EXPERIMENTAL INVESTIGATION AND NUMERICAL ANALYSIS OF STEEL FOAM CONCRETE COMPOSITE WALL PANELS UNDER AXIAL COMPRESSION

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Abstract: composite wall is a form of construction with flat bar profiled steel sheets as the facing material with an infill concrete in between. Though the composite wall is intended for use a partition and shear walls in steel framed buildings, it has the potential to be used as structural elements in load bearing construction. In the present study, axial compression behaviour of the full scale wall panels of dimension 100x300x130 mm is to be studied. The research proposes a steel foam concrete composite (SFCC) panels made of thin profiled steel sheet of thickness 0.8 mm as the outer skins and aerated foam concrete (FC) of density 850 kg/m^3 as the infill. The interaction between sheet and concrete is achieved by using through mild steel studs. The number of studs and the spacing between the studs are provided appropriately such that failure of the panel is by yielding of the steel sheets rather than buckling, which is the design criterion.

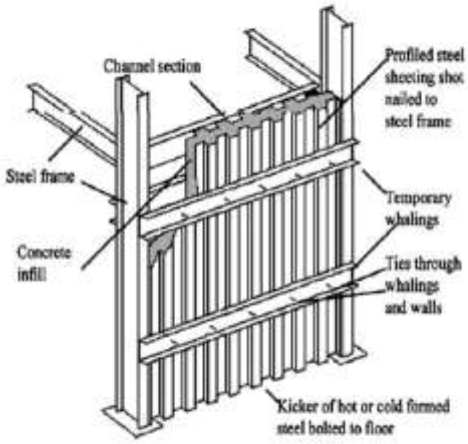
***Index Terms* – SFCC (steel foam concrete composite), axial compressiom, stud.**

I. INTRODUCTION

Growing needs of society and rapid industrialization demand modern techniques and innovative materials. Conventional materials like hot rolled steel and concrete have given way to new materials which are energy efficient, lightweight, aesthetically attractive and efficiently handled and erected. Composites are products with performance superior to existing building elements, from the combinations of materials. Composites include embedded light gauge components, filler materials, coatings of steel materials etc. Materials good at different properties are efficiently assembled to behave as a single unit for improved properties like strength, stiffness, acoustic properties, fire behaviour, ductility etc. Concrete is a commonly used construction material due to its easy availability of constituents and manufacturing. The problem with ordinary concrete is it's self-weight. Much of the load carried by a concrete member is its own self-weight. Lightweight concrete minimizes this problem partly. Lightweight concrete is defined as a kind of concrete which incorporates an expanding agent that increases the volume of the mixture reduce the dead weight. Foam concrete is one of the lightweight concretes classified under cellular concrete. It has a uniform distribution of air voids throughout the paste or mortar, while "no-fines" concrete or lightly compacted concrete also contains large, irregular voids. Lightweight foamed concrete is suitable for both precast and cast-in-situ applications. Good strength characteristics with reduced weight make lightweight foam concrete appropriate for structural and semi-structural applications like lightweight partitions, wall and floor panels and lightweight blocks concrete.

The major function of the steel sheet is to confine the concrete core and thus it contributes indirectly to the strength. To improve the bonding screw studs can be provided. Different studies used different shear connectors to ensure composite action. Among them through studs were found to be the superior one. The common failure modes of cold form steel can be avoided by the use of infill and steel adds to the ductile property also (Zhifeng Xu and Zhongfan Chen (2017). The steel foam concrete composite panels can be effectively used up to four storied buildings and it can be used as retaining walls and shear walls. Engineered cementitious composites were found to be superior to self-compacting concrete since it gives more ductility and energy absorbing (79.5% higher) characteristics to the wall. Facing sheets of mild sheets provides more ductility to the panels than high strength facing sheets (Rafiei et.al.(2015).

Steel foam concrete composite wall panels comprise of vertically aligned profiled steel sheet with infill concrete. Steel components are relatively thin and prone to buckling, whereas the infill concrete provides restraint against buckling and thermal insulation at high temperatures. The schematic diagram of composite wall panels is shown in Fig. 1



Steel-concrete composite wall panel

II. DETAILS OF SFCC WALL PANELS

The details of the SFCC panel along with the stud positions are shown in Fig 4.3. The SFCC panel is having 1000 mm width, 3000 mm height and 130 mm overall thickness. It consists of the trapezoidal crest of length 95 mm and trough portions of length 35 mm. In the corrugated cross-section, a pair of 0.8 mm thick cold-formed steel sheet is separated by a 128.4 mm thick lightweight foam concrete and the composite action is ensured by using 7 mm diameter through connectors in each rib portion. The dimensions of the profiled sheet are selected based on the buckling capacity of the cold foamed sheet. The interaction between the core and facing sheet is ensured by providing mild steel through studs. Studs are placed in every depression with 290 mm spacing along the length. A total number of 66 studs are required for each panel.

