EXPERIMENTAL AND NUMERICAL STUDY ON THE FLEXURAL BEHAVIOR OF PRECAST LIGHT-WEIGHT CONCRETE SANDWICH PANELS

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Abstract

Use of light-weight structural elements in buildings is becoming popular in the recent years. This paper presents the experimental and numerical studies carried out to understand the flexural behavior of prototype precast light-weight concrete sandwich panels under four-point bending. In the experimental study, two prototype panels were cast and tested. Transverse deflections of the panels were recorded during testing and the results are presented and discussed. Numerical studies were carried out using the general purpose finite element software ABAQUS. 8-noded linear brick element and 2-noded linear truss element were used to model the wythes and mesh reinforcements, respectively. Saenz model is used to model the behavior of concrete in compression. It is observed from the tests that, the panels behaved as composite elements until failure. Experiments indicate that the thickness of the panel affect the load carrying capacity of the concrete sandwich panel significantly. The load-deflection curves of the panels determined using numerical studies are comparable to that of the experimental results.

KEYWORDS *Precast, Sandwich Panels, Light-Weight Panels, Expanded Polystyrene, Self Compacting Concrete*

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1. INTRODUCTION

Precast concrete structural elements are manufactured under controlled factory conditions and therefore concrete structural elements with good precision in geometry and finishing can be manufactured. Background information on precast technology can be found in the literature [1-3]. Precast concrete elements besides being structurally and economically efficient [4], also have social and environmental benefits [5]. Precast structural elements if light-weighted also have advantages such as (i) less attraction of seismic forces, (ii) ease of handling and transportation and (iii) cost effective. Light-weight concrete sandwich panels produced by replacing core concrete using lesser dense material consist of two skins of concrete called wythe, one on either side of the core. Welded wire mesh or conventional steel rebars may be used to reinforce the wythes. The core is made of material that provides significant thermal and sound insulation. In this study, EPS (Expanded PolyStyrene) is used as the core. In order to achieve composite action of the panel under flexural load shear transfer between the two wythes is ensured by using shear connectors that connect the two wythes.

Experimental studies on the behavior of light-weight concrete sandwich panels under different load conditions can be found in the literature [6-18] which have proved the feasibility of using these panels for floors, roofs and walls of the buildings. Nevertheless, it is noted that in the literature no studies are found reported on the flexural behavior of light-weight concrete sandwich panels with wires as shear connectors. In this paper the results of the experimental study carried out to determine the flexural behavior of prototype precast light-weight concrete sandwich panels with wires as shear connectors under four-point bending are presented. Two prototype panels are tested in the present study to study the effect of percentage of reinforcement in wythes and the total thickness of the panel, both of which are directly proportional to the moment carrying capacity, ultimate load carrying capacity and the flexural behavior of light-weight concrete sandwich panel. The variation in the thickness of the panel is achieved by using different core thicknesses. The paper is organized as follows. Section 2 presents the materials used and casting of the panels, Section 3 presents the test set-up and the instrumentation details, Section 4 presents the results and discussions and Section 5 presents summary and conclusions.

2. EXPERIMENTAL STUDY

2.1 MATERIALS USED

Two numbers of prototype precast light-weight concrete sandwich panels with different thicknesses (100mm and 150mm) are tested to failure. The panel with thickness 150mm is named FA and the one with 100mm is named FB. The length and breadth of a panel is 1200x3000mm. The schematic sketch of the components of panels considered is shown in Fig. 1. Welded wire mesh of grid size 50x50mm was used for reinforcing concrete wythes. The two meshes were connected at equal intervals using shear connectors inclined at an angle of 45°. The wires of the mesh and the shear connectors were nearly 2.2mm in dia. The average tensile strength of the steel wire as supplied by the manufactures is 651.64MPa. Self Compacting Concrete (SCC) was used for making the wythes. The mix proportion for SCC was arrived based on the guidelines of ACI[19] and it is 1:1.89:2.34:0.3:0.41:0.6% in the order of Cement, Coarse aggregate, Fine aggregate, Ground Granulated Blast Furnace Slag (GGBFS), Water and Superplasticizer (by weight of binder content). It was ensured that the SCC mixture considered satisfies the recommended[6] minimum requirements. Coarse aggregates passing 10 mm sieve were used in SCC. Same mix proportion was used for casting both panels. The average compressive and flexural tensile strengths of SCC were found to be 45.97MPa and 4.34MPa, respectively. Table 1 gives the details of the prototype precast light-weight concrete sandwich panels considered for the present experimental study.

