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BEHAVIOUR OF UNREINFORCED EXPANDED POLYSTYRENE LIGHTWEIGHT CONCRETE (EPS-LWC) WALL PANEL ENHANCED WITH STEEL FIBRE

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Abstract

This study used steel fibre as reinforcement while enhancing the EPS-LWC strength. In line with architectural demand and ventilation requirement, opening within wall panel was also taken into account. Experimental tests were conducted for reinforced and unreinforced EPS-LWC wall panel. Two samples with size of 1500 mm (height) x 1000 mm (length) x 75 mm (thickness) for each group of wall panel were prepared. Samples in each group had opening size of 600 mm (height) x 400 mm (length) located at 350 mm and 550 mm from upper end respectively. EPS-LWC wall panel had f_{cu} of 20.87 N/mm^2 and a density of 1900 kg/m^3. The loading capacity, displacement profiles and crack pattern of each sample was analyzed and discussed. Unreinforced EPS-LWC enhanced with steel fibre resist almost similar loading as reinforced EPS-LWC wall panel. The presence of steel fibre as the only reinforcement creates higher lateral displacement. Wall panel experience shear failure at the side of opening. The number of micro cracks reduces significantly due to presence of steel fibre.

Keywords: EPS-LWC, Reinforced, Steel fibre, Unreinforced, Wall panel.

1. Introduction

Nowadays wall panel did not just contributed to the gravity load of a building. Wall panel itself can act as a load bearing structure. By taking into account this function, the improvement of wall panel strength was highly demanded while reducing the self weight of the wall panel itself. The concrete wall panel was the most common material used. It was understood that concrete requires reinforcement to resist tensile capacity. The presence of steel fabric reinforcement contributes to the heavier wall panel, although lightweight concrete was adopted. Therefore, steel fibre was chosen as reinforcement due to its tensile resistance capacity and it was lighter compared to normal steel reinforcement [1].

Wall panel construction also taken into account the opening built as windows and doors. The location of the opening chose created deep beam effect at the upper and base ends of the wall panel. The focuses of this research were on the loading capacity, displacement profile, crack and failure pattern of unreinforced EPS-LWC wall panel enhanced with steel fibre.

2. Related Works

Chen and Liu [2] had conducted cube test of EPS-LWC with steel fibre. Different percentage of EPS replacement was adopted. It was found that the compressive strength, f_{cu} of EPS-LWC with steel fibre was 21.4 N/mm^2 for concrete density of 1884 kg/m^3 with 25% EPS replacement. Since this study used 30% amount of EPS replacement, the compressive strength obtained should be slightly lower than value obtained by [2] since the strength of EPS-LWC is inversely proportional with volume of EPS replacement. These properties can be used to verify the properties obtained for EPS-LWC with steel fibre used in this study.

Abd.Rahim et al. [3] studied the behaviour of steel fibre lightweight concrete (SF-LWC) for solid wall panel. Experimental works were carried out in order to find the loading capacity, mode of failure and cracking pattern of unreinforced SF-LWC. The ultimate load obtained was twice higher than theoretical value obtained through empirical equation. The excessive loading capacity of unreinforced solid SF-LWC shows the effect of steel fibre in that particular sample where it contributed to the increase of wall panel fracture toughness.

Ding and Kusterle [4] had compared the behaviour of steel mesh reinforced concrete (SRC) with steel fibre reinforced concrete (SFRC) plate. At the same age of concrete, SRC for the most part failed whilst some failed in flexural mode. Contrary, SFRC results showed more sample failed in flexure. This shows that steel fibre reinforcement enhanced the punching shear capacity of the plate while able to act as part of concrete reinforcement. In addition, the ductility of concrete has been enhanced greatly by the presence of steel fibre.

