Inplane Shear Behaviour of Steel – Foam Concrete Composite Wall Panels

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***Abstract-*The concept of a double skin profiled composite shear wall using mechanical shear connectors is one of the new and design methods. In this paper, the behaviour of a new form of composite shear wall system consisting of two skins of profiled steel sheeting and an infill light weight foam concrete core under in-plane monotonic shear loading is presented.Steel sheet-concrete connections are provided by mild steel intermediate fasteners to generate composite action. The experimental investigations on composite shear wall panels have been conducted to obtain information on strength, stiffness, load deformation response, steel sheet-concrete interaction, stress-strain characteristics and failure modes. The intermediate fasteners provided sufficient steel-concrete composite action to prevent early elastic buckling of the profiled steel sheets.**

Keywords: Cold-formed steel, profiled sheets, in-plane shear, light weight foamed concrete, steel-concrete composite wall panel.

I INTRODUCTION

Shear walls plays a crucial role in the energy dissipation and seismic performance of tall buildings. Reinforced concrete (RC) shear walls have been traditionally used as lateral load resistingsystems in many structures. Recently steel plate shear walls have also been used as lateral load resisting system in mid-rise and tall buildings. Despite many economical and structural advantages, both steel and RC shear walls have some disadvantages. The main disadvantage of a RC shear wall is the development of tension cracks in the tension zones and compressive crushing in the localized compression areas during large cyclic loadings. The disadvantage of a steel shear wall is associated with the buckling of the compression zone, which results in reduced shear stiffness, strength, and energy dissipation capacity (Zhao and Astaneh 2004).

A steel-concrete composite shear wall can have the benefits of both steel and RC shear walls to yield the best traits of concrete as well as steel. The concept of composite wall was originated from the floor structure using profiled steel deck and concrete (Wright et al. 1992). Composite walling as shear or core walls in steel frame buildings has many advantages (Hossain and Wright 2004 a,b,c). In building construction stage, profiled steel sheeting can act as a bracing system to the steel frame against lateral loads and also can act as a permanent formwork for infill concrete. During the in-service stage, profiled steel sheets and infill concrete work together to resist lateral loads (Wright et al. 1994; Hossain 1995). A typical composite walling system consisting of two skins profiled steel sheets and a concrete infill is shown in Figure 1. The interaction between the profiled steel sheet and concrete has an important role in thecomposite action of the system (Hossain and Wright 1998). The interface shear bond failure is alimiting criterion for designing this kind of system. The bond between the steel sheet andconcrete can be improved by embossments or using other forms of shear connector. Themechanical interlock at the sheet-concrete interface may govern the brittle or ductile mode offailure of such composite wall panels (Hossain et al. 2004c).

