

# Structural Behaviour of Precast Lightweight Concrete Sandwich Panel Under Eccentric Load: An Overview

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## Abstract

This paper presents the overview on structural behaviour of precast lightweight concrete sandwich panel. In Malaysia, demand of affordable housing is increasing due to increasing number of population. Precast concrete sandwich panel is an alternative solution to the conventional construction method due to its ease of construction. The question arises on how to develop a precast panel which is lightweight but with higher strength to sustain the applied load. This paper aims to provide some findings from previous research in this field especially on the panel's structural behaviour subjected to eccentric load. It is hoped the overview on this subject matter could be used as guidance for future research on developing a lightweight sandwich panel system in low to medium rise building construction.

**Keywords:** Precast Lightweight Concrete, Sandwich Panel, Eccentric Load

## 1. Introduction

Concrete is a heterogeneous mixture of sand, gravel, cement and water, plus air, salts, fine inert materials and other additives or admixtures which modify the characteristics of concrete (PCI, 1991). Historically, concrete is a widely used construction material in civil engineering projects throughout the world. Other than building construction, concrete has also been used in structure such as shelter, retaining wall, barrier, offshore structures, and nuclear reactor containment. The reasons for using concrete in construction material are it has excellent resistance to water, it can be formed into a variety of shapes and sizes and it is usually the cheapest and most readily available material for the job (Mehta and Monteiro, 2006). Concrete strength depends upon many factors such as materials used, placement, curing, mix design and control during the mixing process.

The conventional concrete is strong but high in selfweight. This factor effects the ease of construction which will lengthen the construction period. More construction workers are needed to accelerate the progress of the construction work. Due to increase of workers, the cost will also increase. The traditional labor-intensive practices which includes the three problems; namely, dirty, difficult and dangerous have always been associated with the construction industry. The construction industry suffers from low productivity, safety and quality control due to this syndrome. Therefore, the use of precast lightweight concrete to substitute the conventional concrete has become vital because of its advantages and environmental friendly.

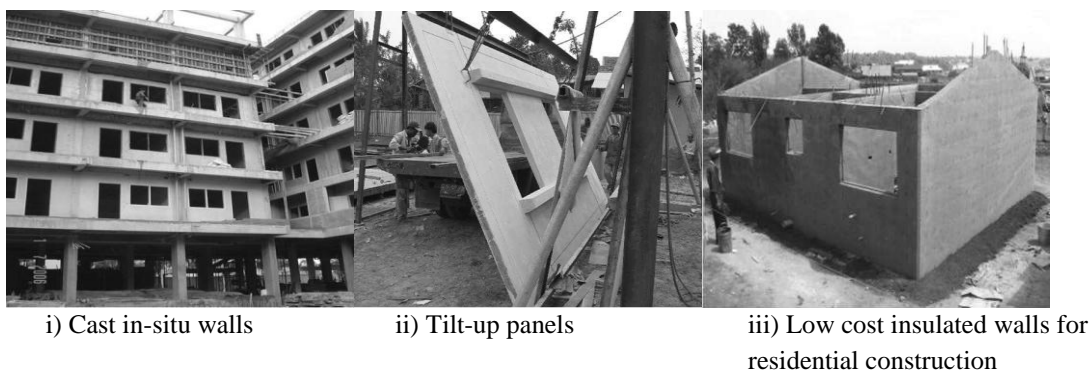
The essential characteristic of lightweight concrete is its porosity. Lightweight concrete can be described as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as nailibility and lessened the dead weight (Zakaria M.L., 1978). The density of lightweight concrete is often more important than the strength lightweight concrete with same strength level may reduce the self-weight consequence of a decreased density

(Rossignolo et. al, 2003). The practical range of densities of lightweight concrete is between about 300 kg/m<sup>3</sup> and 1850 kg/m<sup>3</sup>. It is 23 to 87 percent lighter than the conventional concrete (Neville A.M., 1981). Lightweight concrete has its obvious advantage of high strength to weight ratio, high tensile strength, low coefficient of thermal expansion, waste utilizing, heat preservation, noise insulation characteristic, and energy saving, as well as good absorbability of impacting energy due to air void in lightweight aggregate (Lo et. Al, 2004; Mouli and Khelafi, 2008; Aldrige, 2005).

