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Testing of Precast Lightweight Foamed Concrete Sandwich Panel With Single and Double Symmetrical Shear Truss Connectors Under Eccentric Loading

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Abstract: This paper reports the structural behavior of precast lightweight foamed concrete sandwich panel, PLFP, subjected to eccentric loading. An experiment was conducted to investigate the structural performance of PLFP under this load. Two PLFP panels, PE-1 and PE-2 were cast with 2000 mm in heights, 750 mm in width and 100 mm in thickness. The thickness of the wall is actually a combination of three layers. Skin layers were cast from lightweight foamed concrete while the core layer is made of polystyrene. The skin layers were connected to each other by 9 mm steel shear truss connector which were embedded through the layers. Panel PE-1 was strengthened with single diagonal shear truss connectors made of 6 mm steel rebar while panel PE-2 was strengthened with symmetrical diagonal shear truss connectors of similar steel diameter. Both panels were tested under eccentric load till failure. The results showed that panel with symmetrical double truss connectors, PE-2, is able to sustain higher load compared to panel with single shear truss connector. The load-deflection profiles indicate that both panels achieved certain degree of composite action especially during the later stage of loading where the wythes tend to move in the same direction until they reached failure. The load-strain curves for both panels highlight the inconsistent distribution of surface strain along the height of panels. The overall trend of the strain curves show that they are under compression.

Introduction

Precast concrete sandwich panel usually consists of two layers of high strength skins or wythe and are separated by a lower strength core layer. The wythes are relatively thin while the core is relatively thick but lighter in weight. The common materials used for wythes are steel, aluminium, wood, fiber reinforced plastic or concrete while the materials used for the cores are balsa wood, rubber, solid plastic material or polyethylene, rigid foam material (polyurethane, polystyrene, phenolic foam), or from honeycombs of metal or paper. This type of wall panels provide the dual function of transferring load and insulating the structure. Sandwich panel is similar to other precast concrete members with regard to design, detailing, manufacturing, handling, shipping and erection; however, because of the presence of an intervening layer of insulation, they do exhibit some unique characteristics and behavior. The compositeness of the panel is achieved when the different layers in the sandwich panel act as a single unit. Precast concrete sandwich panel can act as load-bearing or non load-bearing structural element. The ultimate thickness of the panel is determined by the panel's type and application such as for fire resistant requirement. The wythe of non-composite panel are usually thicker than composite panel. [1]

A new alternative construction system is required to provide fast construction, safe and energy efficient to replace the traditional system. Recent development of this sandwich system has encouraged studies on various lightweight material as structural wall panel systems. This system comply to IBS concepts, which enable cost saving, energy efficient and quality improvement. The cost saving is achieved through the reduction of labor intensity and ease of construction. Apart from this, it offers minimal wastage, less site materials, cleaner and neater environment and controlled quality.

N. Mohamad et al. investigated the structural behaviour of sandwich precast lightweight foamed concrete panel under axial load. The panel consists of two lightweight foamed concrete wythes and a polystyrene insulation layer in between the wythes. The concrete panels are reinforced with 9 mm diameter high tensile steel bars. The rebars are tied to each other through the insulation layer by shear connectors which are made of 6mm mild steel bars bent to 45˚ angle. Total number of four specimens was tested under axial load. It was observed that the experimental ultimate strength achieved are affected by the compressive strength of the foamed concrete forming the wythes, the presence of concrete capping at panel's ends and the slenderness ratio, H/t. Specimens with capping at both ends recorded higher ultimate loads with no premature crushing. Failure of panels with slenderness ratio, $H/t < 18$ were by premature buckling near the supports whereas for panels with higher H/t ratio, slight bending was observed in the middle zone. The results also indicate that a certain degree of compositeness is achieved in the panel. [2]

The research question arises on how this panel system behaves when it is subjected to eccentric load. Therefore, an investigation to study the structural behavior of Precast Lightweight Foamed Concrete Sandwich Panel or PLFP under eccentric load is undertaken. PLFP consists of two thin layers of foamed concrete called skins or wythes which are separated by a polystyrene core layer. The concrete wythes are connected to each other by steel shear truss connectors which function to sustain the load and transfer it between the wythes.

