

# Ultimate Load Carrying Capacity of Precast Lightweight Foamed Concrete Sandwich Panel (PLFP) with Double Shear Truss Connectors Under Axial Eccentric Loading

N. Mohamad, W. I. Goh, R. Abdullah, Ismail Ahmad, S. Samsuddin and M. H. A. Rahman

**Abstract** This paper studies the ultimate carrying capacity and structural behavior of precast lightweight foamed concrete sandwich panel (PLFP) with double shear truss connectors under axial and eccentric loading. Eight small scale PLFPs with various slenderness ratio were casted and tested. Ultimate load carrying capacity, load deflection profile, surface strains and crack pattern were recorded and analysed to compare the PLFP structural behaviour under two different loading conditions. Results obtained showed that PLFP was able to sustain higher axial loading compared to eccentric loading. PLFP with lower slenderness ratio achieved higher ultimate load carrying capacity compared to higher slenderness ratio. Comparison of deflection profiles also proved that PLFPs under axial loading achieved higher ultimate carrying capacity and compositeness reaction compare to PLFP under eccentric loading.

**Keywords** Sandwich panel · Lightweight · Foamed concrete · Double shear truss connectors · Axial loading · Eccentric loading

## 1 Introduction

As stated in [1], sandwich panel is similar to other conventional precast concrete members regarding to its design, detailing, manufacturing, handling, shipping and erection; however, because of the presence of a core layer of insulation, sandwich

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panels exhibit some unique characteristics and behaviors. Sandwich panel have all of the desirable characteristics of conventional precast concrete wall panel such as durability, economy, fire resistance, large vertical spaces between supports, and can be used as shear wall, bearing wall and retaining wall [1].

Various types of sandwich panel with different material and structural behavior had been developed by researchers for different usage and application. The application of lightweight foamed concrete was introduced by researchers either used in core layer or outer wythe [2–4]. Lightweight foamed concrete with density of 400–600 kg/m<sup>3</sup> can be used in partition as insulation material and structural load bearing material in low load bearing system such as walls in low rise residential buildings [2, 5, 6]. Therefore, PLFP is one of the precast systems which uses lightweight foamed concrete as outer wythe layer. Mohamad et al. [7] investigated the structural performance of PLFP with single shear truss connectors as a load bearing wall using foamed concrete as outer wythes and polystyrene as the core. It was observed that PLFP can sustain the axial load applied in transferring the load from one wythe to another and slenderness ratio, H/t was found to have significant effect on the strength capacity of PLFP.

Although PLFPs were studied by previous researchers, they were focused more on axial load effect on the panel compared to the research work on PLFP under eccentric loading. Thus, this research focused and compared the axial and eccentric loading effect on PLFP with double shear truss connectors.

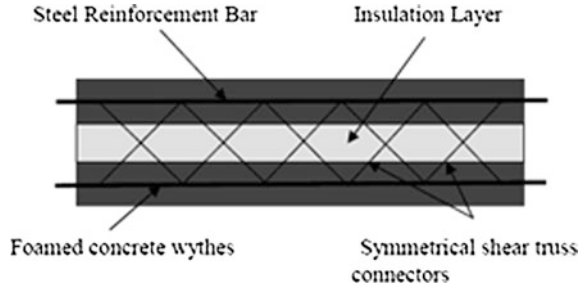
## 2 Design of PLFP with Double Shear Truss Connectors

A total of 8 small scale PLFPs were casted to study its structural behaviour and determine its ultimate load carrying capacity due to axial and eccentric loading effect by using Magnus frame until it failed. The slenderness ratio of PLFP is between 12 and 18.

The fabrication and the materials properties were referred to previous research conducted [8]. The concrete cover of 8 mm used and the thickness of each concrete wythe was fixed at 20 mm. Inner and outer wythe was made of lightweight foamed concrete with wet densities from 1,700 to 1,800 kg/m<sup>3</sup> to achieve the target compressive strength of 10–15 MPa for all panels. Expanded polystyrene (EPS) was used as an insulation material in the core layer. The polystyrene sheet was cut into pieces and inserted in between the steel mesh.

A horizontal and vertical reinforcement with 4 mm diameter bars were tied to each other at 75 mm center to center as main reinforcement. Thus, it was strengthened by using 3 mm diameter steel bar as double shear truss connectors as illustrated in Fig. 1. Double shear truss connectors were bent to an angle of 45°

**Fig. 1** Design of PLFP [3]



and tied to vertical reinforcement in the steel mesh. Five double shear truss connectors were used for each panel to transfer the load from one wythe to another. Every panel in this study was casted with 50 mm length with normal concrete capping at both ends to prevent from premature cracking around loading and supports areas as referred to [8].

