

# Investigation of Steel Foam Concrete Composite Lightweight Panels

Priyanka bharati, Satish Parihar\*

Faculty of Engineering & Technology, Rama University, Kanpur, India

**Email Id:** satishparihar.fet@ramauniversity.ac.in

## Abstract:

The current priority is to advance the production of enhanced goods and systems using industrialized construction techniques in order to meet the substantial demand for mass housing and ensure seismic safety in buildings and residences. The use of prefabricated building methods is the only feasible approach to address the escalating need for housing. The demand for sandwich panels in the housing sector has shown a notable increase in recent years, mostly driven by its advantageous characteristics such as structural efficiency, insulation capabilities, lightweight composition, and aesthetic appeal. Steel-concrete composite panels are a subject of extensive study within the field of sandwich construction due to their favorable attributes of strength, ductility, and stiffness. These properties make them very promising for the development of earthquake resistant buildings. The use of composite wall construction is a notable addition to the repertoire of regularly employed building materials, including composite columns, beams, and slabs. This innovative approach involves the use of flat or profiled steel sheets as the outer layer, with an intermediate layer of concrete serving as the infill material. The primary aim of the current research is to create prefabricated steel-concrete composite panels that are lightweight, capable of withstanding seismic activity, and able to carry loads. Additionally, the study aims to establish the necessary connections to assemble these panels into a fully functional building structure. The prefabricated panel being suggested has the potential to function as both wall and floor/roof components in structures, in contrast to the traditional construction methods that use cast in-situ columns, beams, and brick walls. The current study introduces a novel Steel-Foam Concrete Composite (SFCC) panel, consisting of thin profiled steel sheets with a thickness of 0.8 mm as the external layers and foam concrete with a density of 1200 kg/m<sup>3</sup> as the core material. These components are interconnected by using through-through mild steel studs. The primary objective of this research is to gain insight into the structural response of SFCC panels subjected to axial compression and the associated connection assembly. An assembly for joining SFCC wall-to-wall and wall-to-floor/roof panels has been developed and its performance is investigated via experimental testing under shear and moment stress conditions. The connection assembly comprises an SFCC connecting panel that serves to link the upper SFCC wall panel to the lower SFCC wall panel. This connection is further established by using angles and bolts to attach the SFCC floor panel to the bottom wall panel. The test specimen serves as a representation of the junction between an outer wall and a floor.

**Keywords:** SFCC, Studs, Light Weight Foam Concrete, Axial compression

## I. INTRODUCTION

Throughout reaction to the substantial need for inexpensive housing units, the building sector in India is increasingly adopting industrialized methods of construction. The pre-engineered technology is a rapidly expanding construction technology that is well-suited for non-residential low-rise structures, in contrast to traditional steel buildings. The use of factory-manufactured components enhances the overall quality of the construction process, while concurrently reducing the duration of construction, exertion, and environmental pollution. In the Indian context, the use of prefabricated wall panels, ceiling panels, and flooring systems has become prevalent in the construction of office and commercial buildings, specifically for the purpose of interior design and construction. The use of prefabricated panels results in a significant reduction in the load exerted on the structure, about eight to ten times less than that of brick walls. Consequently, this reduction in load contributes to a decrease in the total cost of constructing the building. The use of pre-fabricated concrete panels as shear walls and roof slabs has been adopted by the home building sector. Prefabricated construction exhibits a cost differential of around 15-20% when compared to conventional construction methods. Nonetheless, the use of prefabricated techniques may provide enhanced efficiency, reduced waste generation, diminished

pollution levels, and decreased labor expenses, hence resulting in a notable reduction in total costs, particularly for large-scale structures. India is characterized by extensive areas that are susceptible to seismic activity, as shown by the significant destruction seen in previous earthquake events. The problem of seismic safety in structures and the well-being of residents has emerged as a significant concern, leading to increased attention on the topic of building and housing safety in India. In previous seismic events, brick or masonry structures exhibited brittle behavior, resulting in significant damage even during relatively minor earthquakes. This vulnerability may be attributed to their inadequate structural integrity, rendering them unsuitable for habitation. In order to enhance earthquake resistance, it is essential to design structures that possess a combination of lightweight properties, high strength, and significant ductility or deformability, as opposed to rigid structures.

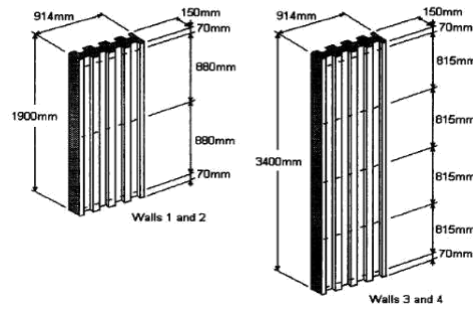
In order to address the demands for mass housing and ensure occupant safety, it is imperative to embrace novel approaches and materials within the realms of manufacturing and building technology. In recent years, there has been an introduction of cold formed steel sections and lightweight steel frame systems in the housing market. The use of steel-concrete composite construction has the capacity to enhance the overall performance of structures. However, its implementation in residential construction inside India has been limited owing to the intricate nature of analysis and design processes.

## II. LITERATURE REVIEW

This part provides a comprehensive evaluation of the existing literature pertaining to the performance evaluation of Double Skin Composite Wall (DSCW) panels under different loading scenarios. The evaluation also encompasses an examination of the several facets pertaining to the prospective use of Foam Concrete (FC) as a structural material. This includes an analysis of the component materials, mix proportioning, as well as the fresh and hardened characteristics.