Figure 1 shows a cross section of PLFP panel with the foamed concrete wythes enclosing an insulating layer which is made of polystyrene. It is strengthened by diagonal shear truss connectors tied to the main reinforcement embedded in the withes. Figure 2 shows the similar panel but with double diagonal symmetrical steel shear truss connectors. The function of these shear truss connectors is to take up the applied load and transfer it from one wythe to the other. This truss-shaped shear connectors is equally spaced along the length of the panel as depicted in the figure.

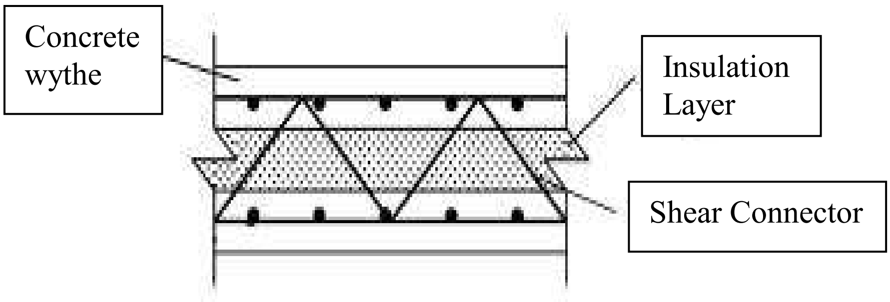

Fig.1: Sections of PCSP with Shear Connectors [3]

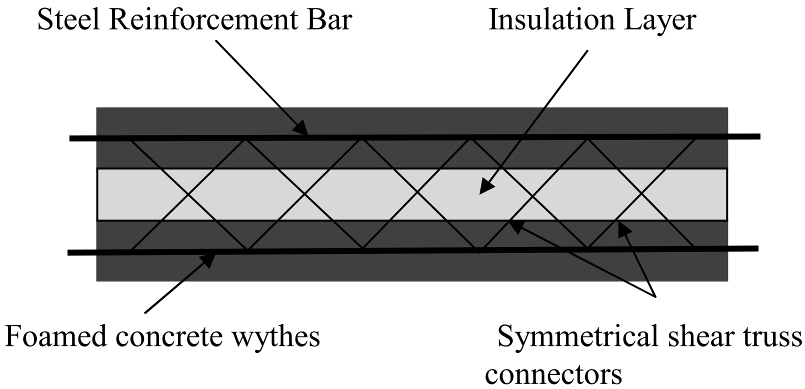

Fig. 2: Precast Concrete Sandwich Panel

Foamed Concrete

Foamed concrete is a lightweight material produced by incorporating preformed foam, into a base mix of cement paste or mortar, using standard mixing plant. The entrapped air bubbles reduce the density of the base mix and have a strong plasticizing effect on it. It is easily placed, requires no compaction and flows into the most restricted and irregular cavities. Foamed concrete can be produced with dry densities of 400 to about 1600kg/m^3, with 7-day strengths of approximately 1 to 10N/mm^2 respectively. Foamed concrete is fire resistant, and its thermal and acoustical insulation properties make it ideal for a wide range of purposes, from insulating sub-bases and roof screeds [4].

The physical properties of foamed concrete are closely related to the type, quantity and quality of the foam liquid concentrate used, the constitution and proper proportioning of the other mix ingredients, the production method employed and the execution of proper batching, mixing, molding, and curing process [5].

There are mainly two types of foaming agents; namely natural foaming agent and synthetical foaming agents. Natural foaming agent is a natural waste based foaming agents ordinarily used in the industry. Synthetically foaming agents are produced in accordance with technical requirements so that they have permanent properties and working life much longer; this gives them application advantages.[6]

Experimental Programme

The experimental program includes two specimens of PLFP which were cast using steel formwork in the laboratory. The materials used for the preparation of the specimen include foamed concrete as the outer wythes, extended polystyrene as the core layer, 6 mm steel rebar as the reinforcement bar and 6 mm steel bent at 45˚ as the shear truss connectors.

