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Structural behaviour of eccentrically loaded precast sandwich panels

A. Benayoune [a,*], A. Aziz A. Samad [b], D.N. Trikha [c], A. Abdullah Abang Ali [d], A.A. Ashrabov [e]

[a] *University of Kuala Lumpur, MFI Section 14, JLN Teras Jernang, 43650 B. B. Bangi, Selangor, Malaysia*
[b] *Department of Civil Engineering, KUiTTHO, Malaysia*
[c] *Department of Civil Engineering, UPM, Malaysia*
[d] *Housing Research Centre, UPM, Malaysia*
[e] *Department of Civil Engineering, UPM, Malaysia*

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Abstract

Results of an experimental investigation to study the ultimate strength behaviour of precast concrete sandwich panels (PCSP) with steel truss shear connectors are reported. Six full-scale sandwich panels with variable slenderness ratio were cast and tested under eccentric loads. Deflection characteristics, variations of strains across the insulation layer, strains in shear connectors, crack appearance and propagation under increasing load were recorded and analysed. The role of the shear truss connectors in transferring load from the outer wythe (layer) to the inner and ensuring composite behaviour was also observed. Results obtained showed that all panels behaved in a fully composite manner under eccentric load till failure. The ultimate strength of the PCSPs was found to decrease non-linearly with the increase in the slenderness ratio. Because of the complex behaviour of PCSP due to its material non-linearity and the interaction between its various components, finite element analysis (FEA) was conducted. Comparison with test results indicated that the FEA closely estimate the wall strength and formulae based on reinforced concrete principles underestimate the wall strength.

Keywords: Precast concrete; Sandwich construction; Finite element analysis; Structural walls; Truss shear connectors

1. Introduction

Concrete sandwiched insulated wall panels (PCSP) have recently become more widely used in the building industry in Malaysia due to their economical advantages, superior thermal and structural efficiency. PCSP consists of two layers of concrete called wythes separated by a layer of insulation. The concrete wythes are connected to each other by concrete webs, steel connectors or a combination of the two. A typical PCSP with a truss type shear connectors is shown in Fig. 1. Depending on the extent of composite action, the PCSPs can be non-composite, partially composite, or fully composite. To take full advantage of the strength of the two wythes, and to prevent individual wythe buckling, the shear connectors should be designed to provide for full shear transfer between the two concrete wythes. A technical definition of the percent of composite action is not well established in the literature [1–8].

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

* Corresponding author. Tel.: +60 3 8926 2022; fax: +60 3 8925 8845.
E-mail address: benayoune@mfi.edu.my (A. Benayoune).

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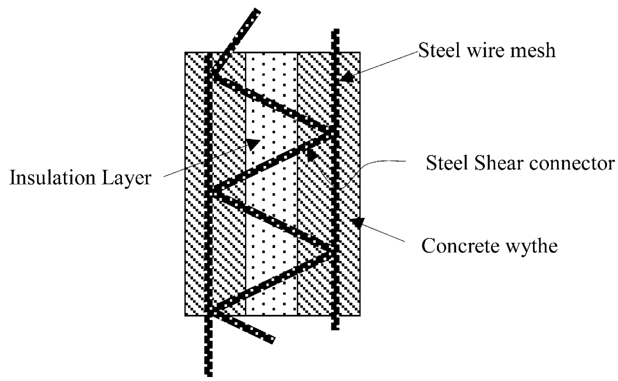

Fig. 1. Typical precast concrete with truss shaped shear connector.

models. Furthermore, many sandwich panels in use in the North America and Europe are proprietary and the producers are thus reluctant to share information with their competitors [8,9].

In the majority of the compression loaded members, the loads do not act ideally at the centroid of the members (i.e. loads act eccentrically). The accidental eccentricity specified by the code (BS8110 Part: 1, 1997) [10] is not to be less than $t/6$ or 20 mm. In the present eccentric load tests, the load was applied at an eccentricity of 40 mm so that the panels were subjected to high bending moments.

The aim of this paper is to investigate experimentally and theoretically the ultimate strength behaviour of the PCSP under eccentric load and study the impact of slenderness on its load bearing capacity, as the proposed PCSP is designed for use in low rise residential and office buildings.

2. Experimental program

2.1. Dimensions of test specimen

A total of 12 specimens were cast in timber formwork and tested in the Civil Engineering Laboratory of the Universiti Putra Malaysia [8]. The 12 specimens consisted of two identical groups, PA and PE of six panels each. The panels in the PA group were tested under purely axial loads, while the remaining six panels in the PE group were tested under eccentric loads. Each group comprises 3 sets of panels, each set having two panels of the same height and width but different thickness. In this paper only test under eccentric loading is reported. The test specimen heights of 1400–2400 mm had been selected to achieve a height to thickness ratio in the range of 10–20. Further details of the six specimens with their designations, aspect ratio H/B and slenderness ratios H/t are indicated in Table 1.

2.2. Materials

Reinforcement: Square welded mild steel BRC mesh of 6 mm diameter bars with 200×200 mm openings was used as the longitudinal and transverse reinforcement for the inner and the outer wythes.

Shear connectors: Continuous truss-shaped connectors running the full height of the panels were used to tie the inner and the outer concrete wythes so that the panels act as a composite structural unit. These connectors were made of 6 mm diameter mild steel bar bent to an angle of 45°. Four connectors were used over a width of 1200 mm.

Insulation layer: Lightweight polystyrene foam were used as the insulation material in the core as it is economical and readily available. The polystyrene sheet was cut into pieces and inserted between the inner and the outer wythes and between shear connectors.

Material properties of the concrete and the steel used for shear truss connectors and reinforcement were tested in the laboratory and their properties are presented in Tables 2 and 3, respectively.

2.3. Fabrication and casting

For casting the specimen, the formwork was cleaned and placed on a table with electric vibrator. The concrete was then poured from a ready mix truck to form the bottom wythe and compacted by vibration. The BRC was then inserted inside the bottom wythe by maintaining a cover of 15 mm. The top wythe was then laid and fully compacted, its surface was trowelled to obtain a smooth finish. Three test cubes were prepared at the same time as the concrete was poured.

Table 1
Test specimens, with dimension, aspect ratio and slenderness ratio

Panel	H (mm)	B (mm)	t (mm)	H/B	H/t	t_1 (mm)	t_2 (mm)	c (mm)
PE1	1400	1200	130	1.2	10.77	40	50	15
PE2	1400	1200	120	1.2	11.67	40	40	15
PE3	1800	1200	130	1.5	13.85	40	50	15
PE4	1800	1200	120	1.5	15	40	40	15
PE5	2400	1200	130	2	18.46	40	50	15
PE6	2400	1200	120	2	20	40	40	15

Where H, the panel height; B, the width; t, the overall thickness; t_1, thickness of each concrete wythe; t_2, the insulation thickness; c, the concrete cover.