Meanwhile Saheb and Desayi [5] had tested several samples of wall panel with opening under one way action. An empirical equation was proposed on how to calculate the load carrying capacity of wall panel with opening. However, the equation proposed was based on the limitation which includes used of normal concrete and slenderness ratio of 12 that has been set in that particular research. The proposed equations were as follows:

$$P_{uo} = (k_1 - k_2\chi)P_u \tag{1}$$

where

$$P_u = 0.55\left[A_g f_c' + \left(f_y - f_c'\right)A_{sv}\right]\{1 - [H/(32t_w)]^2\} \tag{2}$$

$$\chi = \left(\frac{A_0}{A} + \frac{\eta}{L}\right) \tag{3}$$

$$\eta = (L/2 - \bar{\eta}) \tag{4}$$

$$\bar{\eta} = \left(\frac{\frac{1}{2} t_w L^2 - t_w L_o \eta_o}{L t_w - L_o t_w} \right) \tag{5}$$

$$A_o = L_o t_w \tag{6}$$

$$f'_c = 0.8 f_{cu} \tag{7}$$

P_u was described as an ultimate load of the identical wall panel in one way action. The values of constants k_1 and k_2 were taken as 1.25 and 1.22 respectively. Others parameters to be substituted were obtained from the details of geometry as in Fig. 1 where G_1 and G_2 represent centre of gravity for wall with and without opening, meanwhile G_3 represents centre of gravity for the opening. Other geometry involve are L (length of wall), H (width of wall) and t (wall thickness). From the proposed equations, it was noted that the samples tested by [5] involved reinforcement bars since there were values of yield strength, f_y and area of reinforcement required, A_{sv}.

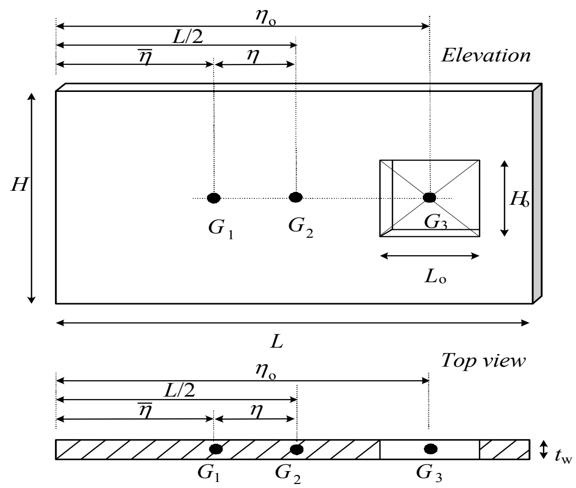


Fig. 1. Geometry of wall panel openings [5].

On the other hands, Doh and Fragomeni [6] conducted experimental works similar to [5] but with different type of concrete. Some modifications have been made while still maintaining the geometrical parameters as shown in Fig. 1. The proposed equations by [6] were;

$$N_{uo} = (k_1 - k_2 \chi) N_u \tag{8}$$

$$N_u = 2.0 {f'_c}^{0.7} (t_w - 1.2e - 2e_a) \tag{9}$$

$$e_a = {H_{we}}^2 / (2500 t_w) \tag{10}$$

$$e = t_w / 6 \tag{11}$$

$$H_{we} = \beta H \tag{12}$$

$$\beta = 1 \; for \; H/t_w < 27 \qquad (13)$$

$$\beta = 18/\left(\frac{H}{t_w}\right)^{0.88} \; for \; H/t_w \geq 27 \qquad (14)$$

The values of constant k_1 and k_2 were taken as 1.175 and 1.188 respectively. However, it was understood that the equations proposed by [6] was developed from experimental works conducted using high strength concrete.

3. Methodology

Experimental test was carried out in order to obtain data that portray the behaviour of reinforced and unreinforced EPS-LWC wall panel. The materials used in this study were shown in Fig. 2. All materials then were mixed together with water to produce concrete paste. For each category of reinforced and unreinforced EPS-LWC wall panel, two (2) samples with the size of 1500 mm (height) x 1000 mm (length) x 75 mm (thickness) were prepared. The detail of dimensions of wall panel samples and it's opening parameters are shown in Table 1. Meanwhile, Figures 3 and 4 show the schematic diagram of the wall panel details. In this study, for reinforced EPS-LWC wall panel samples, the steel fabric B7 was used. The steel fabric has properties of with pitch distance of longitudinal wire being 100 mm, cross wire being 200 mm and nominal diameter for both longitudinal and cross wires being 7 mm as stipulated in [7].