2.2 CASTING OF PANELS

The sequence of casting the panel is shown in Fig. 2. A steel mould of size 1200x3000mm was placed on a level surface and SCC was poured to a depth of 25mm to form bottom wythe. EPS with wire mesh was placed over the concrete. SCC was then poured on the EPS to form top wythe of 25mm thickness. Stiffening concrete beams were provided along the supporting edges to avoid failure due to local crushing of concrete. The panels manufactured were cured for 28 days. The manufacturing methods reported in the literature [6-18] involved either plastering on the EPS panel using cement mortar or placing normal concrete on the EPS panel and vibrating for achieving better compaction of concrete. These methods require skilled labor and sufficient time for casting and finishing the panel. The method of manufacturing adopted in this paper does not require highly skilled labor. Time taken for casting a panel is 30 minutes. This method of manufacturing light-weight concrete sandwich panel using ready-made EPS panel and SCC is expected to suit mass production of the panels.

2.3 TEST SET-UP AND INSTRUMENTATION

The panels manufactured were tested under four-point bending. This type of loading was chosen because of constant bending moment being developed between the loading points. Displacement controlled loading was applied until the panels failed. One edge of the panel was supported by a hinge and the other was supported by a roller. It was ensured that the supports were provided on the stiffening beams. Linear Voltage Displacement Transducers (LVDTs) with 50mm range were used to measure the deflections of the panels. Strain gauges with gauge length of 2mm and 30mm were used to measure the strains on the wires and concrete surface, respectively. Schematic sketch of the test set-up and the locations of the LVDTs are shown in Fig. 3. Photograph of a panel ready for testing is shown in Fig. 4.

3. NUMERICAL STUDY

Numerical studies were carried out in the general purpose finite element software ABAQUS to model the nonlinear behavior of the concrete sandwich panels. In ABAQUS, the behavior of concrete was modeled using the material model *concrete damaged plasticity*. In this model, concrete is assumed to be isotropic in elastic and inelastic regime both in compression and tension. To describe the behavior of concrete under compression, stress-strain curve for concrete under uni-axial compression is constructed by using the model proposed by Saenz [24]. The Young's modulus of concrete was determined using the empirical relation given in IS 456:2000 [25].

$E = 5000\sqrt{f_{ck}} = 5000\sqrt{45} = 33541$ MPa.

Under tension, the concrete is assumed to behave linearly elastic until tensile strength of the concrete. The tensile strength of concrete is chosen by inverse analysis so as to predict the load-deflection curves comparable to that of experimental results. The post-peak behavior of concrete under tension is specified using fracture energy method. The fracture energy of the concrete was determined using the relation given in CEB-FIB Model Code [26], which is a function of concrete cylinder strength (f_{cm}). The cube strength is converted to equivalent cylinder strength by multiplying a factor of 0.8.

Fracture energy, $G_f = 73 f_{cm}^{0.18} = 73 x (0.8x45)^{0.18} = 139$ J/m^2

8-noded linear brick and 2-noded linear truss elements were used to model the wythes and mesh reinforcements, respectively. It is assumed that there is no slip between the mesh reinforcements and the concrete and hence the bonding is assumed to be perfect. The shear connectors were modeled as springs. The slope of the load-deflection curve of the wires under uni-axial tension within elastic limit is specified as the stiffness of the spring. Considering the symmetry of the panel, one quarter of the sandwich panel is modeled. The support condition specified for the model is shown in the Fig. 5. The FE model developed in ABAQUS is shown in Fig. 6.

4. RESULTS AND DISCUSSIONS

The picture of a panel tested is shown in Fig. 7. No separation of wythes was observed for both panels tested and hence, it can be concluded that both panels behaved as composite elements until failure. For both panels first crack appeared in the tensile region of the panel between one of the loading points and the nearest support.

