Ultimate Strength of Precast Concrete Sandwich Panel with Opening Under Axial Load

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ABSTRACT

A precast sandwich panel which is being developed as a building system consists of a single layer of insulation sandwiched between two layers of reinforced concrete. At present, an equation to predict the ultimate strength of precast concrete sandwich wall panel with opening, to the best of authors' knowledge, is not available. This paper reports a research effort to determine the suitability of the load equations developed by earlier researchers for thin reinforced concrete solid wall with opening when used to estimate the ultimate load of precast concrete sandwich wall panel with opening. Nine sandwich panels with different window and door opening combination were prepared and tested under uniformly distributed load. The load was applied and increased in stages till failure. At each stage of the load, deflection gauges and strain gauges reading were recorded. The development of cracks was also monitored. The experimental ultimate loads of precast concrete sandwich wall panels with opening tested in the laboratory were compared with and found close to the theoretical values derived from the equation proposed by Saheb and Desayi for ordinary precast concrete wall panels with opening.

Keywords : *Precast Concrete, Sandwich Panel, Ultimate Load, Concrete Design*

INTRODUCTION

Precast concrete components have been widely used in the building sector. The rapid growth of the building industry plus the increasing demand for quality buildings necessitates the building industry to continuously seek improvement, leading to industrialisation in the building industry. The advent of industrial methods had shown that mass production of precast concrete components had increased the quality as well as reduced the cost of construction. Cost reduction is achieved through lesser construction time and amount of labour [1].

Precast concrete is defined as concrete which is cast in some location other than its position in the finished structure. One possible building elements in a precast building system is precast concrete sandwich wall panel. The difference between precast concrete wall panel and precast concrete sandwich wall panel is the presence of an intervening layer of insulation. An opening refers to a void area in the wall. In practice, it can be a door or a window. This paper presents the results of an experimental investigation comparing between the experimental and theoretical ultimate loads of precast concrete sandwich panel with opening under static loading.

Very little information is available on the behaviour of concrete panels with openings. Seddon [2] studied wall panel supported at the top and bottom with a symmetrical opening. His conclusions were as follows:

1. Openings cause beam element behaviour above and below the opening. Portions adjacent to openings in the direction of the load exhibited column element action. It was found that panels ultimately failed through one of the column elements due to the cracks extending to the corners of openings.
2. To fully utilise the concrete strength, there is a need for adequate reinforcement in the beam elements.

Saheb and Desayi [3] realised the need for more detailed information on panels with openings. The authors carried out test on twelve panels; six were supported at the top and bottom only and the others were supported on all four sides. Each panel was provided with a window or a wall opening in different regions. The size of the panels was 600mm high x 900mm long and 50mm thick. The test panels were subjected to in-plain vertical loads applied at an eccentricity. The test panels had identical vertical and horizontal reinforcement ratios, i.e., either r = 0.173 or 0.236, and the concrete strength was set at 28 N/mm^2. The slenderness ratio i.e. the height to thickness ratio was constant at 12, the thickness ratio at 18, and the aspect ratio at 0.67. To prevent premature failure due to cracking at corners, reinforcement was placed at 45 degrees in these areas. The conclusions to these tests were:

1. The failure of the concrete panels appeared to be due to buckling influenced by bending of slender column strips adjacent to the openings.
2. Empirical equations were developed for panels with openings for both one-way and two-way panels by modifying the ACI formula and the introduction of a reduction parameter that allowed for the geometry of the openings.
3. The panels supported on four sides appeared to be slightly stronger than the one-way panels. The cracking load was marginally greater for panels under two-way action. But more importantly, the ultimate load was found to be nearly equal.

