STRUCTURAL BEHAVIOUR OF PRECAST LIGHTWEIGHT FOAMED CONCRETE SANDWICH PANEL AS A LOAD BEARING WALL

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Abstract: A study was carried out to develop a Precast Lightweight Foamed Concrete Sandwich Panel, PLFP, as a new industrialized building system, IBS. Experimental investigations and finite element simulations using LUSAS software to study its structural behaviour was undertaken. The PLFP panel is made of foamed concrete wyhtes which enclose a polystyrene layer and reinforced with high tensile steel bars as its vertical and horizontal reinforcements. The panel is further strengthened by steel shear connectors bent at an angle of 45˚ which are inserted in the panel through the polystyrene layer. The panels are tested using Magnus Frame and loaded with axial load until failure. The ultimate load carrying capacity, load-deflection profiles, and the failure mode are recorded. The panel was modeled using plane stress element for foamed concrete and bar element for its reinforcement and shear connectors. Series of simulations were conducted for PLFP panel models with various slenderness ratios and sizes of steel bar. The results obtained from the experiment show good agreement with the results obtained from simulations. Partial composite behaviour is observed in all specimens when the cracking load is achieved. It is also found that the steel shear connectors are able to transfer the load from one wythe to the other. It is concluded from the results that the PLFP panel proposed in this research is able to achieve the intended strength for use in low to medium rise building. Considering its lightweight and ease of construction, PLFP panel is feasible to be developed further as a competitive IBS building system.

Keywords*:* Foamed concrete, Industrialised Building Sytem, Load Carrying Capacity, Load Deflection, Profile, Partial Composite Behaviour

INTRODUCTION

Precast concrete sandwich panel, PCSP, has gained much attention as an effective structural element in engineering field. It has been used as load-bearing members in naval structures [1]. However, in the building and construction industry, most of the research published on sandwich panels are related to the study of the non-load bearing non-composite type of PCSP [2, 3, 4, 5]. Previous research on sandwich panel have shown that various materials could be used as the core layer and skin faces or wythes.

Lightweight concrete, density in the range of 1440 kg/m^3 to 1840 kg/m^3, is one of the alternative lightweight material used in lightweight sandwich panel [6]. British Standard, BS 8110: Part 2 (1985) classifies the lightweight concrete as concrete with density of 2000 kg/m^3 or less. Among the advantages in using the lightweight materials is it helps to reduce the self weight of the panel and overall cost of the construction. Foamed concrete is one type of cellular lightweight concrete which has been used in the lightweight PCSP especially as the core layer due to its good insulation as discovered by Rice *et al*. (2006) [7]. However, when it is used as a core, the cost will relatively gets higher since the thickness of the core is usually greater than the thickness of the wythe in a typical sandwich panel. Therefore, this research focused on the structural behaviour of precast sandwich lightweight foamed concrete panel, PLFP, as a load bearing wall using foamed concrete as the facing materials and polystyrene as the core. The panel‘s strength is enhanced by embedding steel shear truss connectors with a diagonal orientation across its layers as shown in Figure 1.

EXPERIMENTAL PROGRAMME

The experimental program includes a total of fourteen specimens of PLFP panels. The thickness of concrete wyhte for all the panels was kept constant at 40 mm. The concrete cover of 15 mm was used in every specimen. The size and desingnation of all panels are tabulated in Table 1.

Materials

(a) Wythe: Inner and outer wythe were made of foamed concrete with compressive strength 12 Mpa to 17 MPa for the panels. (b) Core: Polystyrene was used as the insulation material in the core. (c) Reinforcement: A total number of ten high tensile steel of 9 mm diameter bars were used as the vertical rebar (top and bottom). (d) Shear connectors: Continuous truss-shaped connectors running the full height of the panels were used to tie the inner and the outer wythes. (e) Capping: Panels were cast with normal concrete capping of 100 mm thick at both ends to prevent from premature cracking near loading and support areas. Figure 2 shows the details of a PLFP specimen with concrete capping at both ends.

