Numerical Investigation of Structural Performance & FRP Shear Mechanism for Pre-cast Concrete Sandwich Panels

Sanjana Unnikrishnan, Nisha Varghese

Abstract— In this paper, flexural behavior of thin precast concrete sandwich panels with different shear connectors was studied. The external wythes were made of High Performance Fiber Reinforced Concrete. High dosage of small 24 mm coated glass fibres were used in mix design for concrete wythes. Expanded Polystyrene insulation was used as core material. Full height panels for three different widths were modeled and tested by way of three point bending. Studies were done by finite element analysis. Steel meshes were provided parallel to concrete to increase the load carrying capacityof thin panels. Different models with CFRP, BFRP and GFRP as shear connectors were studied. The result showed that thin concrete panels and light weight claddings is a plausible solution and can meet the design wind loads.

Index Terms— Precast concrete sandwich panels (PCSPs), High performance fibre reinforced concrete, Flexural testing, Finite element analysis (FEA), Thin panel section, Fibre reinforced polymer (FRP), shear connector.

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1 INTRODUCTION

Pre-cast concrete sandwich panels consists of two external wythes and a low density core material(Fig. 1). The external wythes are made of materials like sheet metal, plywood, cement, concrete, magnesium oxide board etc. Thin-walled precast concrete sandwich panels provide an interesting option for future low energy building construction. The PCSPs have several beneficial features such as high quality, proven durability, fast erection, thermally efficient and decorative alternative to traditional brick and mortar construction. Heavy mass of panel sections was the major challenge faced by Designer Engineer. In early times PCSPs had thick cross sections due to use of reinforced concrete as external wythes. Steel act as thermal conductor and thus reduces the thermal efficiency of structure. Also strength of PCSPs may deteriorate due to corrosion of steel. This led the engineers to look for more efficient structures. In recent years, PCSPs with thinner wythes have been developed. PCSP with thinner wythes have commercial and environmental benefits as a result of material and space savings. Here the conventional steel is replaced by fiber reinforced polymers.

The structural behavior of the sandwich wall panel depends greatly on the strength and stiffness of the concrete wythes and connectors, whereas the thermal resistance of the insulation layer governs the insulation value of the panel. Shear connectors made of fibre reinforced polymer (FRP) is used to transfer in-place shear forces between the two wythes. Shear connectors also help develop a composite action. This helps to further reduce the thickness of concrete wythes.

The sandwich wall panels can be produced with almost any surface finish on both sides, the interior and exterior. Sandwich panels provide economical, attractive, and energy-efficient hard walls and are found on virtually every type of structure, including residential buildings, schools, office buildings, industrial buildings and hospitals.

Here thin PCSPs are designed and analysed for three different widths. Also three types of FRP shear grid connectors are studied for its strength and stiffness. The assessment is conducted using three point bending load.

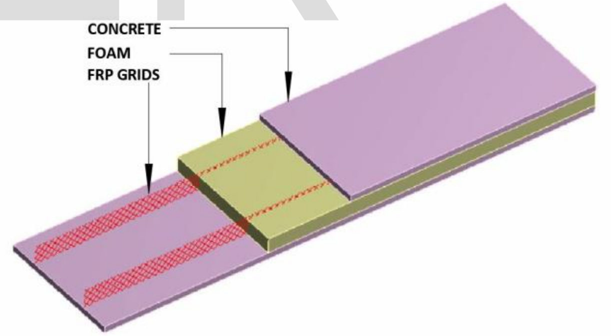

Fig.1. Preccast concrete sandwich panel with FRP shear grid and foam

2 METHODOLOGY

The sandwich panel section proposed in this paper has High Performance Fibre Reinforced Concrete (HPFRC) as external wythes and expanded polystyrene (EPS) as core [1]. Steel meshes of 3 mm dia and 50 mm spacing are provided on both side of EPS insulation. To ensure proper transfer of shear stress Fibre reinforced polymer (FRP) were used as shear connector. A comparative study is performed for three different types of grid made of Carbon fiber reinforced polymer (CFRP), Basalt fiber reinforced polymer (BFRP) and Glass fiber reinforced polymer (GFRP). Shear connector helps to increase the composite action of wall panel. Their flexural behavior

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tested under three point bending test and results were obtained in the form of Load vs Deflection graph.

