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PERFORMANCE OF CONNECTED PRECAST LIGHTWEIGHT SANDWICH FOAMED CONCRETE PANEL UNDER FLEXURAL LOAD

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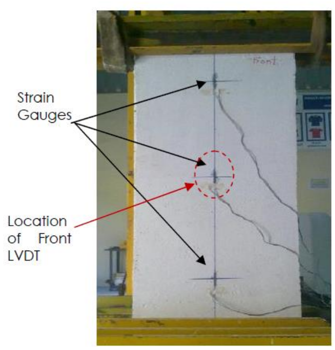
Graphical abstract



Abstract

This paper investigates the structural behaviour of two connected Sandwiched Precast Lightweight Foamed Concrete Panel (PLFP) in term of their load bearing capacities and failure modes. Three (3) connected PLFP panels were cast using foamed concrete as the wythe and polystyrene as the core layer. Each connected panel were cast from two single panels connected using L-bar connection. The panels were strengthened with steel bar reinforcement embedded in both wythes which were connected to each other by the steel shear truss connectors. The connected PLFP panels were tested under flexural load. A single PLFP panel was cast as a control panel and tested under axial load. The results were analysed in term of the panel's ultimate load, crack pattern and mode of failure. Results showed that the two connected PLFP panels were able to sustain slightly lower ultimate load compared to single PLFP panel. Crack at 45 degree angle at top half of panel and small crack at surface between joint of the connection were observed.

Keywords: Precast concrete lightweight panel, structural behaviour, ultimate load, crack pattern, failure mode

Abstrak

Kajian ini mengenai kelakuan struktur dua panel konkrit berbusa pasang siap (PLFP) dari segi keupayaan tanggung beban dan mod kegagalannya. Tiga (3) panel PLFP bercambung disediakan menggunakan konkrit berbusa sebagai lapisan luar dan polisterin sebagai lapisan dalam. Setiap panel bersambung ini terdiri dari dua panel tunggal yang disambung menggunakan sambungan L-bar. Panel ini dikuatkan dengan tetulang besi yang di letakkan di dalam lapisan luar wythe yang diikat kepada tetulang penyambung ricih. Panel bersambung ini diuji di bawah beban lenturan. Panel tunggal sebagai panel kontrol diuji di bawah beban paksi. Keputusan yang direkodkan dianalisa dari segi kekuatan muktamad, paten rekahan dan mod kegagalannya. Analisa keputusan menunjukkan panel bersambung di bawah beban lentur ini mampu menanggung beban yang kurang sedikit daripada beban yang ditanggung oleh panel PLFP tunggal di bawah beban paksi. Rekahan pada 45 darjah pada bahagian atas panel dan rekahan kecil pada permukaan di antara sambung dua panel telah direkodkan.

Kata kunci: Panel konkrit ringan pasang siap, kelakuan struktur, beban muktamad, paten rekahan, mod kegagalan

1.0 INTRODUCTION

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 self compactibility and lighter weight [1]. It is lighter than the conventional concrete with a dry density of 300 kg/m^3 up to 1840 kg/m^3 which is 23% to 87% lighter. It was first introduced by the Romans in the second century [2].

One of the main properties that are associated with the lightweight concrete is its low density which leads to reduction in weight and its total load. Foamed 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. It is stated that lightweight concrete is a concrete that have a low density concrete compared to the normal concrete [3].

Current research on precast wall panel only focuses on the performance of solid panel from conventional concrete. Little research has been conducted to study precast from lightweight material for solid or sandwiched wall panel, let alone the study on two sandwiched panel connected together.

Connection design is one of the most important considerations for a successful construction of precast reinforced concrete structures in terms of its structural behaviour [4, 5, 6, 7]. Connections can be defined as those system used for connecting one precast component to another and also to connect precast components to the structural frame of cast-in-situ, steel or masonry [8]. The main purpose of the structural connection is to transfer forces between the precast concrete elements in order to obtain structural interaction once the system is loaded.