The two specimens are designated as PE-1 and PE-2 which means both panels were tested under eccentric load. Both panels' wythe have compressive strength of about 13 N/mm^2 and have similar width, height and total thickness.. Panel PE-1 was strengthened with single diagonal shear truss connectors made of 6 mm steel rebar and panel PE-2 was strengthened with symmetrical diagonal shear truss connectors of similar steel diameter. The concrete cover of 15 mm was used in every specimenFurther details of all the PLFP specimens with their designation, dry density and slenderness ratio are tabulated in Table 1.

Table 1: Dimension and Properties of PLFP Panel Specimens

Panel	Dimension [mm] h×b×t	Dry Density [kg/m^3]	Compressive Strength [N/mm^2]	Polystyrene Thickness [mm]	Slendernes Ratio	Reinforcement (vertical & Horizontal) [mm]	Truss Connector [mm]
PE-1	2000×750×100	1610	12.56	20	18	9	6
PE-2	2000×750×100	1620	12.87	20	18	9	6

PE-1: Sandwich Lightweight Foamed Concrete Panel with Single diagonal Truss
PE-2: Sandwich Lightweight Foamed Concrete Panel with Symmetrical diagonal Truss

Fabrication

There are generally three (3) steps of casting concrete sandwich panel as shown in Figure 3, Figure 4 and Figure 5.[7]

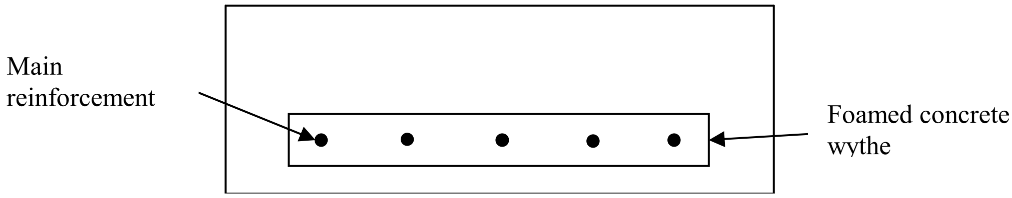

Fig. 3: Placement of the first layer of foamed concrete wyhte and the main reinforcement

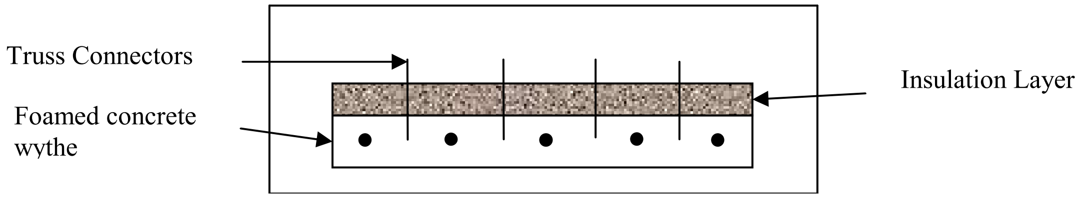

Fig. 4: Placement of the insulation layer (polystyrene) and truss connectors

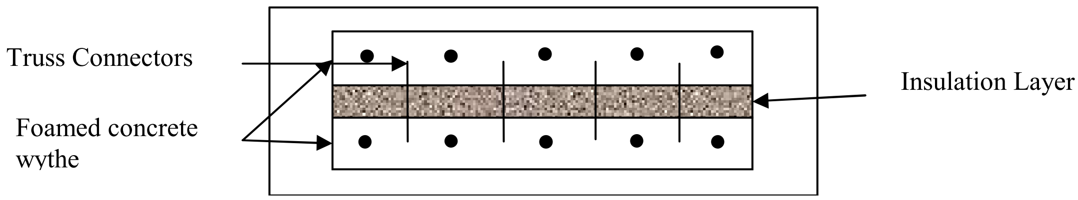

Fig. 5: Placement of the second layer of foamed concrete wythe

Test Set-up

Twelve strain gauges were glued at different locations on both front and rear surface of the panel as shown in Figure 6. In this figure, H is the height of panel whereas B is the width of the panel. These strain gauges were used to measure the strain occured on the foamed concrete wythe surfaces.

