CERTIFICATE

This is to certify that thesis entitled **"Effect of wire mesh orientation on Strength of Retrofitted Beams Using Ferrocement Laminates"**, being submitted by Mr. Akash Jain, in partial fulfillment for award degree of **Master of Engineering in Civil (Structures) at Thapar Institute of Engineering and Technology (Deemed University), Patiala** is a bonafide work carried out by him under our guidance and supervision and that no part of this thesis has been submitted for the award of any other degree.

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(AKASH JAIN)

ABSTARCT

Many existing structures located in seismic regions are inadequate based on current seismic design codes. In addition, a number of major earthquakes during recent years have underlined the importance of mitigation to reduce seismic risk. Seismic retrofitting of existing structures is one of the most effective methods of reducing this risk. In recent years, a significant amount of research has been carried out to study various strengthening techniques to enhance the seismic performance of RC structures. However, the seismic performance of the structure may not be improved by retrofitting or rehabilitation unless the engineer selects an appropriate intervention technique based on seismic evaluation of the structure. Therefore, the basic requirements of rehabilitation and investigations of various retrofit techniques should be considered before selecting retrofit schemes. Various retrofitting techniques are used in field and out of all palte bonding technique is considered as the best. In plate bonding technique, the plates of different materials viz CFRP, GFRP, ferrocement etc are bonded to the surface of structural member to increase its strength. Ferrocement sheets are most commonly used as retrofitting material these days due to their ease availability, economy, durability, and their properties such as ease of being casted to any shape without needing significant formwork are preferred over other sheets.

In the present work, effect of wire mesh orientation on the strength of stressed beams retrofitted with beams ferrocement laminates has been studied. The beams are stressed up to 75 percent of safe load and then retrofitted with ferrocement laminates with wire mesh at different orientations. The result show that the percent increase in load carrying capacity for beam retrofitted with ferrocement laminates with wire mesh at 0, 45, 60 degree varies angle with longitudinal axis of beam, from 45.87 to 52.29 percent. Also a considerable increase in energy absorption is observed for all the orientation. However, orientation at 45 degree shows higher percentage increase in energy absorption followed by 60 and 0 degree respectively.

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b = Width of R.C section

h = Total depth of R.C beam

$\bar{y}$ = Neutral Axis of R.C Beam

h'

b'

y

= Total depth of beam with ferrocement

= Total width of beam with ferrocement

= Neutral axis of beam with ferrocement

m = Modular ratio

A_{st} = Area of steel

I = Moment of inertia

Δ = Deflection at mid span

P = Load

CHAPTER -1
INTRODUCTION

1.1 GENERAL

Reinforced concrete in one of the most abundantly used construction material not only in the developed world, but also in the remotest parts of the developing world. In the rural areas of the developing world, however, due to transference of expertise and technology know how, reinforced concrete poses threat due to its abuse rather than use, and majority of the houses still being are constructed in traditional manner using indigenously developed techniques preferably following simpler and economical procedures. Unfortunately such non-engineered construction is mostly prevalent in earthquake prone areas of the developing world e.g. Turkey, Pakistan, India and Iran. The rural populations in the developing world have mostly to rely on local skill, material and technology. The transformation of non-engineered construction into an engineered one therefore needs to be such that it could be sustained. The methodology should be simple in execution, offer better performance even when handled by less experienced workers, must involve materials, which are readily available, and yet durable, strong and economical. Ferrocement is one such material which could afford to offer answer to such a situation and hence the present study is part of a program to explore the potentials of ferrocement for its utilization in non-engineered construction, for improved performance in the event of an earthquake.

Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. In its role as a thin reinforced concrete product and as a laminated cement-based composite, ferrocement has found itself in numerous applications both in new structures and repair and rehabilitation of existing structures. Compared with the conventional reinforced concrete, ferrocement is reinforced in two directions; therefore, it has homogenous-isotopic properties in two directions. Benefiting from its usually high reinforcement ratio, ferrocement generally has a high tensile strength and a high modulus of rupture. In addition, because the specific surface of reinforcement of ferrocement is one to two orders of magnitude higher than that of reinforced concrete, larger bond forces develop with the matrix resulting in average crack spacing and width more than one order of magnitude smaller than in conventional reinforced concrete (***Shah, Naaman, 1971***). Other appealing features of ferrocement include ease of prefabrication and low cost in maintenance and repair. Based on the aforementioned advantages, the typical applications of ferrocement include water tanks, boats, housing wall panel, roof, formwork and sunscreen (***Kadir, Samadet al. 1997***).The renaissance of ferrocement in recent two decades has led to the ACI design guideline" Guide for the Design, Construction, and Repair of Ferrocement", and publications such as "*Ferro-cement Design, Techniques, and Application*" and "*Ferrocement and Laminated Cementitious Composites*" (***Naaman, 2000***), which provide comprehensive understanding and detailed design method of contemporary ferrocement. However, the rapid development in reinforcing meshes and matrix design requires continuous research to characterize the new material and improve the overall performance of ferrocement. Thus far steel meshes have been the primary mesh reinforcement for ferrocement, but recently fiber reinforced plastic (FRP) meshes were introduced in ferrocement as a promising alternative to steel meshes (***Al-Farabi et al, 1993, Al-Sulaimani,1994*** **)**.

Compared with steel, FRP materials possess some remarkable features such as lightweight, high tensile strength and inherent corrosion resistance. However, unlike steel that has an elastic-plastic stress-strain relationship, FRP materials behave elastically up to failure, thus do not yield and lack ductility. To prevent brittle tensile flexural failure, FRP reinforced members are usually designed to be over-reinforced and thus the nonlinear deformation capacity as well as the strain-softening region of concrete matrix could be utilized. In fact, the over-reinforced condition is intrinsically satisfied for the range of reinforcement ratio used in practice (***Paramasivam et al., 1994***), in particular for thin ferrocement plates. As a laminated composite, ferrocement often suffers from severe spalling of matrix cover and delamination of extreme tensile layer at high reinforcement ratio, resulting in premature failure. Therefore, serviceability consideration rather than strength limit would dominate composite design. Adding discontinuous short fiber to cementitious matrix, which could bring significant improvement in ductility and shear capacity as well as moderate increase in tensile strength, turns to be a logical solution to solve or alleviate these problems.

Ferrocement primarily differs from conventional reinforced or pre-stressed concrete by the manner in which the reinforcing elements are dispersed and arranged. The American Concrete Institute (ACI) Committee 549 defines ferrocement as:

"Ferrocement is a type of thin wall reinforced concrete construction where usually hydraulic cement is reinforced with layers of continuous and relatively small diameter mesh. Mesh may be made of metallic material or other suitable materials."

1.2 FERROCEMENT

Ferrocement is a term commonly used to describe a steel-and-mortar composite material. Essentially a form of reinforced concrete, it exhibits behavior so different from conventional reinforced concrete in performance, strength, and potential application that it must be classed as a completely separate material. It differs from conventional reinforced concrete in that its reinforcement consists of closely spaced, multiple layers of steel mesh completely impregnated with cement mortar. Ferrocement can be formed into sections less than 1 inch thick, with only a fraction of an inch of cover over the outermost mesh layer. Conventional concrete is cast into sections several inches thick with an inch or so of concrete cover over the outermost steel rods. Ferrocement reinforcing can be assembled over a light framework into the final desired shape and mortared directly in place, even upside down, with a thick mortar paste. Conventional concrete must be cast into forms.

These fairly simple differences lead to other, more remarkable differences. Thin panels of ferrocement can be designed to levels of strain or deformation, with complete structural integrity and water tightness, far beyond limits that render conventional concrete useless. Ease of fabrication makes it possible to form compound shapes with simple techniques; with inexpensive materials; and, if necessary, unskilled (but supervised) labour.

Ferrocement is a versatile construction material and confidence in the material is building up resulting in its wider application especially in developing countries such as for housing, sanitation, agriculture, fisheries, water resources, water transportation both in freshwater and marine environment, biogas structure, repair and strengthening of older structure s, and others.

Considered to be an extension of reinforced concrete, ferrocement has relatively better mechanical properties and durability than ordinary reinforced concrete. Within certain loading limits, it behaves as a homogeneous elastic material and these limits are wider than for normal reinforced concrete. The uniform distribution and high surface area to volume ratio of its reinforced results in better crack arrest mechanism i.e. the propagation of cracks are arrested resulting in high tensile strength of the material

1.2.1 History of Ferrocement

The most extensively used building medium in the world today is concrete and steel combined to make reinforced concrete; familiar uses are in high-rise buildings, highway bridges, and roadways. Yet, the first known example of reinforced concrete was a ferrocement boat. Reinforced concrete developed as the material familiar today in fairly massive structures for which formwork to hold the fresh concrete in the wide gaps between reinforcing rods and a fairly thick cover over the rods nearest the surface are required, he observed that reinforcing concrete with layers of wire mesh produced a material possessing the mechanical characteristics of an approximately homogenous material and capable of resisting high impact. Thin slabs of concrete reinforced in this manner proved to be flexible, elastic, and exceptionally strong. Historical profile of ferrocement

The search for the ferrocement roots and its evolution along the time is a trial of understanding the path of this technology. It can be observed that there are three distinct phases in the ferrocement history amongst the 1850's, 1940's, 1960's decades.

In 1850's Lambot began the history of reinforced concrete and ferrocement, but only concrete construction, in its massive form, was done with great success, as a natural development of that time current masonry architecture. This phase had its duration for almost 100 years, with no substantial acquirements.

In the1940's Nervi rediscovered ferrocement, and he gave it a dimension ever seen. In the post-war situation, nevertheless, reconstruction was strongly needed a man labor cost was not so significant in Europe. Ferrocement application continued up to 1960's decade, when its use went to decay, mainly because man labor cost had been increasing and other competitors to thin walled components were developed, as explained Mario, Nerve's son.

In the 1960's decade, Nervi's accomplishment simulated the beginning of other phase, the worldwide application of ferrocement, but mainly in the developing country tries. This phase comes until the present days on age near 35 years. The most single property of ferrocement emphasized along its evolution has been related to its high structural performance which has allowed the application of the material in quite different constructions, from ship hulls to housing panels. However the world economy has been coming still more competitive and two words govern the industry: quantity and productivity.

Amongst other properties, quality of a construction means durability, a satisfactory service life without special maintenance and repair. Productivity is strongly related to the cost of the product, and this latter almost ever is the final criterion of choice.

Ferrocement technology does not have sufficient knowledge about its durability and production costs are competitive in special circumstances.

As comments Hanai and Debs, "looking at the background of ferrocement technology, there were no significant improvement in the material composition and construction procedures since Nervi's experiences. Despite the splendid work performed by many research groups and construction enterprises, no substantial progress was reached to characterize a second generation ferrocement"

1.2.2 Advantages of Ferrocement

Ferrocement is a suitable technology for developing countries for the following reasons:

(a) Its basic raw materials are readily available in most countries.
(b) It can be fabricated into any desired shape.
(c) The skills for ferrocement construction can be acquired easily.
(d) Heavy plants and machinery are not involved in ferrocement construction.
(e) In case of damage, it can be repaired easily. Being labor intensive, it is relatively inexpensive in developing countries.

