EFFECT OF PERCENTAGE OF REINFORCEMENT ON BEAMS RETROFITTED WITH FERROCEMENT JACKETING

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CERTIFICATE

This is to certify that thesis entitled **"Effect of percentage of reinforcement on beams retrofitted with Ferrocement Jacketing"**, being submitted by Mr. Arshdeep Singh Channi,, Roll No. 80722003 in partial fulfillment for award degree of **Master of Engineering in Civil (Structures) at Thapar 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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ABSTRACT

Almost all the structures whether industrial, commercial or housing are constructed of RCC. There structure fare nicely under normal circumstances, but in the event of major earthquakes, higher load imposition etc. the structure may suffer permanent damage. This poses a more difficult scenario for a structural engineer than constructing a new building. This is due to number of restraints an already constructed building throws up like non engineered construction, wear & tear etc. instead of torning apart the structure one can strengthen the deficient structural elements of the structure. Thanks to the advancement in technology with the help of non-destructive testing one can easily identify such deficient elements. Once identified the best way out is to retrofit such elements. Retrofitting is different from repair or rehabilitation. It is basically a process of strengthening and enhancement of the performance of deficient structural elements in a structure or of the structure as whole. Retrofitting of deficient buildings can be done by increasing the strength, stiffness and/or ductility of its specific constituent elements or of the whole building. For any building, depending upon the requirement, a combination of the above may also be selected. Retrofitting of individual members or elements is referred to as local retrofitting. A civil engineer is not really spoilt for choices when it comes to retrofitting, he has to keep in mind a number of options before embarking on the work of retrofitting. The options available include Glass Fibre Reinforced Plastic or GFRP, Carbon Fibre Reinforced Plastic or CFRP or Ferrocement. He has to maintain a balance between aesthetic, availability, ease of working & above all economy. Ferrocement jacketing though lacks a bit in the aesthetical part but it wins by leaps & bounds in all other considerations. The reason for this is it is readily available, is easy to work with and is not even a quarter as costly as GFRP or CFRP.

The endeavour of our present study is to observe the effect of different percentage of tensile reinforcements on the behaviour of beams retrofit with ferrocement jacketing. The effect of percentage increase in tensile reinforcement vis-à-vis the percentage increase in ultimate load carrying capacity is studied. Also the deflections of retrofitted and non retrofitted beams are compared at different stress levels. The results shows an increase in load carrying capacity of retrofit beams though the increase varies with percentage of tensile reinforcements. The percentage increase in load carrying capacity is maximum in case of two bars of 8 mm dia as tensile reinforcement. The deflections also decreased considerably with the increase in percentage of tensile reinforcement.

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l = effective span of R.C. section

b = Width of R.C. section

D = Total depth of R.C. beam

d = effective depth of R.C. section

d' = cover to top/compressive reinforcement

kd = Neutral Axis of R.C. beam

m = Modular ratio

A_{st} = Area of tension steel

A_{sc} = Area of compression steel

f_{cr} = Characteristic strength of concrete

c = Modulus of rupture

E = Modulus of Elasticity

z = Lever arm

I_{gr} = Gross Moment of inertia

I_{cr} = Critical Moment of inertia

I_{eff} = Effective Moment of inertia

Δ = Deflection at mid spam

P = Load

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Most of the structures we lay our eyes on are invariably made of **Reinforced Cement Concrete** or RCC as it is commonly called. Even though it is a wonderful construction material, but once set it is very difficult to increase its strength or alter its shear or flexure strength. Another major drawback with RCC is that at most places it is largely manufactured by unskilled workers, and if seemingly minor but important points, if not kept in mind leads to RCC of reduced strength. Some of these points are increase in water cement ratio, improper curing etc. Strengthening the reinforced concrete may become necessary for a number of reasons, such as substandard detailing of the steel reinforcement and deterioration of the concrete under severe environmental conditions. Other needs for strengthening arise because either the design codes have changed that make these structures substandard or larger loads are permitted on the components of the infrastructure where extensive retrofitting is required. *[Rochette & Labossiere 2000]*. The transformation of non-engineered construction into an engineered one therefore needs to be such that it could be sustained. When talking of RCC buildings they can be made to undergo three different **R's** namely repair, rehabilitation & retrofitting. Repair is partial improvement of the degraded strength of a building after an earthquake. In effect, it is only a cosmetic enhancement. Rehabilitation is a functional improvement, wherein the aim is to achieve the original strength of a building after an earthquake. Retrofitting means structural strengthening and enhancement of performance of deficient structural elements of a building to a pre- defined performance level, whether or not an earthquake has occurred. The seismic performance of a retrofitted building is aimed higher than that of the original building.

Surveys of existing residential buildings reveal that many buildings are not adequately designed to resist earthquakes. In the recent revision of the Indian earthquake code *[IS 1893:2002]*, many regions of the country were placed in higher seismic zones. As a result many buildings designed prior to the revision of code may fail to perform adequately as per new code. It is therefore recommended that the existing buildings be retrofitted to improve their performance in the event of an earthquake and to avoid large scale damage to life and property.

The methodology adopted for these 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. 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 laminated cement based composite, ferrocement has found itself in numerous applications both in new structures and repair, rehabilitation & retrofitting 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 and. Naaman 1971.]*. 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 governs the design. *[Jamal & Ziyyad 2006]* 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.

1.2 FERROCEMENT

Ferrocement is also written as ferrociment, ferrocemento, ferrocimento, and ferrozement. Literally meaning much steel rather than much concrete. Ferrocement is sometimes referred to as *thin-shell concrete*.

In some cases, it is more desirable to have only one strong direction. This type of ferrocement, that has an orthotropic behavior, is achieved by using expanded steel meshes. Slitting steel sheets and expanding them in a direction perpendicular to the slits form expanded steel sheets. Expanded steel sheets have a diamond-shaped mesh pattern. Rolling could flatten these sheets and enhances their performance as reinforcement in concrete or mortar. *[Khaloo & Morshed 2000]*. This type of ferrocement is stronger and relatively stiffer in the long diagonal direction of diamonds and has lower strength and stiffness in the perpendicular direction *[Naaman 2000]*

Ferrocement is a composite material consisting of rich cement mortar matrix uniformly reinforced with one or more layers of very thin wire mesh with or without supporting skeletal steel. Its properties vis-à-vis RCC are given here in **Table 1.1**

Ferrocement when used in retrofitting requires primarily looking at the point of application, and then the meshing or reinforcement is applied at the required point. This can be done with the use of studs, fasteners and covering it with cement plaster. The development of ferrocement evolved from the fundamental concept behind reinforced concrete i.e. concrete can withstand large strains in the vicinity of the reinforcement & magnitude of the strains depends on the distribution & subdivision of the reinforcement throughout the mass of concrete. Ferrocement behaves as a composite because the properties of its brittle mortar matrix are improved due to the presence of ductile wire mesh reinforcement. Its closer spacing of wire meshes (distribution) in the rich cement sand mortar & the smaller spacing of wires in the mesh (subdivision) impart ductility & better crack arrest mechanism to the material.

Over the last two decades, many researchers initiated studies to determine the mechanical properties of ferrocement as well as its potential use in construction applications.

It has been showed that the conventional methods used for reinforced concrete analysis are valid to predict load–deflection relationship of ferrocement. Studies on the tensile properties of ferrocement indicated that the ultimate load of the composite material was equal to the load carrying capacity of the reinforcement in the loading direction and that the geometry of the mesh influenced the behavior of ferrocement. *[Naaman & Shah 1971]*. The properties of wire mesh & skeletal steel normally used in ferrocement are given in **Table 1.2**

1.2.1 Historical Background

The credit of using ferrocement in the present day goes to Joseph Louis Lambot who in 1848 constructed several rowing boats, plant pots, seats & other items from a material he called ferciment. Lambot's construction consisted of a mesh or grid reinforcement made of two layers of small diameter on bars at right angle & plastered with cement mortar with a thin cover to reinforcement Lambot's rowboats were 3.66 m long, 1.22 m wide & 25 mm to 38 mm thick. These were reinforced with grid & wire netting. One of the boat build by him, still in remarkably good condition, is on display in the museum at Brignoles, France.

There was very little application of true ferrocement construction between 1888 & 1942 when Pier Luigi Nervi began a series of experiments on ferrocement. He observed that reinforcing concrete with layers of wire mesh produced a material possessing the mechanical characteristics of an approximately homogenous material capable of resisting high impact. After the Second World War, Nervi demonstrated the utility of ferrocement as a boat building material.

In 1945, Nervi built the 165 ton Motor Yatch "Prune" on a supporting frame of 6.35 mm dia rods spaced 106 mm apart with 4 layers of wire mesh on each side of rods with total thickness of 35 mm. It weighed 5% less than a comparable wooden hull & cost 40% less at that time.

In 1947, Nervi built first terrestrial ferrocement structure ,a storage warehouse of about 10.7 m x 21.3 m .size. The strength of the structure was due to the corrugations of the wall & the roof which were 44.45 mm thick.

In 1948 Nervi used ferrocement in first public structure, the Tutrin Exhibition building. The central hall of the building which spans 91.4 m, was built of prefabricated elements Connected by reinforced concrete arches at the top & bottom of the undulations.

In 1958, the first ferrocement structure - a vaulted roof over shopping centre was built in Leningrad in Soviet Union.

In 1970, a prototype prefabricated ferrocement home was constructed in U.S.A. The house was found much lighter in weight & higher in resistance to dynamic load than the conventionally built brick or block house. In 1971 a ferrocement trawler named "Rosy in I" was built in Hong Kong. It had an overall length of 26 m & is claimed to be the world's longest ferrocement fishing boat.

In 1972, the US National Academy of sciences through its board on sciences & technology for international Development established an adhoc panel on the utilization of ferrocement in developing countries.

In 1974, the American Concrete Institute formed committee 549 on ferrocement. In 1975, two ferrocement aqueducts were designed & built for rural irrigation in China.

In 1976, the International Ferrocement Information Centre (IFIC) was founded at Asian institute of Technology, Bangkok, Thailand. The centre is financed by the United States Agency for International development, the Government of New Zealand & the International Development Research Centre of Canada.

In 1978 an elevated metro station of 43.5 m x 1.6 m in size with continuous ferrocement roofing was erected in Leningrad.

In 1979 RILEM (International Union of Testing & research Laboratries of materials & structures) established a Committee (48-FC) to evaluate testing methods for ferrocement.

In 1984, ferrocement was used in the construction of a shaking table of large scale earthquake simulation facility at the state university of New York at Buffalo.

Recently, it has been reported that the Chinese have been building ferrocement boats even before world war second. It is estimated that they have built 2000 boats. Most of these boats are 12 m to 15 m long & are mainly used in carrying goods.

1.2.2 Constituent Materials

The constituent materials of ferrocement are discussed in the succeeding sub sections.

a) Reinforcing Mesh

One of the essential components of ferrocement is wire mesh. Different types of wire meshes are shown in **Plate 1.1** and these are available almost everywhere, they generally consist of thin wires, either woven or welded into the mesh but main requirement is that it must be easily handled and if necessary, flexible enough to be bent around sharp corners. The function of wire mesh and reinforcing rod is to provide 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 be able to withstand. The specifications and properties of wire mesh & skeletal steel are discussed in **Table 1.2.**

b) Cement

The cement used should confirm to IS specifications. There are several types of cements which are available commercially in the market of which Ordinary Portland cement, Portland Pozzulona cement are the two most commonly used.

c) Aggregates

The most common aggregate used in ferrocement is sand .Sand should comply with IS standard fine aggregate. Aggregate is the term given to the inert material & it occupies 60 to 80 % of the volume of mortar. Aggregates to be used for the production of high quality mortar for ferrocement structure must be strong enough, impermeable & capable of producing a sufficiently workable mix with minimum water / cement ratio to achieve proper penetration of wire mesh. The sand cement ratio is kept from 2 to 4.

d) Water

The quality of mixing water for mortar has a visual effect on the resulting hardened ferrocement. Impurities in water may interfere with setting of cement & will adversely effect the strength of cause staining of its surface & may also lead to its corrosion of ferrocement. Usually water that is piped from the public supplies is regarded as satisfactory. The water cement ratio is generally kept from 0.3 to 0.5.

e) Admixtures

Admixtures are used to alter or improve one or more properties of cement mortar or concrete. Most of the admixtures are used to improve the workability, to lesson water demand & to prolong mortar setting. Admixtures can be classified into groups according to the effect they are expected to achieve. The commonly used admixtures

1.Accelerating admixtures

2.Retarding admixtures

3.Water reducing admixtures

4.Air entraining admixtures.

