

# Computational Finite Element Modelling of Structural Behaviours of Precast Sandwiched Foamed Concrete Slab

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## Abstract

The structural behaviour of Precast Lightweight Foamed Concrete Panel (PLFP) under flexural load is investigated by using ABAQUS 6.13. The PLFP is made up of two Whyte's with a polystyrene insulator placed in between them using a double shear truss connector of diameter 6mm placed at an angle 45°. The panel is reinforced with both vertical and horizontal steel reinforcement of 9 mm diameter. Four panels with varying dimensions are simulated to investigate their Ultimate Strength and Load-deflection profile. The results show that the length to thickness ratio of the panel is the major contributing factor to the ultimate strength of the PLFP. From the load deflection curve, the panel with the least deflection has the highest thickness which also results in a high ultimate strength recorded at 34.43 KN.

## Keywords

Foamed Concrete, Flexural Behaviour, Finite Element, ABAQUS

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## 1. Introduction

A concrete slab is an element member of a modern structural building. The horizontal slab is mostly used to construct the floors or ceiling while the thinner and vertical slabs are used for exterior paving or walls. In many domestic and industrial buildings, a thick concrete slab supported on foundations or directly on the subsoil is used to construct the ground floor of a building. These can either be “ground-bearing” or “suspended” slabs. In high rise buildings and skyscrapers, thinner pre-cast concrete slabs are slung between the steel frames to form

the floors and ceilings on each level. Structural lightweight aggregate has been successfully used for well over two millennia; it has had widespread use for the past ninety years.

This track record of proven performance has demonstrated how structural lightweight aggregate contributes to the sustainable development by conserving energy, lowering transportation requirements, maximizing design and construction efficiency and increasing the service life of the product it is used in [1]. Foam concrete does not contain coarse aggregate, and can be regarded as an aerated mortar. Typically, foamed concrete is made by introducing air or other gases into a cement slurry and fine sand. In commercial practice, the sand is placed by pulverized fuel ash or other siliceous materials, and lime may be used instead of cement [2]. A sandwich panel is a three-layer element comprising of two thin flat facing plates of high-strength material and between which a thick lightweight core of low average strength is attached [3].

Flores-Johnson & Li [4] computed numerically the simulation of sandwich panels in four-point bending. The numerical simulation was employed as a tool to understand the effects of face/core bonding and fasteners on the structural behaviour of the sandwich panels, which were not experimentally investigated due to the limited amount of tests available. It was observed that the face/core bonding plays a crucial role in the structural performance while the contribution of fastening is negligible. This indicates that improvement of the face/core bonding should be addressed when foamed concrete core is used to obtain optimum structural performance of composite sandwich panels. Mohamad [5] carried out series of tests on the PLFP under axial load till failure. Fourteen PLFP panels with various slenderness ratios were tested and also panels with similar dimensions were simulated under similar axial loads. It was observed that most panels finally failed by crushing of concrete at either one or both ends of the panel. The first crack occurred at 30% to 70% of the ultimate load. The ultimate strength obtained from FEM is higher but within an acceptable accuracy with the values of the experiments. The load-deflection profile showed that the width of the panels deflected together especially in the panels with higher slenderness ratio. These panels also recorded higher deflection measurements than panels with lower H/t. The Loaded-deflection behaviour shows that panels carry load as partially composite panels under service loads and the shear connector seemed to manage to transfer the load. Khalil [6] conducted an experimental research on four PLFP panels having length and width of 2000 mm and 750 mm respectively to obtained the ultimate strength by recording the load applied on PLFP at failure. It was observed that the ultimate strength achieved in the PLFP panels did not depend on just one factor alone, but several factors contributed to the panel's ultimate strength capacity which includes the panel's aspect ratio, diameter of its reinforcement and shear connector, Panel 1 and Panel 2 with 100 mm thickness each achieved the ultimate flexural strength of 10.83 kN and 8.23 kN respectively while Panel 3 and Panel 4 with 110 mm thickness each achieved the ultimate flexural strength of 24.03 kN and 25.63 kN respectively. This shows that the thickness contributes to the increase in ultimate strength. From this study, a deeper and clear insight on the behaviour and failure mechanisms of the PLFP under flexural load will be very well understood. The result from this study is very important for the design of PLFP slab because it would be used as a guide to evaluate the structural behaviour in term of its crack pattern, load-deflection profile and also recommendation for further studies.

