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STRUCTURAL PERFORMANCE OF TWO TYPES OF WALL SLAB CONNECTION UNDER OUT-OF-PLANE LATERAL CYCLIC LOADING

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Abstract

Currently, most of the high-rise buildings in Malaysia are constructed using tunnel form system. However, this type of structural system is still questionable of its safety under ground motion. Thus, the main objective of this study is to test and compare the structural performance of two types of wall-slab connection namely cross and anchorage bracings under reversible quasi-static cyclic loading. Two identical sub-assemblage of wall-slab connections are designed, constructed and tested in heavy structural laboratory. A load actuator together with load cell was positioned horizontally at the upper part of the wall for applying the lateral cyclic load. The experimental result shows that the anchorage bracing connection has higher strength, higher ductility, better energy absorption and less structural damage as compared to cross-bracing connections. Based on this experiment, the ductility of anchorage bracing connection is $\boldsymbol{\mu=6}$ which satisfies the requirement of ductility for seismic code of practice. Anchorage bracing connection can resist earthquake loading better than cross-bracing connections. Therefore, it is recommended to the construction industry to adopt this kind of design together with the detailing which consists of double layer of wire fabric at the connections. As a conclusion, the anchorage bracing connection has better seismic performance as compared to cross-bracing connection under lateral cyclic loading.

Keywords: Tunnel form system, Anchorage bracing connection, Cross-bracing connection, Lateral cyclic loading, Ductility, Energy absorption.

1. Introduction

As one of the most favorable architectural systems, shear walls play great role in resisting lateral force which normally located at lift shaft or external wall. The

Nomenclatures

BRC	Steel fabric
EVD	Equivalent viscous damping
F	Force, kN
k	Stiffness, kN/mm
LVDT	Linear variable differential transformer
SG	Strain gauge
UB	Universal beam
Greek Symbols	
Δu	Ultimate Displacement, mm
Δy	Yielding Displacement, mm
δ	Lateral Displacement, mm
μ	Ductility Ratio, %

lateral load may come from wind loading, earthquake loading, hydrodynamic pressure from tsunami and landslide. However, the connections between floor slabs and shear walls constitute a potential weak link in structures to resist the combination of lateral and vertical loading. Wall-slab connection can develop a critical stress contour line under the worst combination of loading in this region during sway mode. To avoid redistribution of forces from wall panel to floor slab, the connection should be designed with sufficient percentage of reinforcement, and by considering stress concentration at the jointing system [1].

Concrete load-bearing panel structures are currently a popular and economical structural system utilized in the residential and commercial international construction markets [2]. These structures can be constructed using two types of joints, namely known as dry jointed system and monolithic system. In monolithic system, the wall-slab connections are constructed using cast-in-situ concrete with fixed-based connections which possess moment resistance, stiffness, strength and ductility. In contrast, dry jointed connection can be assembled either using grouting or silicon sealant. The dry jointed connection has significantly lower stiffness, strength and no moment resistant as compared to monolithic system.

Starting from the tunnel form system and its wide applications nowadays in the construction market, research evolves rapidly on improving the wall-slab connection detailing. The focus nowadays, however, is on the structural performance of the wall slab sub-assemblage to resist lateral cyclic loading which comes from earthquake loading. The structural and seismic performance of the wall-slab connection becomes more important nowadays as there are increasing numbers of projects which utilize this technology in Malaysia and located closed to the most active tectonic plate in the world known as micro-Burma Sunda plate. Wall-slab construction (tunnel form system) technology gains its popularity as time becomes the deciding factor [3]. Moreover, this technology permits architectural flexibility, clean construction, more clear space, less building height, easier formwork, and shorter construction time.

The main aim of this study is to investigate and compare the structural performance of two types of wall-slab connection, namely cross and anchorage under lateral cyclic loading. Structural performance in term of strength, stiffness and ductility are the focus of this research. Furthermore, comparison in term of energy dissipation and crack initiation and propagation between the two types of connection is also evaluated.

Experimental investigations on the inelastic lateral behavior of four-story tunnel form buildings under lateral cyclic loading were conducted by Bahadir and Kalkan (2007) [4]. Their research involved two four-story scaled building specimens that were tested under quasi-static cyclic lateral loading in longitudinal and transverse directions. The experimental results indicated that lightly reinforced structural walls of tunnel form buildings may exhibit brittle flexural failure under seismic action. The propagation of cracks intensified clearly at the region of the connections which constitutes the weak zone.

Nakashima and Lu carried out series of experimental work on the behavior of wall-slab connections in early 1980s [5]. The specimens represented the typical slab system of an idealized multi-storey prototype structure. A total of two floor assemblies were built and tested under various combinations of in-plane and out-of-plane loads. Each specimen consisted of three panels supported by walls at the interior third-points, and by columns at the edge. In all specimens, formation of a major sliding crack extending parallel to the wall, at the boundary where some longitudinal reinforcing bars were limited, governed the in-plane capacity of the slabs.

There is very limited research regarding wall-slab connections in tunnel form system under seismic loading. Previous research was focused more on the overall seismic performance of the whole tunnel form system rather than particular attention on the jointing system especially at wall-slab connection. Therefore, the intention of this paper is to examine the seismic performance of two different types of wall-slab connections namely, anchorage and cross-bracing connections under seismic loading. After conducting the experimental work and analysis of these two types of connections, this paper will propose the best practice of the connection to be constructed especially in Malaysia under long-distant earthquake loading.

