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BUCKLING OF STEEL FIBRE EXPANDED POLYSTYRENE CONCRETE WALL PANEL

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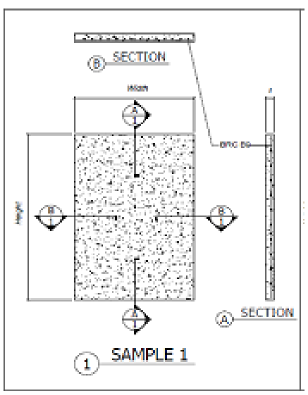
Graphical abstract



Abstract

Steel Fibre Expanded Polystyrene Concrete (SFEPS) wall panel is envisaged as load bearing walls, although it is lightweight by design. The performance of this wall is investigated, incorporating opening to fulfil the demand for ventilation and services conduits or equipments. It focused on the buckling behaviour by comparing the carrying load capacities and deformation profiles of wall panel with and without opening. Primarily, the samples were cast from concrete mixed with expanded polystyrene (EPS) beads, enhanced with hooked end round shaft steel fibre and reinforced with a single layer rectangular steel fabric (BRC) of size B9. The wall panel size is 2000 mm in height (limited due to testing frame allowable height), 1500 mm wide and 100 mm thick which gives the slenderness ratio of 15. The wall falls under the slender wall category for lightweight concrete since the slenderness ratio is greater than 10 [1]. A central opening with a size of 600 mm high by 600 mm wide is created to accommodate the opening criterion. Experimental tests were conducted simulating fixed ends condition. The average compressive strength of SFEPS, f_{cu} is 20.87 N/mm^2 with a density, ρ of 1900 kg/m^3. These lightweight SFEPS wall panels sustained load between 958.0 kN and 1938.9 kN. Wall panels experienced maximum displacement of 22.3 mm at midheight. The wall panels failed in buckling as it should be for slender wall. There was also concrete crushing at the upper and lower ends of the panels. The SFEPS wall panel is suitable to be used as load bearing structures.

Keywords: Buckling; steel fibre; expanded polystyrene; opening; load bearing

1.0 INTRODUCTION

The lightweight concrete wall panel is usually utilized as partitions. Innovation in concrete materials led to few significant research using EPS and steel fibre such as Jamilah *et al*, 2013 [2] and Nurhaniza *et al*, 2008 [3]. Wall panel is known as the most effective alternative method to tedious and time-consuming brick-laying method [4]. It can also act as a load bearing wall where, it helps other structural element by sustaining loads from the building. In view of this, lightweight wall panel with acceptable strength may replace the conventional precast panels used in high rise buildings. In these buildings, openings within the wall panel as ventilation, aesthetic purposes and service conduits are common. The buckling behaviour of these wall panels is looked into to provide insights to promote sustainable construction by adopting lightweight concrete in load bearing wall.

In this study, two (2) SFEPS wall samples were prepared using water, cement, sand (passing 2.36 mm), coarse aggregate (passing 10 mm) with the addition of steel fibre (0.5% of total volume) and EPS (30% of total volume). Both samples used BRC B9 with laboratory yield strength, *fy* of 588.8 N/mm^2 as the reinforcement. Details of samples are shown in Figure1.

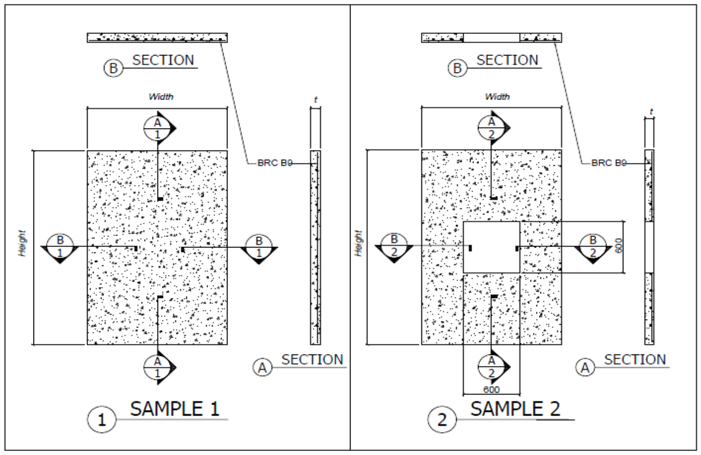


Figure 1 Details of samples

Table 1 List of empirical equations

BS 8110 [5]	Saheb & Desayi, 1990 [6]	Doh & Fragomeni, 2006 [7]
$n_w \leq 0.35 f_{cu} A_c + 0.7 A_{sc} f_y$	$P_{uo} = (k_1 - k_2 \chi) P_u$	$N_{uo} = (k_1 - k_2 \chi) N_u$