This article presents a comprehensive assessment of the existing literature on Double-Skinned Profiled Steel Sheet Composite Wall (DPSCW), Double-Skinned Flat Steel Sheet Composite Wall (DFSCW), and Profiled Steel Sheet-Flat Sheet (PFSCW) panels. The study focuses on experimental, analytical, and numerical investigations conducted in this field. The user's text does not contain any information to rewrite in an academic manner. In their study, Wright and Gallocher (1995) examined the behavior of DPSCW (Double Prestressed Steel Concrete Wall) panels throughout both the construction and service loading stages. To investigate this, they conducted four pilot tests specifically focusing on axially loaded wall parts. The use of Richard Lee Holorib profile decking sheet, characterized by embossments and a thickness of 0.9 mm, typically employed for flooring purposes, was implemented for the construction of walls. Additionally, M 25 grade concrete was utilized as infill material. Figure 1 provides the geometrical specifications of both the profile and the wall panel. The experimental investigation not only confirmed the validity of the suggested building approach, but also brought attention to certain challenges that are not often faced in traditional reinforced concrete construction.

The performance of walls is primarily influenced by two key factors: the bond strength at the interface between steel and concrete, and the local buckling capacity of the external steel sheet. In their study, Hamzah and Badaruzzaman (2009) performed both experimental and numerical investigations to examine the impact of screw spacing, square window opening (as shown in Figure 2), and vertically positioned butt joints on the wall panel made of Pre-Stressed Steel Double-Skin Composite (PSSDB). The system was specifically engineered to function as load-bearing wall panels and underwent analysis when subjected to axial compressive load. Self-tapping and self-driving screws, with a rigidity of 620 N/mm, were used in a proficient manner to establish a connection between the PSS and dry board, which functioned as composite components. The screws made of carbonized steel had a length of 25 mm. The user's text is already academic and does not require any rewriting.



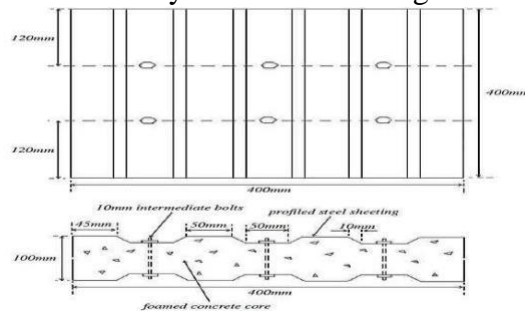
**Figure 1:** Details of pilot composite wall tested by Wright & Gallocher

The emplacement of critical portions was observed in the top corners of the entrance, as well as in the upper section positioned above the opening. The deformation profile of the PSSDB wall panel system exhibited a singular curvature deformation profile, whereby the largest lateral displacement was seen at a height corresponding to two-thirds of the wall panel. Additionally, the crucial parts located at the top corners of the square aperture also experienced significant displacement. Finite Element Analysis (FEA) demonstrated a precise estimation of the structural performance of the PSSDB wall panel system. The user's text is already academic and does not require any rewriting.



**Figure 2:** PSSDB wall panel (Source: Hamzah & Badaruzzaman 2009)

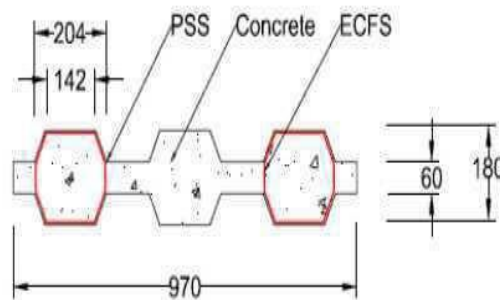
In the research they conducted, Othuman and Wang (2011) provided a comprehensive analysis of both experimental and analytical inquiries into the structural performance of a DPSCW panel system. This system included a lightweight foamed concrete (LFC) core with a density of 1000 kg/m<sup>3</sup>, and was subjected to axial compression. A series of twelve experiments were conducted to examine the effects of varying steel sheet thicknesses (0.4 mm and 0.8 mm) and three different edge conditions on the test specimens. In Figure 3, the connection between the two profiled steel facings was established via the utilization of six 10 mm bolts and accompanying nuts. The steel sheets exhibit one of three edge conditions: (a) they lack coverage of the LFC panel thickness, commonly referred to as the absence of stopping edge; (b) they encompass the LFC panel thickness but remain unjoined, commonly referred to as the presence of stopping edges; (c) they encompass the LFC panel thickness and are connected through welding, commonly referred to as the presence of a welded stopping edge. The composite panel's ultimate load and axial stiffness exhibited a positive correlation with the increase in steel thickness and the enhancement of the edge condition. The use of steel sheet on both sides of the profiled LFC panel significantly enhanced its ductility across various edge conditions and steel thicknesses.



**Figure 3:** DPSCW adopted by Othuman & Wang (2011)

In the research they carried out, Taormina (2012) introduced a unique kind of DPSCW system infill that used a specialized non-conventional developing high performance concrete (HPC) material. This particular material was tested under conditions of higher temperatures and axial loads. The experimental variables included the use of designed cementitious composites as infill material, along with the manipulation of temperatures at four distinct levels: 0°C, 300°C, 400°C, and 500°C. The evaluation of wall performance at different high temperatures was conducted by analyzing factors such as residual axial strength, physical alterations, load-deflection behavior, stress-strain properties, concrete cracking, steel sheet buckling, and overall failure modes. The use of high-performance computing (HPC) has resulted in enhancements to the strength, ductility, and durability properties of the dual-phase steel-concrete wall (DPSCW) system.

In their study, Hilo et al. (2015) examined the response of a DPSCW panel that was already in place, filled with standard concrete, and reinforced with Embedded Cold-Form Steel Tubes (ECFST) together with bar stiffeners, as seen in Figure 4. The present study was to evaluate the impact of several factors, including the thickness of the profile sheet, the use of externally confined fiber-reinforced polymer sheets (ECFST), and the form of ECFST with and without bar stiffeners attached to the internal surfaces of ECFST, on the ultimate axial load and ductility of concrete walls (CW). To achieve this objective, finite element analysis (FEA) software, namely ABAQUS, was used. The finite element analysis (FEA) findings of double-ply steel-concrete-wood (DPSCW) panels, varying in sheet thickness, demonstrated that the axial load behavior of the composite wall was little influenced by the thickness of the sheet.