In order to record the displacement of those wall panel samples, seven (7) linear variable displacement transducers (LVDT) were used. The location of LVDT for each sample was shown in Fig. 5. Since the dimensions for Samples 1 and 3 were identical, therefore the LVDT's locations were identical. Similar concept was also applied to Samples 2 and 4. As for the vertical and side displacements, the readings were taken by LVDTs T7 and T6 respectively.

Coarse aggregate (passing 10 mm) | **Fine aggregate (passing 2.36 mm)** | **Cement** | **Hooked end steel fibre** | **EPS beads**

Fig. 2. Materials preparation.

Table 1. Details sizes of samples.

Data \ Designation	Reinforced EPS-LWC		Unreinforced EPS-LWC	
	Sample 1	Sample 2	Sample 3	Sample 4
Opening locations	550 mm from upper end	350 mm from upper end	550 mm from upper end	350 mm from upper end
Wall panel size (mm)	1500 x 1000 x 75			
Opening size, H x L mm)	600 x 400			

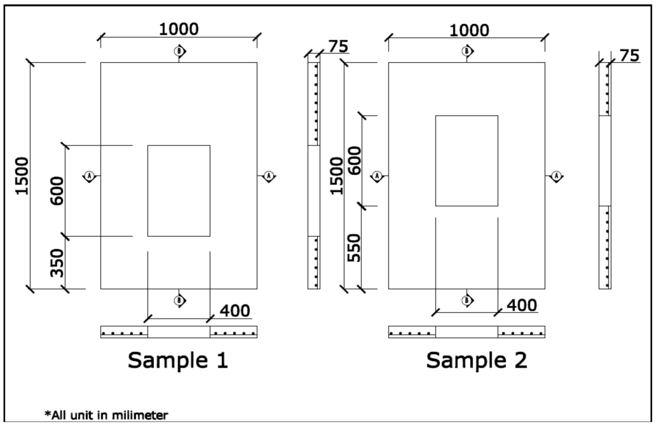


Fig. 3. Details for reinforced EPS-LWC wall panel samples.

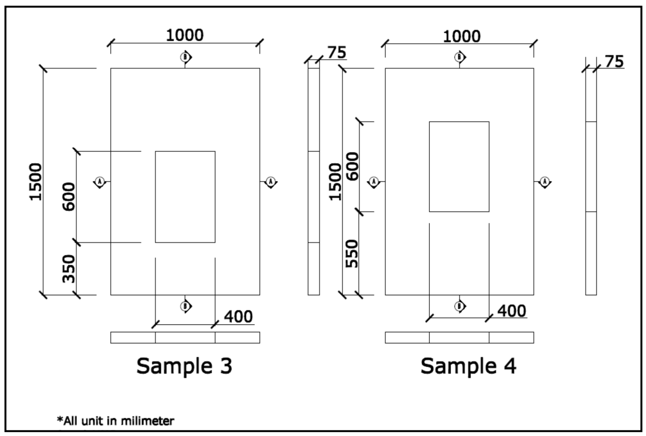


Fig. 4. Details for unreinforced EPS-LWC wall panel samples.

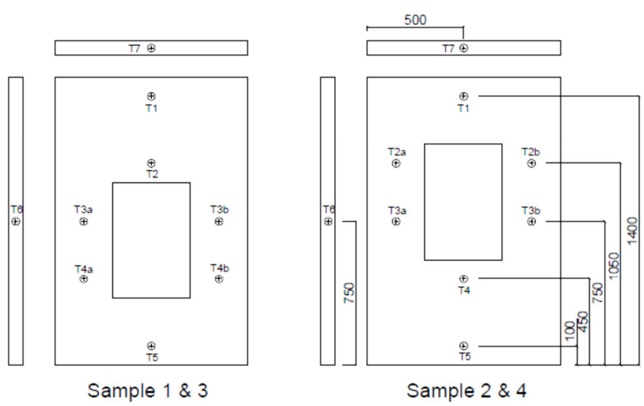


Fig. 5. Locations of LVDT's.