Very few flexural cracks were seen in the maximum bending moment region of panel FB. Panel FA deformed extensively which resulted in relatively more numbers of flexural cracks in the maximum bending moment region. It is noted that, for both panels first crack occurred in the region between one of the loading points and the nearest support (and not in the maximum bending moment region). The formation and propagation of first crack in all the panels is thus attributed to mixed-mode fracture, i.e., combined effect of tensile stress (due to flexure) and shear stress. The load-deflection curves obtained from the experiments and numerical studies are shown in the Fig. 8.

From Fig.8 it is observed that, the panels FA and FB behave linearly upto loads 9.71kN and 5.48 kN, respectively. The ultimate failure load of the panel FA is almost 200% greater than that of the panel FB. This is due to the higher thickness of the panel (and hence larger lever arm). It is observed that, the load-deflection curves obtained using the numerical models are in close agreement with the experimental results. The distribution of inelastic strain (along the span) of the panel is shown in the Figs. 9 and 10.

From Figs. 9 and 10, it can be observed that, as expected, for both panels strains are higher in the maximum bending moment region. For the panel FB the strain in the bottom wythe under (almost) the loading point is observed to be larger comparative to any other location. For both the panels, the inelastic strain is seen to be larger between the points at which the springs are connected to the bottom wythe.

5. SUMMARY AND CONCLUSIONS

The results of the experiments carried out to study the flexural behaviour of precast light-weight concrete sandwich panel are presented in this paper. It is found from the experiments that the thickness of the panel have profound effect on the load carrying capacity of the panel. Numerical study indicates that, the model developed is capable of predicting the load-deflection curves comparable to that determined experimentally. Carrying out further experimental and numerical study with different mesh sizes, with additional conventional steel rebars and thickness of the panel may form future area of the research towards developing design guidelines.

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Table 1 Details of the sandwich panels considered

Specimen	Mesh size (mm)	Thickness (mm)		
		Wythe	EPS	Total
FA	50 x 50	25	100	150
FB	50 x 50	25	50	100

