Study of Flexural Behavior of Sandwich Wall Panel

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Abstract— This paper presents the experimental investigation on cast in-situ sandwich panel frame with provision of shear connectors. Flexural tests with three-point loading is to be performed on frame with shear connectors in order to study the behaviour of panels under bending. The sandwich panel has concrete layer with an insulation material of expanded polystyrene foam. Due to the presence of insulation material the panel is thermally more effective than conventional panels. Shear connectors are used to connect the concrete layer and these connectors also transfer the transverse load more effectively. Flexural tests with flexural loading are to be performed on sandwich panels, in order to study the behaviour of panels under transverse load. EPS foam has closed-celled structure made for thermal insulation. The degree of composite action depends on how effectively the shear force is transferred. The slab is connected by means of 'W' shape 6mm dia mild steel bar at he supports. Concrete is casted monolithically over the frame, thus the frame acts as rigid frame. It is observed that three layer wythes sandwich panel is more thermally effective than two layer wythes sandwich panel. Use of precast technology and lightweight structural members has gained wide acceptance in construction industry. Precast concrete sandwich slabs/panels have combined advantages of precast technology and lightweight structural members. These types of panels may consist of two concrete R/C layers (wythes) separated by a core made of less dense material that often provides significant thermal and sound insulation. Welded wire mesh may be used as reinforcements in the wythes. The degree of composite action achieved by concrete sandwich panels primarily depends on type of shear connectors used to connect the wythes.

Key words: Expanded Polystyrene Foam, Shear Connector, Composite Slab, Flexural Behavior

I. INTRODUCTION

This paper deals with the study of sandwich panels, which is used as structural walls and floors.A structural member composed of two or more dissimilar materials joined together to act as a unit is known to be a composite member. Precast concrete sandwich panel (PCSP) was first prefabricated as a non-bearing system called "cladding panel," which comprised two thick internal and external concrete wythes designed as load and non-load bearing walls. Composite sandwich panels are an advanced method for construction of real building walls. In aircrafts also lightweight and high strength panels are required. Precast sandwich panel is structurally and economically efficient. The sandwich panel has concrete layer with an insulation material of expanded polystyrene foam. Due to the presence of insulation material the panel is thermally more effective than conventional panels. Shear connectors are used to connect the concrete layer and these connectors also transfer the transverse load more effectively.

Flexural tests with one point loading are to be performed on sandwich panels, in order to study the behaviour of panels under transverse load. EPS foam has closed-celled structure made for thermal insulation. The degree of composite action depends on how effectively the shear force is transferred. It is observed that three layer wythes sandwich panel is more thermally effective than two layer wythes sandwich panel. Use of precast technology and lightweight structural members has gained wide acceptance in construction industry. Precast concrete sandwich slabs/panels have combined advantages of precast technology and lightweight structural members. These types of panels may consist of two concrete R/C layers (wythes) separated by a core made of less dense material that often provides significant thermal and sound insulation. Welded wire mesh may be used as reinforcements in the wythes.The degree of composite action achieved by concrete sandwich panels primarily depends on type of shear connectors used to connect the wythes. Shear connectors may be discrete or continuous (truss-shaped) that are span wise distributed.

This panel consist of Expanded Polystyrene Foam (EPS) sandwiched between two concrete layers. These layers are connected by shear connectors, which transfers the longitudinal shear between the layers so that fully composite or semi-composite behaviour is achieved. The degree of composite action depends on how effectively the shear is transferred between the layers. The EPS foam is also called as STYROFOAM, which is actually a trademarked term for closed-cell extruded polystyrene foam made for thermal insulation and craft applications. EPS foam is the correct term for any form of expanded polystyrene. Expanded Polystyrene insulation is a lightweight, rigid, closed cell insulation. EPS is available in several compressive strengths to withstand load and back-fill forces. This closed-cell structure provides minimal water absorption and low vapour performance.

