**This is to certify that the**

**Thesis entitled**

# USE OF FERROCEMENT AS A REHABILITATION/STRENGTHENING MATERIAL FOR RCC COLUMNS

Submitted By

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Has been accepted towards the partial fulfillment
of the requirements
for
Master of Science in Civil Engineering, Specializing in Structural Engineering

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**National University of Sciences & Technology, Pakistan**

# USEOF FERROCEMENT AS A REHABILITATION/STRENGTHENING MATERIAL FOR RCC COLUMNS

By

**Major Muhammad Akmal Hayat**

A Thesis

of

Master of Science

Submitted to the

**National Institute of Transportation, Risalpur**

**of**

**National University of Sciences and Technology**

**Rawalpindi, Pakistan**

In partial fulfillment of the requirements

for the degree of

**Master of Science**

**(April, 2003)**

**Dedicated to my loving family**

# ACKNOWLEDGEMENTS

I bow my head praising Allah Almighty and offer my salat o salam to his beloved Prophet Muhammad (peace be upon him), for all the blessings He showered upon me by providing an opportunity to seek and learn the " Naffay Knowledge".

Completion of this thesis is the result of co-operation of many dedicated and helpful people. It is difficult to gauge their contributions in helping me to carry out this research work.

It is with the great pleasure and profoundest feelings of obligations that, I thank Colonel Dr Tahir Kibriyai, Military College of Engineering, Risalpur, under whose able guidance, this work has been done. His contributions included personal and professional advice. I also feel deeply indebted to Lt Col (R) Muhammad Iqbal and Mr Sardar Khan, Lecturer at Military College of Engineering, Risalpur for taking personal interest in streamlining the scope of research work and paying special attention to my problems during the thesis work by extending their help very generously.

A lot of thanks are also due to Dr Muhammad Jabbar Khan, Chairman Civil Engineering Department, UE&T Peshawar for his full co-operation, guidance and providing the laboratory and other facilities for the preparation and testing of specimens.

I am grateful to Dr Farhat Javed Asst Prof Military College of Engineering, Risalpur for their valuable advice and encouragement. I also wish to place on record my humble thanks to the laboratory and technical staff of UE&T, Peshawar, and MCE ,Risalpur without the skilled assistance of whom it would not have been possible to carry out most of the experiments. At the end my gratitude and abundant thanks are due to my wife for showing patience and continued encouragement.

# ABSTRACT

RCC columns are common in low or medium rise masonry buildings and bridges. These old masonry buildings, bridges and other structures have outlived their durability due to continues environmental effects or these are being used for purposes other than those for which these were originally designed. This has placed higher loads on slabs, columns, beams and foundations. Moreover the existence of many old masonry buildings in the earthquake prone regions is also a serious hazard to life and property. Due to economic constraints, the old distressed structures are being used with complete disregard to loss of human lives.

There are several types of masonry structural elements within a building, among which column is the most vulnerable to environmental effects and earthquake damages. Columns are primarily designed to carry the vertical loads, however, in case of any seismic activity they also experience horizontal loads from the ground movements. Column failure can lead to collapse of structure and result in loss of life and property.

Ferrocement is a highly versatile form of reinforced concrete, constructed of hydraulic cement mortar and reinforced with closely spaced layers of continuous and relatively small diameter wire meshes. Because of the excellent mechanical properties, ferrocement has a wide range of applications in civil works. Among the potential fields, the most recommended is, the field of rehabilitation and repair of old distressed structures. Encasement by ferrocement can be used to increase the load carrying capacity, as well as moment resistance of RCC columns.

In Pakistan most of the old structures including bridges and old cultural heritage are made of brick masonry columns, which have lost their durability and do not fulfill the present ACI safety provisions. This research work investigates the possibility of using ferrocement as a retrofit/ strengthening material for such columns. The potential encouraging results from this research work can lead to a viable and economical solution for these old distressed masonry structures by enhancing their useful life and increasing the safety.

# CONTENTS

## NOTATIONS AND ABBREVATIONS

ACI = American Concrete Institute

ASTM = American Society of Testing Materials

A I T = Asian Institute of Technology, Thailand

Approx = Approximately

Cu = Co-efficient of uniformity

Cc = Co-efficient of conformity

Ft = Feet

Kg = Kilo gram

Lbs = Pounds

Max = Maximum

Min = Minimum

mm = Millimeter

Psi = Pounds per square inch

Ref = Reference

Sq = Square

s.no = Serial number

UN = United Nations

vs = verses

w/c = water / cement ratio

*CHAPTER 1*

# INTRODUCTION

## 1.1 GENERAL

Technological development in civil engineering is a very slow process and introduction of new materials and production methods often takes decades. Pakistan, being an under developed country needs to concentrate on saving resources, which can be effectively done by introducing new technologies in major fields. There are many old bridges and other structures in Pakistan, which demand immediate repair, or else after some time demolishing and reconstruction of these structures, will become imminent. In order to save the extra expenditure for the reconstruction of these buildings, rehabilitation projects should be undertaken in time, so that not only economic burden is avoided but also the useful life and safety of these structures is enhanced.

RCC structures have been used since long. In Pakistan we find most of the old structures including most bridges constructed of RCC. These structures have lost their durability as regards to safety due to age, environmental effects, and do not fulfill the safety standards of various codes of practice.

. Several studies have been carried out to study the problems related to the distressed structures to increase their life by suitable strengthening measures. Steel plates have been mostly used with various bonding techniques on the sides of distressed members. This experimental study aims at studying the application of Ferro cement layers as economical and effective method of strengthening/rehabilitation. Ferro cement, a thin wall cement mortar reinforced with wire mesh is considered to be an innovative construction material. The potential field of application of Ferro cement is the field of rehabilitation and repair of old bridges and other distressed structures.

## 1.2 AIM OF PRESENT INVESTIGATION

An endeavor has been made to investigate the suitability of Ferro cement as a retrofit material for masonry columns and find out experimentally the cracking, failure loads and failure patterns in order to evaluate the potential benefits of Ferro cement as a rehabilitation and strengthening material.

Research on Ferro cement material has been much inclined towards construction of boats, small panels and shelters etc, and no worthwhile work has been done on rehabilitation of ordinary reinforced columns using this technique. Many old distressed bridges and buildings have RCC columns and need immediate repairs or rehabilitation. The potential encouraging results from this research work can lead to a viable and economic solution for particularly building columns having comparatively less design strength. Ferro cement, being a suitable technology for the developing countries needs to be looked upon, as a suitable economic material for the repair and rehabilitation / strengthening work. The main advantages include, availability of raw materials locally, flexibility of applying in desired shapes and ease of application without special skills or machinery.

## 1.3 SCOPE OF RESEARCH

To investigate the possibility of using Ferro cement as a retrofit / strengthening material for RCC columns. The major areas of observations are as follows: -

- Evaluation of increase in compressive strength with the application of Ferro cement coating of commonly available wire mesh.
- Evaluation of crack resistance and crack growth mechanism.
- Comparison of performance of Ferro cement coated columns with increasing the number of meshes.
- Evaluation of maximum design strength for which this Ferro cement of commonly available wire mesh can be useful.