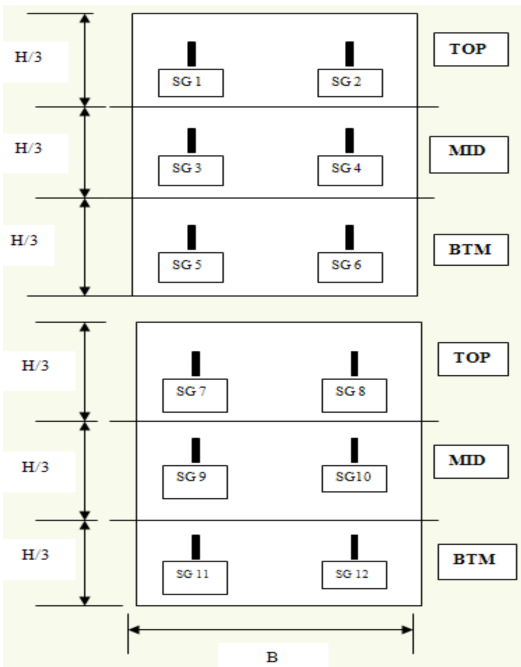

Fig. 6: Position of Strain Gauge for front and rear of PLFP Panels

Linear Variable Displacement Transformer or LVDT were placed at mid-height of the panels on both front and rear surface as shown in Figure 7. They were used to measure the lateral deflection which occured at the mid-height of panel.

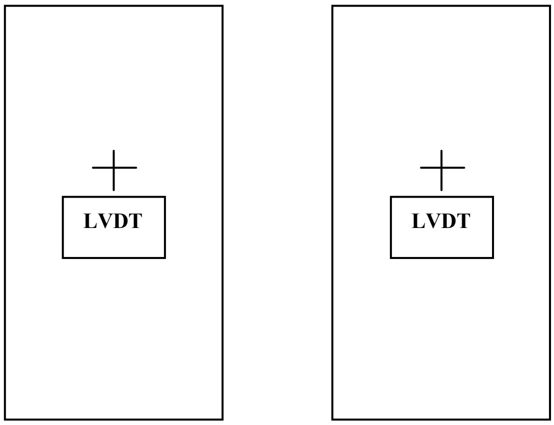

Fig. 7: Position of LVDT for front and rear of PLFP Panels

All the PLFP specimens were tested in the vertical position. The specimen was lifted by using a forklift and placed in the frame. A leveling ruler was used to ensure a proper leveling of the specimen. The panels were tested with the bottom end fixed and the top end pinned. The load was applied using a 100 tonne capacity load cell which was powered by a hydraulic jack of 2000kN capacity. An initial load of 1 kN was first applied to make sure that all the instruments were working. The load was then increased gradually. At each load stage, surface strain and deflection values were recorded automatically by a data logger. Crack pattern was also noted at each load stage.

Results and Discussion

The results are analysed and studied to obtain the ultimate strength achieved, load-deflection profiles, strain distribution across the panels thickness at mid depth and the effect of the symmetrical diagonal truss on the degree of composite action achieved in the PLFP panels.

Ultimate Strength Capacity

Table 2 presents the ultimate load of panel PE-1 and panel PE- 2 with single shear truss connectors and double symmetrycal shear truss connectors, respectively. From the values recorded it was found that panel PE-2 was able to sustain higher load compared to panel PE-1. This proved that the symmetrical shear truss used in panel PE-2 was able to sustain the eccentric load and transfer it from one wythe to the other more effectively compared to the single diagonal truss used in panel PE-1.

The symmetrical truss also has significant effect on the first crack load and the maximum deflection achieved. Panel PE-2 recorded lower deflection measurement and lower first crack load. As shown in Table 2, panel PE-2 recorded lower maximum deflection value at 0.7 mm than panel PE-1 which recorded a maximum deflection of 4.3 mm.