A new class of water reducing admixtures has emerged during last two decades, known as "super plasticizer". There are the high range water reducers.

f) Coatings

To increase the durability of ferrrocement, it may be protected by surface coatings, such as acrylic, latex, polyester & cement based paints.

1.2.3 Applications of Ferrocement

Ferrocement has found wide spread applications in housing particularly in roofs, floors, slabs, & walls. Some researches were also made on the use of ferrocement in beams & columns. Ferrocement roofs investigated included shell roofs , folded plates & the channel shaped roofs, box girders & secondary roofing.

[Kaushik et al 1987] investigated the behaviour of ferrocement cylindrical shell units as roofing elements and found that they can be used as roofing elements for low cost housing & satisfy Indian requirements of loading, deflections & crack width with economy.

Ferrocement can be effectively used for roofing for short spans. Ferrocement technology package for roofing uses state of-the-art design principles to manufacture reinforced shells. Commonly called channels they are produced on specially designed vibrating tables and profiled moulds. The production system is uniquely tailored to provide special end details, consistent shape and thickness; all crucial for high performance. They have a very high density, are impervious to penetration of water and provide high structural strength. Ferrocement roofing technology offers a viable alternative to conventional flat roofing systems such as reinforced cement concrete, reinforced brick cement, sand stone, etc. in both rural and urban areas of the country.

Ferrocement roofing channels are manufactured using designed mix of cement, sand and water to give high strength mortar that is reinforced with a layer of galvanised iron chicken wire mesh of 22 gauge and tor steel bars of 8-12 mm diameter provided in the bottom nibs of the channel. Ferrocement roofing channels can be safely transported for the application after a curing period of 14 days.

a) Advantages of Ferrocement channels

- Fast construction – prefabricated channels enable to construct a roof in just 3 days
- No shuttering required, unlike in-slab slab casting

- 30% cost saving over RCC roofing
- Less dead load on the walls
- High strength to weight ratio
- Appealing aesthetics - elegant profile and uniform size

1.3 OBJECTIVE OF PRESENT WORK

Even though extensive work is done on the use of ferrocement laminates in retrofitting but in particular its behaviour in flexure with respect to different tensile reinforcements need to be studied. Keeping this in mind, this study was undertaken to study the behaviour of RCC beams having different tensile reinforcements and strengthened with ferrocement jacketing.

1.4 OUTLINE OF THE THESIS

The thesis has been organized in the following five chapters:

Chapter 1: This chapter presents the general introduction, historical background and properties of ferrocement

Chapter 2: This chapter deals with the review of literature highlighting and the need for the present study

Chapter 3: Herein, the details of experiment set up are given and the properties of constituent materials have been discussed.

Chapter 4: This chapter deals with the results and their discussion in light of the objectives.

Chapter 5: It details the conclusions of the work carried out.

TABLE 1.1: PROPERTIES OF FERROCEMENT & RCC

SNo.	Ferrocement	Reinforced cement concrete
1	It is a steel mortar composite material	It is a mix of coarse aggregate, fine aggregate, cement & steel
2	Its reinforcement consists of closely spaced, multiple layer of steel mesh completely impregnated with cement mortar	Reinforcement is at tensile & compressive faces with shear stirrups
3	It can be formed into sections about 20-40 mm thick	Minimum section thickness varies from 100 mm for thin shells to 1200 mm in large beams
4	Only a fraction of an inch or 25 mm of cover over the outermost mesh layer	Minimum cover to reinforcement is one inch or 25 mm
5	Ferrocement reinforcing can be assembled over a light or no framework into the final desired shape and mortared directly in place, even upside down, with a thick mortar paste	Heavy framework required to support massive weight of concrete
6	Thin panels of ferrocement can be designed to levels of strain or deformation, with complete structural integrity and water tightness	Very thick panels of concrete required for water tight section due to relatively high permeability of concrete
7	Ease of fabrication makes it possible to form compound shapes	Compound shapes require difficult & cumbersome framework
8	The uniform distribution and high surface area to volume ratio of its reinforcement	Percentage of reinforcement varies from 1-4%
9	A high degree of toughness, ductility, durability, strength & crack resistance	Relatively low degree of toughness, ductility, durability, strength & crack resistance
10	Self weight of ferrocement elements per unit area is quite small	About 5-10 times heavier

TABLE 1.2 PROPERTIES OF WIRE-MESH & SKELETAL STEEL

A) Wire mesh		
1	Wire diameter	0.5 mm to 3 mm
2	Size of mesh openings	6 mm to 25 mm
3	Volume fraction of reinforcement	Upto 8% in both directions corresponding to up to 630 kg/m as steel per cubic meter of mortar.
4	Specific surface of reinforcement	Upto 4 cm^2 /cm^3 in both directions.
B) Intermediate skeletal reinforcement (if used) consists of wire, wire fabrics, rods & strands		
1	Diameter	3mm to 10 mm
2	Grid size	5 cm
3	Portland cement	Any type depending on application
4	Sand to cement ratio	1 to 3 by weight
5	Water to cement ratio	0.4 to 0.5
6	Sand	Fine sand passing I.S sieve No 8 & having 5% by weight passing No 100 with a continuous grading curve in between
7	Thickness	6 to 50 mm
8	Steel cover	1.5 to 5.0 mm
9	Ultimate tensile strength	34.5 N/mm^2
10	Compressive strength	27.6 to 68.9 N/mm^2
11	Allowable tensile strength	10.3 N/mm^2
12	Modulus of rupture	55.1 N/mm^2
13	Cube Strength of mortar	29.9 N/mm^2
14	Young's modulus of wire mesh	2×105 N/mm^2 for welded wire mesh
		1.38×10^5 N/mm^2 for woven mesh.
15	Yield strength of wire mesh	410 N/mm^2 for welded wire mesh.
		385 N/mm^2 for woven mesh.

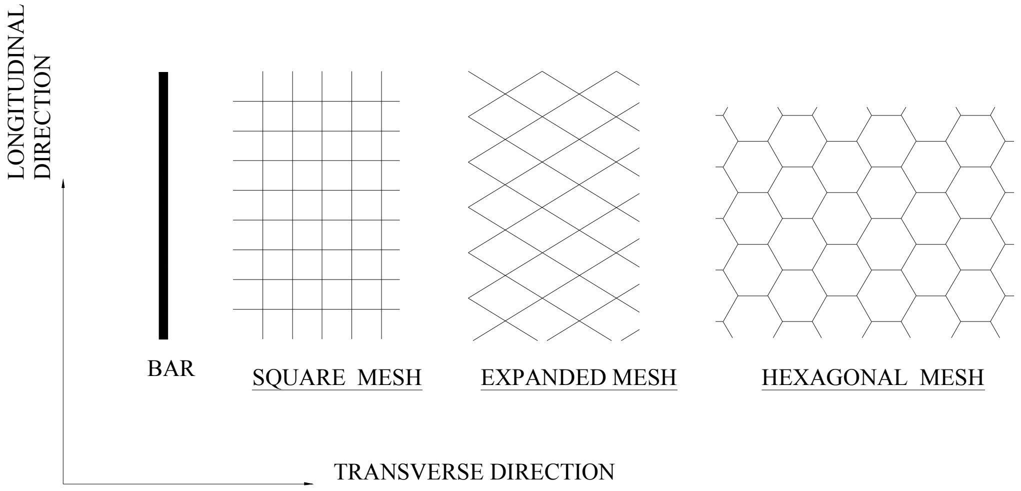


PLATE 1.1: DIFFERENT TYPES OF WIRE MESHES

CHAPTER 2

REVIEW OF LITERATURE

2.1 PRELIMINARY REMARKS

Earthquakes are the major nemesis of all the buildings. While analysing and assessing the damage caused by the earthquakes it was inferred that a building should not suffer collapse total i.e. after a devastating earthquake 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]*.

In this scenario ferrocement comes to our rescue due to its ease in use and its flexibility. It is used in retro-fitting so as to strengthen the 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]*. Reinforced concrete elements are designed to fail in a ductile manner by emphasizing on the detailing requirements due to the brittle nature of concrete *[IS 1893:2000]*.

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 PROPERTIES

Lots of research has gone into ascertaining the properties of ferrocement, its behavior in flexure & shear, advantages & disadvantages of different types of mesh etc. The pioneer work done by few researchers is mentioned here.

[Yuzugullu 1991] reported that using expanded mesh reinforcement increases the load carrying capacity of ferrocement elements.

[*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

[G.J.Al-Sulamani et al 1992] studied the behavior of Ferrocement under direct shear by conducting compression tests on Z-shaped specimens reinforced with wire mesh producing pure shear on shear plane. Tests results indicate that Ferrocement under direct shear exhibits two stages of behavior (cracked and uncracked) while under flexure it exhibits a third stage i.e. plastic stage in addition. The cracking and ultimate shear stresses increase with increasing mortar strength and wire mesh reinforcement. Empirical equations have been developed here using regression on analysis to predict the cracking and ultimate shear stresses in terms of the mortar tensile strength f_t and V_f. It indicates that the shear stiffness in the uncracked stage is not significantly affected by the amount of wire mesh; it is mainly affected by the mortar strength. The shear stiffness in the cracked stage is affected by both amount of wire mesh and mortar strength. Ductility of ferrocement material under direct shear increases with increasing

wire mesh reinforcement and decreases with higher mortar strength. The behavior of ferrocement in flexure has received adequate attention by many researchers and it has been observed to be similar to the reinforced concrete members. The behavior of ferrocement material under direct shear was investigated by conducting axial load tests on direct shear specimen. The direct shear specimen used in this study has Z-shape. It has width of 300 mm; 100 mm thickness height p_f 600mm. There is a triangular notch in the middle of each side of the specimen to force failure along the shear plane which has dimensions of 30mm×220mm.The wire mesh Layers are placed to cross the shear plane. Regular reinforcing bars are placed top and bottom blocks of the specimens to avoid any premature failure of these end blocks. Ferrocement when subjected to flexure, exhibits three stages of behavior; uncracked, cracked and yield or ultimate stage. The third stage is an indication of the ductility that ferrocement possesses under flexure.

[Xiong and Singh 1992] investigated a qualitative mechanistic model to show the flexural fatigue of ferrocement, they showed that the rectangular stress distribution assumption is better for estimating steel stress when designing weld mesh ferrocement against fatigue.

[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 of the order of 50 mm the steel content in reinforced mortar had been varied from 200 kg/m^3 to values as low as that of RCC.

[Kobayashi et. Al 1992] reported the properties of impact damage obtained from lateral impact test of ferrocement.

[Kahn et al 1975] to study the composite behavior of ferrocement, they tested forty composite beams made of 0.25 in. thick steel plates and 1 in. thick plates made of either reinforced concrete (RCC) or ferrocement. They concluded the necessity of using sand-blasted plates to improve the composite action between layers

[Ong et. al. 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.

[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 RCC 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 RCC 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 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. 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.

2.3 FERROCEMENT FOR BUILDINGS

Ferrocement, as already sated, is a boon for the construction industry particularly the retrofitting trade. It is also used in the pre-fabricated industry due to its light weight. Generally ferrocement roofing units are produced in factories or fabricated on site. 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 composite slabs can be safely used for roofing and flooring purposes The ferrocement composites exhibit better performance as compare to CGI composite in terms of load carrying capacity, energy absorption capacity, ductility and recovery in unloaded.