### 3 Experimental Program

All PLFPs were casted using steel formwork. Space blocks used to maintain the concrete cover at 8 mm. A normal Grade 30 concrete was poured into the capping at both ends. After the capping hardened in about half an hour, the foamed concrete was poured into the specimen as inner layer and outer layers and trowel to obtain a smooth surface. Specimens were placed under ambient temperature and protected from direct sunlight with canvas. Formworks were dismantled after 28 days and panels were tested by using Magnus frame.

For axial loading, the load was applied at middle across the thickness of PLFP along top edge of the panel length. For eccentric loading, the loading was carried out by applying the load at an eccentricity  $t/6$  along top edge of the panel length during the experimental programme. Load applied gradually until failure occurred, crack pattern and horizontal deflection were observed at each loading stage.

A total of six strain gauges were used for surface strain measurement and two Linear Voltage Displacement Transducers (LVDTs) were placed at the middle on each side of the panel as shown in Fig. 2.

PLFP specimens were tested using Magnus Frame with 1,000 kN loading capacity. Figure 3 shows the experimental set-up, where the PLFP was clamped to reaction frame correctly in the position to get the targeted end condition.

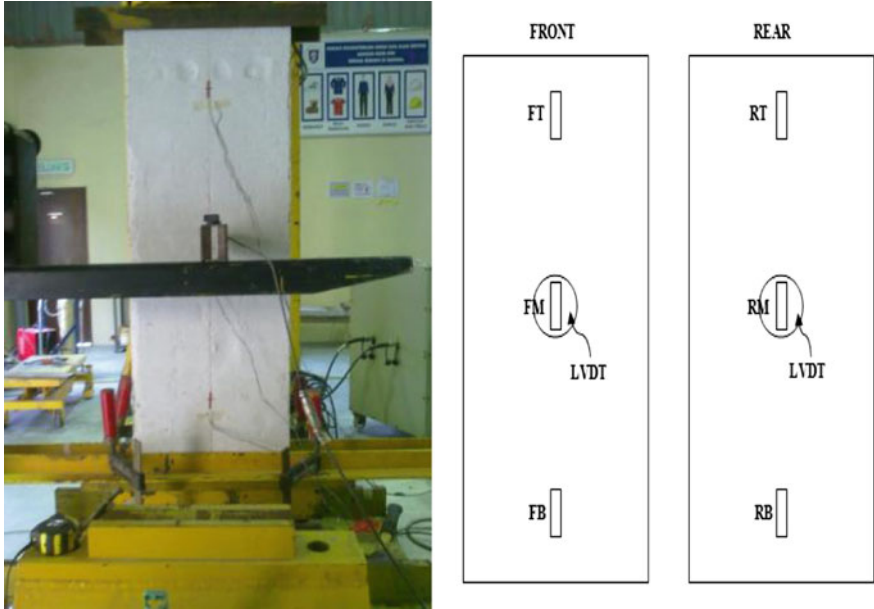


Fig. 2 LVDTs and strain gauges location

Fig. 3 Experiment set up



**Table 1** Mixture ratio for casting of PLFPs

	Sand: Cement	Foam: Cement	Water: Cement
Ratio	2:1	0.65	0.55

**Table 2** Dimensions and designation of PLFP

Panel	H × W × t (mm)	Slenderness ratio	t1 (mm)	t2 (mm)	C (mm)	Reinforcement (Vertical and horizontal) top and bottom	Diameter of shear connectors (mm)
PA-1	1,000 × 370 × 80	12.5	20	40	8	4 mmΦ@75 mm c/c	R3
PE-1	1,000 × 370 × 80	12.5	20	40	8	4 mmΦ@75 mm c/c	R3
PA-2	1,000 × 370 × 70	14	20	30	8	4 mmΦ@75 mm c/c	R3
PE-2	1,000 × 370 × 70	14	20	30	8	4 mmΦ@75 mm c/c	R3
PA-3	960 × 370 × 60	16	20	20	8	4 mmΦ@75 mm c/c	R3
PE-3	960 × 370 × 60	16	20	20	8	4 mmΦ@75 mm c/c	R3
PA-4	960 × 370 × 50	18	20	10	8	4 mmΦ@75 mm c/c	R3
PE-4	960 × 370 × 50	18	20	10	8	4 mmΦ@75 mm c/c	R3

*PA* Precast lightweight foamed concrete sandwich panel (PLFP) with double shear truss connectors under axial loading

*PE* Precast lightweight foamed concrete sandwich panel (PLFP) with double shear truss connectors under eccentric loading

## 4 Results and Analysis

### 4.1 Material Properties, Designation and Dimensions

PLFPs details with its designation, mechanical properties and slenderness ratio are tabulated in Tables 1, 2, and 3. The mixing ratio of specimen is referring to [8]. The foamed concrete mix ratio is given in Table 1; the wet density for foamed concrete is ±1,700 kg/m<sup>3</sup> to achieve dry density at ±1,600 kg/m<sup>3</sup>. Nine cubes and 6 cylinders were prepared at the same time to determine the material properties of foamed concrete.

