CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the past few decades, various new construction materials and techniques have evolved in the construction industry. In this context, it becomes necessary to throw light upon ferrocement which is almost as old as reinforced concrete, an effective and durable construction material. Though the concept of ferrocement is not new, its real development and utilization has been significant only in recent years. It is increasingly being put to numerous applications including construction of new structures and rehabilitation of existing structures.

Ferrocement is not to be seen only as a low cost material. An investigation of its performance, which showed high tensile strength due to meshes embedded in mortar, reveals that it can be used effectively for high quality construction. The use of advanced technologies can improve the applications of ferrocement as a high quality, durable and cost competitive construction material (Naaman and Hammoud 1992).

Ferrocement has a high tensile strength and high modulus of rupture. Its tensile strength can be of the same order as its compressive strength. It has a high specific surface of reinforcement which is the same as or twice that of reinforced concrete. The greater surface area to volume ratio of reinforcement results in higher cracking strength for ferrocement. Ductility,
which is an important characteristic of a structure to withstand an earthquake, increases with an increase in the volume fraction and specific surface of reinforcement, unlike reinforced cement concrete where lower ductility is observed with an increase in reinforcement ratio. The crack width and spacing are less in ferrocement due to the presence of transverse reinforcement. The close spacing of wire meshes imparts ductility to the brittle cement mortar matrix and leads to a better crack arresting mechanism. The multiple cracking process of ferrocement under tension differs from reinforced concrete. At service loads, ferrocement shows a higher number of cracks of small crack-width compared to fewer but wider cracks in reinforced concrete. Because of the above facts, thin ferrocement slabs can be used for roofing/ flooring purpose.

Ferrocement is widely used in marine, terrestrial and housing applications. Owing to its water tightness, thin walls, light weight and impact resistance it is used in the construction of boats, floatation buoys, docks and barges. It is also used in the construction of water tanks, sedimentation tanks, bus shelters, grain storage bins, silos, biogas digesters, etc. The housing applications of ferrocement include construction of water tanks, precast wall panels, roof panels, sandwich panels, hollow core slabs, sunscreens, repair and rehabilitation of existing housing elements.

Under housing applications, an evaluation of its economic viability was carried out in the past comparing ferrocement roofing units and other construction methods. It is observed that ferrocement roofs provide cheap but durable solution. At the same time, they also offer more stability and permanence to the structure as compared to other low cost materials.
1.2 PRECAST FERROCEMENT HOLLOW ROOF SLABS

Ferrocement hollow slabs are one of the alternatives available for roof/floor slabs in housing applications (Koncz 1968, Kushwaha and Duggal 1999, Paramasivam 2002); since they lend themselves to precasting, the precast elements can be prepared and assembled with ease to the final shape in less time and can be used in bad weather conditions.

The stress is zero at the neutral axis of the cross section of a slab under bending and is maximum at the extreme fibres. Hence providing a minimum area close to the neutral axis is sufficient than at the extreme fibres. This concept is made use of in the construction of hollow slabs which can replace the conventional slab of uniform thickness. As the flanges are thin in case of hollow slabs, it is more appropriate to use ferrocement with meshes and skeletal steel as it possesses high tensile strength and ductility. The meshes in ferrocement slabs provide better bonding of the cement matrix and can prevent spalling of cement matrix which is generally the problem observed in the conventional reinforced concrete roof slabs.

In practice, structures are designed to incorporate both precast and in situ reinforced concrete. The core areas of multi-storey buildings are usually constructed of in situ, but the rest of the construction may be precast. The flooring can be precast ferrocement hollow slabs used in conjunction with in situ concrete frames. These floor units may be designed specifically for the structure or may be part of a manufacturer’s standard range of products.

One of the main advantages of precast ferrocement hollow roof slab construction is that the slabs can be precast at one place, transported to site and erected with ease, thereby saving time and enabling faster progress of work (Hartland 1975). The construction is rapid and so the promoter is able to
take possession of a building in a shorter space of time after the site is made available. Generally, there will be a reduction in site costs as scaffolding, shuttering and other temporary supports will not be required in such quantities as for in situ concrete work. Units made can be of excellent standard due to the use of a trained and specialized labour force working under factory conditions; also, units may be cast in the most favourable orientation, to simplify shuttering and to obtain improved finishes on the most important faces of units. The finished product can be inspected before it is erected and there is an opportunity to reject any substandard work before incorporation in the structure.

Ferrocement hollow cored slab units conform to the serviceability requirements given by IS456 – 2000 code for deflection and crack width and can be advantageously used for roofing. Hollow slab panels are about 30% lighter in weight when compared to solid slabs, thereby leading to lighter supporting system, foundation and overall economy (Kaushik et al 1986). Circular cores are preferable owing to its easy formation and minimum stress concentration. Hollow cores are provided in the slab for providing thermal insulation and taking electrical conduit wires and accessories. The cores in the slab provide access for the service lines such as electricity cables, water pipe lines and gas lines to be taken through them in a concealed manner (Bhattacharyya et al 2003). They can be easily precast without any skilled labour. The hollow section is mainly to restrict the passage of heat from outside to inside. This is achieved due to the presence of the trapped air in the hollow space which is a bad conductor of heat (Mathews et al 1991).