1.2.3 Constituent Materials

a) *Cement*:

The cement should comply with ASTM C 150-85a, ASTM C 595-85, or an equivalent standard. The cement should be fresh, of uniform consistency and free of lumps and foreign matter. It should be stored under dry conditions and for as short duration as possible. Cement factors are normally higher in ferrocement than in reinforced concrete. Mineral admixtures, such as fly ash, silica fumes or blast furnace slag, may be used to maintain a high volume fraction of fine filler material. Rice Husk Ash (RHA) cement can be economically used as partial replacement of cement in mortar mixes. When RHA does not exceed 35% by weight of the blended cement, the compressive strength at 28 days is similar to that of Type I Portland Cement Mortar.

b) *Fine Aggregates*:

Normal weight fine aggregate (sand) is the most common aggregate used in ferrocement. It should be clean, hard, strong, free of organic impurities and deleterious substances and relatively free of silt and clay. It should be inert with respect to other materials used and of suitable type with respect to strength, density, shrinkage and durability of the mortar made with it. Grading of the sand is to be such that a mortar of specified proportions is produced with a uniform distribution of the aggregate, which will have a high density and good workability and which will work into position without segregation and without use of a high water content. The fineness of the sand should be such that 100% of it passes standard sieve no. 8. Table 1 gives some guideline on desirable grading.

c) Water:

Water used in the mixing is to be fresh and free from any organic and harmful solution which will lead to deterioration in the properties of the mortar. Salt water is not acceptable but chlorinated drinking water can be used. Potable water is fit for use as mixing water as well as for curing ferrocement structures.

d) Admixture:

Chemical admixtures used in Ferrocement serve one of the following four purposes: water reduction, which increases strength and reduces permeability; air entrainment, which increases resistance to freezing and thawing; and suppression of reaction between galvanized reinforcement and cement.

e) Mortar Mix:

The reaction of Portland cement and water results in formation of hardened cement paste. The ranges of mix proportions recommended for common Ferrocement applications are sand-cement ratio by weight, 1.5 to 2.5, and water-cement ratio by weight, 0.35 to 0.5. Fineness modulus of sand, water-cement ratio and sand-cement ratio should be determined from trial batches to insure a mix that can infiltrate (encapsulate) the mesh and develop a strong and dense matrix. Water reducing admixtures may be used to enhance mix plasticity and retard initial set, as with conventional concretes. The behavior of mortar is similar to that of plain concrete.

f) Reinforcing mesh:

One of the essential components of ferrocement is wire mesh. Different types of wire meshes are available almost everywhere. These generally consist of thin wires, either woven or welded into a mesh, but the main requirement is that it must be easily handled and, if necessary, flexible enough to be bent around sharp corners. The function of the wire mesh and reinforcing rod in the first instance is to act as a lath providing the form and to support the mortar in its green state. In the hardened state its function is to absorb the tensile stresses on the structure which the mortar, on its own, would not able to withstand. A structure is subjected to great deal of pounding, twisting and bending during its life time resulting in cracks and fractures unless sufficient steel reinforcement is introduced to absorb these stresses. The degree to which this fracturing of the structure is reduced depends on the concentration and dimensions of the embedded reinforcement. The mechanical behavior of ferrocement is highly dependent upon the type, quantity, orientation and strength properties of the mesh and reinforcing rod.

g) Skeletal Steel:

Skeletal steel as the name implied is generally used for making the framework of the structure upon which layers of mesh are laid. Both the longitudinal and transverse rods are evenly distributed and shaped to form. The rods are spaced as widely as possible up to 305 mm (12 in.) apart where they are not treated as a structural reinforcement and are often considered to serve as spacer rods to the mesh reinforcements. In some cases skeletal steel is spaced as near as 75 mm (3 in.) center-to-center thus acting as a main reinforcing component wire mesh in highly stressed structures, e.g. boat, barges, tubular sections, etc.

h) Coating:

In general, ferrocement structures need no protection unless they are subjected to strong chemical attack that might damage the structural integrity of their components. A plastered surface can take a good paint coating. In terrestrial structures, ordinary paint is applied on the surface to enhance the appearance. Marine structures need protection against corrosion and vinyl and epoxy coatings were found to be the most successful organic coatings.

1.2.4 Use of Ferrocement for Retrofitting

Large number of building getting deteriorated with time due to various factors and need strengthening. Now days use of ferrocement laminates are extensively used for retrofitting due to its properties such as ease of being casted to any shape without needing significant formwork are preferred over other sheets. Many researchers put their theory for use of ferrocement laminates for retrofitting but no one has studied effect of wire mesh orientations on strength of retrofitted beams using ferrocement laminates for retrofitting. So the aim of the study is to study the effect of wire mesh orientation on the strength of stressed beam retrofitted with ferrocement laminate. Organization of thesis has been organized in the following five chapters:

Chapter 1: This chapter general introduction and history of ferrocement

Chapter 2: This chapter deals with properties, application and future of ferrocement construction

Chapter 3: This chapter details the experimental programme. In this properties of several of various material used in work have been discussed.

Chapter 4: This chapter is about results and discussion related to the work.

Chapter 5: It details the conclusion of work carried out

References follow in sequence and form the end of the thesis

Table 1.1: Guideline on Desirable Sand Grading

Sieve Size	Percent passing
No.8 (2.36 mm)	80-100
No.16 (1.18 mm)	50-85
No.30 (0.60 mm)	25-60

No. 50 (0.30 mm)	10-30
No.100(0.15mm)	2-10

CHAPTER - 2

LITERATURE REVIEW

2.1 PRELIMINARY REMARKS

A 30 years record of major Turkish earthquake shows almost 0.2 million dwellings destroyed by earthquake (***Gulkan and Wasti, 1980***), which is about 65% of the destruction caused by all other natural disasters. Dinar earthquake of 1995 and Kocoeli earthquake of 1999 have substantially increased the percentage.

Almost all post earthquake studies and damage assessment have led to the conclusion that a building should be designed and constructed such that in the event of the probable maximum earthquake intensity: the building should not suffer total or partial collapse; it should not suffer such irreparable damage which would require demolishing and rebuilding and in case it sustain such damage it could be repaired quickly and easily to bring it to its usual functioning (***ISET, 1981***).

Ferrocement over the years have gained respect in terms of its superior performance and versatility, and now is being used not only in housing industry but its potentials are being continuously explored for its use in retro-fitting and strengthening of damaged structural members (***Singh and Kaushik et al, 1998***). Ductility requirements are the main feature of an efficient earthquake restraint design process, and Ferrocement being highly ductile material have led to its application in rehabilitation of houses damaged by earthquake and the effectiveness of its use has been reported by many researchers (***Desia, 1999, Wasti and Erberik et al, 1998***).Taking the lead from its potential use in enhancing earthquake resisting abilities, 5 houses were built in Northern area of Pakistan, using indigenous materials and local skills utilizing Ferrocement bands to improve the earthquake resisting of such houses in 1990 (***NED university, 1998***). The houses since then have performed remarkably well and have sustained low to moderate shocks effectively. The details were simple to follow and execute by the local skilled workers, and materials were readily available from near by cities.

Reinforced concrete elements are designed to fail in a ductile manner by emphasizing on the detailing requirements due to the brittle nature of concrete. Shear failure are also classified as brittle and shear zones are therefore reinforced by provision of stirrups for transformation to ductile failure, however, a limit is imposed on the provision to avoid brittle shear-compression failure. In the event of an earthquake, however, the shear loads can exceed shear capacities, and damage in shear zones may lead to catastrophic failure of such members.

Many experimental studies have been conducted in recent years to strengthen flexure members by using various materials. ***Andrew and Sharma (1998)*** in an experimental study compared the flexural performance of reinforced concrete beams repaired with conventional method and Ferrocement. They concluded that beams repaired with Ferrocement showed superior performance both at service and ultimate load. The flexural strength and ductility of beams repaired by Ferrocement was reported to be greater than the corresponding original beams and the beams repaired by conventional method.

Al-Farabi et al (1993) while investigating the effectiveness of Fiberglass bonded plates for capacity enhancement, reported increased strength and reduced ductility. Premature failure by plate separation was also identified as a potential problem at the plate curtailment place. Steel plates bonded by epoxy were used to repair shear cracked beams utilizing various forms of plate bonding by ***Basunbul et al (1993)***. The experimental investigation clearly demonstrated that the effectiveness of the repair primarily depends on how effectively the diagonal tension cracks in the shear-damaged beams were trapped. Flexural mode of failure was observed surpassing shear capacity for only those specimens where full encasement of the shear zone was carried,

2.2 MECHANICAL PROPERTIES

Flexure of ferrocement has been investigated by the many researchers. ***Singh and Ip (1991)*** investigated the behavior of ferrocement composite; ***Clarke and Sharma (1991)*** take into account lamination effects on ferrocement slabs; ***Yuzugullu (1991)*** reported that using expanded mesh reinforcement increases the load carrying capacity of ferrocement elements while ***Desayi and EI- Kholy (1992)*** studied the deflection and cracking of lightweight fiber reinforced ferrocement in bending proposing a bilinear equation for predicting the deflection in the portion of load-deflection curve

A new qualitative mechanistic model which is reflects the behavior of ferrocement in flexural fatigue was investigated by ***Xiong and Singh (1992)***. This investigation showed that the rectangular stress distribution assumption is better for estimating steel stress when designing weld mesh ferrocement against fatigue. ***Kobayashi, Tanaka and Ono (1992***) reported the properties of impact damage obtained from lateral impact test of ferrocement. ***Ong, Paramasivam and Lim (1992)*** provided additional data on the performance of reinforced concrete beams strengthen and repair with ferrocement laminate. The study focused on Shear connection using Ramset nails at various spacing, epoxy resin adhesive and Hilti bolts. The effects of volume fraction of the ferrocement laminate and the level of damage of the beam were also studied. The performances of the strengthened beams were compared to the control beams with respect to cracking, deflection and ultimate strength. The results showed that all the strengthened beams exhibited higher ultimate flexural capacity and greater stiffness. The behavior of ferrocement under direct shear was investigated by ***Al Sulaimani and Basunbul (1991)*** buy conducting axial compression test on Z – shaped specimen reinforced with woven wire mesh producing pure shear on the shear plane. The major study parameters were the volume fraction of wire mesh reinforcement v_f, the shear plane and mortar strength. Test results indicated that ferrocement under direct shear exhibits two stages of behavior (cracked and uncracked) while under flexure it exhibits, in addition a third stage (plastic stage). The cracking and ultimate shear stresses increase with increasing mortar strength and wire mesh reinforcement. The shear stiffness in the cracked stage is affected by both amount of wire mesh and mortar strength. Ductility of ferrocement materials under direct shear increase with increasing wire mesh reinforcement and decreases with higher mortar strength

Mohd. Warid Hussin (1991) presented extensive data on the cracking and strength behavior of thin ferrocement sheets of 10mm thickness in flexure. Cement replacement by 50% to 70% fly ash and inclusion of super plasticizer can produce mixes of excellent flow characteristics and adequate early strength that can further ease the construction process and enable incorporation of short discrete fibers without difficulties of fabrication. The inclusion of fibers increases stiffness, decrease deflection and shows large ductility at failure. Small opening meshes exercise better cracking control than large opening meshes. However, incorporation of fibers in the mix modifies this pattern as large result in substantial reduction in crack spacing and crack widths compared with conventional ferrocement. For structural application s of ferrocement, deflection is a major design limitation. Fiber ferrocement along with layers of mesh can increases stiffness of the composite and reduces deflection at all stages of loading. The measured crack spacing and crack width can be satisfactorily predicted by the method proposed in this work.

