Study of Light Weight Steel Foam Concrete Composite Panels

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Abstract—**Development of improved products/systems based on industrialized methods of construction is the need of the day to cater to the huge demand for mass housing and seismic safety of buildings and houses. Prefabricated method of construction is the only viable solution to encounter the growing demand for housing. Interest in sandwich panels for housing has been growing over the past few years due to its structural efficiency, insulation property, light weight and aesthetics values. Among the widely researched sandwich construction, steel-concrete composite panels possess adequate strength, ductility and stiffness characteristics that is promising for earthquake resistant structures. Among the commonly used products such as composite columns, beams and slabs in buildings, composite wall is yet another novel form of construction with flat/profiled steel sheets as the facing material and with an infill concrete in between.**

The main objective of the present study is to develop prefabricated, light-weight, seismic-resistant, load-bearing steel-concrete composite panels and the connections to form the complete building. The proposed prefabricated panel can serve as both wall and floor/roof elements in buildings against the conventional construction made of cast in-situ columns, beams and brick wall. The present research work proposes a Steel-Foam Concrete Composite (SFCC) panel made of thin profiled steel sheets of thickness 0.8 mm as the outer skins and foam concrete of density 1200 kg/m3 as the infill, connected together by using through-through mild steel studs.The present study focuses on understanding the behaviour of proposed SFCC panels under axial compression and the connection assembly. A connection assembly is evolved for connecting SFCC wall-towall and wall-to-floor/roof panel and is studied experimentally under shear and moment loading. The connection assembly consists of a SFCC connecting panel to connect the top SFCC wall to bottom SFCC wall panel, which is then connected to SFCC floor panel by using angles and bolts. The test specimen represents an exterior wall to floor joint.

Index Terms—SFCC, Studs, Light Weight Foam Concrete, Axial compression

I. INTRODUCTION

To meet the huge demand of requirement of affordable housing units, building industry in India is rapidly moving towards industrialized methods of construction. One of the fastest growing building systems that are ideal for any non-residential low-rise building is the pre-engineered system as compared to conventional steel buildings. It uses factory-manufactured components which improves the quality of building and also significantly reduces construction time, effort and pollution. In India, office and commercial buildings have been using prefabricated wall panels, ceiling panels and flooring systems for creating interiors. [1]

The load on the structure is reduced around eight to ten times than brick walls on using prefabricated panels, which in turn lowers the overall building cost. The housing construction industry started to use the pre-fabricated concrete panels as shear walls and roof slabs. Prefabricated construction is 15-20% expensive than the traditional ones, however higher efficiency, less wastage, pollution and labour costs can bring down the overall cost substantially for large buildings.[2]

Large regions of India are seismically vulnerable, which is evident from the severe damages experienced during the past earthquakes. Seismic safety of buildings and the occupants are the big triggering issue and hence the discussion on safety of buildings and houses in India has gained prominence. Brick or masonry buildings suffered brittle damages in the past earthquakes of even smaller magnitude due to the lack of structural integrity making them uninhabitable. The earthquake resistant structure needs to be light weight and high strength with large ductility or deformability rather than the stiff structure. The only solution to meet mass housing needs and the occupant safety is to adopt innovative methods and materials for the changes in manufacturing and constructional technologies. In the recent years, application of cold formed steel sections and lightweight steel framing systems are introduced in the housing sector. Steel-concrete [3] composite construction has the potential in improving the overall performance of buildings, but has found little application [4] in residential construction in India due to the complexities involved in analysis and design.

II. LITERATURE REVIEW

This part presents critical review of literature on the performance assessment of Double Skin Composite Wall (DSCW) panels subjected to various loading conditions. The review also covers the aspects related to the potential application of Foam Concrete (FC) as a structural material including the constituent materials, mix proportioning, fresh and hardened properties.

The state-of-the-art review of 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 with respect to experimental, analytical and the numerical studies are presented. [5]. Wright &Gallocher (1995) studied the behaviour of DPSCW panel under construction and service loading by conducting four pilot tests on axially loaded wall elements. Richard Lee Holorib profile decking sheet with embossments and 0.9 mm thickness which was generally used for the flooring was adopted for the walls and M 25 grade concrete as infill. The geometrical details of the profile and the wall panel are given in Figure 1. The experimental study not only validated the proposed construction method, but also highlighted particular problems not encountered with conventional reinforced concrete construction.