More than 60 years ago, Lightweight Construction Methods (LCM) was developed and since then have been used internationally for diverse construction applications. LCM has been used in the building industry for applications such as houses, apartments, schools, hospitals, and commercial buildings. The applications of LCM in civil infrastructure are diversified and include (Haq and Liew, 2007):

- Cast in-place for units of low cost terrace houses, high-rise buildings, and bungalows.
- Lightweight blocks for high-rise buildings.
- Panels and partition walls of various dimensions either pre-cast or poured in place.
- All types of insulation works, including cavity walls.
- Roofing and ceiling panels.
- Soundproofing applications.
- Pre-cast industrial and domestic building panels, both internal and external.
- Pre-cast/in-place exterior wall facades for all sizes of buildings.
- Foundations for roads and sidewalks.
- Subsurfaces for sports arenas, e.g., tennis courts.
- Void filling and infill sections between beams of suspended floors.
- Aircraft arresting beds.
- Crash barriers.
- Explosion-resistant structures.
- Highway sound barriers.
- Floating barges, jetties, walkways, fish cages and floating homes.
- Slope protection.

Examples of applications of lightweight concrete:

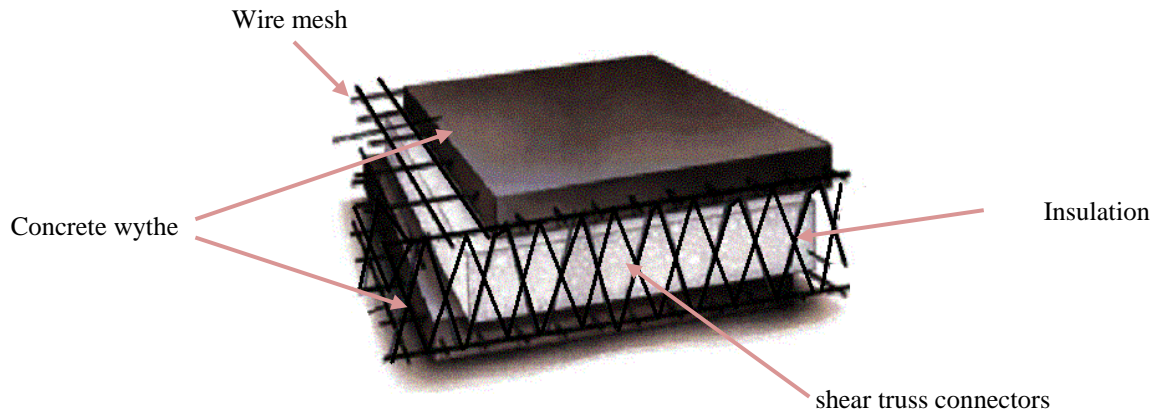


**Figure 1: Examples of applications (Haq and Liew, 2007)**

## **2. Principles Of Precast Lightweight Concrete Sandwich Panel**

The world is witnessing a revolution in construction practices along with a new phase of development fuelled by the rapid economic growth and the high rate of urbanization. Construction provides the direct means for the development, expansion, improvement and maintenance of urban settlements (Suresh, 2004).

The development and construction of lightweight pre-fabricated sandwich structural elements in building construction is a growing trend in construction industry all over the world. The building industries using the precast concrete sandwich panel due to their economical advantages, superior thermal and structural efficiency. At the same time it will contribute to green building by producing a cleaner and neater environment at project site, controlled quality, and a lower total construction time and cost (Salihuddin and Ramli M., 2008). Figure 2.1 shows the basic concept of precast concrete sandwich panel.



