Journal of Engineering and Applied Sciences 12 (Special Issue 3): 6377-6381, 2017
ISSN: 1816-949X

Computational Prediction on Structural Behaviour of Precast Lightweight Panel under Axial Load

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Abstract: Precast system is getting popular in industrialize building system, demands of this product increasing every day. By using precast system more affordable and quality houses able to be constructed. Many previous and recent researches have been focused on precast lightweight concrete panel which provided more benefits than normal reinforced concrete panel. However, the structural behaviour of precast lightweight foamed concrete panel (PLP) had not been explored deeply by researchers. This study presents the results of the structural behaviour of the PLP panel under axial load in terms of its ultimate load, crack pattern, load-deflection profiles and strain distribution load bearing capacity by finite element analysis. The focus on this study is on the structural behaviour of PLP panel. A three dimensional non-linear finite element model was developed and analysed by ABAQUS Software. Results show that the proposed finite element model can be used as economical tool to study the structural behaviour of PLP panel.

Key words: Lightweight panel, finit element analysis, axial load, ultimate load carrying capacity, building, prediction

INTRODUCTION

Lightweight concrete is type of concrete than self-weight lesser than conventional concrete (Goh *et al*., 2013, 2016). The density of lightweight concrete for bearing structure need to be in between 1440-1840 kg/m³ compared to density of conventional concrete in the range of 1224-2400 kg/m³. Lightweight aggregate is one of the option to produce lightweight concrete, the density of lightweight aggregate must be lower than 1120 kg/m³ (Mehta and Monteiro, 2006). Other than lightweight aggregate, foamed concrete is frequently used to produce lightweight concrete. Foamed concrete consists of Portland cement mortar with a homogeneous void. The void is created by introducing air in the form of small bubbles. Although, foamed concrete is low in density, it is able to provide adequate strength and thermal insulation properties to prevent cracking from happening (Samidi, 1997). The homogeneous void is formed through the preformed foaming agent, foaming agent need to be mixed with water to form foam before being added to the mixture (Ramamurthy *et al*., 2009; Jihad and Jihad, 2014). A lot of experimental study and FEA simulation had been conducted to study its potential application in construction. Sulaiman studied the development and behaviour of lightweight foamed concrete panel with two different wet densities which are 1400 kg/m³ (W1400) and 1600 kg/m³ (W1600), the study was studied in terms of lateral displacement and strain under axial load. The size of both panels was 1500 mm height by 750 mm width and 75 mm thickness. The results showed that the ultimate load at failure for panel W1400 and W1600 were 418 and 755 kN, respectively. The initial crack was observed to appear at the lower portion of panel W1600 after achieving 85% ultimate load. Meanwhile, no initial cracks were observed in panel W1400.

A study completed by Benayoune *et al*. (2007) studied the structural behaviour of precast reinforced composite sandwich panels with single shear truss connectors under axial loading. Six full scaled panels were tested experimentally under axial loading. From the observation during the testing, there was only a small continuity of strain across the section in the beginning through foamed concrete at outer wythes and polystyrene at core layer. The discontinuity increasing and become bigger when the load approaching failure.

It had witnessed the adequate compositeness for the panel. Goh *et al*. (2014) carried testing on the structural behaviour of precast lightweight foamed concrete

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sandwich panel as a load bearing wall. There are 6 PLFP panel are cast using steel form work with the height of panels varies from 1800-2000 mm. From the testing, it show that the foamed concrete is suitable to be used as a bearing structure for precast wall with more benefits.

While many advantages are offered by lightweight panels, this type of construction panel makes them difficult to analyse. Due to the cost of experimental study for full scale panel is very expensive, it is not practical to cast the full scale specimens with different sizes and different loading acting on the panel in order to conduct the parametric study. Therefore, FEA provides a powerful mean where it can be used to simulate the behaviour of various type and orientation of loading which is nearly impossible to achieve from the experimental work alone. However, lab testing is still necessary to verify the accuracy of FEA Model which can help to reduce the mistakes done during the analysis process. A three dimension non-linear material model was used for PLP panel in this study. PLP panel with various slenderness ratios and heights were analysed using the same structural model. This study were also compare between results of using ABAQUS finite element program with the result of experimental work which was done by other researcher. Parametric study on the PLP using different height and thickness was carried out to determine the structural behaviour of the panel.