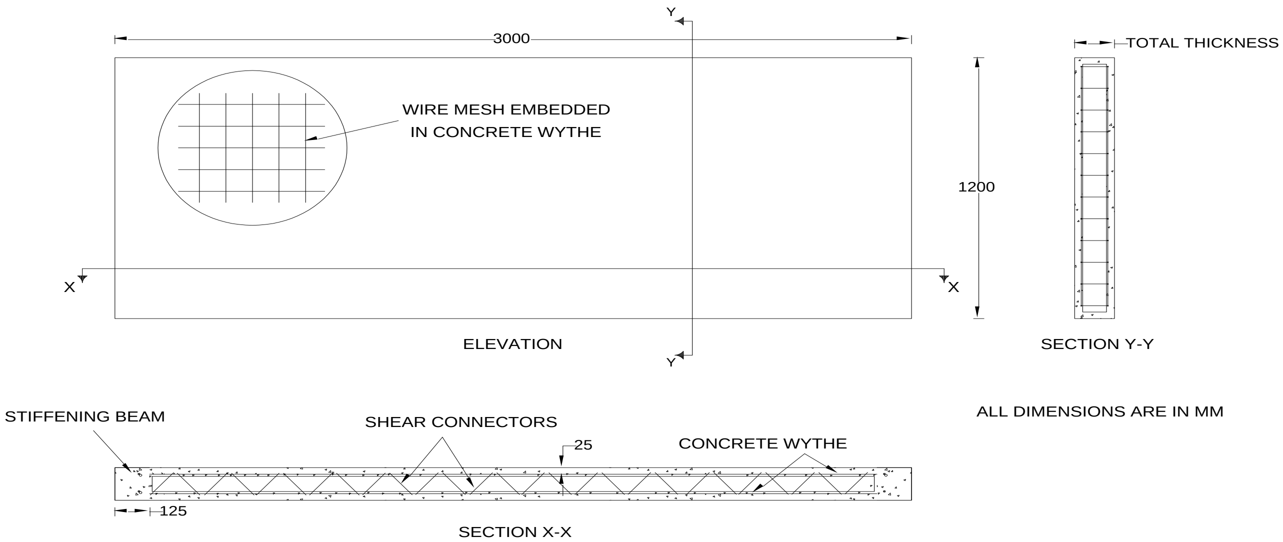

Fig. 1 Schematic sketch of sandwich panel

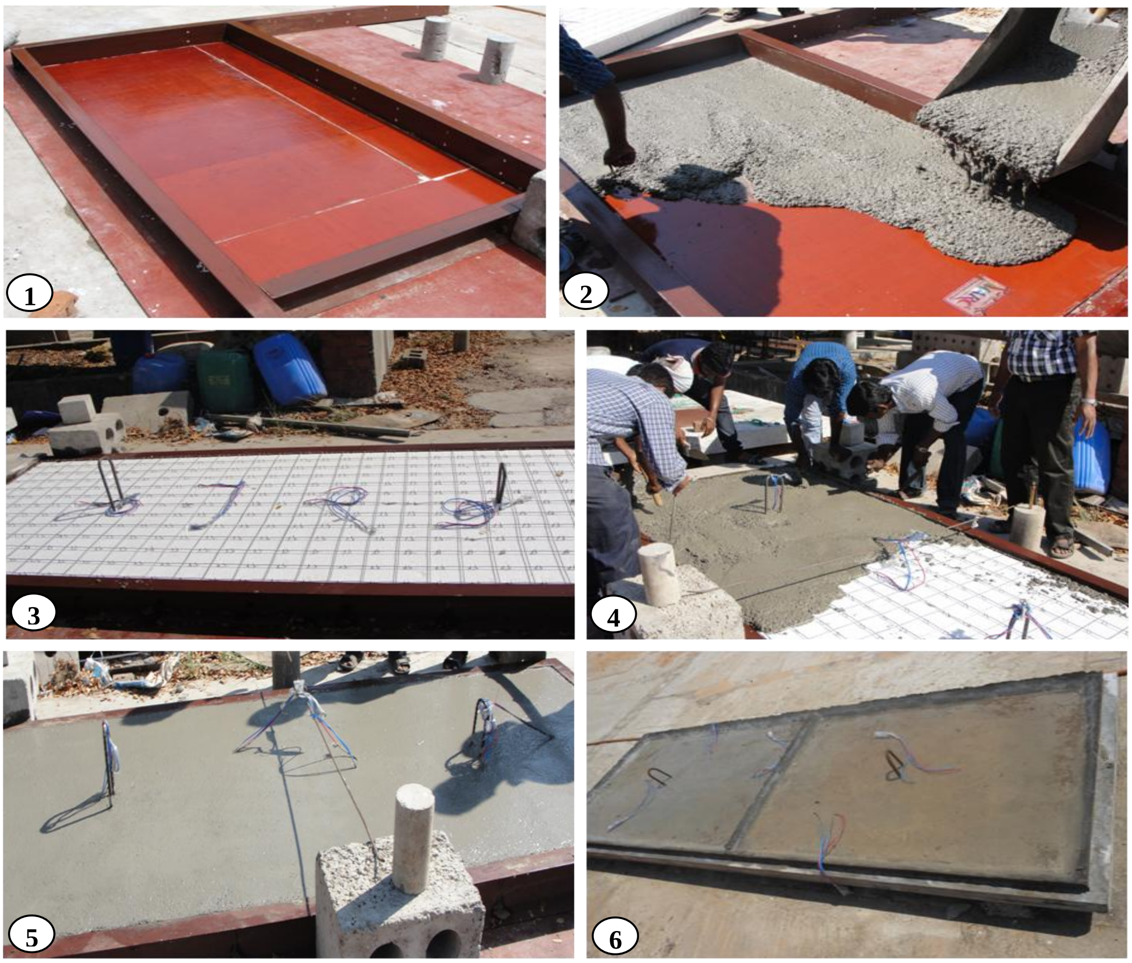

Fig. 2 Sequence of casting a panel

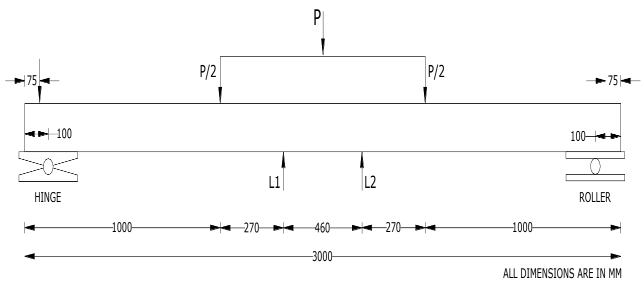

Fig. 3 Schematic test set-up and locations of LVDTs

Fig. 4 Photograph of a panel ready for testing

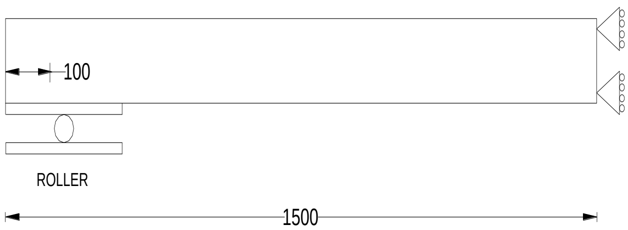

Fig. 5 Support condition assumed in FE model