**Figure 2.1: Precast concrete sandwich panel**

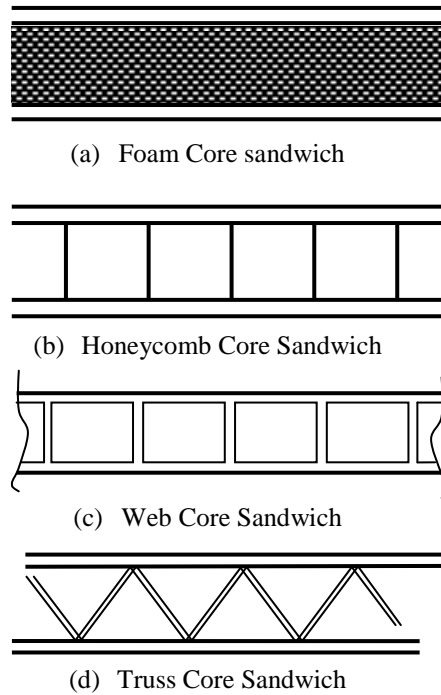
## 2.1 Sandwich Structural Elements/Members

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 (Benayoune et. al, 2005).

The uniqueness of each sandwich panel includes the various types of insulation material and various material and dimensions of a wythe connectors. The insulation or core materials of a sandwich structure in general, fall into four types, as shown in Figure 2.2 (Vinson J., 1999).

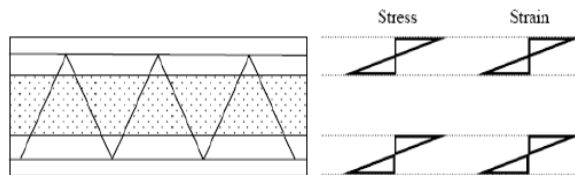
Precast lightweight concrete sandwich panel systems can be designed to be composite or non-composite structural members. In non-composite walls, one wythe is counted on to resist the entire applied loading, and the second wythe is considered to be non-structural. In composite construction, the two concrete wythes share in the load resistance through the connectors that are capable of resisting the interface shear force resulting from composite action. Precast lightweight concrete sandwich panel systems can be classified into three major categories (Maximos N. et. al, 2007):

- i. Fully composite panels
- ii. Non-composite panels
- iii. Partially composite panels

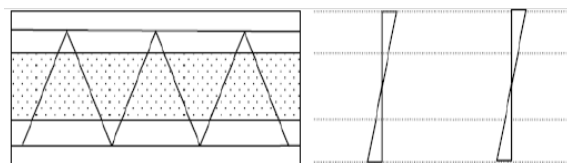


**Figure 2.2: Types of sandwich construction (Vinson R., 1999)**

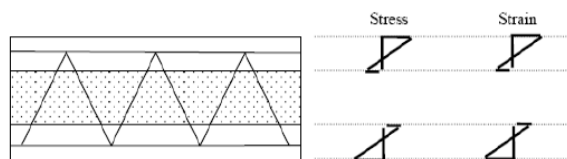
Traditionally, sandwich wall panels are assumed to behave as either fully composite or fully non-composite systems. Fully composite panels are designed so that the two concrete wythes act together as a single unit to resist lateral loads. The decisive indication of composite behavior is a through-thickness strain profile that remains continuous at all locations along the height and width of a panel. A linear strain profile across the thickness of the panel is identified by a single neutral axis. Fully non-composite behavior results from each wythe acting independently to resist applied loads. Fully non-composite panels will have independent strain profiles and unique neutral axes for each wythe (Frank B. A., 2008). Figure 2.3, Figure 2.4, and Figure 2.5 show the stress strain profile of the different type of panel (PCI, 1997).



**Figure 2.3: Non-composite panel**



**Figure 2.4: Composite panel**



**Figure 2.5: Semi-composite panel**

## **2.2 Benefits of Precast Insulated Wall Panels**

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

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

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. Bush and Stine (1994) stated that 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. These thermally efficient systems can save nearly 20 percent in energy cost compared to framed walls (Gleich, 2007).

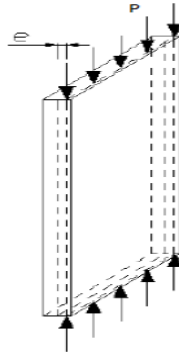
Precast concrete sandwich wall panels not only enhance the thermal efficiency, but also decreases the structural costs. An insulated wall panel can withstand equivalent flexural strength to a solid wall yet consume nearly half the concrete material; however, if the compression zone is greater than the thickness of the compression wythe, then a lower flexural strength may be experienced. Wall panels can exhibit higher ductility than solid concrete walls due to the reduction of the moment of inertia. As a result of high ductility, panels should be carefully designed to minimize the lateral deflections (Frank B.A., 2008).