**Figure 4:** DPSCW panels strengthened with ECFST shapes (Source: Hilo et al 2015)

### III. LIGHT WEIGHT FOAM CONCRETE

The most common application of lightweight concrete in the field of construction is to mitigate the dead load imposed on load-bearing structural components. Cellular concrete, sometimes referred to as aerated concrete, is a lightweight substance comprised of cementitious mortar enveloping isolated bubbles that are formed by physical or chemical means, wherein air is injected into the mortar mixture (Tikalsky et al., 2004). Numerous global entities have recognized the need for building materials in the future to possess characteristics such as lightweightness, durability, cost-effectiveness, and environmental sustainability (Jones & McCarthy, 2005). Foam concrete (FC) is classed as lightweight concrete and has promise in meeting the diverse needs of the construction sector, since it can attain a broad range of densities (400-1600 kg/m<sup>3</sup>) and exhibit strength up to 25 MPa. While the concept of fiber-reinforced concrete (FC) was first patented in 1923 by Valore (1954), its use in construction as a non-structural and semi-structural material has shown significant growth only in recent years.

The fundamental components of the mixture consist of Portland cement, fine aggregate, and water. The use of coarse aggregates is not employed, while the fine aggregate has the potential for partial or complete substitution with recycled or secondary resources. Foam concrete is a substance that exhibits a fluid-like behavior and has the ability to level itself due to the even dispersion of air bubbles measuring between 0.1 and 1.0 mm in size. These air bubbles are introduced into the concrete mixture by the use of foaming agents, resulting in a homogeneous distribution across the whole of the concrete mass. FC, known for its porous internal structure, has a very low thermal conductivity value of 0.23 and 0.42 w/mK at dry densities of 1000 and 1200 kg/m<sup>3</sup> respectively (Jones & McCarthy, 2005). This characteristic makes it suitable for use as an insulating material or for its fire-resistant properties. Foam is generated by the use of

either natural or manufactured foaming chemicals. The resilience of foam in concrete is a crucial factor in achieving a consistent and homogeneous texture throughout the whole process of solidification.

The absence of established mix proportioning procedures for fiber concrete (FC) necessitates the use of a trial and error approach in order to get the desired target plastic density, which is considered the primary design requirement (Nehdi et al., 2001). The incorporation of fly ash as a partial or whole substitute for filler in FC has been shown to provide a greater strength to density ratio compared to FC mixes that use sand as filler. Furthermore, this difference in strength to density ratio tends to grow as the age of the FC mixture rises. According to a study conducted by Kearsley and Wainwright in 2001, it was shown that a substantial portion of cement, namely 67%, may be substituted with both graded and ungraded fly ash without causing any notable decrease in strength. According to a study conducted by Kearsley and Mostert in 1997, the use of polypropylene fibers was shown to improve the tensile and flexural strength of fiber-reinforced concrete (FC) while also reducing its brittleness. The flexural strength to compressive strength ratio of cellular concrete falls within the range of 0.25 to 0.35, as reported by Valore in 1954a. The splitting tensile strengths of fiber-reinforced concrete (FC) are found to be greater in mixes including sand compared to those using fly ash. According to Jones and McCarthy (2005), the static modulus of elasticity of FC ranges from 1.0 to 8.0 kN/mm<sup>2</sup>, corresponding to dry densities ranging from 500 to 1500 kg/m<sup>3</sup>.

The favorable combination of reduced weight and satisfactory strength properties makes fiber cement (FC) a viable choice for many structural and semi-structural uses, including but not limited to partition walls and lightweight concrete blocks. The achievement of FC densities ranging from 400 to 1600 kg/m<sup>3</sup> may be accomplished by precise regulation of foam dosage, enabling its use as a material for structural, partition, and insulation purposes. Fiber-reinforced concrete (FC) has the potential to exhibit sufficient compressive strength, hence enabling its use as a load-bearing material.

The use of fiber-reinforced concrete (FC) in load-bearing construction may be effectively achieved by using it in conjunction with steel in a composite action. This approach is particularly advantageous due to the great ductility shown by steel, which compensates for the brittle failure characteristics of FC. The use of fiber-reinforced concrete (FC) in composite panels has the advantage of reduced pressure exerted on the steel sheet due to its low density. Consequently, this enables the utilization of thinner sheets compared to those required when using conventional strength concrete. Additionally, the use of structural lightweight fiber composites (FC) offers a higher level of efficiency in terms of the strength-to-weight ratio for composite panels. The act of reducing weight will lead to a decrease in the size and cost of foundations, resulting in total cost advantages. Therefore, the use of FC as an infill material is suggested in this research for the purpose of sandwiching it between the profiled steel sheets.

#### IV. PROPOSED SFCC PANEL

The SFCC panel under consideration comprises profiled steel sheets serving as the external layer, while the infill material consists of fiber cement (FC) with a density of 1200 kg/m<sup>3</sup>. According to the British Standard, specifically BS 8110: Part 2 (1985), concrete having a density equal to or below 2000 kg/m<sup>3</sup> is categorized as lightweight concrete. The use of lightweight fiber-reinforced concrete (FC) in composite panels results in a 40% reduction in the panel's self-weight when compared to a brick wall of equal dimensions. Figures 5 and 6 provide the configuration of the profiled steel sheet and the dimensions of the SFCC panel, respectively. The measured thickness of the profiled steel sheet is 0.8 mm. The dimensions of the SFCC panel are 685 mm in width and 130 mm in thickness, measured from sheet to sheet. The middle plate element is maintained at a width of 110 mm, while the edge plate has a width of 60 mm. The selection of the SFCC panel size is determined by two key factors: the capacity of the current loading facilities and the practicality of specimen manufacture, taking into account the availability of materials. The connection between a sheet and concrete is established by the use of mild steel studs that penetrate through both materials.