Hani H. Nassif, Husam Najam (2004), had performed an experimental study to examine a shear transfer between composite layers. They have concluded that in order to provide full composite action between both the layers a minimum of five studs are needed. They also concluded that beams having shear studs with hooks exhibited better pre-cracking stiffness as well as cracking strength than those with L- shaped studs and also beams specimens with square mesh exhibited better cracking capacity than the control beams as well as beams with hexagonal mesh.

Mohammad Taghi Kazemi et al (2005) had performed a study to evaluate a retrofit technique for strengthening shear deficient short concrete columns. Ferrocement jacket reinforced with expanded steel mesh is used for retrofitting in this study. They had concluded that expanded meshes were more effective ties in shear strengthening of concrete columns and also specimens strengthened with expanded meshes showed distributed fine shear cracking even at large amounts of displacement ductility capacity.

Abdullah A, Katuski Tskiguchi (2003), had strengthened reinforced concrete columns with ferrocement jackets. They had used circular and square ferrocement jackets strengthening square reinforced concrete columns with inadequate shear resistance. They had concluded that by providing external confinement over entire length RC columns, the ductility is enhanced tremendously. They had also concluded that ferrocement jacket can be used to strengthen RC column with inadequate shear strength to enhance its ductility and also les number of layers of wire mesh within center position of the circular ferrocement jacket could be adopted in strengthening shear failure type RC column

Ohama and Shirai (1992) compared the durability of polymer-ferrocement with conventional ferrocement. The polymer-ferrocement, using styrene- butadiene rubber latex, is prepared with various polymer-cement ratios, and tested for accelerated carbonation, chloride ion penetration and accelerated corrosion. It is concluded that the carbonation and chloride ion penetration depth of polymer-ferrocement decreases markedly with an increase in polymer-cement ratio regardless of exposure and immersion periods, and are strongly affected by polymer-cement ratio and water-ratio and water cement ratio. The corrosion inhibiting property of polymer-ferrocement is remarkably improved with an increase in polymer-cement ratio.

As in the case of conventional reinforced concrete, the mechanical properties of ferrocement depend to a large extent on the properties of the cementitious matrix and the reinforcing steel. The apparent tensile properties of ferrocement represent a significant departure from that of ordinary reinforced concrete in that the dispersed reinforcement changes the observed cracking pattern. At a microscopic level the cementitious matrix is responding in the same way, but at the macroscopic level the first tension cracks generally appear at stress levels higher than for unreinforced mortar. The setting of Portland cement is the basic reaction in the fabrication of ferrocement. This setting process is identical to that of hardening conventional concrete, but special precautions must be taken if high levels of performance are expected. To produce an impermeable thin shell, for example, the mortar must have a low water-to-cement ratio. A proper moist-cure period is also imperative. Both of these ideals are readily appreciated by engineers and architects, but it may take special attention to achieve them in the field.

Figure 2.1 shows a typical stress-strain curve for ferrocement. In stage I the material behaves in a linearly elastic manner with both the reinforcement and the matrix deforming elastically. Then, as the load increases, the cementitious matrix cracks, and stage II begins where there is a change of slope in the stress-strain curve. It has been shown that the stress at the first crack can be increased by increasing the surface area of the steel exposed to the cement, by decreasing the diameter of the wire, by increasing the volume of reinforcement. These cracks are very fine and can be seen only by special lighting effects or microscopic investigation. For most purposes, the materials are unchanged by loading into this region, which constitutes ferrocement's practical working limit. Finally, stage III corresponds to the latter stages of deformation where the full load is being carried by the reinforcement. The stress limit of stage III can be predicted by considering the maximum load-carrying capacity of the steel reinforcement alone.

To put the mechanical properties into perspective, it is important to keep in mind that there is a transition from the characteristic behavior of ferrocement to that of conventional reinforced concrete and that much of the use of ferrocement in developing countries probably will fall on or near this transition. One of the important objectives in the future development of ferrocement will be a rational design system to cover the response of the structure to normal conditions, as well as the ultimate behavior of the structure. Engineering research is needed in this area.

The influence of the water-cement ratio on porosity has a great effect on the shrinkage, strength, and permeability of the final product. However, the practical upper limit of water-cement ratio for ferrocement depends on the acceptable value of permeability, since it is clear from Figure 2.2 that ferrocement made from mortar with a water-cement ratio of more than about 0.6 has a very high permeability.

The primary requirement for making waterproof mortar is tight control of the water/cement ratio, with the workability obtained by the gradation and quantity of sand as well as by the optional use of certain admixtures. This is also the prescription for making high-quality conventional concrete. Ferrocement is not as forgiving of careless practices as conventional concrete, and in the field it demands new degrees of control, compared to the simplicity of poured-concrete techniques.

Applying the mortar and ensuring that it penetrates the layers of mesh without leaving air pockets-a problem in ferrocement construction-is a particularly severe problem in boatbuilding. Because ferrocement reinforcing has a somewhat different purpose from that of conventional reinforced concrete, these two considerations apply:

1. Adequate cover to protect the steel from corrosion is necessary because in almost every application of ferrocement, the durability and resistance to environmental effects depend on the thin mortar cover over the steel mesh and its ability to protect the easily corroded steel mesh.
2. It is desirable to have the mesh as near the surfaces as possible.

In a thin shell of ferrocement these considerations conflict; therefore, it is necessary to use a mesh of high-specific surface area (small-diameter wires) in the outer layers, and to use the lowest possible water-cement ratio to achieve the lowest permeability and greatest protection from reinforcement corrosion.

2.3 FERROCEMENT FOR REPAIR AND STRENGTHENING OF STRUCTURES

Defects, failure and general distress in the structure could be the result of structural deficiency caused by erroneous design, poor workmanship or overloading of the structure. It could also be caused be corrosion, fire and natural disasters. A damaged or distressed re-strengthening of structures because it improve crack resistance combined with high toughness, the ability to be cast into any shape, rapid construction with no heavy machinery, small additional; weight it imposes low cost construction

Anwar, Nimityongskul. Pama and Robels-Austriaco (1991) investigated the rehabilitation technique for reinforced concrete structural beam elements using ferrocement. The technique involved strengthening of the reinforced concrete beams by application of hexagonal chicken wire mesh and skeletal steel combined by ordinary plastering. The basic parameters involved were the amount of wire mesh applied, its geometrical configuration and the degree of distress in the beams. The test results were in good compliance with the original design capacity of the beams. From the best test obtained, a design chart was developed to determined the parameters for rehabilitation of the beams elements the rehabilitation technique offers several advantages; it is easier to work with as it requires no specialized labor or equipment.

It does not require any formwork. By using ferrocement, with small quantities, considerable improvements can be achieved. The dead weight of the rehabilitation materials is almost negligible and hence it does not require catering for additional dead weight as in most of the other rehabilitation materials. In view of all these advantages, this method of using ferrocement is appropriate for rehabilitation of structural beams elements. Ngoiro, a wooden ferry in New Zealand has been preserved as a historical artifact and moored in an inner harbor location at which she recently sank. Subsequent examination of the hull showed severe damage by gribble worm. Replanking of the hull was estimated to cost US$ 120000 and would have required annual maintenance by the way of repainting and antifouling treatment in order to obtain an extended life. Fiberglassing the hull was expected top cost between US$30000 and US$ 40000 and would have had limited durability. The ferrocement retrofit was estimated to cost US$ 15000 to US$ 16000 and would in contrast to the other options, provide long term durability. After consideration of the alternatives of replanking or fiberglassing, a retrofitted skin of ferrocement was selected on the grounds of durability and cost.

2.3.1 Housing applications

Ferrocement technology is becoming more attractive construction particularly for roofs, slabs, floors and walls becau8se of its relatively low cost, durability and weather resistance. Its versatility further increases its utility for producing prefabricated components required in housing. The fabrication technique of ferrocement is easy to earn and ferrocement structures, if properly built, are practically maintenance free) ferrocement roofing units and other elements can be produced in factories or fabricated on site using local materials and labor. On site construction allows a one piece fabrication of structural components. Thus, in some cases, it proves to be more economical, more feasible and more practical than mass production in factories. It provides savings in the use of materials and labor for joining the smaller units. The result is a structure that is more stable, durable and requires little maintenance. Some researchers were also made on the use of ferrocement in beams and columns. Analytical and experimental investigation of hollow ferrocement units were studied by ***Mathews et, al.(1998)*** the system consists of top and bottom flanges connected by webs, there by leaving hollow spaces in between. The hollow section is selected mainly the passage of heat from outside. Based on the investigation the load deflection of the developed section is quite similar to that of a typical ferrocement element. There appears to be good potential for the use of these elements for roof/floor in residential buildings for span up to 3.5m

Kaushik, et.al. (1997) investigated the behavior of eight simply supported concrete steel and concrete ferrocement composite slabs of span 1.5m and 3.0 the results show that the ferrocement and corrugated galvanized iron (CGI0 composite slabs can be safely used for roofing and flooring purposes The ferrocement composite s exhibit better performance as compare to CGI composite in terms of load carrying capacity, energy absorption capacity, ductility and recovery in unloaded. The cost analysis for composite elements of 3.0m span designed for the same ultimate load shows hat the CGI ferrocement composite slabs are economical than conventional reinforced concrete slabs by 5% and 20% approximately. The behavior and performance of composite ferrocement brick reinforced slab without ferrocement panels especially to be shaped into simple geometric forms was carried out by ***Mattone (1991)***. The advantages afforded by this building technique are numerous: prefabrication ensures product quality by optimizing aggregate grain, the water cement ratio binder and addictive quantities and may entail a reduction in cost, while the simplicity of the operation to be performed to obtain a structural element from the semi-finished product make the process ideally suitable for self-help activities, enabling even unskilled workers to participate in the construction of their homes.

Ahmed and Dawood discussed the design, fabrication erection and construction technique for shell-type ferrocement units to cover a large span gymnasium, to form a composite roof. Using ferrocement considerable savings in materials cost, about 20% and a substantial reduction of construction time can be achieved. The test results show that the composite roof acts as a diaphragm and results in a reduced column section and is more durable than the conventional asbestos cement or galvanized iron sheets. Using this technique major formwork is totally eliminated and the form chosen gives a neat and clean appearance. Also drainage water proofing details are simple and quality control is not difficult.

Anwer (1993) presented the advantages and application of ferrocement for low-cost housing especially in Pakistan. Ferrocement roof and wall system provide a cheaper but durable solution. At the same time, they give a more permanent look to the structure as compared to other low-cost materials. There is a reasonable amount of economy achieved by using ferrocement. Tables 2.1 to Table2.4 show the economic analysis of housing ferrocement wall panels and brick masonry roofing units are 40% cheaper than the reinforced concrete roofs.

*Cost is as per year of investigation

2.4 FUTURE OF FERROCEMENT IN CONSTRUCTION

Some questions are launched for argumentation on the future of ferrocement in construction which are factors that have inhibited the full development and dissemination of ferrocement technology e.g., is ferrocement cost-competitive? Is high structural performance always needed in ferrocement applications/ is ferrocement durability reliable?

