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RC Wall-slab Connection Enhanced with Steel Fibre under Lateral Cyclic Load

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Abstract

The natural problems of concrete, such as cracking and brittleness, have become major problems, especially when it comes to the weaker point of a structure where there is connection. Extensive research work on steel fibre reinforced concrete (SFRC) has established that the addition of steel fibres to normal concrete improves its strength, durability, toughness, ductility and post-cracking load resistance. This paper presents the influence of steel fibres to the connection of wall-slab connection in terms of strength, ductility and cracks propagation under lateral cyclic load whereby each drift consists of two cycles for 60 seconds time duration. A dosage of 30kg/m^3 steel fibre with end hooks of 0.75mm diameter and 60mm length and concrete strength of grade 30 was used in the wall panel area only of the wall-slab sample. Steel fabric type B385 (B7) was used as reinforcement for the wall and slab panel. Two samples were constructed using two different connection detailing; anchorage and cross wall slab connections. The results show that the strength for cross connection (22.85 kN) is higher than anchorage connection (20.64 kN). In terms of ductility for both types of connection with steel fibres, the anchorage connection specimen is better at sustaining its load for larger displacement with 37.6% greater than cross connection.

Further, based on the visual observation, anchorage connections perform well and prolong the propagation of cracks while the cross connection tends to experience damage faster as compared to the anchorage connection. Ductility of the specimen is considerably enhanced with the addition of steel fibre.

Keywords

Wall-slab connection, steel fibre reinforced concrete, lateral cyclic load, structural failure, cracks patterns.

1. Introduction

Reinforced concrete structural walls are often a critical structural component of buildings. Walls are used to resist the lateral loads due to wind and seismic effects on buildings, and the vertical loads due to dead loads and live loads from the slabs of the buildings. This makes wall and slab an important load bearing component in the building structure. The most critical part between wall and slab is the wall-slab connection since wall-slab connection may be the weakest section under lateral cyclic load to support structural system of the building. An innovation design method has been developed to solve this problem. The method is by adding steel fibre to the concrete mix.

Steel fibres are one of the composite materials that have recently been widely used in various application of construction. The real contribution of the fibres is to increase the toughness of the concrete under any type of loading. Concrete fibre composites have been found as an ideal solution to overcome the serious disadvantages of concrete by making it into a ductile and delay sudden failure material. The influence of the lateral cyclic load on the wall-slab connection is not sufficiently investigated, especially when associated with steel fibres. This study is to evaluate the performance of the connection enhanced with steel fibre compared to the connections of normal reinforced concrete. Besides that, steel fibre reinforced concrete has a better potential in terms of commercial purposes because of its material properties and because it is expected that the application of steel fibre reinforced concrete will become widely used in the incoming years.

2. Previous Research

In recent decades, steel fibre reinforced concrete (SFRC) became very popular and widely used in various engineering applications because of its good mechanical performance. The addition of steel fibres into the concrete mix improved the compressive, tensile and shears strengths, flexural toughness, durability and resistance to impact (Holschemacher et al., 2010).

SRFC may be defined as composite materials made with Portland cement, aggregate, and incorporated discrete discontinuous fibre which has a high resistance to cracking and crack propagation (Chanh, 2009).

Previous studies by Holschemacher et al. (2010) and Constantin & Chris (2009) have been conducted and basically include the effectiveness of the use of steel fibres on concrete beams. Constantin & Chris (2009) found that sudden brittle failure was prevented by the addition of steel fibres. Moreover, it was stated that the torsional strength of the rectangular beams with 1% and 3% steel fibre volume fraction has increased on average about 18% and 21% respectively compared with T-flanged beams.

Spadea & Bercandino (2007) reported that fibres can be very advantageous for the structures in seismic zones where the strength and the ductility of the structure are crucial. Strain in reinforcing steel, deflections and curvatures were reduced in conventionally reinforced concrete beams by including steel fibres (Byung, 2009). Other studies that been conducted by Byung (1992) in terms of behaviour of the beam have indicated that the crack widths were reduced about 10% while the steel stress increased as the amount of fibre increased. It was also reported that fibre reinforced concrete demonstrated considerably less cracking and had high resistance to tensile cracking.