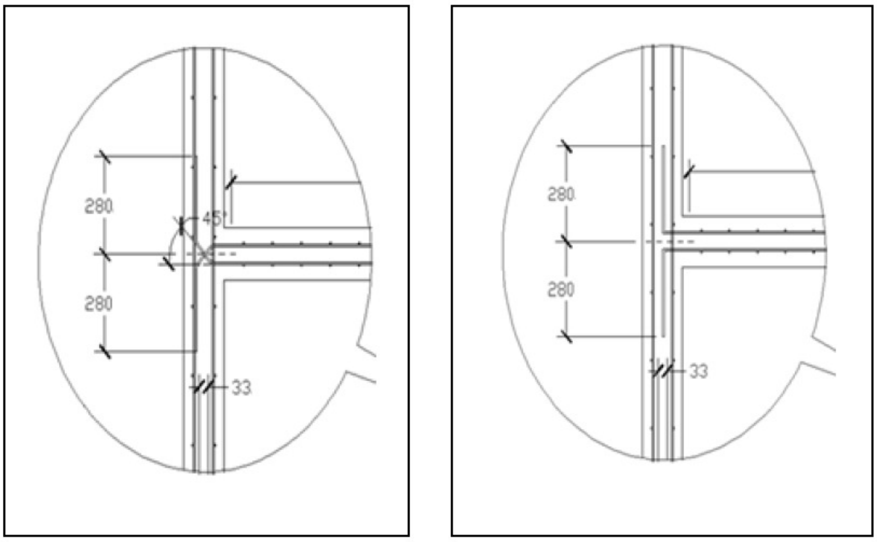
2. Experimental Work

This research concentrates on the structural performance of the wall-slab connection by testing two types of connection detailing, namely cross and anchorage bracings. The experiment utilized control displacement type of experiment where the applied load was allowed to change with time. In the sub-assemblage of wall slab system, slab end condition was set to be fixed; remain stationary, as well as the lower part of the wall. On the other hand, upper end of the wall was set to be free and receive out-of-plane lateral cyclic loading.

2.1. Specimen detailing

The specimen was constructed by considering the sub-assemblage of outer shear wall, of which represents the extension of half-scale two floors and sandwiched a slab in the middle height of the wall. The connection part of the system, of which the slab meets the wall, was detailed in two different types, namely cross and anchorage bracings. Figure 1(a) shows the detailing of cross-bracing wall-slab connection at the intersection. Figure 1(b) shows the detailing of anchorage bracing wall-slab connection at the intersection. The lapping length of steel fabric from slab to the wall is 280mm on top and bottom of connection. Although, both specimens were provided with double layered steel fabric in both slab and wall, but the connection detailing differed in them.

This study considers only the sub-assemblage of reinforced concrete wall slab connection with lateral cyclic loading applied at the upper end of the wall. The proposed dimension of the wall panel is 2000×1000×150 mm and the slab dimension is 2000×1000×150 mm. The sub-assemblage of the specimen was attached to a foundation beam with dimension of 1800×900×375 mm. Figure 2 shows the isometric view of wall, slab and foundation which was prepared in heavy structural laboratory before testing take place.



(a) Cross-bracing Connection **(b) Anchorage-bracing Connection**

Fig. 1. Connection Detailing of both Specimens.

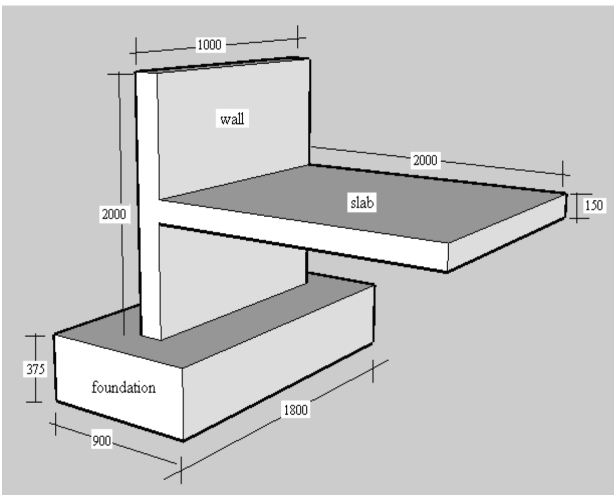


Fig. 2. Typical Dimensions of Wall-Slab Sub-Assemblage.

2.2. Preparation of samples

Two identical half-scaled of wall-slab connections as shown in Fig. 2 with two different types connections were constructed in the laboratory. The first specimen was constructed with cross-bracing connection arrangement while the second specimen was anchorage-bracing connection arrangement. The initial work started by cutting the steel fabric (BRC B-7) according to the size as specified in the design. It was followed by bending the wire fabric mesh into T-shape and tied them together using tie wires as shown in Fig. 3.

Plywood was used as a formwork to obtain the intended shape of the sample as shown in Fig. 4. The formwork was prepared on the foundation block before casting of concrete was executed. Subsequently, the BRC-A7 steel fabric was installed inside the formwork with spacer blocks of 25mm thickness to define the nominal concrete cover.

The construction of the wall-slab specimens was started by preparing the formwork, pouring the concrete and then followed by 28 days curing period. It was then followed, by setting-up the specimen inside the heavy structure laboratory and then clamping the foundation block and the slab far end to the strong floor to ensure fixed conditions occurred.

Before pouring the concrete, a total number of eighteen (18) strain gauges were glued and attached to the BRC-A7 at various locations at slab, wall and its intersection. Strain gauge is used to measure the elongation of reinforcement bar during out-out-plane lateral cyclic loading. It is important to detect, using strain gauge, weather the reinforcement bars behave linearly or non-linearly under incremental drift. The collapse mechanism occurred when the reinforcement bars started to fracture when they reached the ultimate strain and elongation. Figure 5 shows the locations of strain gauges at prescribed locations all over the specimen in both slab and wall reinforcement bars (BRC-A7). All the strain gauges were connected with wires which eventually were connected to the data logger before testing the specimen.