Test Set-up and procedure

The panel specimen was placed in the magnus frame correctly in position to get the targeted end conditions as shown in Figure 3. A small load of 1 kN was first applied to make sure all the instruments were working. The load was then increased gradually with an increment of 50 kN until failure. The crack pattern and horizontal deflection were observed at each load stage. Linear Voltage Displacement Transducer (LVDT) was fixed at mid height on both front and rear faces of every panel for horizontal deflection measurement. These horizontal deflection measurements on both faces of panel were used to determine the load-deflection profiles and to study the deflection‘s trend of the two foamed concrete wythes.

FINITE ELEMENT METHOD

The main objective of FEM analysis is to study the load carrying capacity and the effect of slenderness ratio, H/t, on the behaviour the PLFP panels under axial load.

FEM Modeling

Physical Model

A 2-D plane stress element is used to model the foam concrete wyhte. A vertical cross section of width with one shear connector along the height of the wall was modeled. The thickness assigned for the PLFP panel was 750 mm. The steel shear connectors and reinforcement were each modeled by 2-D bar elements, having two degree of freedom at each node. The reinforcement used in the foamed concrete wythes are used as the longitudinal and transverse reinforcement for the inner and outer wythes. The shear connectors used to connect the two wythes are continuous truss shaped connectors made of 6 mm and 9 mm diameter steel bar and bent to an angle of 45°. The support conditions were pinned in x-direction at the top and pinned in the x and y direction at the bottom. The loading conditions were line loads along the concrete wythes thickness. The physical model for panel PA-1 is as shown in Figure 4.

Material model

Foamed Concrete Wythe:The multi-crack concrete (model 94) has been chosen for foamed concrete wythes. The material properties for foamed concrete used in the analysis are determined earlier in the experimental work.

Steel Reinforcement and Shear Connectors: A Von Mises continuum plasticity model had been chosen for the steel reinforcement bars and steel shear truss connectors. This modeling represents ductile behaviour of materials that exhibit little volumetric strain. The values of initial yield stress, ultimate stress, strain at failure, and Young Modulus are determined from the tensile test carried out on steel with the two different diameters used. The values of Poisson’s ratio, mass density and coefficient of thermal expansion for the steel are adopted from the LUSAS material library.

Concrete Capping: The capping at both ends of panel used normal concrete material. Only the elastic properties were assigned for the concrete capping to avoid cracks from occurring around this area.

Loading/Analysis Control: A globally distributed load per unit length was applied axially on the top of PLFP panel are as shown in Figure 3. A non-linear analysis was carried out assuming both concrete and steel to have non-linear characteristics. Nonlinear and transient analysis was used because it takes into account the changes in geometry and material due to geometry deformation and yielding of the material under applied load. Transient analysis was used to carry out analysis over a period of time and progressed in a step by step manner, giving results at each time-step.