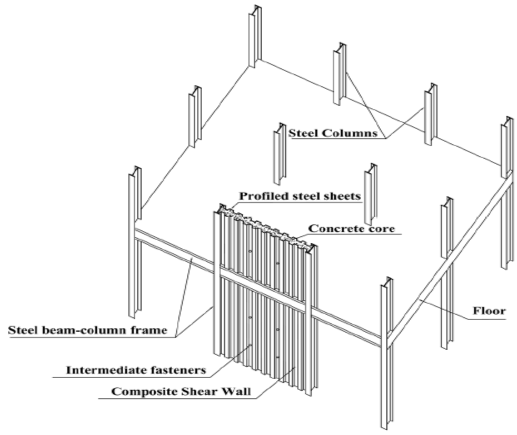

Fig. 1. Schematic layout of steel concrete composite construction

Ozaki et al.(2004)conducted pure in-plane shear tests on steel-concrete wall panels by using specially designed test set up and specimens.The experimental results indicated that as the steel plate becomes thicker,post-cracking shear modulus, yield strength, and maximum strength become higher and shear strain at maximum strength becomes smaller. Hossain and wright(2004 b)studied the possible potential application of composite wailing systems as shear or core walls in steel framed buildings. They reported that the composite walls provide, shear strength and shear stiffness higher than the summation of the individual contributions from the pair of sheeting and concrete core.Varma and Zhang(2011) presented a simple mechanistic representation of the complex in-plane shear behavior of SC composite walls and a design equation for calculating their in-plane shear stiffness and strength.Results proved that the in-plane shear behaviour of SC composite walls can be predicted reasonably and conservatively by using the tri-linear shear force-shear strain response based on the simple mechanics based model. Abdul Hamid and Fudzee (2013)tested specimen of insulated sandwich wall panels (ISWP) under in-plane quasi-static lateral cyclic loading starting with a small percentage of ±0.01% drift and was increased gradually by 0.1% drift until the maximum strength capacity was achieved. The in-plane ultimate lateral strength recorded for ISWP was 5.6 kN at ±1.8% drift.

For the first time in India, composite panels, a novel building component comprising of outer skins of cold formed steel (CFS) sheeting with infill light weight cellular foam concrete was developedat CSIR-SERC. Experimental studies were conducted to study the applicability of proposed light weight panel (Fig 2) to act as wall and floor/roof slabs. Prabha (2013)conducted detailed experimental as well as analytical studies on the axial load carrying capacity of steel-foam concrete composite wall panels. Studies were conducted on 7 specimens (2 profiled foam concrete panels, and 5 composite panels). The study concluded that the capacity of wall panel increases with the degree of confinement provided by the studs and improved sheet edge conditions. In continuation with the studies on axial behaviour of steel-foamed concrete wall panels, further experiments have been conducted to explore its applicability as floor panels (Prabha 2014).The panel configuration, one which exhibited better performance as wall panel, has been adopted for the floor panel.From the experimental studies, the panel is found to have adequate lateral load carrying capacity and ductile deformations as required for floor/roof panels in low-rise residential constructions. The tests revealed that the strength and behaviour aspects of these panels are found to be superior due to the confinement action of steel sheet under axial compression and out-of-plane lateral loads.

Due to its high ductility characteristics, the structural response of panel needsto be studied under static in-plane shear loading. Hence a pilot study is conducted on the developed composite wall under in plane shear loading.

Fig. 2. Proposed composite panel [2]

II DETAILS OF THE COMPOSITE SHEAR WALL PANEL

The configuration of profile sheet and the plan of composite wall panelare shown in Figure 3.The dimensions of the wall panels are chosen based on the capacity of the existing loading facilities and the feasibility of specimen fabrications.The wall panel dimensions are 1250 mm high, 685 mm wide and 130 mm thick. The thickness of profile sheet is 0.8 mm and does not have embossments. The mild steel studs (f_y-250MPa) of 8 mm diameter are used for the interconnection between sheets. The specimen is connected by using 16 studs in the smaller plate width portion at a spacing of 290 mm in the height direction. The material properties of the sheet are obtained from tensile test. The average yield and ultimate stress of the sheet obtained is 190 MPa and 320 MPa and the young's modulus is $2x10^5$ MPa.