TABLE 1
DETAILS OF SPECIMEN

Specimen	L (mm)	W (mm)	D (mm)	t_c (mm)	t_i (mm)	FRP grid
SP-C	3000	750	100	25	50	CFRP
SP-B	3000	750	100	25	50	BFRP
SP-G	3000	750	100	25	50	GFRP
SP-C	3000	750	90	20	50	CFRP
SP-B	3000	750	90	20	50	BFRP
SP-G	3000	750	90	20	50	GFRP
SP-C	3000	750	80	15	50	CFRP
SP-B	3000	750	80	15	50	BFRP
SP-G	3000	750	80	15	50	GFRP

PCSPs can be both, load bearing and non-load bearing element. The main aim of the study was to find out whether thin panels provide the same resistance to wind load and thermal efficiency.

2.1 Specimen Details

In this study, nine specimens were modelled. Three types of FRP shear connectors were considered. Table 1 lists the geometry of the components forming sandwich wall panels. All the nine specimens were identical in length, width and core thickness.

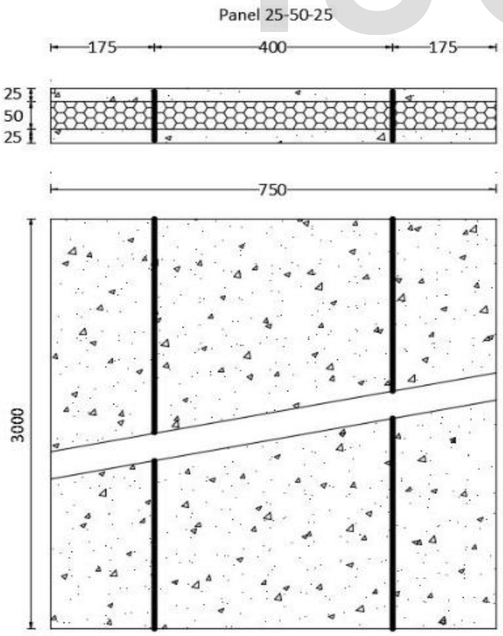

Fig.2. Cross-section of precast concrete sandwich panel

2.2 Material Properties

Both the external wythes are made of HPFRC having a compressive strength of 96 Mpa and contains macre fiber of about 60 kg/m^3. Fibers used in HPFRC are 24 mm long straight alkali resistant glass fibers with a diameter of 0.7 mm have a tensile strength greater than 1000 MPa and an elastic modulus of 42 GPa. The core insulation is made of Expanded Polystyrene insulation. EPS foam has high bond capacity. Wire mesh with diameter 3 mm and 50 mm in both directions was used as flexural reinforcement of concrete wythe.

TABLE 2
MATERIAL PROPERTY USED IN PROPOSED MODELS

Material	Youngs Modulus (GPa)	Tensile Strength (MPa)
EPS	6.9	0.24
HPFRC	48.9	15.25
CFRP	171	1758
BFRP	71.8	1185
GFRP	46	874
Steel	210	689

2.3 Loading Pattern

PCSPs are subjected to wind loading conditions and need to be designed accordingly. Therefore, it is necessary to understand the flexural behaviour of PCSPs. PCSPs can be tested in flexure by applying a uniform pressure against the face of the panel. The loading method used in this study is full scale three point bending load to the beam, where the point load is applied at midpoint of section. Load deflection curve was plotted after the linear static analysis. Simply supported boundary conditions were applied.

