete with the foundation beam.

(a) Fuse-bars made from 25mm bars

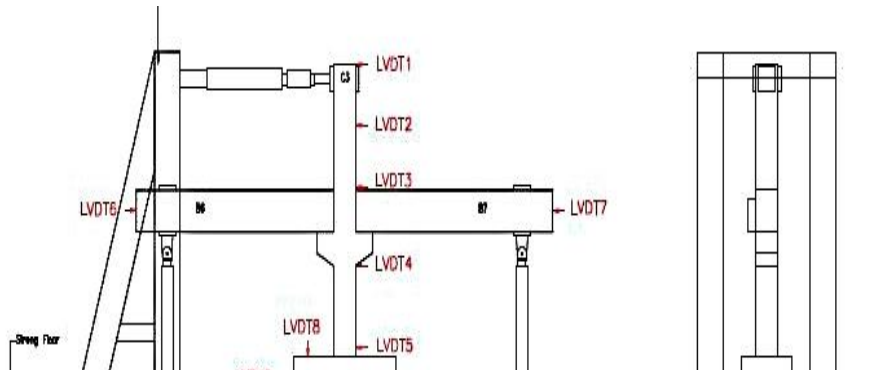
(b) Installation of fuse-bars

Fig.2: Installation of fuse-bars at the beam-column joint

4. Instrumentations, Experimental Set-up and Testing Procedure

Once the specimen is assembled together, wet concrete was poured into the foundation, beams, beam-column joints and column. After 28 days and compressive strength achieved 45MPa, foundation beam was clamped to strong floor using highly threaded rods and bolts. Figure 3(a) shows the experimental set-up of the sub-assemblage full-scale interior beam-column joint on strong floor with systematic arrangement of linear potentiometers (LVDT) along the column and support of the beams. LVDT is used to measure the lateral and vertical displacement of the structure during experimental work. Pinned supports conditions were designed at the end of all beams (B1, B2 and B3) and fixed end support for the column. All strain gauges wires from the specimen were connected to a data logger in order to convert the data into load versus displacement graphs or also known as hysteresis loops. Figure 3(b) shows the sub-assemblage of interior beam-column joint completed with LVDT is ready for testing.

A double actuator with 500kN capacity load cell was connected to the reaction frame to apply the lateral load to the specimen. Fourteen sets of drifts were applied at top of the column starting at ±0.01%, ±0.05%, ±0.1%, ±0.2%, ±0.5%, ±0.75%, ±1.0%, ±1.15%, ±1.25%, ±1.50%, ±1.75%,±2.00%, ±2.25%,and ±2.50% drift. Two numbers of cycles were applied for each drift. Cracks width, cracks patterns, gap opening, and spalling of concrete were monitored in successive two-cycle intervals of the drift. The cracks were marked with black and white markers to indicate the extension and crack propagations for every drift.



(a) Systematic arrangement of LVDTs along the column and beams

(b) Specimen is ready for testing

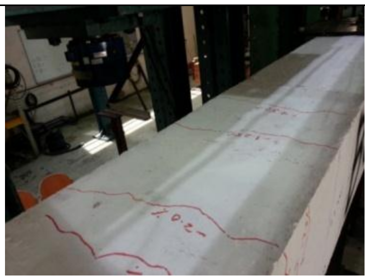
Fig. 3: Experimental set-up and specimen is ready for testing.

5. Experimental Results

5.1 Visual Observations of Crack Propagation

Figure 4 shows the transverse and longitudinal cracks occurred at top of beam Beam B1, Beam B2 and Beam B3 (B2) measurement of 0.05mm width between ±0.75% and ±2.50% drift. Figure 5(a) illustrates the hairline cracks were visible at front surface of Beam B2 for the drift between ±0.5% to ±2.25% drift. There is no structural crack such as diagonal and flexural crack occurred either on the beams or column. The hairline cracks also continuously to form at the soffit of beam between ±0.75% and ±2.25% drift as shown in Figure 5(b). Figure 6(a) shows diagonal cracks occurred at top surface of column C1 between ±0.75 % and ±2.50% drift with cracks width of 1mm. Figure 6(b) exhibits the more diagonal cracks occurred at beam-column interface. Even though there are cracks occurred on the beam and column but it can sustain higher lateral load and bigger lateral displacement. It is indicated that the interior beam-column joint which designed using Eurocode 8 is strong enough to survive under earthquake as compare to interior beam-column joint with corbel which designed using BS 8110.

