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Stress-Strain Relationship of Unbonded Fuse Bars Subjected to In-Plane Lateral Cyclic Loading

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Abstract: *Past earthquakes demonstrated that beam-column joint of RC buildings had suffered severe damage, spalling of concrete and buckling of reinforcement bars due to insufficient transverse reinforcement when designed to BS8110. The non-seismic design of beam-column joint without energy dissipators cannot dissipate energy which comes from earthquake load. This paper investigates the stress-strain relationship of unbonded steel fuse bar embedded at interior beam-column and tested under in-plane lateral cyclic loading. Fuse-bars were designed using Eurocode 8, constructed and tested until it's failed. The interior beam-column joint was tested up to 2.25% drift before partial collapse at 2.5% drift. Based on the experimental results, it was found that fuse-bar yielded at 1.15% drift. As the percentage of drift increase, the ductility of the structure increase and the building will survive under moderate earthquake. It can be concluded that the theoretical agrees to the experimental results of sub-assemblage interior beam-column joint when tested under in-plane lateral cyclic loading.*

Keywords: *unbounded fuse-bars, collapse, energy dissipators, stress-strain, ductility*

1. Introduction

An earthquake can cause major disaster and damage to the buildings, infrastructures and business interruption. The existing multi-storey and high-rise buildings in Malaysia which were designed in accordance with British Standard (BS8110-1:1997: Part 1: Code of practice for design and construction) did not have any provision for the earthquake which cause the failure and collapse of these buildings under severe or strong earthquake [1,3]. Previous study shows that interior, corner and exterior beam-column joint which were designed according to BS8110 can only sustain up to 1% drift [4,7,8]. Generally, the damages in RC buildings after the earthquake mostly occurred due to poor detailing, poor workmanship, low compressive strength of concrete, lack of transverse reinforcement at beam-column joints and strong beam-weak column mechanism [6]. The non-seismic design beam-column joint becomes significant, especially under moderate to high earthquake. Recent earthquakes have demonstrated catastrophic failures associated with joint core damage [5].

Eurocode 8 has a specific set of guidelines for seismic design of structures and substructures. Energy dissipator such as fuse-bar is made from high yield reinforced bars can reduce the damage of joint which acting efficiently in tension and compression zone. By incorporating fuse-bar as energy dissipator, the ductility of the beam-column joint can be improved and damage can be reduced [2]. A study on the performance of mild steel acting as fuse-bars and post-tensioned as self-centering mechanism in the hybrid moment resisting frame[10]. They found that the seismic performance can improve in terms of life cycle costs, simplicity, speed and safety. A similar approach was conducted using precast hollow core walls were filled with unbonded prestressing tendons and a pair of fuse bar. The end result shows no damage after being tested up to 4% [11].

However, the intention of this study is to investigate the stress-strain relationship of interior beam-column joint designed using Eurocode 8 and furnished with unbonded fuse-bars under in-plane lateral cyclic loading. By conducting this experimental work, it is expected that this kind of joint will survive under moderate earthquake and remain functional after the earthquake.

2. Specimen Design

2.1 Fuse Bars

Control condition of tensile strength properties is that the tensile strength must not be less than 1.25 times the actual yield strength [10]. Steel threads of 20mm diameter were fabricated from steel reinforcement bars of 25mm diameter by using the lathe machine. Tensile test is carried out to analysed the stress-strain behavior of the 20mm fuse bars. Two anchorages were fixed on both ends of the specimen and extensometer was clamped to the middle section of the fuse bar. The gauge length of the extensometer, L_o is 100mm. The tension loading rate was 5mm/min and the load was applied until the bar breaks. The yields stress is 534MPa and yields strain is 0.0015. The low strain result of the fuse bar indicates that the bar have lower ductility. The stress and strain result was then used to analysed the effects of sizes of fuse bars on lateral strength of the interior beam-column joint. Figure 1 shows 20mm diameter fuse bar with strain gauge while Figure 2(a) shows the stress-strain curve of 20mm fuse bar and (b) proposed lateral strength curve. It was found that the proposed ultimate lateral load for 20mm diameter fuse bar was 305.01kN for push and pull.