2.4.1 Durability

Durability is the main question about performance of ferrocement and reinforced mortar elements. Reinforced corrosion particularly seems as a first problem to be solved to give a safe margin of quality assurance to thin-walled constructions. Ferrocement or reinforced mortar members are typically built with 3 mm to 8mm reinforcement cover thickness. Despite relatively low water/cement ratio recommended for the mortar mix (0.38-0.45). This is not itself enough to ensure reinforcement protection against corrosion, even if it is in orderly aggressive environments.

Direct approaches to ferrocement durability problems are not given in a sufficient number.

2.4.2 Cost

Ferrocement uses steel wire meshes that are about 2 to 5 times more expensive by weight than ordinary steel bars. The assemblage of those meshes medium level or non-skilled labor, which is an advantage in developing countries where the cost of labor is relatively low. However, this work often takes much time and the productivity goes down. In prefabrication plants this lack of productivity can raise the cost and so ferrocement or reinforced mortar may become non competitive against other industrialized products. The tendencies are in general to reduce the mesh content or to substitute them for other suitable meshes and fibers that may reduce the production cost. There are examples of production rationalization, by using long beds and stretching the meshes, or by using pre-stressing. Application of short fibers in conjunction with continuous wires also has been proved to be economical in many situations.

The application of pre-stressing techniques to ferrocement (or generally to thin walled reinforced mortar or "fine grain concrete") has a great potential in the light weight prefabrication and some of the pre-cast concrete production techniques can be adapted to ferrocement. This also should reduce the cost, because mesh content and wiring labor could be minimized.

Quality control is a very important aspect in prefabrication, not only because a good quality of the elements must be reached, but also because quality control can reduce the cost.

2.4.3 A versatile ferrocement

Brazilian experiences have shown that under reinforced ferrocement may be structurally efficient even in long span structures. ***Martinelli, Hanai, Schiel (1991)*** showed a set of application that was that were developed by the Sao Carlos Group. In those applications, thin walled long span structural elements were made with reinforced mortar, by using large opening meshes (50 mm). the steel content in reinforced mortar had been varied from 200 kg/m^3 to as lower values as found in reinforced concrete.

In the same way it occurs at any types of structures, ferrocement structures must be designed to satisfy several performance requirements, such as strength, durability and so forth. Thinking ferrocement as a material to be applied to thin walled it is necessary to adjust the materials properties to the construction type and acting forces in the structures, to obtain the proper strength stiffness, cracking control, ductility and impact resistance.

The structural analysis should take the following aspects as references:

a) Ultimate limit strength must be verified for the overall structure and its internal parts. Continuous reinforcing elements (meshes, wires and tendons) usually are the appropriate ones to assure the structural safely.
b) The use of adequate structural shape dimensions of the sections, strength and modulus of elasticity of the mortar or micro concrete, reinforcement tensile strength and bond strength, cracking configuration, etc, will allow the proper stiffness.
c) Cracking control should be done by employing pre-stressing, by selecting the type and properties of the meshes, wires and tendons, and by using fiber as secondary reinforcement. Also ductility and impact strength will be determined by those parameters.

d) When high performance ferrocement is necessary, it will result the need of high reinforcement content, high specific surface of the reinforcement, a high performance mortar, and a small cover thickness. Moreover, special protection, easures against corrosion will be necessary.

e) In the most civil engineering applications, t be competitive ferrocement has to be applied as possible with lower content of meshes, but still using a high, at least medium performance, mortar or micro-concrete. A cover thickness much larger than the current ones which have been applied in ferrocement should be necessary to prevent corrosion of the reinforcement and to avoid too much expensive protection measures.

In broadest meaning, we can say that ferrocement (or reinforced mortar, or fine grain reinforced concrete, or reinforced micro concrete) is a special type of reinforced concrete to be applied in thin-walled constructions and elements. This material results from the association of a small sized aggregate concrete with continuous reinforcing elements that may include discrete fiber as complimentary reinforcement

2.4.4 Continuous and Discontinuous Reinforcing Elements

Thin-walled cementitious products have been made either with different and fiber reinforced cement or cement mortar. What differentiates ferrocement products from fiber reinforced cement product is that ones uses a distributed reinforcement made with continuous reinforcing elements (meshes) and the other uses distributed reinforcement made with discontinuous elements (short fibers)

Continuous reinforcing elements are better to absorb impact high and concentrated tensile loads, because the bonding strength is developed along a large strength. Thus, preference should be given to continuous reinforcement for the ultimate strength limit, otherwise, short fibers cab absorb impact load stresses and secondary tensile stresses with a relatively low fiber volume , they can be easily placed in some circumstances.

In this way a hybrid composite should be interesting to reduce the amount of meshes in ferrocement, to make easier the execution, to improve the corrosion resistances and to reduce the cost of the products.

Table 2.1 Ferrocement Wall Panel Economic Analysis

No.	Item	Quantity	Unit (Rs)	Total Price(Rs)
1	Steel 6mm dia @ 300m c/c both ways	m	66	224.60
2	Steel 6mm dia. For anchorages	m	3.40	34.0
3	Wire mesh	m^2	20.0	360.0
4	Binding wire	kg	20.0	20.0
5	Portland cement	Bag	110.0	440.0
6	Sand	m^3	45.0	12.60

Table 2.2 Brick Masonry wall panel

No.	Item	Quantity	Unit (Rs)	Total Price(Rs)
1	Brick	Pieces	66	224.60
2	Portland cement	Bags	3.40	34.0
3	Sand	m^3	20.0	360.0
Grand total				1557.25
Cost per m^3				173.03

Table 2.3 Ferrocement roofing Units

No.	Item	Quantity	Unit (Rs)	Total Price(Rs)
1	Longitudinal skeletal steel 4mm dia.(bottom)	m	75	105.0
2	Longitudinal skeletal steel 4mm dia.(sides)	m	110	154.0
3	Transverse steel stirrups 3mm dia.	m	80	67.20
4	Binding wire	kg	1	20.0
5	Portland cement	Bag	5.5	605.0
6	Sand	m^3	0.28	12.60
Grand total				1713.80
Cost per m^3				190.40

Table 2.4 Reinforced concrete roof

No.	Item	Unit	Quantity	Unit Price (Rs)	Total Price (Rs)
1	Reinforcement steel 12.5 mm dia. @250 mm c/c	m	80	14.00	1120.00
2	Portland cement	bag	6.5	10.00	715.00
3	Sand	m^3	0.50	45.00	22.50
4	Coarse sand	m^3	1.0	450.00	450.0
5	Shuttering	m^3	9.0	10.00	90.00
Grand total					2397.50
Cost per m^2					266.40

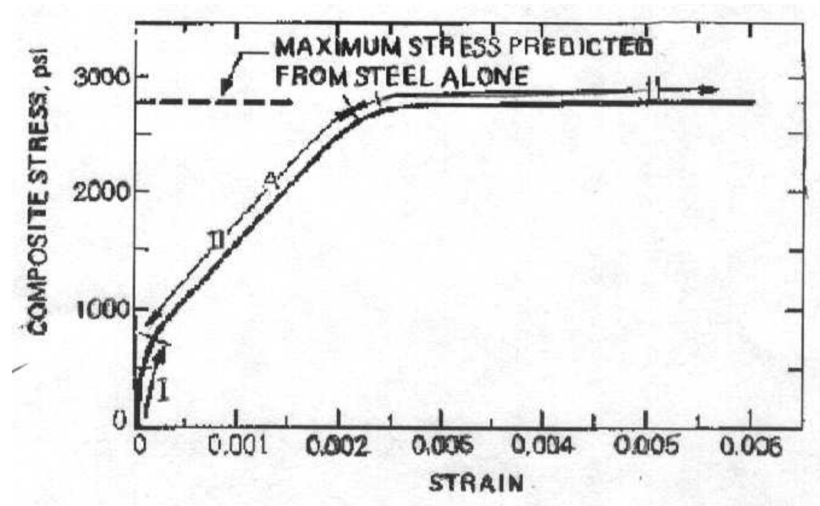

Figure 2.1. The three stages of typical stress-strain curve for ferrocement (Walkus, I.R. and T.G. Kowalsky, 1971)

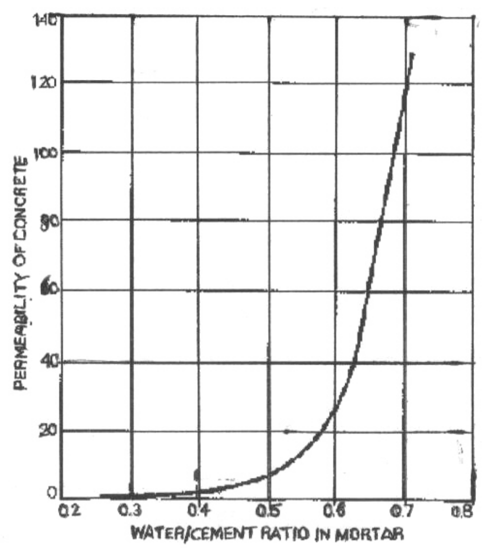

Figure 2.2: Relationship between permeability and water-to-cement ratio (Weight basis) for mature Portland cement pastes (cement hydrated 93%). (R.B. Williamson)

CHAPTER-3
EXPERIMENTAL PROGRAMME

3.1 INTRODUCTION

As very little information is available in literature of stressed RC beams retrofitted with ferrocement laminates using different orientation of wire mesh. Thus, the main objective of this experimental programme is to study the behavior of under reinforced concrete beams retrofitted with ferrocement laminates at different wire mesh orientations. To carry out the investigation eight real size beams were cast out of these eight beams two beams are taken as control beams and tested to failure to find out the load carrying capacity. Other six are then stressed to 75 percent of safe load and then retrofitted with ferrocement laminates using different orientation of wire mesh viz 0, 45 and 60 degree. The strength behavior of these beams under different cases is observed and analyzed

3.2 TEST PROGRAMME

The test programme was to find out the properties of materials and the behavior of retrofitted beams. The test programme involved

1. Determinations of basic properties of constituent materials namely cement, sand, coarse aggregates and steel bars as per relevant Indian standard specifications.
2. Eight real size beams (127 x 17 x 4100mm) were casted using M 20 grade concrete.
3. The beams are stressed to 75% of safe load and then retrofitted with ferrocement laminates using cement slurry as bonding agent having mesh at an angle of 0, 45, 60 degree to the longitudinal axis of beam

3.3 MATERIALS

Cement, fine aggregates, coarse aggregates, reinforcing bars are used in casting of beams and MS welded wire mesh, cement slurry are used for retrofitting of these beams. The specifications and properties of these materials are as under:

3.3.1 Cement

Portland pozzolana cement 43 grade cement from a single lot was for the study. The physical properties of cement as obtained from various tests are listed in Table 3.1. All the tests are carried out in accordance with procedure laid down in IS: 8112-1989.

3.2 Fine Aggregates

Locally available sand was used as fine aggregate in the cement mortar and concrete mix. The physical properties and sieve analysis results of sand are shown in Table 3.2 Table 3.3.

3.3.3 Coarse Aggregates

Crushed stone aggregate (locally available) of 20mm and 10mm are used through out the experimental study. The physical properties and sieve analysis of coarse aggregate are given in Table 3.4 and Table 3.5 and Table 3.6.