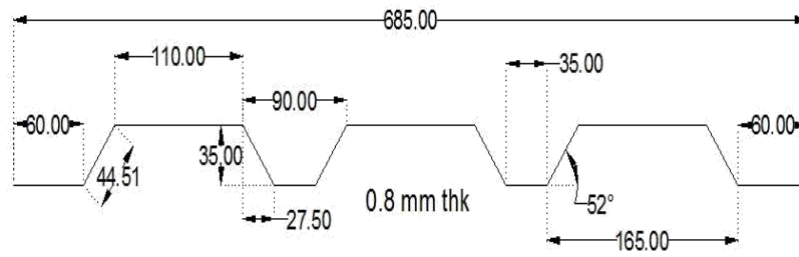


Figure 5: Profiled steel sheet configuration (All dimensions are in mm)

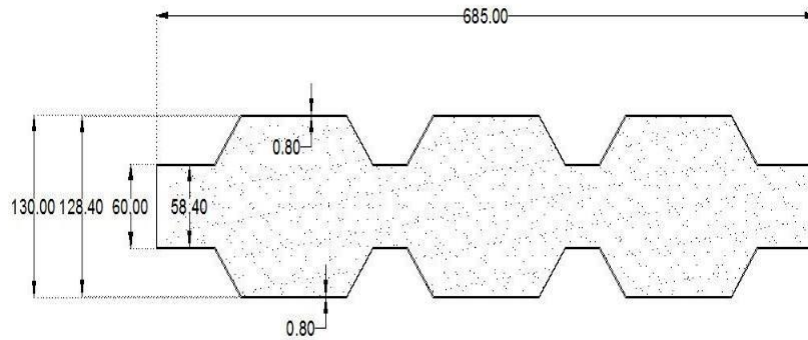


Figure 6: SFCC panel dimensions

The findings of literature research indicate that the use of appropriate load transfer mechanisms, such as embossments or other mechanical linkages between the sheet and concrete, is essential for achieving complete composite action and enhancing the performance of the panel. Moreover, the axial capacity of the panel is significantly affected by the occurrence of early local buckling in the steel sheets. In the experiments documented in the literature, a uniform load is applied to both steel and concrete simultaneously. The application of direct compression stress on steel sheets leads to premature local buckling of the sheets, which subsequently diminishes the performance of the panels in the post -peak range. Therefore, the loading conditions are designed in such a way as to apply load only to the concrete section in order to investigate the impact of the confinement of fiber-reinforced concrete (FC) by the outer steel sheets and interconnecting studs on the load-deflection characteristics of steel fiber-reinforced concrete (SFCC) panels.

**Specimen 1** – This specimen has two studs in the wider plate width portion and is connected by using total of 30 nos. of studs along the height. The spacing between studs is kept as 72 mm along width and 200 mm along height.

The edges of the sheet remain free. The plan and elevation of Specimen 1 is shown in Figure 7. Total of 30 nos. 8 mm stepped studs and spreader plates of size (100 mm  $\square$  30 mm  $\square$  1 mm) are used for the interconnection.

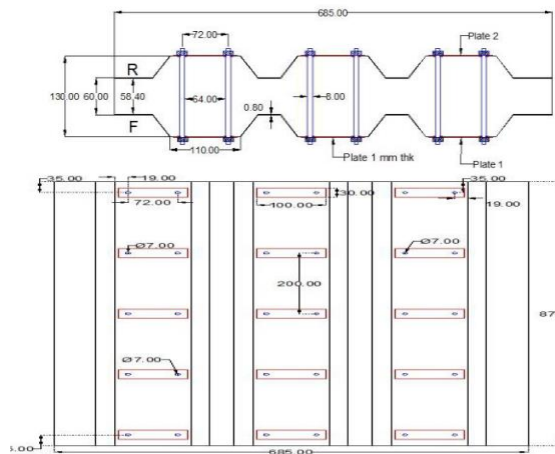
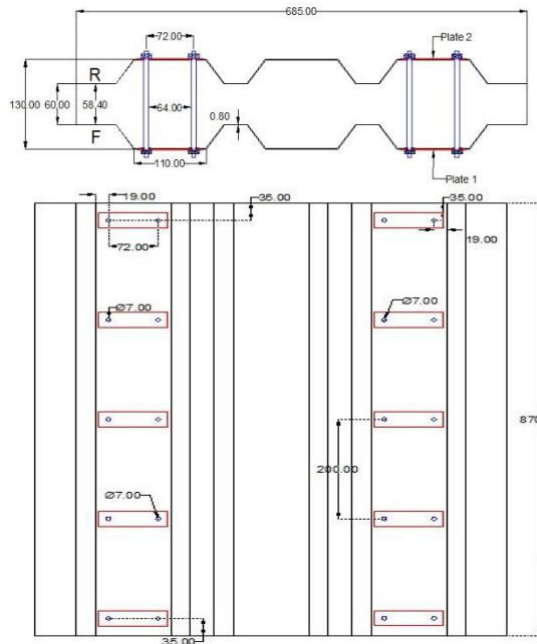


Figure 7: Plan and elevation of Specimen 1

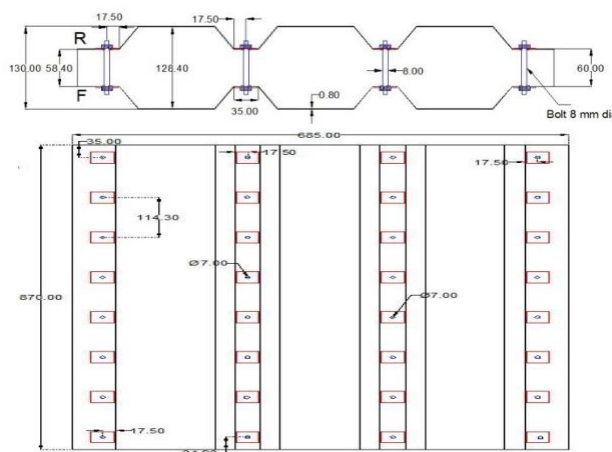
**Specimen 2** – This specimen is similar to Specimen 1 except for the middle crest portion does not have any connection. The plan and elevation of Specimen 2 is shown in Figure 8. The spacing between the studs is 72 mm along the width direction and 200 mm along the length direction Total of 20 nos. of 8 mm stepped studs and spreader plates of size (100 mm x 30 mm x 1 mm) are used for the interconnection. The edges of the sheet remain free.



