CHAPTER 1

INTRODUCTION

1.1 GENERAL

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 is 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. 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.

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 composite construction has the potential in improving the overall performance of buildings, but has found little application in residential construction in India due to the complexities involved in analysis and design.

1.2 PRECAST SANDWICH PANELS

The trend for stronger and lighter product is becoming increasingly important in the construction industry. Light weight precast sandwich panel has become an alternative to traditional brick wall construction due to its sustainability and environmental friendly aspects. Sandwich panel is a layered structural system made of low density core material and high strength facing material. Various forms of sandwich construction can be obtained by combining different wythes such as concrete, steel, aluminium or carbon fiber material and core or insulation materials. The core layers may be composed of light weight concrete, fibre reinforced composite, balsa wood, foam, polymer foam or aluminium honeycomb concrete. The combination of these materials lead to optimum design of composite panels for particular application.

Steel and concrete are the popular combination, where two distinct materials complement each other by effective utilization of both the material properties. Steel brings ductility into the structure, whereas the concrete serves as buckling restraint, protects corrosion and provide thermal comfort at high temperatures. These two materials are generally connected by headed
studs or other form of connectors. Some of the steel-concrete composite structural elements that have been extensively researched in the past years are composite deck slabs, beams and columns. Composite slabs comprises of profiled steel decking at the bottom and reinforced concrete cast on top. The deck acts as formwork during construction and as tensile reinforcement after construction. The composite beam is constructed by using rolled steel section with cast in place or precast reinforced concrete slab. The composite columns are of three types such as concrete-filled, concrete-encased and battered sections. It is used as load bearing member in composite framed structures. Steel-concrete composite construction though popular in industrial sectors for over two decades due to the strength and stiffness that can be achieved with minimum use of dissimilar materials is yet to be explored in residential construction. Superior seismic performance characteristics to resist lateral loads can be achieved by proper configuration of steel-concrete composite system.

1.2.1 Double Skin Composite Construction (DSCC)

Double Skin Composite (DSC) systems are basically steel-concrete-steel sandwich elements that consists of unreinforced concrete core sandwiched between two steel plates. Double Skin Composite Wall (DSCW) is a novel form of composite construction, which consists of a core of concrete sandwiched between relatively thin steel plates. DSCW has the benefit of acting as bearing, retaining, partition and shear walls due to its unique combination of materials. The applications of DSCW system in buildings are presented in Figure 1.1. DSCW system is classified into three types based on DSCW shape namely Double-Skinned Profiled Steel Sheet Composite Wall (DPSCW), Double-Skinned Flat Steel Sheet Composite Wall (DFSCW) and Profiled Steel Sheet-Flat Sheet Composite Wall (PFSCW). DPSCW is a new type of Composite Wall (CW) that consists of two profiled
steel sheets (PSSs) infilled with concrete (Figure 1.2a). It has the potential for application as a bearing, retaining and shear wall to resist axial, lateral and cyclic loads. The development of DPSCWs came about as an extension of the composite flooring system developed by Wright et al. (1989), which is currently popular worldwide.

Figure 1.1 Applications of DSCW system in buildings (Source: Rafiei et al. 2015 & Nie et al. 2014)

This type of walling system was used as core wall to stabilize the steel building frames in buildings as shown in Figure 1.1 although it has potential to be used in load bearing construction. This type of CW has the benefits of having both PSSs and infill concrete that can resist axial loads, such as reinforced concrete thin walls, which are now well-known and widely used (Hossain & Wright 2005). DFSCWs typically consist of thick or thin concrete walls with two exterior steel face plates (Figure 1.2b) connected by using mechanical connectors and stiffener/batten plates. Many studies have been conducted on the performance of DFSCW for use in tunnels, blast-resistant shelters, gas-retaining structures, building structures and as shield
walls in third-generation nuclear power plants (Bruhl et al. 2015). PFSCW system consists of two sheets filled with or without concrete, where one of the sheets is profiled cold formed sheet and the other is flat sheet made of dry board, plaster board, PRIMAflex, cemboard or plywood (Figure 1.2c). Both of the sheets are attached by self-drilling, self-tapping screws or other connection techniques. PFSCW system was used widely as flooring and bearing wall systems (Ahmed et al. 2000) in the light weight construction of buildings and office spaces in factories.

During construction stage, profiled steel sheet act as a bracing system to the steel frame and permanent formwork for infill concrete. During the in-service stage, profiled steel sheets and infill concrete work together to resist lateral loads (Wright & Gallocher 1995). The interaction between the profiled steel sheet and concrete has an important role in the composite action of the system (Hossain & Wright 1998). The interface shear bond failure is a limiting criterion for designing this kind of system. The bond between the steel sheet and concrete can be improved by embossments or using other forms of shear connector. Numerous shear connections such as steel headed studs, welded channels, bolts, hooks, tie rods, stiffener/batten plates, through-through bolts and self-drilling screws are used to achieve the composite action. The shear connectors perform the function of holding together the sheets and enhances the stability of steel plates by preventing buckling. The efficiency of the mechanical interlock at the sheet-concrete interface govern the brittle or ductile mode of failure of CW. CW as shear or core walls in steel frame buildings has many advantages (Hossain & Wright 2004, 2004a).