The two main factors affecting the performance of the walls are the interface bond strength between steel and concrete and local buckling capacity of the external steel sheet.

Hamzah&Badaruzzaman (2009) conducted experimental and numerical studies to determine the effect of screw spacing, square window opening in Figure 2 and butt joints vertically positioned on the PSSDB wall panel. This system was designed as load-bearing wall panels and was analyzed under axial compressive load. The self-tapping and self-driving screws with stiffness 620 N/mm were used to effectively connect both the PSS and dry board as composite components. The carbonized steel screws were 25 mm long. [6]

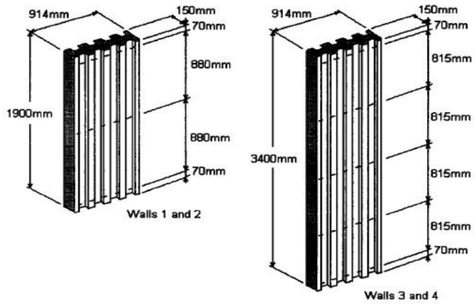

Figure 1: Details of pilot composite wall tested by Wright &Gallocher

Critical sections were located at the upper corners of the opening and in upper section above the opening. The deformation profile of PSSDB wall panel system showed a single curvature deformation profile with maximum lateral displacement at the two-thirds height of wall panel and at critical sections on the upper corners of the square opening. FEA provided an accurate prediction of the structural behavior of PSSDB wall panel system.[7]

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

Othuman& Wang (2011) presented details of experimental and analytical investigations on the structural behaviour of DPSCW panel system with lightweight foam concrete (LFC) core of density 1000 kg/m3 under axial compression. A total of 12 tests were carried out with two steel sheet thicknesses (0.4 mm and 0.8 mm) and three edge conditions of the sheet. The two profiled steel facings were connected by using 6 nos. of 10 mm bolts and nuts in Figure 3. The steel sheets have one of the three edge conditions: (a) they do not cover LFC panel thickness (referred to as no stopping edge), (b) they cover LFC panel thickness but are not joined (referred to as with stopping edges), (c) they cover LFC panel thickness and are joined by welding (referred to as welded stopping edge). The ultimate load and axial stiffness of the composite panel increased with increase in the steel thickness and improved edge condition. The use of steel sheet on both the faces of profiled LFC panel considerably increased the ductility of the panel for all the edge conditions and steel thicknesses.

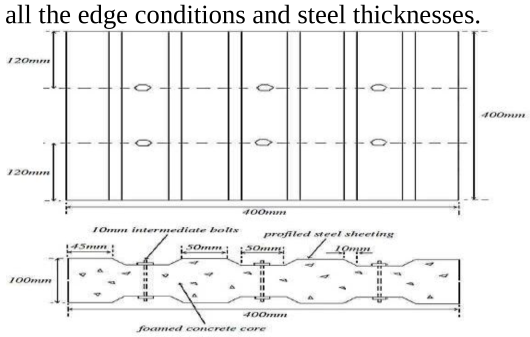

Figure 3:DPSCW adopted by Othuman& Wang (2011)

Taormina (2012) presented a novel form of DPSCW system infill with special non-traditional emerging high performance concrete (HPC) subjected to elevated temperatures and axial loading. Experimental variables included the use of engineered cementations composites as infill and varying temperatures (0°C, 300°C, 400°C, and 500°C). The performance of the walls subjected to varying elevated temperatures was described based on residual axial strength, physical changes, load–deflection response, stress–strain characteristics, concrete cracking, steel sheet buckling and overall failure modes. The use of HPC improved the strength, ductility and durability characteristics of DPSCW system.

Hilo et al. (2015) investigated the axial load behaviour of an existing DPSCW panel filled with normal concrete and strengthened with Embedded Cold-Form Steel Tubes (ECFST) with bar stiffeners in Figure 4. The effects of various variables such as the thickness of the profile sheet and ECFST as well as the shapes of ECFST with and without bar stiffeners tied to ECFST internal surfaces on the ultimate axial load and ductility of CW were investigated by using FEA software, ABAQUS. FEA result of DPSCW panels with different sheet thicknesses proved that the sheet thickness had little effect on the axial load behaviour of the composite wall.