It is observed that, the thermal and acoustic insulation in more in three Wythe panel when compared to two Wythe sandwich panel. Most tests were performed on full scale panels to study the real behaviour of panels under axial, eccentric and flexural loading.

A. Scope

- Sandwich panels have high stiffness.
- Cost effective compared to other composite structures.
- Casting and erection of sandwich panel is much easier than conventional walls.
- The degree of thermal and acoustic insulation is high in sandwich panels.
- Sandwich panels have high strength to weight ratio.
- Sandwich panels can be used as load and non-load bearing walls with reduced thickness.
- It has the advantage of both light weight and precast technology.

B. Objective

- The main objective of the project is to find the bending behaviour and to obtain maximum bending stress at the bottom wythe of the panel.
- To determine the ultimate load carrying capacity of the frame.
- To study the load – deflection behavior of composite frame.
- To compare the ultimate loads obtained from experimental tests and analytical results.
- To study the behaviour of connection pattern.
- To compare the results of simply supported and fixed frame.

II. EXPERIMENTAL INVESTIGATION

Based on the various researchers, it is observed that sandwich panels are proved to be more advantageous in terms of both strength and light weight. Truss shape shear connectors are more efficient to transfer the shear throughout its thickness. Concrete wythes are responsible to take up the shear and hence M40 grade of concrete partly replaced by GGBS tends to be more effective. The strength of the frame depends on effective transfer of shear from slab to wall.

Sl.No.	Panel Size	Type of Connection
1	1000x500x130 mm slab panel 800x500x130 mm wall panel	Rigid Frame with 'W' rod of 6 mm diameter.

Table 1: Panel Dimension

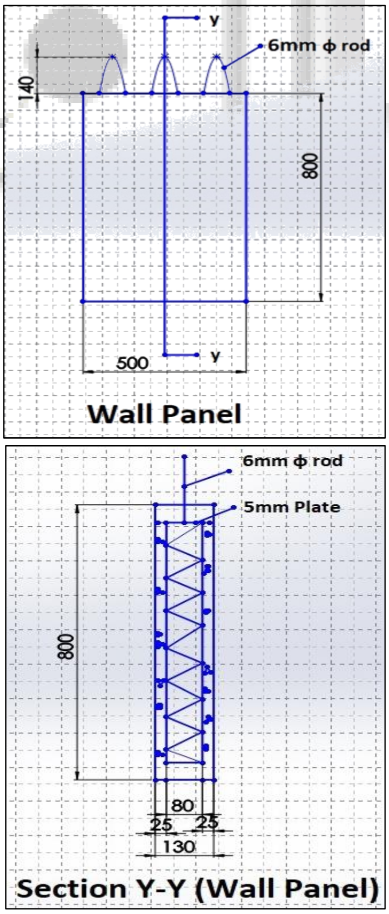

Fig. 1: Rigid Frame with 'W' connection (Wall Panel)

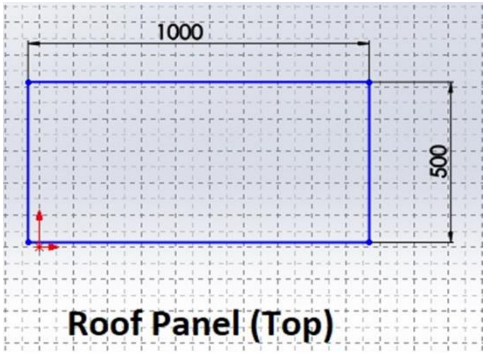

Fig. 2: Rigid Frame (Roof Panel)

A. Materials used and Mix Proportion

1) Concrete:

Ordinary Portland cement of 43 grade conforming to IS: 1269-1987 was used. Locally available manufactured sand free from silt, organic matter and passing through 4.75mm sieve conforming to zone II of IS: 383-1970 was used as Fine aggregate. The tests on fine aggregate were conducted to determine the specific gravity and fineness modulus. Locally available crushed granite aggregate passing through 20mm sieve and retaining on 4.75mm sieve was used as Coarse aggregate. The aggregate was conforming to IS:383-1970.The tests on coarse aggregate was conducted in accordance with IS:2386-1963 to determine specific gravity.