MATERIALS AND METHODS

Finite element analysis

Material properties: A three dimensional non-linear finite element model was developed using ABAQUS Software to study the behaviour of the foamed concrete panel under axial load. Table 1 and 2 show the constitutive parameters used in concrete damaged plasticity model used for foamed concrete.

Modelling of PLP panel: PLP panel with different thickness were simulated to obtain the ultimate load of the panel. Panel with different thickness were affected by the slenderness ratio which are one of the important causes in the failure of the panel. The cracking pattern were recorded for all the different panel. Table 3 listed the designation of PLP panel. The selection of specimens dimension are according to the convenient of the process of installation of the precast PLP panel in the industry. The propsoed dimension as shown in Fig. 1 is to reduce the transportation cost and installation time.

Boundary condition and load application: Material properties of each part were assigned with data from previous research and experimental results. All parts were assigned with part section, material properties and loading. Loading were assigned at the top part of the panel and supports was assigned at the bottom part of the panel. At the top reference point, displacement was assigned at Y direction to simulate the applied loading on the top of the panel. From the applied vertical displacement, the maximum axial loading applied on PLP panel can be determined from the history output in the result file. Lastly, the convergence of PLP panel was checked with mesh density study by choosing the final mesh size for PLP FEA model. Figure 2 shows the structural model of PLP panel.

Table 1: Properties of foamed concrete (Goh *et al*., 2014; Niza, 2012)

P_c (MPa)	Tensile strength F_t (MPa)	Modulus young E (MPa)	Mass density ρ (kg/m^3)	Poisson ratio (υ)
10.032	0.87	12,000	1,600	0.2

Table 2: Concrete damaged plasticity of foamed concrete (Goh *et al*., 2014; Niza, 2012)

Concrete damaged plasticity				
Dilatation angle	Eccentricity	Initial biaxial/uniaxial ratio, σ_{c0}/σ_{b0}	K	Viscosity
30°	1	1.12	1	0

Compressive behavior			Tensile behavior		
Yield stress (MPa)	Inelastic strain	Damage parameter	Yield stress (MPa)	Cracking strain	Damage parameters
8.7510	0.0000	0.000	0.861	0.00000	0.000
9.8500	0.0017	0.000	0.776	0.00159	0.204
10.356	0.0033	0.000	0.605	0.00409	0.476
10.032	0.0041	0.215	0.518	0.00526	0.582
9.7140	0.0047	0.337	0.431	0.00638	0.673
9.3570	0.0055	0.456	0.345	0.00746	0.752
8.7340	0.0066	0.577	0.259	0.00854	0.824
7.7250	0.0078	0.682	0.173	0.00966	0.889
5.4500	0.0127	0.862	0.086	0.01082	0.947
3.9620	0.0194	0.934	0.000	0.01202	1.000