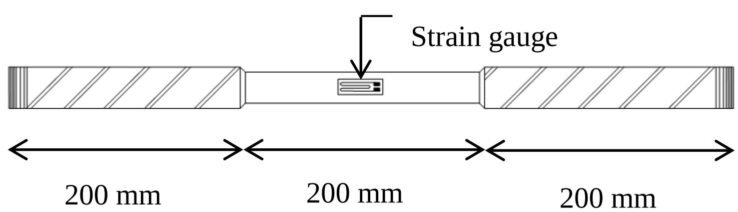
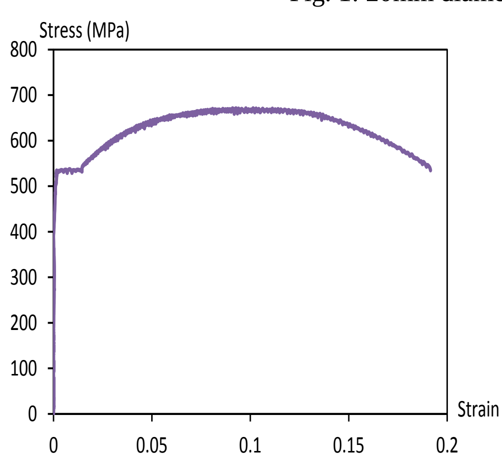
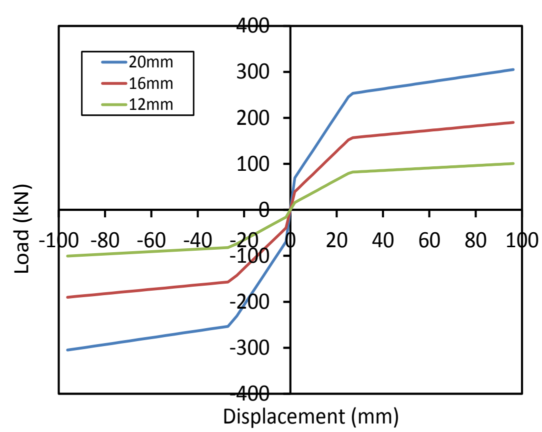


Fig. 1: 20mm diameter fuse bar with strain gauge



(a) Stress-strain of 20mm fuse-bars



(b) Analysis of lateral strength for 12mm, 16mm and 20mm diameter fuse-bar

Fig. 2: Analytical modeling of beam-column joint using difference size of fuse-bar.

2.2 Beam-Column Joint

The interior beam column joint was designed according to Eurocode 8 with 0.2 g PGA value. Two in-plane beams and one out-of-plane beam were anchored to the column. The reinforcement bars near the joint were replaced with fuse-bars and connected using bar-break coupler. The bar-break couplers help to avoid the conventional lap splicing near the joint. A total of eight gauges were placed on all each fuse bars located in the beam-column joint to measure the stress and strain performance of the beam-column joint. Strain gauges 1 to 4 (SG1, SG2, SG3, SG4) were located along the top fuse bars while strain gauges 5 to 8 (SG5, SG6, SG7, SG8) were located at the bottom fuse bars. The fuse bars were left unbonded to avoid the strain gauges from getting in contact with concrete. However, only SG2, SG3, SG6 and SG7 is analysed in this paper. The interior beam-column joint specimen was tested under in-plane lateral cyclic loading under 14 set of drifts. The drifts starts from 0.01% ended at 2.5% where the specimen failed. Percentage drift is taken as displacement over height of the specimen times by 100. Figure 3 shows the detailing of the interior beam-column joint while Figure 4 shows the position of fuse bars with strain gauge in the joint, located in (a) top reinforcement bars and (b) bottom reinforcement bars.