**Table 3** Mechanical properties of PLFPs

Panel	Wet density (kg/m <sup>3</sup> )	Dry density (kg/m <sup>3</sup> )	Compressive strength, Fc (N/mm <sup>2</sup> )	Split tensile strength, Ft (N/mm <sup>2</sup> )	Modulus young, E (Mpa@ N/m <sup>2</sup> )
PA-1& PE-1	1,760	1,751	12.00	1.56	12,500
PA-2 &PE-2	1,764	1,674	13.67	1.71	14,500
PA-3 & PE-3	1,725	1,445	7.10	0.99	7,800
PA-4 & PE-4	1,700	1,619	8.50	1.24	5,900

**Table 4** Ultimate load carrying capacity of PLFPs

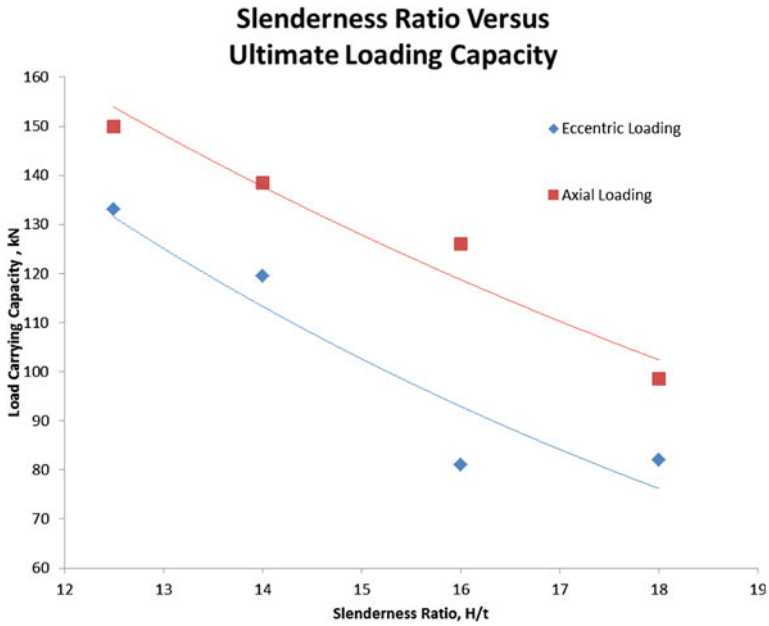
Panel	Ultimate load carrying capacity (kN)	Panel	Ultimate load carrying capacity (kN)	Percentage different in between PA and PE
PA-1	150	PE-1	133	11.33
PA-3	138.5	PE-2	119.5	13.70
PA-4	126	PE-3	81	35.71
PA-5	98.5	PE-4	82	16.76

## 4.2 Ultimate Load Carrying Capacity

Table 4 and Fig. 4 presents the ultimate load carrying capacity of PLFPs under axial and eccentric loading, from results, it was found that the ultimate load of PLFPs were decreased when the slenderness ratio increased. The loading condition also has significant effect on the ultimate load carrying capacity of PLFP, the ultimate carrying capacity of PLFPs decreased during eccentric loading compared to axial loading. The percentage different of ultimate loading under axial and eccentric loading were between 11 and 35 %.

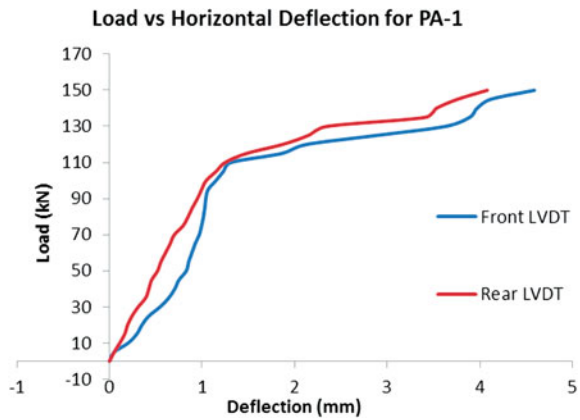
## 4.3 Load Deflection Profile

As shown in Figs. 5 and 6, the relationship between load and horizontal deflection were well presented. All panels achieved certain degree of compositeness reaction; both wythes tend to move in the same direction until the panel reached ultimate load carrying capacity and failed.