The samples were tested using Universal Testing Machine (UTM) with loading capacity of 2000 kN. Axial load was delivered by hydraulic jack connected to the load cell located along the centroidal axis of wall panel at the upper end. Steel bar welded to steel plate was placed onto angle plate to assure the load are equally distributed. At the lowest end, the sample was held by angle plate and bolted to the steel platform to make it in a fixed condition. Before being tested all samples were painted in white to ease the crack observation process. Strain gauges were also installed onto the concrete surface in order to gauge the strain values during loading. Actual and schematic diagrams of experimental setup were shown in Fig. 6 where red circles represent the LVDT's locations. Details of support condition were as in Fig. 7.

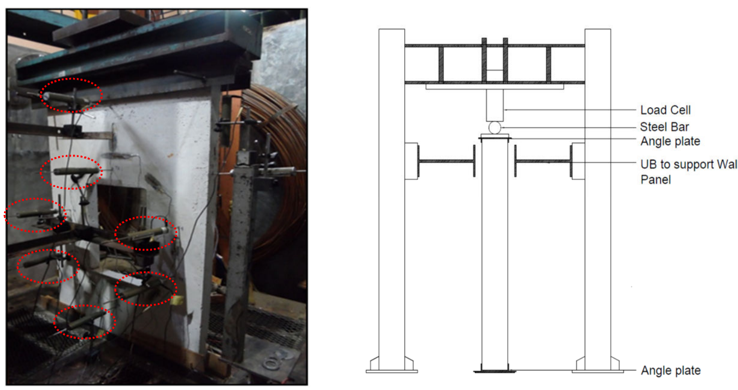


Fig. 6. Actual and schematic test setup [8].

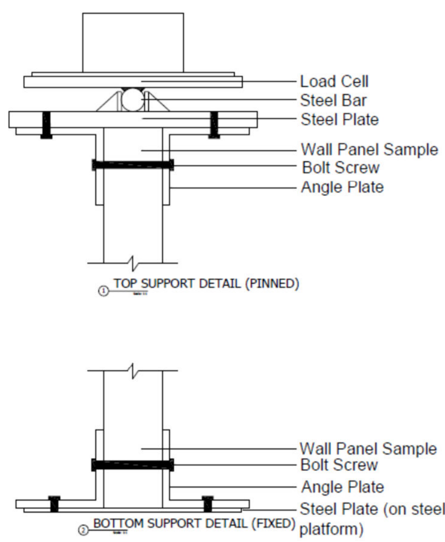


Fig. 7. Details of support condition setup [3].

4. Results and Discussions

Preliminary test was conducted to obtain the properties of EPS-LWC. Compressive strength, f_{cu} value was 20.87 N/mm^2 with a density of 1900 kg/m^3. Meanwhile, yield strength, f_y for the steel fabric was 588.44 N/mm^2 The property values were substituted into the empirical equations in order to calculate the theoretical ultimate loading for each sample.

4.1. Loading capacity of EPS-LWC wall panel

Ultimate loading capacity, Pult obtained from the experiment was shown in Table 2. Those values were compared to the calculated values using empirical equations.

Table 2. Comparison of ultimate loading.

Wall Panel designation			Experimental (kN)	Theoretical (kN)		
				[5]	[6]	BS 8110,[9]
Opening at 550 mm from top	Reinforced EPS-LWC	Sample 1	477.70	596.17	557.68	672.39
	Unreinforced EPS-LWC	Sample 3	443.30	524.66	557.68	551.25
Opening at 350 mm from top	Reinforced EPS-LWC	Sample 2	463.70	596.17	557.68	672.39
	Unreinforced EPS-LWC	Sample 4	361.00	524.66	557.68	551.25

For reinforced EPS-LWC wall panel, Sample 1, the ultimate loading capacity obtained from experimental test was 477.70 kN. However, when being associated with the values obtained from the empirical equations, the difference in percentages were 19.87%, 14.34% and 28.9% for [5], [6] and [9] respectively. It was understood that there were no actual equations used specifically for wall panel with opening. Therefore, those proposed equations and equations stipulated in the code of practice were used as a benchmark in order to predict up to what extent the loading capacity of these wall panels would be. Meanwhile, for Sample 3 the maximum loading capacity obtained was 443.30 kN. The difference in percentage when compared to theoretical calculations lies within 15.51% to 20.51% only. The variation of loading capacity between experimental and theoretical values caused by different parameters adopted while proposing the equations.