Test	Results
Cement	
Specific gravity	3.15
Fine aggregate	
Specific gravity	2.54
Coarse aggregate	
Specific gravity	2.7

Table 2: Material characterization

Based on the properties of the materials obtained and the specifications as per IS: 10262-2009 the mix proportion for M40 grade of concrete was obtained as 1 :1.87:2.34 with a W/C ratio of 0.45. The obtained mix proportion is shown in Table-3.

Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)
438	592	1257	197

Table 3: Mix Proportion

2) Ground Granulated Blast Furnace Slag

Blast furnaces produce pig iron, together with a slag by-product: a tightly controlled and stable material with the same constituent's qualities are preserved. Dried and ground to a fine powder, GGBS can be used to make quality, sustainable concrete. To ensure its activation, GGBS is most often used with normal cement. It will typically replace 30-70% of cement on an equal weight basis. The manufacture of normal cement results in the emission of 930kg of CO_2 tone of cement approximately 50% from decarbonation of the limestone raw material (process emissions), 40% from fossil fuel consumption, and 10% from generating the electricity used in the process. GGBS manufacture typically releases 35kg of CO_2 tone of GGBS: less than 4% of the carbon of normal cement.

3) EPS Foam

EPS is Expandable Polystyrene. A versatile plastic available in the form of sheets in varying thickness, moulded and cut pipe section for low temperature insulation of cold stores to preserve perishables, industrial plants operating at temperatures below ambient temperature, thermal insulation in building and versatile packaging material which can be moulded into any shape and design for packing electronics, glassware and other fragile products. Milky snow white EPS improves present ability of the product packed in it. EPS is also used for manufacturing ice boxes, picnic boxes and containers to keep the food hot. From the view point of construction, the roof no matter of what design is the most vulnerable part of the building for absorption of solar radiation particularly in tropical countries like INDIA. If the roof is to fulfil its protective function, EPS will play a significant role in providing thermal protection. Whether a flat roof or a pitched roof, a home or an office building, a factory, workshop or warehouse, EPS will always be an advantage because of its outstanding insulation property. Specific thermal movement for large areas and lengths where the temperature gradients are such that substantial thermal movement of various construction materials vary, EPS can be successfully used as an expansion jointing material. While designing specific joints the relative movement of construction materials used should be taken into account.

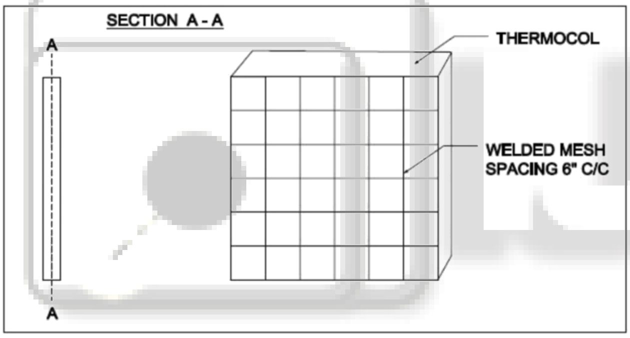

Fig. 4: EPS FOAM

4) Shear Connector:

Welded mesh is mesh is a metal wire screen that is made up of low carbon steel wire or stainless steel wire. It is available in various sizes and shapes. A grid consisting of a series of parallel and longitudinal wires with accurate spacing are welded to cross wires at the required spacing. Machines are used to produce the mesh with precise dimensional control. The product can result in considerable savings in time, labor and money.

