ARTICLE IN PRESS

Alexandria Engineering Journal (2016) xxx, xxx–xxx

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Alexandria Engineering Journal

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ORIGINAL ARTICLE

Flexural behavior of precast concrete sandwich panels under different loading conditions such as punching and bending

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Received 25 May 2016; revised 22 September 2016; accepted 6 November 2016

KEYWORDS

Punching;
Bending;
Precast;
Concrete sandwich panel;
Insulated structural panel;
EPS

Abstract Precast concrete sandwich panels having two wythes separated by a core may serve dual purposes of transferring load and insulating. Research studies with respect to flexural behavior of these panels under four-point bending are available in the literature. Nevertheless, experimental and analytical studies with respect to flexural behavior of concrete sandwich panels under punching load are not found. In this paper experimental and analytical studies carried out to understand and compare flexural behavior of concrete sandwich panels under two different loading conditions such as punching and four-point bending are presented and discussed. Experimental study indicates that, type of loading conditions affects the flexural behavior of the concrete sandwich panels significantly. The panel subjected to punching load failed in flexural mode, and its behavior is similar to conventional RC slab. Under four-point bending the panel failure is attributed to failure of concrete by combined effect of shear and flexural stresses. For both types of loading conditions, analytically predicted cracking moment is comparable to the experimental cracking moment. Further experimental and analytical studies are required in this area to develop design guidelines for practical applications of these types of panels under different loading conditions.

1. Introduction

Precast concrete sandwich panels, also known as Insulated structural panels, consist of two skins of concrete called as wythe separated by a core made of Expanded PolyStyrene (EPS) that provides significant thermal and sound insulation. Wythes may be reinforced by using welded wire mesh or conventional steel rebars. Composite action of the panels may be achieved by connecting the wythes using discrete or continuous shear connectors [1] made of wires or steel rebars. The panels being precast may have good precision in geometry and finishing, and structurally and economically efficient [2] and also have social and environmental benefits [3]. Information on precast technology can be found elsewhere [4–6]. These panels being lightweight have relatively less attraction of seismic forces, and also have advantages such as ease of handling and transportation.

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.11.016
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Early in 1965, Pfeifer and Hanson [7] carried out number of tests to determine stiffness of small-scale concrete sandwich panels. Different types of shear connectors and core thickness were considered in their experimental study. They reported that, the amount and distribution of shear connectors significantly affect the flexural behavior of panels. They also noted that, the presence/absence of edge ribs affected the flexural behavior, and the failure load of the panels that had edge ribs was higher than the panels that did not have edge ribs. Pantelides et al. [8] have carried out experiments on concrete sandwich panels to determine the effect of using hybrid GFRP shell connectors on their flexural behavior and composite action. The experiments indicated that, the GFRP shell connectors provided resistance to horizontal shear between the concrete wythes and at the same time the panel could withstand out-of-plane loads. Bush and Wu [9] proposed equations to determine the deflection and flexural stresses of concrete sandwich panels. They found that the predicted deflection is comparable to the experimental deflection. Nevertheless they reported that, correction factors were required in order to get closer agreement with the experimental results.

Gara et al. [10] studied flexural behavior of precast concrete sandwich panels under four-point bending through experiments and numerical simulations. In their study, panels with different length and core thickness were considered. Wire mesh was used to reinforce wythes and non-shear connectors were used to connect the wythes. The authors reported that, all the panels tested behaved as semi-composite elements, and increasing panel thickness was necessary for increasing load carrying capacity. It was also noted that, provision of concrete beams at supporting edges was necessary to reduce longitudinal slip of wythes, and also to achieve higher bearing strength. Benayoune et al. [11] carried out experimental and theoretical studies on flexural behavior of precast concrete sandwich panels. Panels with three different sizes were tested. They used conventional rebars for wythe reinforcements and shear connectors. The authors reported that, the panels behaved as composite elements and the behavior was comparable to that of reinforced cement concrete (RC) slabs. Einea et al. [12] carried out experimental and analytical studies on flexural behavior of precast concrete sandwich panels with inclined Fiber Reinforced Polymer (FRP) bars as shear connectors. They reported that, the panel behavior was ductile, and the axial strength of the shear connectors governed the shear strength of the panels. Effect of truss connectors on the behavior of concrete sandwich panels was studied by Bush and Stine [13]. They reported that, high degree of composite stiffness and composite flexural strength may be obtained by using truss girders oriented longitudinally in the panels. They also reported that constructional details have significant effect on shear distribution in the elements crossing the interface. They also noted that, the insulation provided as the core offered significant shear resistance to the panel. Salmon et al. [14] showed that, use of FRP connectors improved thermal efficiency of panels compared to steel or concrete connectors. The ultimate load carrying capacities of the panels were found to be comparable to the panels that act as fully composite elements. They reported that, the actual stiffness of the panel was higher than the predicted stiffness. They also reported that the thermal efficiency of the panel using FRP connectors is nearly 1.75 times higher than that of using steel connectors.

Tomlinsons and Fam [15] examined the effect of adhesion and friction between concrete and insulation and reported that, adhesion and friction between concrete and EPS contributed to 44–59% of the ultimate load. Analytical model to predict shear stress of composite panels with truss shear connectors was proposed by Bush and Wu [9]. Recently, Adawi et al. [16] reported experimental studies to investigate composite action between machine-cast hollowcore slab and concrete topping. Tests were carried out to determine bond strength and shear strength of the panels. Their experimental studies also included testing prototype panels under three point bending with variations in panels based on panel thickness and discontinuity in concrete topping. Vertical deflection, slip between hollowcore and topping, and strain variations were monitored. The results indicated that, intentional surface roughness provided on hollowcore panels was higher than the machine cast finish. Bond and shear strengths were found to satisfy Canadian standard [17] and North American design standard, respectively. Flexural tests indicated that, hollowcore slabs with machine cast finish and acceptable roughness can provide composite action of the panels. They also conclude that slip and peel deformation did not affect the overall flexural behavior of the panels that may be attributed due to confining action provided by the load. Adawi et al. [18] also have provided analytical methods for determination of peel and shear stresses of panels cast with machine cast hollowcore and concrete topping. Structural engineers may use these methods to evaluate the peel and shear stresses for judging composite action of these types of panels. Literature survey indicates that research studies with respect to flexural behavior of concrete sandwich panel under punching load are not available in the literature.

2. Research significance

The present experimental study investigates effect of different types of loading conditions such as punching load and four-point bending on flexural behavior of precast concrete sandwich panels. The study also investigates possible effect of edge ribs provided along the supporting edges of panels on the flexural behavior of panels. The area of reinforcement in wythes and numbers of truss-like shear connectors are the same for the panels considered in this study. Also, predictability of linear elastic theory to determine the cracking moment of the panel is verified. The need for test results under different loading conditions for validating analytical and finite element models toward developing guidelines for design of precast concrete sandwich panels is the motivation for the present study.

3. Panel description and materials

Two prototype panels are cast and tested in the present study. The dimension (Length × Breadth × Thickness) of the panels tested under punching load and four-point bending was 1220 × 1220 × 150-mm and 3000 × 1220 × 150-mm, respectively. Pictures of typical EPS panel used and the schematic sketch of the components of a concrete sandwich panel used are shown in Figs. 1 and 2 respectively. On either side of EPS welded wire mesh of size 100 × 100-mm is used as wythes reinforcements. The wythes are connected using truss-like shear connectors that span along the longitudinal direction with their wires inclined at an angle of 45°. The wires of mesh