If both Samples 1 and 3 loading capacity was compared, there was only a small margin of difference as illustrated in Fig. 6. The ratio of the maximum loading capacity for Sample 1 to Sample 3 EPS-LWC wall panel was 92.8. The vertical displacement recorded for both Samples 1 and 3 also similar. Both samples experience vertical displacement of less than 3 mm. This proves that steel fibre had high capacity of tensile resistance as claimed by Timuran Engineering [10]. Besides, steel fibre can be used as the replacement of steel fabric in EPS-LWC wall panel. A part of producing almost similar tensile resistance, steel fibre also improved the ductility and crack behaviour [11, 12].

On the other hand, for sample with opening located at 350 mm from the upper end, Samples 2 and 4 produced ultimate loading capacity of 463.70 kN and 361.00 kN respectively. When compared to values calculated by the empirical equations, Sample 2 has difference percentages in the range of 16.85% to 31.04%. Meanwhile Sample 4 recorded difference in percentage lies between 31.19% to 35.27%. It can be said that the ultimate loading capacity of Sample 2 was 22.15% higher than Sample 4. This shows that even without steel fabric the EPS-LWC wall panel still can achieve up to 75% of reinforced EPS-LWC strength. Both samples experience only marginal difference in strength, but the vertical displacement recorded significant differences as in Fig. 8.

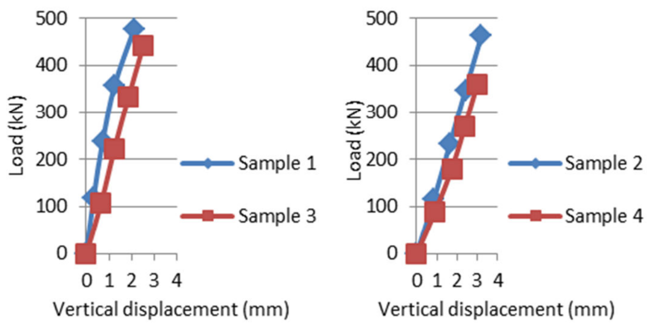


Fig. 8. Comparison of loading capacity.

The values of ultimate loading capacity obtained from the experimental test did not give significant difference between reinforced and unreinforced EPS-LWC wall panel. The percentage of difference only lies within the range of 7% to 23% only. This had proven that steel fibre can be used as reinforcement in plain concrete wall panel. It was also shown that similar patterns of deep beam effect happened in both cases, meaning that either the wall panel was reinforced or unreinforced, sample with deep beam effect at the upper end sustained higher strength. This is confirmed by findings from [8] and [13]. The loading applied was absorbed by the deep beam section at the upper end, then transferred through column-like section at the sides of the opening towards the lower section of the wall panel. The higher the surface area of the beam, the more loading can be sustained by the wall thus resulting in higher loading carrying capacity.

4.2. Displacement of EPS-LWC wall panel

Displacement data recorded by LVDTs's for all samples were presented in Tables 3 and 4.

EPS-LWC wall panel with opening located at 550 mm from upper end recorded maximum displacement of 1.45 mm and 5.34 mm for Samples 1 and 3 respectively. The value was significantly different. Sample 3 has a maximum displacement which is almost five (5) times higher than Sample 1. On the other hand, Sample 2 and Sample 4 recorded the marginal difference in maximum lateral displacement of 1.18 mm and 1.95 mm respectively. The difference of lateral displacement experience by both cases contributed by the presence and absence of steel fabric reinforcement. Steel fabric reinforcement holds the concrete paste better than steel fibre alone. Therefore, this condition results in lesser lateral displacement for reinforced EPS-LWC compared to unreinforced EPS-LWC. In order to improve the lateral displacement of unreinforced EPS-LWC, addition of steel fabric may be considered at certain locations where the maximum displacement occurred.