In studies on the design of beams (as opposed to walls) with openings, an important consideration is the stress concentration that occurs due to a sudden reduction in beam cross section. Inadequate reinforcement or improper detailing may lead to wide cracking and even premature failure of the beam. To deal with this stress concentration, Nasser et al. [4] suggested the use of diagonal bars at each corner of the opening and recommended that a sufficient quantity be provided to carry twice the amount of external shear. However, Lorenston [5] and Barney et al. [6] suggested the use of stirrups in the solid section adjacent to each side of the opening. These stirrups should be designed to carry the entire shear force, but without any magnification.

The PCI Committee [1] report on Precast Concrete Sandwich Panel defined the openings as being completely contained within the panel or as blockouts in the panel sides, top or bottom. Panel openings should have re-entrant corners reinforced with diagonal bars in both layer to limit the width of corner cracks. Punched opening located near one edge of the panel are very susceptible to cracking and it is advisable to eliminate the insulation in this area and reinforce the side with additional reinforcement.

Previous research work on panel with opening was very limited. Only Saheb and Desayi [3] had suggested an equation to calculate the ultimate load of reinforced concrete wall panel with opening. In order to compare the experimental ultimate load with the theoretical value, the Saheb and Desayi [3] equation for panels with opening was used to estimate the theoretical load as follows:

$$P^{c}_{uoc} = (k_1 - k_2\alpha)P^{cu}_{c} \tag{1}$$

where, P^{c}_{uc} is the theoretical ultimate load for panel without opening, which is given by:

$$P^{c}_{uc} = 0.55\phi\,[A_g f_c' + (f_y - f_c')A_{sv}]\,[1-(H/32t)^2][1.2-H/10L] \tag{1b}$$

and k_1 *and* k_2 = *constant*
A_g = *gross area of the wall panel section*
A_{sv} = *area of vertical steel in wall section*
f_c' = *cylinder strength of concrete*
f_y = *yield strength of steel*
H, L = *height, length of wall panel*
t = *thickness of the wall*

The influence of size and location of the opening(s) was taken into account through the parameter a, where

$$a = \frac{A_o}{A} + \frac{a}{L} \tag{2}$$

Where

$A_o = L_o t$
$A = Lt$
$a = \left[(L/2) - \bar{a} \right]$
$\bar{a} = \dfrac{(L^2 t/2 - L_o t a_o)}{Lt - L_o t}$
Lo = *length of panel opening*
ao = *distances of the centres of gravity of the opening from the left edge of the panel*
$\bar{a}$ = *distances of the centres of gravity of the panel without opening from the left edge of the panel*
a = *distance between centres of gravity of panels with and without opening*

METHODOLOGY

Test Specimen

In this study, three types of precast concrete sandwich panels were designed and classified as: -

- Precast concrete sandwich panel with door opening;
- Precast concrete sandwich panel with window opening; and
- Precast concrete sandwich panel with door and window opening.

A total of nine test specimens were prepared; three specimens each for the three types. The panels were named as OA, OB and OC for panels with door opening, panels with window opening and panels with both door and window openings, respectively. Number 1, 2 and 3 were designated to the three specimens in

Table 1: Test Specimen Details

Type of specimen	Specimen No. (h x w x t) mm	Size of panel (h x w) mm	Size of opening (h x w x t)		No. of Shear Connector	Column size (h x w x t) mm
			Door	Window		
With door opening	OA1 OA2 OA3	900 x 1000 x 120	700 x 300	-	4@ 200mm c/c	900 x 100 x 120
With window opening	OB1 OB2 OB3	900 x 1000 x 120	-	460 x 400	5@ 200mm c/c	-
With door and window opening	OC1 OC2 OC3	900 x 1000 x 120	700 x 300	360 x 400	6@ 200 mm c/c	900 x 100 x 120

