

# STRUCTURAL BEHAVIOUR OF PRECAST LIGHTWEIGHT FOAMED CONCRETE SANDWICH PANEL UNDER AXIAL LOAD: AN OVERVIEW

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## Abstract

The development of precast sandwich concrete has gained acceptance worldwide in conjunction with the Industrial Building System (IBS). The advancement and improvement of using wall panel has gone through a lot of achievements through the decade. The usage of precast lightweight sandwich panel has become the alternative to conventional construction using brick wall. The usage of this panel system contributes to a sustainable and environmental friendly construction. This paper presents an overview of the latest development in precast concrete sandwich panel as an IBS. The purpose of this report is to provide comprehensive information on latest research development of sandwich panel for building construction purposes. The information on sandwich panel's composition, material, properties, strength, availability, and its usage as structural element are reported. An innovative concept used in the design of these systems and the use of lightweight materials is also discussed.

**Keywords:** Precast Lightweight Foamed Concrete, Sandwich Panel, Axial Load

## 1.0 Introduction

Construction material like bricks, timbers, concretes and steels are increasing in demand due to rapid expansion of construction activities, housing and other buildings. In addition, the world economic and financial upheaval results with the rising cost of construction material production. With these two reasons, there is a need for alternative system to fulfill the construction demand in term of its quality and affordability. Of the many materials used in construction industry, concrete is a very widely used material. This is because the constituents of concrete are easily obtained. For structure which is constructed by using conventional concrete, its self weight represents a very large proportion of the total load on the structure. The strength and other properties of concrete are dependent on how its ingredients are proportioned and mixed. It depends on the usage of a good quality concrete, which can be defined as having a workable fresh concrete and unlikely to segregate. When the concrete hardens, it must achieve the required strength. Therefore, a good mixture design is one of the crucial parts in construction [1].

Lightweight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as nailibility and lessen the dead weight (Mat Lazim, 1978). It is lighter than the conventional concrete with a dry density of 300 kg/m<sup>3</sup> up to 1840 kg/m<sup>3</sup> which is 87% to 23% lighter. It was first introduced by the Romans in the second century where 'The Pantheon' has been constructed using pumice. [2]

One of the main properties that are associated with the lightweight concrete is its low density. Lower in density leads to reduction in weight and this means reduction in the total load. Foam concrete is one of the lightweight concrete and is classified as cellular concrete. It has a uniform distribution of air voids throughout the paste or mortar, while "no-fines" concrete or lightly compacted concretes also contain large, irregular voids. Scanlon, 1998, stated that lightweight concrete is a concrete that have a low density concrete compare to the normal concrete.[3] Table 1 shows the density classification of the concrete aggregates.

**Table 1. Density classification of concrete aggregates [3]**

Category	Unit Weight of Dry-Rodded Aggregates (kg/m <sup>3</sup> )	Unit Weight of Concrete (kg/m <sup>3</sup> )	Typical Concrete Strengths (MPa)	Typical Application
<b>Ultra Lightweight</b>	< 500	300 – 1100	< 7	Nonstructural insulating material
<b>Lightweight</b>	500 – 800	1100 – 1600	7 – 14	Masonry Units
<b>Structural Lightweight</b>	650 – 1100	1450 – 1900	17 – 35	Structural
<b>Normal Weight</b>	1100 – 1750	2100 – 2550	20 – 40	Structural
<b>Heavy Weight</b>	> 2100	2900 – 6100	20 – 40	Radiation Shielding

\*kg/m<sup>3</sup> x 0.062 = lb/ft<sup>3</sup> ; Mpa x 145 = lb/in.<sup>2</sup>

Lightweight foamed concrete is suitable for both precast and cast-in-place applications. Good strength characteristics with reduced weight make lightweight foamed concrete suitable for structural and semi-structural applications such as lightweight partitions, wall and floor panels and lightweight blocks concrete. This structure has become more popular in recent years because it offers more advantages compared to conventional concrete. Modern technology and a better understanding of the concrete have also helped much in the promotion of the lightweight foam concrete.

## 2.0 Precast Lightweight Concrete Sandwich Panel

Precast concrete can be defined as a concrete member that is cast and cured at a location other than its actual location. The precast wall panel is part of the precast concrete structure that is purposely constructed to speed up the wall making construction and to reduce the dependencies of the skilled worker as well as to reduce the construction waste and cost. Precast concrete sandwich panels are a layered structural system composed of a low-density core material bonded to, and acting integrally with, relatively thin, high strength facing materials. The insulated shell reduces heating and cooling cost.