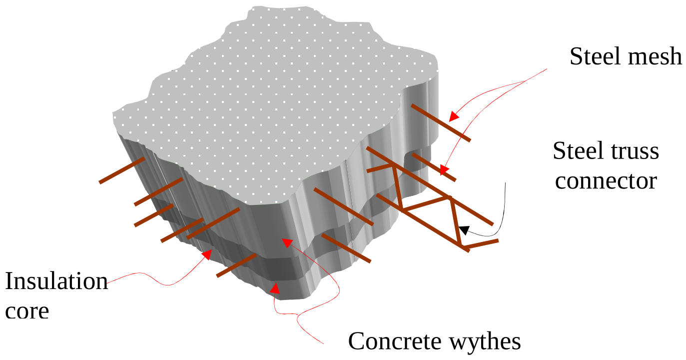

Figure 1: PLFP Panel

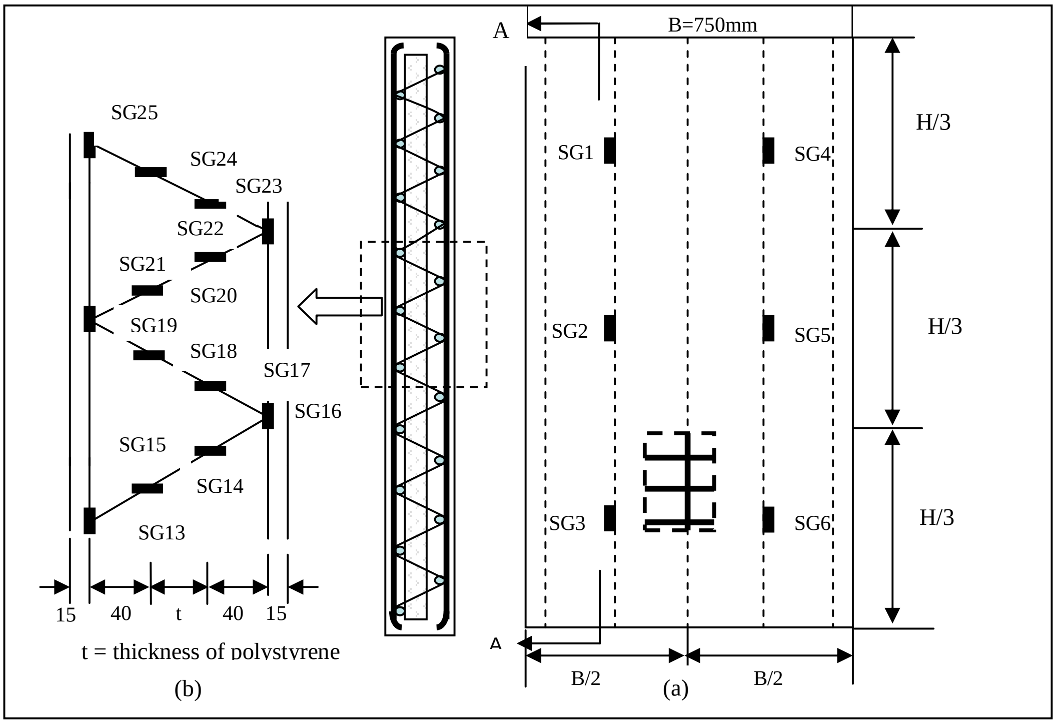

Figure 2: Locations of Strain Gauges

Figure 3: Magnus Frame

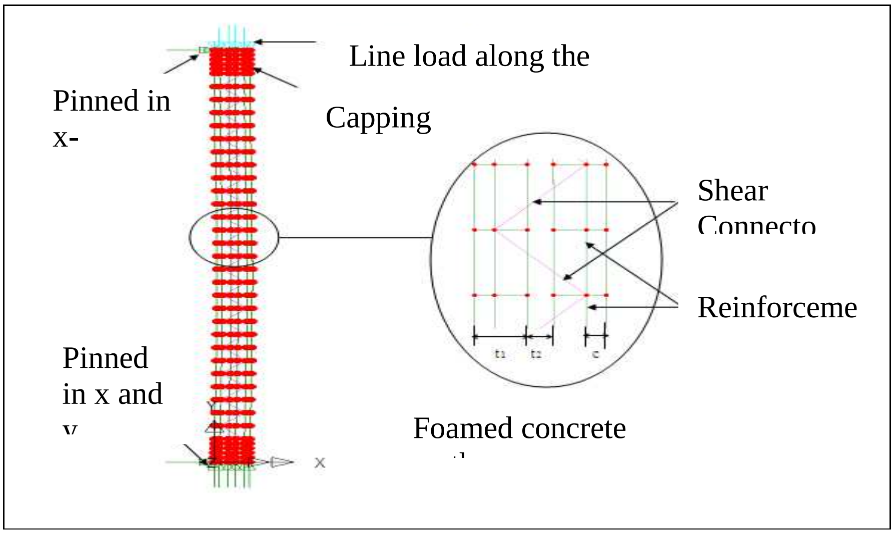

Figure 4: 2-D plane stress element model of PLFP panel

RESULT AND ANALYSIS

Ultimate Strength Capacity

From the ultimate strength values in Table 1, it is found that the FEM results gave higher values compared to the experimental results. This is further translated by the graphs drawn in Figure 5 which shows the limits of the ultimate strength values as obtained from the experiment and FEM analysis. It is found from the figure that the percentage differences between these ultimate strength values are within the lower and upper limit of -20% and +20%. Even though the results of the ultimate strength recorded from experiment have certain percentage of difference between the values from FEM, the similar trend of relationship between the ultimate strength and slenderness ratio were noticed in both where the panel's ultimate strength reduces with increasing slenderness.

The suitability of PLFP panel as load bearing wall in a low rise building is examined by determining the load acting on PLFP wall panel in a 5-storey residential building. The calculation is presented in Appendix H. It is found that the load act on PLFP wall panel in the building is 310 kN/m. The ultimate load recorded from the experiment for PLFP panel PA-1 to PA-14 is within 373 kN/m and 1173 kN/m. As such, the PLFP panel is suitable for use as a load bearing wall in a low rise building.

Crack Pattern and Mode of Failure

Cracks were observed from experiment in either or both concrete wythes. The specimens finally failed by the crushing of concrete. Panel PA-9 and PA-12 show crack and crushing at the middle zone of panel as shown in Figure 6 and Figure 7, respectively. The figures indicate signs of buckling and certain degree of compositeness were achieved in the panels in which both wyhtes were found to deflect together.

The load at first crack and failure load of PLFP panels PA-1 to PA-14 obtained from FEA are shown in Table 2. From the values in the table, it can be seen that first crack occurred at 58% to 70% of the failure load. It is noticed that the slenderness ratio have significant effect on the first crack load and failure load achieved in the panels.