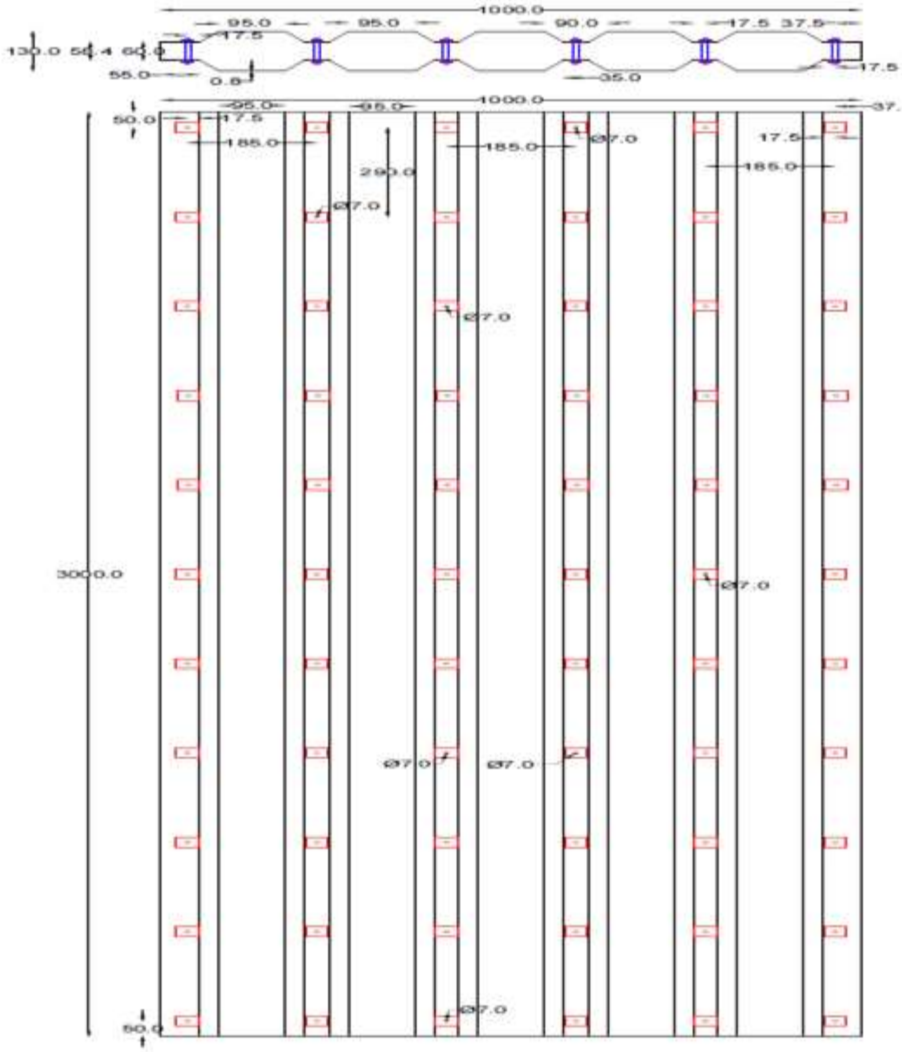


Fig 2 Details of Composite Wall Panel

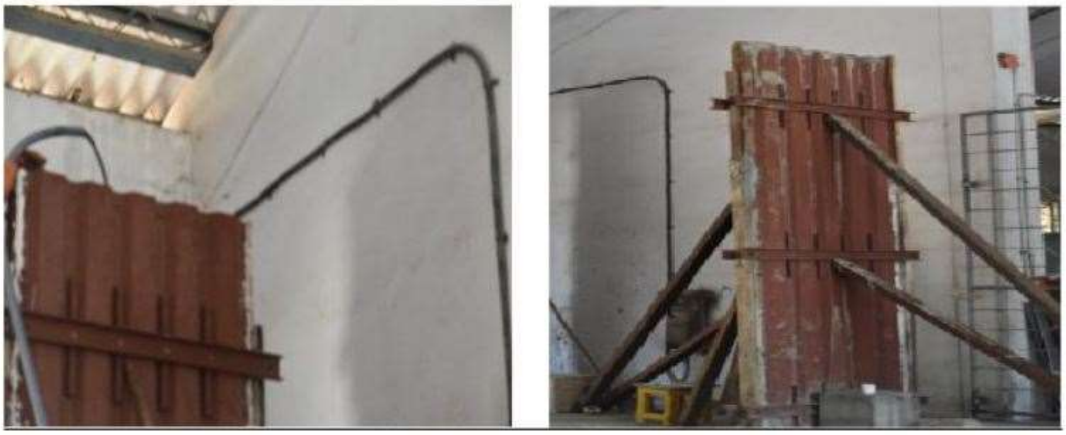
III. LIGHT WEIGHT FOAM CONCRETE

Foam concrete infilled between the steel sheets is the important component of SFCC panel. It serves the purpose of preventing inward buckling of the cold-formed sheets to a certain extent. The current study deals with foam concrete with a density of 850 kg/m3 as infill material. Ordinary Portland Cement (OPC) (53 grade) conforming to IS: 12269 (1987) is used. Fly ash is also added as a supplementary cementitious material. River sand passing through 1.18 mm sieve conforming to IS : 383 (1970) is used as fine aggregate. The size of the fine aggregate is limited to ensure good flow characteristics and to avoid foam breakage. The mix ratio to achieve the desired density of 850kg/m3 is 1:0.8:0.87:0.7:0.041 (cement: fly ash: fine aggregate: water: foam). The foam density is kept around 70-80 gm/litre by adjusting the pressure. Natural protein based foaming agent FC liter is used as the foaming agent. The foaming agent is diluted with water in the ratio 100:3.5 (water in litres: foaming agent in litres).

The modulus of elasticity of foam concrete is obtained as 2000 N/mm2 from the slope of the elastic region of the stress-strain curve. For computing, the Poisson's ratio strain gauges of gauge length 10 mm are attached to the foam concrete cylinder specimen. Both longitudinal and transverse strains are recorded. Poisson's ratio obtained is 0.2. The tensile strength of FC is found by conducting split tension test. The average split tensile strength is found to be 0.53 N/mm^2.

IV. CASTING OF SFCC WALL PANEL

The facing sheets of the SFCC panels, which also acts as a foam work is erected vertically on the floor as shown in Fig3. The panels are supported by means of wooden planks on both sides. The levels are checked by means of a spirit level. For proper supporting and to avoid bulging of the sheets during casting due to concrete pressure, some additional shuttering is provided. The panels are cast vertically in the direction of loading.



(c) Casting (d) Cast panel

Fig 3.Casting of SFCC wall panel

V.EXPERIMENTAL INVESTIGATION