***CHAPTER 2***

# LITERATURE REVIEW

## 2.1 HISTORY AND DEVELOPMENT

The history of Ferro cement dates back to 1848 and many regard it as the earliest use of reinforced concrete. Joseph Louis Lambot constructed several rowing boats, plant pots, seats and other items from a material that he called " Ferciment" in a patent, which he took out in 1852 (Ref 2.1). The patent reads, in part as follows: -

" My invention is a new product that can replace timber (in wood flooring, water container, plant pots, etc) that is exposed to damage by water or dampness. The base for the new substance is a metal net of wire, or rods interconnected to form a flexible woven mat. I fashion this net into a form that is similar to the article I want to create, then I use hydraulic cement or a bitumen tar or mix to fill up the joints."

Lambot's rowboats now rest in the Brignoles Museum in France. These boats were built 12 ft long and about 4 ft across with thin walls of 1 inch to 1.5 inch thick reinforced with grid and wire netting. Many boat builders followed the Lambot's techniques in the later half of the nineteenth century. During its early period of development, the Dutch also built reinforced mortar barges of 50 tons to 60 tons capacity for carrying ashes and refuse on canals.

A few small mortar boats and river crafts were built in the 1900’s including the first concrete vessel named “concrete” to be used by the United States government.

The boat was 18 ft long and had a hull thickness of ¾ inch. It had a cruising speed of 10 Knots. It was during the First and Second World Wars that serious attention was given to the use of concrete in shipbuilding, and this was only because of the shortage of traditional materials.

In the early 1940’s, a noted Italian engineer- architect, Pier Luigi Nervi (Ref 2.2) resurrected the original idea of Lambot when he observed that reinforcing concrete with layers of wire mesh produced a material, which possessed the mechanical characteristics of an equivalent homogeneous material and showed great resistance to impact. Professor Nervi established the preliminary characteristics of Ferro cement through a series of tests. He went on to design and construct several roofs, which today still remain rational and aesthetic model in structural design.

The Italian Navy Registry and the Italian Navy also accepted Ferro cement and thus, a number of crafts were built during World War-II. Nervi also pioneered the architectural use of Ferro cement in buildings. He built a small storehouse of Ferro cement in 1947. Later he covered the swimming pool at the Italian Naval Academy with a 15-meter vault and built the famous Turin Exhibition Hall, a roof system spanning 300 feet. In both the structures, Ferro cement was used as one of the structural components.

Despite the evidence that Ferro cement was an adequate and economical constructional material, it gained wide acceptance only in the early 1960' s in United Kingdom, New Zealand, and Australia. In 1972, the National Academy of Science of United States of America set up an Ad Hoc panel on the utilization of Ferro cement in developing countries. The panel included personnel experienced in research and application of Ferro cement and others familiar with constructional needs in developing countries (Ref 2.3). The main tasks and objectives were as follows: -

- Evaluating the current state of art on Ferro cement as an engineering material in order to identify its known properties and characteristics.
- Evaluating the principal areas of applications on both land and water.
- Developing specific recommendations for promoting the use of Ferro cement in a logical and effective manner.

The report of the panel first published in early 1973 has had an immense impact on Ferro cement applications. The panel identified Ferro cement as an overlooked appropriate technology / material with wide potential applications, especially in developing countries. In early 1977, the American Concrete Institute (ACI) had set up Committee 549 (Ref 2.4) on Ferro cement to review the present state-of-art and possibly to formulate a code of practice for this material. The committee found out that Ferro cement is a versatile construction material and has a bright prospect and will definitely find better utilization in the near future.

## 2.2 DEFINITION OF FERROCEMENT

ACI Committee 549 on Ferro cement concluded that the definition of Ferro cement couldn't be limited to steel reinforcement even if most of the present applications emphasize this kind of reinforcing material. Accordingly, the committee defines it as follows:

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

The basic idea behind this material is that concrete can undergo large strains in the neighborhood of the reinforcement, and the magnitude of the strains depends on the distribution and subdivision of the reinforcement throughout the mass of the concrete.

## 2.3 ADVANTAGES OF FERROCEMENT

The material, which is a special form of reinforced concrete, exhibits a behavior so different from conventional reinforced concrete in performance, strength and potential application that it must be classified as a separate material. In rationally designed Ferro cement structures, the reinforcement consist of small diameter wire mesh in which the proportion and distribution of the reinforcement are made uniform by spreading out the wire meshes throughout the thickness of the element. This dispersion of the fiber in the brittle matrix offers not only convenience and practical means of achieving improvements in many of the engineering properties of the material such as fracture, tensile and flexural strengths, toughness, fatigue and impact resistance but also provides advantages in terms of fabrication of products and components.

Ferro cement, which is especially advantageous in spatial structures, has relatively better mechanical properties and durability than ordinary reinforced concrete. Within certain loading limits, it behaves as a homogenous elastic material and these limits are wider than for normal concrete. The uniform distribution and high surface area to volume ratio of its reinforcement results in better crack arrest mechanism and the propagation of cracks is arrested resulting in high strength material.

Ferro cement is a suitable technology for developing countries for the following reasons: -

- Its basic raw materials are readily available in most countries.
- It can be fabricated into any desired shape.
- No special skill and heavy machinery or plant is required.
- Being labor intensive, it is relatively inexpensive in developing countries.
- It can be formed into sections less than even 25 mm (1 in) thick and assembled over light formwork.
- The material is very dense, but structures made from it are light in weight.. It is also rot and vermin-proof, impervious to worms and borers, and watertight. Ferro cement is more versatile than RCC and can be formed into simple or compound curves.
- Only a few simple hand tools are needed to build uncomplicated structures;

- Repairs are usually easy and inexpensive;
- No upkeep is necessary;
- Structures are insect, and rat proof, and also non-flammable
- Structures are highly waterproof, and give off no odors in a moist environment
- Structures have unobstructed interior room
- Structures are strong and have good impact resistance

## 2.4 DISADVANTAGES

- Structures made of it can be punctured by forceful collision with pointed objects.
- It may be difficult in some countries to locate skilled repair shops.
- In corrosive environments, it is often observed that after some time the rein forcing material corroded if not properly covered during construction.
- It is nearly impossible to fasten Ferro cement with bolts or screws, because drills usually break against lightly covered reinforcing material.
- Fastening with nails or by welding is not possible.
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- Fastening with nails or by welding is not possible.
- It may be difficult in some countries to locate skilled repair shops.

## 2.5 APPLICATIONS OF FERROCEMENT

Ferro cement is used for a variety of applications in building structures. Since the range of application is very wide and encompasses most of the building industry, it is quite difficult to classify the uses into clearly defined groups or according to technological aspects. However, in order to examine the potential of the material in playing a major role in the building industry, applications of Ferro cement can be divided into following broad categories.