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 1992]*. 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.

2.4 TRAITS OF FERROCEMENT

The traits to be kept in mind when using ferrocement are discussed below

2.4.1 Ease of Placement

Performance of ferrocement jacketing is highly enhanced as it can be easily placed with minimal or no form work. Cement slurry, the generally used bonding agent is very cheap & quite effective. Even though the mortar used has very less water-cement ratio still it can be worked onto the inverted beams.

2.4.2 Workmanship

The application of ferrocement jacketing does not require skilled labour. Even masons well versed with the art of cement plastering can do this job satisfactorily. Only minimal supervision will suffice the job in hand.

2.4.3 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 8 mm reinforcement cover thickness. Despite relatively low water/cement ratio recommended for the mortar mix 0.35-0.50. 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.

2.4.4 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 required medium level or non-skilled labour, 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 prestressing. 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 another 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.

2.4.5 A versatile ferrocement

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, ensures against corrosion will be necessary.

e) In the most civil engineering applications, 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

2.4.6 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.

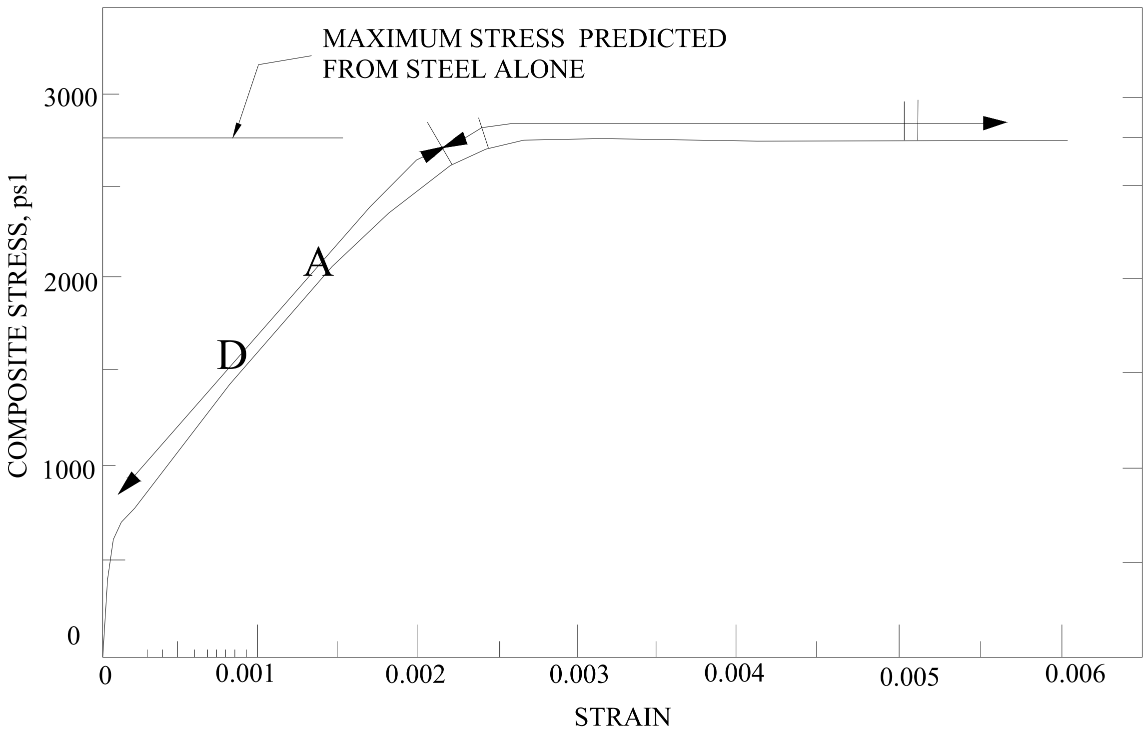


Fig. 2.1: GRAPH SHOWING STRESS AND STRAIN RELATION IN FERROCENMENT

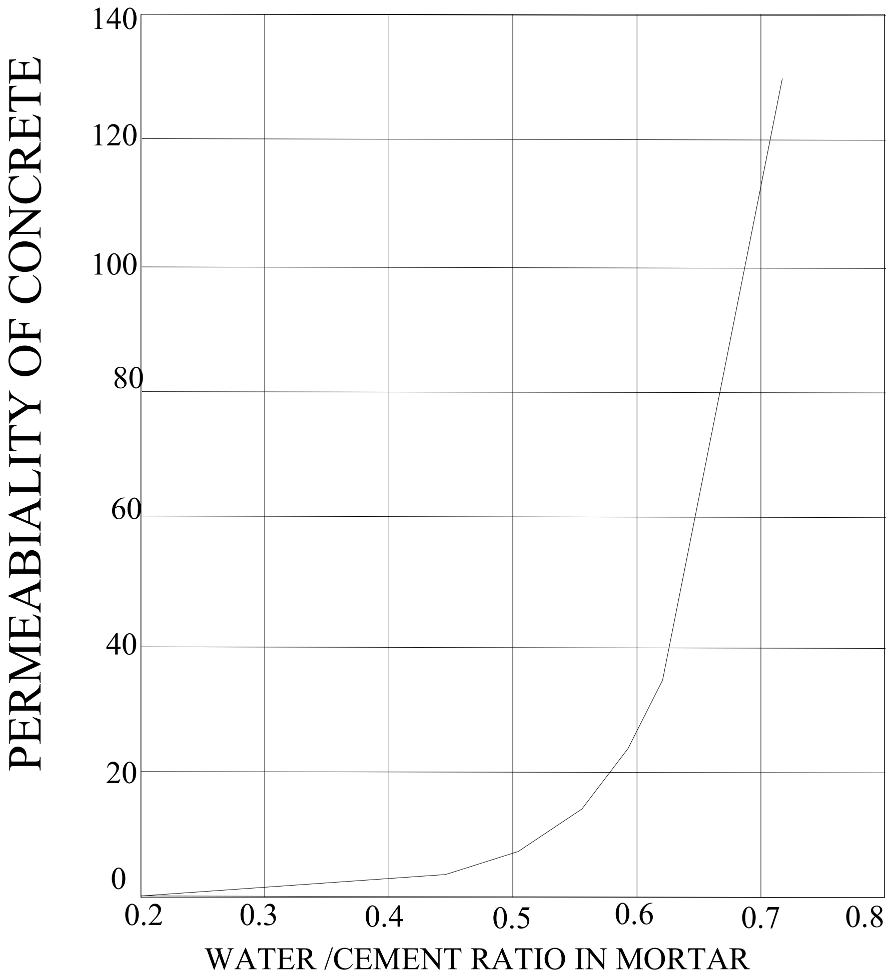


Fig. 2.2: RELATION BETWEEN PERMEABILITY AND WATER TO CEMENT RATIO (WEIGHT BASIS) FOR MATURE PORTLAND CEMENT PASTE (CEMENT HYDERATED 93%). (R.B WILLIAMSON)

CHAPTER 3.0

EXPERIMENTAL PROGRAMME

3.1 INTRODUCTION

Very little information is available in literature regarding RCC beams retrofitted with ferrocement jacketing reinforced with different percentage of tensile reinforcements and tested in flexure to failure. Thus, the main objective of this thesis is to study the behaviour of under reinforced concrete beams retrofitted with ferrocement jacketing, reinforced with different percentage of tensile reinforcements. To carry out the investigation twelve prototype beams, were cast, out of these six beams are taken as control beams and tested to failure to find out the load carrying capacity of the beams. Other six are then stressed to 50 percent of the ultimate load of the control beam and then retrofitted with ferrocement jacketing. The strength behavior, their failure loads, ultimate deflection etc. are observed and analyzed in the subsequent chapter

3.2 TEST PROGRAMME

The aim of the experiment was to firstly determine the properties of constituent materials namely cement, sand, coarse aggregates and steel bars as per relevant Indian standard specifications. Primarily, however it is envisaged the effect of retrofitting with ferrocement jacketing at different percentage of tensile reinforcements, flexural behaviour of the beams with different percentage of tensile reinforcements. The increase in flexure strength if any, the decrease in deflection of control & retrofitted beam at same load and the cost benefits vis-à-vis the strength benefits are studied.

Twelve prototype beams (127× 227 x 4100mm) were cast using M 20 grade concrete. The mix proportion of material comes out to be 1:1.19:1.57:1.57 (cement: sand: 10 mm coarse aggregate: 20 mm coarse aggregate) by weight. Four of the beams having two bars of 8 mm dia as tensile reinforcement, other four having two bars of 10 mm dia as tensile reinforcement & last four having two bars of 12 mm dia as tensile reinforcement, with the compressive reinforcement fixed as two bars of 8 mm dia. In all beams 6 mm dia bars of mild steel @ 150 mm c/c are provided as shear stirrups so that the beam does not fail in shear. The tension and compression reinforcement was of Fe 500 grade, the clear cover to top & bottom bars was kept at 25 mm.

Out of the twelve beams, two beams having two bars of 8 mm as tensile reinforcement plus two beams having two bars of 10 mm as tensile reinforcement & last two having two bars of 12 mm as tensile reinforcement totaling to six beams are termed as control beams. These beams are loaded to failure to know the ultimate load. Now the remaining six beams are stressed to 50 % of the ultimate load and then retrofitted with ferrocement jacketing using cement slurry as bonding agent. The test set up, jack & data acquisition system for taking readings are shown in shown in

3.1, 3.2 & 3.3.

For the convenience of presentation the beams are tagged as shown in **Table 3.1**

3.3 MATERIALS

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

3.3.1 Cement

Potland Pozzolona Cement from a single lot was used for the study. The physical properties of cement as obtained from various tests are listed in **Table 3.2**. All the tests are carried out in accordance with procedure laid down in IS 1489 (Part 1):1991.

3.3.2 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 3.3 & Table 3.4.**

3.3.3 Coarse Aggregates

Crushed stone aggregates (locally available) of 20mm and 10mm in the ratio of 1:1 were used through out the experimental study. The physical properties and sieve analysis of coarse aggregate are given in **Table 3.5, Table 3.6 and Table 3.7**.

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-500 of 8mm 10mm & 12 mm diameters were used as longitudinal steel. 6mm diameter MS bars are used as shear stirrups. The properties of these bars are shown in **Table 3.8**. The reinforcement steel is shown in **Plate 3.4**

3.3.6 Steel Mesh

GI steel wire mesh of 2.4 mm diameter with rectangular grids was used in ferrocement jacket. The grid size of mesh was 45 × 12 mm. The salient properties of mesh wire used are given in **Table 3.8**. Steel mesh is shown in **Plate 3.5, 3.6 & 3.7**

3.3.7 Concrete Mix

M20 grade concrete mix is designed as per IS code design procedure using the properties of materials as discussed above i.e. **Table 3.1 to Table 3.7**. The water cement ratio used in the design is 0.48. The mix proportion of material comes out to be 1:1.19:1.57:1.57 (cement: sand: 10 mm coarse aggregate: 20 mm coarse aggregate) by weight and compressive strength of materials after 7 days and 28 days is 21 and 27 N/mm^2 respectively.

3.3.8 Mortar Mix

The range of mix proportion recommended for common Ferrocement applications are cement: sand ratio by weight, 1:1.5 to 1:25, but not greater than 1:3 and water cement ratio by weight, 0.35 to 0.5. The higher the sand contents the higher the required water contents to maintain same workability. Fineness modulus of the sand, water cement ratio contents to maintain ratio should be determined from trail 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) by weight. The water-cement ratio for mortar was 0.40 for given consistency of cement.