Thus, this research investigated the structural behavior of the Precast Lightweight Foamed Concrete Panel, PLFP, as a single wall tested under axial load and two vertically connected walls tested under flexural load. In this study, PLFP was designed to have a compressive strength of 12 MPa and strengthened with double shear connectors. Eight (8) single PLFP panels with various slenderness ratios were tested under axial load while two connected PLFP panels with L-bar connection was designed and tested under flexural load to study the panel's structural performance.

2.0 EXPERIMENTAL PROGRAMME

The experimental programme included one control single panel specimen tested under axial load and three (3) sets of two single PLFP panels connected using vertical connection tested under flexural load test as listed in Table 1 and Table 2, respectively.

2.1 Fabrication of PLFP Specimens

Fabrication and casting of single and connected PLFP panels started after the formwork, steel reinforcement and shear connectors were prepared. The panels were cast and fabricated using foamed concrete as its outer layers and extended polystyrene as its insulation or core layer. The height of panel was fixed at 900 mm. The concrete cover of 8 mm was used and the thickness of each concrete wythe was fixed at 20 mm for all panels as it is the minimum cover and thickness required to meet the durability and fire resistance requirements according to BS 8110: Part 1: Tables 3.4 and 3.5.

The panel was strengthened with embedded reinforcement bars made of 4 mm diameter mild steel bars with 75 mm x75 mm openings in both skin layers. These reinforcements in the inner and outer wythe were connected to each other by double shear truss connectors which were tied to it as shown in Figure 1.

Schematic diagram of steel reinforcement and shear connectors in the single PLFP panel is illustrated in Figure 2. The PLFP panels were left for curing under ambient temperature for 28 days. The single PLFP panels were tested under axial load while the connected PLFP panels were tested under flexural load.

Table 1 Dimensions and details of Single PLFP panel subjected to axial load test

No.	H x W x t	H/t	t_1	t_2	Reinforcement (Vertical & Horizontal) Top and bottom	Diameter of Shear Connectors
PA-1	900 x 370 x 90	10	20	50	4mmΦ@75mm c/c	4 mm

Table 2 Dimension and details two connected PLFP subjected to four point load test

No.	H x W x t	H/t	t_1	t_2	Reinforcement (Vertical and Horizontal) Top and bottom	Diameter of Shear Connectors
PC-1	900 x 770 x 90	10	20	50	4mmΦ@75mm c/c	4 mm
PC-2	900 x 770 x 90	10	20	50	4mmΦ@75mm c/c	4 mm
PC-3	900 x 770 x 90	10	20	50	4mmΦ@75mm c/c	4 mm

Figure 1 Double Shear truss connectors tied to steel bar reinforcement in PLFP panel

Two single PLFP panels were connected using vertical connection with L-bar reinforcement as illustrated in Figure 3. The material used as the infill for the connection is foamed concrete with density of 1700 kg/m^2 to 1800 kg/m^2.

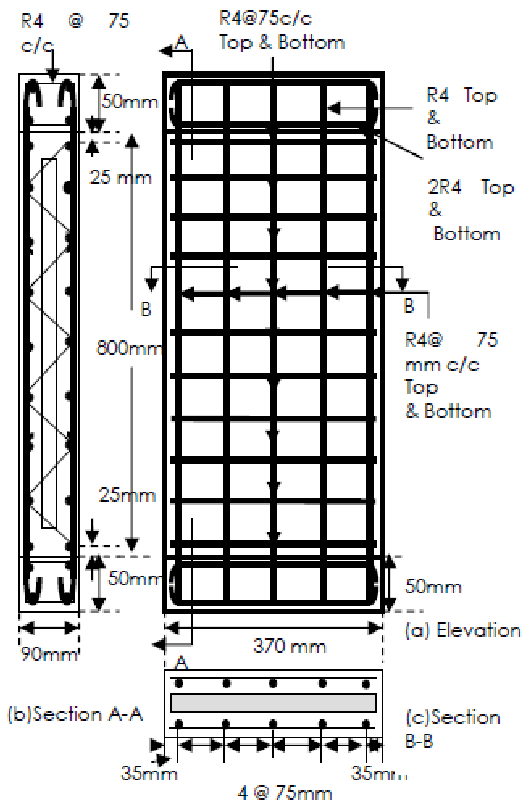


Figure 2 Schematic diagram of steel reinforcement and shear connectors in the single PLFP panel

