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BEHAVIOUR OF PRECAST WALLS CONNECTION SUBJECTED TO SHEAR LOAD

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Abstract

This paper presents a study on the connection between the exterior and interior precast concrete walls. The connection between the walls is called loop bars connection. Between the looping bars, one transverse bar is inserted as to ensure connectivity of all the looping bars. This connection produces a gap between the walls, which would then be filled with concrete to produce rigid connection. The main objective of these experimental studies is to determine behaviour of loop bars connection under shear loading. From a visual observation, most concrete crushing and spalling was concentrated at the joint. Strut and tie model of loop joint used to model flow of forces in the connection. The crack showed zigzag pattern and it was developed as the force from one precast element to the other was being transferred by inclined compressive struts between overlapping loop bar. The connection shows a ductile behaviour by producing a few line cracks and having a large deflection to give a warning before failure. This ductility is within the acceptable ductility of a structure. Therefore, it is recommended to the construction industry to adopt this kind of connection design which can be used for medium rise precast building.

Keywords: Loop bar, Shear loading, Shear stress, Exterior-interior wall connection.

1. Introduction

Nowadays, precast concrete construction has gained popularity among engineers and architects. Precast concrete has advantages over in situ cast concrete as more sustainable construction, improved in quality control, shorten time and reduce construction cost [1, 2]. There are three types of precast building systems which are skeletal structure, portal frame, and wall frame [3]. This research only focused on the last category of the precast system, wall frame that consists of wall and slab.

Abbreviations

BRC	Steel reinforcement fabric
EIWC	Exterior-Interior wall connection
LVDT	Linear variable differential transducer
SG (C)	Strain gauge of concrete
SG (S)	Strain gauge of steel

Compared to cast in situ load bearing walls, precast wall frame structure is more economical and can increase the speed of the construction [4, 5].

Connection design is one of the most important consideration for the successful construction of precast reinforced concrete structures [6]. The configuration of the connection affects the constructability, stability, strength, flexibility and residual force in the structure and redistribution of loads as the structure is loaded [7]. Therefore, engineers should design the connection so as to ensure that forces are transferred between the precast wall panels sufficiently.

Dry joints are constructed by bolting or welding together with steel plates. Welded connections can be used to connect elements by heating through protruding bars or indirectly using plates. Although this connection behaved satisfactorily, but the construction of these specimens required significant welding of the reinforcement [8]. It was found out that welding through surface wetness has the potential to increase micro discontinuities and create visible cracking.

Meanwhile, wet joints are constructed with cast in-situ concrete or grout that is poured between the precast panels. Continuity reinforcement bars can be achieved when steel bars are placed across the joints by which the shear forces can be transferred between the elements by dowel action.

Bolted connections could transmit a combination of axial forces, shear forces moment, shear force and axial force between the panels [9]. The main advantage of this connection is that this connection can be made immediately but it has restricted tolerance required for mating, in which oversize holes are not allowed because the oversized hole caused significant slippage of the bolt [10].

Loop connection is a cast in situ connection which the loop bars protrude from the precast elements and overlap each other. The connection is activated as the joint is filled with grout or concrete. Transverse reinforcement should be placed through the overlapping part of the loop to prevent splitting at the concrete joint. The concrete joint provides protection for the looping bar from corrosion [11]. Loop connection is used in a precast structure or deck for precast bridge.

In this research, loop bar connection is chosen because the connection has higher tolerances allowed as compared to bolt connection and this makes fix on site easier and not depending on the professional worker. However, there are very limited researches regarding loop bar connection in precast wall system under shear loading. Previous research was focused on wall connections but they were merely concentrated on the behaviour of the connection subjected to lateral shear load due to earthquake [12-14]. Hence, the main purpose of this study is to determine behaviour of loop bars connection under shear loading without earthquake effect. It is important to understand of its behaviour in terms of mode of failure since the connection plays a vital role in structure stability and there is no specific details to design of this connection available [15].

2. Experimental Work

2.1. Specimen detailing

Exterior-Interior Wall Connection test were named as EIWC. There are three repetitive exterior-interior wall specimens tested and named as EIWC1, EIWC2 and EIWC3. The specimen consisted of exterior and interior walls that were connected together using loop bars. The height, width and thickness of exterior walls were 1200 mm, 1000 mm and 125 mm and for the interior walls were 1200 mm, 600 mm and 125 mm. The thickness dimensions corresponded to a prototype scale of the precast panels typically used for medium rise construction. Along 1200 mm height of wall, five looping bars of 8 mm diameter were placed at a spacing of 250 mm centre to centre. A longitudinal bar was then inserted in the loop between the two walls. This area created a gap of 150 mm width which then was filled with grade 30 concrete to produce moment resisting connection between the two walls. A double layer steel reinforcement fabric (BRC-7) with dimension of 200 mm x 200 mm vertically and horizontally was used for both walls. The detailing for wall to wall connection is shown in Fig. 1.