3.3.4 Water

Fresh and clean water is used for casting the specimens in the present study. The water is relatively free from organic matter, silt, oil, sugar, chloride and acidic material as per Indian standard.

3.3.5 Reinforcing Steel

HYSD steel of grade Fe-415 of 10mm and 8mm and 6mm diameters were used as longitudinal steel. 10mm dia bars are used as tension reinforcement and 8mm bars are used as compression steel. 6mm diameter bras are used as shear stirrups. The properties of these bars are shown in Table3.7

3.3.6 Steel Mesh

MS welded steel wire mesh of 2.4mm diameter with square grids was used in ferrocement jacket. The grid size of mesh was 40X40 mm. The salient properties of mesh wire used are given in Table.3.7

3.3.7 Concrete Mix

M20 grade concrete mix is designed as per standard design procedure using the properties of materials as discussed above i.e. Table 3.1 to Table 3.6. The water-cement ratio used in the design is 0.5. The mix proportion of material comes out to be 1:1.45:3.123 (cement: sand: aggregate) and compressive strength of materials after 7 days and 28 days is 21.5 and 29 respectively.

3.3.8 Mortar Mix

The range of mix proportion recommended for common Ferrocement application are cement: sand: ratio by weight, 1:1.5 to 1:.25, but not grater than 1:3 and water cement ratio by weight, 0.35 to 0.5. The higher the sand content the higher the required water contents to maintain same workability. Fineness modulus of the sand, water cement ratio and sand-cement ratio should be determined from trial batches to ensure a mix that can infiltrate the mesh and develop a strong and dense matrix. The proportion of cement – sand mortar used for the ferrocement sheets was 1:2 (cement: sand). The water-cement ratio for mortar was 0.40 for given consistency of cement.

3.4 RCC BEAM DESIGN

In the present study the RCC beam is design using M20 grade and Fe415 steel. The RCC beam is design with limit state method considering it to be under-reinforced section. The beam is designed for given steel i.e. 2 bars of 8mm at compression face and 2 bars of 10mm at tension face. The stirrups used were of 6mm diameter. According to design the dimension of the beam comes out to 127 x 227mm. Longitudinal section and cross-section of beam is shown Figure 3.1 and Figure 3.2

3.5 CASTING OF COMPOSITE BEAMS

The casting of beams was done in single stage. The beams were cast in mould of size 127 x 227 x 4100 mm. First of the entire beam mould is oiled. So that can be easily removed from the mould after 24 hours. Spacers of size 25mm are used to provide uniform cover to the reinforcement. When the bars have been placed in position as per design concrete mix is poured in the mould and vibrations are given with the help of needle vibrator, so that that the mix gets compacted. The vibration is done until the mould is completely filled and there is no gap left. The beams are then removed from the mould after 48 hours. After demoulding the beams are cured for 28days using jute bags. Plate no 3.1 shows the beams before and after casing

3.6 TESTING ARRANGEMENT

All the eight beams were tested under simply supported end conditions. Two points loading is adopted for testing. The testing of beams is done with the help of hydraulic operated jack connected to load cell. The load is applied to the beam with the help of load cell and value is obtained from the data acquisition system, which is attached with the load cell. Three dial gauges are placed at quarter positions, one dial gauge is placed at the center and other two dial gauges are place at a distance of span/4 from the end. The value of deflection is obtained from these dial gauges. Out of these eight beams two are control beams, which are tested, after 28 days of curing to find out the load carrying capacity. Rest of six beams is stressed up to 75 percent of the safe load obtained from the testing done on the control beams. Plate no 3.2 shows failure of control beam. Figure #.3 shows the testing arrangement.

3.6.1 Process of Retrofitting

Firstly the surface of beam is cleaned. After cleaning the surface, the cement slurry is applied as bonding agent to the surface of beam. After the application of bonding agent retrofitting of beam is done by applying 15mm thick cement mortar on the three faces as ferrocement laminates having wire mesh at different orientation. The beams are cured for 7days before testing. Then with same procedure as of control beam testing of beam is done in order to calculate ultimate load and corresponding deflections.

3.7 ANALYSIS OF BEAMS

For the loading arrangement shown in Figure 3.3 the deflection at the centre of the beam can be calculated using the expressions.

$$\Delta = \frac{1.98e8 \times P}{EI}$$

Where 'P' is load in 'N'

'E' modulus of elasticity which is taken as 22360.67

'I' is MOI of the beam

The value of I will be different before and after retrofitting and can be calculated using following expression.

For R.C beams:

$$I = bh^3/12 + bh\,(\bar{y} - h/2) + (m-1)\,A_{st}\,(d - \bar{y})^2$$

$$\bar{y} = (bh^2/2 + (m-1)\,A_{st}\,d) / (bh + (m-1)\,A_{st})$$

For composite beams (Ferrocement applied)

$$I = b'h'^3/12 + b'h'\,(y - h'/2) - h/2)^2 + (m-1)\,A_{st}\,(d-y)^2$$

$$y = b'h'/2 + (m-1)A_{st}\,d) / (b'h' + (m-1)A_{st}$$

3.8 RETROFITTING OF BEAMS

The beams are stressed up to 75% of safe load and retrofitted using ferrocement laminates. This safe load is calculated from the allowable deflection corresponding to deflection of l/250. Then corresponding to this deflection load is calculated from the load deflection curve of control beam. After stressing the beams to the pre-decided limit of safe load, the beams are retrofitted using ferrocement laminates having wire mesh at an angle of

a) 0 degree: Refer Plate no 3.3
b) 45 degree: Refer Plate no 3.5
c) 60 degree: Refer Plate no 3.4

Table 3.1: Physical Properties of Cement used

Sr. No	Characteristics	Value obtained Experimentally	Value specified by IS: 8112-1989
1	Standard consistency	34	-
2	Fineness of cement as retained on 90 micron sieve	0.5	<10%
3	Setting time 1. Initial 2. Final	 14mins 5 hours	 <30 mins <10 hours
4	Specific gravity	3.07	-
5	Compressive strength (N/mm^{2}) 1. 7days 2. 28 days	 33 43	 33.5 43.5

Table 3.2: Physical Properties of Fine Aggregates

Sr. No.	characteristics	value
1.	Specific gravity	2.56
2.	Bulk density loose (kg/lt)	1.48
3.	Fineness modulus	2.51
4.	Water Absorption	2.06%
5.	Grading Zone	Zone III

Table 3.3: Sieve Analysis of Fine Aggregates

Total weight taken = 1000gm

Sr. No.	Sieve Size	Mass Retained (gm)	Percentage Retained	Percent Passing	Cumulative Percentage Retained
1.	4.75 mm	95.0	9.5	9.5	90.5
2.	2.36 mm	42.5	4.25	13.75	86.25
3.	1.18 mm	110.5	11.05	24.8	75.2
4.	600 µm	128.5	12.85	37.65	62.35
5.	300 µm	308.0	30.8	68.45	31.55
6	150 µm	281.0	28.1	96.55	3.45
7.	Pan	34.5	3.45		
					Σ = 250.70

Table 3.4: Sieve Analysis of Coarse Aggregate (20mm)

Total weight taken = 3 kg

Sr. No.	Sieve Size	Mass Retained (kg)	Percentage Retained	Percent Passing	Cumulative Percentage Retained
1.	20 mm	0	0	0	100
2.	12.5 mm	2.1865	72.883	72.883	22.117
3.	10 mm	0.6745	22.483	95.366	4.634
4.	4.75mm	0.1300	4.33	99.69	0.31
5.	Pan	0.009	0.3	100	0
					Σ = 127.06

Table 3.5: Sieve Analysis of Coarse Aggregate (10mm)

Total weight taken = 3 kg

Sr. No.	Sieve Size	Mass Retained (kg)	Percentage Retained	Percent Passing	Cumulative Percentage Retained
1.	12.5 mm	0.555	18.5	81.5	18.5
2.	10 mm	0.8905	29.68	51.82	48.18
3.	4.75mm	0.9565	31.88	19.94	80.06
5.	Pan	0.5970	19.90	80.1	99.96
					Σ = 146.74

Table 3.6: Physical Properties of Coarse Aggregates

Sr. No.	characteristics	value	
		20mm	10mm
1.	Type	Crushed	Crushed
2.	Specific gravity	2.655	2.704
3.	Total water absorption	3.645	1.643
4.	Fineness modulus	7.68	6.46

Table 3.7 Physical Properties of Steel Bars and Steel Mesh Wires

Sr. No.	Diameter of bars/ mesh wire	Yield-strength (N/mm^2)	Ultimate strength	Percentage Elongation
1.	10mm	445.55	509.2	15.5
2.	8mm	559.5	634.13	20.3
3.	6mm	442.42	612.7	32.9
4	2.7m	400	511.36	2.52