The development of a usage of sandwich panels are increasing within the past few years because manufacturers are looking for new, viable product lines and architects/engineers are pleased with the energy performance and general aesthetics of the panels. In addition, contractors have found that the use of sandwich panels allows their project site to be quickly “dried in,” allowing other trades to work in a clean, comfortable environment.

Typical precast concrete sandwich panel (PCSP) usually consists of two thin strong layers of concrete called wythes separated by a thicker but lower strength core layer. The concrete wythes are connected to each other by steel shear connectors. The truss-shaped shear connectors are equally spaced along the length of the panel as depicted in Figure 1. The structural behaviour of the panel depends greatly on the strength and stiffness of the connectors, while the thermal resistance of the insulation layer governs the insulation value of the panel)[4]. Precast sandwich panel functions as efficiently as precast solid wall panel but differ in their build-up. PCSP acting as load bearing elements are structurally design to transfer load from floor and roof to the foundations.

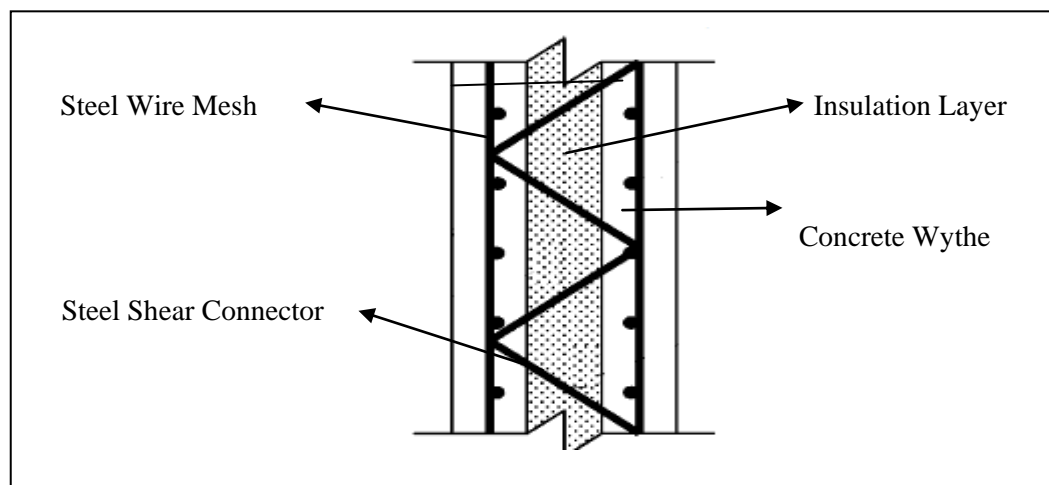
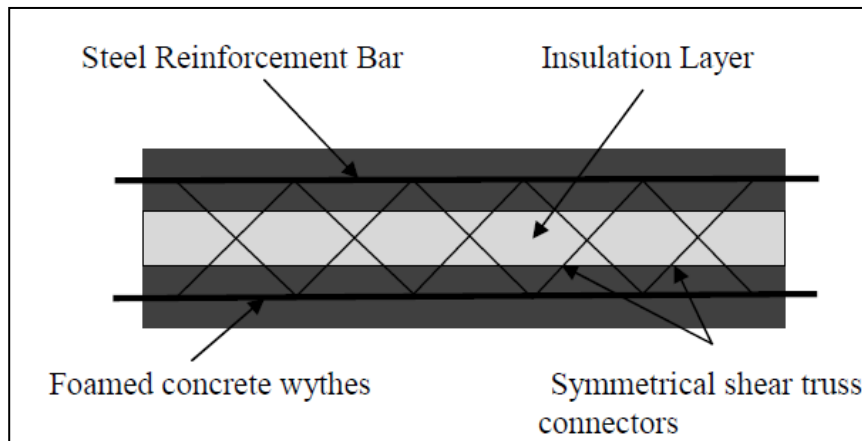