### 2.5.1 Housing Applications

Housing shortages have become a dramatic fact of life in today's world. As housing demands and cost of construction both increase, efficient and modern housing is placed out of reach for many, imposing social and economic burdens on society. The shortage of adequate housing is a critical problem in both developed and under developed countries. This is particularly true in many developing countries, which are experiencing the rural to urban migrations, and disaster hit areas. In these areas, adequate dwelling units must be quickly made available using local material and labor. Ferro cement, which is made of dense, fine concrete reinforced by thin wire meshes, now presents the greatest promise in achieving the above stated goals. The development of Ferro cement components in housing can ensure a reduction in both concrete and steel consumption. The thinness of the components allows for the use of saved space for installations, insulation and increasing the versatility. The most particular attraction of using Ferro cement as a construction material for housing lies in the variety of shapes, which it offers for any structure.

### 2.5.2 Marine Applications

Ferro cement has been adapted to traditional boat designs in Bangladesh, China, Indonesia and Thailand due to timber shortage. The steady growth in application constantly adds to the understanding unusual properties of Ferro cement and how this thin shell of highly reinforced cement mortar can provide a surprisingly strong, yet simply fabricated boat building material. Ferro cement, like any other construction material has strong and weak points, and it is important that the material is applied to boat types and boat sizes where its characteristics are best utilized. In China, 600 Ferro cement boat-manufacturing units produce annual capacity of 600,000 to 700,000 tonnages. Ferro cement boats are divided into four categories according to usage: farming, fishing, transport and working boats. In countries like Hong Kong, Korea, India, Malaysia, Philippines, Sri Lanka and Thailand, Ferro cement boats generally conform to western standards. In Hong Kong, India and Sri Lanka, most of the Ferro cement crafts constructed are used as mechanized fishing trawlers while in Korea, these are used as fishing boats. In addition, the South Asian Fisheries Development Center Philippines uses Ferro cement tanks for prawn brood stock and Ferro cement buoys for a floatation system. This is the large-scale use of Ferro cement for these purposes.

### 2.5.3 Agricultural Applications

Agriculture provides the necessary base for economic growth in developing countries. The use of Ferro cement technology can contribute towards solving some of the production and storage problems of agricultural products. Ferro cement has been used for grain storage bins in Thailand, India and Bangladesh to reduce losses from attack by birds, insects, rodents and molds. Recent development in Ferro cement technology has shown distinct advantages in building silos of Ferro cement. They can be made in site and /or in prefabricated form. Ferro cement is watertight and with appropriate sealants, it can also be made airtight. In an airtight Ferro cement bin, respiration of grain or similar products quickly removes oxygen from the atmosphere inside and replaces it with carbon dioxide. Any insects and aerobic microorganisms present, cannot survive to cause damage to the stored products. An underground Ferro cement lined storage unit has been developed in Ethiopia to replace the traditional unlined storage pits. The use of Ferro cement canal lining prevents seepage loss according to the research on the construction techniques and behavior of Ferro cement canal lining undertaken at AIT, Thailand.

### 2.5.4 Water and Sanitation Applications

Ferro cement can be effectively used for various water supply structures like well casings for shallow wells, water tanks, sedimentation tanks, slow sand filters and for sanitation facilities like septic tanks, service modules and sanitary bowls.

Ferro cement water tanks of 20 to 2000 gallon capacity are mass produced In India, Thailand and Indonesia, Ferro cement and bamboo-cement rainwater collection tanks are being built on a self help basis by villagers under the supervision of an appropriate technology group to provide clean drinking water (Ref 2.5). Bamboo-cement well casings have been built in Indonesia to prevent contamination of the water. Prefabricated service modules have been developed and constructed in India. A service module is a unit, which provides water supply for drinking and washing together with toilet facilities. Ferro cement septic tanks are in use in Thailand, India, Indonesia, Philippines and Papua New Guinea, while Ferro cement toilet bowls have been developed and constructed in Thailand and Bangladesh (Ref 2.5).

### 2.5.5 Rural Energy Applications

Biogas and solar energy are two alternate sources of energy for the rural areas in which Ferro cement can be used for their production. Biogas can be used for cooking, lighting and refrigeration. In Thailand and India, biogas digesters and biogas holders have been constructed with Ferro cement, which lead to a considerable cost reduction. Ferro cement has also been used as a digester lining where bricks are not economically available. Use of Ferro cement biogas digester will promote conservation of timberlands and it will encourage farmers to raise livestock providing additional income to the family.

### 2.5.6 Miscellaneous Applications

Ferro cement is proving to be a technology that can respond to the diverse economic, social and cultural needs of the society. Ferro cement has been used to strengthen older structures, a medium for sculpture and for many other types of structures. Ferro cement as a medium for sculpture proves its versatility and the unlimited dimension to which it can be used. Ferro cement in art is an exciting development and has opened new horizons.

It also includes aqueducts, bus shelters, bridge decks, concrete road repair, factory build homes, food and water storage containers, irrigation structures, sculptures and traffic-caution signboards.

CHAPTER 3

# CONSTITUENT MATERIALS AND CONSTRUCTION PROCEDURES

## 3.1 CONSTITUENT MATERIALS

A Ferro cement panel, which is usually a thin section, consists of layers of wire mesh impregnated with a very rich mix (high ratio of cement to sand) and cured for specified period of time.The range of materials, which can be effectively used for the durable repair of concrete structure, is fairly limited. Those most widely used are concrete and mortar, made as for as practicable with the same type of cement and aggregates as were used in the original structure. When deterioration is due to chemical attack, it may be necessary to use different cement and protective coatings. When repaired areas fail it is in many cases due to failure or partial failure of the bond between the old and new work. The standard of bond development between the old and new concrete is directly related to the care taken in the preparation of the base concrete. In recent years a great deal of attention has been paid to the development of bonding agents.The vast majority of concrete structure, which need repair, are reinforced and the corrosion of the reinforcement plays and important part in the deterioration of the structure. When ferrous metals corrode the corrosion products occupy a larger volume than the original metal and the resulting expansion causes disintegration of par of the surrounding concrete.The selection of suitable materials to replace defective and spelled concrete and to reintroduce a protective and durable environment around the reinforcement is of great importance. A brief description of the materials used for Ferro cement is given below in the succeeding paragraphs.

### 3.1.1 Reinforcing Mesh

One of the essential components of Ferro cement 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 these 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, cannot withstand. A structure is subjected to a 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 cracking of the structure is reduced, is dependent on the concentration and dimensions of the embedded reinforcement. The mechanical behavior of Ferro cement is highly dependent upon the type, quality, orientation and strength properties of the mesh and reinforcing rod. The various principal types of wire mesh currently used are described below.

#### 3.1.1.1 Hexagonal wire mesh

This is the most popular and commonly used mesh readily available in many countries. It is known to be the cheapest and the easiest to handle. This mesh is commonly known as chicken wire mesh and is fabricated from cold drawn wire, which is generally woven into hexagonal patterns. The wire mesh used in Ferro cement is usually 1/48 inch to 1/24 inch (0.5 mm to 1.00 mm) in diameter, and the mesh opening vary from 0.4 inch to 1 inch (10 mm to 25 mm). The wire mesh can be woven at site from coils of straight wire, allowing the user an opportunity to choose the mesh size and wire diameter appropriate for the job. For most purposes, the mesh needs not be welded. Standard galvanized meshes are adequate. Non-galvanized wires with non-galvanized steel rod are excellent but the problem of rusting in open air limits their use.