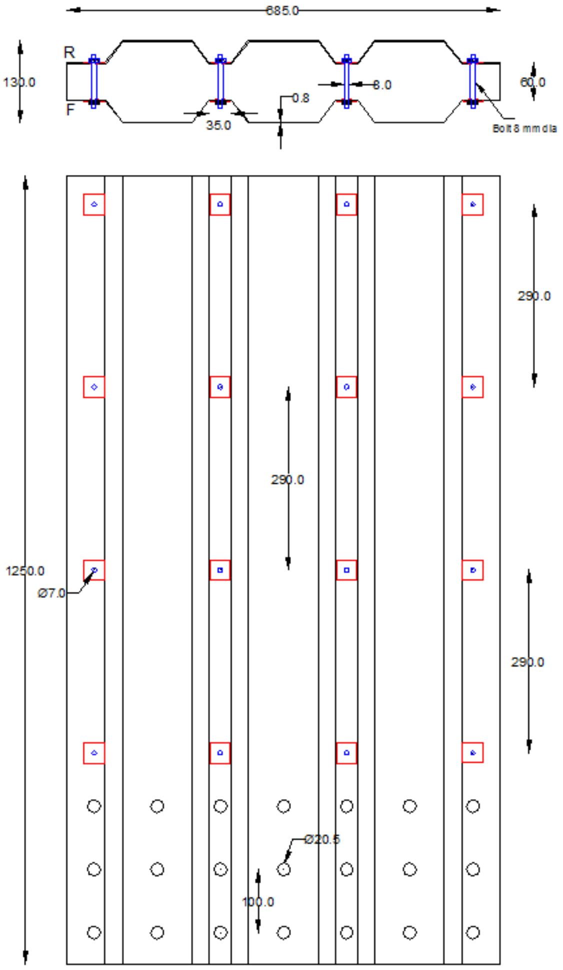

Fig. 3. Plan and elevation of specimen

III LIGHT WEIGHT FOAM CONCRETE (LFC) AS INFILL MATERIAL

The infill concrete in composite panel serves the main purpose of restraining the inward buckling of sheets to a certain extent. Light weight foam concrete (LFC) is a type of porous concrete, produced by mechanical mixing of foam (bubbles of size 0.1–1.0mm) prepared in advance with the concrete mixture composed of cement-sand matrix. Foam is prepared in a special device called foam generator and later mixed by using special mixer. By controlling the dosage of foam, density range of 200–1600 kg/m^3 can be attained for application as structural, partition and insulation material. As observed from literature, the major limitation of LFC is its brittle failure. In load bearing construction, LFC can be used in composite action with steel, which has high ductility. Hence, LFC of density 1300kg/m^3 is selected as infill material for present study. Rheocell – a Protein based chemical is used for the preparation of foam. One kg of chemical can produce 660 litres of foam. Ordinary Portland cement (OPC) of 53 grade conforming to IS:12269 (1987) is used. In addition to cement, flyash is also used as supplementary cementitious material. Fine sand passing through 1.18 mm sieve and conforming to IS:383 (1970) is used for LFC 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 step by step preparation of LFC is shown in Fig 4. A concrete block of size 785x300mm is casted around the panel for a height of 285 mm, so as to connect the panel to the testing frame. The concrete block is alone water cured for 28 days to achieve the target strength. The casted panel with the block is shown in Fig 5. The cubes (100x100x100mm) and cylinders (100mm dia and 200mm length) are tested on the day of testing the wall panels (80 days). The average compressive strength of cube at the 80^{th} day is 6.4 MPa and the split tensile strength is 1.08 MPa. The young's modulus of LFC is 4500 MPa.

(a) Mixing of foam to mortar

(b) Foam Concrete

Fig. 4. Production of Foam Concrete

Fig. 5. Casted panel with base concrete

IV EXPERIMENTAL INVESTIGATIONS

Experimental studies are conducted on steel-foam concrete composite panels to study their in-plane shear behaviour under static loading. The cantilever type of test set up along with instrumentation is shown in Fig 6. Special fixtures are fabricated to connect the composite panel to the reaction frame. The composite panel is sandwiched between two plates by using 21 nos. of HTS studs of dia 16mm and 8.8 grade. The panel sandwiched between the plates is then connected to one of the columns of the reaction frame by using 15 nos. of HTS studs of dia 16mm and 8.8 grade. The panels are instrumented with 6 rosettes(B-1,B-2,B-3,T-1,T-2,T-3) and 6 single strain gauges(S-1,S-2,S-3,S-4,S-5,S-6). Three rosettes(B-1,B-2,B-3) are pasted at 150mm from the bottom of the panel and remaining three rosettes (T-1,T-2,T-3) are pasted at 300mm from the top of the panel. The position of strain gauges are shown in Fig 7. One LVDT is placed at the bottom portion to measure the top displacement of the wall under shear loading. The panels have been tested by applying in-plane static shear loading on the top portion of the composite panel for a width of 320 mm using the loading plate connected to the actuator head. A computer aided data acquisition system is utilized to record the data from strain gauges and LVDTs. The monotonic tests have been performed based on displacement control by pushing top of thecomposite wall panel at a constant rate of 0.5 mm per minute until the failure of the panel.During loading history, in-plane shear load-displacement response, strain development, steel sheet buckling and overall failure have been observed.