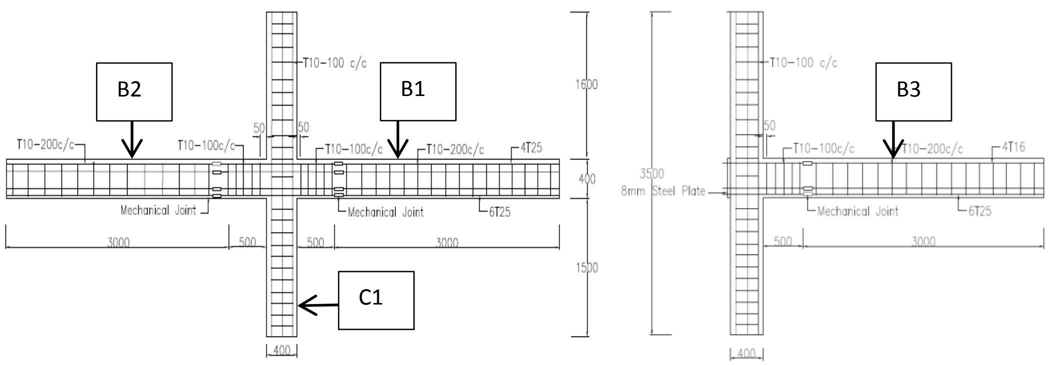
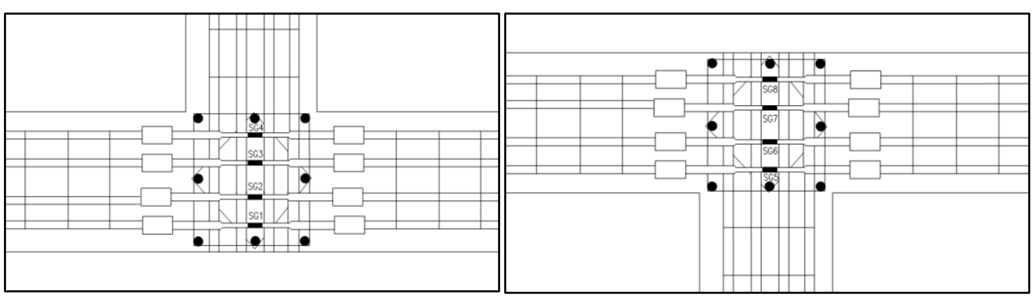


Fig. 3: Detailings of interior beam-column joint



(a) (b)

Fig. 4: Position of strain gauges at the joint.

3. Stress-strain relationship under cyclic loading

3.1 Visual Damage

During experimental work, the crack patterns were observed for every load applied to the top of column with targeted drift. The cracks appeared were marked alongside the percentage of drift that produced after the test. Initially, ±0.01% drift was applied at top of the column and there was no visible hairline crack on the surface and at the contact surface between beam and column interface. Longitudinal cracks occurred at top of beam one (B1), beam two (B2) & beam three (B3) with ±0.05mm opening occured between ±0.75% drift and ±2.50% drift. The drift between ±0.75 % drift and ±2.50% drift, many hairline cracks with ±1mm width started to form on the top surface of column C1 and at interface of column to beam. Figure 5 shows some crack opening near the beam to column interface on B1 and B2.

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Fig. 5: Crack opening at beam to column interface

3.2 Hysteresis Loops

Hysteresis loop measures the performance of structure starting from elastic range to non-elastic range. It can be achieved by plotting the graph of load versus displacement from loading and unloading of a complete one cycle movement. Figure 6 shows the hysteresis loops of the interior beam-column joint under lateral cyclic load and Figure 7 shows the graph of lateral strength obtained based on maximum lateral load from each drifts. The ultimate lateral load is 301.58kN at 2.25% drift and the ultimate displacement is 84.84mm while the yield lateral load is taken at 75% from the ultimate lateral load (Park, 1988). The yield lateral load is 226.19kN and by interpolation, the yield displacement is 40.14mm. The interior beam-column joint experience strength degradation after 2.25% drift. By comparing the experimental and analytical lateral strength, it can be said that the proposed procedure agrees with the data well in pushing direction. However, major difference can be seen in pulling direction where experimental strength exhibits higher lateral load of 381.47kN.