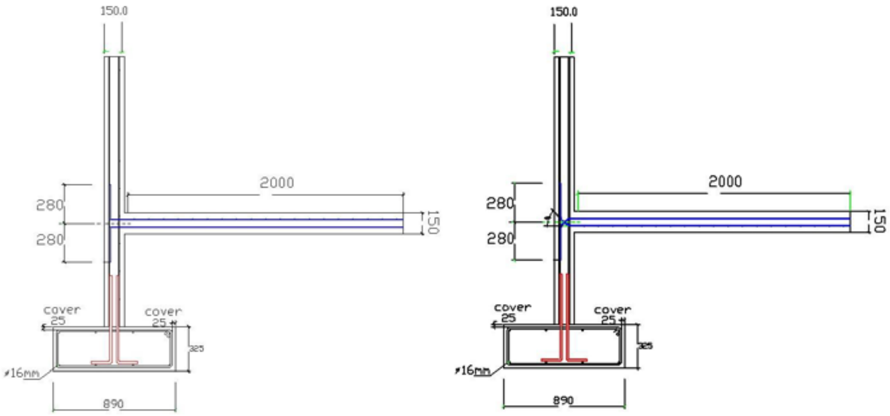
This research is focusing on the effect of SFRC of wall-slab connection under lateral cyclic load due to the lack of study in this area. According to the other previous research, steel fibres exhibited significant advantages in term of mechanical properties that could be beneficial in the future So, instead of using an epoxy resin injection for the wall-slab connection in order to increase the ultimate bearing capacity of the connection by Kudzys et al. (1995), SFRC is used to investigate the performance of the connection under the loading to increase ductility and strengthen the connection.

3. Experimental work

The experimental work was conducted on two wall-slab connection specimens under lateral cyclic load. Each of the samples has a different type of connection with 30kg/m^3 dosage rate of steel fibre in the wall panel. BRC-B7 was chosen as the reinforcement in wall and slab panels since this type of BRC is widely used in the construction industry.

3.1 Specimen characteristics

Different types of wall-slab connection; anchorage and cross connection were prepared. Figure 3.1 shows the reinforcement detail for both samples. Both samples were tested under lateral cyclic loading.



(a) Anchorage (b) Cross bracing

Figure 3.1: Reinforcement arrangement for wall-slab connection

Ordinary Portland Cement (OPC) with normal size (20 mm and 10 mm) aggregate was used. Hooked end type steel fibre with 30kg/m^3 fibre dosage measuring 0.75 mm diameter and 60 mm long were used to improve the ductility of concrete mix and was used in the wall panel. Concrete grade 30 (30Mpa) was designed for this project with 30kg/m^3 fibre dosage of SFRC.

3.2 Test setup

Figure 3.2 shows the locations of Linear Variable Differential Transducer's (LVDT) and the experimental set-up for lateral cyclic load. The lowest end of the wall panel was cast into the foundation and threaded bars were used to clamp the foundation to the strong floor to simulate a fully fixed end condition. The load actuator was clamped to the uppermost end of the wall panel by using steel plate. Steel plates were used to clamp the edge of slab and were attached to steel H-column. The steel column was then clamped to the strong floor in order to get a fully fixed end condition at the end of the slab panel.
5mm strain gauges were installed to measure the deformation of the steel fabric, while the LVDT is used to measure the displacement of the specimen at a specified height during the testing. Load cell, LVDT and strain gauges were connected to the data logger for digital output data. The lateral universal testing machine with a maximum loading capacity of 250 kN produced the lateral cyclic load.

The displacement controlled loading history of the lateral actuator is comprised of two complete reversing cycles to inter-storey drift amplitudes starting from ±0.1% up to ±2.7% drift. Each cycle consists of 60 seconds time duration. Testing was terminated when the specimen failed.