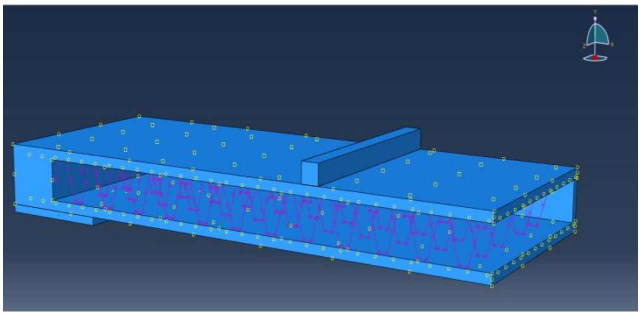

Fig. 6 FE model developed in ABAQUS

Fig. 7 Photograph of tested panel FB

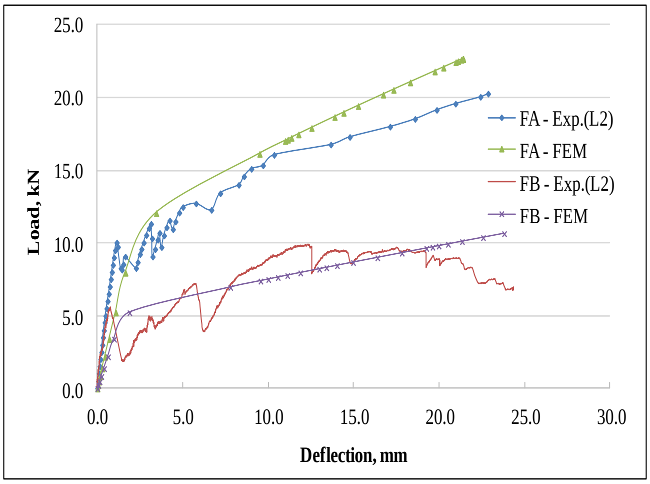

Fig. 8 Experimental and FE load-deflection curves

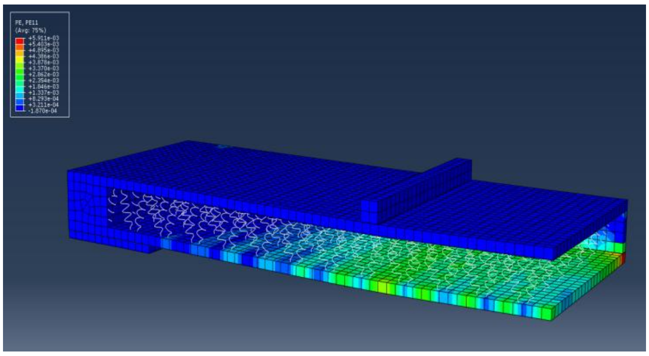

Fig. 9 Inelastic strain distribution along the span of panel FA

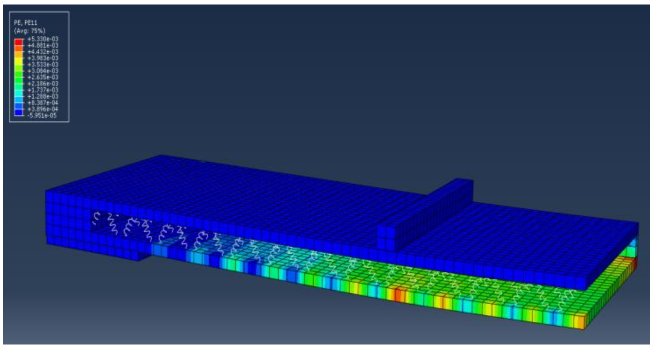

Fig. 10 Inelastic strain distribution along the span of panel FB