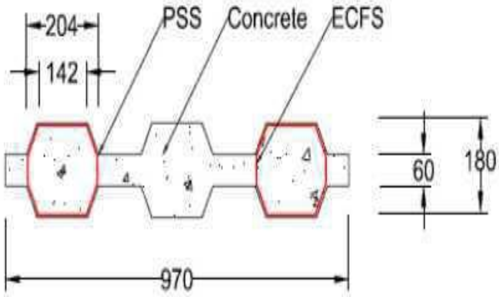

Figure 4:DPSCW panels strengthened with ECFST shapes (Source: Hilo et al 2015)

III. Light Weight Foam Concrete

The main use of light weight concrete in construction is to reduce the dead load of load bearing elements. Cellular concrete, also known as aerated concrete is a light weight material composed of cementations mortar surrounding disconnected bubbles as a result of either physical or chemical processes during which air is introduced into the mortar mixture (Tikalsky et al. 2004). The future need for construction materials to be light, durable, economic and environmentally sustainable was identified by many groups around the world (Jones & McCarthy 2005). With the possibility of producing a wide range of densities (400-1600 kg/m3) and strength achievement of upto 25 MPa, foam concrete (FC) has the potential to fulfill these requirements in the construction industry and is classified as light weight concrete. Though FC was first patented in 1923 (Valore 1954) and its construction applications as non and semi-structural material are increasing only in the last few years.

The basic constituents of the mix are Portland cement, fine aggregate and water. Coarse aggregates are not used and the fine aggregate can be partially or fully replaced with recycled or secondary materials. Foam concrete is a free flowing, self-leveling material created by uniform distribution of air bubbles of size 0.1–1.0 mm (using foaming agents) throughout the mass of concrete. Due to its porous internal structure, FC has very low thermal conductivity value of 0.23 and 0.42 w/mK at 1000 and 1200 kg/m^3 dry densities respectively (Jones & McCarthy 2005) for use as insulating or fire resisting material. Natural or synthetic foaming agents are used to generate foam. Foam stability in concrete is one of the important aspects to ensure the fine and uniform texture throughout the whole hardening process.

Due to lack of standard mix proportioning methods available for FC, trial and error process is adopted to achieve the specified target plastic density (Nehdi et al. 2001), which is the prime design criterion. The compressive strength of FC using fly ash, as a partial/complete replacement for filler, resulted in higher strength to density ratio than equivalent sand based FC mixes and this difference increases with increase in age. Studies reported that 67% of cement can be replaced with graded and ungraded fly ash without any significant reduction in strength (Kearsley& Wainwright 2001). Use of polypropylene fibers was reported (Kearsely&Mostert 1997) to enhance the performance with respect to tensile and flexural strength of FC and mitigate brittleness. The ratio of flexural strength to compressive strength of cellular concrete is in the range of 0.25–0.35 (Valore 1954a). Splitting tensile strengths of FC is higher for mixes with sand than those with fly ash. The static modulus of elasticity of FC varies from 1.0 - 8.0 kN/mm^2, for dry densities between 500 and 1500 kg/m3 respectively (Jones & McCarthy 2005).

Reduced weight with reasonable strength characteristics make FC suitable for structural and semi-structural applications such as partition wall, light weight concrete blocks etc. FC densities of 400–1600 kg/m3 can be attained by appropriate control in dosage of foam for application as structural, partition and insulation material. FC can be made to have adequate amount of compressive resistance, making it possible to use it as load bearing material.

Due to the brittle failure of FC, a suitable method of using FC in load bearing construction would be to use it in composite action with steel, which has high ductility. Because of the low density of FC, pressure on the steel sheet of composite panel would be much lower than using normal strength concrete, allowing lower thickness of sheet. Moreover, the structural light weight FC provides more efficient strength-to-weight ratio for composite panels. Reduction of weight will result in reduced foundations and overall cost benefits. Hence, it is proposed to use FC as infill material in the present study for sandwiching between the profiled steel sheets.