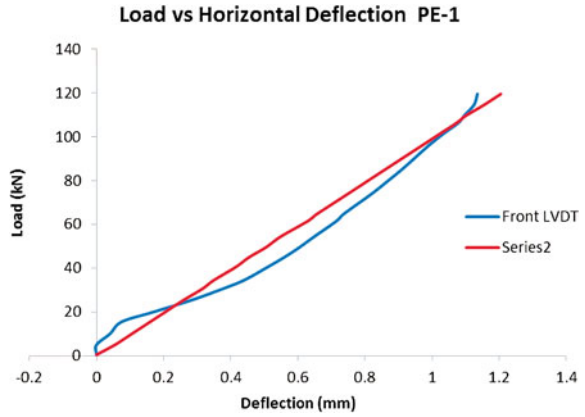


**Fig. 4** Ultimate load carrying capacity of PLFP with various slenderness ratios under axial and eccentric loading

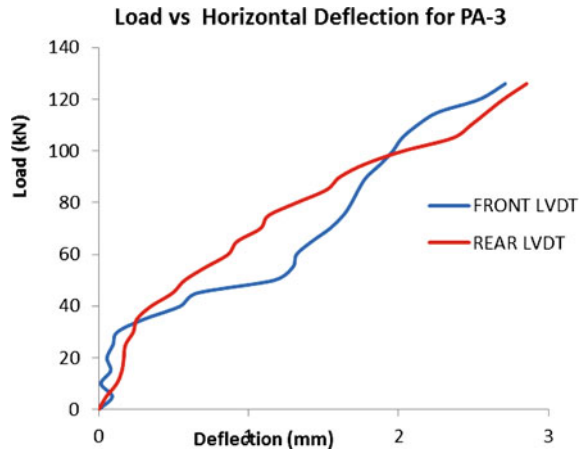
**Fig. 5** Load versus horizontal deflection of PA-1



**Fig. 6** Load versus horizontal deflection of PE-1



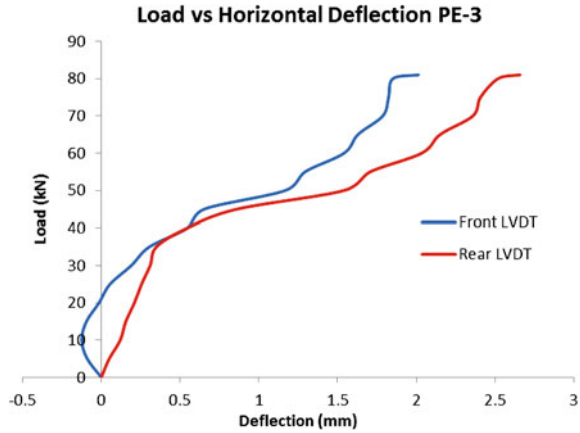
**Fig. 7** Load versus horizontal deflection of PA-3



The trend of curves were similar to [9], at early stage of loading, deflection curves were nearly linear and behaved as elastic material. However, after first crack occurred, PLFPs behaved as nonlinear material. Deflections of PLFPs under axial loading were found to be more significant than PLFP under eccentric loading, higher deflection occurred when axial loading were applied.



**Fig. 8** Load versus horizontal deflection of PE-3

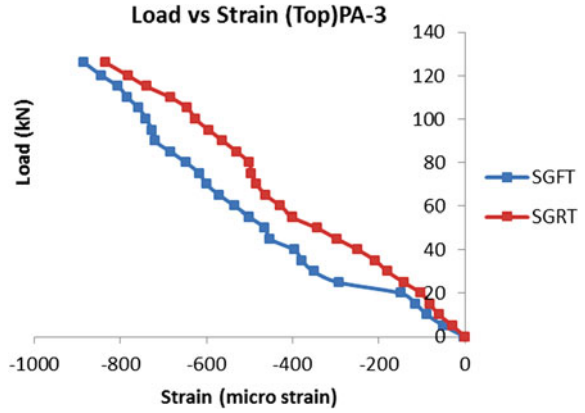


PLFP with double shear truss connectors can be categorized as partially composite panel as referred to [1]. As stated in [1], the initial composite action (horizontal shear transfer) is attributed to the bond between the concrete and insulation layer with any contribution from the wythe connectors (Figs. 7, 8).