Plate-3.1: Beams Before and After Casting

Plate-3.2: Failure of control beam

Plate 3.3: Beam with wire mesh at 0 degree

Plate 3.4: Beam with wire mesh at 60 degree

Plate 3.5: Beam with wire mesh at 45 degree

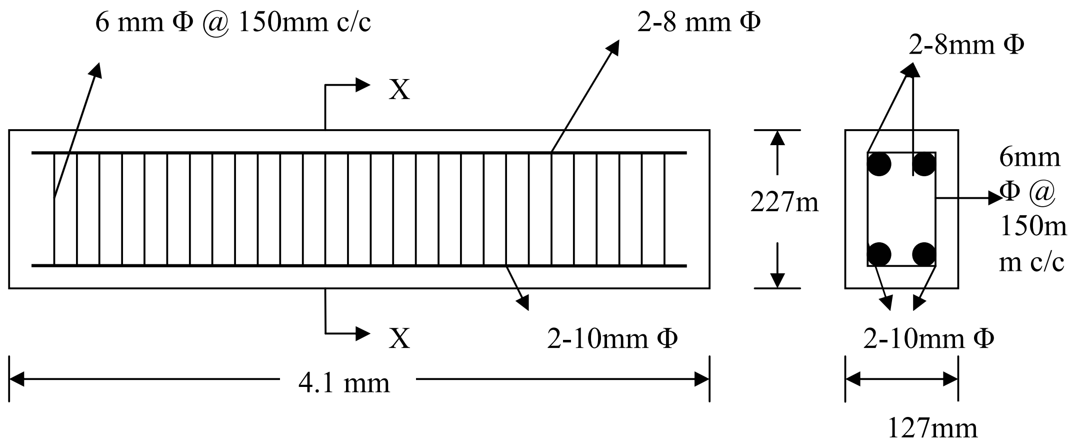

Figure 3.1: Longitudinal and Cross-Section of Unretrofitted Beam

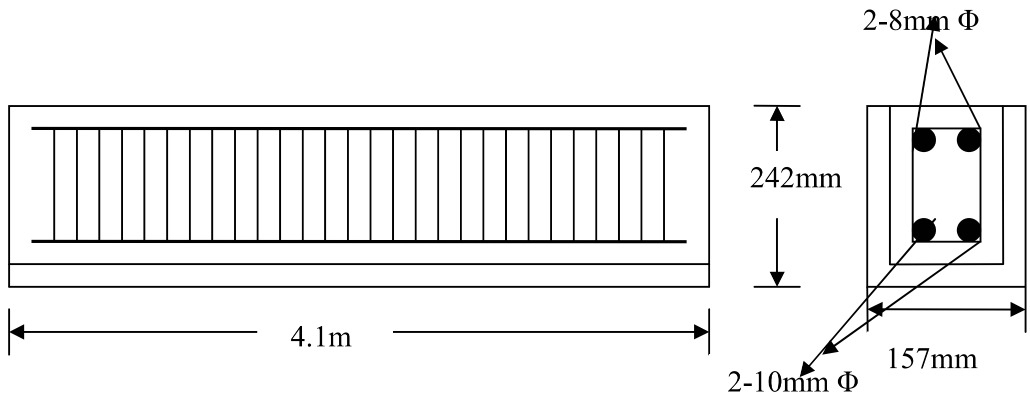

Figure 3.2: Longitudinal and Cross-Section of Retrofitted Beam

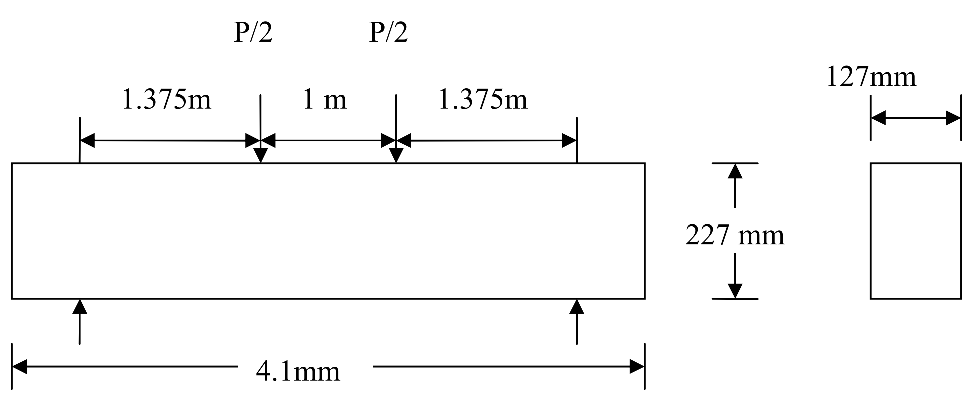

Figure 3.3: Loading System of Beam

CHAPTER 4
RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this work the effect of different mesh orientations of ferrocement laminates on the strength of retrofitted beams have been studied. Initially, control beams are tested to failure and subsequently other beams are stressed to 75 percent of safe load and then retrofitted with ferrocement laminates with wire mesh at different orientation. Single layer of welded wire mesh is used in the ferrocement laminates. A comparative study of flexural strength of control beam and retrofitted beam is presented in the succeeding sections.

4.2 TEST PROCEDURE

In the experimental programme the beams are tested using two point loading arrangement as shown in Plates. The testing of the beam is done with the help of hydraulically operated jacks connected to the load cell. This load cell is used to apply the load over the surface of the beam and the value of load is read from the data acquisition system connected to the load cell. Total setup is shown in Plate no 4.1.The value of deflection is measured using dial gauges, which are placed at quarter positions i.e. one at the centre and the other are placed at a distance of L/4 from each end. First of all two control beams are tested to failure to find out ultimate load and moment. Then rests of six beams are stressed up to 75 percent of safe load. The safe load is calculated from load deflection curve for allowable central deflection of L/250 which is equal to 15mm and the value of load observed from the curve is 12.15 KN. The beams are stressed up to 75 percent of this safe load which is 9.1125kN. The six beams to be retrofitted are then retrofitted using wire mesh at different orientation. These retrofitted beams are then again loaded to failure and data is recorded in form of load and deflection. The subsequent sections presents the results of these retrofitted beams and discussion of the effect of each orientation is handled separately.

4.3 BEAMS RETROFITTED WITH WIRE MESH AT ZERO DEGREE ORIENTATION

This section deals with effect on strength of retrofitted beams when wire mesh is palced at an angle of zero degree to the longitudinal axis of beam. Table 4.1 shows the value of load-deflection curve for control beam and beam retrofitted with ferrocement laminates having wire mesh oriented at zero degree.

Figure 4.1 shows the behavior of load deflection at centre of control beam and beam retrofitted with wire mesh at zero degree at L/4 and Figure 4.2 shows the variation of deflection at centre. From load deflection curves, it is observed that the load increases the deflection initially increases linearly, then suddenly increases at much higher rate due to yielding of reinforcement. The first crack was observed at a load of 8.5KN under the point load. Thereafter with increase in the point load the no. of cracks keep on increasing but the spacing of cracks decreases 45mm as compared to the control beam where it is 90 mm, which shows better distribution of stresses in the beams retrofitting with ferrocement laminates. Crack pattern is shown in Plate no 4.2 .The failure for control beam occurs at a load of 21.8 KN. with ultimate deflection of 44.85mm at centre whereas retrofitted beam fails at a load of 31.8KN with ultimate deflection of 56.82mm at the centre showing that there is considerable increase in load carrying capacity.

It is also seen that corresponding to the serviceability requirement of deflection of 15mm the load increases from 12.8KN for control beam to 14.2KN for retrofitted beam resulting in increase by 10.93 percent for safe deflection. It is also observed that corresponding to the ultimate load of control beam, the load for retrofitted beam with wire mesh at zero degree corresponding to the deflection value of 44.85mm is 27.6KN showing 45.87 percentage increase in ultimate load carrying capacity.

4.4 BEAMS RETROFITTED WITH WIRE MESH AT 45 DEGREE ORIENTATION

This section deals with effect on strength of retrofitted beams when wire mesh is placed at an angle of 45 degree to the longitudinal axis of beam. Table 4.2 shows the value of load-deflection curve for control beam and beam retrofitted with ferrocement laminates having wire mesh oriented at 45 degree.

Figure 4.3 shows the behavior of load deflection at centre of control beam and beam retrofitted with wire mesh at 45 degree at L/4 and Figure 4.4 shows the variation of deflection at centre. From load deflection curves, it is observed that the load increases the deflection initially increases linearly, then suddenly increases at much higher rate due to yielding of reinforcement. The first crack was observed at a load of 9.2 KN under the point load Thereafter with increase in the point load the no. of cracks keep on increasing but the spacing of cracks decreases 85mm as compared to the control beam where it is 90 mm, which shows better distribution of stresses in the beams retrofitting with ferrocement laminates. Crack pattern is shown in Plate no 4.4. The failure for control beam occurs at a load of 21.8 KN. with ultimate deflection of 44.85mm at centre whereas retrofitted beam fails at a load of 33.2KN with ultimate deflection of 69.05 mm at the centre showing that there is considerable increase in load carrying capacity.

It is also seen that corresponding to the serviceability requirement of deflection of 15mm the load increases from 12.8KN for control beam to 13.8KN for retrofitted beam resulting in increase by 7.8 percent for safe deflection. It is also observed that corresponding to the ultimate load of control beam, the load for retrofitted beam with wire mesh at 60 degree corresponding to the deflection value of 44.85mm is 31.2 KN showing 52.29 percentage increase in ultimate load carrying capacity.

4.5 BEAMS RETROFITTED WITH WIRE MESH AT 60 DEGREE ORIENTATION

This section deals with effect on strength of retrofitted beams when wire mesh is placed at an angle of 60 degree to the longitudinal axis of beam. Table 4.3 shows the value of load-deflection curve for control beam and beam retrofitted with ferrocement laminates having wire mesh oriented at 60 degree.

Figure 4.5 shows the behavior of load deflection at centre of control beam and beam retrofitted with wire mesh at 60 degree at L/4 and Figure 4.6 shows the variation of deflection at centre. From load deflection curves, it is observed that the load increases the deflection initially increases linearly, then suddenly increases at much higher rate due to yielding of reinforcement. The first crack was observed at a load of 9.4 KN under the point load Thereafter with increase in the point load the no. of cracks keep on increasing also the spacing of cracks increase to 108 mm as compared to the control beam where it is 90 mm. Crack pattern is shown in Plate no 4.3.The failure for control beam occurs at a load of 21.8 KN. with ultimate deflection of 44.85mm at centre whereas retrofitted beam fails at a load of 31.9 KN with ultimate deflection of 45.51 mm at the centre showing that there is considerable increase in load carrying capacity.

It is also seen that corresponding to the serviceability requirement of deflection of 15mm the load increases from 12.8KN for control beam to 15.5 KN for retrofitted beam resulting in increase by 21.09 percent for safe deflection. It is also observed that corresponding to the ultimate load of control beam, the load for retrofitted beam with wire mesh at 60 degree corresponding to the deflection value of 44.85mm is 27.5 KN showing 46.33 percentage increase in ultimate load carrying capacity.

4.6 COMPARATIVE ANALYSIS OF THE WIRE MESH ORIENTATION

Table 4.1 to Table 4.3 shows the value of load deflection of retrofitted beams with wire mesh at 0, 45, 60 degree. Figure 4.7shows the behavior of load deflection at L/4 for control beam and beam retrofitted with wire mesh at different orientations. Figure 4.8 shows behavior of load deflection at centre for control beam and beam retrofitted with wire mesh at different orientation. It is observed that spacing of cracks is less i.e. 45mm in case of beam retrofitted with wire mesh at zero degree as compared to retrofitted beam with wire mesh at 45 for which it is 85mm, 60 degree for which it is 108mm. This shows better distribution of stress with wire mesh at zero degree.

It is also found that deflection at centre is maximum in case of beam retrofitted with wire mesh at 45 degree which is 69.05mm as compared to retrofitted with wire mesh at zero for which it is 56.82mm and for 60 degree it is 45.51mm. However the energy absorption values is maximum for beam retrofitted with wire mesh at 45 degree followed by beam retrofitted with wire mesh at 60 and zero degree. Beams retrofitted with wire mesh oriented at zero degree were the most efficient of the three orientations as its strength to cost ratio was more i.e. 0.0729 as compared to the other orientations for which the value is 0.0727 for wire mesh at 45 degree, it is the least for wire mesh oriented at 60 degree it is 0.594.

4.8 COST ANALYSIS

This section deals with detailed analysis of the cost incurred on the retrofitting of beams using the three different orientation viz 0, 45, 60 degree. A comparative analysis of strength parameters and cost is presented in Table 4.4 and Table 4.5, respectively.

The cost analysis shows that the strength to cost ratio is more in case of beams retrofitted with wire mesh oriented at zero degree. Whereas, it is the least for wire mesh oriented at 60 degree.