Table 3. Lateral displacement for Samples 1 and 3.

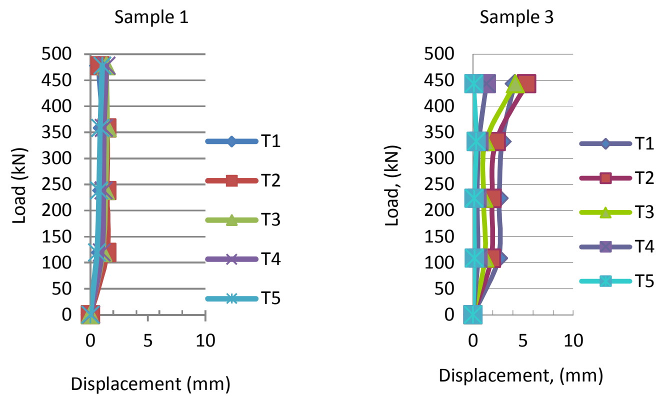
Load (kN)		P_o (initial)	P_{25}	P_{50}	P_{75}	P_{ult}	P_o (initial)	P_{25}	P_{50}	P_{75}	P_{ult}
		Sample 1					Sample 3				
Displacement (mm)	T1	0.00	0.87	0.98	1.05	0.72	0.00	2.54	2.61	2.91	4.12
	T2	0.00	1.43	1.43	1.45	0.82	0.00	1.83	1.90	2.29	5.34
	T3	0.00	1.07	1.31	1.45	1.38	0.00	1.19	1.07	1.26	4.21
	T4	0.00	0.99	1.14	1.18	1.40	0.00	0.49	0.41	0.59	1.35
	T5	0.00	0.57	0.75	0.85	1.03	0.00	0.14	0.11	0.33	0.07

Table 4. Lateral displacement for Samples 2 and 4.

Load (kN)		P_o (initial)	P_{25}	P_{50}	P_{75}	P_{ult}	P_o (initial)	P_{25}	P_{50}	P_{75}	P_{ult}
		Sample 2					Sample 4				
Displacement (mm)	T1	0.00	0.22	0.29	0.22	0.51	0.00	0.99	1.32	1.62	1.95
	T2	0.00	0.27	0.53	0.36	0.96	0.00	0.85	1.19	1.55	1.88
	T3	0.00	0.43	0.55	0.41	1.18	0.00	0.49	0.72	0.99	1.27
	T4	0.00	0.33	0.48	0.40	1.07	0.00	0.32	0.55	0.8	1.05
	T5	0.00	0.07	0.29	0.22	0.37	0.00	0.18	0.29	0.44	0.58

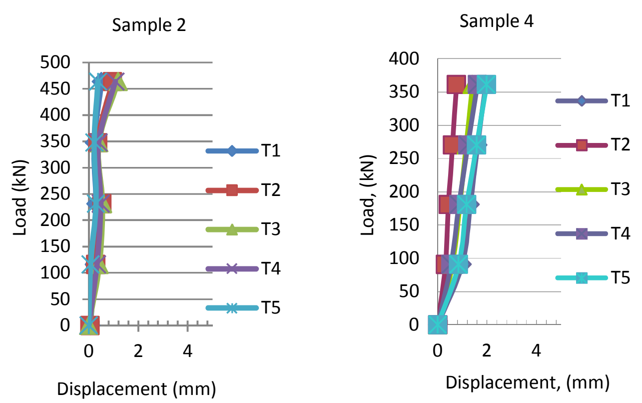
All samples were tested under axial load. There should be loads and displacement relationship obtained since the axial load applied would cause the wall panel to deform. Figure 9(a) shows the load and lateral displacement for EPS-LWC wall panel with deep beam effect at the upper end. For Sample 1, LVDT's T1, T2 and T3 indicated gradual increase with loading until maximum displacement recorded prior to maximum loading, and in turn decreased when P_{ult} is reached. Concrete being brittle when exceeding its elastic region contributed to the reduction in displacement values. This happened when bonded molecules within the EPS-LWC wall panel slipped while experiencing P_{ult}. This behaviour did not match the theoretical concept of load-displacement relationship of concrete. However, LVDT's T4 and T5, located underneath the opening, recorded continuous increment of displacement until reaching the maximum load Meanwhile, from Fig. 9(b) a linear load and displacement relationship was obtained. It shows that at the loading stages of P_{25} until P_{75} the displacements increment were almost consistent until the displacement increase significantly prior to ultimate load.