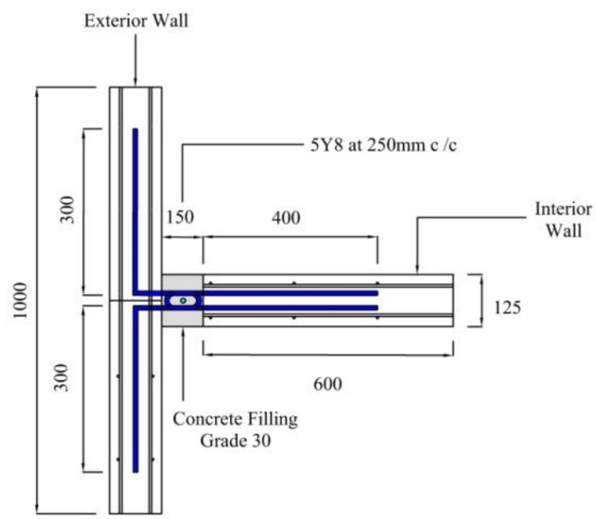

Fig. 1. Top View of Exterior-Interior Connection.

2.2. Test material

The specimen was ready-mixed concrete with concrete grade of 30 N/mm^2 in both walls and concrete joint. High-tensile reinforcements were used to connect the walls. Steel reinforcement fabric or own as BRC was used as the replacement of reinforcement bars in both precast walls. The flexural and shear induced on the walls were resisted with the existing BRC embedded in the concrete. Loop bar of 10 mm and the transverse bar of 12 mm placed at the centre inside the loop were used. For each type of rebar, four tests were done and average value of the test results was taken as shown in Table 1.

Table 1. Types of Steel Reinforcements.

Type	Diameter (mm)	Cross Section (mm^2)	Yield Strength (N/mm^2)	Tensile Strength (N/mm^2)
BRC	7	38.49	467.25	496
Loop bar	8	78.54	483.25	549.75
Transverse Bar	10	113.01	586.25	607

2.3. Sample preparation

The plywood formwork was prepared and was greased to make demoulding easier before casting of concrete was executed. Then the BRC steel fabric was placed inside the formwork with spacer blocks of 20 mm, after which the concrete was poured into the formwork through the top opening of the wall panel. The specimens were cured for 28 days before testing was conducted.

2.4. Test set-up

The test set-up is shown in Fig. 2 where a uniformly distributed load was applied at a rate of 0.02 kN/sec the top of the interior wall. The wall has been rotated to a horizontal position for ease of handling. To prevent any unwanted movement of the exterior wall, the edge was restrained and consider as fixed end. The displacement was recorded by 4 Linear Variable Differential Transducers (LVDT) as shown in Fig. 3. The load was progressively increased up to the failure and at every load interval the crack patterns were marked.

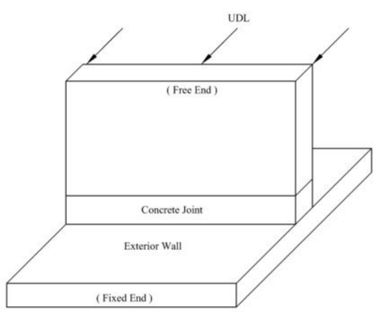

Fig. 2. Experimental Set-Up.

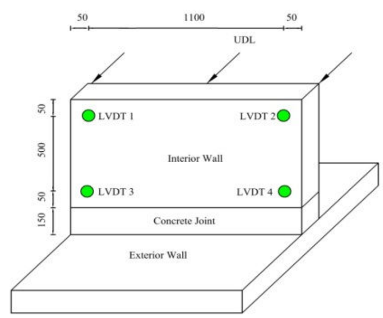

Fig. 3. Location LVDT on the Specimen.

A total number of three strain gauges were attached to the loop bars as shown in Fig. 4. Strain gauges of 5 mm length were installed to read the change in strain of 10 mm diameter reinforcement. On the other hand, strain gauge of 60 mm length was used to measure surface concrete strain. This gauge length is sufficient to measure maximum crack width of 0.2 mm. Total of six strain gauges were also placed on the concrete surface as shown in Fig. 5 because the formation of the crack was expected to occur at the interface between the concrete joint and precast wall and the concrete joint caused by high stress level in this area. All strain gauges are quarter bridge circuit as it measured strain reading on one surface of the material only.