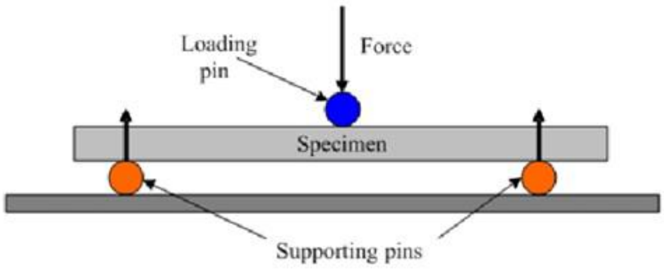

Fig.3. Test setup for three-point test

2.4 Composite Action

PCSPs can be designed with various degrees of composite action as non-composite, partially composite or fully composite [3]. Composite action is achieved when the shear forces that are developed at the face of one wythe are transferred to the other wythe through the shear connectors. For fully composite panels, the two concrete wythes act together as one complete section and there is a linear strain profile from the external wythe to the internal wythe. Providing a composite action can significantly increase the structural efficiency and reduce both initial and lifecycle costs of these types of panels. In the non-composite panels, the two wythes still share the load but bend independently about their own neutral axes and there is no lateral shear transfer between them. In this case, the two wythes are designed as two separate sections, each with its own load share depending on the wythe thicknesses and the ability of the insulation to transfer load. The degree of composite action depends on the nature of the connection between two concrete wythes.

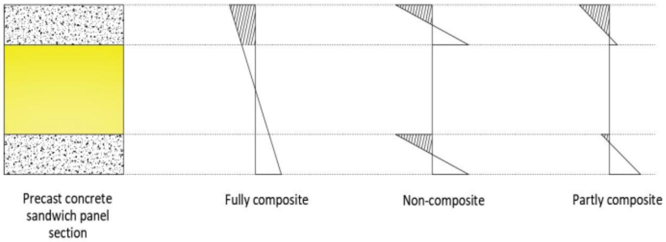

Fig.4. Typical strain profiles for the different composite and non-composite cases.

Pessiki and Mlynarczyk defined the degree of composite action (k%) based on the measured deflection (δ) during linear elastic behavior to determine the experimental moment of inertia (Iexp) and compare it to the theoretical fully composite (Ic) and non-composite (Inc) moments of inertia. Eqs. (1) and (2) are used to calculate the degree of composite action and the Youngs modulus E is taken as 49.6 GPa.

To calculate the bending moment and second moment of inertia for composite and non-composite panels, equations from the table 3 is used. Here, I_1 and I_2 is the second moment of inertia of top and bottom wythes. The moment of inertia of the non-composite panel is denoted by I_{nc} and is calculated using eqs. (3) to (5) from Table 3. For a fully composite panel, the bending stiffness (I_c) depends on the location of the neutral axis of the panel which depends on the thickness of each wythe and is calculated according to eqs. (6) to (8) from Table 3. Relevant dimension is displayed if Fig. 5.

TABLE 3
EQUATIONS TO CALCULATE MOMENT OF INERTIA OF PCSP WITH DIMENSION TAKEN FROM FIG. 5

Non-composite panel		Fully composite panel	
$I_1 = \frac{b_1 t_1^3}{12}$	(Eq. (3))	$A = b\,(t_1 + t_2)$	(Eq. (6))
$I_1 = \frac{b_1 t_1^3}{12}$	(Eq. (4))	$c_1 = \frac{[0.5bt_1^2 + bt_2(h - 0.5t_2)}{A}$	(Eq. (7))
$I_{nc} = I_1 + I_2$	(Eq. (5))	$I_1 = \frac{b_1 t_1^3}{12} + bt_1 y_1^2 + \frac{b_1 t_1^3}{12} + bt_1 y_1^2$	(Eq. (8))

2.5 Finite Elemental Modelling

The PCSPs were modeled using the finite element (FE) code ANSYS 16.1/WORKBENCH, which allows simulating nonlinear deformation effectively. Finite Element Analysis (FEA) is a computer-based method of simulating or analysing the behaviour of engineering structures and components under a variety of conditions. Mathematical equations help to predict the behaviour of each element.