2.0 LITERATURE REFERENCES

Empirical equation from BS 8110 [5] was used to verify the design loading capacity of solid wall. Since there were no empirical equations stipulated in any code of practice for calculating the design capacity of wall panel, two (2) renowned empirical equations by Saheb & Desayi (1990) [6] and Doh & Fragomeni (2006) [7] were used to verify the experimental results for wall panel with opening. The equation are shown in Table 1.

According to Nurfariza *et al*, 2014 [8], wall panel with a slenderness ratio of 15 failed in buckling regardless of its aspect ratio. They have tested four (4) samples of plain SFEPS wall with fixed-fixed ends condition. It is found that the serviceability limit increased by 23.52% from the theoretical load for wall with aspect ratio of 1.5.

Rai and Joshi (2014) [9] conducted experimental study of the properties of fibre reinforced concrete and concluded that steel fibre reinforced concrete are ductile. They deduced this concrete exhibited high impact loading absorption. Steel fibre was also expected to affect the failure mode of the concrete, however the effect depends on the quantity used within the mixture.

Rohana *et al*, (2014) [10] proceeded with EPS lightweight concrete wall panel with different opening configurations. The wall panel samples have two (2) different opening locations which created a deep beam effect at the upper and lower ends of the wall panel. The ultimate carrying capacity obtained from the experimental work was 22% less than the theoretical calculation. The sample with deep beam effect at upper end produced 3% higher capacity than the sample with a deep beam at the lower end. End restraints and slenderness are more prominent, portraying buckling failure mechanism. The number of crack patterns reduced significantly with the presence of steel fibre in the concrete mix.

Based on findings from previous researches, there is potential for the SFEPS wall panel to be used as load bearing walls.

3.0 METHODOLOGY

Two samples of the SFEPS wall panel were prepared. Samples then tested using Universal Testing Machine (UTM) with loading capacity of 2000 kN. Details of experimental setup were illustrated in Figure 2. Linear variable displacement transducers (LVDT) were installed to record the displacement of the SFEPS wall.

4.0 FINDINGS

Data obtained from the experimental test were analysed and the findings were discussed in details.

4.1 Loading Capacity

Ultimate loading capacity, P_{ult} obtained from the experimental tests was compared to the theoretical values calculated using empirical equations. Sample 1 experienced two (2) cycles of axial load test, first testing aborted when the maximum loading limit was reached, and second to ascertain the residual carrying capacity. Meanwhile Sample 2 was tested until failure. Table 2 shows the difference in percentage of the load carrying capacity during each test. SFEPS wall panel sustained high carrying capacity, suitable for load bearing. The linear relationship between load and displacement is significant during serviceability region and reduced gradually beyond yield point, with the sample gaining lateral displacement with smaller load increments. Strain hardening took place after initial micro cracking happened as the effect from ductility of SFEPS mix protects the sample from abrupt cracked failure.