Wall panels can also provide a lighter system which is critical for the construction industry. Precast wall panels provide a quick and efficient construction system when construction costs are critical or the job site is subjected to harsh construction environments. Panels can be cast in a controlled environment ensuring structural quality, and then placed in the field with less labor than an in-situ wall. These panels not only provide structural and thermal benefits but also provide architectural benefits. It is common to provide an architectural overlay to the structural wythes making the panels aesthetically pleasing. Not only can these panels be overlaid, but wythe surface textures can be customized to the particular job and architect (Losch 2005).

## **3. Eccentric Load**

Load bearing walls in structures are normally designed to act in compression. The wall carries vertical load from above and may also be subjected to additional bending moments resulting from the continuity between floors and walls and due to eccentricity of vertical loading. Eccentric load is a load imposed on a structural member at some point other than the centroid of the section (McGraw-Hill, 2003).

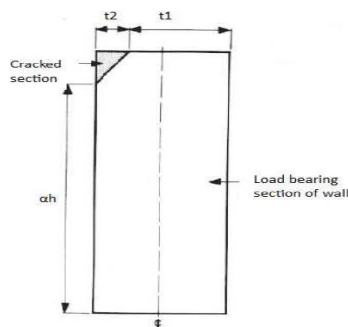
Loads on wall are usually in plane axial loads and lateral load but often they could become accidental eccentric loads due to constructional imperfections also non uniform distribution of load on wall panel. Practically the thickness of wall varies from 100mm to 225mm. As the thickness of the wall panel is small and the wall is a slender element thus the analysis of wall panel shall include the considerations of the stability (Ruzitah S. and Hawa H., 2009). In a real case, it is common to find situations where the loads are applied eccentrically as shown in Figure 3.0.



**Figure 3.0: Eccentrically loaded wall.**

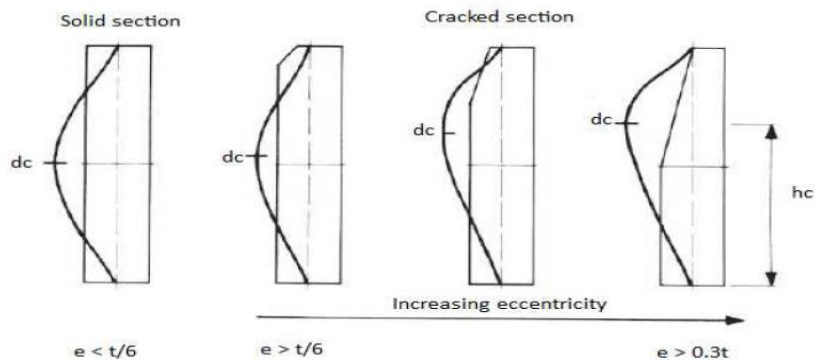
### 3.1 Effect on Wall under Eccentric Load

Eccentric load is compression force or end force. The maximum eccentric load refers to how much weight can be placed on top of the wall with buckling or crushing. When the load is applied on a solid wall with an eccentricity greater than  $t/6$ , the wall develops tension within a certain zone. The zone is shown in Figure 3.1. It is assumed that this portion of the wall cracks slightly at each joint, in compliance with the assumption of a no tension material. The geometry of the cracked section changes for different values of eccentricity of load application. It is therefore necessary to apply the principles of the basic approach to the remaining uncracked portion of the wall (Kuddus, 2010).



**Figure 3.1: Tension zone in a solid eccentrically loaded wall.**

Figure 3.2 shows, schematically, the effect of increasing eccentricity ratio on the size of the wedge shaped cracked section. The position of the maximum deflection rises progressively above the mid-height of the wall. In addition, the critical load of the wall is progressively reduced as the area of the tapered portion of the wall becomes smaller (Kuddus, 2010).



