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Computational Behaviour of Precast Lightweight Concrete Sandwich Panel with Double Shear Truss Connectors Under Flexural Load

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ABSTRACT

This study presents the computational behavior of precast lightweight foam concrete sandwich panel (PFLP) under flexural load and vibration using SAP2000. PLFP and other types of precast panels with various sustainable materials were proven to have a capacity at par with precast panel fabricated from conventional concrete. However, the number of studies on precast panel which focus on vibration are very limited. Thus, this study undertook the computational analysis on PLFP panel subjected to flexure load and vibration. Two PLFP panels from previous research, designated as PLFP-1 and PLFP-2, were modelled and simulated. The model of panel was first validated by comparing the deflection values of PLFP under flexure load, obtained from experiment and FEM. The validated models were then simulated against vibration and the natural frequencies obtained in each panel were recorded. It is found that PLFP-1 and PLFP-2 panels from FEM managed to obtain deflection significantly smaller than experiment which is 12.49mm and 18.44mm, respectively. The natural frequency recorded from the simulation against vibration are 18.9Hz and 19.32Hz, respectively.

Keywords: *Precast foam concrete sandwich panel, Flexural load, Vibration, Deflection, Natural frequency*

1. INTRODUCTION

Precast Lightweight Foam Concrete Sandwich Panel (PLFP) is a building component consists of two wythes or skin layers of reinforced lightweight foam concrete with polystyrene layer as an insulator. The two wythe layers are bounded by double shear connectors that are embedded inside it diagonally. The connector's function is to transfer the loads applied between the wythes. These shear connectors effectiveness will influence the degree of compositeness of the wall panel (Mohamad et al., 2014).

Using foam concrete as the wythes, PLFP sandwich panels are lightweight but have a higher strength-to-weight ratio compared to precast sandwich systems that use conventional concrete as the surface layer. Conventional concrete has been commonly used as materials in precast concrete elements in the construction industry for quite some time. However, this trend is changing rapidly due to more advantages found when using other innovative materials. Previous studies have demonstrated that precast concrete systems from foam concrete and self-compacting concrete exhibited partially composite behavior. Precast concrete fabricated from recycle aggregate was proven to be ductile and exhibited large deflections. In addition, because ordinary concrete has a less strength to weight ratio compared to lightweight concrete, it is anticipated that construction projects would consume lesser time and require less labors.

Thus, in this study, simulations were carried out by using software SAP 2000 to investigate the computational behavior of PLFP panel with double shear truss connector subjected to flexural load and vibration. Two specimens with difference thickness will be used in this study. The results of the simulation were validated with the data obtained from previous experimental results to prove its accuracy or validity.

2. SAP2000 MODELLING

2.1. Materials Properties

Foam concrete are composed of upper wythe and bottom wythe with similar thickness for both models. Using properties determined from Mohamad et al., (2014), the foam concrete thickness, t_1 is fixed to 40mm with a density of 1800Kg/m3. The spacing between foam concrete layer, t_2 was fixed at 20 mm. Table 1 shows detail properties of the PLFP model that was used in the foam concrete. Reinforcement steel bar with 9mm diameter has a yield stress of 559MPa while 6mm shear truss connectors have a yield stress of 518Mpa. The materials properties in Table 2 were used in modeling the steel reinforcement in the PLFP.

Table 1 Details and properties of PLFP model

Previous Specimen	Model	t_1 (mm)	t_2 (mm)	Concrete cover (mm)	Total thickness (mm)	Density of foam concrete (Kg/m³)	Compressive strength of foam concrete (N/m²)
PLFP-2	PLFP-1	40	20	15	100	1800	10.6
PLFP-4	PLFP-2	40	30	15	110	1800	19.0

*Note:
t_1 = Thickness of foam concrete layer
t_2 = Spacing between foam concrete layer

Table 2 Properties of steel (Mohamad et al., 2014)

Steel	Yield stress (MPa)	Tensile strength (MPa)	Es (kN/mm²)
9mm reinforcement bars	559	626.5	203.68
6mm truss connector bars	518	544.28	197.8

2.2. Design of Reinforcement and Shear Connectors

The model was designed as close as possible with the experimental setup in the laboratories. Small imperfection differences between the simulation setup and experimental setup were ignored in the designing process as it almost impossible to get 100% similar with the specimen. The polystyrene element in the specimen is not defined in the model as it did not affect the strength of the PLFP. Reinforcement bar and truss connector are defined as frame elements during the modelling. The double shear truss connectors frame is set at an angle of 45˚. The frame is placed at three locations with 300mm spacing between each. 9mm steel bar are drawn acting as longitudinal steel on top and bottom of the truss frame as illustrated in Figure 1.