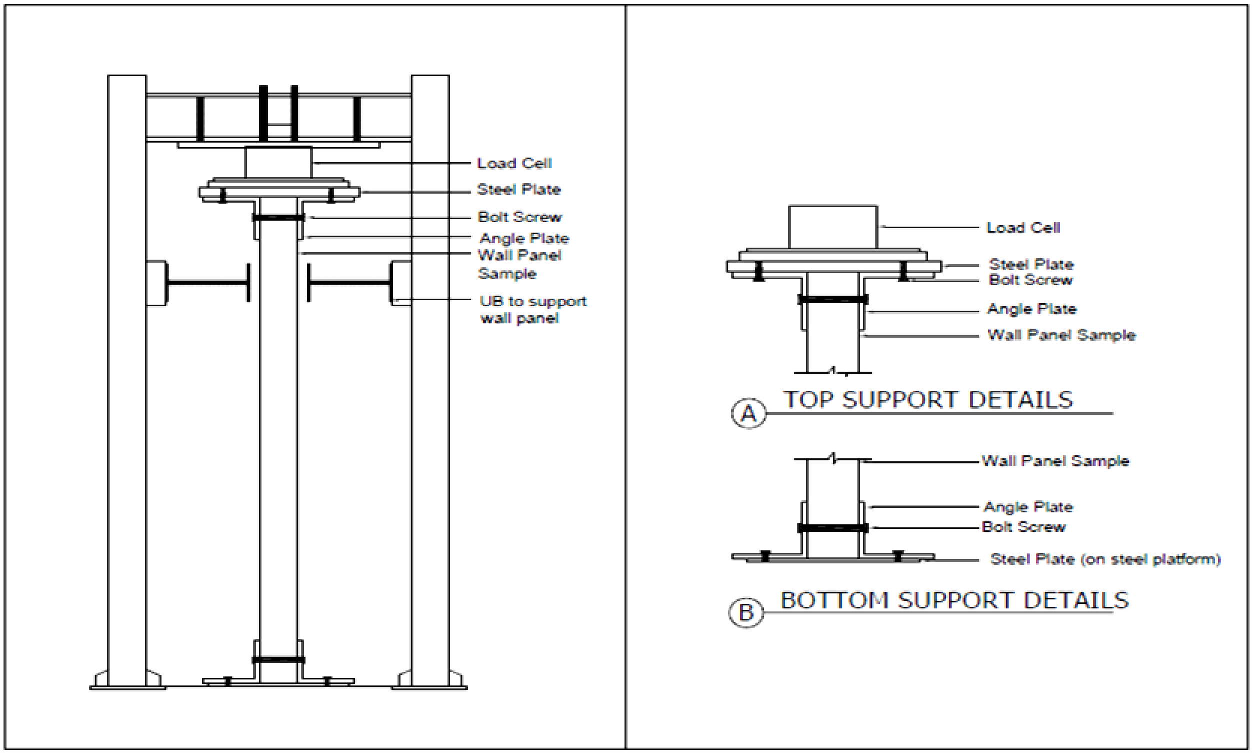


Figure 2 Experimental setup

Table 2 Ultimate loading capacity of the wall panel

Sample 1 (solid)		Sample 2 (with opening)	
Experimental (P_{ult})		Experimental (P_{ult})	
1st test	2nd test	1st test	
1938.90	958.00	1085.50	
Theoretical (P_{theory})		Theoretical (P_{theory})	
BS 8110		Saheb & Desayi	Doh & Fragomeni
1596.09		1180.82	1280.76
Difference Ratio (P_{ult}/P_{theory})		Difference Ratio (P_{ult}/P_{theory})	
1.21	0.6	0.92	0.84

The solid wall panel (Sample 1) recorded substantial carrying capacity of 1938.90 kN, 20% more than the theoretical calculated magnitude. The significant difference is contributed by the steel fibre, in which cohesive bonding within the concrete matrix happened, confirmed by [8]. Subsequent testing in ascertaining the residual strength showed carrying capacity reaching 958.00 kN, 40% lower than the theoretical findings. For a lightweight wall panel which had undergone testing beyond the elastic region and yet to be able to withstand almost half of its original strength indicate that the presence of steel fibre bridged the concrete paste and the EPS as found by [2] for a wall with a slenderness ratio of 15. The solid wall panel did not fail abruptly as expected, even after experiencing high load, implying the positive impact from the steel fibre making the wall behave in a more ductile manner instead of total collapse after reaching its ultimate carrying capacity. This shows that steel fibre in concrete help to minimise post-disaster failure, such as structures experiencing seismic and impact loads.

Subsequently, wall with opening (Sample 2) is less favourable to satisfy the theoretical ultimate loading capacity by a small margin of 16%. Nevertheless, the carrying capacity was 33% less than the theoretical value for solid wall. The presence of opening that has taken out part of the wall volume affected the carrying capacity by disturbing the stress path within the wall. However, for a lightweight concrete wall panel, the P_{ult} obtained for Sample 2 was reasonable. For both Samples 1 and 2, the difference in the load capacity proved that presence of opening affects the carrying capacity as found by [11].