Fig. 6. Test set-up and instrumentation

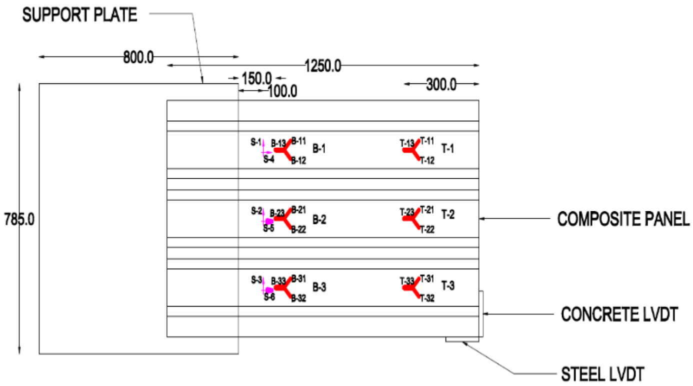

Fig. 7. Location of strain gauges

V RESULTS AND DISCUSSIONS

The shear load versus top wall deflection behaviour of the composite panel is shown in Fig 8. The load - deflection curve is linear till 59 kN. Region 1-2 in the curve indicates the crushing of foam concrete followed by compression buckling of steel sheet at the base.Region 2-3 indicates in-plane loading initiated compression buckling of the sheeting at the base followed by local crippling of sheets along the studs in the width direction leading to dropping of load. Further application of load caused redistribution of load to other portions and the panel sustained almost 90% of the peak load with increase in ductile deformations (Region 3-4). The failure of shear wall (Fig. 9) initiated due to cracking of foam concrete followed by yielding of sheet associated with buckling of profiled steel sheet. The development of diagonal tension band bounded by the profiled ribs leading to loss of profiled geometry. The diagonal cracks in foam concrete indicated the shear action. The support concrete block remained uncrushed. High ductility is observed for all the specimens after the failure load. The ultimate load capacity and stiffness of the wall specimen are 63 kN (at 13 mm displacement) and 4.84 kN/mm, respectively.

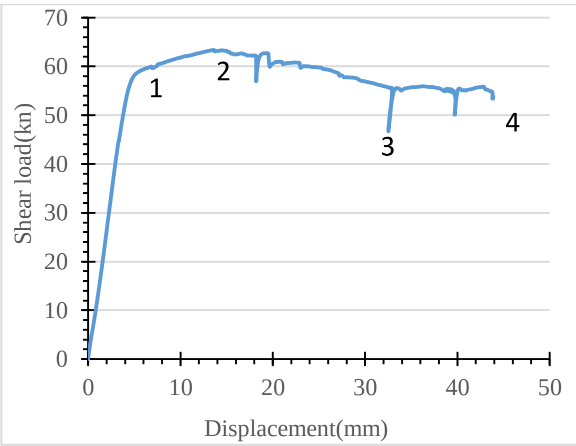

Fig. 8. Shear load versus displacement response of wall panel

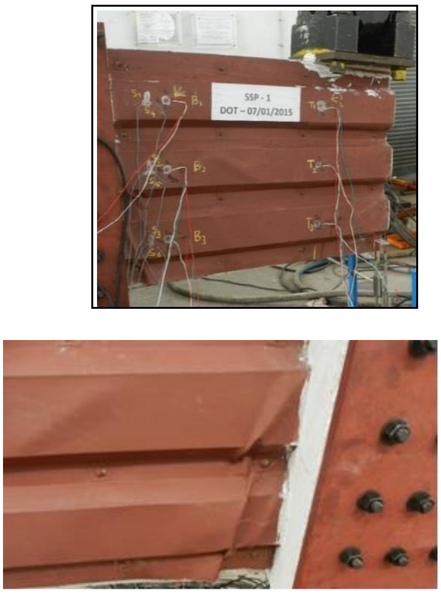

Fig. 9. Failure of shear panel under static loading

The maximum and minimum principal strains at the profiled steel sheet (calculated from the rosette strains during the loading history) and corresponding stresses are shown in Fig. 10. The maximum and minimum principal stresses are calculated from principal strains based on following equations.