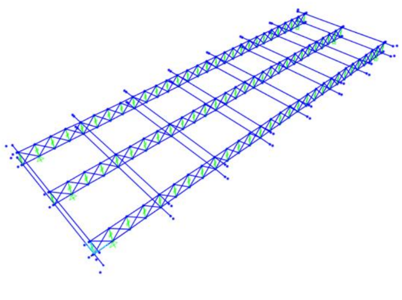

Figure 1. Orientation of steel reinforcement and double shear truss connectors in PLFP.

2.3. Design of Foam Concrete

Foam concrete wythe are defined as area to draw on the steel frame. The area of foam concrete is drawn as seven rectangular sections for top and bottom wythe. The area was extruded to solid element to get the solid properties of foam concrete including concrete cover. The area was extruded 15mm upward and 25 mm downward to create a 40mm thickness of solid for top wythe while 25mm upward and 15mm downward for bottom wythe. The area of foam concrete is meshed into appropriate size before it is extruded to solid to obtain a more accurate result. Figure 2 shows one of the models after it has been meshed by dividing the area into the maximum size of the PLFP panel while Figure 4 shows the extruded foam concrete.

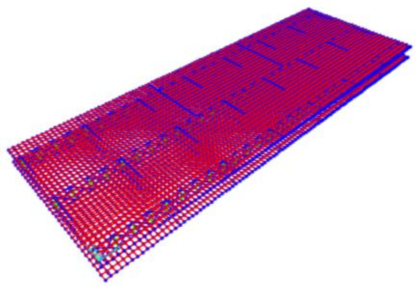

Figure 2. Meshing of PLFP.

2.4. Assign Load and Boundary Condition

The model then was restrained at 100mm from both ends. From the left, pin support was used and roller support at the right was used as restrained. There are two uniform distributed loads acting as line load exerted on 300mm from both side of the center of the panel as shown in Figure 3. The load is set to 8.2kN for PLFP-1 and 25.6kN for PLFP-2. The load was set to simulate the actual ultimate load (kN) that was obtained through the experimental work done by Mohamad et al., (2014). The load applied on two lines across model width in z direction will show the direction of the displacement of the model.

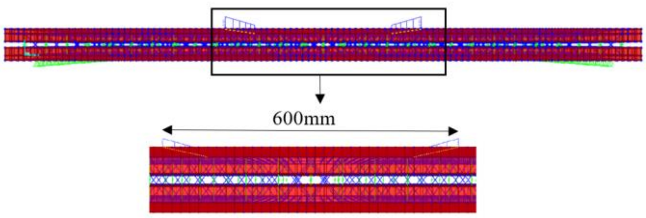

Figure 3. Loading and restrained of the PLFP.

3. RESULTS AND DISCUSSION

3.1. Modelling

Figure 4 below shows the 3D view of the complete PLFP model. Each model dimension has a length of 2000mm and width of 750mm. The thickness of the wythe is fixed at 40mm for both models while the middle layer of the model has a different dimension to differentiate the thickness of the model which is 20mm for PLFP-1 and 30mm for PLFP-2.

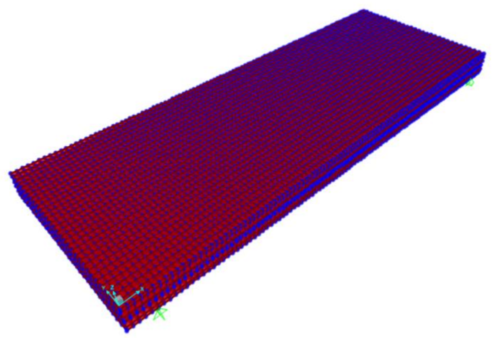

Figure 4. Full 3D PLFP model.