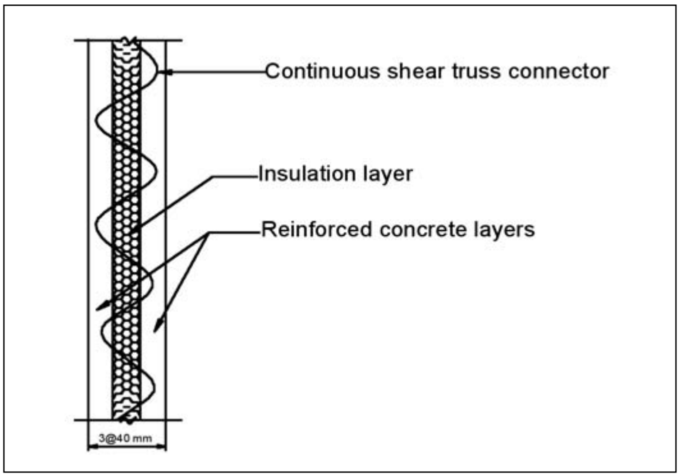

Figure 1 : Sandwich Panel Layers

each type. The specimen size was 900mm x 1000mm by 120mm thick. Table 1 shows the details of the specimens. The thickness of the sandwich panel was made of two 40mm layers of concrete and a layer of insulation material in between. The two concrete layers were connected through the insulation layer by continuous shear truss connector along the length of the panel (Figure 1). The shear truss connectors were located at every 200mm centre to centre across the width of the panel.

The precast concrete sandwich panel with door opening (OA) was prepared with a door opening of 700 x 300mm. Figure 2(a) shows the door position as well as the locations of steel reinforcement. The small area of concrete next to the door opening was designed as a column to prevent failure at that area. Four 6mm diameter bars were used as reinforcement. At the edge of the opening, two diagonal bars were placed at both concrete layers. The diagonal bars were placed at 45° to the opening edge.

The precast concrete sandwich panel with window opening (OB) had an opening 270mm from the bottom of the panel. The opening was designed at the centre of the panel. The size of the window opening was 460 x 400mm. The diagonal bars were placed at the four corners of the opening in both concrete layers. The detailed drawing of the panel is as shown in Figure 2(b).

The precast concrete sandwich panel with door and window opening (OC) have 700 x 300mm door and 360 x 400mm window

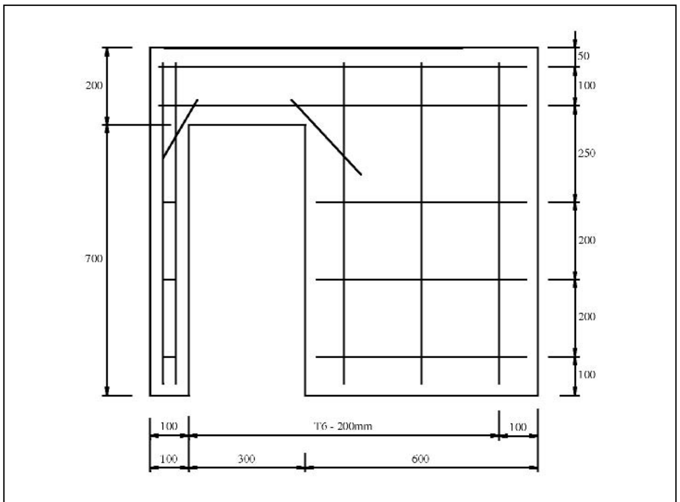

Figure 2(a) : Panel with Door Opening (OA)

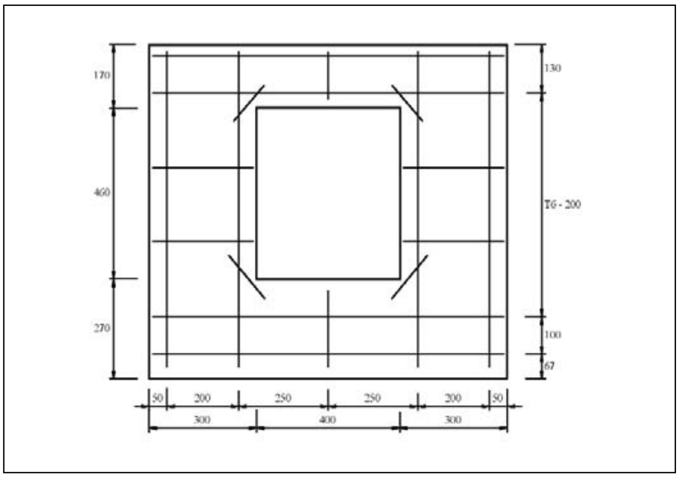

Figure 2(b) : Panel With Window Opening (OB)

