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Structural Behaviour of Precast Concrete Wall as Industrialized Building System Subjected to Axial Load: A Review

Chuan Zhi Chai[1], Noridah Mohamad[1]*,

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn, Parit Raja, Johor, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: Industrialized Building System (IBS) is a building skill that involves the manufacturing of components such as slabs, columns and walls in a factory and installed at the construction site. Precast concrete wall has more advantages compared to in-situ concrete because it has shorter building time and lower overall cost. Precast solid wall is made with conventional concrete and without insulating materials, but precast sandwich wall is produced with self-compacting concrete and foam concrete containing a layer of insulation. This study focuses on the structural behavior of both types of walls and comparison were conducted on which wall has greater structural performance. The methodology of this analysis consists of two steps in which all the data derived from the previous experimental work were collected and compared. The analysis was done from three papers and journals by examining the axial strength, crack pattern and load-deflection profile. After the review from the previous studies, it can be concluded that precast foamed concrete sandwich wall has a higher structural performance than precast solid wall.

Keywords: Industrialized Building System, Precast Concrete Wall, Precast Sandwich Wall, Structural Behaviour

1. Introduction

Industrialized Building System (IBS) is new technology for current and future construction. IBS is one of the advanced building methods that produced to accomplish target of faster construction, by utilizing building components manufactured in places other than its final location in a building [1]. The components are pre-fabricated in factory and once done will be transported to the construction site for assembly and composition [2]. The system can be deduced as a system that is industrial in the factory and then related on site based on size and dimension of construction part according to the drawing requirement. IBS has many advantages from many aspects. First, IBS is a cheaper construction method compared to the outdated method, which is cast in-situ method [3]. This usage of prefabricated materials can reduce the practice of frameworks and other short-term supports. Moreover, IBS is able to decrease the number of labors for plasterer, concreting workers and carpenters. This will reduce the dependency

*Corresponding author: noridah@uthm.edu.my

of foreign workers from neighbouring countries such as Indonesia, Vietnam, Myamar and Bangladesh and improve economy of our country. In addition, IBS also able to fasten construction time period and this can save treasured time and help to moderate financial deficits. The installation of IBS elements is not affected by weather situations [4].

There are several types of precast concrete which are fabricated from conventional or normal concrete, self-compacting concrete and foam concrete. Conventional Concrete or normal concrete is a solid aggregate mix that involves mechanical vibrations and poking to eliminate air pockets that get stuck during the process of pouring and mixing, also known as regular concrete or conventional vibrated concrete (CVC) [5]. Self-compacting concrete (SCC) is using new admixtures and some mix changes, we can create concrete that flows easily without segregating [6]. In order to reduce its self-weight, Foam concrete (FC) is a concrete composite with enclosed-air voids [7]. The lightweight characteristics are caused by the introduction of bubbles of air into cement paste using suitable preformed foam [8].

This study is mainly focused on precast concrete wall as Industrialized Building System (IBS). Structural behaviour of both solid and sandwich precast concrete wall subjected to axial load will be determined from the analysis of its ultimate strength, crack pattern and load-deflection profile. Last but not least, the structural performance of both precast walls will be compared subjected to axial load.

2. Materials and Methods

The materials used in this study are precast conventional concrete, precast self-compacting concrete, precast foamed concrete, continuous steel truss-shaped shear connector, wood formwork and expanded polystyrene (EPS) [9]. Ultimate load, load deflection profile, crack pattern, and strain behaviour are among the structural behaviours were examined in this section. All of these things may be evaluated by doing an axial load test on the wall. Axial load tests were separated into two types: four-point bending tests and punching load tests. All specimens were casted in wood formwork and cured for 28 days [10] before the testing starts. Shear connections were utilised to keep the concrete wythes together in the precast sandwich panels and expanded polystyrene (EPS) foam was used as an insulation material in the panel's core. The SCC mixture satisfied the recommended minimum requirements [11].