Likewise for Sample 2, similar linear load and displacement relationship is produced as in Fig. 10(a). The difference only happened at the loading state of P_{75} where all LVDTs recorded decreament in displacement. This is similar to the expected causes as demonstrated in Sample 1. During a particular loading state, the brittleness of concrete prevailed with the occurrence of initial cracks. Sample 4 on the other hand shows the proportional relationship of load and displacement as illustrated in Fig. 10(b). The load and displacement relationship profile match the theoretical pattern for normal concrete as mentioned by Hamzah et al. [14] before reaching the maximum load. It shows that the properties of EPS-LWC in terms of load displacement relationship is similar to the normal concrete.



(a) **(b)**

Fig. 9. Load vs. lateral displacement.



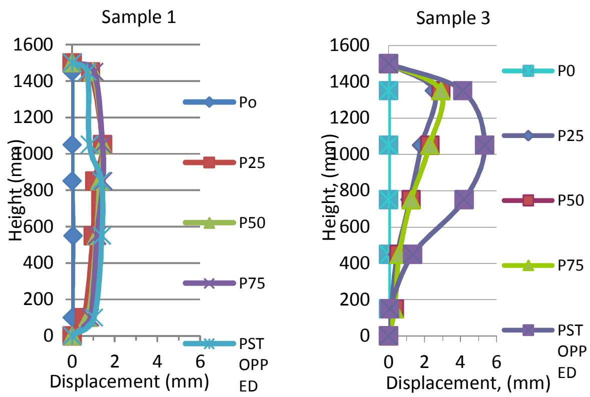
(a) **(b)**

Fig. 10. Load vs lateral displacement.

As for vertical LVDT (T6) and side LVDT (T7) the maximum displacement obtained were less than 3.2 mm for all wall samples. This shows that the presence of opening did not give significant effect to the vertical displacement of structure due to dominance of bending action in the wall panel as mentioned by [15].

4.3. Deformation profile

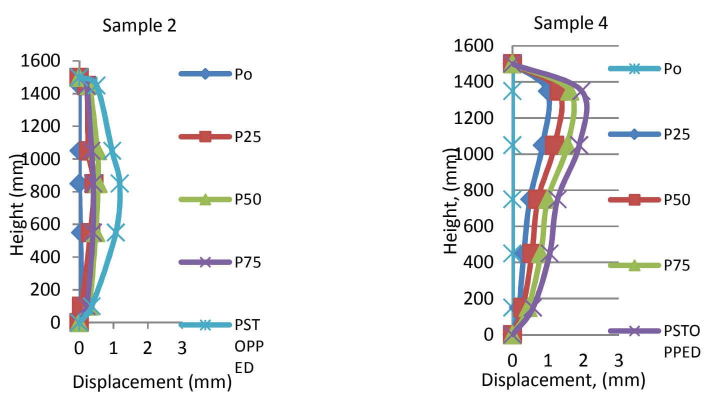
Since EPS-LWC wall panel was subjected to compressive axial load, there would be deformation profile recorded to ascertain failure mode of the wall samples. For reinforced EPS-LWC wall panel, the deformation profile of Sample 1 and 3 were shown in Figs. 11(a) and (b). using pinned-fixed end support conditions, a single curvature deformation profile was obtained for both samples. This result matches the findings obtained by [16] and [17]. Maximum displacement took place at 0.7H (1050 mm) from the base end. Maximum displacement recorded were 1.45 mm and 5.34 mm for Samples 1 and 3 respectively. Since the theoretical displacement obtained is 3.6 mm, displacement obtained by Sample 1 is acceptable. This condition exhibits that steel fabric should complement the steel fibre to reinforce critical sections of the wall panel.



(a) **(b)**

Fig. 11. Deformation profile for EPS-LWC with deep beam effect at upper end.