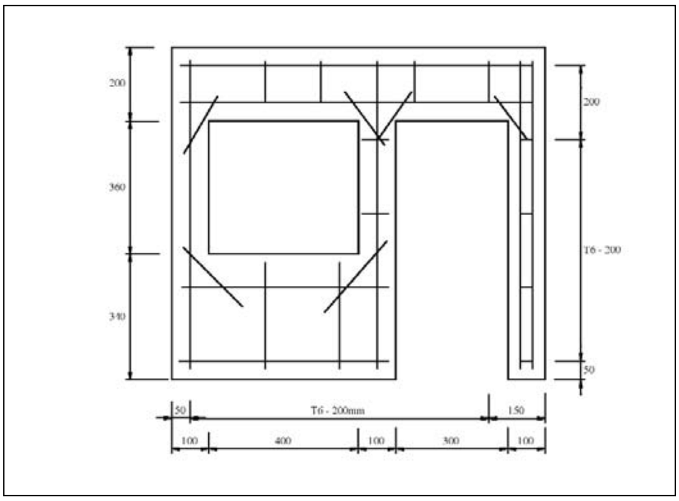

Figure 2(c) : Panel with Door and Window Openings (OC)

openings. Diagonal bars were placed at every corner of the openings in both concrete layers. Similar to the panel with door opening, in order to prevent failure, the small area of concrete near the door opening was designed as a column. Figure 2(c) shows the details of this panel.

Materials

A ready mix concrete with a mix ratio of 1: 2.22: 2.46 and a water-cement ratio of 0.57 by weight was used. The maximum size of aggregate was 10mm. The concrete was designed for 28-day cube strength of 30 N/mm^2. Concrete compression test was carried out on 150mm cubes at concrete age of 28-days to obtain the concrete compression strength.

6mm diameter mild steel bars were used for vertical and horizontal reinforcements. The percentages of vertical and horizontal reinforcements used were 0.12 and 0.2 percent of gross concrete area respectively. This was based on ACI 318-83 Section 14.3.2 and 14.3.3 (minimum vertical and horizontal reinforcement in reinforced concrete wall); applied to steel bar diameter less than 16mm with the specified yield strength not less than 413.7 N/mm^2. The maximum allowable spacing of reinforcement in wall according to Section 14.3.5 for vertical and horizontal reinforcement was three times the wall thickness or 457mm whichever was less. BRC bars with 200 x 200mm opening were

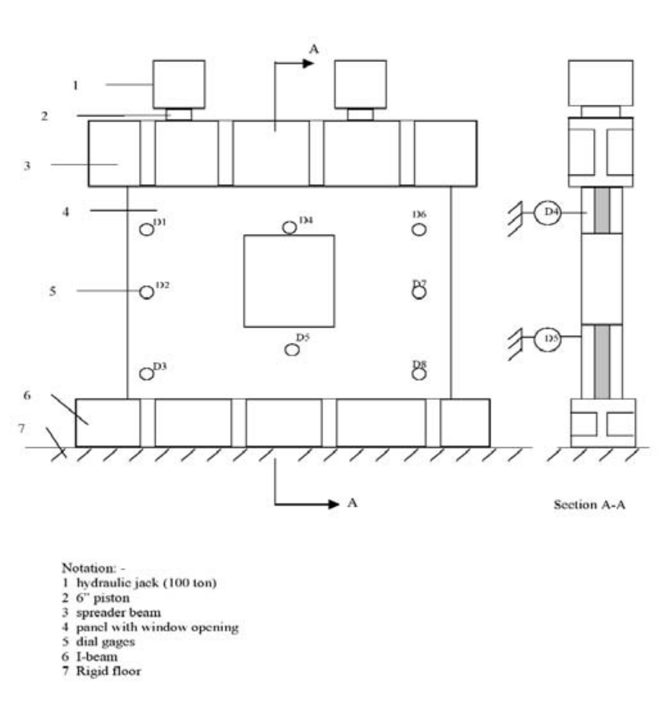

Figure 3 : Schematic View of the Test Frame (back view)