Ferrocement hollow slabs can be used safely as floors in multistorey buildings (IS 10297-1982, IS 4386-1993). Floor units of hollow slab are preferable in cases where a flat soffit is required. The behaviour of the member under loads has been excellent. Roofing element made of this
section consumes lesser quantity of materials. Hence, when compared to conventional roof, a saving of about 30% of cementing material is noted. This type of roofing is generally simply supported over load bearing walls to achieve economy.

1.3 CYCLIC LOADING OF FERROCEMENT HOLLOW SLABS

Ferrocement hollow slabs are recommended for flooring and roofing units in earthquake prone areas since they have lesser self weight compared to reinforced cement concrete and hence attract lesser inertia force during an earthquake. Ferrocement has been widely accepted as a construction material for roof slabs, but only limited research has been done on the flexural behaviour of ferrocement hollow slabs. A few investigations have been done on ferrocement hollow slabs to study their behaviour under monotonic loading.

Structural elements of increased ductility have become an imperative need in the present scenario, especially after the revision of seismic maps in various countries. The researcher believes that it is important to study the performance of hollow slab under earthquake loads. When these slabs are subjected to repetitive stresses as in cyclic loading (Parameswaran et al 1987), failure can occur at a load less than the failure value obtained for monotonic loading. Therefore an experimental investigation was carried out by the researcher on the behaviour of one way ferrocement hollow slabs under one way cyclic loading to test whether these slabs can undergo large plastic deformation and absorb large strain energy so that they are suitable for earthquake prone areas. About fifteen slabs measuring 2000 mm × 540 mm × 140 mm and ten slabs measuring 3000 mm × 770 mm × 140 mm with circular cores were cast, cured and tested to study their flexural behaviour under cyclic loading.
The slabs should be capable of withstanding any type of loading like seismic, wind load or operation of machinery in addition to conventional dead and live loads. Therefore, the ferrocement hollow slabs were tested under monotonic as well as cyclic loading. Their first crack strength, ultimate strength, deflections, curvature, propagation of cracks and the crack width, stiffness, ductility, toughness and energy absorption capacity under these loadings were investigated.

1.4 HYBRID FERROCEMENT COMPOSITE SLABS

Ferrocement often suffers from spalling of matrix cover and delamination of extreme tensile layer at high reinforcement ratio, resulting in premature failure. In case of bending applications of ferrocement, it is only the extreme layers of mesh that contribute the most. Therefore, the number of layers of mesh can be limited to two or three for thin elements. Adding discontinuous short fibres to cementitious matrix will add to the strength and toughness of the composite in bending and help increase the inter-laminar shear resistance at the interface of the extreme layer of mesh.

Fibres also impart other properties such as reduced crack width and spacing and improved impact resistance. Millions of fibres that are introduced into the mortar mix gives multidimensional secondary reinforcement. Also adding discontinuous short fibres to cementitious matrix (ACI Committee 549 1997), which could bring significant improvement in ductility (Balaguru and Shah 1992) as well as moderate increase in tensile strength, can solve the problem of spalling of matrix cover under service loads. As a result of using fibres in combination with meshes, a hybrid composite with optimized properties can be obtained (Ramesh et al 2003). The ultimate load carrying capacity of the structural element is enhanced by introducing fibres. In this thesis work, the performance of ferrocement hollow slabs reinforced with hexagonal galvanized steel wire mesh and discontinuous polyester fibres
along with skeletal steel under earthquake forces is investigated by applying cyclic loading (Arif et al 2001) and the strength, ductility, deflection and energy absorption capacity is investigated. The mesh and the fibres used are cost competitive and a hybrid composite with optimized properties was aimed at.

1.5 DURABILITY OF HYBRID FERRROCEMENT HOLLOW SLABS

Durability of a structure is measured by its resistance to weathering action, abrasion, chemical attack, cracking or any other process of destruction. It is important from the point of view of both serviceability and safety, since poor durability causes degradation in performance and reduction in the useful life of the structure. For ferrocement to be durable, it is essential that the component materials, namely mortar and wire-mesh reinforcement, must be durable with time when exposed to any environment (Mathews et al 1993).

The researchers experimented on ferrocement hollow roof slabs to conclusively prove their durability in construction. Hence it was attempted to investigate the durability of the ferrocement hollow slabs under cyclic loading after undergoing alternate cycles of drying and wetting (Fwa and Paramasivam 1987).

The results of the experimental investigation concerning the first crack strength, stiffness and crack width of cored ferrocement roof slabs subjected to alternate drying and wetting cycles when tested under cyclic loading are discussed in this work. It was proved at the end of the investigation that for a duration of up to 90 cycles of alternate drying and wetting, the ferrocement slabs retained their first crack strength, stiffness and ultimate strength under cyclic loading.
1.6 ANALYSIS OF FERROCEMENT HOLLOW SLABS

The analysis of hollow ferrocement sections in flexure was carried out using the conventional reinforced concrete theory as the mesh layers and skeletal reinforcements were concentrated near the edges. However, the effect of the wire mesh and fibres were included in the calculation of the resistances of the section under ultimate conditions.