**Figure 8:**Plan and elevation of Specimen 2

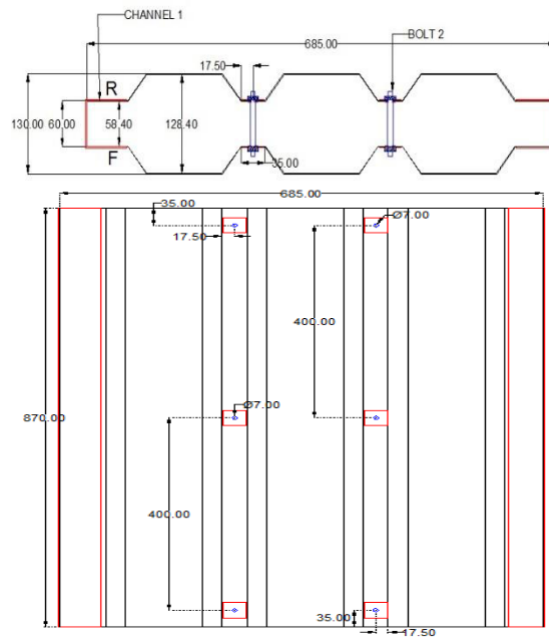
**Specimen 3** – This specimen consist of connections in the smaller plate width portion. The plan and elevation of Specimen 3 is shown in Figure 9. Total of 32 nos. of 8 mm stepped studs and 64 nos. of spreader plates of size (32 mm x 32 mm x 1 mm) are used for the interconnection. The spacing between the studs is 114.3 mm in the length direction. The edges of the sheet remain free.

**Specimen 4** – This specimen has tack welded channels of size (60 mm x 63 mm x 1.5 mm) on both the sides as confined edges and is connected by using 6 nos. of studs in the smaller plate width portion at the top, middle and bottom of the wall. Totally 12 nos. of spreader plates of size (32 mm x 32 mm x 1 mm) are used. The spacing between studs is 400 mm along height direction. The plan and elevation of Specimen 4 is shown in Figure 10.

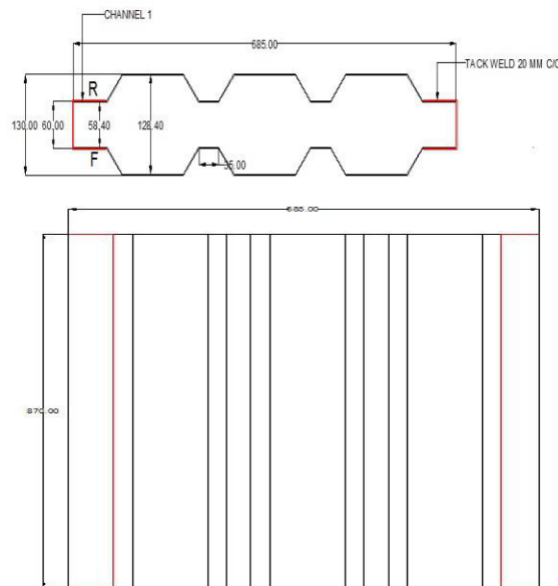


**Figure 9:**Plan and elevation of Specimen 3

**Specimen 5** – This specimen also has confined edges similar to Specimen 4, but does not have any other interconnection (through-through connectors). The plan and elevation of Specimen 5 is shown in Figure 11.



**Figure 10:**Plan and elevation of Specimen 4



**Figure 11:**Plan and elevation of Specimen 5

### Assembly of SFCCP-ACL Specimens

Figure 12 shows the step by step assembling of SFCCP-ACL specimens. The inner surface of SFCC panel is cleaned from dirt and is wiped by using acetone. The washers are provided at the stepped ends (Figure 12) and the sheets are connected to both the sides of the stud. The spreader plates are provided outside the sheet before placing the washers and nuts. The assembled test specimens are shown in Figure 13.





Figure 12:Assembling of SFCCP-ACL specimens



Figure 13:Assembled SFCCP-ACL specimens

### Foam Concrete (FC) for SFCCP-ACL

The infill concrete in composite panel serves the main purpose of restraining the inward buckling of sheets to a certain extent. FC of density  $1200 \text{ kg/m}^3$  is used as infill material for the present study.