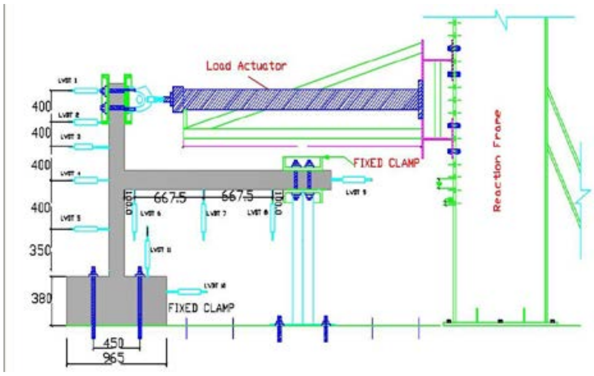
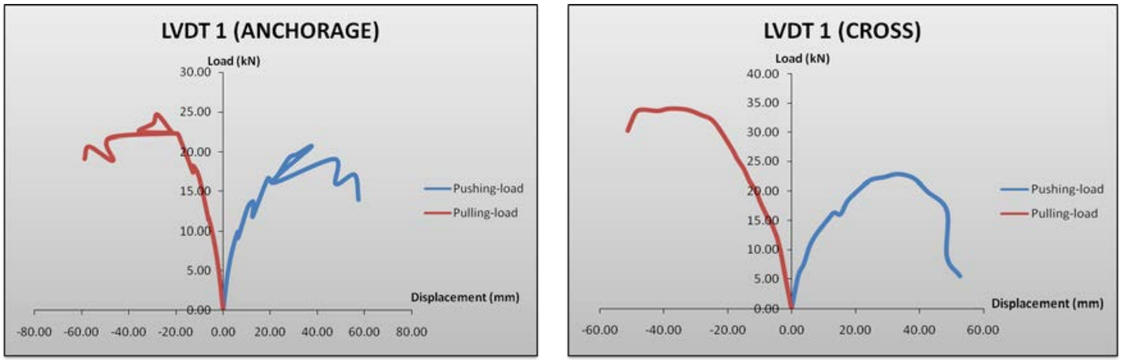


Figure 3.2: Transducers placed on the specimen

4. Results and Discussion

4.1 Strength

A total of 18 drifts were imposed on the wall-slab connection specimen. Maximum load was observed at LVDT 1 since this transducer was placed at the same point of load actuator as shown in Figure 3.2. Since this is the maximum point for lateral cyclic load impact, result analysis was done based on the data at LVDT 1. Maximum loads were at 1.75% drift with 22.85 kN and 20.64 kN for the cross and anchorage connection specimens respectively. Based on the graph, cross connection developed a higher load compared with the anchorage wall-slab connection to reach the same displacement. This indicates that the stress developed at the cross specimen is higher than the anchorage specimen at the connection region. Thus it has been shown that the cross connection specimen performs well in term of strength than the anchorage connection wall-slab sample since this sample was able to sustain a higher load.



(a) (b)

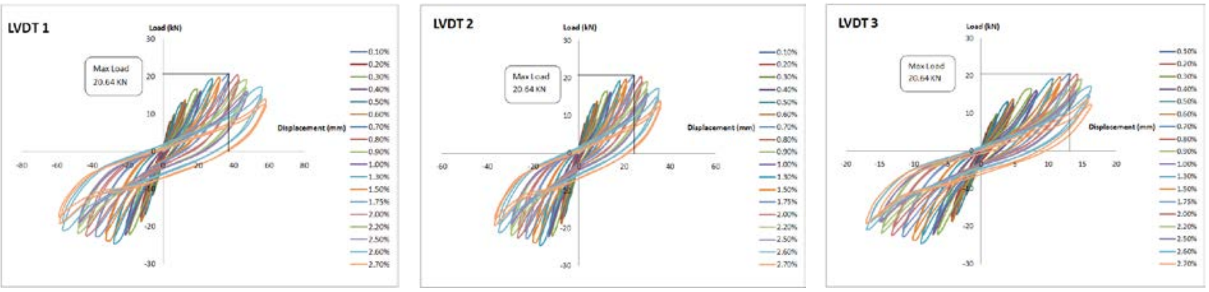
Figure 4.1: Load-displacement of wall-slab samples at LVDT 1.