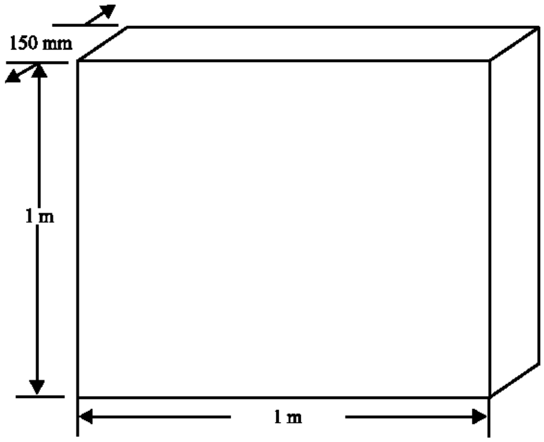

Fig. 1: PLP panel designation

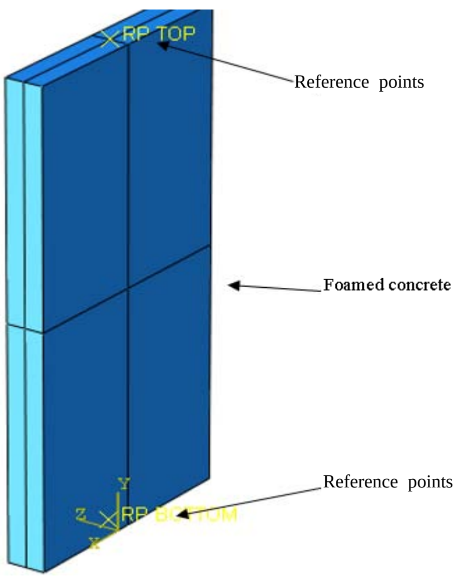

Fig. 2: Structural model of PLP panel

Table 3: List of solid PLP panels with 150 mm thickness

Panel	H×W×t (mm³)	t-value (mm)	Slenderness ratio (H/t)
PLP 1	500×1000×150	150	3.330
PLP 2	1000×1000×150	150	6.670
PLP 3	1500×1000×150	150	10.000
PLP 4	2000×1000×150	150	13.330
PLP 5	2500×1000×150	150	16.670
PLP 6	3000×1000×150	150	20.000
PLP 7	3500×1000×150	150	23.330
PLP 8	4000×1000×150	150	26.670

RESULTS AND DISCUSSION

Model verification: Model validation was performed to assess the validity of the concrete damage plasticity model used to model foamed concrete. Experimental results by Sulaiman were used to validate the finite element model. Sulaiman studied the development and behaviour of lightweight foamed concrete panel with two different densities. After the validation, the model was used to simulate the PLP panel under axial load to study its structural behaviour. The scopes included horizontal and vertical displacement, failure mode and to obtain ultimate load carrying capacity. Table 4 shows the ultimate load carrying capacity of PLP panel. In wall panel W1600, the initial crack appeared at the lower portion of the specimen after achieving 85% (642 kN) of the ultimate load. As for the FEA Model, it showed a significant mode of failure where the initial crack appeared at the lower part of the panel.

In wall panel W1600, the initial crack appeared at the lower portion of the specimen after achieving 85% (642 kN) of the ultimate load. As for the FEA Model, it showed a significant mode of failure where the initial crack appeared at the lower part of the panel. Figure 3 shows the crack pattern of panel.

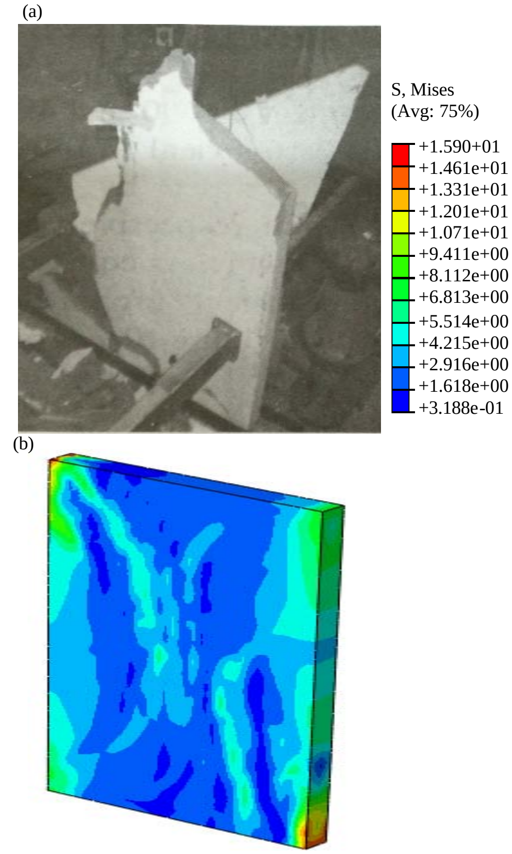

Fig. 3: a, b) Validation of crack pattern of panel with experimental cracks pattern by Sulaiman

Ultimate load carrying capacity: Ultimate load carrying capacity is the maximum loading that can be sustained by the panel before it failed by cracks and

Table 4: Verification of model

Ultimate load (kN)		
Experiment 1500×750×75 (mm)	FEA (perfect geometry model)	P_u (FEA)-P_u (Exp)/P_u (Exp)×100%
755	785	3.97

Table 5: Results of FEA analysis

Panel	H/t	Ultimate load (kN)
PLP 1	3.33	1549
PLP 2	6.67	1432
PLP 3	10.00	1212
PLP 4	13.33	1244
PLP 5	16.67	1265
PLP 6	20.00	1203
PLP 7	23.33	1229
PLP 8	26.67	1243

Table 6: Failure mode of PLP panel

Panel	Failure mode for FEA
PLP 1	Cracked and crushed located at the bottom half of the panel
PLP 2	Cracked and crushed located at the bottom half of the panel
PLP 3	Cracked and crushed located at the bottom half of the panel
PLP 4	Cracked and crushed located at the lower part of the panel
PLP 5	Cracked and crushed located at the lower part of panel
PLP 6	Cracked and crushed located at the top half of panel
PLP 7	Cracked and crushed located at the top half of panel
PLP 8	Cracked and crushed located at the top half of panel