3.4 TESTING PROCEDURE

3.4.1 RCC Beam Design

When using two bars of 8mm dia (A_{sc}=100.53 mm^2) as compression steel & two bars of 12 mm dia (A_{st}=226.28 mm^2) bars as tension steel and for M20 grade of concrete, & taking the size of the beam as 127 mm deep & 227 mm wide the section comes out to be under-reinforced. As the steel available in market is 12 m long, so the length of beam was kept at 4 m to economize the whole study. 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 6 mm diameter at a spacing of 150 mm c/c. According to design the dimension of the beam comes out to 127 × 227 mm. Longitudinal section and cross-section of beam is shown **Figure 3.1, 3.2, 3.3.**

3.4.2 Casting of Beams

The casting of beams was done in single stage. The beams were cast in moulds of size 127 × 227 × 4000 m. First of the entire beam mould is oiled. This is done so that the set RCC beam can be easily removed from the mould after 24 hours. Now the bottom/ tensile reinforcement steel, top/hanger bars & the stirrups are bound together with the help of binding wires. The steel is then placed in the oiled moulds. Cover blocks of size 25mm are placed at bottom and fixed at sides to provide uniform cover to the reinforcement. Coarse aggregates, fine aggregates, cement & water are mixed in a mechanical mixer as per the proportion of design mix. The concrete is then 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 24 hours. After demoulding the beams are cured for 28 days using jute bags.

3.4.3 Testing of beams

All the twelve beams were tested under simply supported end conditions. Two points loading is adopted for testing. The reason for adopting two point loading is that as we want to test the beams in flexure i.e a pure bending case. 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 recorded from the data acquisition system, which is attached with the load cell. Three dial gauges are placed one at centre of the span of the beam and other two at mid points of support & load. The value of deflection is obtained from these dial gauges. The experimental set up is shown in **Plate 3.8** and a systematic line diagram shown in **Fig 3.1, 3.2 & 3.3**. Out of twelve beams, two beams each of same tensile reinforcement and with three different tensile reinforcements totaling six beams are control beams, which are tested after 28 days of curing to find out the ultimate load and deflection. Rest of six beams is stressed upto 50 percent of the ultimate load obtained from the testing done on the control beams. **Plate 3.9** shows failure of beams.

3.4.4 Process of Retrofitting

The remaining six beams which were stressed to 50 % of the ultimate load are now ready for retrofit. Firstly, the surface of beam is cleaned. Then cement & water are mixed in the ratio of 1:20 to prepare cement slurry. This slurry is applied on bottom & two sides of the beam for ensuring a proper bond of cement mortar with RCC beam. The wire mesh which is already in U shape is wrapped around the beam from three sides and its two open ends tied with each other with the help of steel wire. Now cement slurry which consists of cement & water is applied as bonding agent to the surface of beam. After the application of bonding agent retrofitting of beam is done by applying 20mm thick cement mortar on the three faces as ferrocement laminates on all the remaining six beams with three different tensile reinforcements. The beams are cured with jute bags for 7 days before testing. They are then tested with the same procedure as adopted during the testing of control beams to calculate ultimate load and corresponding deflections.

3.5 ANALYSIS OF BEAMS

For the loading shown in **Fig 3.3**. the Moment of Resistance (MOR) of the beams having three different tensile reinforcements are calculated, Similarly the deflections at a load interval of 1 kN are also calculated. The following assumptions are used when calculating the design strength of ferrocement members for flexure.

1) Strain in reinforcement & concrete should be assumed directly proportional to the distance from the neutral axis.

2) Maximum strain at extreme concrete compression fibre should be assumed equal to 0.003.

3) Stress in reinforcement below specified yield strength should be taken as Effective modulus 'E_r' times the steel strain where E_r for expanded steel mesh that we used has a value

of 138000 MPa in longitudinal direction & 69000 Mpa in transverse direction. For strains greater than that corresponding to yield strength of mesh reinforcement, stress in reinforcement shall be considered independent of strain and equal to yield strength of mesh reinforcement.

4) Tensile strength of concrete is neglected.

5) Stress-Strain distribution of concrete may be considered satisfied by the use of equivalent rectangular concrete stress distribution.

These values are discussed in detail in Chapter 4.

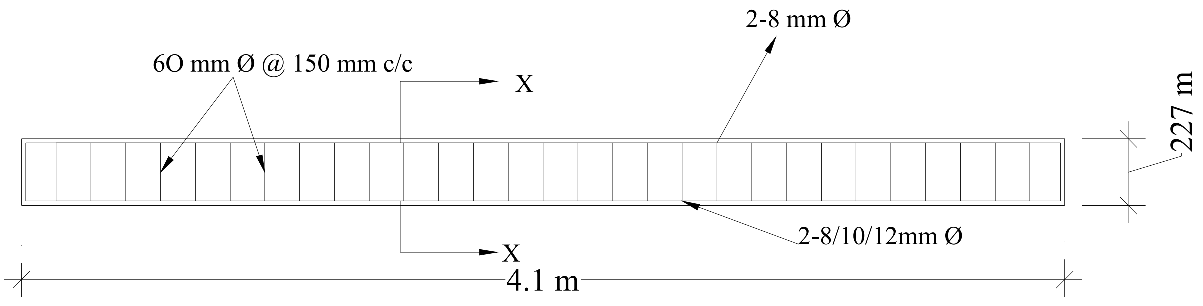
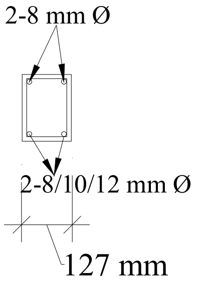


Figure 3.1: Longitudinal Cross- Section of Unretrofitted Beam



Section X-X

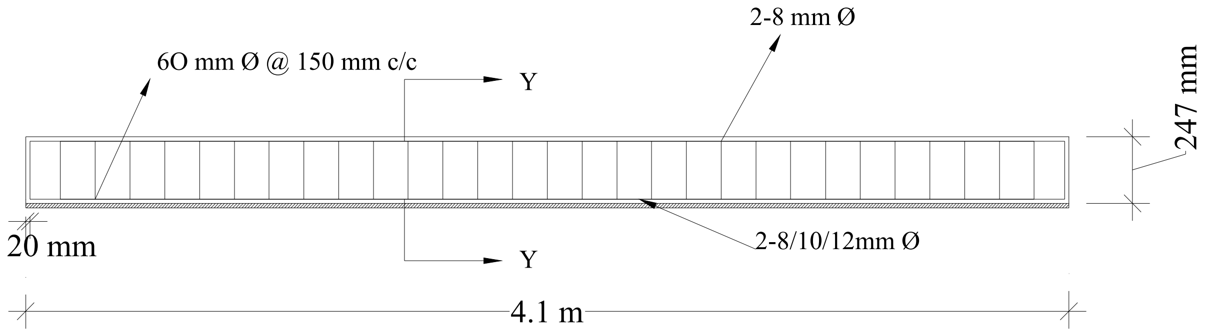
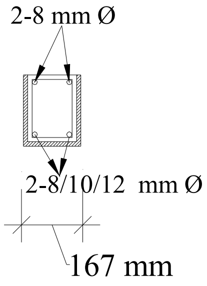


Figure 3.2: Longitudinal Cross- Section of Retrofitted Beam



Section Y-Y

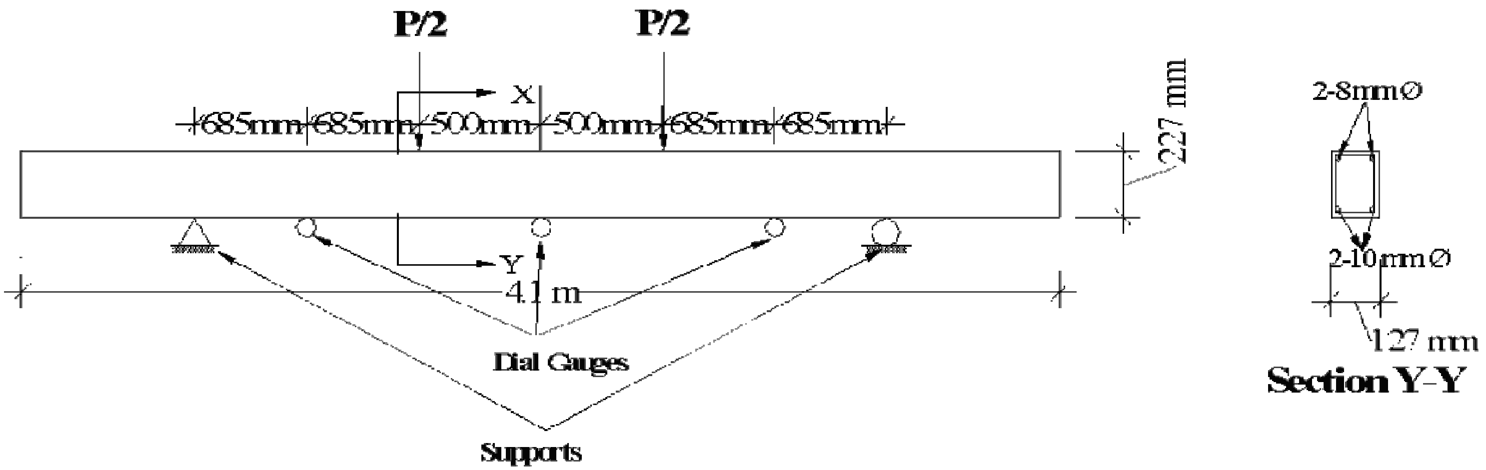


Figure 3.3: Testing System of Beam

TABLE 3.1: THE DETAILS OF TAGGING OF BEAMS

SNo.	Description of beams	Tag
1	Two beams having two bars of 8 mm as tensile reinforcement and tested to failure. A_{st}=100.57 mm^2	**C1**
2	Two beams having two bars of 10 mm as tensile reinforcement and tested to failure. A_{st}=157.14 mm^2	**C2**
3	Two beams having two bars of 12 mm as tensile reinforcement and tested to failure. A_{st}=226.29 mm^2	**C3**
4	Two beams having two bars of 8 mm as tensile reinforcement and stressed to 50 % of ultimate load & retrofitted with ferrocement jacketing. A_{st}=100.57 mm^2	**R1**
5	Two beams having two bars of 10 mm as tensile reinforcement and stressed to 50 % of ultimate load & retrofitted with ferrocement jacketing. A_{st}=157.14 mm^2	**R2**
6	Two beams having two bars of 12 mm as tensile reinforcement and stressed to 50 % of ultimate load & retrofitted with ferrocement jacketing. A_{st}=226.29 mm^2	**R3**

TABLE 3.2: PHYSICAL PROPERTIES OF CEMENT

Sr. No.	**Characteristics**	**Value obtained Experimentally**	**Value specified by IS : 1489-1991**
1.	Standard consistency	33	-
2.	Fineness of cement as retained on 90 micron sieve ‘in %’	0.5	Min 0.1
3.	Setting time 1.Initial 2.Final	 90 mins. 410 mins	 Min 30 mins Max 600 mins
4.	Specific gravity	3.12	-
5.	Compressive Strength(N/mm^2) 1. 7 days 2. 28 days	 28.00 37.00	 Min 22 Min 33

TABLE 3.3: PHYSICAL PROPERTIES OF FINE AGGREGATES

SNo.	**Characteristics**	**Value**
1.	Specific gravity	2.50
2.	Bulk density loose (kg/lt)	1.50
3.	Fineness modulus	2.52
4.	Water Absorption	1.99 %
5.	Grading Zone (Based on percentage passing 0.60 mm)	Zone II

TABLE 3.4: SIEVE ANALYSIS OF FINE AGGREGATES

Total weight taken = 1000gm

Sr No.	**Sieve Size**	**Mass Retained (gm)**	**Percentage retained**	**Cumulative Percentage Retained**	**Percent Passing**	**Permissible limits in % age**
1.	4.75 mm	0	0	0	100.00	**90-100**
2.	2.36 mm	0	0	0	100.00	**75-100**
3.	1.18 mm	214	21.4	21.4	78.60	**55-90**
4.	600 µm	327	32.7	54.1	45.90	**35-59**
5.	300 µm	293	29.3	83.4	16.60	**8-30**
6.	150 µm	97	9.7	93.1	6.90	**0-10**
				Σ=252.0		

FM of Sand = 252 = 2.52

100

TABLE 3.5: SIEVE ANALYSIS OF COARSE AGGREGATES (20 mm)

Total weight taken = 3 kg.