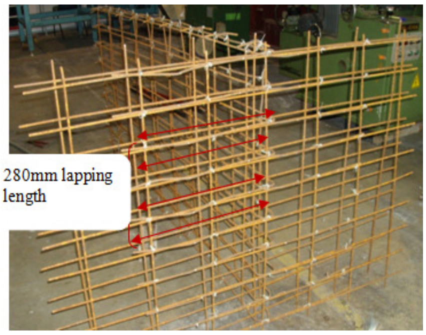


Fig. 3. Steel Fabric Prepared to be Placed inside the Formwork.

Fig. 4. Formwork Erected on the Foundation Block.

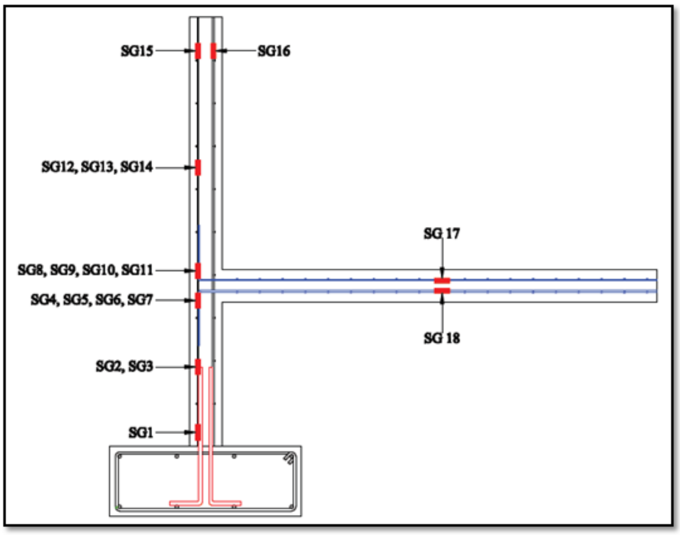


Fig. 5. Location of Strain Gauges.

2.3. Instrumentation and testing procedure

This research is a sole focus on the comparison of structural performance between the cross-bracing and anchorage type of connection. Visual inspection and observation were carried out on each specimen to determine the initial cracks, crack propagations, buckling and fracture of reinforcement bars until failure. The crack patterns, width and length of cracks were marked and measured as the cyclic loading was imposed on the top part of the wall for each successive drift. There were eighteen successive drifts that were imposed on each of the both types of connections. Damage crack pattern was highlighted using black marker pen during testing and captured using a camera.

A load actuator was positioned horizontally at the centre of top part of the wall in order to apply the lateral cyclic load on the sample. The top part of the wall was clamped using a couple of steel plates and connected to load actuator’s head. The load actuator is bolted to reaction frame as shown in Fig. 6. A total number of ten (10) LVDTs were placed on the surface of wall and floor slab in order to record the deflection when out-of-plane lateral cyclic load was applied on the specimen. Basically, there were five (5) units of LVDT located along the height of wall while the other five (5) units were placed along the span of the slab. The end of the slab is supported by the Universal Beam (UB) which is acting as fixed-end connection.

The loading regime was applied on both samples which was programmed to run into 18 succession drift with an incremental of 0.1% drift. Two cycles of loading were applied for each drift. Figure 7 shows the loading regime for wall-slab connections with displacement controlled under out-of-plane lateral cyclic loading. Drift is the ratio of lateral displacement divided by effective height of wall multiplied by 100 percent. Table 1 shows the total numbers of 36 cycles and the maximum applied drift is 2.7% equals to maximum lateral displacement of 53.49 mm.

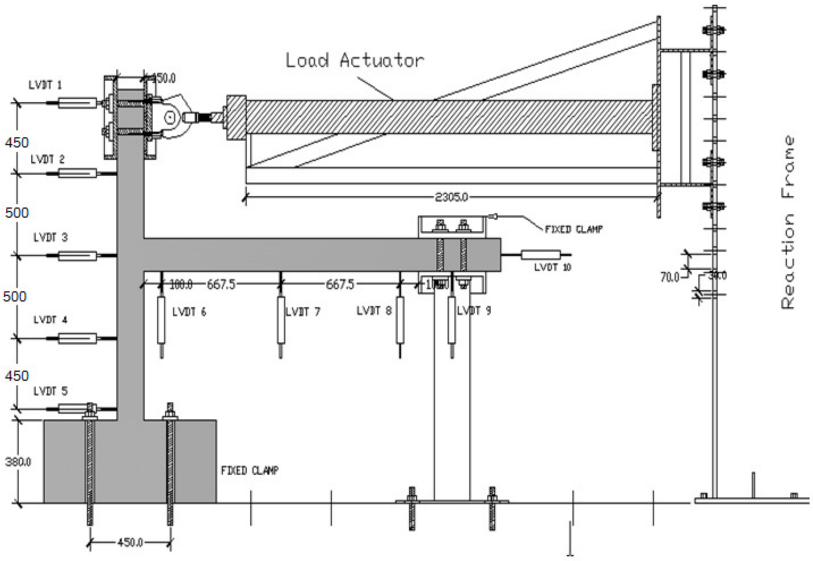


Fig. 6. Experimental Set-up and Location of LVDTs on the Specimen.

Table 1. Total Number of Cycles and Drift Applied on Specimen.