## 2. Finite Element Model of PLFP

### 2.1. General Overview

Three (3) dimensional finite element models were developed to study the structural behaviour of the PLFP using four points bending test. The finite element results were validated by comparing the values obtained with the experimental results and theoretical calculation. ABAQUS 6.13 [7] was the software used for creating and analysing of the models. ABAQUS [7] is a very powerful engineering simulation program that has been adopted in recent years for solving challenging non-linear simulations. Extensive libraries of element types and list of material models can be found in ABAQUS documentation, this helps in the simulation of any kind of engineering materials. For non-linear simulations, the necessary parameters are the geometry, boundary conditions, material characteristics and loads. Load increments and related tolerances in non-linear analysis are automatically given by the software. A 3D nonlinear quasi static finite element model was developed using ABAQUS Dynamic/Explicit module to study the flexural behaviour of PLFP. Material properties of foamed concrete obtained from previous experiment were used to calculate the concrete damage plasticity (CDP) parameters. The parameters were calculated based on the relationship between the stress-strain tension and compression loading.

## 2.2. Foamed Concrete Materials

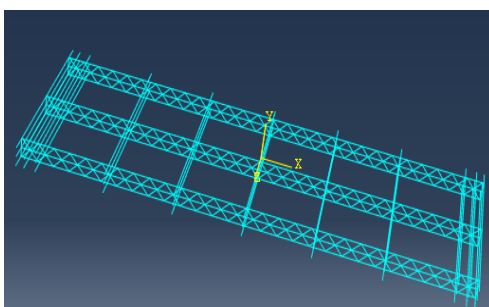
The foamed concrete is composed of inner and outer wythe with different concrete densities. The concrete damage plasticity, available in ABAQUS 6.13 [7] was used as the parameter for modelling the foamed concrete. **Table 1** shows the values used in computing the CDP for the foamed concrete. Using results obtained by Mohamad *et al.* [8], the equation for calculating the concrete damage plasticity parameters is  $D = 1 - (E/E_0)$ , where  $D$  is the damage parameter of foamed concrete in compression and tension,  $E_0$  is the initial (undamaged) elastic stiffness and  $E$  is the damaged elastic stiffness of the foamed concrete with compressive strength of 10MPa

## 2.3. Steel Reinforcement Modelling

There were both horizontal and vertical reinforcements at top and bottom with diameter bar 9 mm of yield strength 559 MPa and tied to each other at 300 mm centre to centre. The material properties summarised in **Table 2** was used in modelling the steel reinforcement in the PLFP.

## 2.4. Shear Connector Modelling

Three 6 mm mild steel double shear truss connector bent to an angle 45° were used for each panel to transfer the load from one wythe to the other. The double shear truss connectors were joined to the vertical reinforcement in the steel mesh. This shear connector had yield stress of 518 MPa, tensile strength of 544.28 MPa and young modulus of 197.8 GPa. The shear connectors where arranged in such a way that they were evenly spaced across the width of the PLFP slab (**Figure 1**).