SNo.	Sieve Size	Mass Retained (gm)	Percentage Retained	Cumulative Percentage Retained	Percentage Passing
1.	40 mm	0.00	0.00	0.00	0.00
2.	20 mm	138.00	4.60	4.60	95.40
3.	10 mm	2480.00	82.67	87.27	12.73
4.	4.75 mm	272.00	9.07	96.33	3.67
5	Pan	110	3.67	Σ=188.20	

FM of 20 mm Coarse aggregate = $\mathbf{\frac{188.20 + 500}{100} = 6.88}$

TABLE 3.6: SIEVE ANALYSIS OF COARSE AGGREGATES (10 MM)

Total weight taken = 3 kg.

SNo.	Sieve Size	Mass Retained (gm)	Percentage Retained	Cumulative Percentage Retained	Percentage Passing
1.	40 mm	0.00	0	0.00	100.00
2.	20 mm	0.00	0	0.00	100.00
3.	10 mm	295.00	9.83	9.83	90.17
4.	4.75 mm	2509.00	83.64	93.47	6.53
5	Pan	196.00	6.53	Σ=103.30	

FM of 20 mm Coarse aggregate = $\mathbf{\frac{103.30+500}{100} = 6.03}$

TABLE 3.7: PHYSICAL PROPERTIES OF COARSE AGGREGATES

Sr. No.	**Characteristics**	**Value**	
		20 mm	10 mm
1.	Type	Crushed	Crushed
2.	Specific gravity	2.66	2.70
3.	Total water absorption	3.645	1.643
4.	Fineness modulus	6.88	6.03

TABLE 3.8: PHYSICAL PROPERTIES OF STEEL BARS AND STEEL MESH WIRE

Sr. No.	**Diameter of bars / mesh wire**	**Yield strength (N/mm^2)**	**Ultimate strength**	**Percentage Elongation (%)**
1.	12 mm	550.00	610.0	16.2
2.	10 mm	445.55	509.2	15.5
3.	8 mm	559.5	634.13	20.3
4.	6 mm	442.42	612.7	32.9
5.	2.4 mm	400	511.36	2.52