1.7 NEED FOR THE PRESENT STUDY

For a structural component to possess good earthquake resistance, it should have sufficient ductile materials at points of tensile stresses. To avoid collapse during major earthquake, structural members must be ductile enough to absorb and dissipate energy by post elastic deformations. The order of ductility involved may be associated with very large and permanent deformations. Since the addition of discontinuous short polyester fibres could bring sufficient improvement in ductility, its significance when mixed with the cementitious matrix is investigated. The thickness of ferrocement members are smaller compared to its plan dimensions and hence the small size laboratory specimens may not indicate the exact behaviour of the structures. So there is a need for testing large specimen of size nearly equal to prototype. This is especially true when ferrocement is recommended for precast purpose.

This study aims to underscore the advantages of ferrocement hollow slabs as a floor element in residential and industrial buildings. Hence the prototype slabs of size 770 mm × 140 mm and 3 m length were cast and tested under cyclic and monotonic loading. The load deflection characteristics of the slabs are compared based on the key parameters such as deflection ductility factor, energy absorption capacity and toughness index.
Addition of fibres reduces the crack width propagation. In order to avoid failure by vertical shear, stirrups were used extensively throughout the ribs.

The behaviour of ferrocement hollow slabs have been studied in recent years and it is observed that the slabs perform well under service loads regarding deflection. The present investigation studies the reduction of the crack width in ferrocement one way slabs at service loads especially after the first crack. Hybrid ferrocement with polyester fibres and hexagonal galvanized steel wire mesh, commonly called as chicken mesh, along with skeletal reinforcement are used to precast the one way slabs. Polyester fibres are introduced in the cement matrix. These discontinuous short fibres bridge the cracks and reduce their further propagation once they are formed. Also, a theoretical model is developed for deflection of polyester fibre reinforced hybrid ferrocement hollow slabs.

The researcher believes that this study dealing with cyclic loading on hybrid ferrocement hollow slab with chicken mesh and alkali resistant polyester fibres is important, in respect of the parameters such as ductility and energy absorption which are essentially needed for resisting the effects of vibration induced by an earthquake or operation of machinery. This study will be useful in developing composite structures technology.

1.8 SCOPE OF THE PRESENT STUDY

An experimental study of the mechanical behaviour of hybrid ferrocement hollow slabs is conducted to:

1. Determine the load carrying capacity of ferrocement hollow slabs for various percentages of longitudinal skeletal steel reinforcement.
2. Study the deformation characteristics of hybrid ferrocement hollow slabs.

3. Study the enhancement in the bending behaviour of ferrocement hollow slabs due to addition of alkali resistant polyester fibres.

4. Investigate the failure modes of ferrocement hollow slabs.

5. Investigate the control of crack width propagation due to addition of polyester fibres.

6. Investigate the stiffness, energy absorption and ductility.

7. Develop an analytical model for deflection at service stage.

8. Compare the experimental moment and curvature with the theoretical results.

9. Develop a numerical model using ANSYS software for deflection and curvature.

10. Investigate the durability of ferrocement hollow slabs.

1.9 ORGANISATION OF THE THESIS

This thesis has been arranged in seven chapters. A brief description of each chapter is given below:

Chapter 1 provides an introduction to ferrocement hollow slabs performance as a roofing / flooring unit. Also the need for hybrid ferrocement to improve the strength and durability performance of roof slabs is discussed. The role of fibres is explained. The overall scope of the research work is presented.
Chapter 2 provides information about hybrid ferrocement used for bending applications. A brief review of literature about hybrid ferrocement and their effect on strength and durability behaviour of ferrocement is presented. Literature regarding durability of ferrocement is also discussed.

Chapter 3 details the experiments that were carried out to study the performance of ferrocement hollow slabs with various percentages of reinforcement that is provided for reinforced concrete slabs. Experiments were done on 1.8 m and 2 m span slabs. The flexural strength of the ferrocement hollow slabs were compared with that of the solid slab of reinforced concrete. The modes of failure were discussed. The percentage of reinforcement determined has been used in the further investigations.

Chapter 4 presents the performance of hybrid ferrocement hollow slabs of 3 m span under monotonic and cyclic loading. The enhancement in the load deflection behaviour, moment curvature, load - crack width, load cycle - ductility and load cycle - energy absorption capacity of hybrid ferrocement hollow slabs are presented.

Chapter 5 presents the durability studies of hybrid ferrocement hollow slabs by alternate drying and wetting cycles in fresh water and subjected to cyclic loading. The load deflection behaviour of the slabs and the effect of polyester fibres on the crack width are presented.

Chapter 6 presents the theoretical investigations of hybrid ferrocement hollow slabs. An analytical model for deflection is presented. Also the theoretical results of moment curvature are compared with the experimental values. A theoretical equation for load deflection relationship is presented. A numerical model developed using ANSYS is also presented and the results of deflection and curvature are compared with the experimental values.

Chapter 7 presents conclusions from the different experimental, theoretical and numerical studies. The scope for further work is also discussed.