Plate 4.1: Test Setup

Plate 4.2: Crack Pattern of Retrofitted Beam with 0 Degree Wire Mesh

Plate 4.3: Crack Pattern of Retrofitted Beam with 60 Degree Wire Mesh

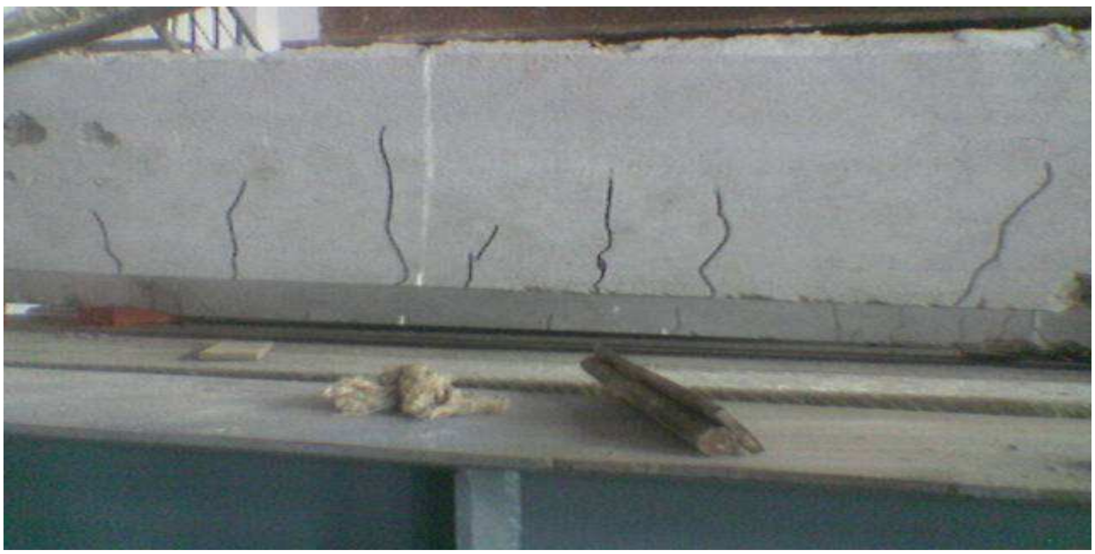

Plate 4.4: Crack Pattern of Retrofitted Beam with 45 Degree Wire Mesh

Table 4.1: Load vs. Deflection data for control beam and beam retrofitted with wire mesh at 0 degree

S.r No.	Control beam			Beam with ferrocement at 0 degree		
	Load (KN)	Deflection(mm)		Load (KN)	Deflection (mm)	
		L/2	L/4		L/2	L/4
1	3	2.1	1.20	3	2.8	1.8
2	4	3.0	1.82	4	4.4	3.0
3	6	5.0	3.02	6	7.0	4.89
4	8	8.3	5.00	8	9.0	6.48
5	10	10.98	7.00	10	10.87	7.76
6	12	14.0	9.22	12	12.8	9.2
7	14	17.0	11.2	14	14.76	10.15
8	16	20.0	13.50	16	17.95	13.42
9	20	23.0	16.00	18	20.34	15.36
10	21.8	44.85	33.4	20	22.76	16.9
11				22	24.76	18.5
12				24	28.4	20.22
13				26	36.0	24.0
14				28	47.05	32.04
15				30	53.82	-
16				31.8	56.82	-

Table 4.2: Load vs. Deflection data for control beam and beam retrofitted with wire mesh at 45 degree

S.r No.	Control beam			Beam with ferrocement at 45 degree		
	Load (KN)	Deflection(mm)		Load (KN)	Deflection (mm)	
		L/2	L/4		L/2	L/4
1	3	2.1	1.20	3	3.35	2.12
2	4	3.0	1.82	4	4.42	3.0
3	6	5.0	3.02	6	6.50	4.5
4	8	8.3	5.00	8	8.87	6.0
5	10	10.98	7.00	10	10.9	7.74
6	12	14.0	9.22	12	13.75	9.26
7	14	17.0	11.2	14	15.75	11.45
8	16	20.0	13.50	16	17.63	13.98
9	20	23.0	16.00	18	20.42	16.76
10	21.8	44.85	33.4	20	23.2	17.5
11				22	26.8	21.0
12				24	32.0	25.0
13				26	34.4	28.0
14				28	38.0	31.45
15				30	41.95	35
16				32	57.37	40.2
17				33.2	69.05	42.82

Table 4.3: Load vs. Deflection data for control beam and beam retrofitted with wire mesh at 60 degree

S.r No.	Control beam			Beam with ferrocement at 60 degree		
	Load (KN)	Deflection(mm)		Load (KN)	Deflection (mm)	
		L/2	L/4		L/2	L/4
1	3	2.1	1.20	3	2.43	1.82
2	4	3.0	1.82	4	3.58	2.4
3	6	5.0	3.02	6	5.61	3.16
4	8	8.3	5.00	8	7.30	4.20
5	10	10.98	7.00	10	9.76	4.87
6	12	14.0	9.22	12	11.85	6.0
7	14	17.0	11.2	14	13.24	7.76
8	16	20.0	13.50	16	15.73	9.84
9	20	23.0	16.00	18	18.00	11.95
10	21.8	44.85	33.4	20	21.00	13.72
11				22	23.33	15.0
12				24	27.00	17.5
13				26	34.00	124.0
14				28	50.00	36.34
15				30	58.20	41.52
16				31.9	63.00	45.51

Table 4.4: Cost Analysis

Material	Rate(Rs.)	Cost (Rs.) of Beam type			
		A	**B**	**C**	**D**
Concrete Ingredients					
Cement (kg)	215	215	215	215	215
Rebars (kg)					
10mm	30.10	148.724	148.724	148.724	148.724
8mm	30.75	97.14	97.14	97.14	97.14
6mm	33.75	111.52	111.52	111.52	111.52
Coarse Aggregates (cft)	14.0	50.89	50.89	50.89	50.89
Fine aggregates (cft)	17.0	29.56	29.56	29.56	29.56
Labour for control beams		200	200	200	200
Cost of ingredients		852.834	852.834	852.834	852.834
Retrofitting material					
Welded Wire mesh	Lump sum	-	330	420	480
Additional material like cement, Fine aggregates, screws etc.	Lump sum	-	107	107	107
Labour	Lump sum	-	192	192	192
Cost of retrofitting		-	629	719	779
Total Amount	**Lump sum**	**852.834**	**1481.834**	**1572.834**	**1631.834**
Strength/cost ratio		-	0.622	0.619	0.507
Increase in strength (Per cent)		-	45.87	52.29	46.33

Beam Type A = Unretrofitted beam/control beam
Beam Type B = Beam retrofitted with wire mesh oriented at zero degree
Beam Type C = Beam retrofitted with wire mesh oriented at 45 degree
Beam Type D = Beam retrofitted with wire mesh oriented at 60 degree

Table 4.5: Test Results of Beam Specimens

Sr. No	Beam type	P_u (kN)	M_u (kN-m)	Max deflection (mm)	Ductility Ratio(*)	Energy Absorption(**) KN-m	Percentage increase in Ultimate load
1	Unretrofitted	21.8	15.33	33.4		312.065	
2	Retrofitted with F/C at 0 degree	31.8	21.862	56.15	1.681	1116.46	45.87
3	Retrofitted with F/C at 45 degree	33.2	22.825	69.05	2.06	1431.52	52.29
4	Retrofitted with F/C at 60 degree	31.9	21.93	63.0	1.88	1366.36	46.33

* *Ductility ratio is defined as ratio of deflections of retrofitted and un-retrofitted beam at ultimate load*

** *Area under the load deflection curve*

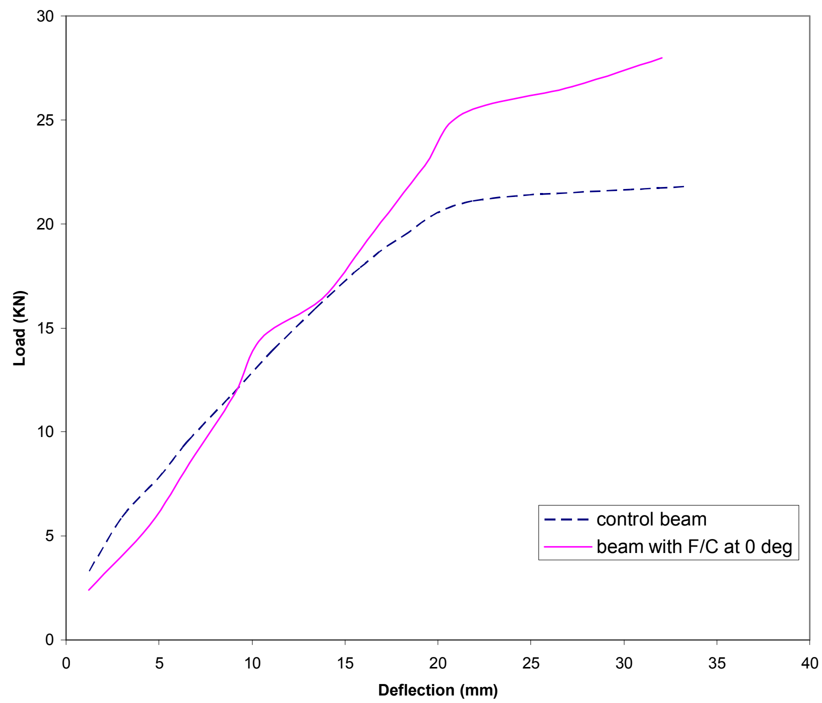

Figure 4.1 Load vs. Deflection curve at L/4 for control beam and beam retrofitted with wire mesh at 0 deg

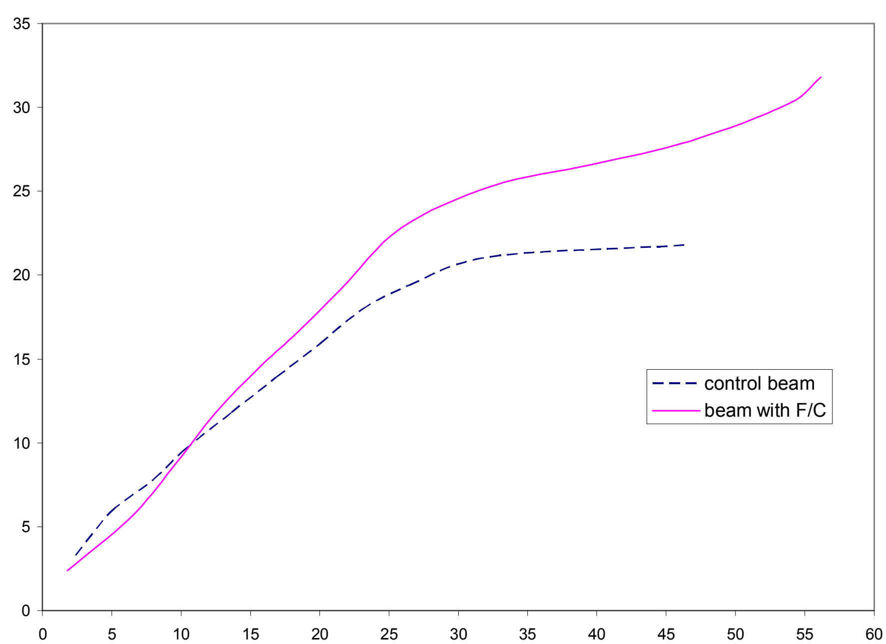

Figure 4.2 Load vs. deflection curve at centre for control beam and beam retrofitted with wire mesh at 0 deg