Axial compression behaviour of SFCC wall panel is studied by testing two full-scale panels of size 1000×3000×130 mm. The main objective is to study the applicability of SFCC panel for housing purpose. The failure modes, load-displacement response and the load-strain response are studied. The SFCC panel is subjected to axial compression loading in a servo-controlled UTM of capacity 2000 KN.

A base plate of size 1200 ×1200 mm having 25 mm thickness is placed below the specimen. To ensure uniform distribution of load a loading beam of dimension 1200×160×40 mm is placed on top of the specimen. The load from the actuator will be transferred to the panel through this loading beam only. The panel is placed in between two channels attached to the reaction frame for safety. The channels do not have any contact with the specimen while loading. The specimen is lifted and placed in the exact position by means of a crane. Additional channels are fixed to the SFCC panel for the purpose of lifting. The lifting and positioning of the specimen is shown in Fig 4 .

Fig 4. Lifting and positioning of SFCC wall panel

VI. NUMERICAL MODELING

6.1. FE model of SFCC panel

Finite element modelling of SFCC panel includes two parts, lightweight foam core and cold-formed steel facing sheet. The process of modelling includes discretizing geometry, assigning element section properties, material properties, loads, boundary conditions, analysis type and output requests. The major components are shown in Fig 5. The FE simulation of the composite panel model is developed using three dimensional deformable solid and shell elements. The cold-formed facing sheet is modelled using 4 noded shell element with reduced integration since it is subjected to bending. Element in this has three rotational and three translational degrees of freedom (DoF). The lightweight core is modelled using 8 noded brick element with reduced integration (C3D8R). This element has 3 three translational degrees of freedom and can be used nonlinear analysis accounting for contact, plasticity, large deformation and failure. The composite action is achieved using the interconnecting through studs. These shear connectors were not modelled in order to simplify the analysis. The purpose of shear connectors is to prevent the detachment of facing sheet from the core, so the movement of steel sheets at the stud points were restrained in the model. This serves the same purpose as shear studs.