Once the concrete hardens, axial, lateral and in-plane loads will be carried through both the steel and concrete. The preferred design criteria is the failure of panels through yielding of steel sheets rather than buckling to optimize the shear resistance and ductility of the proposed composite systems.
a. Double-skinned profiled steel sheet composite wall (DPSCW) (Source: Howard Wright 1998)

b. Double-skinned flat steel sheet composite wall (DFSCW) (Source: Hongsong Hu et al. 2012)


Figure 1.2 Types of DSCW systems
These criteria can be easily achieved by controlling the spacing of intermediate steel–concrete interface fasteners by checking the buckling capacity of steel sheets. In addition to the structural benefits, the use of profiled CWs enable reduced wall thickness for increased floor areas in buildings. These walls can be used in retrofitting and rehabilitation of existing steel and concrete structures. Reduction in overall weight of the structure reduces foundation costs and faster construction facilitates quicker return on the invested capital. Hence, overall use of composite panels is cost effective based on life cycle cost analysis.

1.3 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 cementitious 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/m$^3$) and strength achievement of upto 25 MPa, foam concrete (FC) has the potential to fulfil 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-levelling 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/m³ 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 (Kearsley & 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 to 8.0 kN/mm², 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.

1.4 MOTIVATION OF RESEARCH

In the last three decades, prefabrication has been applied to small houses and tall building construction and precast concrete panels have become one of the widely used structural elements in construction system. Additionally, the structure of a precast building should be able to withstand dynamic load cases, particularly seismic load is becoming an important consideration. Reinforced concrete and steel plate shear walls are traditionally used as axial or cyclic load-resisting systems in structures such as mid and high-rise buildings. Out of the three DSC systems, DPSCW system is preferred for seismic resistant structures due to the profiled sheet rather than the flat sheet, which provides improved shear capacity and ductile resistance to cyclic loads (Qian et al. 2012). DPSCW panels have been used so far as partition and shear walls to stabilize steel frame building structure, although it has potential to be used in load bearing construction and blast resistant structures. If designed appropriately, these panels could serve as an alternative to load carrying brick walls and conventional floor/roof slabs and therefore low-rise buildings can be constructed by using these panels.
The self-weight of sandwich panels made of conventional concrete represents a very large proportion of the total load on structure and does not contribute to strength over weight ratio reduction. However, construction in earthquake prone areas demand a lightweight system with high strength and ductility for in-plane and out-of-plane loading. Development of innovative precast lightweight structural panels can make housing safer, durable, stronger, energy efficient, comfortable, affordable and faster constructions. FC is one type of cellular lightweight concrete which can be used as infill material in sandwich panel to improve the performances such as dead load reduction, fire resistance and thermal conductivity of buildings. The compressive strength of FC using fly ash as filler has high strength to density ratio than equivalent sand based FC mixes. Further, the cost can also be reduced by replacing large volumes of cement with Pozz-fill, without significantly affecting the long-term strength.

The use of FC in sandwich panels is not investigated adequately, where enormous reduction in the weight and savings in the energy is feasible. Studies on the effect of confinement action of FC in the composite panel strength are inadequate, which is essential for load bearing panels. So far, many prefabricated systems have been developed and adopted in construction industry. Till now, no research work is reported on the connection between composite panels. Hence, there is need and scope for development of lightweight steel-foam concrete composite panels and their connections and to conduct experimental and analytical studies on these panels under different loads.

1.5 SCOPE AND OBJECTIVES OF PRESENT RESEARCH

The scope of the present research work is to develop prefabricated lightweight Steel-Foam Concrete Composite (SFCC) panels and the
connections for seismic-resistant low-rise buildings. The objectives of the research work are as follows:

- Development of profiled SFCC panel with appropriate load transfer mechanism
- Experimental studies on the behaviour of proposed SFCC panel under axial compression, flexural and in-plane lateral loads
- To evolve a connection assembly to connect SFCC wall and floor/roof panels and to experimentally evaluate its performance
- Numerical studies for simulating the behaviour of SFCC panels under axial compression, flexural and in-plane lateral loads and the connection assembly
- To propose simplified expressions for evaluation of capacity of SFCC panel under axial compression, flexural and in-plane lateral loads

The scope of the present research is limited to studies at component level only for the specified load cases.

1.6 ORGANIZATION OF THESIS

The thesis is organized into seven chapters.

Chapter 1 presents brief introduction to the topic of research, motivation, scope and objectives of the present study.

Chapter 2 presents a detailed literature review on the development and performance of various types of double skin composite structural systems
under different loading conditions and the potential use of foam concrete as infill material.

**Chapter 3** explains the experimental investigations conducted on the five different arrangement of proposed SFCC panels subjected to axial compression and recommends a better performing arrangement for further studies. Numerical modeling and simplified expressions for the axial strength evaluation of SFCC panels are also explained in this chapter.

**Chapter 4** presents the details of experimental and numerical studies on SFCC panels subjected to flexural load with two different types of infill concrete namely plain foam concrete and fibre reinforced foam concrete. Simple expressions for evaluation of flexural capacity of SFCC panels are proposed.

In **Chapter 5**, the experimental studies on SFCC panels subjected to monotonic and cyclic in-plane lateral loads are presented. This chapter also presents the details of numerical studies on SFCC panel under monotonic in-plane lateral loads and comparison with the experimental results. Simplified expressions for evaluation of shear strength are proposed based on the studies.

In **Chapter 6**, the details of evolution of the connection assembly to join SFCC panels and the related experimental studies are discussed. The experimental study is complimented further with numerical studies.

**Chapter 7** presents the contributions and conclusions arrived based on the present research work along with suitable recommendations for future work.