**Figure 1.** Shear connector and reinforcement arrangements.

**Table 1.** Concrete damaged plasticity of foamed concrete. [8].

Dilatation angle	Eccentricity	Initial/biaxial/uniaxial ratio, $\sigma_{c0}/\sigma_{b0}$	K	Viscosity	
27°	0.1	1.16	1	0	
Compressive behaviour from experiment			Tensile behaviour from experiment		
Yield stress (MPa)	Inelastic strain	Damage parameter, D	Yield stress (MPa)	Cracking strain	Damage parameter, D
8.751	0	0	0.861	0	0.000
9.850	0.0017	0	0.776	0.00159	0.204
10.356	0.0033	0	0.605	0.00409	0.476
10.032	0.0041	0.215	0.518	0.00526	0.582
9.714	0.0047	0.337	0.431	0.00638	0.673
9.357	0.0055	0.456	0.345	0.00746	0.752
8.734	0.0066	0.577	0.259	0.00854	0.824
7.725	0.0078	0.682	0.173	0.00966	0.889
5.450	0.0127	0.862	0.086	0.01082	0.947
3.962	0.0194	0.934	0	0.01202	1.000

**Table 2.** Properties of steel.

Steel	Yield stress $\sigma_y$ (MPa)	Tensile strength $\sigma_t$ (MPa)	Strain at failure	Young modulus ES (MPa)
6 mm bars	518	544.28	0.0478	197,800
9 mm bars	559	626.5	0.1934	203,680

## 2.5. Capping

The model was in such a way that there was capping at both ends so that the applied load would be evenly distributed. Therefore, a 100 mm length normal concrete capping at both ends were added to the model so as to prevent it from premature cracking around the loading and supports areas. CDP was also used for modelling the normal concrete as proposed Tomasz [9].

## 2.6. Polystyrene Core

Polystyrene was used as an insulation material in the core layer. The polystyrene sheet was inserted in between the steel mesh. It had a mass density of 16 kg/m<sup>3</sup>, a Young's Modulus of 0.896 MPa and poisson ratio of 0.4

## 2.7. Boundary Condition and Loading

The load, boundary condition, and field managers are used to view and manipulate the step wise history of prescribed conditions. The PLFP is simply supported along two lines parallel with the x-axis; the distance is 1800 mm for panel 1, 2 and 4 while it is 2300 mm for panel 3. The PLFP has been extended with a capping of 100 mm from the support in order to increase the area over which the reaction stresses can be distributed. There were two (2) concentrated loads exerted on two different points of the PLFP slab since this is a four points bending setup. The ultimate load is however computed by adding the two concentrated loads. **Table 3** gives the dimensions and properties of all the PLFP while **Figure 2** shows the setup of the panels and how they are modelled. The boundary conditions are applied in such a way that displacement will occur in the z direction which is in the direction of the applied load.

## 3. Mesh Density Study

For this study models with different mesh sizes were analysed to determine the best mesh density that would give a result which is closer to the experimental work and theoretical work. **Figure 3** shows one of the panels after it has been meshed to an appropriate size. **Table 4** shows the results of various mesh density for panel 2. The most suitable mesh density for this study was taking from the lowest percentage difference when compared to the sum of the theoretical and experimental ultimate strength value of the panel.

## 4. Results and Verification

### 4.1. Ultimate Load

The four panels are treated as separate models because they all have different dimensions. The ultimate strength achieved by the PLFP panels depended on various factors and not just the materials that are used for the analysis of various panels. The values for the ultimate strength of the panels were recorded by summing the values of P. ( $p/2 + p/2$ ). Factors that had very significant effects on the ultimate strength include the panel's aspect ratio and the number of shear connectors used. Panel 4 had the highest ultimate load of 34.43 kN while panel 3 had the lowest ultimate load of 16.21 kN and this was as a result of their length to thickness ratio as Panel 4 had the highest and panel 3 the lowest. **Table 5** shows the ultimate load and deflection of the four PLFP panels.