4.2 Ductility

The ductility of the specimen plays a major role in sustaining the load with the maximum allowable displacement. The displacement ductility, μ, can be defined as the ratio between the measured top yielding displacements, Δy, and at the onset of ultimate displacement of the specimen, Δu. From the hysteresis loops obtained in Figure 4.2, the ductility for LVDT 1, LVDT 2 and LVDT 3 was determined as tabulated in Table 1. It is shown that the anchorage connection ductility is higher which indicated that the anchorage connection specimen is more ductile than the cross connection specimen. The average ductility of the anchorage connection specimen (μ=5) was greater than the cross connection specimen (μ=3.12). The percentage difference of ductility between anchorage connection and cross connection is 37.6%. Thus, this shows that the anchorage connection is better at sustaining loads at larger displacement before rupture.

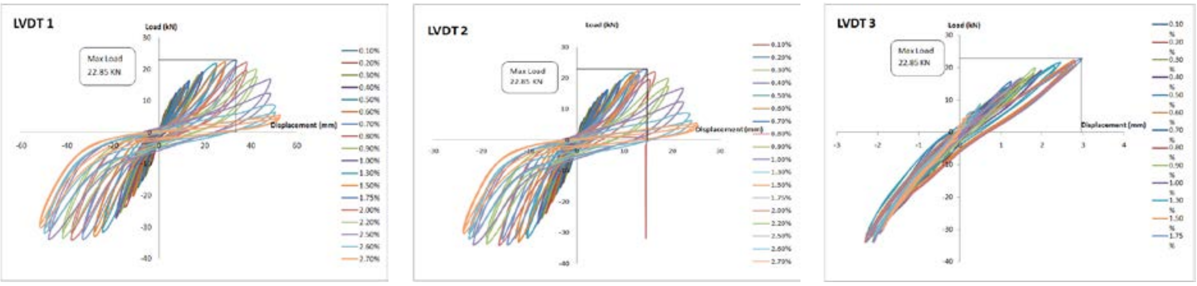
Table 1: Summary of measured ductility

	Anchorage connection specimen					Cross connection specimen				
	Yield displacement		Ultimate displacement		Ductility	Yield displacement		Ultimate displacement		Ductility
	Δy	drift %	Δu	drift %	μ	Δy	drift %	Δu	drift %	μ
LVDT 1	10.6	0.5	57.5	2.7	5.42	13.23	0.7	48.42	2.5	3.66
LVDT 2	6.78	0.5	35.52	2.7	5.24	6.27	0.7	21.69	2.5	3.46
LVDT 3	3.77	0.5	16.38	2.7	4.35	1.25	0.7	2.79	2.5	2.23



(a) (b) (c)

Figure 4.2: Hysteresis loops for anchorage connection.



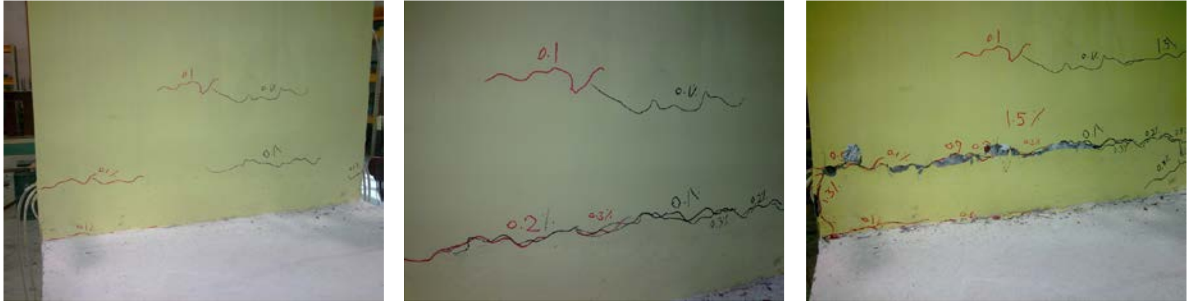
(a) (b) (c)

Figure 4.3: Hysteresis loops for cross connection.