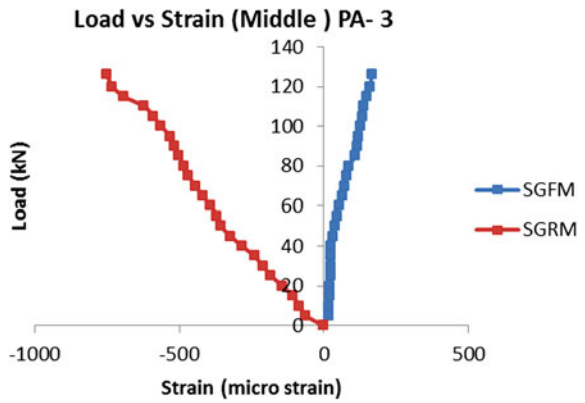
#### 4.4 Surface Strain Distribution

Figures 9, 10 and 11 presents the surface distribution profile for PA-3 under axial loading. Figures 9, 10, and 11 indicate that the top and bottom parts of panel are under compression for front and rear wythes, where both wythes of the panel tend to move at same direction. However, at the middle part of panel as in Fig. 10, front wythe was under tension and rear wythe was under compression. This is due to bending during the loading until failure. For other PLFPs, the surface strain distribution was also under similar surface strain distribution and bending effects. From the trend of graphs the surface strain for both sides were moving along the same direction with unequal strain values. It proved that PLFPs with double shear truss connectors were achieved partially compositeness reaction.

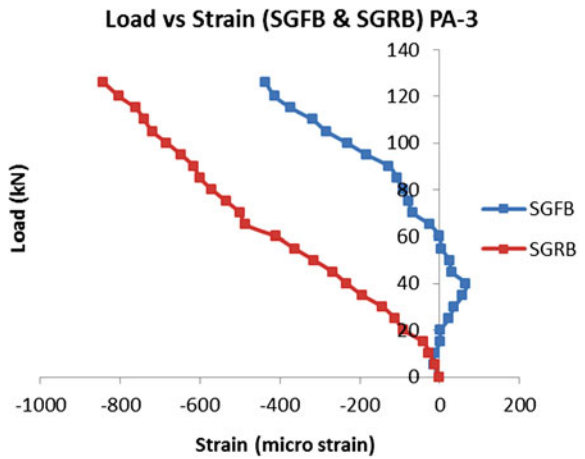
**Fig. 9** Strain distributions at top of PA-3



**Fig. 10** Strain distributions at middle of PA-3



**Fig. 11** Strain distributions at bottom of PA-3



**Fig. 12** Crushing at the bottom of PA-1



PA 1

#### ***4.5 Failure Pattern and Failure Mode***

All PLFPs were loaded with axial and eccentric loading in a similar manner. It was observed that horizontal cracks occurred during loading. For PLFPs under axial

**Fig. 13** Cracking at the middle of PA-3



PA 3

loading in Figs. 12 and 13, PLFPs cracked at the middle and bottom half, those cracks occurred because the loading were distributed evenly to both wythes.

As shown in Figs. 14 and 15, PLFPs under eccentric loading cracked at top half, those cracks may be attributed by the bending moment induced by eccentric loading.

**Fig. 14** Crushing at the top part of PE-1



PE 1

One of the factor that attribute to the cracks at top part of panel may due to poor concrete quality and wired connections in between capping, main reinforcement and shear connectors.



PE 2

**Fig. 15** Crushing at the top half of PE-2

## 5 Conclusion

Structural behavior and ultimate strength of PLFP with double shear truss connectors and slenderness ratio from 12.5 to 18 were studied under axial and eccentric loading. Test results were analyzed in terms of its ultimate load carrying capacity, load deflection profile, surface strain distribution, failure pattern and failure mode.

It was observed that, PLFP with double shear truss connectors was able to sustain both axial and eccentric loading with partially compositeness reaction. However, the ultimate load carrying capacity of PLFP decreased under eccentric loading compared to axial loading. The percentage difference of ultimate loading under axial loading and eccentric loading were between 11 and 35 %. This is due to the loading not applied at the neutral axis where one wythe will need to support higher load than the other. When the wythe with higher loading failed, the whole panel failed.

Therefore, the ultimate load achieved in PLFP was due to several factors which included its material strength, compressive strength, slenderness ratio, panel's height, reinforcement and loading conditions. For the load deflection profile, the similar trend of curves on both faces proved that both wythes in PLFP deflected together along the same direction and acted as partially composite panel.

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