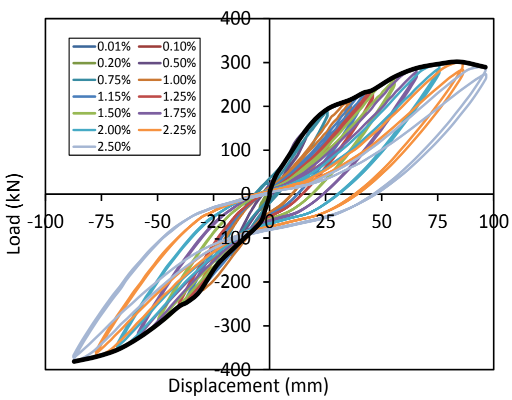


Fig. 6: Hysteresis loops of interior beam-column joint.

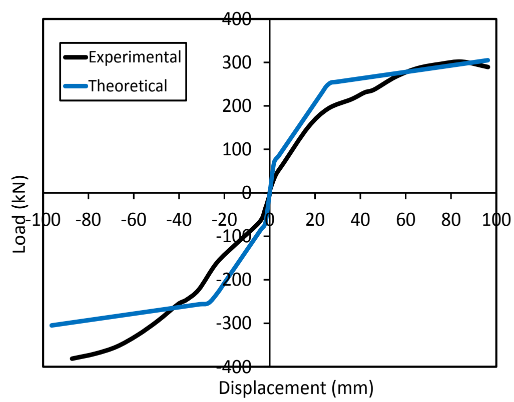
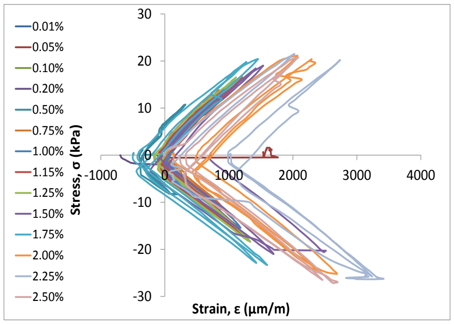


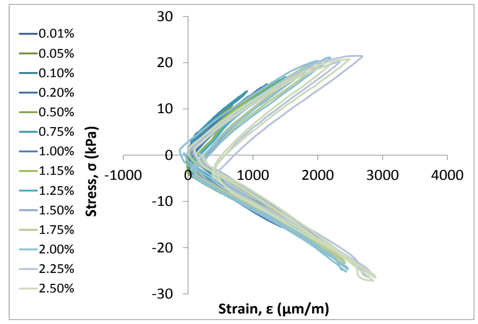
Fig. 7: Comparison between analytical modeling and experimental results of the joint.

3.3 Stress-strain Under Cyclic Load

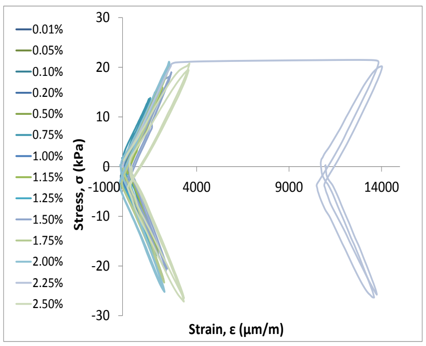
The reinforced concrete members suffered crack opening and closing throughout their loading and unloading history. Figure 8 shows the stress-strain relationship for interior beam-column joint with eight 20mm unbonded fuse bars under lateral cyclic loading. The stress-strain relationship differs from many aspects. Based on graph of lateral strength, the beam-column joint started yielding at 1.15% drifts. There is an obvious weakening effect on the tensile capacity for the bottom fuses and this shows that the two fuse bars (SG 6, SG 7) located at the bottom of the joint yielded earlier than top fuses with the development of plastic strain and undergo major deformation towards reaching the ultimate load. This result goes in hand with the theory that under cyclic test, buckling of a longitudinal reinforcing bar takes place in the tensile strain region of the cyclic stress-strain curve [12].