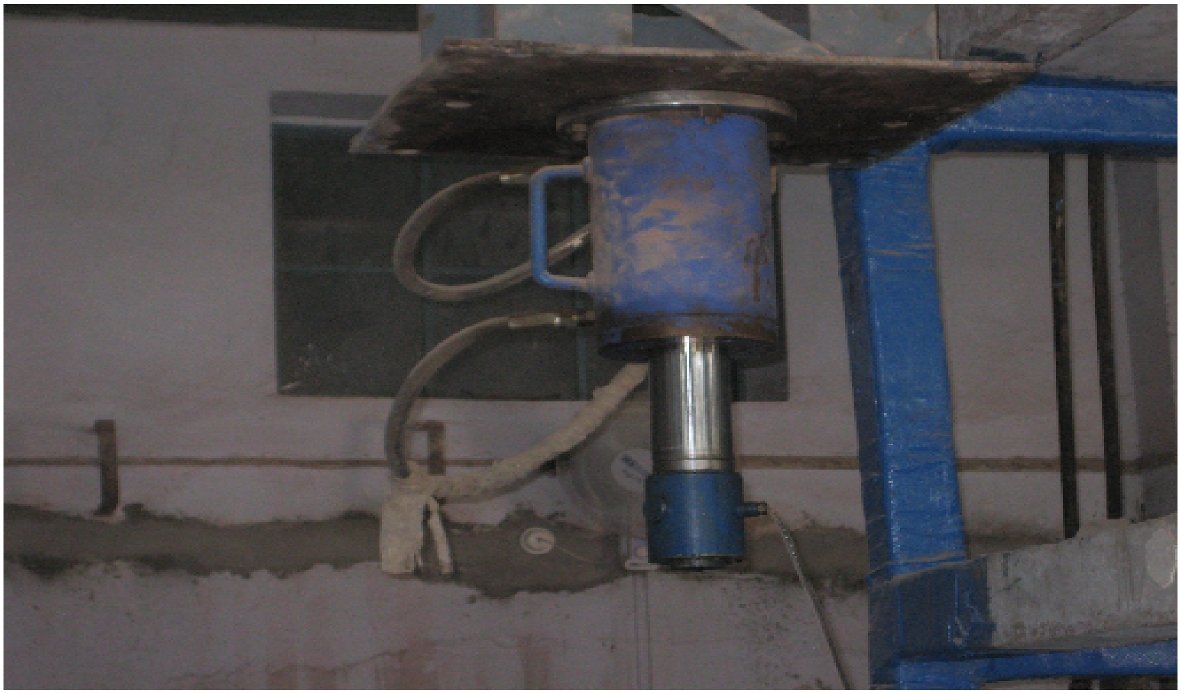


PLATE 3.1: TESTING JACK SHOWING FULL TRAVEL OF THE JACK

PLATE 3.2: DATA ACQUISTION SYSTEM CONNECTING WITH LOAD CELL

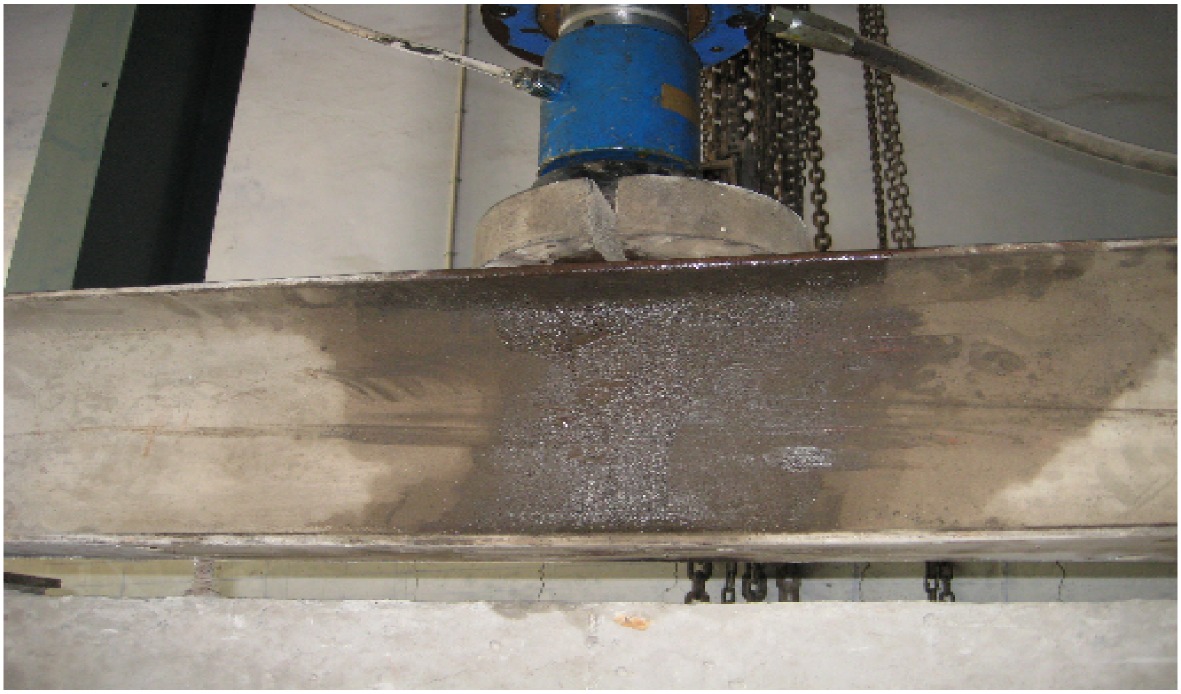


PLATE 3.3 TESTING JACK WITH SYSTEM FOR CONVERTING CONC. LOAD TO TWO POINT LOAD

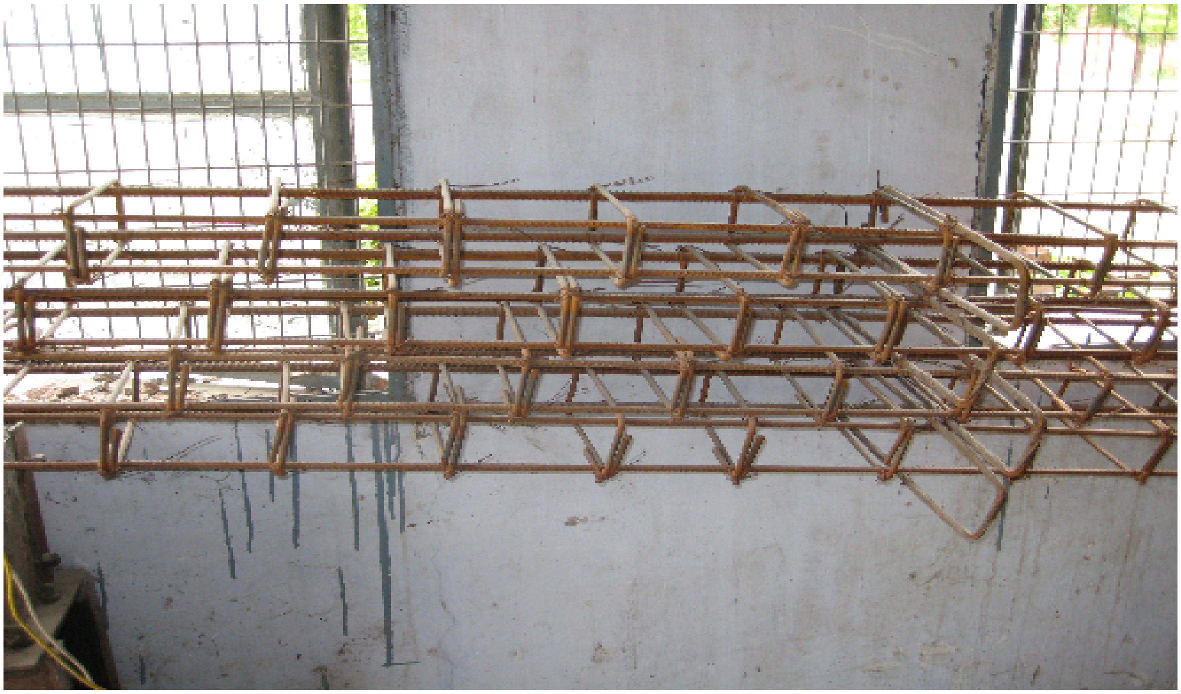


PLATE 3.4: TENSILE REINFORCEMENT STEEL, WITH HANGER BARS & STIRRUPS

PLATE 3.5: STEEL MESH BEND IN SHAPE TO ENCAPSULATE THE BEAM

PLATE 3.6: STEEL MESH SHOWING LONGITUDINAL DIMENSION

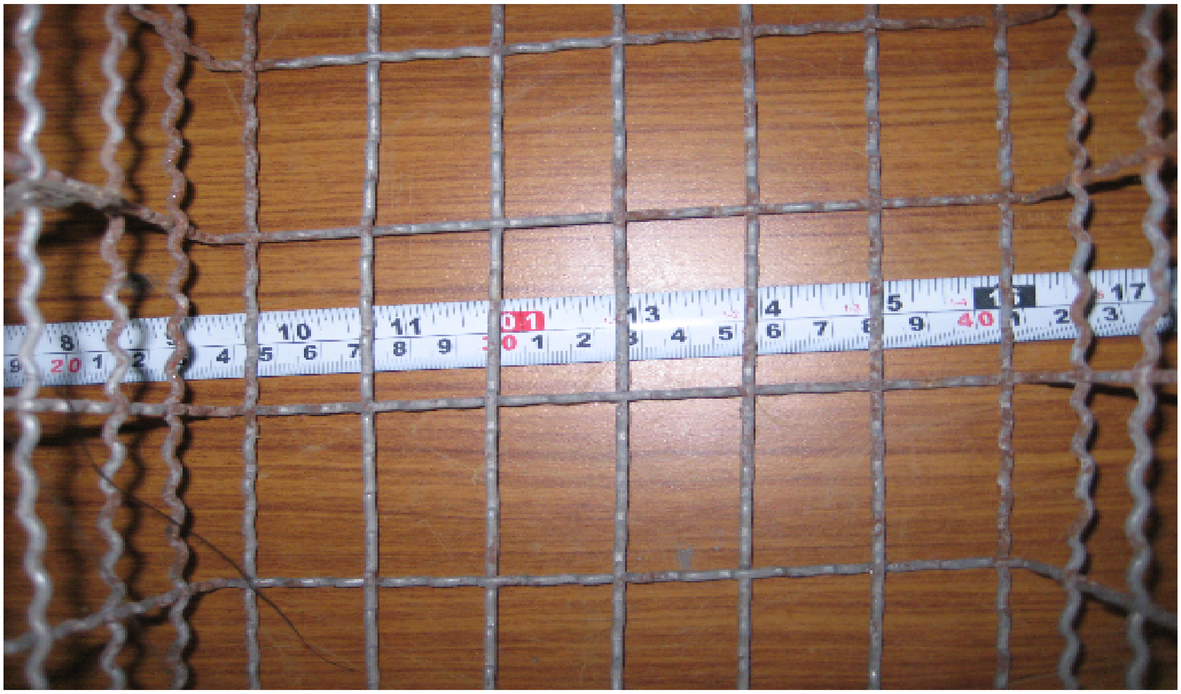


PLATE 3.7: STEEL MESH SHOWING TRANSVERSE DIMENSION

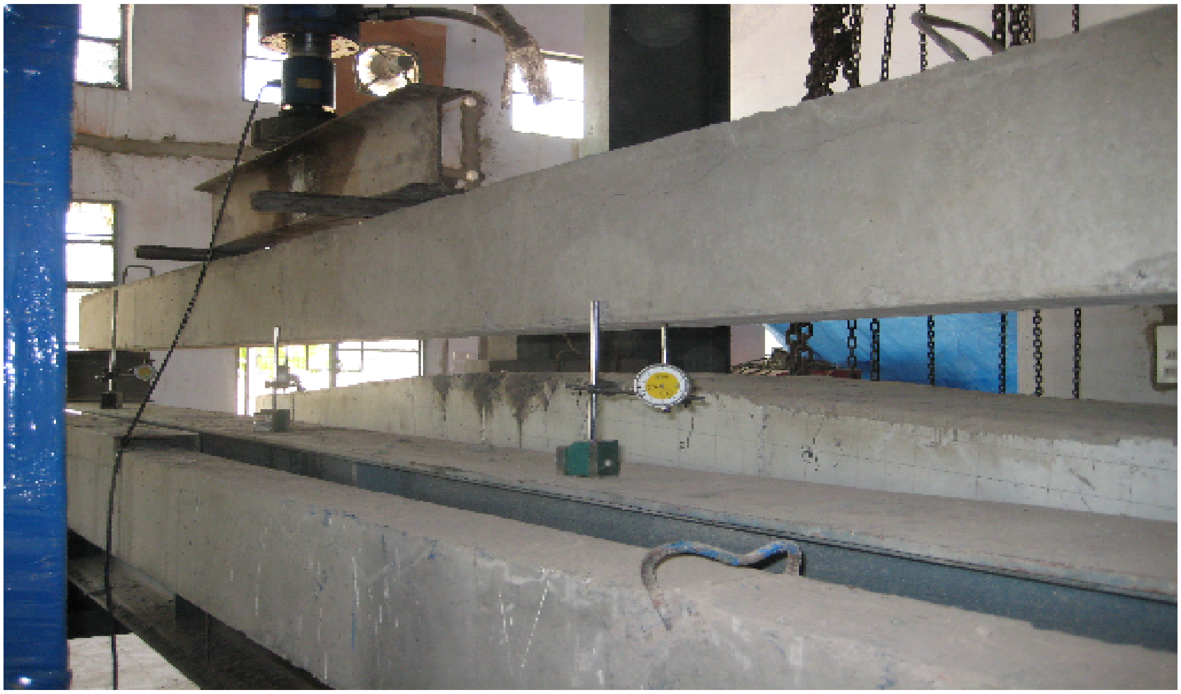


PLATE 3.8: EXPERIMENTAL SET UP SHOWING POSITION OF DIAL GAUGES

PLATE 3.9: FAILURE OF BEAMS

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In the present work it is envisaged to study the effect of different percentage of tensile reinforcements on the strength of the retrofitted beams. Twelve beams are cast using M20 grade of concrete having three different percentages of tensile reinforcements tagged as C1, C2 & C3 for Control beams & R1, R2 & R3 for retrofitted beams. The compressive reinforcement was kept fixed at 2 bars of 8 mm dia TMT steel bars at top and 2- legged stirrups of 6 mm diameter mild steel bars at a centre-centre distance of 150 mm was kept as shear reinforcement. After testing the control beams to failure the flexural & serviceability properties are observed. The remaining beams are then stressed to 50 % of the ultimate load & subsequently retrofitted as per the procedure detailed in Chapter 3. These beams are again tested to failure & variations in strength & serviceability properties are again observed. The subsequent section presents a detailed discussion of these observed values.

4.2 CONTROL BEAMS

Out of a total of twelve beams cast, six control beams are tested for ultimate load & maximum deflection. Their failure load & deflections are shown in **Table 4.1.** From the table it is observed that in beam C2 there is an increase of83.33 % from 12 KN to 22 KN & in beam C3 there is a 133.33 % increase of from 12 KN to 28 KN ultimate load as compared to beam C1, similarly there is an increase in the values of safe loads & energy absorptions. The percentage increase in these values is shown in **Table 4.2**. These increases in ultimate loads, safe loads & energy absorption values are due to the increase in percentage of tensile reinforcements.

The load deflection curve for different percentages of tensile reinforcements is shown in **Fig 4.1, 4.2 & 4.3**.

From the curves it is deduced that as the load increases the deflection initially increases linearly, then increases at much higher rate. This is attributed to the yielding of reinforcement.

Fig 4.4 shows the load-deflection behaviour vis-à-vis each other for the control beams, where in the load-deflection curves C1, C2 & C3 are shown at a same time enabling us to comment on their respective curves better.

The three curves also emphasize the observation made earlier that there is an increase in ultimate load carrying capacity and deflection strength of beams as we proceed from curves C1 towards C3. From these graphs the ultimate load of all the three different types of reinforcement is known which is shown in **Table 4.2.**

The nature of beams whether they are under reinforced or over reinforced is calculated and presented in **Table 4.3**

4.3 STRESSING OF BEAMS

Now the remaining six beams viz. two each of R1, R2 & R3 are stressed to 50 % of the ultimate load values given in **Table 4.2**. The deflections corresponding to a uniformly increasing load obtained are shown in **Table 4.4**

These load-deflections curves follow a pattern similar to that for control beams as shown in **Table 4.1** and are represented graphically in **Fig 4.5**

The curves having same reinforcement i.e. C1 & R1, C2 & R2, C3 & R3 trail each other. This shows that when stressed to 50 % of the ultimate load the beams retain their elasticity as they follow the same path.

4.4 BEAMS AFTER RETROFITTING

The six beams stressed to 50 % of ultimate load are now retrofitted using ferrocement jacketing. These are tested to failure & their load-deflection along with that of non-retrofitted counterparts is presented in **Table 4.5** & shown graphically in **Fig 4.6, 4.7, 4.8 & 4.9**

4.4.1 Behaviour of retrofitted beams

The retrofitted beams R1 & R2 follow the curves of their respective control beams C1 & C2 exactly for initial loading, and after that the curves of R1 & R2 run parallel & above the curves of C1 & C2. This shows an increase in the load carrying capacity of the retrofitted beam. However, the curves of retrofitted and control beams, R3 & C3 almost coincide till 75 % of the ultimate load, after which they follow the same pattern as R1 & R2.

Load-deflection curves of all the beams C1, C2, C3 & R1, R2 & R3 are plotted in **Fig 4.9.** Also for beams having same percentage of reinforcements the retrofitted beams have a much smaller deflection as compared to control beams, this is due to increased stiffness of the retrofitted beams.

4.4.2 Effect of percentage of reinforcement on ultimate load

The absolute values of ultimate loads, ultimate deflections & energy absorptions are shown in **Table 4.6**. Also shown are the % age increase of the values of retrofitted beams w.r.t. control beams i.e. increase in value of ultimate deflection of beam R1 in comparison to the value of C1 & so on. It is observed that with the retrofitting of beams there is an increase in ultimate load value of all set of beams. This increases with increase in percentage of reinforcement for R1 to R2 but as we have observed in **Table 4.3,** for beam R3 in over reinforced so the increase in ultimate load is less than that of R3. This can be attributed to the beam R3 being over reinforced as compared to others.

4.4.3 Effect of percentage of reinforcement on energy absorption

The values of energy absorption also follow a similar pattern as the values of ultimate deflection.

The retrofitted beam R1 and R2 follow the curves of C1 and C2 exactly till small loads after that the curves of R1 and R2 run parallel and above the curves of C1 and C2.This shows an increase in the load carrying capacity of the retrofitted beam .The curves of R3 and C3 almost coincide till 75% of ultimate load after which this follow the same pattern as R1 and R2.

Comparing the percentage increase in energy absorption value of C1-R1,C2-R2 and C3 -R3, we observe that the range of this is increase is between 5%-10%.hence there is not a substantial increase in energy absorption capacities of the beams after retrofitting .This is due to the fact that we had retrofit the beams after prestressing it to 50 % of ultimate load.

Load – deflection curves of all beams C1,C2,C3, and R1,R2,R3 are plotted in fig 4.9.

Also the beams having same percentage of reinforcements the retrofitted beams have a much smaller deflection as compared to control bams ,this is due to increased stiffness of the retrofitted beams .

4.5 COST ANALYSIS

Finally cost analysis is done in **Table 4.7, 4.8 & 4.9.** Here the percentage increase in cost & percentage increase in strength after retrofitting of beams with ferrocement jacketing is calculated. The ratio of the two is termed as strength/cost ratio. From the tables it is observed that the strength-cost ratio of R2 beam is much higher than that of R1 & R3. The strength-cost ratio's of R1 & R3 are almost equal indicating the effect of under reinforcement and over reinforced respectively..