(a) Top of Beam B1



(b) Top of Beam B2

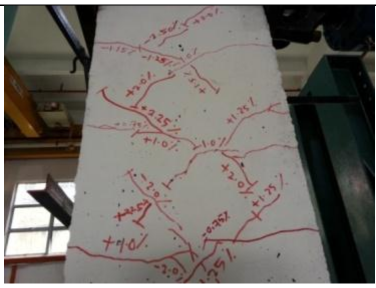
(c) Top of Beam B3

Fig. 4*:* Longitudinal cracks with ±0.05mm width at between ±0.75% drift and ±2.50% drift.

(a) Cracks at interface between Beam B1 and Column C1

(b) Spalling of concrete at interface Beam B2 and Column C1

Fig.5*:* Large cracks with ±5mm width were observed at between ±2.25% and ±2.50% drift.



(a) Diagonal cracks at top surface of Column C1

(b) Cracks at interface beam and column

Fig. 6*:* Diagonal cracks with ±1mm width were observed between ±0.75 % and ±2.50% drift.

5.2 Hysteresis Loop (Load vs Displacement)

Figure 7 shows the hysteresis loops of the specimen based on lateral displacement data recorded by LVDT 1. The hysteresis loops has a uniform increment of ±0.25% drift from 0.01% to 2.50% drift. However, at 2.50% drift, the specimen had experienced the strength degradation where the reduction of strength after the ultimate strength achieved. From hysteresis loops, the lateral strength capacities of specimen started with linear elastic region and continue to inelastic region before reaching strength degradation at ±2.50% drift. The interior beam-column joint was responses to in-plane cyclic loading in pushing directions (+ve) and pulling direction (-ve). Figure 8 shows the comparison of load versus displacement backbone for both cycles for every drift between Eurocode 8 and BS 8110. The ultimate lateral strength in pushing direction is 301.58 kN and ultimate lateral displacement of 84.84 mm. The yield displacement (Δ_y=25.71 mm), yield load (F_y = 194.22 kN), ultimate lateral displacement (F_{ult} = 84.84 mm) and ultimate lateral load (F_{ult} = 301.58 kN). These values of yield displacement and ultimate displacement are used to calculate displacement ductility.

5.3 Ductility

The displacement ductility of the specimen is determined based on the ratio of applied lateral displacement (Δ_x) to the yield lateral displacement (Δ_y). Table I shows the displacement ductility factor for the pushing direction of the tested specimen. The maximum displacement ductility for interior beam-column joint is 3.74 for the second cycle which is higher than the first cycle, μ = 3.71. The acceptable ductility value for a reinforced concrete structure to withstand a moderate earthquake is between 3 and 6 (3<μ<6). Based on the result obtained, the calculate ductility is exceeding 3.

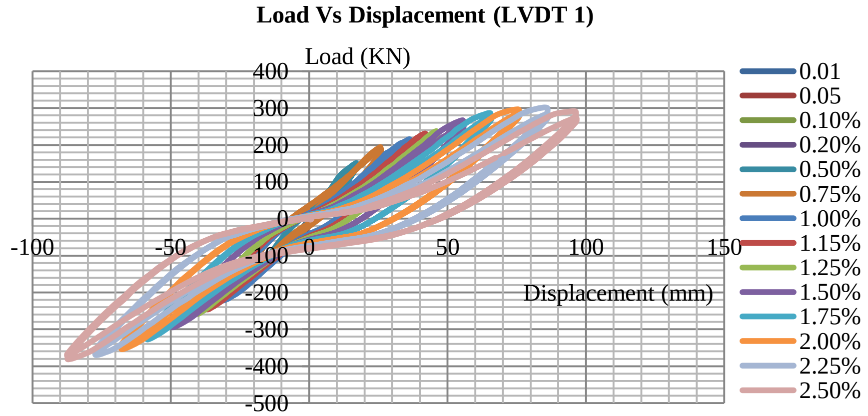


Fig. 7: Hysteresis loops for tested specimen until ±2.50.0% drift.