Table 2: Ultimate Failure Load and Deflection For PLFP Panels

Panel	First Crack [kN]	Maximum Load [kN]	Maximum Deflection [mm]
PE-1	176	188	4.3
PE-2	226	355	0.7

Load-deflection Profiles

Figure 8 and Figure 9 show the relationship between load and horizontal deflection recorded in panels PE-1 and PE-2. The graphs indicate that both panels achieved certain degree of composite action especially during the later stage of loading. It was observed that both wythes in both panels initially moved in the opposite drection. After the first crack occured, the wythes tend to move in the same direction until they reached failure.

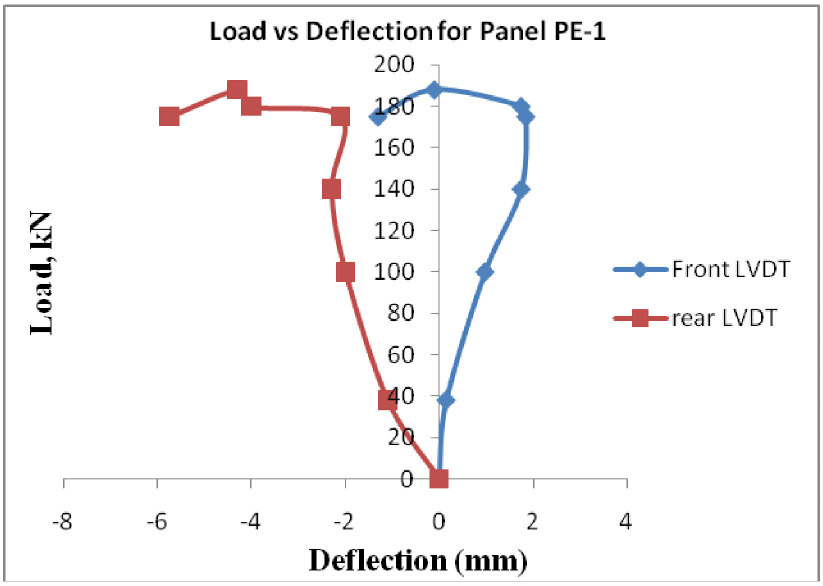

Fig. 8: Load Vs Horizontal Deflection for Panel PE-1

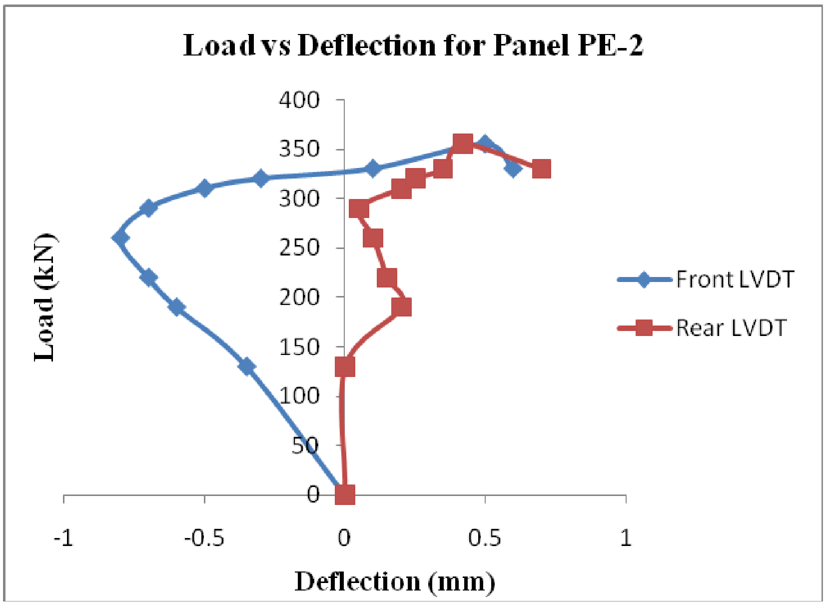

Fig. 9: Load Vs Horizontal Deflection for Panel PE-2

Surface Strain Distribution

The load-strain curves for both panels highlight the inconsistent distribution of surface strain along the height of panels. The strains recorded were very small where all the units are in mikro strain. The overall trend of the strain curves show that they are under compression where the strain curves for both faces recorded negative measurements and were moving in the same direction. This is clearly seen in Figure 10 to Figure 15 for panel PE-1. However, at the later stage of loading, the strain curves tend to move in the opposite direction which indicates that slight tensile strain has occurred. This is seen in the middle zone of panel PE-1 as shown in Figure 17 and Figure 18. It can be concluded that for panel PE-1, the middle zone experienced tensile strain while the upper and lower half of the panel experienced compressive strain.