TABLE 4.1: LOAD & DEFLECTION VALUES OF DIFFERENT PERCENTAGE OF TENSILE REINFORCEMENTS

LOAD ‘kN’	DEFLECTION ‘mm’		
	C1	C2	C3
0	0	0	0
2	2.2	2.0	2.37
4	5.1	4.3	4.6
6	8.5	6.7	6.72
8	12.3	9.6	8.25
10	16.2	12.4	10.4
12	23.1	15.2	13.15
14	50.0	18.3	16.2
16		21.0	19.9
18		23.5	20.5
20		27.0	24
22		29.4	26.6
24		38.0	27.7
26			29
28			35
30			53

TABLE 4.2: CHANGE OF ULTIMATE LOAD, SAFE LOAD & ENERGY ABSORPTION VALUES WITH INCREASE IN TENSILE REINFORCEMENTS

SNo.	Beams	% age reinforcement ‘%”	Ultimate load 'kN'	% increase in Ultimate load ‘%’	Safe load 'kN'	% increase in safe load ‘%’	Energy Absorption ‘kNmm’	% increase in Energy Absorption ‘%’
1	C1	0.35	12	-	9.5	-	367.28	-
2	C2	0.55	22	83.33	12.0	26.32	590.14	60.67
3	C3	0.78	28	133.33	13.1	37.90	663.23	80.57

TABLE 4.3: CALCULATE DEPTH OF NEUTRAL AXIS & CHECK IF THE BEAM IF UNDER OR OVER REINFORCED

Sr. No.	Description	C1	C2	C3	R1	R2	R3
1	Breath of beam 'b' mm	127.00	127.00	127.00	167.00	167.00	167.00
2	Effective depth of beam 'd' mm	198.00	197.00	196.00	218.00	217.00	216.00
3	Depth of beam 'D' mm	227.00	227.00	227.00	247.00	247.00	247.00
4	Area of tensile reinforcement 'A_{st1}' mm^2	100.50	157.10	226.20	100.50	157.10	226.20
5	Area of wire mesh 'A_{st2}' mm^2	0.00	0.00	0.00	73.64	73.64	73.64
6	Area of tensile reinforcement 'A_{sc}' mm^2	100.50	100.50	100.50	100.50	100.50	100.50
7	Characteristics Strength of concrete 'f_{ck}' N/mm^2	20.00	20.00	20.00	20.00	20.00	20.00
8	Strength of Steel 'f_y' N/mm^2	500.00	500.00	500.00	500.00	500.00	500.00
9	Depth of neutral axis 'n_a' mm	48.74	58.79	68.21	59.43	66.81	74.28
10	Solving by taking the areas	0.00	0.00	0.00	0.00	0.00	0.00
11	Depth of critical neutral axis 'n_c' mm	68.30	68.30	68.30	68.30	68.30	68.30
12	Section under reinforced if $n_a<n_c$ & over reinfroced if $n_a>n_c$	under	under	under	under	under	over

TABLE 4.4: LOAD & DEFLECTION OF DIFFERENT TENSILE REINFORCEMENTS WHEN STRESSED TO 50 % OF ULTIMATE LOAD

LOAD 'kN'	Deflection 'mm'		
	R1	R2	R3
0	0.00	0.00	0.00
1	1.11	1.16	0.82
2	2.18	2.50	1.72
3	3.60	3.92	2.84
4	5.03	4.85	3.82
5	7.05	6.22	4.72
6	8.70	7.05	6.10
7		8.50	6.70
8		9.40	7.70
9		10.75	8.48
10		12.05	9.50
11		13.45	10.72
12			11.59
13			12.70
14			14.20

TABLE 4.5: LOAD VS DEFLECTION DATA FOR CONTROL BEAMS & RETROFITTED BEAMS

	DEFLECTION					
LOAD	C1	R1	C2	R2	C3	R3
0	0.00	0.00	0.00	0.00	0.00	0.00
2	2.18	2.60	2.00	2.10	2.37	1.20
4	5.12	5.80	4.25	4.60	4.60	3.60
6	8.50	8.05	6.72	7.10	6.72	5.50
8	12.30	11.35	9.60	9.05	8.25	7.40
10	16.20	14.05	12.40	12.00	10.40	10.00
12	23.10	17.30	15.20	13.75	13.15	12.80
14	50.00	21.70	18.30	16.00	16.20	16.00
16		55.00	21.00	17.85	19.90	18.45
18			23.50	19.90	20.50	20.02
20			27.00	22.20	24.00	23.05
22			29.40	24.00	26.60	25.92
24			38.00	26.30	27.70	27.65
26				30.40	29.00	29.40
28				57.00	35.00	33.60
30					53.00	39.00
32						42.00
34						57.00

TABLE 4.6: VALUES OF ULTIMATE LOAD, DEFLECTIONS AND ENERGY ABSORPTION OF THE CONTROL & RETROFITTED BEAMS

Sr No.	Beam type	Ultimate load 'kN'	% increase in ultimate load '%' w.r.t to control beam	Ultimate deflection 'mm'	% increase in ultimate deflection	Energy absorption 'kN-mm'	% increase in Energy absorption
1	C1	14.00	-	38.00		367.28	
2	C2	16.00		50.00		590.14	
3	C3	24.00		50.00		663.23	
4	R1	28.00	14.29	55.00	100.00	406.45	10.67
5	R2	30.00	16.67	53.00	87.50	626.79	6.21
6	R3	34.00	13.33	57.00	41.67	697.09	5.10

TABLE 4.7: COST ANALYSIS OF BEAM WITH 8 mm STEEL AS TENSILE REINFORCEMENT

SNo.	Material	Unit	Qty '/beam'	Rate 'Rs/unit'	Amount 'Rs'
A	**RCC Beam only**				
1	Cement	kg	48.76	5.00	243.79
2	Steel '8 mm'	kg	3.20	45.00	143.91
3	Steel '8 mm'	kg	3.20	45.00	143.91
4	Steel '6 mm'	kg	3.08	40.00	123.20
5	Binding wire	kg	0.95	50.00	47.38
6	Coarse Aggregate	cum	0.106	700.00	74.47
7	Fine Aggregate	cum	0.053	600.00	31.91
8	Form work	sqm	2.38	500.00	1191.05
9	Labour	L.S.	1	500.00	500.00
	Total	**Rs**			**2499.61**
B	**Retrofitting of Beam**				
1	Cement	kg	47.64	5.00	238.21
2	Fine Aggregate	cum	0.071	600.00	42.88
3	Expanded wire mesh	sqm	2.86	150.00	428.78
4	Labour	L.S.	1	250.00	250.00
	Total	**Rs**			**959.87**
Increase in cost '%'					38.40
Increase in strength '%'					15.00
Strength/Cost Ratio					0.39

TABLE 4.8: COST ANALYSIS OF BEAM WITH 10 mm STEEL AS TENSILE REINFORCEMENT

Sno.	**Material**	**Unit**	**Qty '/beam'**	**Rate 'Rs/unit'**	**Amount 'Rs'**
A	**RCC Beam only**				
1	Cement	kg	48.76	5.00	243.79
2	Steel '10 mm'	kg	5.08	45.00	228.78
3	Steel '8 mm'	kg	3.20	45.00	143.91
4	Steel '6 mm'	kg	3.08	40.00	123.20
5	Binding wire	kg	1.14	50.00	56.81
6	Coarse Aggregate	cum	0.106	700.00	74.47
7	Fine Aggregate	cum	0.053	600.00	31.91
8	Form work	sqm	2.38	500.00	1191.05
9	Labour	L.S.	1	500.00	500.00
	Total	**Rs**			**2593.91**
B	**Retrofitting of Beam**				
1	Cement	kg	47.64	5.00	238.21
2	Fine Aggregate	cum	0.071	600.00	42.88
3	Expanded wire mesh	sqm	2.86	150.00	428.78
4	Labour	L.S.	1	250.00	250.00
	Total	**Rs**			**959.87**
Increase in cost '%'					37.00
Increase in strength '%'					17.00
Strength/Cost Ratio					0.45

TABLE 4.9: COST ANALYSIS OF BEAM WITH 12 mm STEEL AS TENSILE REINFORCEMENT

Sno.	Material	Unit	Qty '/beam'	Rate 'Rs/unit'	Amount 'Rs'
A	**RCC Beam only**				
1	Cement	kg	48.76	5.00	243.79
2	Steel '12 mm'	kg	7.30	45.00	328.41
3	Steel '8 mm'	kg	3.20	45.00	143.91
4	Steel '6 mm'	kg	3.08	40.00	123.20
5	Binding wire	kg	1.36	50.00	67.88
6	Coarse Aggregate	cum	0.106	700.00	74.47
7	Fine Aggregate	cum	0.053	600.00	31.91
8	Form work	sqm	2.38	500.00	1191.05
9	Labour	L.S.	1	500.00	500.00
	Total	**Rs**			**2704.61**
B	**Retrofitting of Beam**				
1	Cement	kg	47.64	5.00	238.21
2	Fine Aggregate	cum	0.071	600.00	42.88
3	Expanded wire mesh	sqm	2.86	150.00	428.78
4	Labour	L.S.	1	250.00	250.00
	Total	**Rs**			**959.87**
Increase in cost '%'					35.49
Increase in strength '%'					13.00
Strength/Cost Ratio					0.37