used as reinforcement mesh in both concrete layers.

For continuous shear truss connectors, the 6mm mild steel bar was bent to an angle of 60° (against horizontal plane) with a height of 90mm. The continuous shear truss connectors were placed at 200mm centre to centre along the width of the panels. Premature failure may occur at two critical areas; the corners of the opening and the small width adjacent to the door opening. In order to prevent this, the corners of the opening were reinforced with 6mm diameter bars placed diagonally at 45° to the corners and a concrete column with four 6mm diameter bars provided at the small width next to the door opening.

In this investigation, polystyrene was used as insulation material because it has good thermal resistance, economical and easy to acquire from the local market. The insulation material chosen depends upon the thermal properties of the material, the design temperature of the structure and the desired thermal resistance of the panel.

Table 2: Analysis of Panel With Opening

Type of panel	No. of panel	$\frac{A_o}{A}$	$\frac{a}{L}$	α	P^e_{uo} (kN)	P^e_{uo} / P^c_{uc}
With door opening	1	0.3	0.116	0.416	951.3	0.70
	2				996.6	0.73
	3				860.7	0.63
With window opening	1	0.4	0	0.400	724.8	0.53
	2				1177.8	0.86
	3				906.0	0.66
With door and window opening	1	0.7	0.026	0.726	634.2	0.47
	2				634.2	0.47
	3				498.3	0.37

Test Setup

For the experimental test, the panels were placed vertically and simply supported at the top and bottom as shown in Figure 3. This allows for the rotation at the support, but restrains horizontal and/or vertical displacement. The horizontal movement was restrained by the top support. The panels were subjected to uniformly distributed load, applied through a spreader beam. The horizontal levels of the panel and spreader beam were checked prior to loading. Two hydraulic jacks with 100-tonne capacities each applied the load in stages up to failure. The hydraulic pressure recorded on the pump meter controlled the load applied to the panel. The calibration factor of the pump was 0.85. At every 53.3kN increment, the load was kept constant for a while to allow the panel to stabilise before the strain gauges and deflection dial gauges readings were recorded. The ultimate loads and the crack patterns were also recorded.

RESULTS AND DISCUSSION

Material

The average compressive strength (f_{cu}) of the concrete cubes recorded from the compression tests was 35.2N/mm^2. The equivalent compressive strength of concrete cylinder (f_c') was taken as $0.85f_{cu}$ or 29.9N/mm^2.

As for the steel, the tensile test was carried out on three samples of 6mm diameter BRC bars and three samples of 6mm diameter mild steel bars as the shear connector. The average yield strength (fy) of the BRC bars and the shear connector was 572.9N/mm^2 and 546.8N/mm^2 respectively.

Ultimate Load Analysis

In the ultimate load calculation, the thickness of an insulation layer was not taken into consideration. The total effective thickness of the panel was taken as 80mm. Loads at first crack were about 28% to 74% of the ultimate loads. Panels with door opening had the first crack at 54% to 74% of ultimate loads. Panels with window opening had its first crack at 30% of ultimate load. The first crack for panels with door and window opening occurred as early as 28% of its ultimate load. This showed that, the panels with door and window opening had the earliest crack when compared to the other types of panel. The strain gauges and dial gauges readings were also recorded during the experiments but not presented in this paper. The ultimate loads and the crack patterns were also recorded.