B. Casting of Frame

The raw materials for casting are cement, fly ash, ground granulated blast furnace, chips, manufactured sand, glenium and water. All these materials have been collected and the aggregates are cleaned and preserved. The preliminary test of materials are specific gravity of fine aggregate, coarse aggregate, fly ash and manufactured sand. The proportioned mix design for the sandwich panel is M 40 grade of standard concrete. Cement is partly replaced by GGBS and fly ash. Dry mixing of aggregates and source materials by mixing all the materials manually in the laboratory at room temperature. The panels were casted individually and after a curing period of 28 days, a framed structure is formed with the help of high strength bolt of grade 8.8.The rigid frame is casted monolithically with the help of form work and for curing Gunny bags are used and cured for 28 days. The wall panel frame is tested in the laboratory using Universal Testing Machine and the strength was calculated after 28 days.

C. Testing Procedure

The highest or maximum bending stress occurs under the loading anvil in three point flexural bend tests. In four point bend tests, the maximum flexural stress is spread over the section of the beam between loading points. Also, a three point test best applies where the material is homogeneous, such as plastic materials. A four point test tends to be the best choice if the material is not homogeneous, such as composites or wood. The stress concentration of a three point test is small and concentrated under the centre of the loading point, whereas the stress concentration of a four point tests is over a larger region, avoiding premature failure. A three point test is easier to perform than a four point test. The deflection measurement in three point tests is commonly measured using the machine’s crosshead position sensor (typically a digital encoder), whereas the four point bend test is commonly measured using a deflectometer.

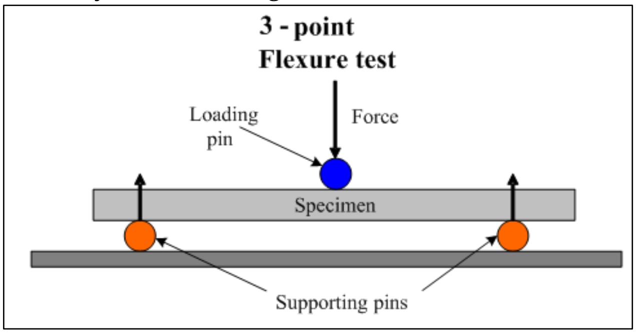

Fig. 5: Loading arrangements

Load was applied gradually using Hydraulic jack in increment till failure of the specimens. The behaviour of the frame was observed throughout the loading range till the specimen failed. The deflection of slab and wall were obtained by using dial gauge. Load Deflection curves for each beam was obtained manually for each loading. Also the appearance of separation, propagation of cracks and slip were observed and recorded.

Fig. 6: Experimental Loading Setup

III. EXPERIMENTAL RESULT

A. *For Rigid Frame*

A fully fixed beam will have lesser moments and deflection at midspan than simply supported beam. It allows neither vertical movement nor rotation at the supports. This is the basic difference between a fixed beam and simply supported beam. So in a fixed beam the supports generate vertical reactions as well as rotational moments.

The ultimate load carrying capacity is 18.3 KN and the maximun deflection is 2.89mm which is well within the permissible limit.

1) Load-Deflection Table for Rigid Frame:

LOAD (KN)	DEFLECTION (mm)		
	LEFT WALL	SLAB	RIGHT WALL
0	0	0	0
2	0	0.05	0
4	0.02	0.18	0.03
6	0.08	0.23	0.06
8	0.12	0.36	0.14
10	0.18	0.39	0.36
12	0.21	1.03	0.39
14	0.64	1.26	0.59
16.1	0.81	1.93	0.76
17.8	0.93	2.45	0.86
18.3	1.2	2.89	0.98

Table 5: Load-Deflection Table for rigid frame

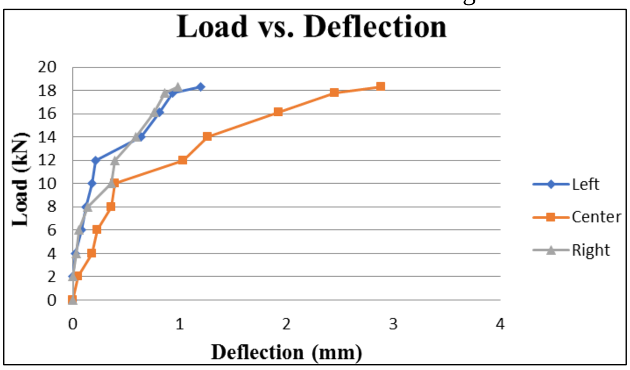

Fig. 7: Load Vs Deflection Graph

IV. RESULTS AND DISCUSSION

A. *Result Comparison*

Both type of connection shows similar behaviour in bending and the failure pattern observed is FLEXURAL BRITTLE type in the frame.