IV. PROPOSED SFCC PANEL

The proposed SFCC panel consists of profiled steel sheets as the facing and FC of density 1200 kg/m^3 as the infill. British Standard, BS 8110: Part 2 (1985) classifies concrete with density of 2000 kg/m^3 or less as lightweight concrete. The use of lightweight FC in composite panel reduces the self-weight of panel by 40% compared to an equivalent brick wall. The configuration of profiled steel sheet and the SFCC panel dimensions are given in Figures 5 and 6 respectively. The thickness of profiled steel sheet is 0.8 mm. The SFCC panel dimensions are 685 mm wide and 130 mm thick (sheet to sheet). The width of the intermediate plate element is kept as 110 mm and the edge plate has a width of 60 mm. The dimensions of the SFCC panel are chosen based on the capacity of the existing loading facilities and the feasibility of specimen fabrication considering availability of materials. The interaction between sheet and concrete is achieved by using through-through mild steel studs.

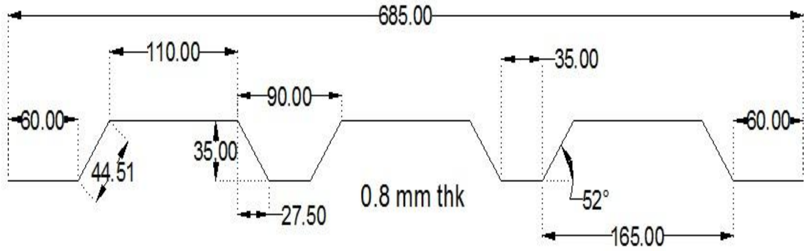

Figure 5: Profiled steel sheet configuration (All dimensions are in mm)

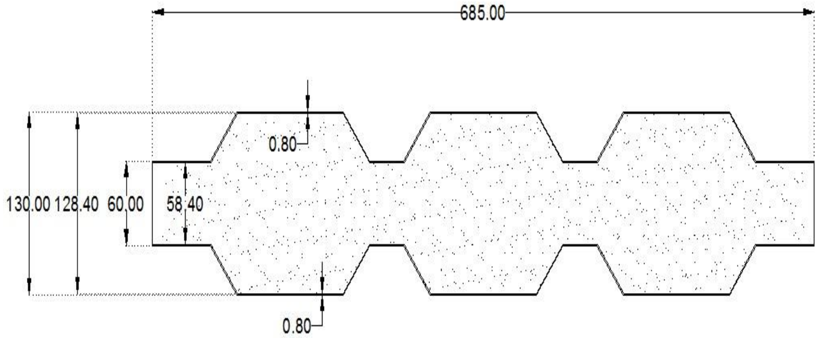

Figure 6:SFCC panel dimensions

Literature studies revealed that adequate load transfer devices in the form of embossments or other mechanical connections between sheet and concrete are necessary to fully mobilize the composite action and to improve the panel performance. Also the axial capacity of panel is highly influenced by early local buckling of steel sheets. In the studies reported in literature, the steel and concrete are loaded together uniformly. The direct compression loading of steel sheet causes the early local buckling of sheets and impairs the panel performance in the post-peak range. Hence, the loading conditions are so made to load the concrete portion only to study the effects of confinement of FC provided by the outer steel sheets and the interconnecting studs on the load-deflection behaviour of 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 × 30 mm × 1 mm) are used for the interconnection.

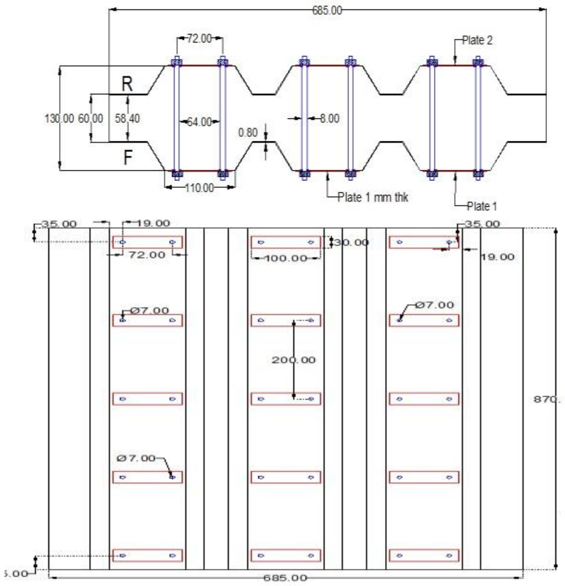

Figure 7: Plan and elevation of Specimen 1

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.