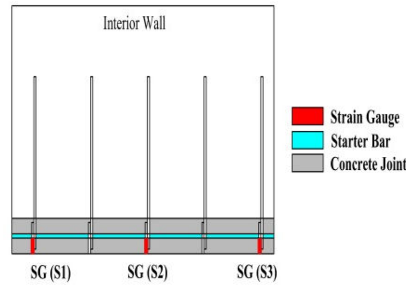

Fig. 4. Location of Strain Gauges on Loop Steel Bars.

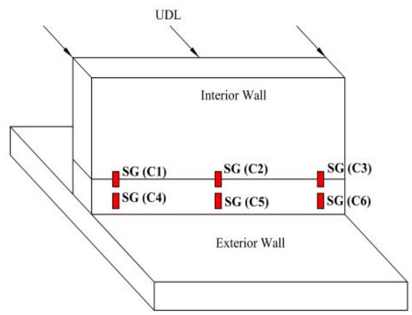

Fig. 5. Location of Concrete Strain Gauges.

Experimental Result and Discussion

3.1. Moment vs lateral displacement

The lateral displacement of the interior wall was measured by four LVDTs as in Fig. 3 and the applied load measured from the data logger was converted to moment by multiplying it with the arm length. The moment-displacement relationship of EIWC1, EIWC2 and EIWC3 are shown in Figs. 7 to 9. All specimens have shown consistent displacements at the free end as well as near the connection; however less displacement was measured on fixed end as compared to the free end, which allowed more movement.

Stiffer loop connection was shown by EIWC2 with no displacement measured until 2 kNm, whereas EIWC 1 and EIWC 3 showed immediate displacement when loaded. At failure, all three specimens reached a maximum value of 6.08 kNm (EIWC1), 5.32 kNm (EIWC2) and 5.72 kNm (EIWC3) that give an average of 5.71 kNm. From the test, the experimental ultimate moment was higher than the calculated moment of 5.39 kNm as proposed by [16] as the connection was tested up to failure. Therefore, there is good agreement between the predicted result and experimental result.

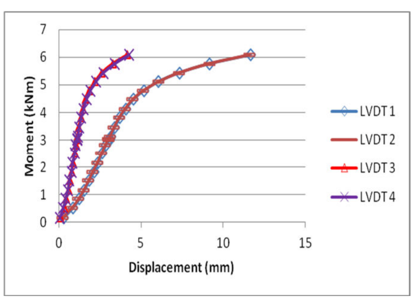

Fig. 7. Moment versus Lateral Displacement of EIWC1.

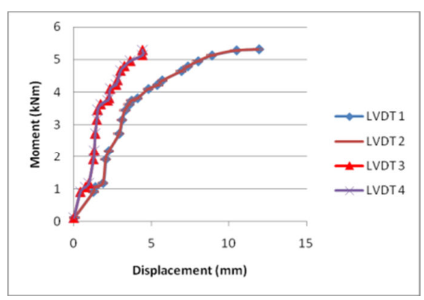

Fig. 8. Moment versus Lateral Displacement of EIWC2.

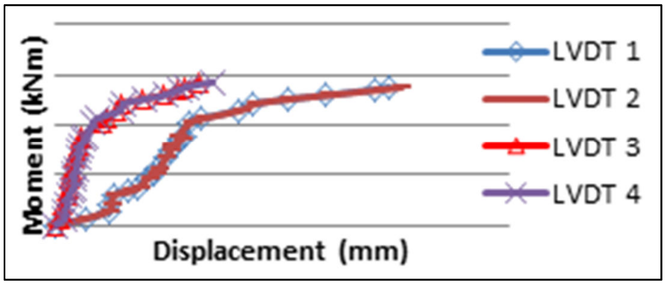

Fig. 9. Moment versus Lateral Displacement of EIWC3.

The capacities of the structural elements to deform beyond the elastic limit with minimum loss of strength depended on their ductility. Therefore, based on the maximum displacement measured, the ductility of the connection is calculated using Equation 1. Ductility is defined as the ability of the structure to have large deformation before failure. The ductility ratio of this loop bar connection can be calculated based on its maximum displacement and yield displacement. Yield displacement is computed when the load reaches the yield load (at 80% of maximum capacity). At the same time, the ultimate displacement can be defined as the maximum displacement reached by the specimen before failure.

$$\textit{Ductility ratio}, (\mu) = \frac{\text{maximum displacement } (\Delta u)}{\text{yield displacement } (\Delta y)} \qquad (1)$$

Due to insignificant difference between LVDTs 1 and 2, the ductility of the specimens is based on the moment-displacement measured by LVDT 1. Hence based on eqn. 1, the ductility ratio for EIWC1, 2 and 3 are 5, 3.6 and 4.7 and in average the ductility for exterior-interior connection is 4.4, which is in the range of requirement for structure ductility which is normally between 3 and 6 [16].