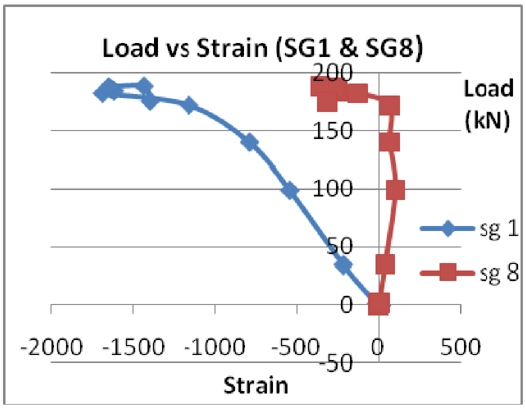

Fig. 10: Load Vs Strain for Strain Gauge 1 and 8

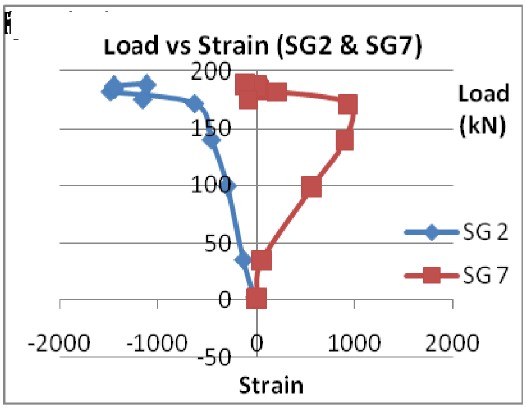

Fig. 11: Load Vs Strain for Strain Gauge 2 and 7

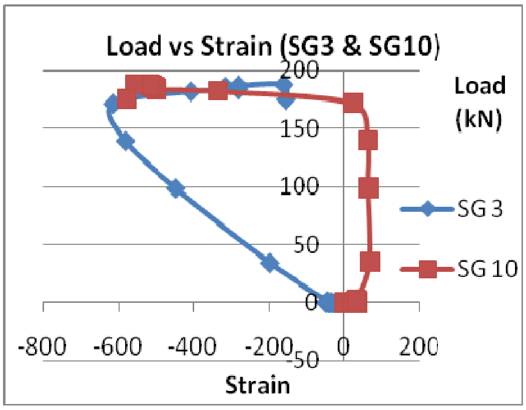

Fig. 12 : Load Vs Strain for Strain Gauge 3 and 10

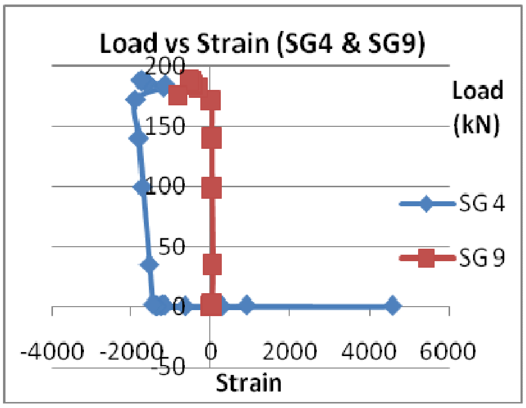

Fig. 13: Load Vs Strain for Strain Gauge 4 and 9

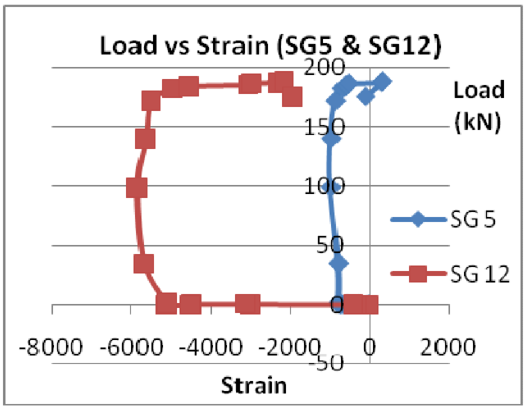

Fig. 14: Load Vs Strain for Strain Gauge 5 and 12

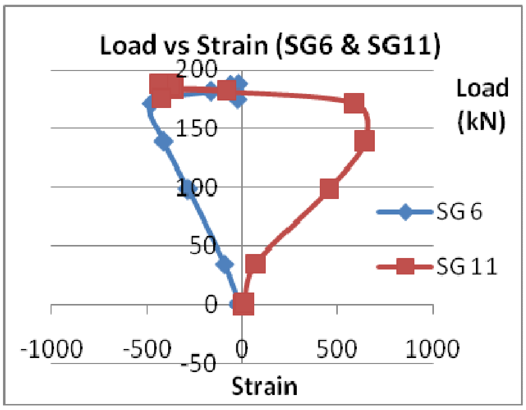

Fig. 15: Load Vs Strain for Strain Gauge 6 and 11

Figure 16 to Figure 21 for panel PE-2 has shown that almost all of the strain measurements recorded except SG2 and SG7 shows a remarkably close result. The strains recorded were very small. The overall trend of the strain curves show that panel PE-2 is controlled by compression where the strain curves for both faces recorded negative measurements for the upper half, bottom half and midle zone of panel.