4.2 Deformation Profile.

SFEPS wall panel deformation profile tested under one way in plane action illustrated a single curvature towards the frontal surface. Regardless of the presence of the opening, similar profile is obtained in both samples as depicted in Figure 3. However, the location of maximum lateral displacement was different. According to the Euler buckling theory, the fixed end condition should experience maximum lateral displacement at midheight. Sample 1 depicted the theory and as found by [8] for fixed-fixed ends wall panel. In contrary, the structural integrity of Sample 1 which has been disturbed, could only take about 30% of the maximum lateral displacement in the second test, with it happening closer to the upper end support, assuming the pinned-fixed ends condition. It was later evidenced with concrete crushing happening at the upper end affecting the deformation profile in the second test of the solid wall panel.

As for Sample 2, it recorded the maximum lateral displacement at 0.7*H* from the base end almost similar with Sample 1 from the second test. This finding proved that when there is an abrupt change in geometry of SFEPS, the buckling behaviour changed. Sections above and below the opening acted as deep beam element and coupled with both side sections behaved as columns. The geometric disturbance caused the SFEPS wall panels to redistribute it's compressive stress, creating some unstable stress distribution within the element which lead to the maximum lateral displacement took place closer to the load source. It might not give significant effect on loading capacity, but when the stress within the wall becomes unstable, it affects the stability of the wall panel structures.

4.3 Crack Pattern.

SFEPS wall panel experienced buckling failure in both samples. Concrete crushing were evidenced at both lower and upper ends as shown in Figure 4.
Meanwhile, only few hairline cracks were observed. Steel fibre helped to inhibit minor crack by arresting the propagations [12]. For Sample 2, cracks initiated at the opening corners. This result agreed with the findings by [2], [10] and [11].

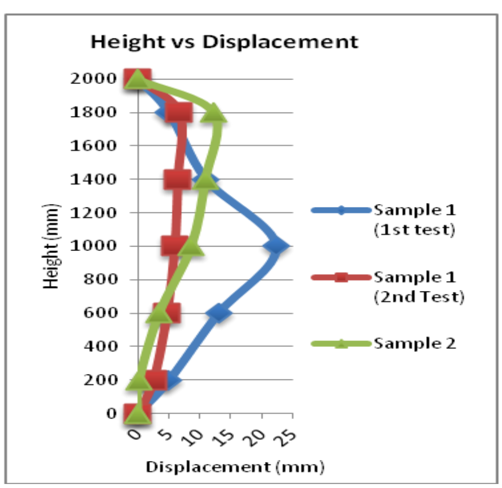


Figure 3 Deformation profile of SFEPS wall panel

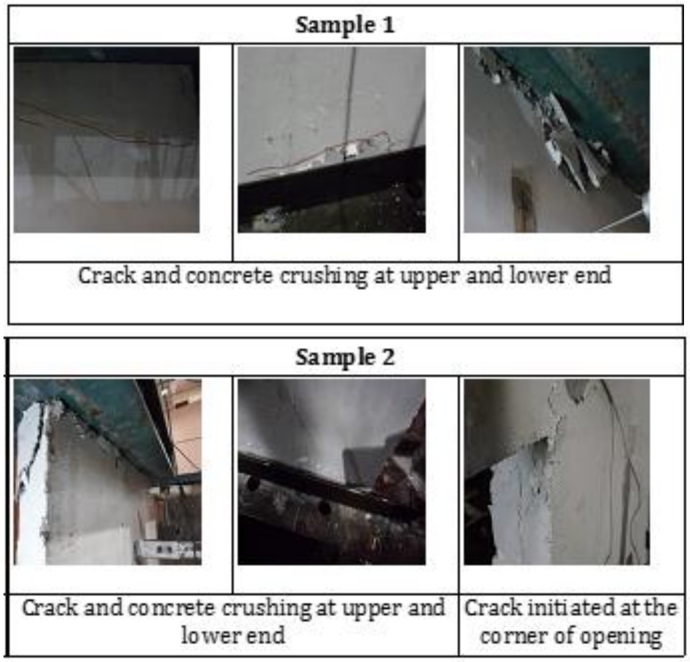


Figure 4 Crack pattern for Samples 1 & 2

5.0 CONCLUSIONS

To conclude, the SFEPS wall panel can serve as load bearing walls. Though opening affects the carrying capacity of the wall panel, the presence of steel fibres have provided significant resistance from excessive lateral displacement and still within the expected buckling behaviour.

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