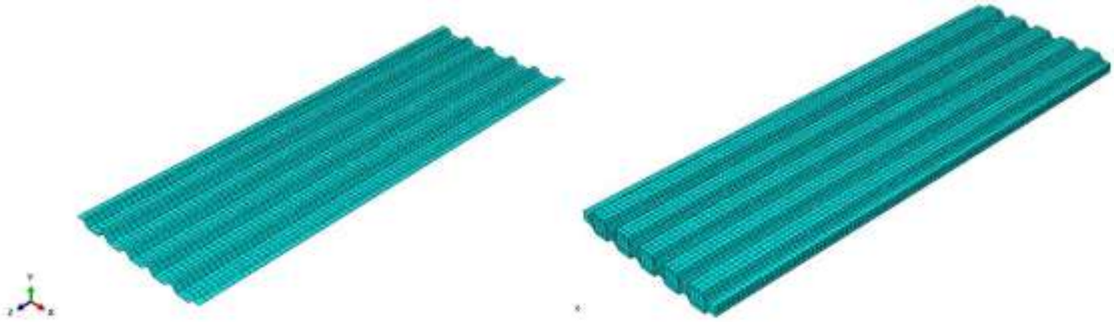


Fig 5. Components of FE model

VII.RESULTS AND DISCUSSION

7.1. Experimental Investigation

7.1.1. Load Vs axial deflection

The load axial deflection response of SFCC panel 1 is shown in Fig 6. The response of the panel is gradual with initial portion almost linear up to first peak load (27.19 KN). The first peak is the failure of foam concrete. Then the load remained almost constant with increased deflection due to the shedding of the load to the other portions of the foam concrete and then the load gradually decreased to 15 KN due to the buckling of steel sheet along the regions of foam concrete failure. The small kinks in the curve show the cracking of the FC core.

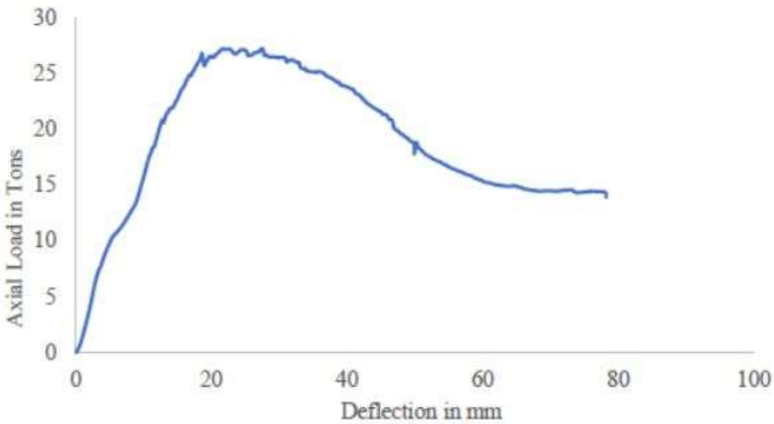


Fig 6 Load axial deflection response of SFCC panel 1

7.1.2. Load Vs lateral deflection

Load lateral deflection response of the SFCC wall panel 1 is shown in Fig 7. Lateral deflection is measured using three LVDTs placed along the length of the panel as shown in Fig 4.21. The plot shows that the lateral deflection is maximum at the top of the SFCC panel and minimum at the bottom. Initially, the lateral deflection increases with load, later the load increases with constant lateral deflection up to the peak load. Post-peak the lateral deflection increases along with falling axial load.

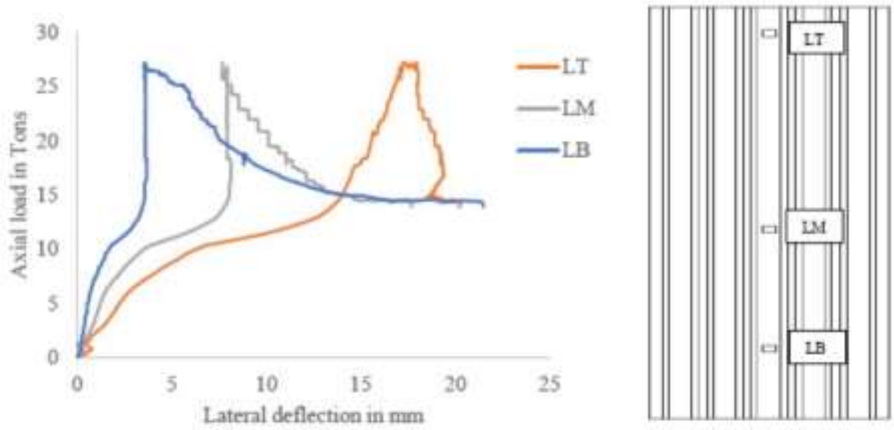


Fig 7 Axial load -lateral deflection response

7.2. Numerical Modeling

The behaviour of the SFCC panel under combined axial and bending load is studied. Finite element model of the full-scale panel created using ABAQUS software is used for the study. The effects of sheet thickness, number of studs are studied in the numerical model.