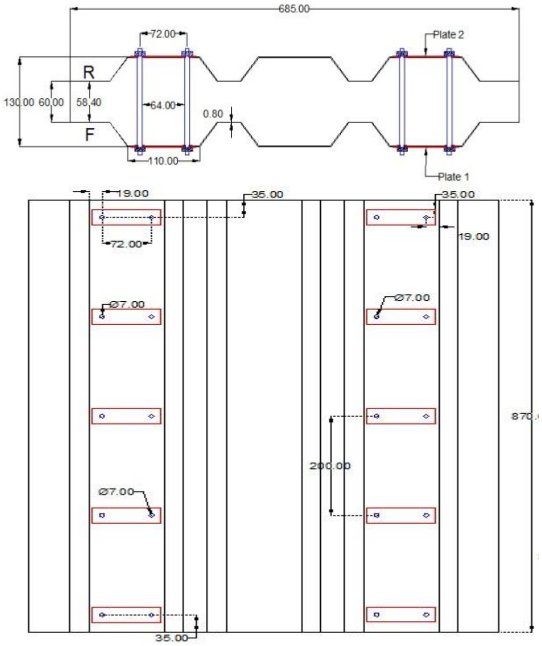

Figure 8: Plan and elevation of Specimen 2

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 × 32 mm × 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 × 63 mm × 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 × 32 mm × 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.

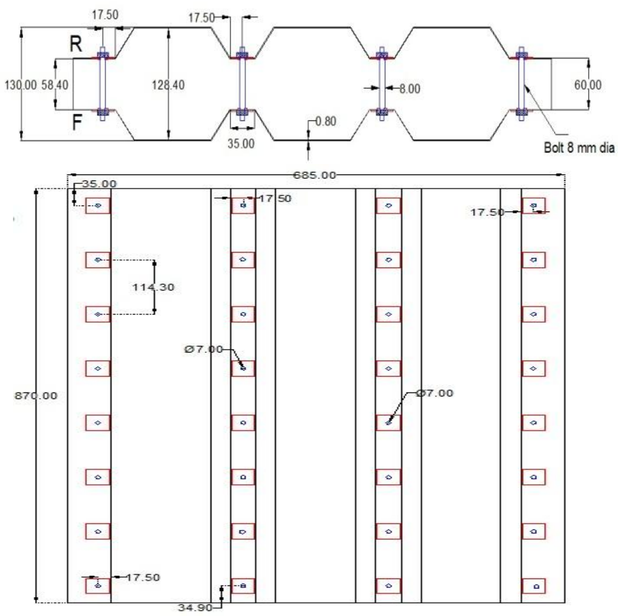

Figure 9: Plan and elevation of Specimen 3

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.