A small width of the panel is chosen to reduce the complexity of geometry in the finite element modeling (FEM) simulation. The core and concrete wythes were meshed using solid 186 element with plane stress condition. FRP grids were meshed using beam 188 element.

Based on the test setup used by Richard et al. (2019), the sandwich wall panel is assumed simply supported on all sides. Face and core sheets are prevented from penetrating each other by defining contact areas.

3 RESULT

For the wind speed of 50 m/s, the approximate factored wind pressure may lie between 1.6 to 2 kPa in a single story build-

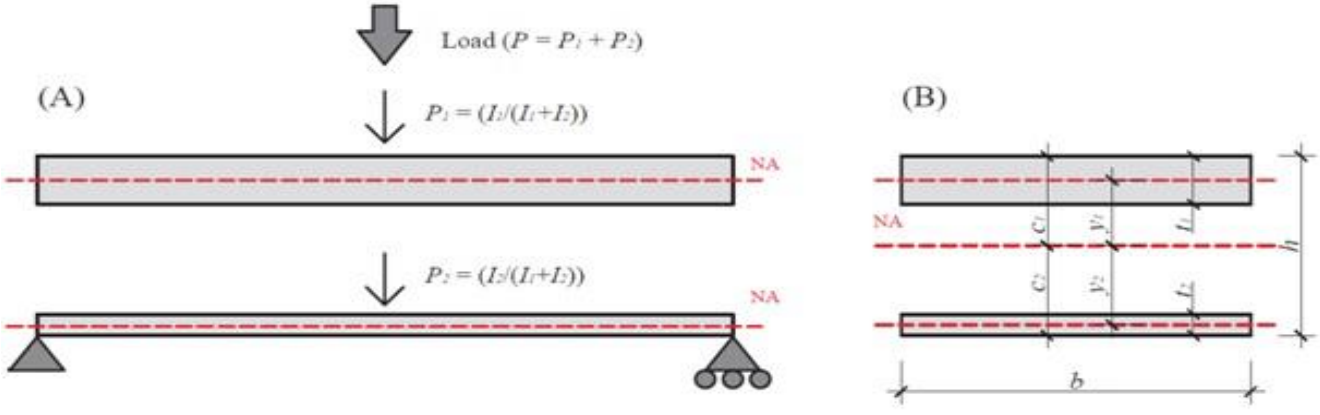

Fig.5. Load distribution of non-composite panels (A) and and important dimensions of composite panel section (B).

ing. This equates to the wind load of aprroximately 2 to 3 kN. The summary of the load-deflection results from graph for all panels showed load carrying capacity higher than that.

3.1 Effect of External Wythe Thickness

The concrete wythe of three thickness (25mm, 20mm, 15mm) were adopted to investigate the influence of concrete thickness on flexural capacity of panel. It can be found that when the thickness of concrete layer is reduced while keeping the thickness of core constant, there is a considerable decrease in bending strength of panel section. The minimum thickness of concrete layer for this study is 15mm, for below this thickness shear connectors may not be properly embedded in concrete layers.

TABLE 4
INFLUENCE OF THICKNESS OF PANEL

Specimen	L (mm)	W (mm)	t_c (mm)	t_i (mm)	Bending Load (kN)
25-50-25	3000	750	25	50	12.42
20-50-20	3000	750	20	50	10.34
15-50-15	3000	750	15	50	8.56

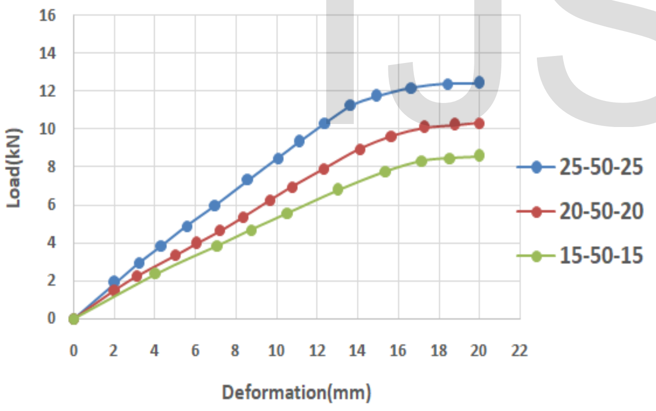

Fig.6. Comparison of bending load for various panel thicknesses.