**Figure 3.2: Effect of increasing eccentricity on the size of cracked section smaller (Kuddus, 2010).**

#### 4. Previous Research on Concrete Wall Panel

Lian (1999) carried out a test program to study the ultimate limit behaviour of reinforced concrete sandwich panels under axial and eccentric loads. 4 specimens were cast and tested. The panels were 1.5m long, 0.75m wide and 40-50-40 mm construction, i.e. 40 mm thick concrete wythes with a 50 mm thick insulating layer. 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. However, it may also be 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, no generalised inferences could be drawn.

Oberlender (1973) tested 54 wall panels with slenderness ratios ( $H/t_w$ ) varying from 8 to 28, aspect ratios ( $H/L$ ) from 1 to 3.5 and thicknesses equal to 75 mm with hinged top and bottom edges under uniformly distributed axial and eccentric loadings. The eccentricity was applied at  $1/6$  of the wall thickness. The reinforcement was disposed in double layers symmetrically and separately placed within the wall thickness. Vertical reinforcement ratios ( $\rho_v$ ) were more than the minimum requirements and varied between 0.0033 and 0.0047. the compressive cylinder strength of the concrete was between 28 and 42 Mpa and yield strength of steel ranged from 512.8 to 604.2 MPa. The following conclusions were reached:

- a) Under axial and eccentric loading, panels with  $H/t_w$  values less than 20 failed by crushing while those with larger values of  $H/t_w$  failed due to buckling. The lateral deflections at the instant of failure did not increase dramatically for  $H/t_w$  values less than 20, while a dramatic increase was observed for values more than 20.
- b) The reduction in strength due to an eccentricity of  $t_w/6$  of the wall thickness varied from 18 percent to 50 percent for variation in slenderness ratios from 8 to 28 respectively.

An experimental study was conducted by Heng (1998) in which 6 precast concrete sandwich panel were subjected to different loadings to cause pure axial compression, pure flexure combined with axial compression. Only one panel was however tested under pure axial load. The test indicated that the panel tended to split near the edges prior to the failure. This could be due to the lack of any stiffener near the edge of the panel. However, the limited data available from this study does not allow to draw any general conclusions.

An alternative method for accounting for the percent composite action, presented by Benayoune et. al. (2008) and Salmon et. al. (1997), was developed by taking the ratio of the experimental behavior with respect to the fully composite behavior. The experimental to composite ratio allows for the maximum applied moment to be increased and the panel designed for fully composite behavior. Benayoune et. al.(2008) tested a series of small scale, two wythe panels under one way and two way bending reinforced with a wire truss shear transfer mechanism and polystyrene foam. The type of polystyrene foam was not specified. The experimental moment of inertia was compared to the fully composite uncracked moment of inertia resulting in percent composite actions ranging from 70% to 90% by doubling the shear transfer reinforcement ratio.

Table 4 gives a summary of experimental tests carried out and an overview of the work undertaken by various researchers on wall. Also plotted in figure 4.0 are the experimental results for various reinforced concrete walls (with an eccentricity of  $t_w/6$ ) along with ACI318-99 and AS3600-01 wall equation predictions (Jeung-Hwan Doh, 2002).

**Table 4. Summary of one-way action tests panels and variables used by different researcher (Jeung-Hwan Doh, 2002).**

Research	Number of test	Concrete Strength (MPa)	Slenderness ratio (H/t <sub>w</sub> )	Aspect ratio (H/L)	Steel ratio (ρ <sub>v</sub> )	Eccentricity (e)
Seddon (1956)	N/A	17.5 to 28	18 to 54	1.5	0.008 single 0.004 double	0 to t <sub>w</sub> /3
Leabu (1959)	Theoretical analysis	-	-	-	-	-
Oberlender (1973)	54	28 to 42	8 to 28	1 to 3.5	0.0033 single 0.0047 double	t <sub>w</sub> /6
Pillai and Parthasarathy (1977)	18	16 to 31.5	16 to 31.5	5 to 30	0.0015 or 0.003	t <sub>w</sub> /6
Kripanarayanan (1977)	Theoretical analysis	28	0 to 32	0 to 0.66	-	t <sub>w</sub> /6
Zielinski et al. (1977)	5	33 to 37.5	72	2.25	N/A	0, t <sub>w</sub> /6
Saheb and Desayi (1982, 1983)	24	20.2 to 25.17	12 to 27	0.67 to 2.0	0.00173 to 0.00856	t <sub>w</sub> /6
Sanjayan (1998)	4	58.5 to 60.5	40	1.33	0.0094 to 0.0122	t <sub>w</sub> /2
Waddick and Swifte (1991)	3	41.1 to 43.2	80	2	0.00245	0
Fragomeni et al (1995)	20	36 to 60.7	12 to 25	2 to 5	0.0025 to 0.0031	t <sub>w</sub> /6
Butler (1998)	8	48.5 to 75.2	30	1	0.00266 to 0.002894	t <sub>w</sub> /6