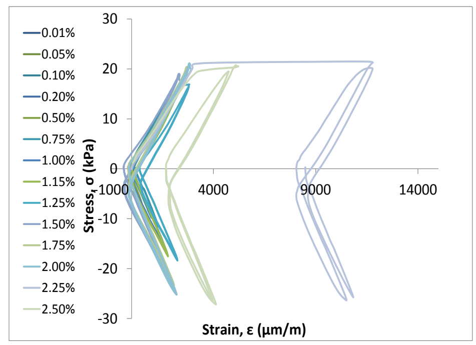
(a) SG 2



(b) SG 3



(b) SG 6



(d) SG 7

Fig. 8: Stress strain relationship for 20mm fuses bars in interior beam-column joint

4. Conclusion

This study evaluate the stress-strain relationship for interior beam-column joint equipped with unbonded 20mm unbonded fuse bars taken from a 25mm diameter high tensile bar. The specimen was subjected to lateral cyclic load starting at 0.01% drift until 2.5% drift. It was shown that the onset yielding of the unbonded fuse bars started at 1% to 1.15% drift and failed at 2.5% drift. As a conclusion, the beam-column joint shows better stress-strain relationship when designed using Eurocode 8 as compared to BS8110. However, with the installation of the 20mm unbounded seismic fuses as energy dissipators, the lateral strength of the interior beam-column joint can be increased.

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6. References

[1] Ghani, K.D., and Hamid, N.H., “Experimental Investigation on A non-seismic Precast RC Beam-column Exterior Joint Under Quasi-static Lateral Cyclic Loading”, Safety and Seismic Engineering, WIT Press, ISSN No:1743-3509, Vol. No. 134, pp 827-837, 2013.

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

[2] Hamid, N. H. “Seismic Damage Avoidance Design Of Warehouse Buildings Constructed Using Precast Hollow Core Panels”, PhD thesis, University of Canterbury, Christchurch, New Zealand, 2006

[3] Hamid, N.H., “Seismic Performance of Beam-column Joints in Reinforced Concrete Buildings Subjected to Reversible Vertical Cyclic Loading”, Malaysian Journal of Civil Engineering, 22(2), pp 264-290, 2010.

[4] Hamid, N.H. and Anuar, S.A. “Seismic Risk Assessment Of Three Types Of Exterior Beam-Column-Joint Using Fragility Curve”, Risk Analysis IX, Volume 47, pp 85-92, 2014

http://dx.doi.org/10.2495/RISK140081

[5] Hamid, N.H., Hadi, N.D. and Ghani, K.D. “Retrofitting Of Beam-Column Joint Using CFRP And Steel Plate”, International Journal of Civil, Architectural Science and engineers, Vol. 7, pp 542-548, 2013

[6] Hamid, N.H. and Mander, J.B. “A Comparative Seismic Performance Between Precast Hollow Core Walls and Conventional Walls Using Incremental Dynamic Analysis”, Arabian Journal for Science and Engineering, Vol. 7, Issue 7, pg 1801-1815, 2012

http://dx.doi.org/10.1007/s13369-012-0301-7

[7] Kay Dora A.G. & Abdul Hamid, N.H. “Comparing The Seismic Performance Of Beam-Column Joints With And Without SFRC When Subjected To Cyclic Loading”, Advanced Materials Research, 626, 85, 2012

http://dx.doi.org/10.4028/www.scientific.net/AMR.626.85

[8] M.A. Tukiar, K. Dora, A. Ghani and Hamid, N.H. “Seismic Performance and Assessment of Precast Beam-Column Corner Joint Subject to Reversible Lateral Cyclic Loading”, Applied Mechanics and Materials, Vol. 661, pp 128-133, 2014

http://dx.doi.org/10.4028/www.scientific.net/AMM.661.128

[9] Rodriguez, M.E. Botero, J. C. Villa, J. “Cyclic Stress-Strain Behavior of Reinforcing Steel Including Effect of Buckling” Journal of Structural Engineering, Vol. 125, pp. 605-612., 1999

http://dx.doi.org/10.1061/(ASCE)0733-9445(1999)125:6(605)

[10] Shutt, C.A. “Hybrid Precast Frame Meets Seismic Challenges”, ASCENT, Spring 1997, pp. 14-19, 1993

[11] Hamid, N.H. and Mander, J.B. "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] Suda, K., Murayama, Y, Ichinomiya, T. and Shimbo, H. “Buckling Behavior Of Longitudinal Reinforcing Bars In Concrete Column Subjected To Reverse Lateral Loading” Proc. In 11th Conference on Earthquake Engineering, Elsevier Science, New York, Amsterdam, 1996

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