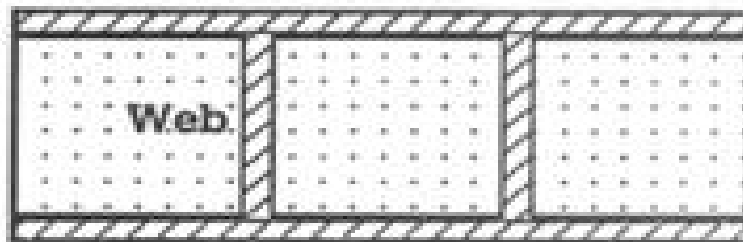
Figure 1. Typical precast concrete with truss shaped shear connector [4]

Figure 2 shows the similar panel but with double diagonal symmetrical steel shear truss connectors in a sandwich precast lightweight foamed concrete panel. The function of these shear truss connectors is to take up the applied load and transfer it from one wythe to the other.[5]



**Figure 2. Precast concrete sandwich panel [5]**

Another type of sandwich panel was proposed in the work of Eina et.al. This insulated sandwich panels are designed to provide a structural shell for buildings. These panels typically consist of two layers or wythes which enclose an insulating layer as depicted in Figure 3. The outer layers are usually constructed of precast or pre stressed concrete and are connected through the insulation layer to form a structurally composite panel. This composite action causes the panel to deflect or bow when the structural wythe experience differences in temperature or humidity due to the presence of the insulation wythe .



**Figure 3. Sandwich elements with webs**

## 2.1 Foamed Concrete as Lightweight Concrete

Foamed concrete is a mixture of cement, fine sand, water and special foam which once harden results in a strong, foamed concrete containing million of evenly distributed, consistently sized air bubbles and cells. It uses a stable foaming agent and a foaming generator to create a lightweight concrete. It can be an alternative material for construction due its low density, high workability and excellent thermal properties. In lightweight foam concrete, the density is determined by the amount of foam added to the basic cement; this way the strength of the concrete is controlled.

Foamed concrete is classified as having an air content of more than 25%. The air can be introduced into mortar or concrete mix using two methods. First, preformed foam from a foam

generator can be mixed with other constituents in a normal mixer or ready mixed concrete truck. Second, a synthetic- or protein-based foam-producing admixture can be mixed with the other mix constituents in a high shear mixer. In both methods, the foam must be stable during mixing, transporting and placing. The resulting bubbles in the hardened concrete should be discrete and the usual bubble size is between 0.1 and 1 mm. The typical mixes are as given in Table 2.

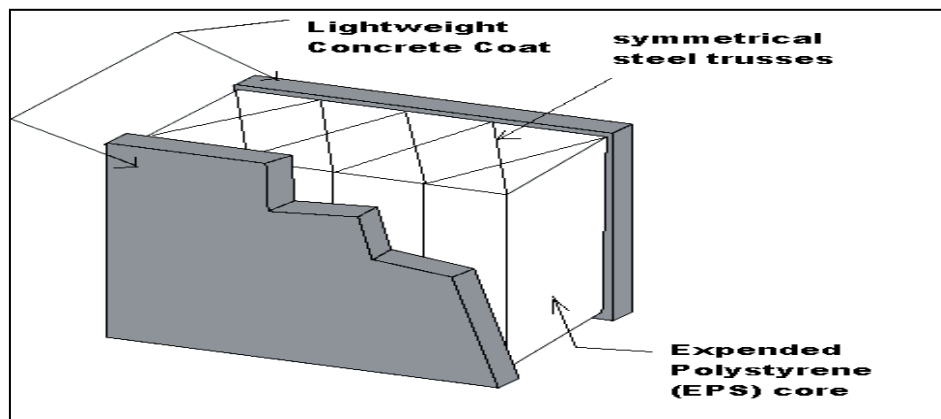
**Table 2. Typical foamed concrete mixes [6]**

Wet Density ( $\text{kg/m}^3$ )	500	525	600	1200	1200
Cement content ( $\text{kg/m}^3$ )	160	340	340	340	340
Foam Volume (%)	72	73	69	44	39
Filler Type	PFA	-	Sand	Sand	PFA
Filler Content ( $\text{kg/m}^3$ )	160	0	66	635	486
Cube Strength at 28 days (MPa)	1.0	2.0	2.0	6.0	7.5
Cube Strength at 91 days (MPa)	1.4	2.2	2.2	7.0	10.0