## 5. Future Research

For future research, the author will investigate the structural behaviour of Precast Lightweight Foamed Concrete Sandwich Panel (PLFP) with double shear truss connectors under eccentric load. This research aims to develop a sandwich wall panel system which is able to sustain eccentric load. At the same time it will contribute to green building by producing a cleaner and neater environment at project site, controlled quality, and a lower total construction time and cost.

In this study, eight (8) PLFP specimens will be cast and tested under eccentric load using Magnus frame. Casting and fabrication of the panel specimens will use foamed concrete as its outer layers and extended polystyrene as its insulation layer. It is strengthened by embedding reinforcement bars in both skin layers which are connected to each other by double shear truss connectors. The panels will be tested under eccentric load till failure.

Various heights, thicknesses and diameters of shear connector are used to study the influence of slenderness ratio and to find the optimum shear connector's size which would ensure the stability of the panel in term of its ultimate strength and degree of compositeness achieved. The load-deflection profiles and strain distribution across the panel's thickness will be recorded to study the efficiency and role of the shear connectors in transferring loads and to evaluate the extent of composite action achieved. The ultimate load achieved from the experiment will be compared to the values obtained from classical formula and previous researchers.

It is expected that the capacity of PLFP panel to sustain eccentric load is influenced by the 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 eccentric load and transfer it from one wythe to the other. The proposed PLFP panel with capping at both ends is expected to be practical both during casting and fabrication work and during handling and placing due to the reduction in its weight.

## 6. Discussion

Precast lightweight concrete sandwich panel have recently become an attractive system to replace the use of conventional concrete in the construction industry. This is due to its economical advantages, superior thermal and structural efficiency. At the same time it also contribute to green building by producing a cleaner and neater environment at project site, controlled quality, and a lower total construction time and cost.



Using lightweight concrete in precast lightweight concrete sandwich panel can increase the volume of the mixture while giving additional qualities. Lightweight concrete has its obvious advantage of high strength/weight ratio, good tensile strength, low coefficient of thermal expansion, waste utilizing, heat preservation, noise insulation characteristic, and energy saving, as well as good absorbability of impacting energy due to air void in lightweight aggregate.

Wall panels can also provide a lighter system which is critical for the construction industry. Precast lightweight concrete sandwich panel provide a quick and efficient construction system when construction costs are critical or the job site is subjected to harsh construction environments. Therefore, therefore, the precast wall panel suitable for use in building construction.

In the majority of the compression loaded members, the loads do not act ideally at the centroid of the members. As such, eccentric load is very important in the study of the structural behaviour of precast concrete wall panel. The results from previous studies on precast concrete wall panel showed that it is able to sustain the intended applied load. This proves that it is suitable to be applied in the construction industry.

## 7. Conclusion and Recommendation

Precast lightweight concrete sandwich panel offers a lighter system which is critical for the construction industry. It provides a quick and efficient construction system when construction costs are critical or the job site is subjected to harsh construction environments. Precast lightweight concrete sandwich panel can be cast in a controlled environment ensuring structural quality, and then placed in the field with less labor than an in-situ wall. These panels not only provide structural and thermal benefits but also provide architectural benefits. However, it should be stressed that to achieve an optimum result, through planning and practical design and detailing is required.

In recommendation, more research should be conducted on precast lightweight concrete wall panel in order to develop a sustainable precast lightweight concrete sandwich panel.

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