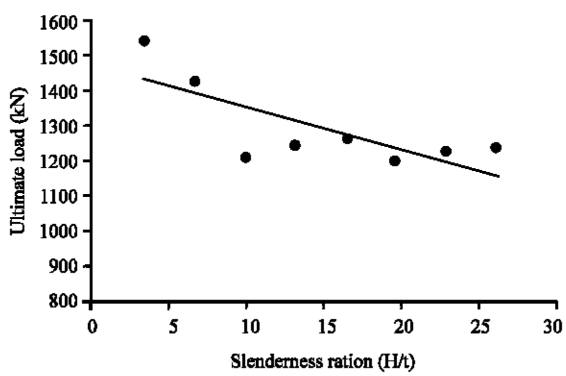

Fig. 4: Ultimate load carrying capacity versus slenderness ratio for PLP 1-8

crushing of the PLP panel is presented in Table 5. From Fig. 4, it is shown that the load carrying capacity reduced linearly with the slenderness ratio (H/t). It indicated that taller panel with higher slenderness ratio tends to fail at lower load than short panel. The ultimate load carrying capacity of the panel not only depended on the slenderness ratio but also on the concrete compressive strength.

Failure behaviour and crack pattern: Failure mode of PLP panel failure mode of PLP panel under various height are explained in Table 6. Panel with slenderness ratio <20 were failed at bottom or lower part of the panel. Meanwhile, panel with higher slenderness ratio were failed by bending, panels were crushed and start cracking at the middle of the panel.

Table 7: Ultimate load carrying capacity of PLP panel and PLP panel with hollow section

Ultimate load (kN)		
Solid PLP panel	PLP panel with hollow section	P_u (solid)-P_u (hollow)/P_u (hollow)×100%
1229	1020	20.5

Table 8: Ultimate Load of PLP panel with difference thickenss

Panel	H/t	Ultimate load (kN)	Maximum horizontal displacement at middle (mm)
3500×1000×100	35.00	818	0.01106
3500×1000×125	28.00	1025	0.12332
3500×1000×150	23.33	1229	0.33433
3500×1000×175	20.00	1436	0.85733
3500×1000×200	17.50	1642	2.55749

Parametric studies of PLP panel with hollow section: From the parametric studies between the solid PLP panel and PLP panel with hollow section. It showed that the solid PLP panel with greater ultimate load compared to the PLP panel with hollow section. This is because the fully compacted lightweight concrete can help to distribute the loading to all the panel itself whereas the PLP panel with hollow section will start to experience failure when the hollow section are not fully withstand the loading exerted. Table 7 show the ultimate load carrying capacity of PLP panel and PLP panel with hollow section.

Parametric study of solid PLP panel with different thickness: Parametric study of panel with 3.5 m height were studied to observe the effect of the slenderness ratio and thickness of the panel. The difference of panel thickness has obviously influence the value of deflection. The thicker panel resulted in lesser deflection. Based on the Table 8, it show that the panel with 200 mm thickness have the highest displacement. As for the panel with 100 mm thickness, it indicated that there are no displacement occurred as it is near to zero. With the thicker foamed concrete panel, bigger cross-sectional area of foamed concrete will increases the ultimate load carrying capacity of PLP panel.

CONCLUSION

Based on the study, it can be conclude that the objectives were achieved. Hence, the results and can be summarized as follow:

- The higher slenderness ratio of the panel, the higher deflection recorded in the panel

- The ultimalte load carrying capacity and overall stability of the panel are influenced by the slenderness ratio and the overall height of the panel with the compressive strength of foamed concrete used
- FEA Software ABAQUS is able to be used to predict the behavior of PLP panel accurately. The finite element model had been validated with experimental results with more than 90% accuracy level
- The increment of height of PLP panel
- Decreased the ultimate load carrying capacity of PLP panel
- Solid panel recorded higher value of ultimate load compared to the PLP panel with hollow section
- Thicker PLP panel sustained higher loading with thicker cross section of PLP panel

ACKNOWLEDGEMENT

The researchers would like to thank the Universiti Tun Hussein Onn Malaysia and Ministry of Higher Education Malaysia (FRGS-VOT 1525) for their financial support for this project.

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