3.2 Effect of FRP grid on Panel thickness

The concrete wythe of three thickness (25mm, 20mm, 15mm) were adopted to investigate the influence of types of FRP grid on sandwich panel. The bending load and deformation are summarized in tables and graphs below. The length and breadth of panels 3000 mm and 750 mm is kept constant. Angle between strands of FRP grid is maintained as 30 deg. The thickness of FRP grid is 3 mm. From the study it can be concluded that thin PCSPs can achieve the same flexural capacity.

3.2.1 Effect of FRP grid on 100mm Panel thickness

Here the concrete wythe thickness is kept 25mm and three types of FRP grids is used as shear connector. Two FRP grids were provided as shear connector at spacing of 400mm. There is not much decrease in the bending capacity of panel with BFRP and GFRP grid when compared to panel with CFRP grids. Hence to make panel section more economical BFRP and GFRP can be used as shear connectors.

TABLE 5
GEOMETRY DETAILS AND BENDING STRENGTH OF 100MM THICK PANEL SECTION

Specimen	Dimension (mm)	t_c (mm)	FRP Grid	Bending Load (kN)
SP-C	3000 X 750 X 100	25	CFRP	19.58
SP-B	3000 X 750 X 100	25	BFRP	16.49
SP-G	3000 X 750 X 100	25	GFRP	14.88

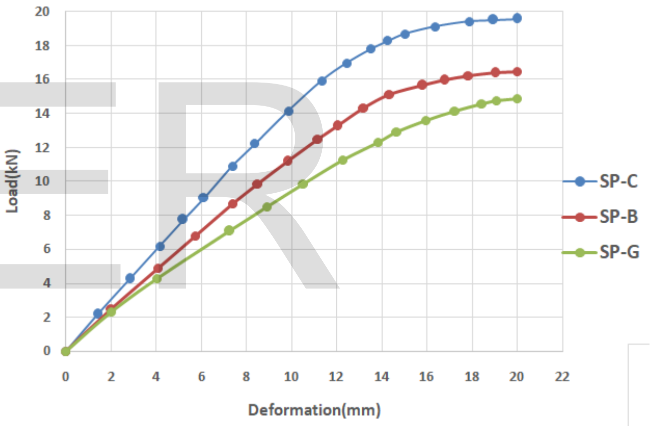

Fig.7. Infuence of FRP grid on 100mm thick panel section.

3.2.2 Effect of FRP grid on 90mm Panel thickness

Here the concrete wythe thickness is kept 20mm and three types of FRP grids is used as shear connector.

TABLE 6
GEOMETRY DETAILS AND BENDING STRENGTH OF 90MM THICK PANEL SECTION

Specimen	Dimension (mm)	t_c (mm)	FRP Grid	Bending Load (kN)
SP-C	3000 X 750 X 90	20	CFRP	16.69
SP-B	3000 X 750 X 90	20	BFRP	13.58
SP-G	3000 X 750 X 90	20	GFRP	11.90