No. of Cycles	Drift (%)	Lateral Displacement (mm)
2	0.1	1.8
4	0.2	2.96
6	0.3	4.42
8	0.4	6.08
10	0.5	7.5
12	0.6	8.98
14	0.7	10.4
16	0.8	11.84
18	0.9	13.32
20	1	14.7
22	1.3	18.78
24	1.5	22.16
26	1.75	25.94
28	2	29.16
30	2.2	30.08
32	2.5	37.08
34	2.6	38.7
36	2.7	53.49

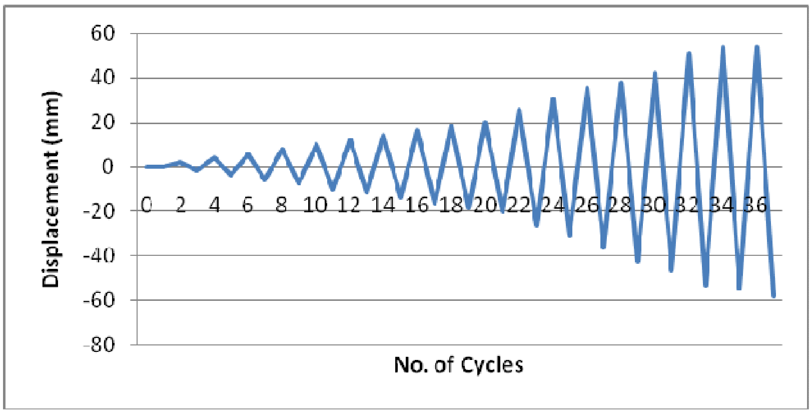


Fig. 7. Quasi-static Cyclic Loading Regime.

3. Experimental Results and Discussion

The experimental results for two sub-assemblages of wall-slab connection comprise of anchorage and cross-bracing by incorporating steel fibre are discussed in this section. The structural performance of this type of wall-slab connections are discussed in term of strength, strength degradation, ductility, equivalent viscous damping and structural damage.

This section provides a structural evaluation of wall slab-connection subjected to out-of-plane lateral cyclic loading. This evaluation presents a comparison approach of two types of connection detailing, namely cross-bracing and anchorage connections. Ductility, strength degradation and viscous damping results will be analyzed and compared between the two types of connections. Eighteen (18) cycles of drifts were imposed on wall-slab connection under out-of-plane lateral cyclic loading with an incremental of 0.1% drift with two cycles for each drift. The maximum applied loads corresponding to controlled displacements were recorded at each level of drift. The hysteresis loops for eighteen drifts have been plotted with respect to the loads.

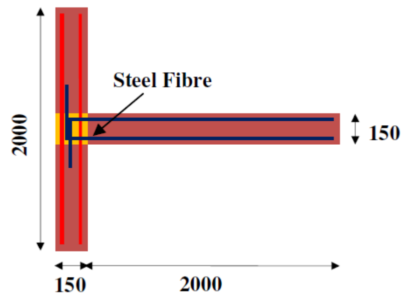
3.1. Visual observation on damage of wall-slab connection

Non-linear behaviour of reinforcement bars and concrete, such as crack prorogation in concrete and fracture of reinforcement bars are the focus areas in this section.

3.1.1. Cross-bracing connection

The specimen with cross-bracing connection has transverse cracks located at wall-slab connection. Figure 8(a) shows the arrangement of cross-bracing fabric wire mesh and location of steel fibre at the wall-slab intersection. Minor hairline cracking started to appear at the intersection section of the sample at 0.3% drift as shown in Figs. 8(b) and (c). The hairline cracks were observed more clearly in the pushing stage (right direction denotes as positive movement) of the loading compared to the pulling stage (left direction denotes as negative direction). At higher drifts level between 0.6% to 0.9%, more cracks started to appear at the upper part of the wall panel and intensified further at the connection part with major cracking started to propagate as shown in Figs. 8(d) and (e). Figure 8(f) shows the spalling of concrete cover at the back of connection because of the lacking of confinement in concrete and inexistent of shear reinforcement or stirrup at the connection regions. Further evidence shows that the diagonal cracks started to develop covering both sides of the connection.

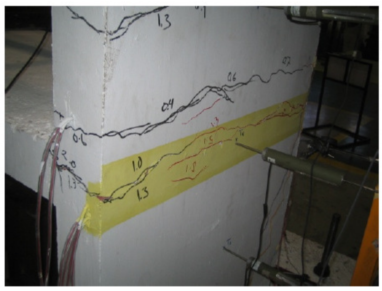
Finally, at 2.7% drift, the connection started collapsing imminently of which large displacement was undergone by the connection in the pushing stage which made it difficult for the experiment to be continued with the LVDTs attached to the wall. It is worth mentioning that, the collapse happened at the connection region, although cracks and spalling of concrete cover occurred at slightly upper part of wall panels. Figure 8(g) shows the fractures of fabric wire mesh and Fig. 8(h) demonstrates that the top part of wall was broken into two pieces under out-of-plane loading. In this type of connection, cracks initiated at wall-slab interface and then propagated diagonally at the connection that could be inferred because of the detailing of the connection at the first place.



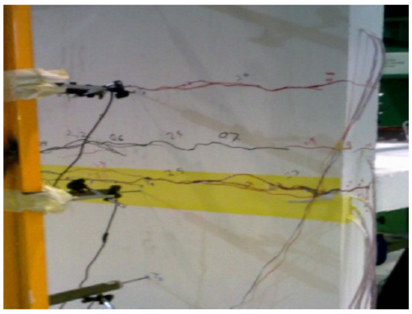
a) Wall-Slab Sub-assemblage with Cross Connection.

b) Minor Hairline Cracks Appearing at the Side at the Connection at 0.3% Drift.