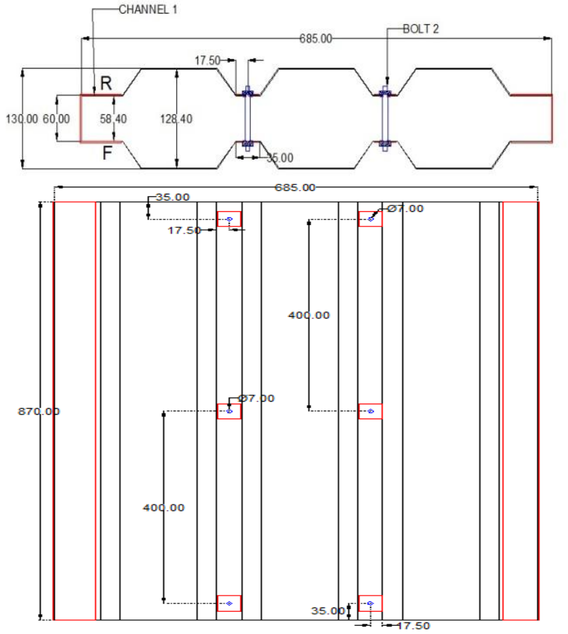

Figure 10: Plan and elevation of Specimen 4

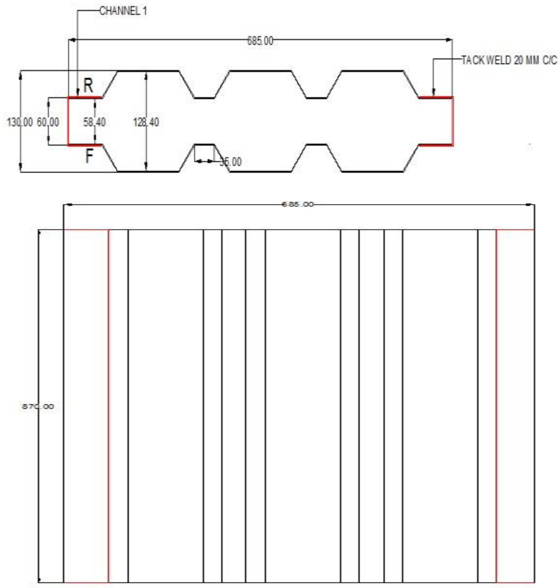

Figure 11: Plan and elevation of Specimen 5

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 kg/m^3 is used as infill material for the present study.

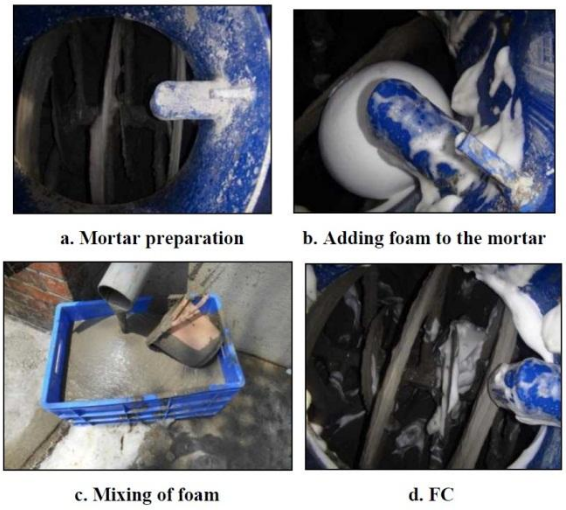

Figure 14: Preparation of FC

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 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 paneSFCC 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.

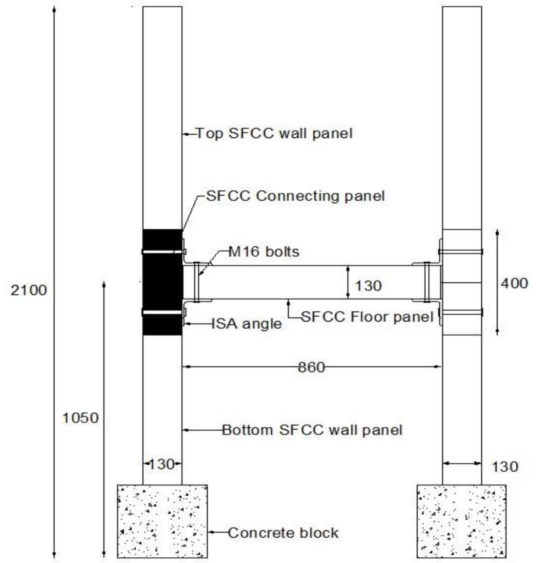

Figure 15: Proposed connection assembly (All units are in mm)

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.