### 4.2. Load Deflection Profile

The maximum deflection of all four panels occurred at mid-span and from the load-deflection curves for Panel 1 to Panel 4, it was observed that Panel 3 had the highest deflection of 20.21 mm and Panel 4 achieved the lowest deflection of 8.51 mm. This occurred due to the different length to thickness ratio which is a very important factor that helps in determining the value of the deflection. The length to thickness ratio of panel 1 was larger

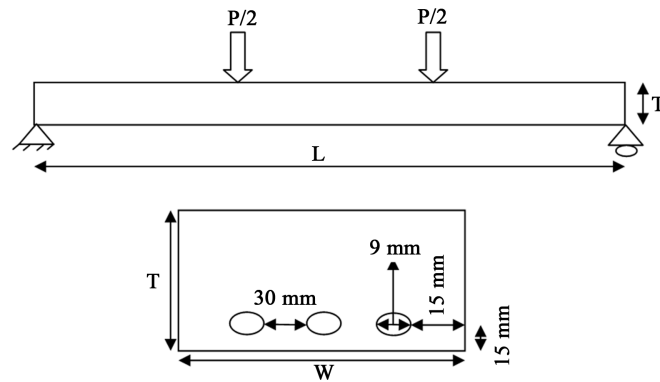


Figure 2. PLFP setup loading and boundary conditions.



Figure 3. Mesh and boundary conditions.

Table 3. Dimension and properties of PLFP.

Panel	$L \times W \times T$ (mm)	$L/t$	Density ( $\text{Kg/m}^3$ )	$F_{cu}$ (MPa)	Young modulus (Concrete) (MPa)
P1	$2000 \times 750 \times 100$	20	1650	10.6	12,000
P2	$2000 \times 750 \times 110$	18.18	1900	20.1	16,700
P3	$2500 \times 750 \times 100$	25	1800	15.0	13,400
P4	$2000 \times 750 \times 150$	13.3	1800	15.0	13,400

Table 4. Mesh density study.

Model type	Total element	Total nodes	Ultimate load (KN)	% Difference from experiment	% Difference from Theory	Average difference
Experiment	-	-	25.63	0	2.3%	2.3%
Theoretical data	-	-	26.23	-2.2%	0	-2.2%
C3D8R-1	2382	3361	29.35	-12.6%	-10.6%	-11.6%
C3D8R-2	12184	17816	29.12	-11.98%	-9.9%	-10.94%
C3D8R-3	18954	20472	28.96	-11.49%	-9.4%	-10.46%
C3D8R-4	33624	43615	23.44	9.3%	11.90%	10.6%
C3D8R-5	62307	83392	23.62	8.5%	11.04%	9.77%
C3D8R-6	153824	185995	23.3	9.8%	12.5%	11.15%

Table 5. Ultimate load and deflections at mid span.

Panel	Ultimate load, (kN)	Deflection, (mm)	Thickness (mm)	Compressive strength (MPa)
1	21.31	14.45	100	10.6
2	23.62	15.08	110	20.1
3	16.21	20.21	100	15
4	34.43	8.51	150	15

than panel 2 but still achieved a lower deflection; this shows not only the length to thickness ratio of the PLFP affects the deflection but the value of their compressive strength. **Figures 4-6** show the thickness, compressive strength and deflection of all panels.

### 4.3. Validation of FEA

The ultimate strength of the PLFP recorded from the finite element analysis is of an acceptable range except for Panel 1 which had a very high ultimate strength when compared to the experimental result. **Table 6** shows the values of the ultimate strength and their maximum deflection values for experimental tests, FEA model and theoretical calculations. The maximum deflections of all four panels were observed at mid span of the slab as predicted by the experimental result. **Figures 7(a)-(d)** show the graphical representation to compare experimental test, FEA simulations and theoretical calculations.

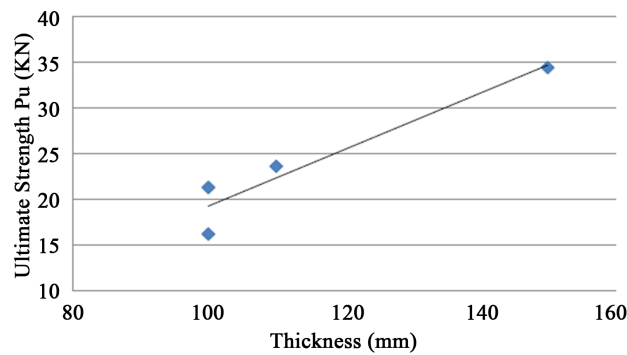


Figure 4. Ultimate load vs thickness.