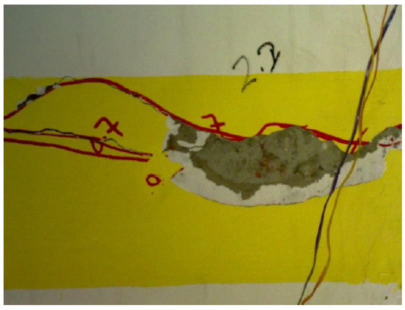
c) Diagonal Cracks Propagate across the Connection.



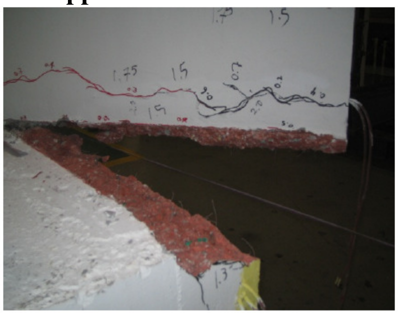
d) Cracks Intensified at the Back of the Connection.



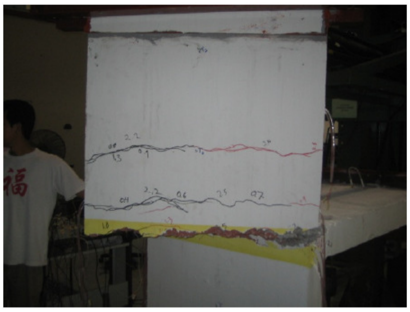
e) Cracks Appear at the Upper Part of the Wall.



f) Concrete Spalling Starts to Appear at the Back of the Connection.



g) Breakage of the Specimen at the Connection Part.



h) Top Portion of the Wall been Held away from the Sample.

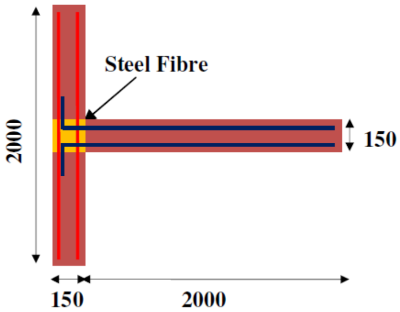
Fig. 8. Visual Observation on Damage for Cross-Bracing Connection.

3.1.2. Anchorage connection

Anchorage connection is the usual type of connection used in the construction of medium and high-rise buildings in Malaysia. In this experiment, it was observed that the structural failure did not occur at the connection of the wall-slab but rather happened at upper part of wall where the location of the anchorage reinforcement cut-off point.

First hairline cracks appeared at approximately 200mm above the anchorage connection. This location is situated at the anchorage steel fabric wire stop. Figure 9(a) shows the arrangement of double layers fabric wire and location of steel fibre. The cracks started at 0.3% drift at both faces of the wall as shown in Figs. 9(b) and (c). As loading increased, potential cracks appeared at the connection and at the top part of the wall as shown in Figs. 9(d) and (e). At later drift of nearly 1.5% and 1.75%, damage intensified at the wall, at anchorage location, followed by spalling of concrete cover. At this higher load intensity, the crack opening became greater and cracks penetrated through the depth of the wall during the consecutive drift stages.

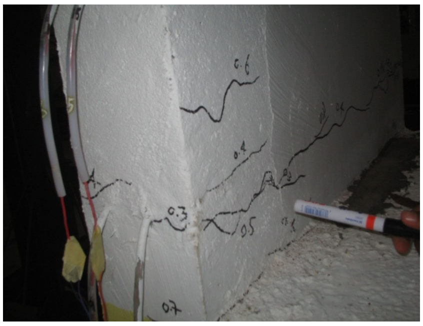
At this connection, it was observed that cracks were first initiated diagonally at the connection, leaving the wall slab interface without any significant appearing of cracks.



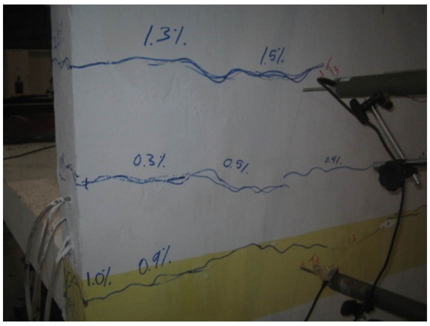
a) Wall-Slab Sub-assemblage with Anchorage Connection Incorporating Steel Fibre.

b) Minor Hairline Cracks Appearing at the Back at the Wall at 0.3% Drift.

c) Spreading of Cracks across the Wall.



d) Cracks intensified at the Front Face of the Wall at the Anchorage Location.



e) Major Cracks intensified at the Anchorage Location and Hairline Cracks at the Connection.

f) Spalling of Concrete at the Anchorage Location and Hairline Cracks at the Top of the Wall.

Fig. 9. Visual Damage on Anchorage Connection.

3.2. Strength

Wall-slab connections in the structural system should have adequate capacity of strength to carry the design loads safely under out-of-plane and in-plane lateral displacement. It should be pointed out that the designer should avoid brittle type of failure (low ductility), by ensuring that the capacity design is properly factored and calculated [6]. Under out-of-plane lateral cyclic loading testing, the wall undergoes successive loading and unloading branch with control displacement. The force-displacement relationship is presented in the form of hysteresis loops. For each drift, a loop which represented as one complete cycle of drift is imposed on the structures and the applied forces are recorded in both directions (push and pull directions). Figure 10 shows the hysteresis loops associated with load and displacement at LVDT1 for cross-bracing connection which located at the top of the wall. The graph is plotted based on out-of-plane lateral load with respect of each percentage of drift. Each loop is plotted with an incremental of ± 0.1% drift until ± 2.7% drift where the wall-slab connections failed. The positive direction shows the pushing force and negative direction shows the pulling force.