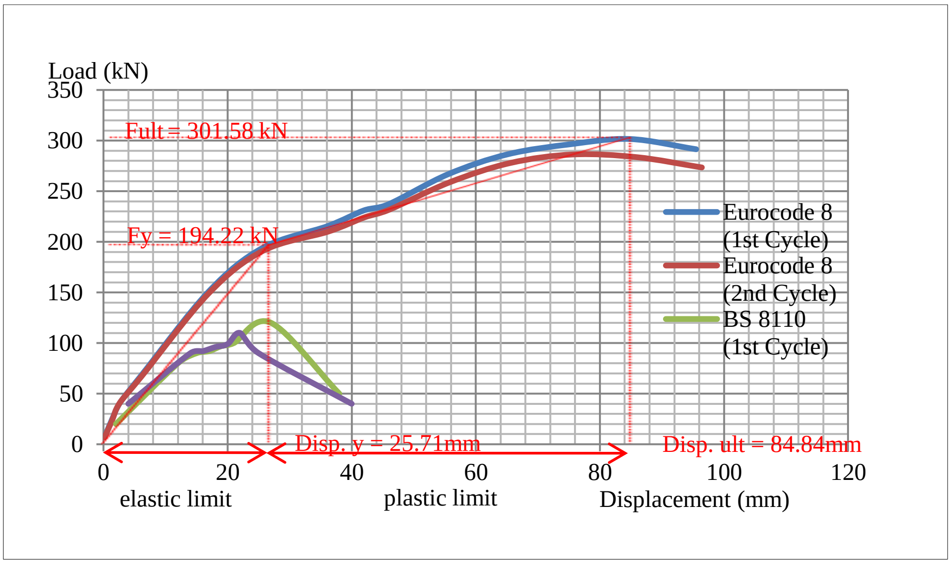


Fig. 8: Load vs Displacement Curve for both cycles

TABLE I: Ductility For Positive Direction Of Tested Specimen

Target drift (%)	POSITIVE DIRECTION (PUSHING)					
	1st Cycle			2nd Cycle		
	Lateral disp	Yield disp	Ductility	Lateral disp	Yield disp	Ductility
	Δx	Δy	μ = Δx/Δy	Δx	Δy	μ = Δx/Δy
0.01%	0.20	25.7100	0.0078	0.16	25.7700	0.0062
0.05%	1.28	25.7100	0.0498	1.30	25.7700	0.0504
0.10%	2.72	25.7100	0.1058	2.60	25.7700	0.1009
0.20%	6.20	25.7100	0.2412	6.16	25.7700	0.2390
0.50%	16.97	25.7100	0.6601	16.95	25.7700	0.6577
0.75%	25.71	25.7100	1.0000	25.77	25.7700	1.0000
1.00%	36.12	25.7100	1.4049	36.24	25.7700	1.4063
1.15%	41.96	25.7100	1.6320	42.06	25.7700	1.6321
1.25%	46.00	25.7100	1.7892	46.04	25.7700	1.7866
1.50%	55.53	25.7100	2.1599	55.75	25.7700	2.1634
1.75%	65.19	25.7100	2.5356	65.59	25.7700	2.5452
2.00%	75.40	25.7100	2.9327	75.72	25.7700	2.9383
2.25%	84.84	25.7100	3.2999	86.00	25.7700	3.3372
2.50%	95.51	25.7100	3.7149	96.43	25.7700	3.7419

5.4 Equivalent Viscous Damping

Figure 9 shows the equivalent viscous damping versus drift curve for both cycles of tested specimen. The equivalent viscous damping for first cycle is higher than second cycle. For the first cycle, the equivalent viscous damping for specimen started to increase at 1.0% drift up to failure at 2.50% drift while for the second cycle it is start to increase at 0.75% drift until failure at 2.50% drift. This is because for the first cycle required more energy to resist the strength capacity of interior beam-column joint as compared to the second cycle. It also shows that interior beam-column joint with fuse-bar can absorb better energy than beam-column joint without fuse-bars or energy dissipater.

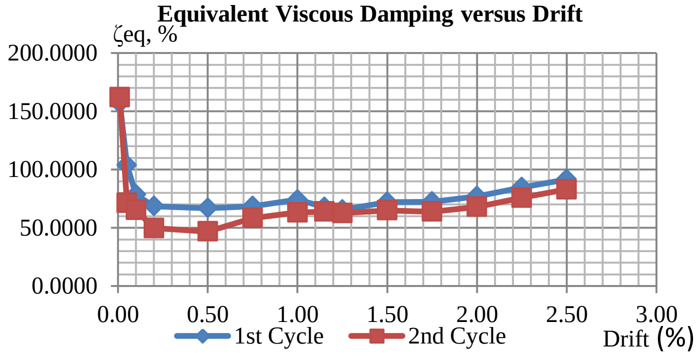


Fig. 9: Equivalent viscous damping vs drift for interior beam-column joint

6. Conclusions and Recommendations

The following conclusion and recommendation can be drawn based on the visual observation, experimental results and analysis of the results:

- The interior beam-column joint with fuse-bars which designed in accordance Eurocode 8 has performed better than the joint designed using BS8110 with maximum drift of ±2.5% drift.
- The maximum ultimate lateral strength in pushing direction is 301.58 kN with ultimate lateral displacement of 84.84 mm. The yield displacement and load are is 25.71mm and 194.22 kN, respectively. The hysteresis loops behave bilinear which composes of linear region and plastic region.
- The maximum displacement ductility for interior beam-column joint for the second cycle is 3.74 which is higher than the first cycle which is 3.71. The acceptable displacement ductility value for a RC structure to withstand a moderate earthquake is between 3 and 6. Since the specimen with

fuse-bars did not experience severe damages, it can be concluded that the RC buildings will survive under moderate or strong earthquake.