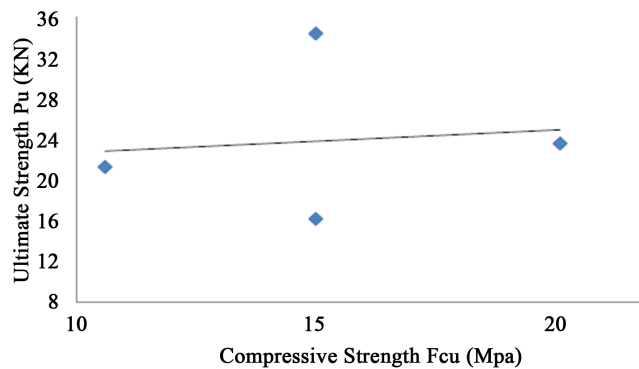


Figure 5. Ultimate strength vs compressive strength.

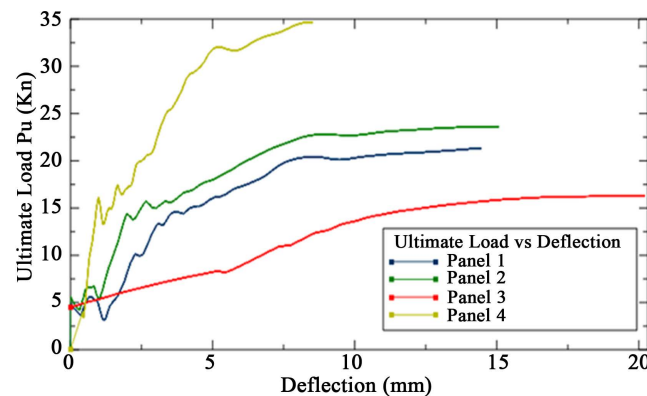
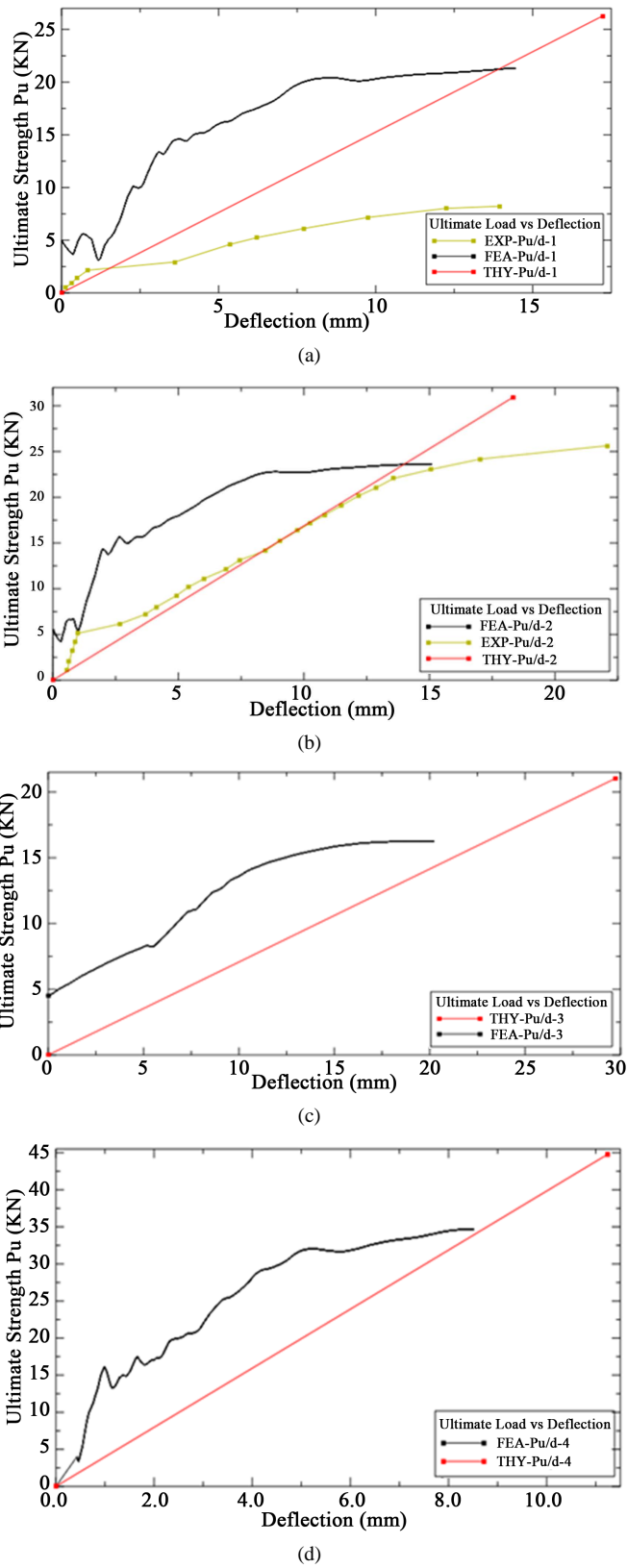