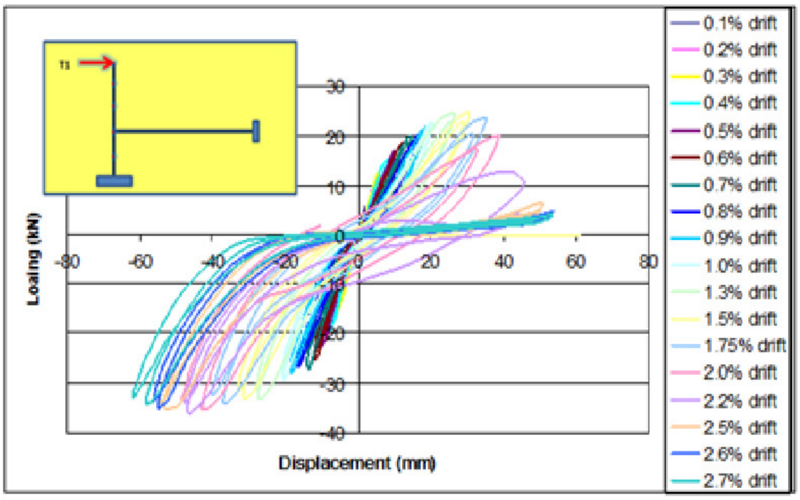


Fig. 10. Hysteresis Loops of LVDT1 for Cross-Bracing Connection.

Figure 11 shows the comparison of the two types of connections in term of load vs. displacement behaviour. Moreover, the graph is showing the pull and the push phases of the loading. Clearly, the cross connection has a higher strength in both phases, the pull and push ones. The cross connection exhibits a relatively higher yielding load of approximately 20.04 kN with yield displacement of 14.07mm corresponding displacement in the pushing direction, whereas the anchorage bracing connection exhibits only 12.99 kN as yielding load with 3.90mm corresponding to yield displacement. Similarly in behaviour, in the pulling phase, the cross connection demonstrates higher yielding load of 26.67 kN with 16.27mm corresponding displacement. On the other hand, the anchorage bracing connection demonstrates only 18.16 kN with 10.26mm corresponding displacement. Overall, the cross connection started yielding at the 0.7% drift, whereas anchorage bracing connection yielded at a lower drift of 0.2%.

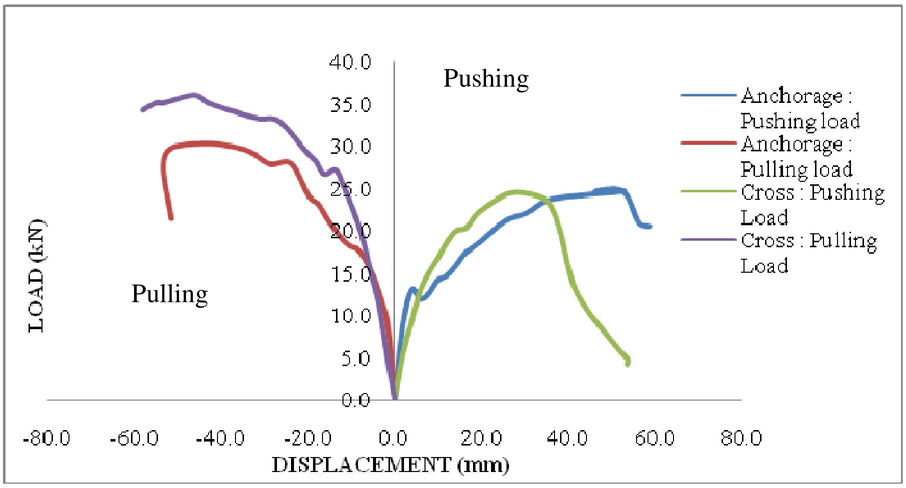
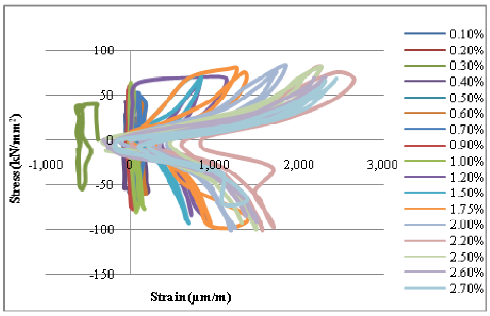


Fig. 11. Comparison of Pushing and Pulling Loading between Both Connections.

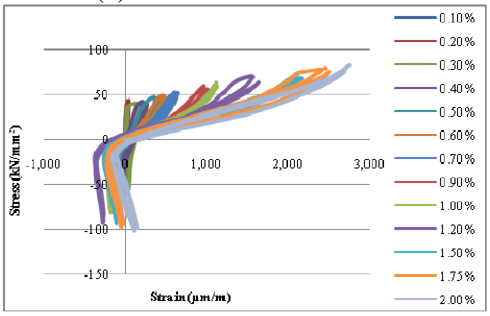
The ultimate out-of-plane loading of the cross connection is 24.41 kN recorded at 1.3% drift under pushing load and 34 kN at 1.75% drift under pulling load. After that, the cross connection experienced an early strength degradation that is marked by drastic drop of loading capacity starting from 1.3% and 2.0% drifts under pushing and pulling loadings respectively. On the other hand, the anchorage bracing connection experienced relatively lower ultimate loads in both pushing and pulling stages but the anchorage bracing connection sustained its strength over wider range of drifts of which the strength degrade after 2.5% drift in pushing stage.