The panels are placed inside a substantial vertical steel frame that is supported by a solid floor, as illustrated in Figure 1. Assuming the panels are built in a genuine single-story structure, the boundary requirements are as follows: The top end is pinned, while the lower end is fastened [9]. A levelling ruler was used to ensure accurate vertical panel levelling. The spender beam (I-welded beam) was utilised as a global equally distributed load over the whole width of the tested panels' top-loaded edge, and a 2000 kN hydraulic jack was placed at the top edge of the panel to transfer loads. The ultimate load was correctly recorded using the load cell output, and each matching load's fracture pattern was carefully inspected. Linear Voltage Displacement Transformers (LVDT) or dial gauges are used to determine the deflection at the midway between the edges. An electrical strain gauge was used to measure the strain value [12].

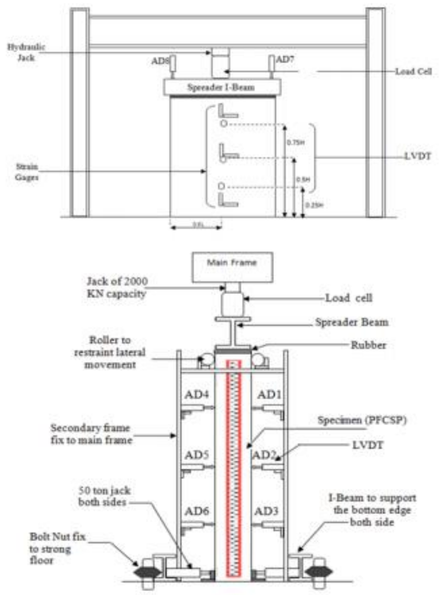

Figure 1: Typical testing setup of the axial load test [9]

3. Results and Discussion

Figure 2 depicts the load against lateral deflection characteristics for a one-way precast conventional concrete wall panel. It demonstrates that the deflections at the wall's centre are usually proportional to those at nearby places. The load deflection pathways for the left and right transducers, as well as the top and bottom transducer readings, are similar in this figure. This means that the data provides a good load vs. lateral deflection estimate. Figure 2 shows the average strength curves had a more nonlinear load-deflection path early in their load history.

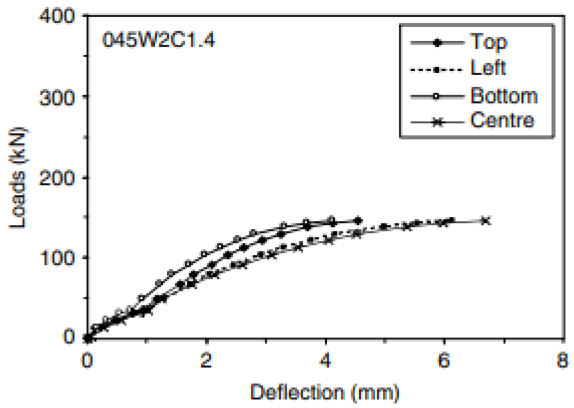

Figure 2: Load versus lateral deflection curves for O45W2C1.4 [12]

Figure 3 shows that the precast self-compacting concrete sandwich wall panel behaved linearly until a load of 17.5 kN was applied, after which it became nonlinear until it failed. The bending moment associated with this load at the loading point is 4.5 kNm, or about 75% of the cracking moment. At the initial fracture load, the load-deflection curve continues to fall. There was no discernible increase in load when fractures occurred in the top wythe. Panel behaviour in a four-point bending test was linear up to 12.5 kN, after which it became nonlinear until failure, as illustrated in Figure 3. Because the initial fracture and subsequent smaller cracks in the bottom wythe occurred, resulting in a loss of stiffness, the slope of the load-deflection curve changed following this load. At the loading point, this load has a bending moment of 5.7 kN m. One of the cracks expanded with a relatively modest percentage (16%) increase in stress, culminating in a breaking sound failure. It should be noted that, regardless of loading circumstances, the stiffness and strength of the panels degrade significantly above 6.8 kNm (average).

The results of the tests show that the kind of loading has a major impact on the flexural behaviour of concrete sandwich panels. When both panels are exposed to the same maximum bending force, only the M- peak curve's behaviour changes. The development of a large number of flexural fractures under a punching force results in a flexural and ductile mode of failure, while fast failure occurs under four-point bending.