$$\sigma_{p1} = \frac{E_S}{1-\upsilon_S{}^2}(\varepsilon_{p1} + \upsilon_S\varepsilon_{p2})(1)$$

$$\sigma_{p2} = \frac{E_S}{1-\upsilon_S{}^2}(\varepsilon_{p2} + \upsilon_S\varepsilon_{p1}) \qquad (2)$$

where, σ_{p1} and σ_{p2} are maximum and minimum principal stresses, $\epsilon_{p1}$and ϵ_{p2} are maximum and minimum principal strains, *Es* is modulus of elasticity of steel plate (*Es* = 2×10^5MPa) and υ_s is Poisson's ratio of steel (0.3).At 24 mm displacement, a sudden increase in the principal stresses is observed possibly due to initiation of cracks in concrete and debonding of the steel sheet and concrete interface.The variation of maximum/minimum principal stresses at the rosette locations are presented in Fig. 10.The absolute maximum/minimum values of the principal stresses at the base of the wall (B2) are almost equal and showed the pure shear condition at the base of the composite shear wall panel.

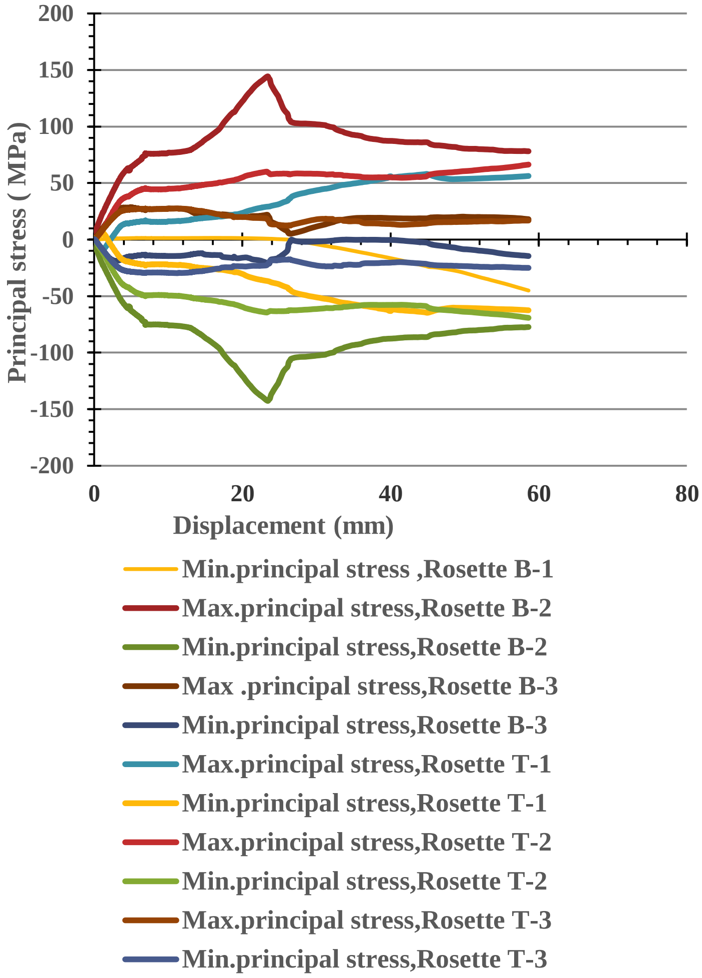

Fig. 10. Maximum and minimum principal stresses

The maximum shear strain and stress are derived from the following equations.