## 2.2 Application Of Foamed Concrete Panel

Losch (2005) investigated the use and benefits of precast insulated sandwich panels.[7][8]. He indicated that the use of a wall panel system provides several benefits over traditional wall construction. Some of the benefits are:

- i. Increased thermal efficiency
- ii. Increased design flexibility
- iii. Increased speed of erection
- iv. Competitive costs



**Figure 4. Precast sandwich panel [7]**

Precast insulated wall panels have been identified to be one of the most structural efficient systems in terms of low material consumption and highly thermal efficient systems. The use of insulated precast wall panels can increase the thermal efficiency of concrete sandwich panels nearly 30 percent over that of a stud wall system [9]. These thermally efficient systems can save nearly 20 percent in energy cost compared to framed walls [10]. Insulated concrete sandwich panels with polystyrene cores can exhibit R-values up to a value of 30 in comparison to a stud wall system with an R-value of 5 to 10 [11]. The presence of steel or concrete thermal bridges can reduce the R-value up to 40 percent resulting in R-values from 12 to 16 [12][13]. In the last 40 years, many tall structures have been constructed with load bearing architectural precast concrete

window wall panels. Among them is the 20-storey Mutual Benefit Building in Philadelphia, Pennsylvania, built in 1969 (Figure 5). The panels are 12 ft high and 20 ft wide (3.66 x 6.10 m) and each has four openings. The mullions are designed for column action. Spandrels are hidden behind dark glass panels permitting an accent of vertical lines. [14]

Examples of load bearing sandwich window wall panel is the 20-storey Mutual Benefit Life building in Philadelphia, Pennsylvania and One Hundred Washington Square office building in Minneapolis, Minnesota, as shown in Figure 5 and Figure 6, respectively. They have a 16 in. (406 mm) interior wythe, 21/2 in. (64 mm) of insulation and a 3 in. (76 mm) exterior skin. The corner columns have cladding at the base and then serve as insulated formwork for cast-in-place concrete for the rest of the height.



**Figure 5. Twenty-story mutual benefit Life Philadelphia, Pennsylvania [14]**



**Figure 6. One Hundred Washington square office building, Minneapolis, Minnesota [14]**

### **3.0 Review of Previous Studies on Concrete Sandwich Panel**

The complex behaviour of PCSP due to its material non-linearity, the uncertain role of the shear connectors and the interaction between its various components has led researchers to rely on experimental investigations backed by simple analytical studies. The scarcity of information on the behaviour of this important type of construction is due to the high cost of full scale testing and the extreme difficulty of fabrication of small-scale. Many sandwich panels used in North America and Europe are proprietary and publicly available are limited [4]. This explains the lack of information on the behaviour of this important type of structure. Tests on sandwich panels under axial load have not been found in the literature.

One of the earliest studies on precast concrete SWPs was conducted by Pfeifer and Hanson, 1964[15]. The study included 50 reinforced SWPs with a variety of wythe connectors. The panels were tested in flexure under uniform loading. Test results showed that welded truss-shaped steel connectors were more effective in transferring shear than steel connectors without diagonal members. The study also demonstrated the beneficial effect of using concrete ribs to

connect the wythes. Hamburger et al. assessed the poor performance of welded-steel-plate connectors in precast concrete shear-wall panels following the Whittier Narrows earthquake in 1987.

Pantelides et al., (2003), tested nine precast concrete wall assemblies with CFRP connectors. Variations in shear area and surface preparation was investigated. Test results showed that failure of the CFRP composite connection was nonductile, similar to that of the steel connection but at three times the lateral load resisted by the steel connection. The development length of the CFRP composite was found to be highly dependent on the geometry and stiffness of the connection.[16]

Lian (1999), carried out a test program to study the ultimate limit between behaviour of reinforced concrete sandwich panel under axial and eccentric loads. 4 specimens were cast and tested. The ultimate load capacity for pure axial loaded panels was computed using expressions applicable to solid walls could not be directly applied to sandwich panel. It is noted that the slenderness ratio ( $H/t$ ) is an important factor influencing the load bearing capacity of axial loaded panels and the number of the tested panels was also small.[17]