3.3. Stress-Strain

Stress-strain relationship was done for both samples. Stress-strain for strain gauges located at the bent-up bars of wire mesh was analysed. Maximum strain was found at strain gauge 5 (SG5) at bottom reinforcement (Fig. 12(a)) and strain gauge 11 (SG11) at top reinforcement (Fig. 12(b)) in anchorage bracing connection. Maximum strain at SG5 is 2647 µm/mm with 65.73 kN stress capacity at 2.2% drift. On the other hand, maximum strain at SG11 for anchorage bracing connection is 2718 µm/mm at 80.83 kN at 2.0% drift. Furthermore, maximum strain in cross bracing connection was found at strain gauge 6 (SG6) at bottom reinforcement (Fig. 13(a)) and strain gauge 11 (SG11) at top reinforcement (Fig. 13(b)). Maximum strain at SG6 is 1779 µm/mm with 114.23 kN stress capacity at 2.7% drift. Maximum strain at SG11 is 2391 µm/mm with 116.73 kN at 2.0% drift. Thus, it showed both connections are still under yield limit since yield capacity from tensile test is 3600 µm/mm. The analysis showed that anchorage bracing connection was able to develop larger strain value compared with cross bracing connection.

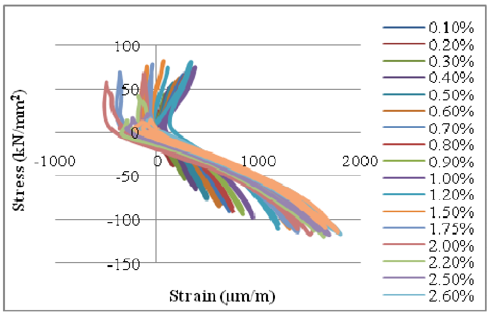


(a) Bottom Reinforcement

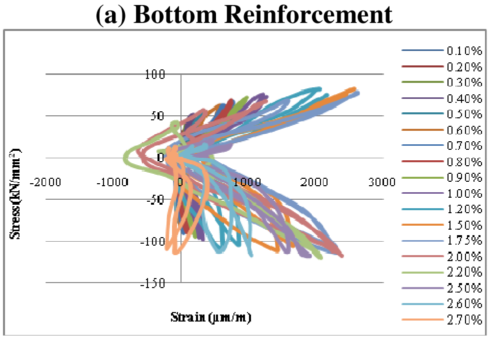


(b) Top Reinforcement

Fig. 12. Stress-Strain Relationship for Anchorage Bracing Wall-Slab Sample.



(a) Bottom Reinforcement



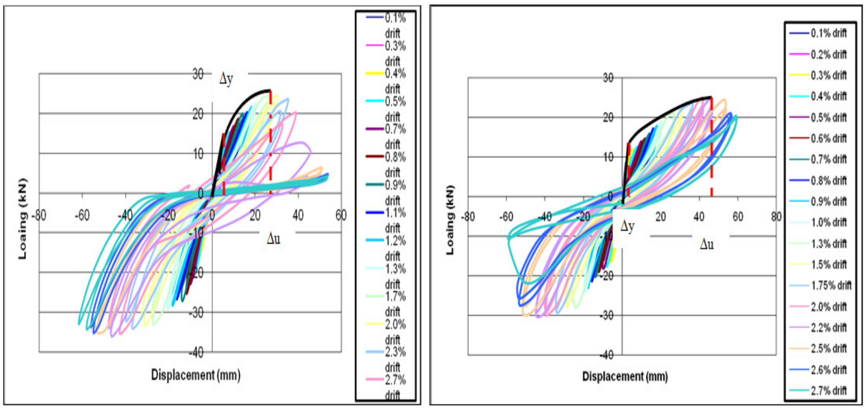
(b) Top Reinforcement

Fig. 13. Stress-Strain Relationship for Cross Bracing Wall-Slab Sample.

3.4. Ductility

Ductility is the ability of the structure to withstand the repeated load-cycles at the post-elastic range, without significant lost of strength [7, 8]. Ductility is an important property of structures to withstand maximum loading with prolong displacements, strain and rotation. In earthquake design, the acceptable ductility of the structures to resist earthquake should be between 3 and 6. The ductile structure is depending on the amount of longitudinal reinforcement bars and the spacing in between stirrup/shear reinforcement in wall-slab connection. The higher percentage of reinforcement bars in wall-slab, the higher ductility of the system where more lateral displacement can occur in the wall. Figure 14 shows the hysteresis loops for both types of wall-slab connections under out-of-plane direction. This graph shows the seismic performance of wall-slab connection where it starts with elastic behaviour as displacement increase linearly with out-of-plane loading until it reaches the yielding displacement (Δy). After yielding, the displacement experiences non-linear behaviour with respect with lateral load. When ultimate load reaches ultimate displacement (Δu), the strength of the wall-slab starts to degrade and partial collapse of the structures achieved. At the stage of ultimate load, the ductility factor can be measured where $\mu=\Delta u/\Delta y$.

Table 2 gives the values of the ductility factor μ for both types of connection. The table shows that anchorage bracing connection enjoys nearly double the ductility that the cross connection get, with μ= 5.91 for anchorage bracing connection and μ= 3.18 for the cross type. The reading reflects that the anchorage bracing connection provides a more ductile structure that possesses ability to maintain higher force carrying capacity while being displaced into the post elastic range. It shows that the anchorage detailing provided favorable confinement which kept the inner structure of the concrete member preserved and hence delayed the failure.



(a) Cross Connection **(b) Anchorage Connection**

Fig. 14. Hysteresis Loops and Ductility Labelling for both Types of Connections.

Table 2. Ductility Ratio of both Types of Connection.