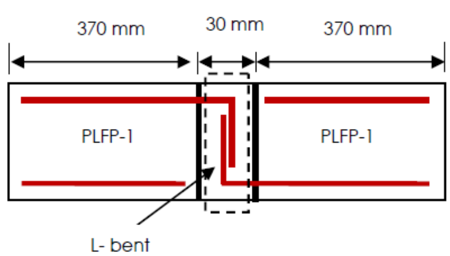


Figure 3 Plan view of reinforcement orientation in L-bar connection

2.1 Axial Load Test

Single PLFP panels were tested using Magnus Frame with capacity 1000 kN to investigate its structural behaviour under axial load. The support conditions were designed as pinned in x direction at the top and pinned in x and y direction at the bottom of the panel. Universal beams and round steel bars were used to fabricate the lateral support at the top edge of panel. A 100 ton load cell was used to measure the applied loading on top of the panel. Figure 4 shows the experimental set-up of wall panel clamped to the frame.

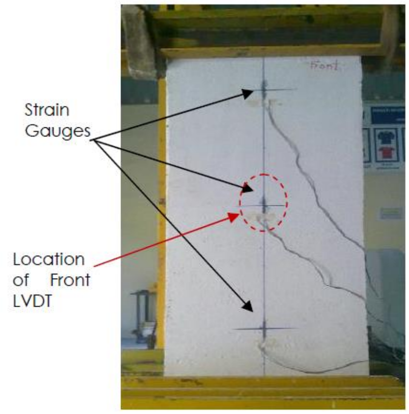


Figure 4 Axial load test set up with arrangement of strain gauges and LVDT

2.2 Flexural Test

Four point load test was carried out to study the structural behavior of two connected PLFP panels. Six (6) strain gauges were glued on the panel's surface at different locations and three (3) LVDT were fixed at mid height and on both upper and lower part of the connection. The panels were tested until it failed.

3.0 RESULTS AND DISCUSSION

3.1 Ultimate Load

The comparison of ultimate strength for single and two connected PLFP panels were studied to find out the ability of the connected panel to sustain load using L-bar connection. From Table 3, the first crack load was recorded at 70 kN for panel PC-3 compared to 112 kN for panel PA-1. This is because the two panels PA-1 in PC-3 were tested as joint beam and experienced bending and the cracks propagated from the shear area to the middle bottom area until it reached total flexure. Single panel PA-1 was tested as single column under axial compression load and experienced slight buckling at the middle zone. The crack was recorded at mid-height and propagated 45 degrees.

Table 3 Ultimate failure load for PLFP panels

No.	Dimension (H x W x t)	Compressive Strength, (MPa)	First Crack Load(kN)	Ultimate Load, (kN)
PA-1	900 x 370 x 90	12.2	112	171
PC-3	900 x 750 x 90	11.6	70	147

It can also be seen that panel PC-3 under flexure load achieved lower ultimate strength compared to single panel PA-1 under axial load. This is as expected because panel PC-3 was made of two panels PA-1 with connections at the middle and subjected to four point load test. However, the percentage difference between these ultimate load values is rather small which about 14% is. The ultimate load recorded in panel PC-3 is 147 kN.

3.2 Crack Pattern and Failure Mode

During the testing of single and connected PLFP panels, axial and flexure load were applied incrementally till failure occurred. Cracks were observed and marked from the early stage of loading till the point when the PLFP crushed. When the load reached the ultimate value, the panels were crushed either at the top or the bottom part of the panels. The details for crack patterns are shown in Table 4 for single PLFP panels under axial load and connected PLFP panels under flexure load.