3.2. Deflection

In this study, the deflection from the model by using SAP2000 V21 is validated with the previous experimental results by (Mohamad et al., 2014). The difference in deflection value from the model must be less than 20% from the experimental results. The results from analysis shows that the maximum displacement for PLFP-1 is 12.49mm while PLFP-2 is 18.44mm as shown in Table 3 below. It is seen in the simulation that both wythes and frame element in the panel deflected together in the same behavior as compared with the experimental work done by Mohamad et al., (2014). This indicates that both simulation and experimental models behave as same composite behavior.

Table 3 Deflection results for PLFP model from FEM analysis

Panels	Thickness (mm)	Load (kN)	Deflection (mm)
PLFP-1	100	8.2	12.49
PLFP-2	110	25.6	18.44

PLFP-2 managed to obtain a higher load thus higher deflection compared to PLFP-1. It is because of the difference in compressive strength between the two models. PLFP-1 had a compressive strength of 10.6N/mm2 which is lower than PLFP-2 with 19N/mm2. From this difference, it can be indicated that the higher compressive strength allows the model to withstand higher compressive strength until failure thus increases the ultimate load capacity of the slab. The higher the load capacity, the higher deflection obtained for the slab. Figure 5 shows the trend linear behavior of the deflection obtained when the load is applied.

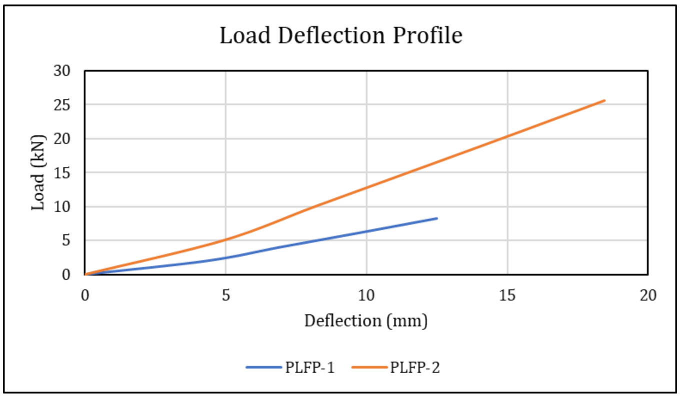

Figure 5. Load Deflection Profile of PLFP model.

3.3. Validation with Experimental Results

The FEM model was validated in terms of its deflection behavior with the double shear truss connectors. Table 4 shows the applied load and deflection of PLFP panel from the previous experiment reported by Mohamad et al., (2014) and FEM analysis for both panels. From the table, it is found that the FEM results are greater than the experimental results. The difference between the value of the deflection obtained from the experimental and simulation work is less than 20%.

Table 4 Deflection difference

Panel	Applied Load (kN)	Deflection (mm)		Percentage Different (%)
		Experiment	FEM	
PLFP-1	8.2	13.9	12.49	10.14
PLFP-2	25.6	22.1	18.4	16.56

3.4. Natural Frequency

The natural frequency of the model recorded are shown to be higher than 10Hz. The first mode for both PLFP model shows that the natural frequency of the model is 18.9 Hz for PLFP-1 and 19.3 Hz for PLFP-2 thus it is above 10Hz which is an acceptable value according to Murray et al., (1997) and BS EN 1992-1-1. It means that the PLFP model can sustain high potential vibration that could occur. Table 5 shows three different mode shape of both PLFP models when subjected to static flexural load. It can indicate that the different mode produces different shape behavior of the model. Each mode shape represents the relative displacements or deformations of various structural components and is linked to a specific natural frequency.

Table 5 Natural Frequency

Model	Mode	Frequency (Hz)
PLFP-1	1	18.9
	5	66.67
	12	154.98
PLFP-2	1	19.32
	5	64.95
	12	147.32

4. CONCLUSION

Model of PLFP specimen from previous experiment is achieved according to its materials, dimension, and condition. Model of PLFP with higher compressive strength recorded a higher value of deflection compared to the model with lower compressive strength. The natural frequency recorded for both models are influenced by material properties, model thickness, and loading condition which produces frequency more than 10Hz which is an acceptable value. Based on this study, several recommendations are suggested on extending the computational analysis into:

i. Further computational analysis is required to understand the behavior of PLFP when subjected under various conditions of dynamic load.
ii. Further computational analysis is required to use different thickness of wythes and polystyrene that influenced the strength of PLFP.
iii. Further computational analysis is required to use various spacing and diameter for reinforcement bar including the concrete cover.

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