#### 3.1.1.2 Welded Wire Mesh

Eighteen to nineteen gauge wires, spaced half an inch apart are normally used in the mesh. These wires are made of low to medium tensile strength steel and are much stiffer than hexagonal wire mesh. Some builders prefer this type of mesh as it can be molded more easily to conform to the desired curves of structure, producing much fairer lines. However, welded wire mesh has the possibility of weak spots at intersections resulting from inadequate welding during the manufacture of the mesh. This deficiency can impose serious limitations even when a higher tensile steel wire is used to give an improved mesh. Tests have shown that, in many cases, mesh made from higher quality wire has a greater tendency to fail than other types of mesh when the intersections are subjected to loading (Ref 2.5). Welded wire mesh, in general, like other types of mesh is galvanized after welding.

#### 3.1.1.3 Woven Wire Mesh

In this type of mesh, the wires are simply woven into the desired grid size and have no welding at the intersections. The mesh wires are not perfectly straight and a certain amount of waviness exists. However, tests have shown (Ref 2.5) that this mesh performs well, if not better than either welded or hexagonal meshes. One of the difficulties encountered is that it is difficult to hold it in position but when stretched it readily conforms to the desired curves.

#### 3.1.1.4 Expanded Metal Mesh

This is another type of mesh sometimes used in Ferro cement construction known as expanded metal or metal plasters lath. It is formed by cutting a thin sheet expanded metal to produce diamond shape openings. The manufacturing process is less labor intensive than the method used for manufacturing hexagonal wire mesh or welded mesh. The expanded metal mesh is not as strong as the woven mesh, but on a cost to strength ratio, expanded metal has the advantage.

#### 3.1.1.5 Watson Wire Mesh

This mesh consists of straight high tensile wires and transverse crimped wires, which hold the high tensile wires together. The high tensile wires are placed in two planes, parallel to each other, and are separated by mild steel wire transverse to the high tensile wires. It is only the tie-crimped wires that have its elasticity limit exceeded and only in the vicinity of the crimp. This means that a vast proportion of the wire is straight without twists, crimps, pressings, punching and welds. The result is a very strong mesh that is not subject to breakage during handling or stressing in the set mortar. The mesh enables complete flexibility and freedom of shape.

#### 3.1.1.6 Skeletal Steel

Skeletal steel as the name implies, 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 I-e up to 12 inch (305 mm) apart where they are not treated as structural reinforcement and often considered to serve as spacer rods to the mesh reinforcements.

### 3.1.2 Cement

Cement in a broad sense, can be described as a material with adhesive and cohesive properties, which makes it capable of bonding mineral fragments into compact mass. The use of some form of mortar to bind together stones, gravel and other material for structural purposes has been practiced since early times. The binding material or matrix in Ferro cement is known as mortar. It is normally made of Portland cement and ordinary silica sand. Cement in the presence of water reacts to form cementations gel, which becomes a firm and hard mass on drying. There are several types of cement available commercially, of which Portland cement is the most well known and easily available. Cements of Portland variety produced today are satisfactory enough to serve the purpose of Ferro cement construction.

Cements are classified as Portland and non-Portland cement.

#### 3.1.2.1 Portland Cement

##### 3.1.2.1.1 Ordinary And Rapid Hardening Portland cement

The basis difference between the 2 cements is the fain of strength. The increase with the rapid hardening cement is largely due to finer hardening and the cement usually has a specific surface of about 4300 $cm^2/gm$. The rapid hardening is accompanied by an increase in the rate of evaluation of heat of hydration, which in turn, raise the temperature of the maturing concrete during the first 15-40 hours after casting.

##### 3.1.2.1.2 Sulphate Resisting Portland cement

The essential difference in the tricalcium aluminates content to a maximum of 3%. It is the tricalcium aluminates in Portland cement, which is attacked by sulphates in solution and this chemical reaction results in the formation of an entringite, which can have a disruptive effect on the concrete, causing dimensional changes and reduction in strength.

##### 3.1.2.1.3 White And Colored Portland cement

These cements would only be used in cases where a color match with the existing concrete was desirable. However, due to color changes with age and weathering, it is likely that the best results would be obtained by using pigments and trial mixes.

#### 3.1.2.1.4 High Alumina Cement (HAC)

HAC differs fundamentally in chemical composition from Portland cement as it consists predominantly of calcium aluminate; it is of much darker color than ordinary and rapid hardening Portland cements. The lighter shade of HAC & darker shades of sulphate resisting Portland cement may approach each other in color. The cement sets and hardens when mixed with water, and under normal conditions of temperature the setting time is similar to that of ordinary Portland cement

The rapid increase in strength is accompanied by a rapid evaluation of the heat of hydration. This has advantages and disadvantage. It is extremely useful when working in low temperatures also it enables emergency repairs and similar work to be carried out within a short period of time. Wet curing is essential to prevent premature drying out of concrete surface, and the concrete must be placed in relatively thin layers so that the heat can be dissipated quickly. To achieve maximum chemical resistance and long tern durability, the same basic principles used for Portland cement concrete should be adopted. These are high cement not less than 400 $kg/m^3$, low water/cement ratio not higher then 0.4 through compaction, and careful water curing. This gives damp, impermeable concrete, which is essential for durability. Its use in repairs is likely to confined to:

(a) Structures in which the original concrete was made with HAC.

(b) Emergency repairs to Portland cement concrete floors

(c) The floors of cold stores.

(d) Repair to marine structures.

(e) Gunite or rendering in cases where the chemical or heat resistance of the cement is an advantage compared with Portland cements.

**3.1.2.1.5 Chemically Resistant Cements: -**

The special cements are not used for concrete except where very small quantities are required, but are used for mortar for bedding and jointing chemically resistant tiles and bricks. This type of construction is used in lining tanks, which hold very aggressive liquids.

The two basic types of cement are resin and silicate cement, certain grades of the latter are resistant to high temperatures.

**3.1.3 Fine Aggregate**

Aggregate is the term given to the inert material dispersed throughout the cement paste. This inert material occupies about 60 to 70 percent of the volume of the mortar. Therefore, aggregate to be used for the production of high quality mortar for Ferro cement structures must be strong, impermeable and capable of producing a sufficiently workable mix with a minimum water/cement ratio to achieve proper penetration of the mesh. The aggregate normally used, is natural sand, which can be a mixture of many types of material such as silica, basalt rock, limestone or even soft coral. An adequately strong mixture based on certain type of coral sand can be obtained by using additional quantities of cement. Great caution should be exercised in the selection of such sands, as very soft sand can be affected adversely by abrasion and chemical reaction. Porous material will allow moisture to penetrate into the thin sections affecting durability and structural performance of the mortar. The grading of the sand particles is important and should, if possible, comply with the ASTM Specification C33-74a for concrete aggregates.