7.2.1. Effect of sheet thickness

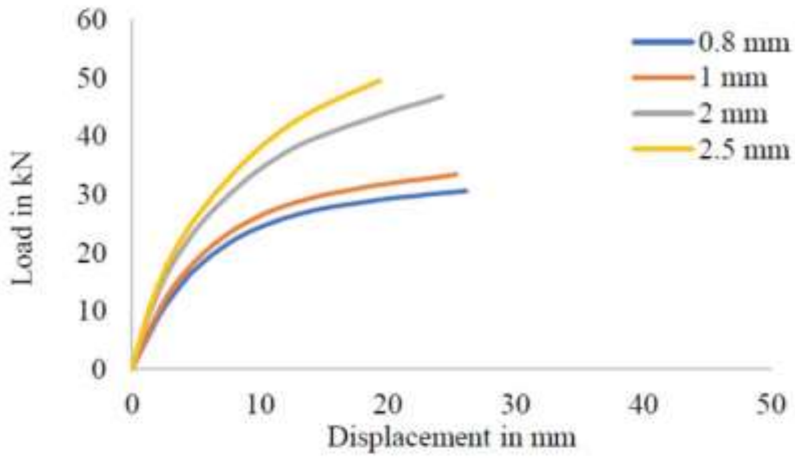


Fig 8 Load deflection graph for different sheet thickness from FEA

7.2.2. Effect of number of studs

By keeping all other properties constant the number of studs is varied to study the effect of spacing of studs in the bending capacity of the panel under combined loading. Three FE models having the number of studs 66, 36 and 18 are studied to understand the variation. The load-deflection curve of varying the number of studs is shown in Fig 9.

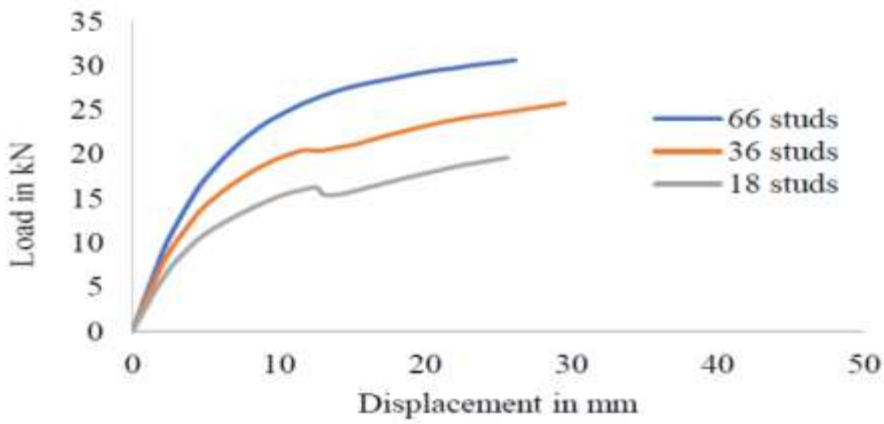


Fig 9. Load deflection graph for varying number of studs from FEA

VIII.CONCLUSION

1. SFCC panel of size 1000×3000×130 mm with infill foam concrete density 850 kg/m3 is capable of taking 33.23 Tons of axial load. The panel failed by the local buckling of the steel sheet and the crushing of foam concrete. The failure is concentrated towards the bottom of the panel only. Top portion suffered from the separation of steel sheet and minor diagonal cracks alone.
2. FE model capable of predicting the ultimate load with an accuracy of 3%. The load-deflection behaviour and failure of the SFCC panel predicted by the numerical model and experiment shows close similarity.
3. Parametric studies conducted on the SFCC panel showed that foam concrete strength is the major parameter affecting the ultimate strength of the wall panel. Profiled sheets are well preferred over the plain sheets as they are capable of taking 12% higher loads with that of the same cross-section. Increasing the sheet thickness and number of stud connectors improves the performance of the SFCC panel but only at a marginal level.
4. SFCC wall panels are able to perform well under combined axial and bending loading. The parametric study conducted showed that sheet thickness, number of studs, the density of concrete has an influence on the combined behaviour. In this case, also the profiled sheet is found to be superior to the plain sheet.
5. Openings drastically reduce the capacity of the wall panel. About 40% reduction in load carrying capacity is observed. The openings make the portion of the wall panel less effective in taking the load. The portion of the wall above the opening becomes critical.

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