Similarly, the EPS-LWC wall panel with deep beam effect at the base end deformation profile is shown in Figs. 12(a) and (b) for Samples 2 and 4. Since the deformation profile depends mostly on the support conditions, Fragomeni et al. 2008 [18] find that opening do not affect the wall panel deformations.



(a) **(b)**

Fig. 12. Deformation profile for EPS-LWC with deep beam effect at base end.

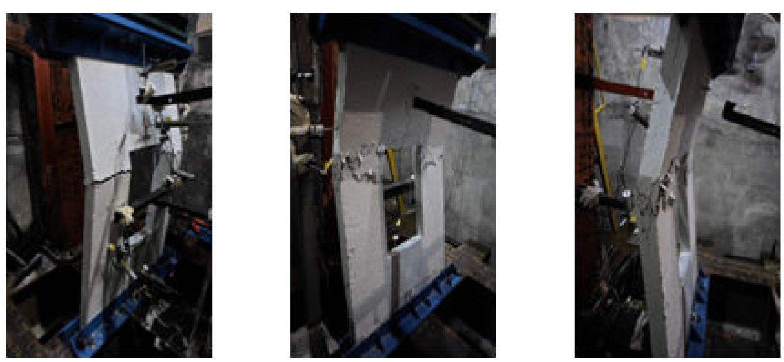
4.4. Crack and failure pattern

Crack patterns were closely monitored in this research. In both cases of reinforced and unreinforced EPS-LWC, the micro cracks were barely seen. Only hairline cracks propagated towards the edges of EPS-LWC wall panel seen and measured. Figures 13 to 16 show the crack patterns in both cases of EPS-LWC wall panel. This result agrees with findings by Holschemacher et al. [20] that mentioned steel fibre offers advantages in terms of hindrance of micro cracks and delay in micro cracks. The number of hairline cracks also reduced significantly. Based on the observations, the crack initiated at the loading state of P_{50} and P_{75} for samples with deep beam effect at base end and at the upper end respectively.

In all samples, crack initiated at the corners of the opening regardless of the opening position, similar to findings obtained by Mays et al. [21]. The wall panel with opening fail in shear. The shear failure happened at the edge of the opening. Meanwhile, from Figs. 15(c) and 16(c), it can be seen that sample 4 demonstrated shear failure at the same location as Sample 2. There were also crushing of concrete experienced by all samples. This type of failure occurred at the base end of the samples due to support conditions.

(a) front view **(b) rear view** **c) side view**

Fig. 13. Crack and failure pattern for Sample 1.



(a) front view **(b) rear view** **c) side view**

Fig. 14. Crack and failure pattern for Sample 3.

(a) front view **(b) rear view** **c) side view**

Fig. 15. Crack and failure pattern for Sample 2.

(a) front view **(b) rear view** **c) side view**

Fig. 16. Crack and failure pattern for Sample 4.

5. Conclusion

As a conclusion, steel fibre replacing steel fabric in EPS-LWC wall panel offers a significant carrying capacity of 443.30 kN which was almost 92% similar to steel fabric reinforced EPS-LWC. However, the presence of deep beam effects at the upper and base end gives significant impact between reinforced and unreinforced EPS-LWC, which result in higher displacement in the latter. This was because the lower surface area at the upper end could not resist high capacity of loading and tend to produce the brittleness effect. Single deformation profile obtained since the wall had pinned-fixed support condition. The presence of the opening affect the stress distribution and result in shear failure at the opening edges. Wall failed in buckling mode and shear at the opening side edges with crack initiated at the corners of the opening. All samples experienced concrete crushing at the bottom edge of the wall. The presence of steel fibre without steel reinforcement caused higher lateral displacement for EPS-LWC wall panel but within the maximum allowable displacement as calculated.

For future works, steel fibres can be cooperated with other type of lightweight concrete in order to verify the effect of steel fibre in lightweight concrete. Also similar scope of research can be adopted by reducing the amount of steel fabric used. Elsewhere, the EPS-LWC enhanced with steel fibre can be used in other structural element, such as beams or column so that further information and details could be obtained.

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