Figure 6. Load deflection curve.



**Figure 7.** (a) Comparison of load deflection profile for Panel 1; (b) Comparison of load deflection profile for Panel 2; (c) Comparison of load deflection profile for Panel 3; (d) Comparison of load deflection profile for Panel 4.

**Table 6.** Comparison of ultimate load and their maximum deflection.

Panel	$P_u$ FEA (kN)	Deflection, ( $\delta$ ) FEA (mm)	$P_u$ experiment (kN)	Deflection, ( $\delta$ ) experiment (mm)	$P_u$ Theory (mm)	Deflection, ( $\delta$ ) theory (mm)
Panel 1	21.31	14.45	8.23	13.94	26.27	17.22
Panel 2	23.62	15.08	25.63	22.07	30.93	18.33
Panel 3	16.21	20.21	-	-	21.03	29.74
Panel 4	34.43	8.51	-	-	44.77	11.24

## 5. Conclusions

The purpose of this research was to study the numerical simulation for the structural behaviour of Precast Lightweight Foam Concrete Sandwich Panel slab under flexural loading. The four panels used for this study had different length to thickness ratio which was used to determine the effectiveness of the length and thickness of a slab when determining its ultimate flexural strength. The result obtained from this study was used to show the accuracy level of computer aided simulation software when compared with an experimental and theoretical study to determine the ultimate flexural load of PLFP. The following conclusions were made after the study.

- 1) The material properties for concrete damage plasticity were obtained from previous research work on concrete. They were carefully factorised to get the appropriate value for each of the panels.
- 2) The length to thickness ratio for each panel affected the value of the ultimate strength attained. Panel 3 and panel 4 had the highest and lowest length to thickness ratio respectively. Panel 3 had an ultimate strength of 16.21 kN and a length to thickness ratio of 25 mm while panel 4 had an ultimate strength of 34.43 kN and a length to thickness ratio of 13.33 mm.
- 3) Although panel 1 and 3 had similar thickness but different comprehensive strength, it can be concluded that the compressive strength did not affect the value of the ultimate strength as much as its length to thickness ratio.
- 4) The ultimate strength increased as a result of an increase in thickness. Panel 3 had the least ultimate strength of 16.21 kN while panel 4 had the highest recorded ultimate strength of 34.43 kN. Their thicknesses were 100 mm and 150 mm respectively.
- 5) The deflection of all 4 panels occurred at mid span.
- 6) The deflection value of all the panels was affected by their respective dimensions. Panel 3 with the highest length to thickness ratio had the highest value of deflection 20.21 mm while panel 4 had the lowest value of 8.51 mm.

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