S.NO	RIGID FRAME
ULTIMATE LOAD CARRYING CAPACITY (Pu)	18.3 KN
FLEXURE CRACK LOAD	14.7 KN
SHEAR CRACK LOAD	12.78 KN
MAX. DEFLECTION	2.89 mm
STIFFNESS (K)	6.3 KN/mm
SHEAR MODULUS (G)	0.89 N/mm2
MAX AND MIN CRACK SPACING	a max : 94.7 mm a min : 64.8 mm

V. FAILURE PATTERN

A. *Failure of Rigid Frame*

Fig. 8: Flexural failure at the roof panel slab

Fig. 9: Flexural failure at bottom of slab and shear failure at support

VI. CONCLUSION

A. *General*

– Load carrying capacity is inversely proportional to slenderness ratio.

- Crack width and spacing depends on mesh size and its yield strength.
- Since the panels are light in weight, high strength concrete should be used.
- The failure of the panel is flexural failure, occurring at the bottom wythe of the panel.
- Cracking behavior of precast lightweight concrete sandwich structural panels that fail in flexural mode with the formation of numerous flexural cracks in bottom wythe is similar to ferro-cement. Under flexural loading, volume ratio of reinforcement and specific surface of reinforcement affect cracking behavior in terms of number of cracks and crack spacing of concrete sandwich panels
- Cracking behavior (in terms of number of cracks and crack spacing) of concrete sandwich panels predicted using models for cracking behavior of concrete slabs reinforced with wire mesh is in good agreement with experimental results.
- Stiffness is influenced by shear transfer capacity.
- Metallic meshes increases the stress redistribution of the panels
- Truss connectors transfer the shear force more effectively thus it also increases the degree of composite action.

B. *Conclusion from experimental analysis*

From the experimental comparison test, the following conclusion has been derived

- The ultimate load carrying capacity under flexure is 18.3 KN with maximum deflection of 2.89mm.
- The stiffness of the rigid frame is 6.3 KN/mm.
- The crack pattern observed is flexure brittle crack formed underneath the bottom of slab.
- Shear crack is formed at the supports at 12.78 KN.
- The max and min crack spacing is 94.7mm and 64.8 mm respectively which is well below the calculated result.
- The behaviour of sandwich panel is similar to ferrocement slab.

APPENDIX I THEORETICAL CALCULATION

A. *Crack Spacing Calculations*

S_t – Spacing of transverse wires (assuming uniform spacing)
L'_t – Length at which force is transferred from wire to concrete
$= K_p$. Ace ft / $\sum 0$
K_p – Bond coefficient
L'_t – Length at which force is transferred from wire to concrete.
A_{ce} – Effective concrete area
$\propto \; = [\frac{2b}{(b+h)}]^{1/2}$
b – Breadth of the section
h – Depth of the section
f_t – Tensile strength of concrete
a_{max} – maximum crack spacing
a_{min} – minimum crack spacing

Sl. No.	Condition	a_{min}	a_{max}
1	$S_t < L'_t$	S_t	$2S_t$
2	$L'_t < S_t < 2L'_t$	$S_t - L'_t$	S_t
3	$2L'_t < S_t < 3L'_t$	$S_t - 2L'_t$	$2L'_t$
4	$3L'_t < S_t < 4L'_t$	$S_t - 3L'_t$	$2L'_t$
5	$nL'_t < S_t < (n+1)L'_t$	$S_t - nL'_t$	$2L'_t$

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