### 3.1.4 Admixtures

A simple definition of an admixture is that it is a chemical compound that is added to concrete, mortar or grout at the time of mixing for the purpose of imparting some additional and desirable characteristic to the mix. Admixtures should only be used when they are really required to produce a particular results, which can be obtained by normal design.

The following are the main purpose for which admixtures are used:

(a) To accelerate the setting of the cement and the hardening of concrete mortar or grout. The compounds are known as accelerators.

(b) To retard the setting of the cement and slow the hardening of the mix. These are known as 'retards'.

(c) To entertain air in the mix. These compounds give an air-entrained mix, which should not be confused with an aerated mix. The latter is obtained by quite different compounds and is used for different purposes.

(d) To entrain air in the mix. The compounds included in this category are water reducing admixtures and water-proffers.

Generally admixtures are used to alter or improve one or more properties of the mortar. Most admixtures are used to improve workability, reduce water demand and delay mortar setting. Admixtures can be classified into various groups, according to their effects. Commonly used admixtures in Ferro cement are: -

- Water reducing admixture: Type A: ASTM C494-71
- Retarding admixtures: Type B: ASTM C494-71
- Water reducing and retarding admixtures: Type D: ASTM C494-71
- Water reducing and accelerating admixtures: Type E: ASTM C 494-71

Since the specific effects produced by various types of admixtures vary with the properties of the other ingredients of the mortar, prior testing with different types of admixtures is necessary before attempting to plaster Ferro cement structures. The quantity of admixture represents generally only a fraction of one percent of the weight of cement in the mix, so that the use of reliable dispensing equipment is essential.

### 3.1.5 Water

The quality of water for the mixing of mortar has vital effect on the resulting hardened Ferro cement. Impurities like clay, loam, acids, soluble salts, decaying vegetable matter and any other organic substances in water may interfere with the setting of cement and adversely affect the strength or cause staining of its surface and may also lead to corrosion of the reinforcement. Necessary care should be taken before using water containing such impurities. Seawater should not in any case be used for mixing the mortar, as it will increase the risk of corrosion of the mesh and reinforcement. Usually water available from the public water supplies is regarded as satisfactory and does not require any further treatment.

### 3.1.6 Coatings

In general, Ferro cement structures need no protection, unless it is subjected to strong chemical attack, which might damage the structural integrity of its components. A plastered surface can take a good point coating. Marine structures need protections against corrosion, and vinyl and epoxy are the most successful organic coatings.

### 3.1.7 Mortar mix

The reaction of Portland cement and water results in formation of hardened cement paste. The ranges of mix proportions recommended for common Ferro cement application are cement-sand ratio by weight 1.5: 2.5, and water cement ratio by weight, 0.3 to 0.4. Fineness modulus of sand, water-cement ratio and sand cement ratio should be determined from trial batches to ensure 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 setting. The behavior of mortar is similar to that of plain concrete. The major distinction is the size of the aggregate used. In general, a good quality mortar is stronger and more durable than good quality concrete; however their basic response to the environment is essentially the same.

### 3.1.8 Polymer Concrete: -

Concrete prepared using some polymer (Tyrone, poly-propylene, methyl methacrylate etc) is used to repair old damaged structure. Defective concrete portions may also be impregnated with a polymer imparting both imperviousness and strength

### 3.1.9 Polymerized Concrete: -

This is sometimes rather loosely referred to as polymer concrete. By polymerized concrete, we mean Portland cement containing monomer and which is polymerized after it has hardened. On the other hand polymer concrete in which the cement is replaced either entirely or principally by an organic polymer such as epoxies polyester resin.

Claims made for polymerized concrete include the following:

(a) A considerable increases in the compressive and tensile strength.

(b) The resistance to chemical attack and the effect of freeze-thaw are greatly increased.

(c) Absorption and permeability are greatly reduce

### 3.1.10 Butyl Rubber Sheeting: -

Butyl rubber is a tough, black and flexible sheeting with considerable abrasion resistance. It is described as a co-polymer of ploy-ISO-butylenes together with a smaller percentage of isoprene. The sheets are used as waterproof membrane in roof construction. The thickness of sheets vary from 0.5 mm to 3 mm.

### 3.1.11 Poly-ISO-Butylenes: -

PIB is somewhat similar to butyl rubber but it has a number of important qualities not possessed by the latter materials. It has marketed as black flexible sheeting. Two of its more important features are its low restitution as experience over a long period has shown that it is not adversely affected by ultra-violet light, Ozone, a wide range of chemical, and does not support fungi growth. The low regains its original dimensions and thus stress is reduced. Solvent welding normally joins the sheets. The solvent softens and activates the material and completely evaporates, resulting in genuine weld, having the same strength and durability as the original material.

### 3.1.12 Glass Fiber Reinforced Plastics: -

This material is usually referred to as GRP. It as a composite material composed of polyester resin and glass fiber. There are various types of glass fiber. The process of applications consists in building up successive layers of the resin and glass fiber on the substrata. Hand or spray can do this.

### 3.1.13 Epoxy Grouts, Mortars And Coatings: -

Epoxy grouting under pressure using a special gun, epoxy grouting under gravity epoxy-sand mortars have been extensively used to repair cracks. Epoxy coatings have also proved to be used successful in ensuring waterproofs.

### 3.1.14 Latex Modified Concrete Or Mortars: -

Latex or acrylic modified mortars have greater strength. This technique has been used to strengthen bridge decks or factory floors to carry heavier loads.

### 3.1.15 Dry Pack: -

Portland cement with low water cement ratio is used to repair small areas by hand applications, especially to obtain water tightness.

### 3.1.16Shotcreting Or Gunting: -

Shot Crete or gunite is mortar or concrete conveyed through a pressure hole and applied pneumatically at high velocity on to a surface. Gunite has strength of about $20N/mm^2$ and it has been extensively used to carry out major repair works on reinforced and un-reinforced structures.

### 3.1.17 Ferro cement Laminations: -

The repair of existing structures may involve structural considerations or they may be non-structural in nature. In the first category are structures, which have development active cracks. Traditional repairing technique may help only temporarily, as the cracks are liable to reoccur or occur in adjacent locations. Repairs in case of dormant cracks and especially to affect waterproofing have been successfully done by traditional means.

Ferro cement may entail greater initial cost in such cases, because of its efficienacy over much longer periods; it may ultimately prove to be economical. For repairs of structures with active cracks and for strengthening to cope with heavier loads. Ferro cement scores definitely over other techniques. In such situations, it is important to assess the additional strength gained by Ferro cement application.

## 3.2 CONSTRUCTION PROCEDURES

Ferro cement construction unlike other sophisticated engineering construction requires minimum skilled labor and it utilizes readily available materials. The basic material required for Ferro cement construction is described in early sections. Proper attention is needed in order to control the quality of construction to achieve the desired goals. The skills for Ferro cement construction techniques can easily be acquired and requisite quality control can be achieved using fairly unskilled labor for the fabrication under the supervision of a skilled foreman. The most important advantage of Ferro cement is that it can be fabricated into almost any desired shape to meet the user needs.