Load-horizontal deflection Profil

From the load-deflection curves in Figure 8, small initial readings of the horizontal deflection measurement were recorded at the beginning in all panels. However, upon reaching their cracking points, the readings started to increase gradually until failure. The maximum deflection recorded is 9.4 mm in panel PA-7 with height 2800 mm which is smaller than the limiting value of L/250 as stated in Section 3.2 in BS8110: Part 2: 1985 for structural member under vertical load. All panels deflected elastically before the first crack appeared. Therefore the load-deflection curves were approximately linear at the early stage of loading. After the first crack appeared, the load-deflection curve became non-linear. The maximum deflection measured in all panels did not really represent its correlation with the slenderness ratio as there are panels with lower H/t which still recorded high maximum deflection values. It is the trend of the deflection curves that ought to be studied here since it represents the degree of composite action between the two wyhtes in the panel. It also represents the effectiveness of the shear truss connectors in taking up the applied load and transfers it from one wythe to the other.

From the observations, panels PA-5, PA-6, PA-7 PA-9, PA-10, and PA-12 recorded all positive values for the rear and front surfaces. Load-deflection curves at mid-height of panels PA-5 and PA-12 are as shown in Figure 9. The load-deflection curves tend to move in the same direction since the early stage of loading. The similar trend of curves for both faces proved that both wythe in those panels deflected together in the same direction. Panel PA-11 recorded all negative values with the curve for both faces of panel tend to move in the same direction which shows that both wythe deflected together. Panel PA-8 recorded both negative and positive values. Its two wyhte are shown to deflect together

since the early stage of loading up to the point of failure. This indicates the effectiveness of the shear connectors in taking up and transferring the applied axial load between the two wythes in all these panels. All these panels have high slenderness ratio in the range of 22.4 to 28.