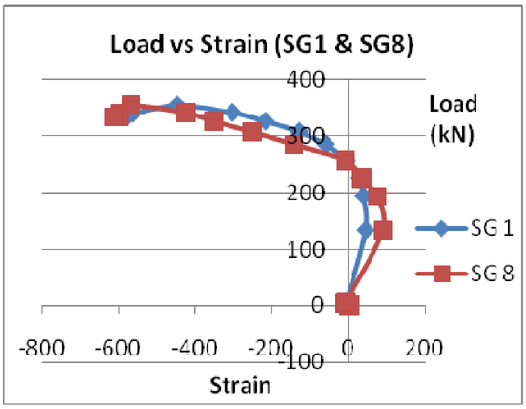

Fig. 16: Load Vs Strain for Strain Gauge 1 and 8

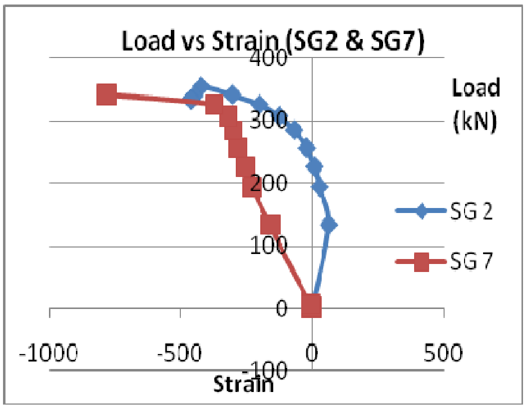

Fig. 17: Load Vs Strain for Strain Gauge 2 and 7

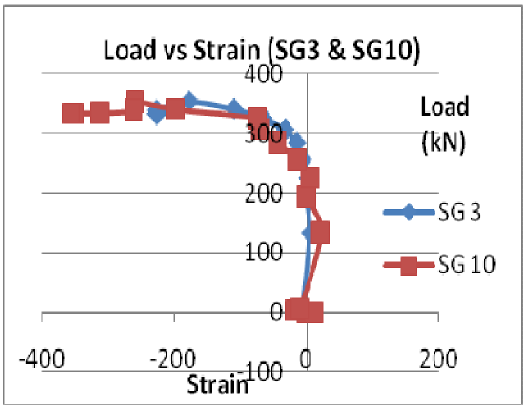

Fig. 18: Load Vs Strain for Strain Gauge 3 and 10

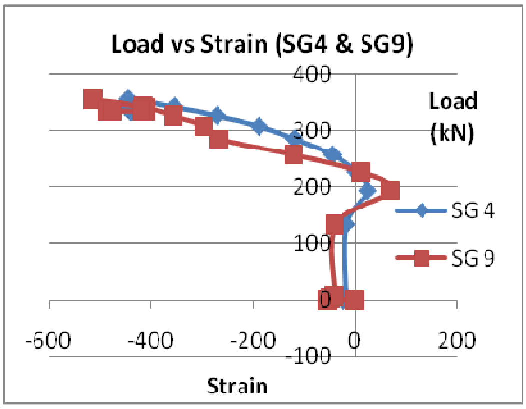

Fig. 19: Load Vs Strain for Strain Gauge 4 and 9

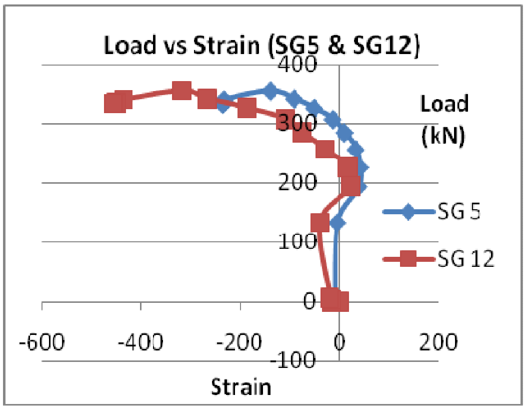

Fig. 20: Load Vs Strain for Strain Gauge 5 and 12

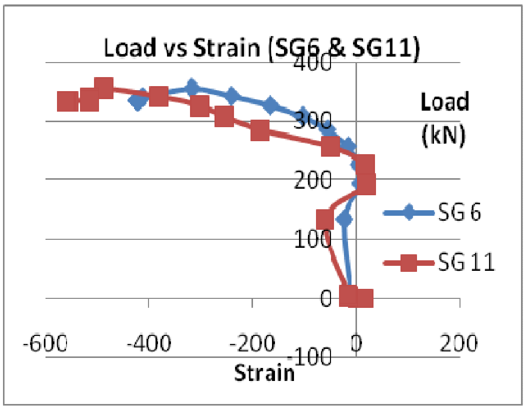

Fig. 21: Load Vs Strain for Strain Gauge 6 and 11

Failure Pattern and Failure Mode

During the testing of the two PLFP panels, load was applied incrementally till failure occurs. Both panels were tested under the eccentric loading in a similar manner until failure. Crack pattern was observed since the early loading stage till the point when panel was crushed. When the load reaches the ultimate value, the panels were crushed either at the top or the bottom part of the panels. The recorded crack pattern shows that the panels were crushed at the top part of the panel. This is presented in Figure 22, Figure 23, and Figure 24. This indicates that it is a premature failure due to material failure. This is due to the insufficient compressive strength of the panels that were supposed to be around 15 MPa but manage to get around 12.87 MPa only.

Fig. 22: Crushing at the Top Part of Panel 2

Fig. 23: Cracking at Top Part of Panel 2

Fig. 24: Crushing at the Top Part of Panel 2

CONCLUSION

The use of symmetrical truss to strengthen the PLFP panel is able to improve its ultimate strength capacity. The results of the ultimate strength capacity show that panel PA-2 (with symmetrical truss) has a higher strength at 355 kN than panel PE-1 (single diagonal truss) which is at 188 kN. Therefore, the targeted strength for panel PE-2 is achieved.

For the load- deflection profiles, panel PE-2 shows smaller deflection measurement than panel PE-1. This indicates that a stronger panel will deflect lesser.

Based on the results, the panels failed at the top and bottom of the panel but did not crack at the middle part. This is due to premature material failure which caused local buckling. Premature material failure was caused by lower compressive strength to achieved which is 12.87MPa compared to targetted compressive strength of 15Mpa.

Despite the failure of the materials which will cause an early crushing, it is believed that by using the double symmetrical truss, it manages to help holding the two concrete wythe together.

Acknowledgement

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