The four major steps in Ferro cement constructions are placement of wire mesh in a proper position, mortar mixing, mortar application and curing. A general description of these steps is given in the succeeding paragraphs.

### 3.2.1 Reinforcement

For highly stressed structures like boats, barges etc, steel rods along with wire mesh, is considered as a component of the reinforcement imparting structural strength and stiffness. For the terrestrial structures, wire mesh is treated as main reinforcement. The reinforcing rods, pipes (in boat and barge construction) and wire mesh are evenly distributed and shaped to the desired form. The steel contents of Ferro cement vary from 1% to 8% by volume. In highly reinforced structures the arrangement of steel rods and mesh should be in such a manner as to allow adequate penetration of the mortar, thereby resulting into a void free dense material. The reinforcement network should be securely welded or other wise fastened together, so that it should remain in its original position during the vibration caused by application of the mortar.

In general mild steel rods are recommended but for highly stressed structures such as boats, barges etc high tensile rods are desirable. Presently 0.20 inch to 0.25-inch (5.0 mm to 6.25 mm) diameter rod is the most commonly used for longitudinal as well as for transverse steel? Generally the spacing of the steel rods varies from 3 inch (76.2 mm) to as high as 12 inch (304.8 mm), depending upon the type of structure (Ref 2.9). Overlapping length varies from 9 inch (286.6 mm) to 12 inch (304.8 mm) for most of the structures. Wire mesh either galvanized or un galvanized is placed on both the sides of steel rods. The number of layers varies from two to as high as eight depending on the design. The wire meshes are tied up with steel rods at 6 inch (152.4 mm) to 12-inch (304.8 mm) intervals with galvanized wires. It is important to allow the mesh to take its own lay as far as possible, even if this means a vary large overlap in some parts. Overlaps can be cut off to avoid difficulty in workmanship. However, a minimum overlap of 2 inch (50.8 mm) is to be maintained.

### 3.2.2 Mortar preparation

The proportion of the mix is based on the weight ratios. The proportion of cement-sand generally varies from 1 part cement to 1.5 to 2 parts sand. The water/ cement ratio is to be maintained as low as possible to give the material a consistent quality and workability. In all construction, the water/cement ratio should be maintained at nearly .3 0 to .40 by weight if possible. If required pozzolan or other additives according to their prescribed quantity can be used at the time of mixing.

Experience shows that for most cases properly carried out hand mixing is satisfactory. But for large structures and factory made components, a horizontal paddle bladed mixer is recommended. The paddle mixer requires comparatively less water than the barrel mixer. In practice, dry sand and cement are mixed together properly and then the required amount of water is added to them. The batches are to be mixed until a uniform mix is formed. The minimum mixing time is three minutes.

### 3.2.3 **Plastering**

Plastering is often considered as the most critical phase in the whole Ferro cement construction techniques. Before plastering, it should be ascertained that all the steel rods and wire meshes are in the proper position, free from mill scale, grease and any other contaminants. They should be brushed before start of plasterwork. Plaster by hand has proved to be the most satisfactory method. Fingers and trowels are used to apply the mortar in the wire mesh formed structures. Generally formwork is not needed, as the mortar remain in its position after placing due to stiff mix. However, in some cases a plank of wood or iron sheet can be used as temporary support, which can be removed after plastering and vibrating the mortar.

Different methods of plastering techniques have been developed specially in boat building industry like one stage and two stage methods. The one stage method refers to a single monolithic application of mortar to fill up the steel mesh and finishing the surface before the initial set of the cement mortar takes place. Two-stage method refers to the procedure of first plastering from one side in which pressing through the mortar, just pass the inner surface of the central wire rod, finishing the outer side and curing is carried out. The remaining voids are filled from the other side, and then finished and cured.

#### 3.2.3.1 One Stage Technique

It is recommended practice to force the mortar from outside to the inside of the mesh and subsequently finishing it off to a smooth surface. But this technique is very difficult and requires considerable skill in getting the mortar to penetrate through the layers of wire mesh and steel rods without any voids being left inside. The one sided mortar should not be applied until it penetrates fully from the other side. Plastering from both sides at the same time should never be done, as this invariably results in air being trapped between the layers, causing lamination in the skin of the hull. When using the one stage technique, perhaps the most desirable way is to place the mortar from one side with sheets of plywood or similar wooden planks on the other side as a temporary frame work against which the vibrators can work. In most of the cases, a hand vibrator with a piece of wood with a handle attached to it is enough for complete penetration of the mortar to the mesh and for ensuring good compaction. From experience, it has been found that the conventional orbital sanders (a simple tool used widely in the wood working industry) with a metal plate substituted for the sand paper pad gives the correct amount of vibration. The vibrations are localized, so already placed mortar is not shaken out of the mesh. However, the use of vibrator should be carefully supervised to ensure that mortar already placed is not disturbed.

#### 3.2.3.2 Two Stage Technique

As many difficulties are experienced in single stage plastering, two stage plastering technique is preferred in most of the cases, especially in the boat building industry. The vibrator is essential when the second layer of plaster is being applied. Failure to do this will result in trapped air and voids between the two layers. The use of vibrator removes air and ensures a thorough compaction. After the first stage of mortar application, the structure must be wet cured for at least 10 to 14 days. Before applying the second layer, it is essential to clean the surface and remove loose material. Then a cement grout consisting of water and cement mixed to a thick consistency can be spread or painted onto the surface prior to the application of the mortar. This step eliminates the risk of separation between the two layers but doubts still remain regarding the quality of the joint between the two layers.

### 3.2.3.3 Sectional Plastering

When undertaking the plastering operation of large Ferro cement structures, it may be preferable to plaster in sections, using the single stage process. In this case it is desirable to keep the constructional joints as tidy as possible, and if practicable, surplus mortar on the edges should be blown away with compressed air before setting takes place. Before starting the next plastering operation, the joints should be coated with grout or if preferred, a wet to dry epoxy resin, which will ensure a more perfect joint, may be applied. In many cases this sectional plastering has proved extremely successful. The main disadvantage of this method is the difficulty in obtaining a fair and smooth joint between the sections and this, once again is due to the differential shrinkage of the layers of mortar, which are of different ages.

### 3.2.3.4 Finishing

In the course of normal plastering operation, surface job should be completed before the final set has occurred. The clear cover should not exceed than 1/12 inch (2.15 mm), however 1/16 inch (1.6 mm) is considered acceptable in most of the cases. Large wooden batten should be used at all times during the plastering process to ensure that the surface is fair and to avoid bumps and hollows between steel rods. This helps to identify where additional mortar is required to fill the hollows, or where excess mortar needs to be removed. On completion of the aforesaid operation, the surface should be smoothened with wooden floats. On completion of wooden floating the surface is steel toweled for a very smooth finish. If a rough surface for subsequent painting is required, a sponge should be used.