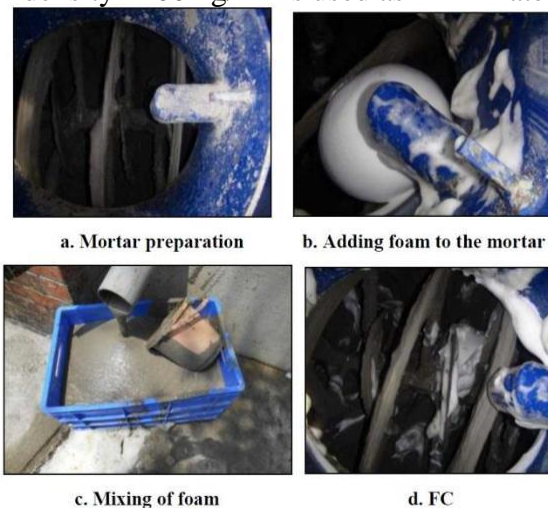


Figure 14:Preparation of FC

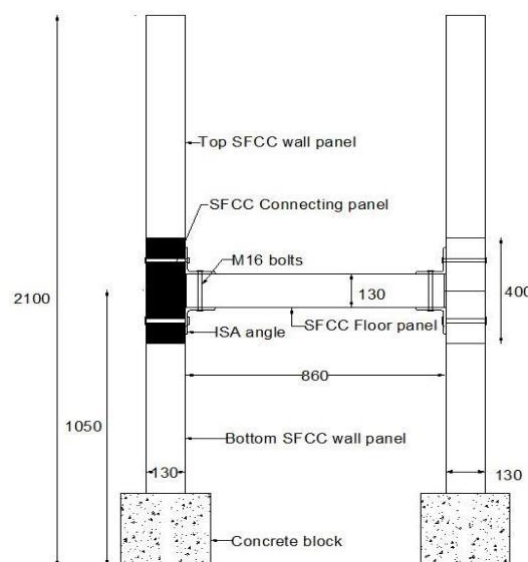
Ordinary Portland cement (OPC) of 53 grade conforming to IS:12269 (1987) is used. In addition to cement, fly ash is also used as supplementary cementitious material. Fine sand passing through 1.18 mm sieve and conforming to IS:383 (1970) is used for FC to obtain good flow characteristics and foam stability. The water binder ratio is kept as 0.39 and the cement-sand ratio is maintained as 1:0.87. The mix ratio to achieve the desired density of  $1200 \text{ kg/m}^3$  is 1:0.80:0.87:0.7:0.124 (cement:flyash:sand:water:foam). The density of foam is around 70-80 gm/litre. In the present study, KV LITE – a protein based chemical is used to generate foam. One kg of chemical produces 660 litres of foam. The foaming agent is diluted with water in the ratio of 100:3.4 (water in litres: volume of foaming

agent in litres) to achieve the desired foam density of around 70 -80 gm/litre. The calculated quantity of water is added to FC mixer machine. The fine sand followed by fly ash is added one by one and are mixed thoroughly in the mixer. Finally cement is added to the mixture and the mortar is prepared. The foam is prepared in the foam generator and the required quantity is added to the mortar to achieve the desired density. The foam is mixed with mortar uniformly using the specially designed screw mixer blades so as to avoid the foam breakage. The step by step preparation of FC is shown in Figure 14.

## V. DEVELOPMENT OF CONNECTION ASSEMBLY FOR SFCC PANELS TO FORM BUILDINGS

Many prefabricated systems are developed and adopted in low and medium rise residential and community buildings. The connection between wall and floor/roof slab constitute a potential weak link in the structure to resist the combination of lateral and vertical loads requiring skilled man power. Hence, it is required to develop an effective connection system to join the wall panels to the floor/roof panels to form a building system. The proposed connection assembly consists of SFCC connecting panel to connect the top SFCC wall panel to bottom wall panel, which in turn is connected to SFCC floor panel by using ISA angles and bolts. The entire connection is developed in such a manner that the connecting components can be prefabricated and assembled at site with ease. The schematic diagram of the proposed connection assembly is shown in Figure 9. The test specimen represents an exterior wall and floor joint of low-rise buildings. The components of the test specimen consist of top and bottom SFCC wall panel, SFCC floor panel and connection assembly. The present study aims to investigate the behaviour of proposed connection assembly under combined axial and bending loads.

The SFCC panel arrangement, one which exhibited better performance under axial, flexural and in-plane lateral loads is adopted for fabrication of wall and floor/roof panels. The total height of test specimen is 2100 mm. The centre-to-centre distance between SFCC wall panels is 1000 mm. The size of SFCC wall panel is 685 mm wide, 1050 mm high and 130 mm thick (outer to outer). The width and span of SFCC floor panel is 685 mm and 860 mm respectively. The thickness of SFCC floor panel is similar to wall panel thickness (130 mm). The width of SFCC connecting panel is similar to that of SFCC wall panel and is 400 mm high. The thickness of SFCC connecting panel is 126 mm (outer to outer), which is less by 4 mm than the SFCC wall panel thickness and enables the SFCC connecting panel to fit exactly into SFCC wall panel. This connecting SFCC panel is inserted into the bottom portion of the top SFCC wall panel for 200 mm and the remaining 200 mm is inserted into the top portion of bottom SFCC wall panel to have a composite connection and are connected by using bolts.



**Figure 15:** Proposed connection assembly (All units are in mm)

The entire SFCC wall panel is then connected to the SFCC floor panel by using M16 bolts and ISA (100 mm 100 mm 8 mm) angle arrangement as shown in Figure 15. The base of SFCC wall panel is embedded inside the concrete block and the base concrete block is then anchored to the reaction floor by using tie rods while testing.



**Figure 16:** Fabricated sheets for the components

The inner surface of all the sheets are wiped clean from dust with the cotton waste and the excess oil/grease is removed using acetone. Similarly all the washers, nuts, bolts, studs and hollow pipes are cleaned using acetone.

## VI. RESULTS AND DISCUSSION ON CONNECTION ASSEMBLY

The test specimen resembles the beam-column joint in a steel framed building. The deformation of test specimen at the failure stage is shown in Figures 17 to 22.



**Figure 17:** Location of LVDTs

From the recorded data, the load-deflection behaviour of SFCC floor panel and the connection assembly are plotted. The load versus mid-span deflection of SFCC floor panel is plotted in Figure 23.