Type of Connection	Δy	Δu	$\mu = \Delta u/\Delta y$
Cross Connection	8.08	25.73	3.18
Anchorage Connection	7.84	46.32	5.91

3.5. Stiffness of the wall

Stiffness of the wall is the ability of the wall to resist the lateral load under elastic deformation. Stiffness is given by the ratio of lateral load over lateral displacement which denote as $k = F/\delta$. Properly designed structures have large inherent stiffness which means that displacement during severe lateral loadings are reduced, thus providing a high degree of protection against damage to structural and non-structural elements [8, 9]. Figure 15 shows the stiffness versus. Drift comparison of results between both types of connection under pushing and pulling stages. Although at the early stages of drift, the anchorage bracing connection shows a stiffness that is nearly double what is found in the cross connection, but the stiffness reading was approximately similar for both connection types throughout the rest of the drifts. Overall, it has been noted that both connections demonstrated similar stiffness during the pushing and pulling stages of loading. That is because stiffness is highly related to the properties of the shear wall panel and both specimens have almost the same shape and size of wall.

In all cases, stiffness readings show a decreasing trend result throughout the drift series because the wall losing its stiffness under reversible cyclic loading. The highest stiffness was recorded at 0.1% drift for the anchorage bracing connection where the highest force is required to achieve the elastic deformation before the wall starts to crack. The lowest stiffness occurs at the 2.7% drift for the cross connection because the minimum force is required to deform under inelastic behavior of the wall system. The cross-bracing connection has slightly higher stiffness as compared to anchorage bracing connection.

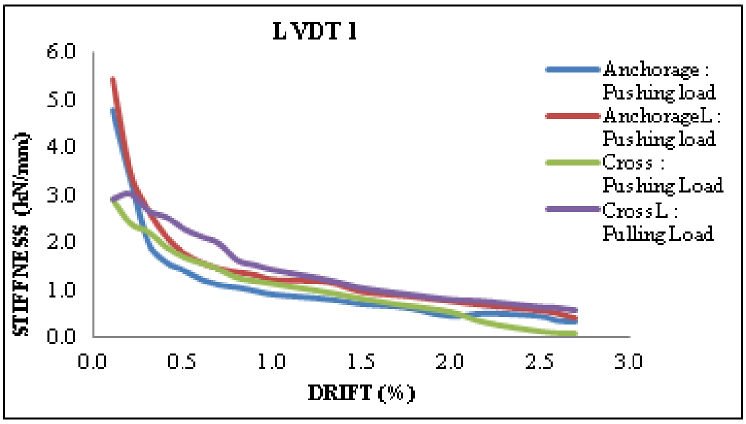


Fig. 15. Stiffness Comparison of both Connections under Push and Pull Direction.

3.6. Equivalent viscous damping

Equivalent viscous damping (EVD) ratio is defined as a function of displacement ductility under the crucial parameter in the application of the control displacement method. For the reinforced concrete wall-slab connections under complete one cyclic loading, EVD ratio was derived based on their hysteretic response and hysteretic energy dissipated under fully reversed cyclic loading. The equivalent viscous damping ratio for anchorage and cross bracing connections were calculated based on the area under hysteresis loops for each drift. Figure 16 shows EVD ratio for both anchorage and cross-bracing connections for the first cycle for each drift. It clearly shows that the anchorage bracing connection recorded higher EVD ratio as compared to the cross-bracing connection up to 1.5% drift and then, the cross-bracing connection has higher EVD ratio as compared to anchorage bracing connection up 2.7% drift. At 2.3% drift, the cross connection recorded the highest EVD ratio nearly 24% equivalent viscous damping whereas at the same drift, the anchorage bracing connection recorded only 8% EVD ratio. In general, it can be concluded that the cross connection has greater ability to absorb more energy during out-of-plane lateral cyclic loading as compared to cross-bracing connection.

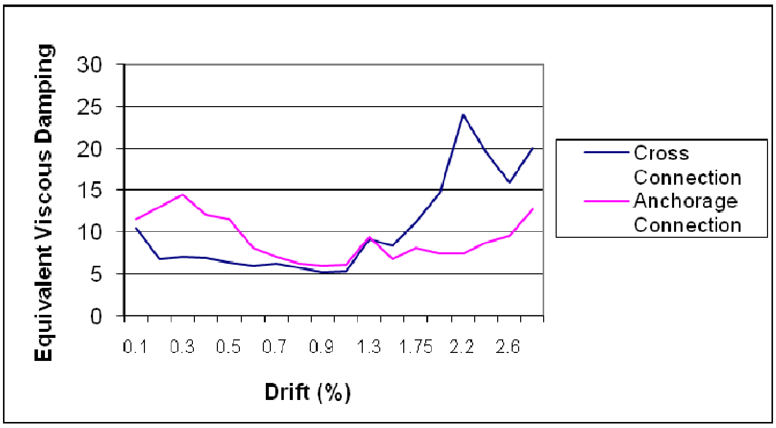


Fig. 16. Comparison of Equivalent Viscous Damping between the Two Types of Connection.

4. Conclusions

Overall, the anchorage bracing connection performed remarkably better in resisting the lateral cyclic load compared to the cross type of the connection. That is because of the significant ductility it experienced and the minimum damage it exhibited at the connection. Although, failure happened for the anchorage bracing connection but the location of the failure was at the wall of which a further increase at the anchorage length would help increase the ductility of the wall and prevent the formation of the plastic hinge. In the case of the cross connection, an increase in the steel ratio in the connection in term of stirrups could be recommended so that to help improve the energy dissipation mechanism at the connection. Therefore, it is recommended that wall-slab connection with anchorage-bracing should be adopted in the construction of medium and high-rise buildings using tunnel form system in Malaysian environment.

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