A series of six precast concrete sandwich panels conducted by Adbelfattah (Adbelfattah, 1999) shows that the panels were 140 mm thick, 2.4m long and 1.2 m wide with different reinforced concrete ribs shear connector layouts (2 identical specimens for each connectors layout) with vertical and inclined ribs at  $45^{\circ}$  and  $67.5^{\circ}$ , respectively. Each specimen was subjected to three types of lateral loading within elastic range, axial loading within elastic range and combined axial and lateral loading till failure. They were then theoretically evaluated by using STAAD III finite element software to simulate the physical tests to the elastic phase. Based on the theoretical investigations, it was found that the contribution of the shear connectors in carrying the axial load was very small. It was reported that the concrete wythes carry most of the axial loads.[18]

Tarek K. Hassan and Sami H. Rizkalla (2010), on the studies of “Analysis and design guidelines of precast, prestressed concrete, composite load-bearing sandwich wall panels reinforced with CFRP grid”, investigated three different precast concrete sandwich wall panels, reinforced with carbon-fiber-reinforced-polymer shear grid and constructed using two different types of foam, expanded polystyrene (EPS) and extruded polystyrene (XPS), were selected from the literature to validate the proposed approach. The results of the analysis indicated that the proposed approach is consistent with the actual behavior of the panels because the predicted strains compared well with the measured values at all load levels for the different panels. Besides that, the approach is beneficial to determine the degree of the composite interaction at different load levels for different panels at any given curvature. A simplified design chart is provided to calculate the nominal moment capacity of EPS or XPS wall panels as a function of the maximum shear force developed at the interface. A simplified design chart is proposed to calculate the nominal moment capacity of EPS and XPS foam-core panels at different degrees of composite interaction. The chart is valid only for the panel configuration, geometry, materials, and reinforcement used in the current study. However, it can easily be produced for different panels. The chart demonstrates the effect of composite interaction on the induced curvature.[19]

Bernard A. Frankl et.al. (2011), investigated six precast, prestressed concrete sandwich wall panels were designed and tested to evaluate their flexural response under combined vertical and lateral loads. The study included panels fabricated with two different insulation types: expanded polystyrene (EPS) insulation and extruded polystyrene (XPS) insulation. According to the manufacturer, the selected EPS insulation had a nominal density of 1 lb/ft<sup>3</sup> (16 kg/m<sup>3</sup>) and a nominal compressive strength of 13 psi (90 kPa). The selected XPS insulation had a nominal density of 1.8 lb/ft<sup>3</sup> (29 kg/m<sup>3</sup>) and a nominal compressive strength of 25 psi (170 kPa). The panels were 20 ft tall  $\times$  12 ft wide (6.1 m  $\times$  3.7 m) and all panels were 8 in. (200 mm) thick and consisted of three layers. The flexural behaviors of six full-scale insulated precast, prestressed concrete sandwich wall panels were investigated. The panels were subjected to monotonic axial and reverse-cyclic lateral loading to simulate gravity and wind pressure loads, respectively. Based

on the findings of this study, it was found that panel stiffness and deflections are significantly affected by the type and configuration of the shear transfer mechanism. Panel stiffness is also affected by the type of foam.[20]

#### **4.0 Review of Current Research**

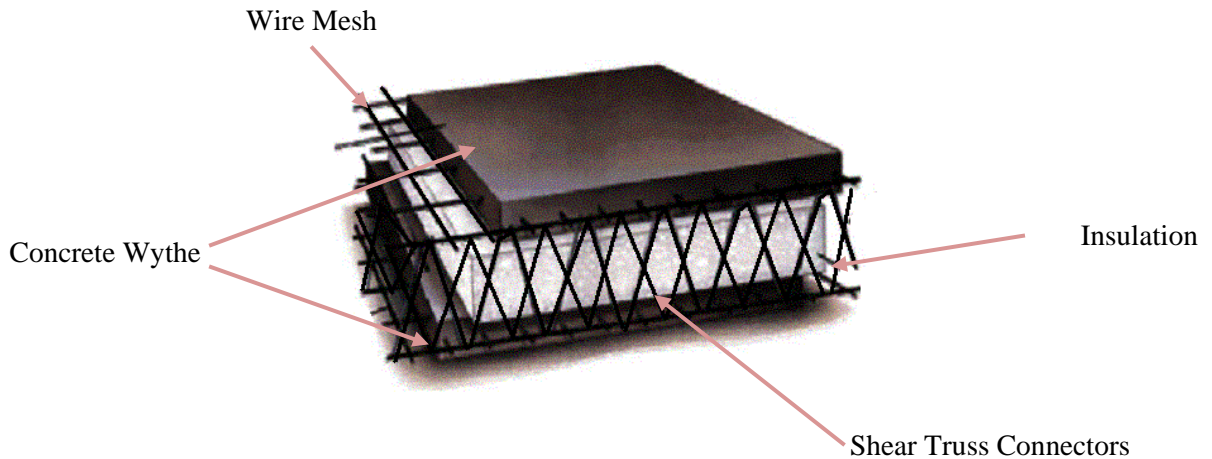
Based on the previous research, can be seen that the research of PLFP is still limited and there are still many weakness that arise such as the research done by Lian (1999). This study discussed about the ultimate limit behaviour of reinforced concrete sandwich panels under axial and eccentric loads. However, the numbers of the tested panels was also so small which is only 4 specimens were cast and tested to carry out the result of the research, , no generalised inferences could be drawn. Compared to the author research, the number of tested panels are 8 specimens which is we can compare the result by find the average of the result thus, to obtain the precise and accurate results. The ultimate load capacity for pure axial loaded panels was computed using expressions for design of solid reinforced walls. It was reported that some of the expressions applicable to solid walls could not be directly applied to the sandwich panel.