**Figure 18:** Crack initiation in SFCC floor panel

The test results exhibited nonlinear behaviour of connection assembly. Initially, the load is carried by the FC in the SFCC floor panel. The load deflection response is linear upto 4.96 kN load and due to release of bond, a slight slip is observed. Then again the behaviour is linear upto 18.63 kN load and a slight slip is observed due to the formation of first tensile crack in the exposed portions of FC in SFCC floor panel. This is followed by number of hair line cracks occurred at the loads of 17 kN, 22 kN in the exposed portions of FC. The first tensile crack is noticed below the point of loading followed by subsequent cracks in the SFCC floor panel.

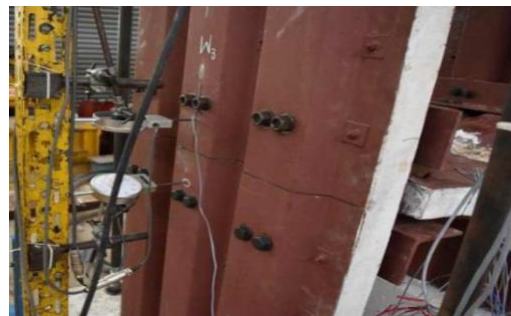


**Figure 19:** Crack formation in SFCC floor and wall panel

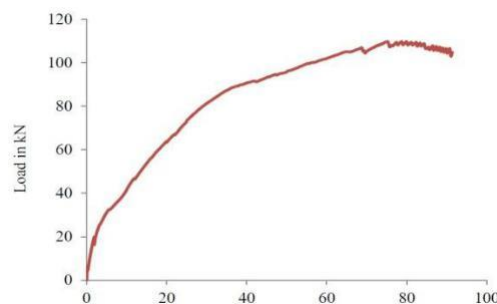


**Figure 20:** Deformed view of SFCC floor panel

The cracks in the edge portion of SFCC floor panel along with sheet debonding below loading point is observed at 34 kN. The punching of steel sheet near the loading point is observed at 40 kN load followed by a flexure crack in the middle of SFCC floor panel inclined at 45 degrees. The crack develops and reaches the top compression face at 76 kN. On further loading, the angle leg started yielding at 80 kN and transferred the load to SFCC connecting panel.

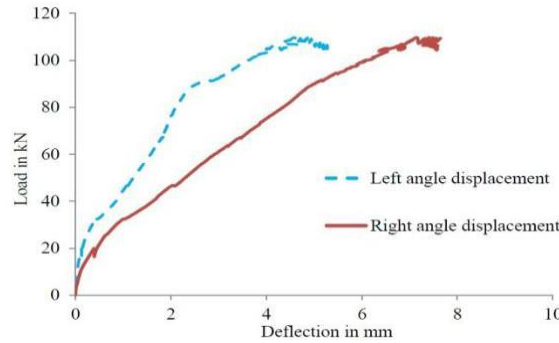


**Figure 21:** Lateral deflection of SFCC wall panel



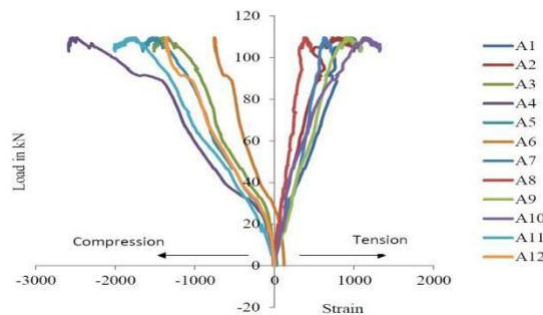
**Figure 22:** Load versus mid-span deflection of SFCC floor panel

Due to this, a crack has initiated at 104 kN in the exposed FC portion of SFCC wall panel on one of the sides followed by few cracks on both the sides (Figure 4.30). After this, the loading rate is increased to 3 mm/min. Due to the use of higher thickness of angle and larger dia of bolts in the connection assembly, the failure is by excessive deflection of SFCC floor panel (Figure 20) at the load of 107 kN. The reduction in load-deflection response is observed beyond the failure load and the experiment is terminated due to the excessive deflection (90 mm) of SFCC floor panel. No visible lateral deflection of the sheet or buckling is observed in the SFCC connecting panel (Figure 21).



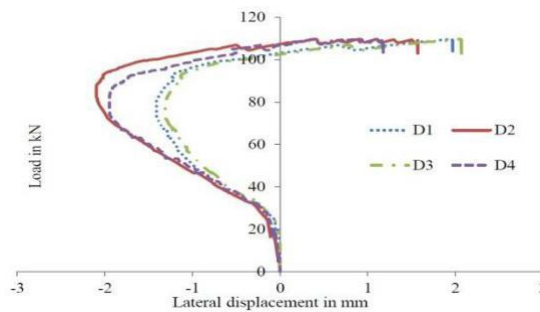
**Figure 23:** Load versus deflection in angle

The deflection of bottom angles on both the sides of connection assembly are measured by using LVDT's and the corresponding loaded flexion behaviour is plotted in Figure 23. Maximum deflection of around 7.63 mm is observed in the angle at failure. The strain gauge readings (A1 to A12) observed in the tension and compression side angles versus load is plotted in Figure 24. The maximum tensile strain of 2500 microns is observed in the top angle and compression strain of 1200 microns is observed in the bottom angle.