CONCLUSION

(a) It is proven from the experiment and FEM results that the PLFP panel developed in this study can sustain the axial load applied and the shear connectors used are effective in transferring the load from one wythe to another. (b) The ultimate strength capacities of PLFP panels under axial load as obtained from experiment were compared to those obtained from using FEM model. It was found that FEM predicts the ultimate strength of panels within the acceptable accuracy when the panel was subjected to axial load. (c) The slenderness ratio, H/t, is found to have a significant effect on the strength capacity of PLFP panel.

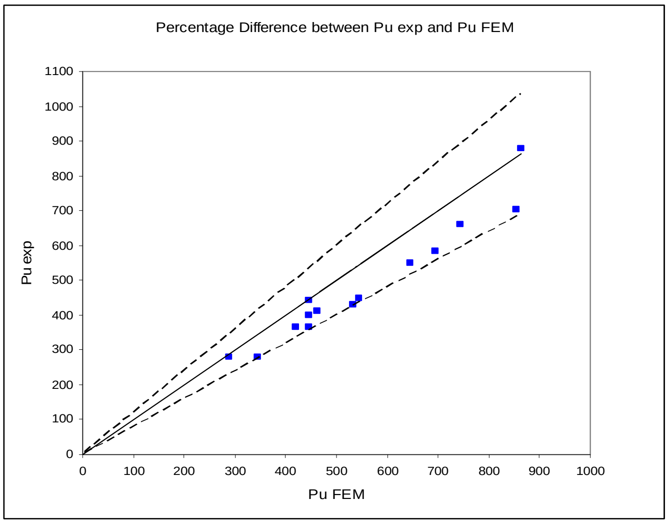

Figure 5: Percentage difference between ultimate strength from experiment and FEA

Table 1: Ultimate Loads of PA-1 to PA-14

Panel	H x W x t	Compressive Strength, Pc (N/mm^2)	H/t	Ultimate Load, Pu		$P_{u(FEM)}$ - $P_{u(EXP)}$ ------------------- % $P_{u(FEM)}$
				Exp	FEM	
PA-1	1800 x 750 x	12	18	280	345	18.8
PA-2	1800 x 750 x	13	18	365	446	18.2
PA-3	2000 x 750 x	13	20	365	421	13.3
PA-4	2000 x 750 x	15	20	450	545	17.43
PA-5	2800 x 750 x	17	28	583	695	16
PA-6	2800 x 750 x	16	28	550	645	14.7
PA-7	2800 x 750 x	10	22.4	280	289	3
PA-8	2800 x 750 x	17.5	22.4	660	745	17
PA-9	2500 x 750 x	12	25	400	445	10
PA-10	2500 x 750 x	12	25	441	445	1
PA-11	2500 x 750 x	15	25	431	534	19
PA-12	2500 x 750 x	17.2	25	880	864	2
PA-13	2500 x 750 x	12	12.5	413	463	10.8
PA-14	2500 x 750 x	17	12.5	703	855	17.8

Figure 6: Crushing at mid-height of panel PA-9 due to buckling in the middle zone of panel

Figure 7: Crack and crush at mid-height of panel PA-12

Table 2: First Crack Load and Failure Load of Panel PA-1 to PA-10 As Obtained From FEM

Panel	H/t	First Crack	Failure Load
PA-1	18	200	345
PA-2	18	315	446
PA-3	20	295	421
PA-4	20	385	545
PA-5	28	487	695
PA-6	28	455	645
PA-7	22.4	205	289
PA-8	22.4	520	745
PA-9	25	315	445
PA-10	25	315	445
PA-11	25	375	534
PA-12	25	605	864
PA-13	12.5	295	463
PA-14	12.5	515	855