The anchorage connection specimen developed the load within the maximum allowable displacement as illustrated in Figure 4.2. The displacements were 37.28mm, 24.23mm and 13.23mm for LVDT1, LVDT2 and LVDT3 respectively. On the other hand, the displacement for the cross bracing specimen was smaller than that at the anchorage connection specimen 33.26mm, 14.44mm and 2.97mm for LVDT1, LVDT2 and LVDT3 respectively as illustrated in Figure 4.3. This indicates that the cross-bracing connection specimen performs better in strength but not in ductility.

4.3 Cracks propagation

4.3.1 Anchorage connection



(a) (b) (c)

Figure 4.4: Cracks at anchorage connection specimen

As the load was applied starting with 0.1% drift, a minor flexural crack appeared at the upper part of the front and rear wall surfaces as shown in Figure 4.4(a). During the 0.2% drift and 0.3% drift cycles as shown in Figure 4.4(b); minor cracks connected with each other parallel to the wall slab connection at the cut-off end of the reinforcement in the wall. The reinforcement start to yield as the concrete spalling can be seen on the wall at the front and rear part of the wall at 0.5% drift. Cracks also can be seen at the surface intersection of wall and slab as the number of drift was increasing. At 1.75% drift the maximum load was recorded at the uppermost end of the wall with the corresponding displacement of 37.28mm. A deep crack occurred at the cut-off point of the anchorage reinforcement bars when the drift reached at 2.5% drift [see Figure 4.4(c)].

4.3.2 Cross connection

(a) (b) (c)

Figure 4.5: Cracks at anchorage connection specimen

At 0.2% drift, minor flexural cracks occurred at the upper part of the front and rear wall surfaces as shown in Figure 4.5(a). With the increasing number of drift, more cracks appeared as the minor flexural cracks interconnect to each other and became inclined diagonally at the edge of the wall and slab connection as observed in Figure 4.5(b). Moreover, during the 0.5% until 0.7% drift, more longitudinal and flexural cracks were observed at both the rear and front surfaces of the wall and also at the wall-slab connection. A concrete spalling was observed at 1.75% drift as numbers of cracks develop longitudinally along the wall-slab connection. At this point, the maximum load of 22.85kN and displacement of 33.26mm was recorded at the uppermost end of the wall. The specimen is considered damaged, deformed, and permanently inelastic after it reached 2.5%. As the drift stopped at 2.7% the bars in the connection fractured and a deep crack occurred longitudinal along the wall-slab connection [see Figure 4.5(c)].

5. Conclusion

From the experimental results obtained in this investigation, it was observed that the anchorage connection performs better and prolongs the propagation of cracks at the connection location when compared to the cross connection specimen. Based on the visual observation and level of damage, cross-bracing connections tend to experience damage faster as compared to an anchorage connection. In terms of ductility for both types of connection with steel fibres, the anchorage connection specimen has a greater value of ductility than the cross connection specimen. Further, the maximum displacement was recorded from the anchorage connection specimen at 37.28mm while 33.26mm was recorded from the cross connection specimen. The anchorage connection specimen performs better than cross bracing connection specimen in terms of displacement. The results indicate that the anchorage wall-slab connection with steel fibre performs better than cross-bracing wall-slab connection with steel fibre under lateral cyclic loading. The use of steel fibre enhanced the wall-slab connection by improving the ductility of the connection specimen to delay sudden failure at the connection. This fibre can give significant benefit for structure in seismic zones where it is necessary to strengthen structures and increase their ductility.

6. Acknowledgement

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