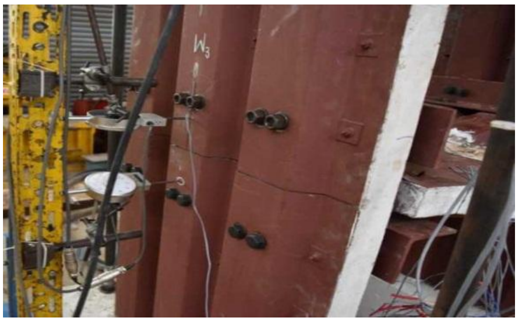

Figure 21: Lateral deflection of SFCC wall panel

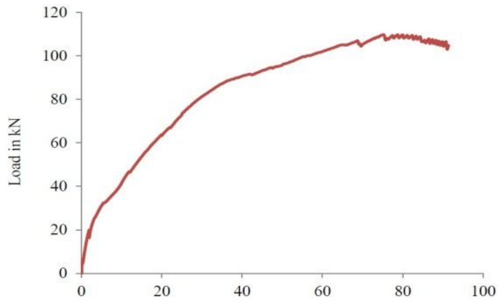

Figure 22: Load versus mid-span deflection of SFCC floor panel

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).

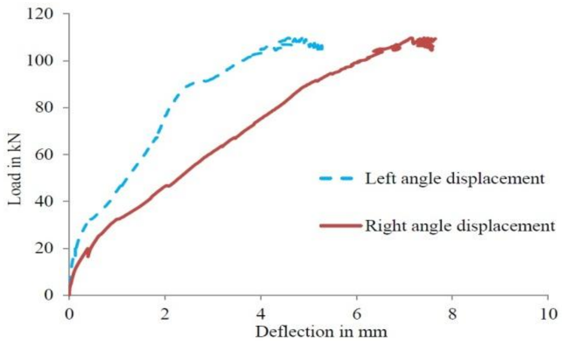

Figure 23: Load versus deflection in angle

The deflection of bottom angles on both the sides of connection assembly are measured by using LVDT's and the corresponding loaded flection 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.

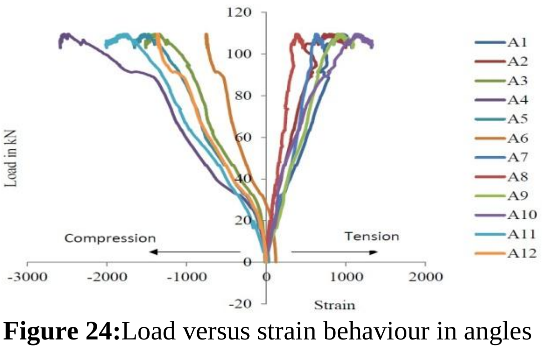

Figure 24: Load versus strain behaviour in angles

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.

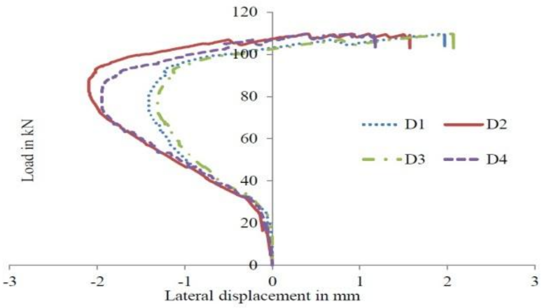

Figure 25: Load versus lateral deflection of SFCC wall panel

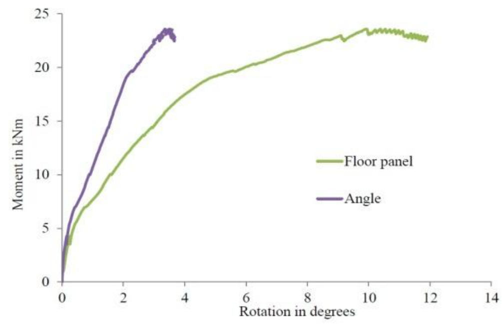

Figure 26: Moment-rotation behaviour of angle and floor panel

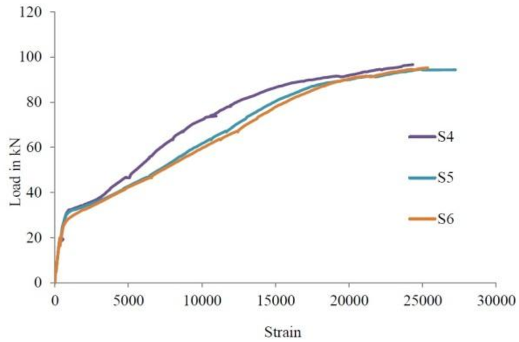

Figure 27: Load versus strain behaviour of SFCC floor panel

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.

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