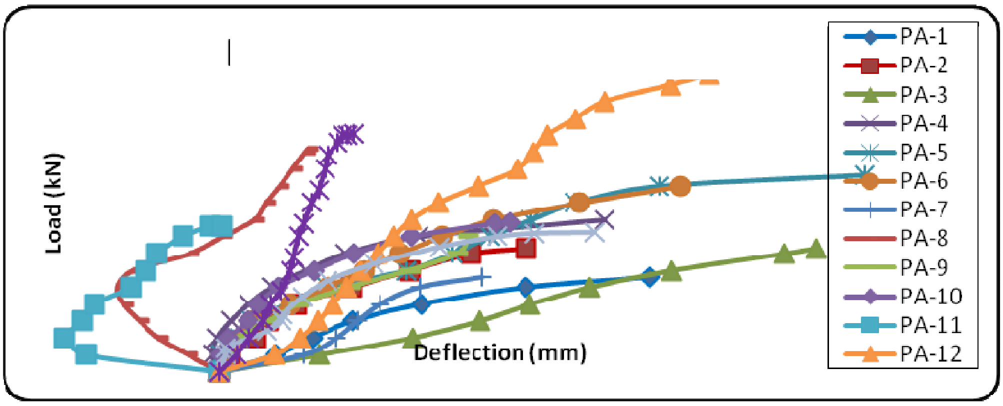

Figure 8: Load-deflection profile for PLFP panels

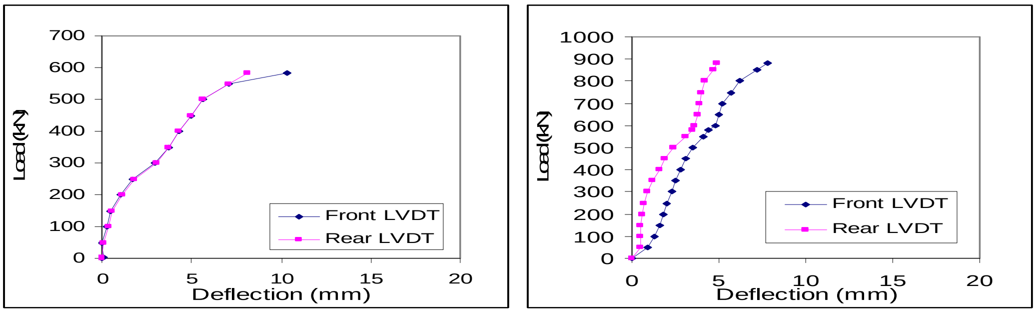

Figure 9: Load-deflection curves at mid-height of panels PA-5 and PA-12

The results from both experiment and FEM analysis have proved that the ultimate strength capacity decreases as the slenderness ratio increases. (d) The wyhte in the panels with higher slenderness ratio tend to deflect together and behave in a more composite manner compared to the lesser slender panels. They also recorded higher lateral deflection measurements than panels with lower H/t. This proves that slenderness ratio has significant effect on the deflection profiles of PLFP panels.

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REFERENCES

[1] Aicher S. & Hofflin L. (1999). Long-term Performance Test of Eccentrically Loaded Sandwich Wall Elements With Wood-Based Skins. *Otto-Graf-Journal*, *10*, 128-142.

[2] Jokela J. & Sarja, A. (1981). Development of Reinforcement for Sandwich Facade Element. *Research Note No. 19*, VIT-Technical Research Center of Finland, Finland.

[3] Olin J., Ravio J., & Jokela J. (1984). Development of Heat Economy and Construction Façade Elements. *Research Report No. 28*, VIT-Technical Research Center of Finland, Espoo, Finland.

[4] Hopp J. & Hemerstad A. (1986). Sandwich Elements - Construction Handbook of Concrete Elements. Norvegian Indusries Association, Oslo, Norway.

[5] Bush T. D. & Wu Z. (1998). Flexural Behavior of Composite Prestressed Sandwich Panels with Continuous Truss Connectors. *PCI Journal*, *43*(5), 112-121.

[6] PCI Committee. (1977). State of the Art of Precast/Prestresses Sandwich Wall Panels. *PCI Journal*, *42*(2), 92-133.

[7] Rice M. C., Fleischer C. A., & Zupan M. (2006). Study on the Collapse Of Pin-Reinforced Foam Sandwich Panel Cores. *Journal of Experimental Mechanics*, *46*, 197-204.