- The specimen with fuse-bars has high lateral strength, stiffness, ductility and equivalent viscous damping and can be adopted for the construction of building in medium seismic regions in the world.
- It is recommended to use fuse-bars together with designed in accordance with Eurocode 8 for interior beam-column joints and RC buildings to cater for Ductility Class Medium (DCM) for the moderate seismic regions in East Malaysia especially in Sabah regions.

7. Acknowledgment

The authors wish to acknowledge the funding from the Ministry of Science, Technology and Innovation of Malaysia (MOSTI) and the Research Management Institute, University Teknologi MARA, Malaysia for their support. Nevertheless, the authors also want to express their gratitude to the technicians of Heavy Structures Laboratory, postgraduate and undergraduate students of Faculty of Civil Engineering, UiTM for their involvement and conducting this research work successfully.

8. References

[1] N.H. Hamid, S.M. Saleh and S.A. Anuar, "Seismic performance of double-unit form building under in-plane lateral cyclic loading", Structures Under Shock and Impact XIII, Vol. 141, ISSN No: 1743-3509, pp 467-472, 2014.

http://dx.doi.org/10.2495/susi140401

[2] K.D. Ghani and N.H. Hamid, "Experimental Investigation on a non-seismic precast RC beam-column exterior joint under quasi-static lateral cyclic loading", Safety and Seismic Engineering V, Vol. 134, WIT Press, pp 827-837, 2013.

http://dx.doi.org/10.2495/safe130731

[3] N.H. Hamid and M.A. Masrom, "Seismic performance of wall-slab joints in Industralized Building System (IBS) under out-of-plane reversible cyclic loading", IACSIT International Journal of Engineering and Technology, Vol. 4, No.1, pp 26-33, 2012.

http://dx.doi.org/10.7763/IJET.2012.V4.313

[4] P.L.Y. Tiong, A. Adnan, N.H.A Hamid, "Behaviour factor and displacement estimation of low-ductility precast wall system under seismic actions, Earthquakes and Structures, Vol. 5, Issue 6, Techo-press, pp 625-655, 2013.

[5] W. Xue and X. Yang, "Seismic tests of precast concrete moment resisting frames and connections, PCI Journal, Vol. 55, Issue 3, pp102, 2010.

http://dx.doi.org/10.15554/pcij.06012010.102.121

[6] A.G. Kay Dora and N.H. Abdul Hamid, "Experimental Investigation on Non-Seismic Precast Beam-Column Interior Joint Subjected to Lateral Cyclic Loading", Proceeding the 6th Civil Engineering Conference in Asia Region: Embracing the Future through Sustainability ISBN No: 978-602-8605-08-3, pp. 1-8, 2013.

[7] X. Lu, T.H. Urukap, S. Li and F. Lin, "Seismic behaviour of interior RC beam-column joints with additional bars under cyclic loading", Earthquakes and Structures, Vol. 3, No. 1, pp 37-57, 2012.

http://dx.doi.org/10.12989/eas.2012.3.1.037

[8] C.A. Shutt, "Hybrid precast frame meets seismic challenges" ASCENT, Spring 1997, pp14-19, 1997.

[9] J. Restrepo and A. Rahman, " Seismic performance of self-centering structural walls incorporating energy dissipaters," Journal of Structural Engineering, Vol. 133, Special Issue: Precast-prestressed concrete structures under natural and human-made hazards, pp1560-1570, 2007.

[10] G.W. Rodgers, R.P. DHakal, J.G. Chase, J.B. Mander, G.A. MAcRae, T.J. Mander and K.M. Solberg, "Investigation of Rocking Connections Designed for Damage Avoidance with High Force-to-Volume Energy Dissipation," Proceedings of the 14th World Conference on Earthquake Engineering 2008, Beijing, China, October 12-17. 2008.

[11] N.H. Hamid and J.B. Mander, "Lateral Seismic Performance of Multipanel Precast Hollowcore Walls." Journal of Structural Engineering, ASCE, Vol.136, Issue 7, pp. 795-804. 2010.

http://dx.doi.org/10.1061/(ASCE)ST.1943-541X.0000183

[12] D.J. Miller, L.A. Fahnestock and M.R. Eartherton, "Self-Centering Buckling-Restrained Braces for Advanced Seismic Performance," Proceedings of the Structures Congress 2011, Las Vegas, NV, April 14-16, 2011.

http://dx.doi.org/10.1061/41171(401)85