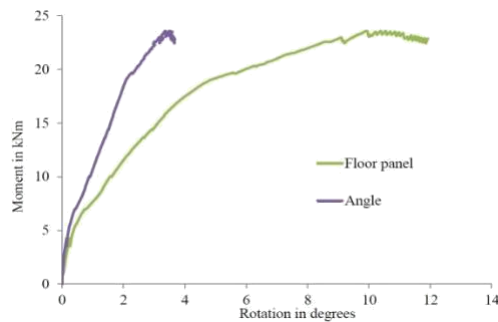


**Figure 24:** Load versus strain behaviour in angles

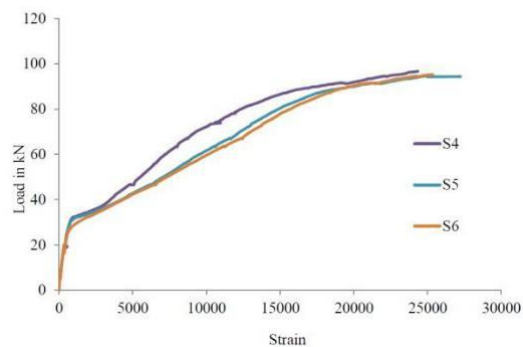
The strain gauges S4, S5, S6 placed in the tension side of sheet recorded the maximum tensile strain of 24,500 microns, which shows the full plastic yielding of the sheet. SFCC floor panel behaves as a fixed slab with plastic hinge formation in the supports and mid-span. The failure load for fixed boundary condition at wall-floor panel interface can be computed as 100 kN, which matches well with the experimental value.



**Figure 25:** Load versus lateral deflection of SFCC wall panel



**Figure 26:** Moment-rotation behaviour of angle and floor panel



**Figure 27:** Load versus strain behaviour of SFCC floor panel

The strain values indicate that the angle has just yielded at the failure stage. The load versus lateral deflection of SFCC connecting panel plotted in Figure 25 shows the negligible lateral deflection of 2 mm enabling the connection to maximize the loading on SFCC floor panel. The moment-rotation behaviour of angle in the connection assembly and the floor panel plotted in Figure 26 shows nominal angle rotation of around 3.5 degrees as compared to the floor panel rotation of 13 degrees. The deflection, strain readings and rotation values confirm the rigid behaviour of connection assembly, which prevents the further yielding of angles. The load versus strain behaviour of the sheet in SFCC floor panel is plotted in Figure 27.

## VII. CONCLUSION

In the present research work, light weight Steel-Foam Concrete Composite (SFCC) panel with appropriate load transfer mechanism is proposed for use as structural load-bearing elements in low-rise buildings as an alternative to conventional systems. Experimental studies have been conducted to examine the behaviour of proposed SFCC panel under axial compression. Five small scale load tests are carried out on SFCC panels with different patterns of arrangement of load transfer mechanism and edge boundary conditions under axial compression loading (SFCCP-ACL). Out of five specimens, three specimens have exposed concrete surface at both ends and have different arrangement of studs in between.

A simple prefabricated connection assembly is proposed for connecting SFCC panels. The proposed connection assembly consists of SFCC connecting panel proposed to connect the top SFCC wall to bottom SFCC wall panel. The entire connection assembly is developed in such a manner that the connecting components can be prefabricated and assembled at site with ease. The behaviour of proposed connection assembly under combined axial and bending loads is investigated experimentally.

## References

- [1] Rafiei, S, Hossain, KMA, Lachemi, M & Behdinan, K 2015, 'Profiled sandwich composite wall with high performance concrete subjected to monotonic shear', *Journal of Constructional Steel Research*, vol. 107, pp. 124-136.
- [2] Zhenyu, H & Richard Liew, JY 2016, 'Structural behaviour of steel-concrete-steel sandwich composite wall subjected to compression and end moment', *Thin Walled Structures*, vol. 98, pp. 592-606.

- [3] Ahmed, E, Badaruzzaman, WHW & Wright, HD 2000, 'Experimental and finite element study of profiled steel sheet dry board folded plate structures, *Thin Walled Structures*, vol. 38, pp. 25-143.
- [4] BS EN 450:1995, Fly Ash for Concrete, Definitions, Requirements and Quality Control', British Standards Institution, London.
- [5] Chen, B, Wu, Z & Liu, N 2012, 'Experimental research on properties of high-strength foamed concrete', *Journal of Materials in Civil Engineering*, vol. 24, pp. 113-118.
- [6] Flores-Johnson, EA & Li, EA 2012, 'Structural behaviour of composite sandwich panels with plain and fibre-reinforced foam concrete cores and corrugated steel faces', *Journal of Composite Structures*, vol. 94, no. 5, pp. 1555-1563.
- [7] Hamzah, SH & Badaruzzaman, WHW 2009, 'Structural evaluation of PSSDB wall panel with square opening and varied screw spacing', *Journal of Engineering Science and Technology*, vol. 4, pp. 32-46.
- [8] Hossain, KMA & Wright, HD 2005, 'Finite element modelling of the shear behaviour of profiled composite walls incorporating steel– concrete interaction', *International Journal of Structural Engineering and Mechanics*, vol. 21, pp. 659-676.
- [9] Hossain, KMA 2000, 'Axial load behaviour of pierced profiled composite walls', in: IPENZ Conference, NewZealand.
- [10] Alireza, F & Sina, S 2012, 'Investigation of the foamed concrete properties containing nano silica, as compared with the foamed concrete containing micro silica', *ACI Journal SP-289.30*, pp. 399-411.
- [11] BS 3892-2:1996, Pulverized-fuel ash; Specification for Pulverized Fuel Ash to be Used as a Type I Addition, British Standards Institution, London.
- [12] IS1608:2005, Metallic materials - Tensile testing at ambient temperature, Bureau of Indian Standards, New Delhi.
- [13] OthumanMydin, MA & Wang, YC 2012, 'Mechanical properties of foamed concrete exposed to high temperatures', *Construction and Building Materials*, vol. 26, pp. 638–654.
- [14] Riley, WF, Sturges, LD and Morris, DH 2006, *Mechanics of Materials*, 6th Edition, John Wiley & Sons Inc., pp. 720.
- [15] Taormina, KMAHA 2012, 'Behaviour of profiled composite walling system under elevated temperatures', in: *Proceedings of the Annual Conference of the Canadian Society for Civil Engineering Leadership in Sustainable Infrastructure*, CSCE.
- [16] Wright, HD & Evans, HR 1986, 'Profiled Steel Sheeting for the replacement of timber flooring in building renovation', SERC Grant, GR/D/76875, United Kingdom.