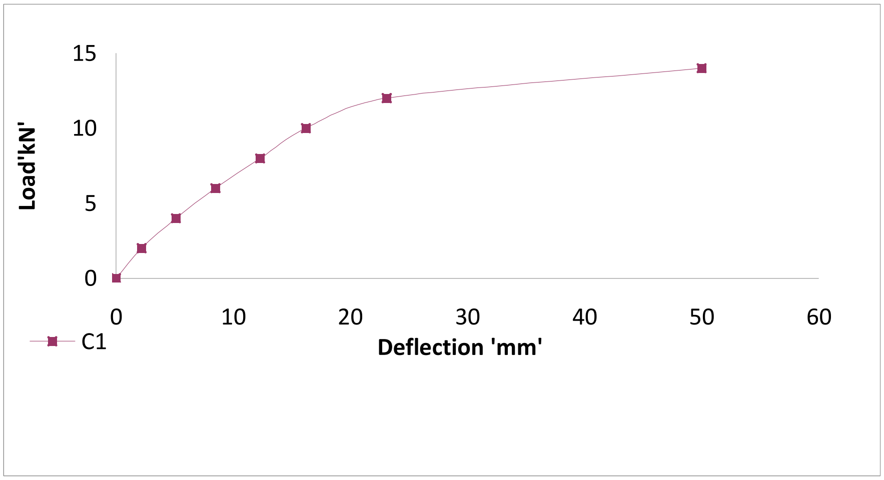


Figure 4.1: Load vs deflection curve for beam C1

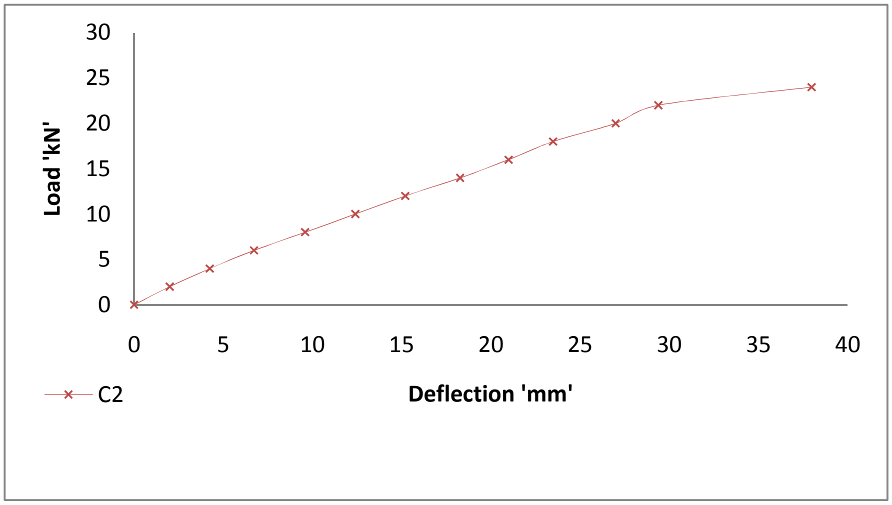


Figure 4.2: Load vs deflection curve for beam C2

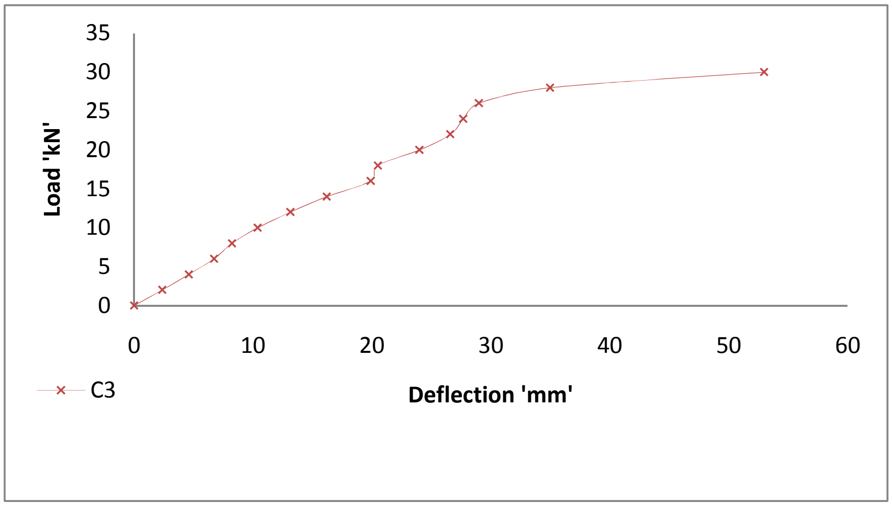


Figure 4.3: Load vs deflection curve for beam C3

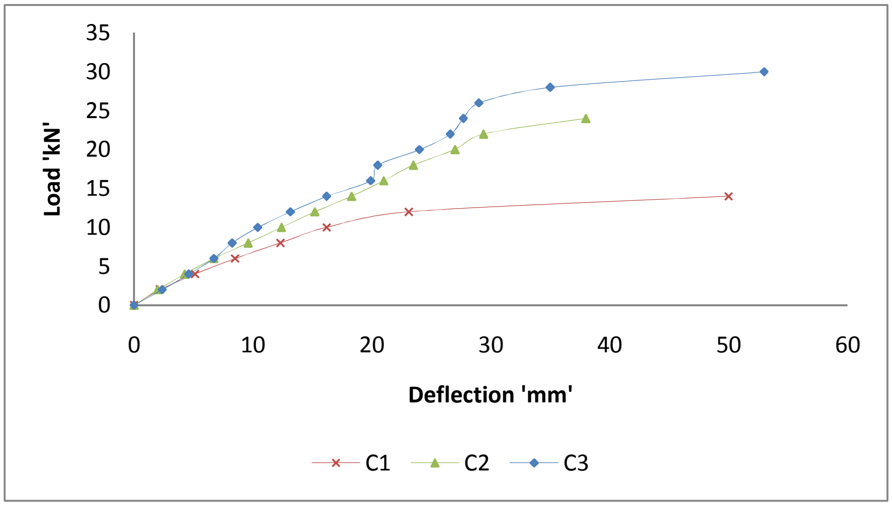


Figure 4.4: Load vs deflection curve for beams C1, C2 & C3

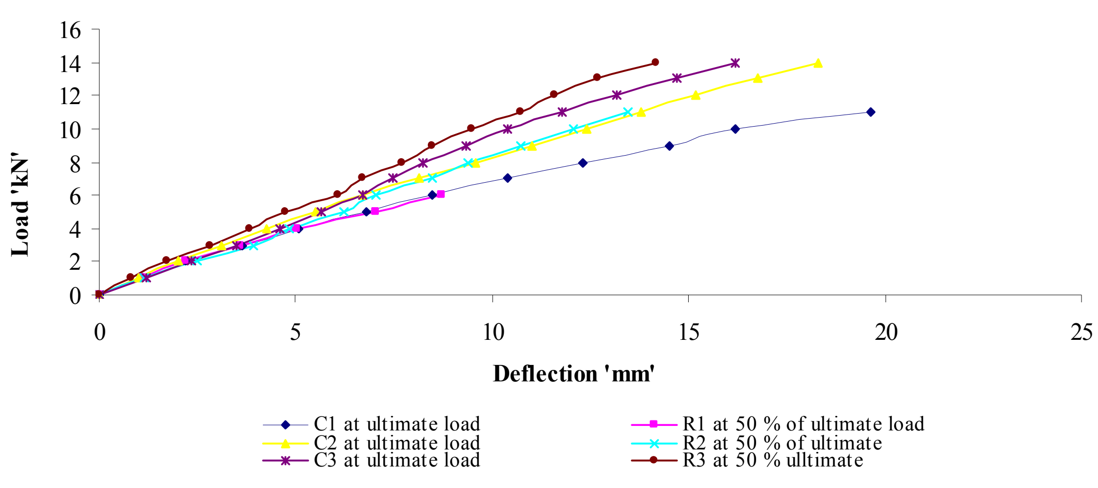


Figure 4.5: Load vs deflection curves for beams C1, C2 & C3 & R1, R2 & R3 with R1, R2 & R3 stressed to 50 % of ultimate load of C1, C2 & C3

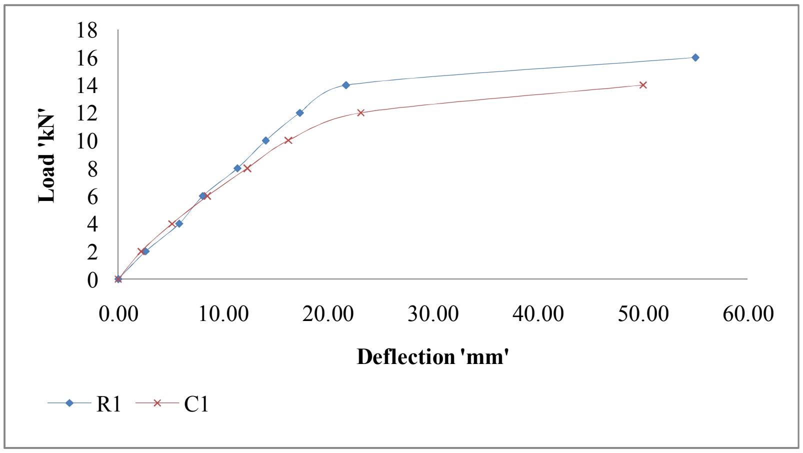


Figure 4.6: Load vs deflection curves for beams C1 & R1

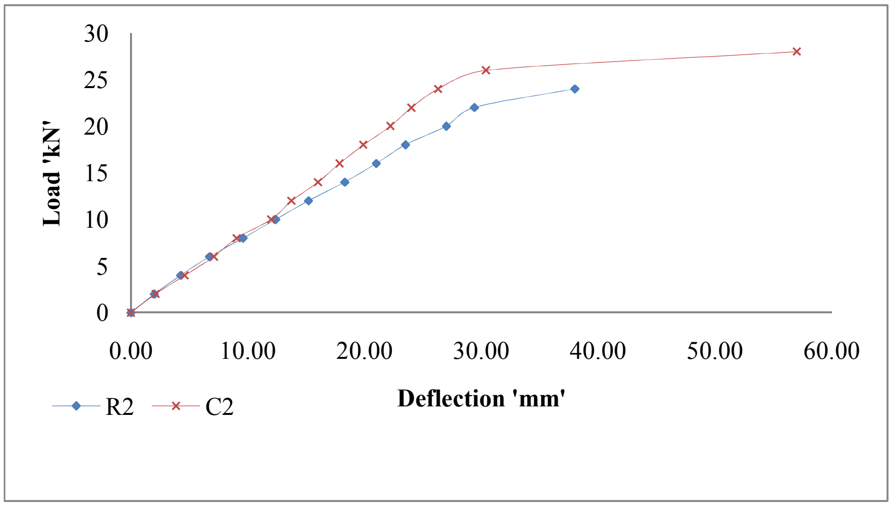


Figure 4.7: Load vs deflection curves for beams C2 & R2

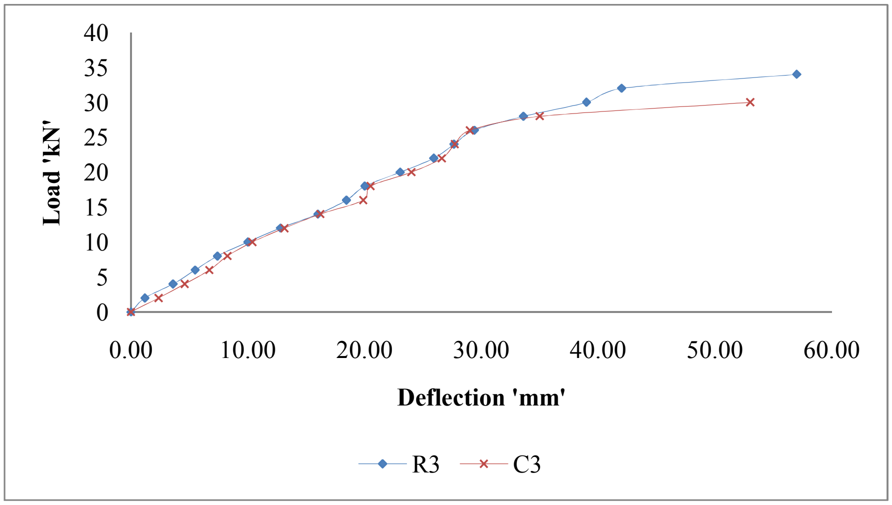


Figure 4.8: Load vs deflection curves for beams C3 & R3

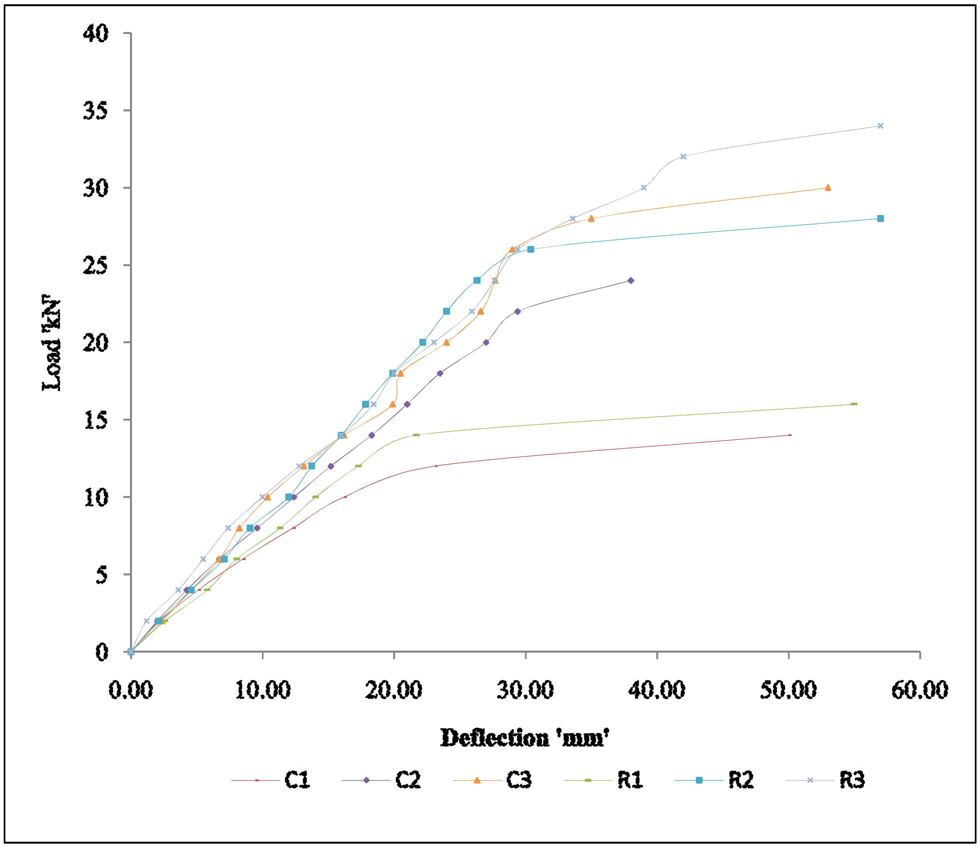


Figure 4.9: Load vs deflection curves for beams C1, C2 & C3 & R1, R2 & R3

CHAPTER 5
CONCLUSIONS

5.1 GENERAL

The study is carried out to analyse the effect of ferrocement jacketing on strength and service ability parameters of strengthened RC beams varying percentage of tension steel. Based on the work carried out

1)The ultimate load ,the energy absorption values & safe load increases with the increase in percentage of tensile reinforcement beam.

2) Retrofitting using ferrocement jackets is effective for all beams stressed to 50%of their ultimate load for all under reinforced beam .

3)Retrofitting of beams with ferrocement jacketing substantially decrease the deflection of the beam indicating a higher degree of stiffness of beam.

4)Retrofitting provides higher energy absorption capacity for all under reinforced beams but become constant with increase in percentage of tension reinforcement.

5.2 Scope for further work

The present work has been carried out only retrofitting on beams having for strengthening of tension steel only. This work can be further extended to parameter as well

Effect of following parameters as well

1) Effect on doubly reinforced beams
2) Effect of variation of member of ferrocement reinforced beams
3) Variation in compression reinforcement only.

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