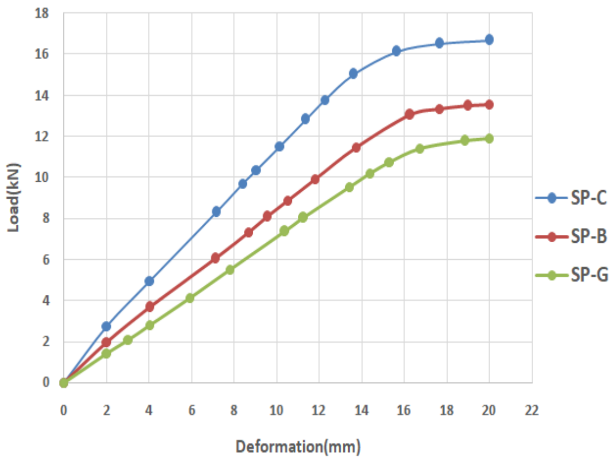

Fig.8. Infuence of FRP grid on 90mm thick panel section.

3.2.3 Effect of FRP grid on 80mm Panel thickness

Here the concrete wythe thickness is kept 15mm and three types of FRP grids is used as shear connector.

TABLE 7
GEOMETRY DETAILS AND BENDING STRENGTH OF 100MM THICK PANEL SECTION

Specimen	Dimension (mm)	t_c (mm)	FRP Grid	Bending Load (kN)
SP-C	3000 X 750 X 90	20	CFRP	16.69
SP-B	3000 X 750 X 90	20	BFRP	13.58
SP-G	3000 X 750 X 90	20	GFRP	11.90

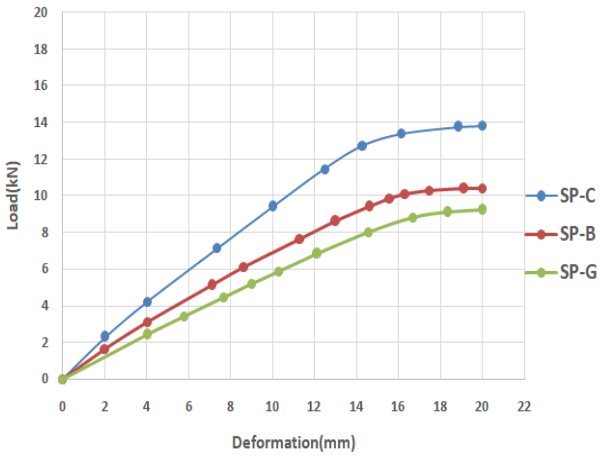

Fig.9. Infuence of FRP grid on 80mm thick panel section..

4 DISCUSSION

This precast concrete sandwich panel with thin concrete wythe and web core is still under development The corresponding finite element model was established to investigate the performance of panels with very thin concrete and foam thickness and different FRP grids as shear connector. A thin panel section makes it more economical. Minimum weight design procedure will also be provided after conducting more experimental or numerical testing of specimens. In the meantime, although the sandwich panel shows good flexural strength, its thermal studies should be done in future because thickness of panel section effects the thermal efficiency of PCSPs. The shear and transverse response can be studied. Also, the panel needs to be tested under different support condition.

5 CONCLUSION

Thinner PCSPs have both commercial and environmental benefits. This paper presents the analytical studies on the pre-cast concrete sandwich panels with HPFRC as external wythes and EPS foam as insulation. Two FRP grids are provided as shear connector. The sandwich panels were loaded under three – point bending. The main findings of this study are summarized as follows:

(1) The flexural behavior and composite action of precast concrete sandwich panels loaded in three point bending was studied.
(2) The shear flow mechanism for various FRP shear connectors was also studied.
(3) These panels had the characteristics of more than required bending strength and stiffness, simple construction, fast erection and good surface finish.
(4) Thinner panels can be used to replace standard PCSPs and provide material and space saving.
(5) For sandwich panels with BFRP and GFRP shear grids, flexural capacity decreased only by 6% and 14%.
(6) BFRP and GFRP grids can be used to replace CFRP shear grids thus making panel sections more economical.
(7) Wire mesh used in thin panels work as reinforcement and helps improve flexural capacity.
(8) All the thin panels have been shown to withstand bending load above 10 kN which is way higher than that required to resist wind speed of 50 m/s.

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