### 3.2.4 Curing

In order to obtain a good quality curing in a suitable environment during the early stages of hardening must follow hardened mortar, the placing and compaction of the mortar. Curing is the name given to the process used for promoting the hydration of cement. It consists of controlling the temperature and the moisture movement from and into the mortar. More specifically, the object of curing is to keep the mortar saturated, until the products of hydration of cement have filled the space occupied by water in the fresh cement paste. Hydration cannot take place without water and if the mixing water is allowed to dry out of the mortar, hydration and consequently, the strength development and durability will be adversely affected. There are different methods of curing, which have been developed so far, but the actual procedure used depends upon the site conditions, size, shape and position of the Ferro cement structure.

### 3.2.5 Coatings

Generally the adequately plastered Ferro cement structures need no protection unless exposed to severe environmental conditions. The paintwork in most cases is only for aesthetic reasons. However, protective coating is necessary when the structure is subjected to strong chemical attack that might damage the structural integrity of its components. Generally there may be a need of prevention from chemical attack on Ferro cement in such places like floors of laboratories, food plants, chemical process plants, chemical storage tanks, sewer and sewage plants and almost all types of marine structures. For structures, where extra protective coating is not essential from the structural point of view, ordinary paint can be used. The external protection of the structure susceptible to chemical attack can be done successfully with organic coating like vinyl and epoxy. There are many varieties of coating materials available in the market and careful consideration is essential in selecting a particular type of coating material. Any type of coating should have following ideal characteristics: -

- Good adhesion to mortar.
- Tolerance for alkalinity in the Ferro cement.
- Good abrasion and chemical resistance.
- Ability to insulate against electric current.
- Impermeability to water and chemicals.
- Be non toxic and suitable for use by unskilled labor.
- Simple application technique, preferably by brush.
- Single pack product is desirable throughout.
- No critical time interval between coats.
- Be fast drying.
- Not be affected by exposure out of water.
- Easy maintenance.

Epoxy coatings are widely recommended for small boats. They are two pack products, requiring careful proportioning and having limited pot life when mixed.

*Chapter 4*

# SPECIMENS CASTING AND MATERIAL DETAILS

## 4.1 AIM

The aim of this investigation is to study the suitability of Ferro cement as a retrofit/ strengthen material for RCC columns, and to evaluate the potential benefits of Ferro cement. An experimental study was carried out to determine the cracking, failure loads and failure patterns of Ferro cement coated vs. normal RCC columns.

## 4.2 RESEARCH METHODOLOGY

Among the available coating procedures, a thin overlay of Ferro cement has been suggested for use with RCC columns that require in plane and out of plane strengthening. This investigation deals with the compressive behavior of RCC columns coated with Ferro cement. A total of 36 RCC columns were constructed and treated with different encasement cases. The sizes of the RCC column were kept as 4 in square, 4 in circular, 6 in square, and 6 in circular. The specimens were divided into 12 groups and for each group three columns were constructed. These specimens were steam cured and air dried in the laboratory for four weeks each. The testing was conducted after six weeks for all the specimens. For the identification purpose the twelve groups were labeled in alphabetic order whose details are given in the subsequent paragraphs. The summary of proposed matrix for subject investigation is given in Table 3.1.

## 4.3 TEST PROCEDURE

The specimens were tested using universal testing machine of 200 tons capacity. After placing the specimens in the testing machine, vertical alignment was adjusted to eliminate any eccentricity. All the specimens were tested for axial loads only. The observations were made for cracking, failure loads and vertical strains. The measurements of vertical strain were done with the help of compressometers attached to the specimen with the help of proving rings. Compressometer was attached on the faces of the specimen to record the vertical strains. The readings were taken at the loading increment of 5 ton. The load was applied incrementally until the final failure occurred. The following characteristics were observed for every specimen during testing: -

- Cracking load
- Failure load
- Cracking pattern
- Stress- strain behavior.

## 4.4 PREPARATION OF SPECIMENS

The experimental investigation was carried out for twelve different groups of columns. Each group consisted of three columns and each group was labeled in alphabetic order for identification purpose. The original RCC columns were constructed using 1:2.2:3.2 concrete mix construction detail of each group is given below: -

### 4.4.1 Case A, Simple 4 in circular Columns

Three simple 4 in circular Columns were constructed with concrete mix of 1: 2.2: 3.2 and 3#4 bars were used. The specimens were labeled as 4C-A, 4C-B, and 4C-C.These three Columns were to act as control specimens. During testing, observations were made for cracking and failure loads, cracking pattern and stress- strain characteristics. These readings were compared with the readings of other cases to see the potential benefit of Ferro cement encasement.

### 4.4.2 Case B, 4 in circular RCC Columns coated with one layer of Ferro cement

In case B three specimens were coated with one layer of Ferro cement coating. The total thickness of layer was kept 15mm.Initially a mortar of 10mm thickness was applied on the specimen and the mesh layer was wrapped around the column and fixed with the help of screws. It was ensured that the mesh is wrapped tightly and sticks firmly to the initially applied mortar on the surface of RCC column. A cover of 5mm mortar was provided on the outer side of mesh to give it a smooth finish. The mortar ratio 1: 2 was used for Ferro cement encasement. The columns of Case B were labeled as 4C1-A, 4C1-B, and 4C1-C. Same observations were made during the testing as for Case A.

### 4.4.3 Case C, 4 in circular RCC Columns coated with two layers of Ferro cement

In case C three RCC columns labeled as 4C2-A, 4C2-B, 4C2-C were coated with two layers of wire mesh wrapped with the help of screws. Initially, a mortar cover of 5mm was applied on the surface of RCC columns and over that first layer of wire mesh was wrapped tightly and screwed to it. After that a cover of 15mm was given over the first layer and while the mortar was still in green form, second layer was wrapped around it and screwed to the surface, finally a mortar cover of 5mm was provided to give it a smooth finish. The total thickness of encasement was 20 to 25mm. The mortar ratio was kept as 1:2. During testing, observations were made for cracking, failure load, cracking pattern and vertical strains.

### 4.4.4 Case D, Simple 6 in circular Columns

Three simple 6 in circular Columns were constructed with concrete mix of 1: 2.2: 3.2 and 6#4 bars were used. The specimens were labeled as 6C-A, 6C-B, and 6C-C.These three Columns were to act as control specimens. During testing, observations were made for cracking and failure loads, cracking pattern and stress- strain characteristics. These readings were compared with the readings of other cases to see the potential benefit of Ferro cement encasement.

### 4.4.5 Case E, 6 in circular RCC Columns coated with one layer of Ferro cement

In case E three specimens were coated with one layer of Ferro cement coating. The total thickness of layer was kept 15mm.Initially a mortar of 10mm thickness was applied on the specimen and the mesh layer was wrapped around the column and fixed with the help of screws. It was ensured that the mesh is wrapped tightly and sticks firmly to the initially applied mortar on the surface of RCC column. A cover of 5mm mortar was provided on the outer side of mesh to give it a smooth finish. The mortar ratio 1: 2 was used for Ferro cement encasement. The columns of Case E were labeled as 6C1-A, 6C1-B, and 6C1-C. Same observations were made during the testing as for Case A.