Table 2 tabulated the values of α and experimental ultimate load of panels with opening to theoretical ultimate load of panel without opening (P^e_{uo} / P^c_{uc}). The theoretical ultimate load of panel without opening (P^c_{uc}) was taken as 1363kN. This value was calculated using Saheb and Desayi for panel without opening equation. The strength reduction factor (f) is taken as 1 in order to compare with the actual ultimate load.

Values of parameter α and P^e_{uo} / P^c_{uc} c from Table 2 were plotted as in Figure 4. The values of k1 and k2 are 1.0027 and 0.779 respectively, were calculated from the best-fit linear line of graph in Figure 4. By using equation 1, the theoretical ultimate loads were compared to the experimental values.

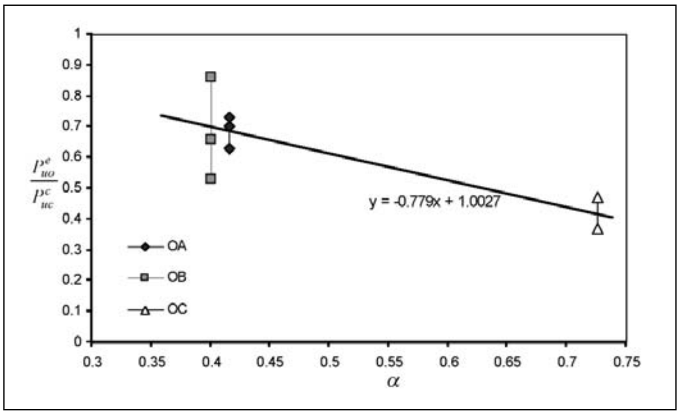

Figure 4 : P^e_{uo} / P^c_{uc} ***verses*** α

Table 3 shows the ratio of experimental to theoretical ultimate loads of panel with opening varied from 0.77 to 1.25. The panels with door opening (OA) showed one panel having a 7% lower experimental value compared to the theoretical value. For panel with window opening (OB), two panels had lower values (23% and 4%) than the theoretical while for panels with door and window openings (OC) only one panel showed a lower value of 16%.

The average ratio of experimental ultimate loads to the corresponding theoretical values varies from 0.99 to 1.01 for the three types of panel with opening. This showed that the theoretical equation by Saheb and Desayi [3] for ordinary reinforced concrete wall with opening could be used to estimate the ultimate load for sandwich panels with opening.

CONCLUSIONS

The theoretical ultimate loads were calculated using Saheb and Desayi [3] equation for ordinary reinforced concrete wall with opening. The calculations were made with an assumption that the total thickness of the sandwich panel is equal to the total thickness of the two reinforced concrete layers only. After analysing the experimental data, the average ratios of experimental to theoretical ultimate loads for sandwich panels were found to vary between 0.99 and 1.01. This shows that the ultimate load equation for ordinary reinforced concrete wall with opening proposed by [3] can be used to estimate the ultimate load of precast concrete sandwich wall panels with opening.

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Table 3 : Theoretical and Experimental Ultimate Loads for Panels With Opening

Panel No.	*Experimental ultimate load* P^e_{uo}	*Average experimental ultimate load* P^e_{uo} *(ave)*	*Theoretical ultimate load* P^c_{uo}	*Experimental/ theoreticald ultimate load* P^e_{uo} / P^c_{uo}	*Average experimental/ theoretical ultimate load* P^e_{uo} *(ave)* / P^c_{uo}
OA1	*951.28*			*1.03*	
OA2	*996.59*	*936.19*	*924.98*	*1.08*	*1.01*
OA3	*860.69*			*0.93*	
OB1	*724.79*			*0.77*	
OB2	*1177.79*	*936.19*	*941.97*	*1.25*	*0.99*
OB3	*905.99*			*0.96*	
OC1	*634.19*			*1.06*	
OC2	*634.19*	*588.89*	*595.83*	*1.06*	*0.99*
OC3	*498.29*			*0.84*	