$$\gamma_{max} = \varepsilon_{p1} - \varepsilon_{p2} \qquad (3)$$

$$\tau_{max} = \frac{E_S}{1-\upsilon_S}\gamma_{max}(4)$$

where,$\gamma_{max}$is the maximum shear strain,$\tau_{max}$is the maximum shear stress.The variation of maximum/minimum principal strains and stresses at the rosette locations of the wall are presented in Figs 11 and 12.The values of principle stress and shear stress at the location rosette strain gauges reached the failure stress according to von-Mises yield criterion before wall panel failure showing adequacy and effectiveness of the provided intermediate steel sheet-concrete fasteners.The calculated shear strain and stress at the rosette locations are shown inFigs. 10 and 11 respectively. The maximum shear stress reached to 320 MPa which is higher than the maximum theoretical shear yield stress in the steel sheet based on von-Mises yield criterion(110 MPa). This indicates that the failure load of the wall is due to the shear yielding of steel.The global buckling of the sheets is prevented by using adequate intermediate fasteners (providing sheet-concrete interface connection) along the height and width of the composite wall for the enhanced shear resistance.

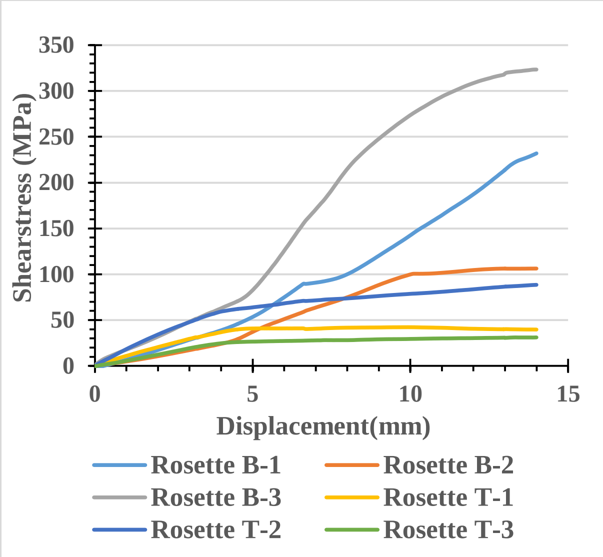

Fig. 11. Shear stress versus displacement

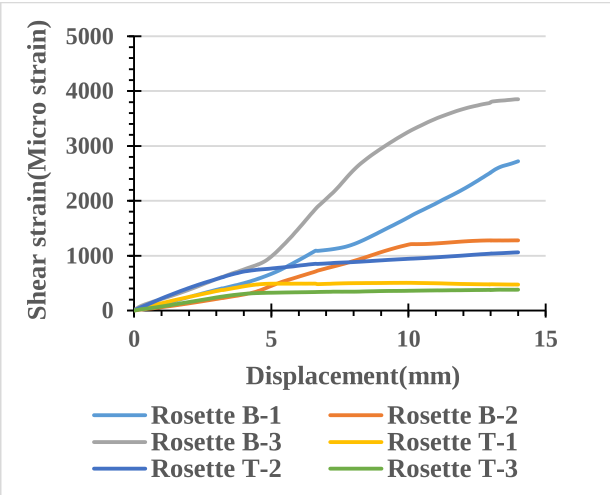

Fig. 12. Shear strain versus displacement

VI CONCLUSIONS

A composite panel made of cold formed steel sheeting as skin and lightweight foam concrete as infill material has been developed and tested under monotonic in-plane shear load. This research provided information on the strength, stiffness, load-deformation response, interaction between profiled steel sheets and concrete, and also the possible failure modes, based on the experimental investigations. The number of steel-concrete intermediate fastenersalong the height and width of the specimens provided sufficient steel-concrete composite action which prevented early elastic buckling of the profiled steel sheets and initiated failure due to steelyielding. The ductile behaviour is observed after post-peak with controlled lateral deformations of the panels due to steel sheets interconnected with studs. The ccomposite shear wall exhibited higher shear resistance in static loading. Hence the proposed composite shear wall with enhanced ductility would be a suitable alternative for other types of shear wall to construct buildings in areas of high seismic risk which has to be conformed from further experimental studies under cyclic loading.

ACKNOWLEDGMENT

This paper is published with the kind permission of the Director,CSIR-SERC, Chennai, India.

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