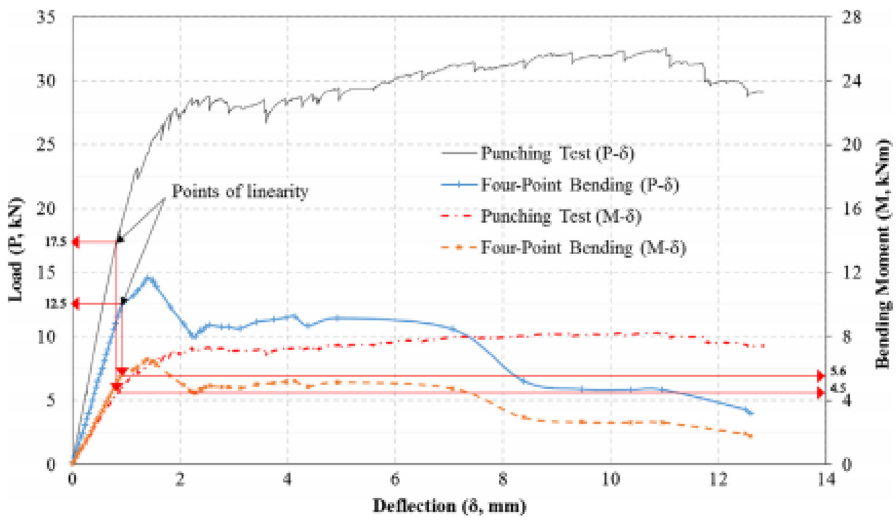

Figure 3: Load-deflection and moment-deflection curves [10]

Figure 4 depicts the load-deflection curves for precast foamed concrete sandwich panels (PFCSP) wall GA1-GA6 at mid-height point AD2. The PFCSP wall panels were deflected elastically until the first fracture developed on the concrete surface, as shown in Figure 4, indicating that the connection was almost linear. The load-deflection relationship became nonlinear when significant concrete cracking occurred, but the deflection curves remained approximately proportional to the rise in axial load. Because these three instances, unlike panels GA2, GA3, and GAC, were built as non-slender panels, their behaviours were almost identical. Because their lengths were the same, the ultimate loads of similar panels (GA2 and GAC) were tested. The only difference was in the concrete components used in casting. Because the ultimate load of GAC was about 36.6 percent greater than that of GA2, the impact of concrete strength heterogeneity was negligible. However, when the wythe thickness in both panels increased, lateral deflection became more severe.

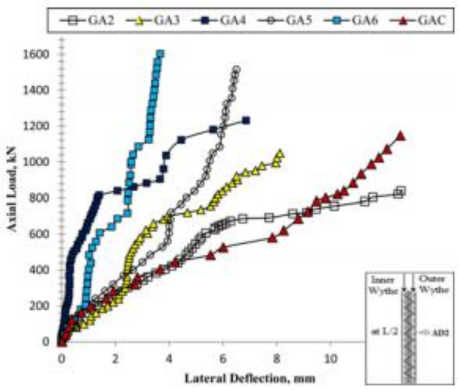

Figure 4: Axial load versus lateral deflection at AD2 of mid-height for panels GA2-GA6 and GAC [12]

Furthermore, the cracking patterns of a precast self-compacting concrete sandwich wall and a precast foamed concrete sandwich wall are compared. Table 1 summarised the test findings of a precast self-compacting concrete sandwich wall. The first fracture formed below the loading point in the panel's bottom wythe during the punching load test with a load of 23.2 kN, which equates to a bending moment of 5.9 kNm. After fractures in the top wythe, horizontal cracks developed at the EPS-concrete contact at the supporting margins. As a result, the fracture pattern in the panel's bottom wythe is similar to that of a square RC slab exposed to a punching force. As a result, the flexural behaviour of the precast concrete sandwich panel investigated in this research is comparable to that of a typical RC slab under punching force. The lack of edge ribs at supporting edges has been related to horizontal fractures at the EPS-to-concrete contact. The first fracture in the bottom wythe was discovered during a four-point bending test with a weight of 12.5 kN. At a cross section about 30 mm from one of the loading sites in the constant shear zone, a crack developed on the panel's sides and the panel broke with a cracking sound at 14.6 kN. The lower wythe had fewer fractures than the panel tested under punching force. A cross section in the continuous shear zone failed at the maximum bending moment area. Furthermore, shear area fractures were broader than bending moment zone cracks. According to these findings, concrete failure in the bottom wythe as a result of the combined impact of shear and flexural loads may be to blame for the panel's collapse. Because there was no wythe separation, as evidenced by horizontal fractures at the concrete-to-EPS contact, the panel could be regarded a composite component until collapse.