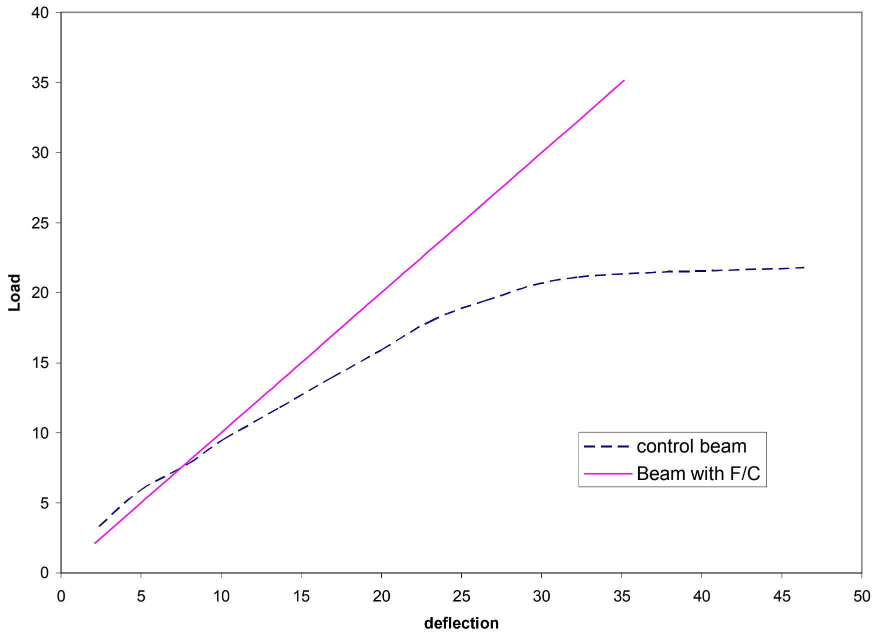

Figure 4.3 Load vs. Deflection curve at L/4 for control beam and beam retrofitted with wire mesh at 45 deg

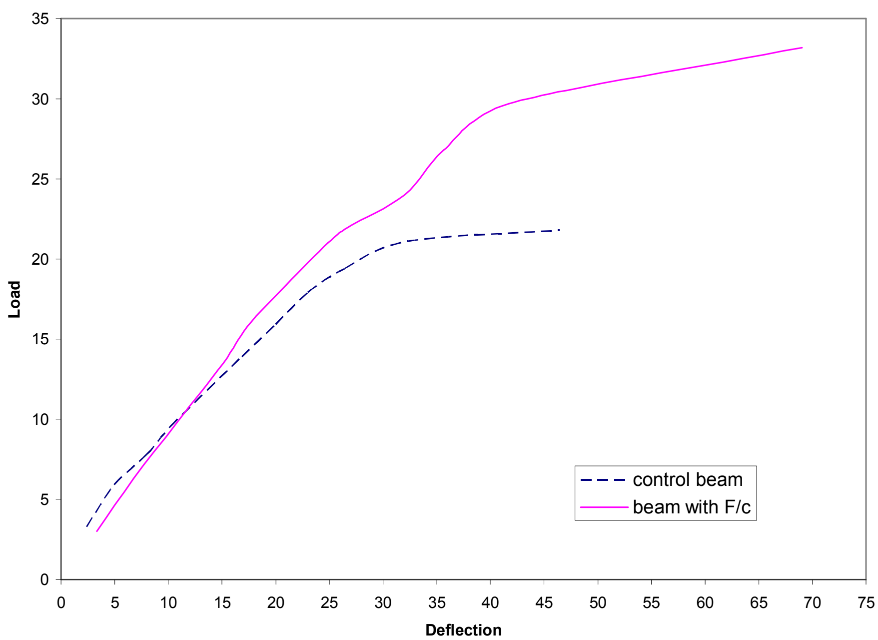

Figure 4.4 Load vs. Deflection curve at L/2 for control beam and beam retrofitted with wire mesh at 45 deg

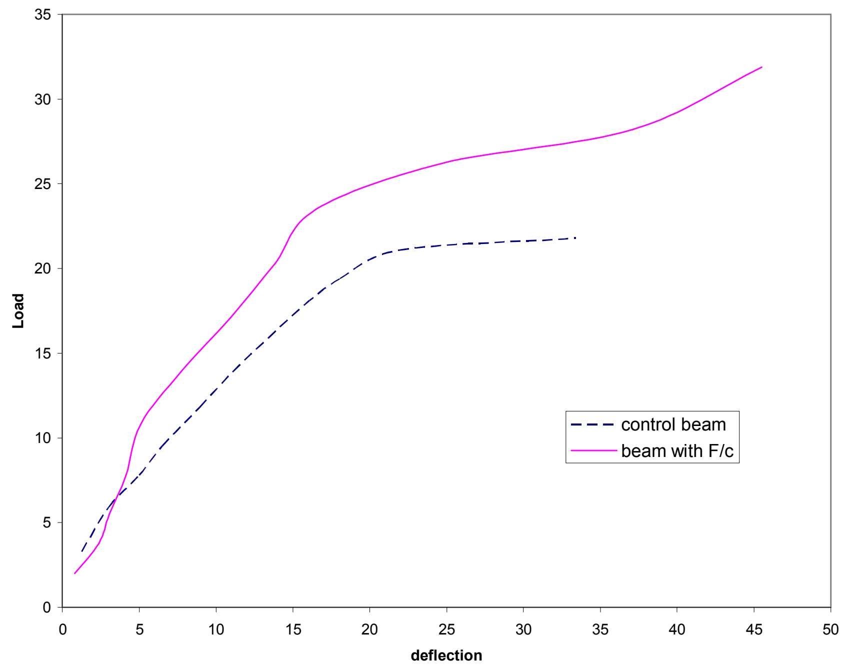

Figure 4.5 Load vs. Deflection curve at L/4 for control beam and beam retrofitted with wire mesh at 60 deg

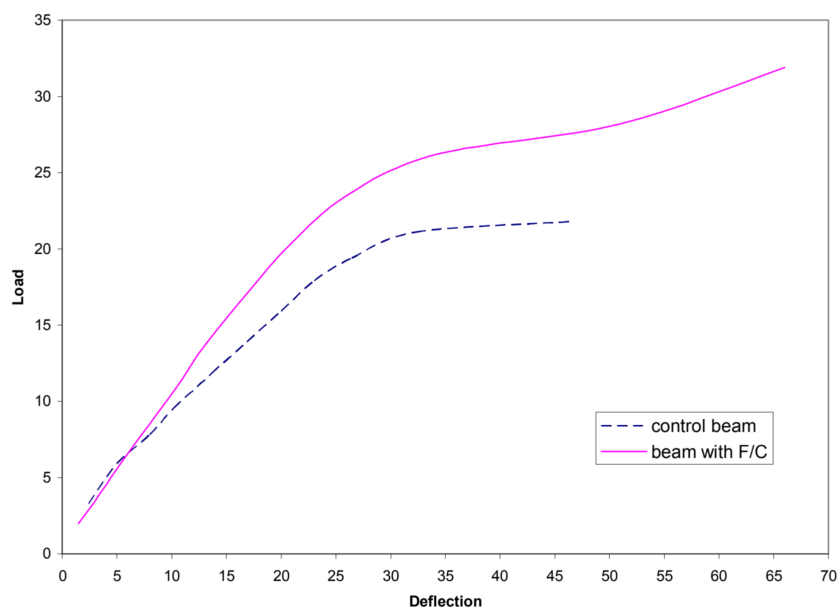

Figure 4.6 Load vs. Deflection curve at L/2 for control beam and beam retrofitted with wire mesh at 60 deg

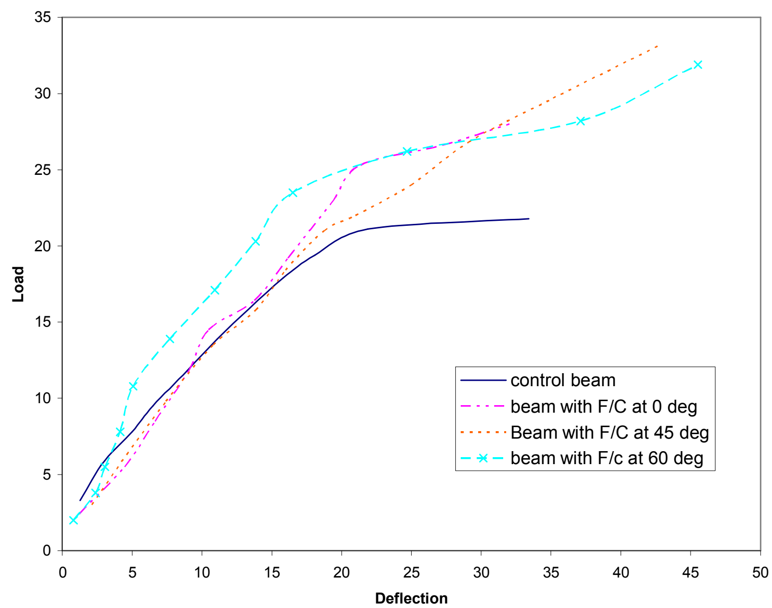

Figure 4.7 Load vs. Deflection curve at L/4 for control beam and beam retrofitted with wire mesh at different orientation

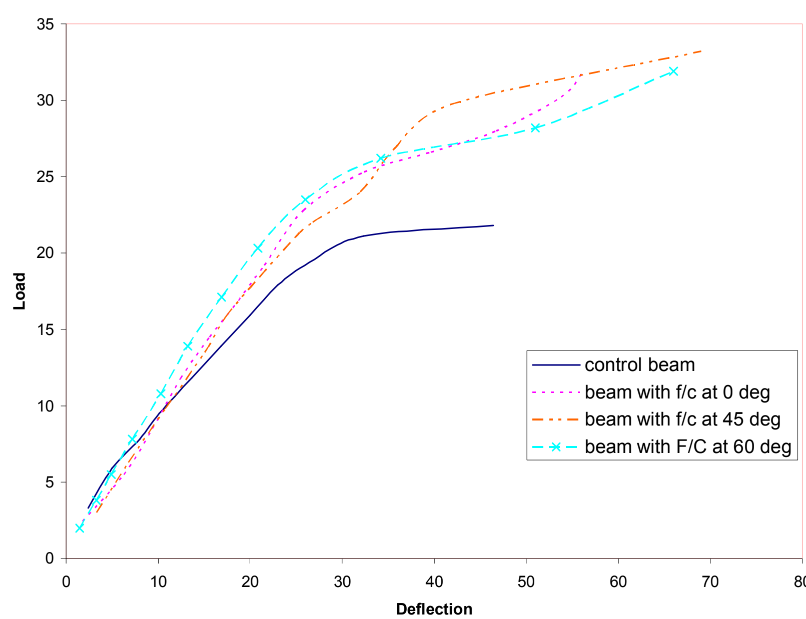

Figure 4.8 Load vs. Deflection curve at L/2 for control beam and beam retrofitted with wire mesh at different orientation

CHAPTER-5
CONCLUSION

Based upon the test results of the experimental study undertaken, the following conclusions may be drawn:

1. The beams retrofitted with wire mesh at different orientations do not de-bond when loaded to failure.

2. The failure of the composite is characterized by development of flexural cracks over the tension zone. The spacing of cracks is reduced for beams retrofitted with wire mesh at zero and 45 degree orientations, indicating better distribution of stress.

3. Wire mesh orientated at 45 degree for retrofitting the stressed beams has the highest load carrying capacity as compared to control beam as well as other beam retrofitted using different orientations.

4. After retrofitting, all the test specimens showed reduced crack widths, large deflection at the ultimate load, a significant increase in the ductility ratio, and considerable increase in the energy absorption as well, making the different orientation of wire mesh useful for application in components subjected to dynamic loads.

5. Beams retrofitted with wire mesh oriented at zero and 45 degree were the most efficient as their strength to cost ratio which is 0.62 and 0.61 respectively, is high as compared to wire mesh oriented at 60 degree for which it is 0.507.

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