3.2. Crack patterns

A strut and tie model with compressive stresses as a compressive strut and the tension stresses from the loop as tension reinforcement was used to model flow of forces in the zone [17, 18]. The force from one precast element to the other was transferred by the inclined compressive struts between overlapping loop bar as shown in Fig. 10. The transverse bar that was placed inside the loop was used to balance the forces in inclined compressive strut.

Figures 11 to 13 show the crack patterns for all the specimens at their ultimate capacity. In general, the severe concrete cracking and spalling occurred at the joint where plastic hinges were expected to form. The cracking was first propagated along the interface between the interior wall, concrete joint and the exterior wall. The first interface crack occurred at about 57% to 68 % of ultimate moment, while the first inclined crack occurred at about 80% of the ultimate moment. It showed that connection bars were able to give sufficient resistance before the concrete failed. This was shown by an interface crack at the concrete joint while the inclined crack formed near the loop bar connection was at almost at its ultimate moment.

Apart from interface cracks, forces from the interior wall were also transferred to the connection using inclined compressive strut which originated from radial stress and acting against the bend of the loop (Fig. 14). This radial stress increased the tensile stress and caused concrete inside the loop to split and form the incline crack. The effect of compression and tension stresses have caused zig zag cracks, particularly obvious at the ultimate state of 4.9 kNm, 4.25 kNm and 4.53 kNm for EIW1, EIWC2 and EIWC3 specimen. Similar inclined cracks formation was observed on EIWC1 and EIWC2 specimens. However EIWC3 showed inclined cracks that propagated from the centre of the wall towards the interface between precast interior wall and the concrete joint. It showed that the interface between the precast wall and concrete joint also experienced a high stress [19]. Hence at the end of the experiments, severe damage was observed at the concrete interface while none on precast walls.

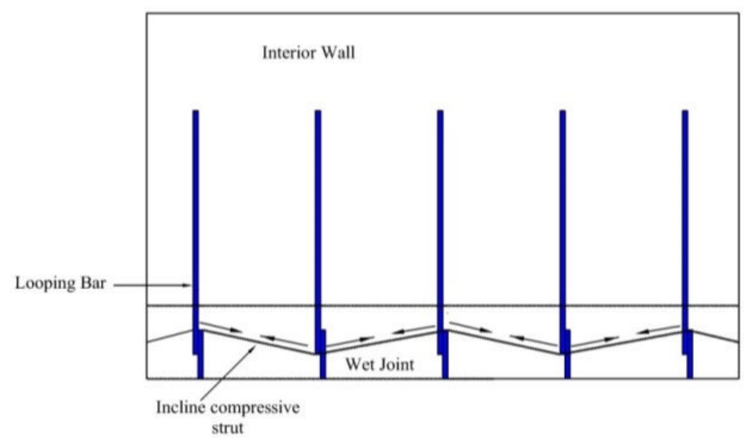

Fig. 10. Inclined Compressive Strut between Overlapping Loops.

Fig. 11. EIWC1 Specimen at Failure.

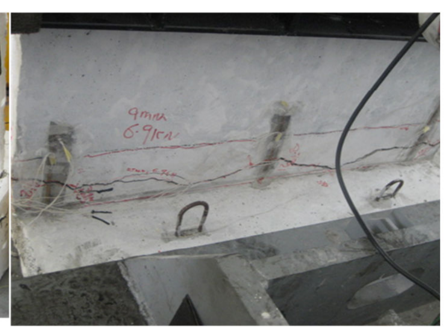

Fig. 12. EIWC2 Specimen at Failure.

Fig. 13. EIWCS3 Specimen at Failure.

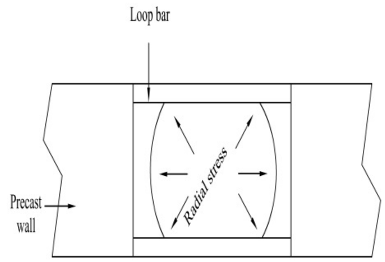

Fig. 14. Radial Stresses against the Bend.

3. Conclusions

This connection can be categorised as ductile when it is subjected to out of plane shear load because the specimen have a large deflection to give a warning before it totally failed. This ductility is within the acceptable ductility of a structure. Therefore, it is recommended to the construction industry to adopt this kind of construction design together with the detailing which can be used for medium rise precast building.

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