Table 1: Summary of test results [10]

No	Loading condition	First crack load (kN)	Cracking moment (kN m)	Calculated principal tensile stress at first crack load (N/mm^2)	Ultimate load (kN)	Ultimate moment (kN m)	Moment up to which panel behaved linearly (kN m)	Remarks
1	Punching	23.2	5.90	1.9	31.9	8.1	4.5	Flexural mode of Failure
2	Four-point bending	12.5	5.70	1.8	14.6	6.6	5.6	Combined effect of shear and flexural stress caused panel failure

The cracking patterns and failure loads of precast foamed concrete sandwich panels evaluated under axial load are illustrated in Table 2. Throughout the testing, the fracture patterns were clearly visible and meticulously documented. The primer crack and failure load, on the other hand, were reported in relation to cracking patterns and applied axial loads. Under loads of 620, 540, 720, 740, and 980 kN, primer fractures were found in the tested panels. Regardless, priming fractures were discovered at loads ranging from 39 to 74% of the ultimate failure load. When the panels achieved their maximum pressures under both circumstances, significant crushing occurred at the top, bottom, or both sides of the panels.

Table 2: Cracking Patterns and Failure Loads of Panels Tested Under Axial Loads [12]

Group No	Name of panel	Slenderness ratio, H/t	Aspect ratio, H/w	First crack, kN	Axial ultimate load capacity, kN "Experiment"
A1	GA1	28.57	2.50	-	759.9
	GA2	24.00		620	839.5
	GA3	20.00		540	1048.6
	GA4	17.14		720	1231.1
	GA5	15.00		740	1515.1
	GA6	13.33		980	1602.7
B1	GAB	24.00		620	762.2
C1	GAC	24.00		840	1147.8

The structural performance of precast solid concrete wall, precast self-compacting concrete sandwich wall and precast foamed concrete sandwich wall is comparable. The difference in using of concrete affect the cracking pattern and load-deflection which represent structural behaviour of each type of wall. From the experiment conducted by previous researchers, it is obvious that precast foamed concrete sandwich wall has the best structural performance. It can be reviewed form the load-deflection curve and first crack pattern. Precast foamed concrete sandwich wall is the strongest because it strengthened with shear connectors from steel reinforcement. For example, precast foamed concrete sandwich wall is 50% higher strength compare to the others two precast walls. This can be study from the load-deflection curves in the previous study.

4. Conclusion

The previous journals were used to determine the structural behaviours of precast conventional solid walls, precast self-compacting concrete sandwich walls, and precast foamed concrete sandwich walls. Three types of precast walls are compared, and the precast concrete sandwich panel has a superior structural performance because it is reinforced with shear connections made of steel reinforcement between the two sides of the wythes. Previous study examined the structural performance of precast concrete walls, including deflection and cracking pattern. All of the findings indicated that the precast foamed concrete sandwich wall had the best structural performance among the three precast concrete walls. The panel that was exposed to four-point bending broke suddenly, and the crack initiation and propagation that resulted in panel failure may be attributed to the combined action of flexural and shear stresses. When compared to normal concrete, the benefits of employing foamed concrete were found to reduce structural foamed concrete wythes self-weight by up to 23 percent [13].

In addition, the use of precast concrete sandwich panels for flat plates and slabs seems to have a promising future [14]. Experimental and computational studies are required to understand the behaviour of precast lightweight concrete sandwich panels under different kinds of loading and support conditions in order to provide design suggestions for practical applications.

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