From the previous research, it is noticed that most of the panels developed are made of conventional concrete which made up the outer skins. This does not contribute to strength over weight ratio reduction. Therefore, further research on this type of panel with lightweight materials is very much in need. The author will investigate the structural behavior of Precast Lightweight Foamed Concrete Sandwich Panel, PLFP, with double shear truss connectors under axial Load. The aim of this research is to achieve the intended strength for use in low to medium rise building. Considering its lightweight and precast construction method, it is feasible to be developed further as a competitive IBS building system. The result from this research could be used as a guideline for future research to develop PLFP panel as a walling unit in the industry and the future development of PLFP as a structural material.

The capacity of PLFP panel is expected to sustain the axial load but is influenced by compressive strength of the foamed concrete, presence of concrete capping at both ends of panel and the ability of the shear truss connectors to sustain the axial load and transfer it from one wythe to the other.

The wythes in PLFP panels with no capping at both ends tend to deflect in different direction far from each other especially at the later stage of loading. Wythes in panels with capping at both ends tend to deflect together in the same direction. The proposed PLFP panel with capping at both ends is found to be practical either during casting and fabrication work or during handling and placing. This panel is easy to handle due to the reduction in its weight.





**Figure 7. Precast concrete sandwich panel**

#### **4.1 Experimental Programme**

An experimental programme which includes eight (8) full-scaled specimens will be conducted to study its behaviour and axial load carrying capacity. The panels will be cast and fabricated using foamed concrete as its outer layers and extended polystyrene as its insulation/core layer. It is strengthened by embedding reinforcement bars in the both skin layers which are connected to each other by double shear truss connectors.(Figure 8) The panels will be tested under axial load using magnus frame till failure.

The results will be studied in term of its load carrying capacity, load-deflection profiles, strain distribution and efficiency of the shear connectors. Various height, thickness and diameters of shear connector were used to study the influence of slenderness ratio and to find the optimum shear connector's size which ensures the stability of the panel in term of its ultimate strength and degree of compositeness achieved. The strain distribution across the panel's thickness will be used to study the efficiency and role of the shear connectors in transferring loads and to evaluate the extent of composite action achieved. The axial load achieved from the experiment will be analysed and compared with the values from classical formulae and previous researchers.



**Figure 8. shear connectors**

## 5.0 Conclusion

Sandwich panels have all of the desirable characteristics of a normal precast concrete wall panel such as durability, economy, fire resistance, large vertical spaces between supports, and use as shear walls, bearing walls, and retaining walls. Sandwich panels can be relocated to accommodate building expansion. In addition, the insulation provides superior energy performance as compared to many other wall systems. The hard surface on both the inside and outside of the panel provides resistance to forklift damage and vandalism and a finished product requiring no further treatment.

The results from previous research related with sandwich panel bring a lot of benefit to others which is the usage of material, manpower and cost were decreases. This proves that this material is capable and suitable to apply in our construction world. As overall studies, the author can conclude that the Precast Lightweight Concrete Sandwich Panel has much advantages and it's good if the development of the sandwich panel were commercialised.

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