Table 4 Crack Pattern and Failure Mode for Panels PA-1 and PC-3

Specimen	Compressive Strength, f_{cu} (N/mm^2)	Crack Pattern and Failure Mode
PA-1	12.2	Crack and crush near bottom half of panel
PC-3	11.6	Crack at 45 degree angle at top half of panel. Small crack at surface between joint of the connection.

Cracks were observed in either or both concrete wythes and the specimen finally failed by crushing of the concrete. When the load reached the ultimate value, failure occurred in all cases by crushing either at one or both ends of the panels. This indicates that when the load reached its maximum, failure occurred in most panels by crushing near the area of either one or both ends of panels. Panel PA-7 cracked at higher load which is 70 percent of the ultimate load. Panel PA-1 showed crack and crush at its bottom part as shown in Figure 5 and Figure 6. The crack and crush might be caused by the stresses concentrated at the bottom part due to imperfection during the test set-up. Panel PC-3 experienced crack at 45 degrees within its top left and right areas near the points of load applied. This is as expected when panel is loaded under flexure. Small crack at the surface was also observed near the connection area.

Figure 5 Crack and crush at bottom part of panel PA-1

Figure 6 Crack and crush on the diagonal angle approximately 45° at the top of panel PC-3

Figure 7 and Figure 8 depicts the load-horizontal profile for panels PA-1 and PC-3. In both profiles, it is observed that small initial deflection was recorded at the early stage of loading. Both panels recorded elastic behavior before the first crack occurred. Upon reaching higher load, both panels started to behave in a nonlinear manner until they failed. The difference noticed in the load-deflection profiles recorded for the two panels are the yield point and point of failure observed in panels. Panel PA-1 failed almost without yielding while panel PC-3 failed after yielding. This somehow indicates that the L-bar reinforcement which connected the two panels in PC-3 was efficient and managed to hold the two panels.

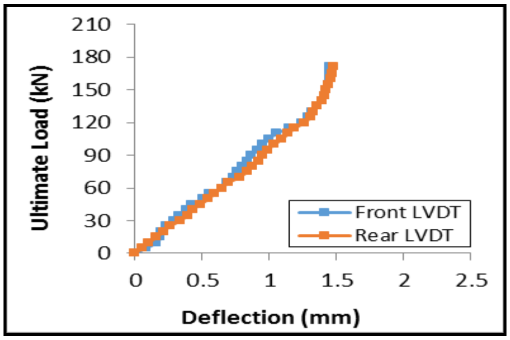


Figure 7 Load-deflection Profile for PA-1

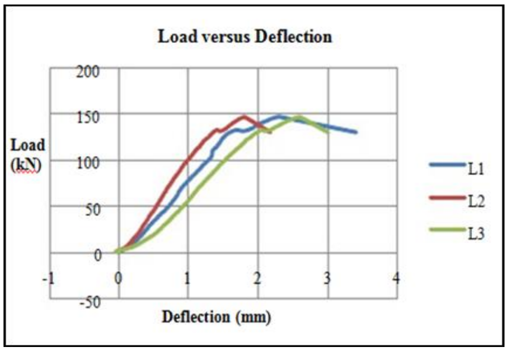


Figure 8 Load-deflection Profile for PC-3

4.0 CONCLUSION

From the experimental results, it can be seen that single PLFP panels PA-1 can sustain the axial load applied and the shear connectors used are effective in transferring the load from one wythe to another. Cracks were observed in either or both concrete wythes and the specimen finally failed by crushing of the concrete.

For two PLFP panels connected and tested under four point load test, the first crack occurred at about 50 to 70 percent of the ultimate load achieved. Cracks were observed particularly within the connection area.

Two PLFP panels PA-1 connected using L-bar vertical connection, PC-3, subjected to flexure load is able to sustain slightly lower ultimate load compared to single panel subjected to axial load. Single panel PA-1 failed without yielding while connected panels with connection PC-3 failed after yielding. L-bar connection used in panel PC-3 is efficient and managed to hold the two PLFP panels PA-1 together.

Acknowledgment

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