### 4.4.6 Case F, 6 in circular RCC Columns coated with two layers of Ferro cement

In case F three RCC columns labeled as 6C2-A, 6C2-B, 6C2-C were coated with two layers of wire mesh wrapped with the help of screws. Initially, a mortar cover of 5mm was applied on the surface of RCC columns and over that first layer of wire mesh was wrapped tightly and screwed to it. After that a cover of 15mm was given over the first layer and while the mortar was still in green form, second layer was wrapped around it and screwed to the surface, finally a mortar cover of 5mm was provided to give it a smooth finish. The total thickness of encasement was 20 to 25mm. The mortar ratio was kept as 1:2. During testing, observations were made for cracking, failure load, cracking pattern and vertical strains.

#### 4.4.7 Case G , Simple 4 in Square Columns

Three simple 4 in square Columns were constructed with concrete mix of 1: 2.2: 3.2 and 4#4 bars were used. The specimens were labeled as 4S-A, 4S-B, and 4S-C.These three Columns were to act as control specimens. During testing, observations were made for cracking and failure loads, cracking pattern and stress- strain characteristics. These readings were compared with the readings of other cases to see the potential benefit of Ferro cement encasement.

#### 4.4.8 Case H 6 in circular RCC Columns coated with one layer of Ferro cement

In case H three specimens were coated with one layer of Ferro cement coating. The total thickness of layer was kept 15mm.Initially a mortar of 10mm thickness was applied on the specimen and the mesh layer was wrapped around the column and fixed with the help of screws. It was ensured that the mesh is wrapped tightly and sticks firmly to the initially applied mortar on the surface of RCC column. A cover of 5mm mortar was provided on the outer side of mesh to give it a smooth finish. The mortar ratio 1: 2 was used for Ferro cement encasement. The columns of Case E were labeled as 4S1-A, 4S1-B, and 4S1-C. Same observations were made during the testing as for Case A.

#### 4.4.9 Case I 4 in Square RCC Columns coated with two layers of Ferro cement

In case I three RCC columns labeled as 4S2-A, 4S2-B, 4S2-C were coated with two layers of wire mesh wrapped with the help of screws. Initially, a mortar cover of 5mm was applied on the surface of RCC columns and over that first layer of wire mesh was wrapped tightly and screwed to it. After that a cover of 15mm was given over the first layer and while the mortar was still in green form, second layer was wrapped around it and screwed to the surface, finally a mortar cover of 5mm was provided to give it a smooth finish. The total thickness of encasement was 20 to 25mm. The mortar ratio was kept as 1:2. During testing, observations were made for cracking, failure load, cracking pattern and vertical strains.

#### 4.4.10 Case J , Simple 6 in Square Columns

Three simple 6 in square Columns were constructed with concrete mix of 1: 2.2: 3.2 and 8#4 bars were used. The specimens were labeled as 6S-A, 6S-B, and 6S-C.These three Columns were to act as control specimens. During testing, observations were made for cracking and failure loads, cracking pattern and stress- strain characteristics. These readings were compared with the readings of other cases to see the potential benefit of Ferro cement encasement.

#### 4.4.11 Case K, 6 in Square RCC Columns coated with one layer of Ferro cement

In case K three specimens were coated with one layer of Ferro cement coating. The total thickness of layer was kept 15mm.Initially a mortar of 10mm thickness was applied on the specimen and the mesh layer was wrapped around the column and fixed with the help of screws. It was ensured that the mesh is wrapped tightly and sticks firmly to the initially applied mortar on the surface of RCC column. A cover of 5mm mortar was provided on the outer side of mesh to give it a smooth finish. The mortar ratio 1: 2 was used for Ferro cement encasement. The columns of Case E were labeled as 6S1-A, 6S1-B, and 6S1-C. Same observations were made during the testing as for Case A.

#### 4.4.12 Case M, 6 in Square RCC Columns coated with two layers ofFerro cement

In case M three RCC columns labeled as 6S2-A, 6S2-B, 6S2-C were coated with two layers of wire mesh wrapped with the help of screws. Initially, a mortar cover of 5mm was applied on the surface of RCC columns and over that first layer of wire mesh was wrapped tightly and screwed to it. After that a cover of 15mm was given over the first layer and while the mortar was still in green form, second layer was wrapped around it and screwed to the surface, finally a mortar cover of 5mm was provided to give it a smooth finish. The total thickness of encasement was 20 to 25mm. The mortar ratio was kept as 1:2. During testing, observations were made for cracking, failure load, cracking pattern and vertical strains.

## 4.5 TESTING OF MATERIAL

Ferro cement is a kind of composite material where filler material, usually brittle in nature, called matrix is reinforced with fibers dispersed throughout the composite resulting in better structural performance. In other words, Ferro cement is a composite material, which contains a high percentage of ductile steel wire, meshes with a high surface area to volume ratio in a brittle cement-mortar matrix and enables the matrix to assume the ductile characteristics of the reinforcements. The performance and mechanical properties of Ferro cement depend upon its constituent materials. The materials used in casting the specimens were tested to evaluate their desired properties. A brief description of various materials used in the subject testing is presented here along with their laboratory test results.

### 4.5.1 Fine Aggregate

. Normal weight sand is the most common aggregate used in Ferro cement. It should be clean, hard, strong, well graded and free of organic impurities, deleterious substances, silt and clay. Grading of sand is to be such that a mortar of specified proportion is produced with a uniform distribution of the aggregate, which will have a high density and good workability and will work into position without segregation and increase in water content. The tests were performed as per the specification laid down in ASTM 422-63. The standard grain analysis was carried out with the help of sieves to find out the relative proportion of different grain sizes as they are distributed in a certain size ranges. The sieves used were of standard sizes, as specified in ASTM Specification 422-63. From the distribution curve drawn (Ref Fig 3.1), the value of D10 was observed as 0.08 (D10 mean the diameter of 10% passing particles), the value of D30 and D60 was observed as 0.35 and 0.5 respectively. The value of Cu and Cc were calculated as 6.25 and 3.0 respectively. This result suggests that the sand was well graded (SW).

### 4.5.2 Wire Mesh

Expended metal mesh of welded type was used in the experimental work. The diameter of wire mesh was 1 mm and opening was 15 mm. The tests were performed and the value of yield strength and ultimate strength were observed as 28624 psi and 37942 psi respectively.

### 4.5.3 Cement

The cement should comply with ASTM C 150-85a, ASTM C 595-85, or an equivalent standard. Ordinary Portland Cement Type-1 was used through out the experimental work. Portland Cement of Type-1 is not recommended for structures, subjected to strong sulphate attack in the soil, ground water and seawater, and subjected to excessive rise in temperature due to hydration. The typical values of compound composition of Portland Cement Type–1 are given in Table

### 4.5.4 Nails

Normal steel screws were used to tie the wire mesh around the RCC columns.

### 4.5.5 Bonding Agent, Sikka Latex

Sikka-Latex was used in all of the specimens as a bonding agent. It is a synthetic rubber emulsion for adding to cement mortar where good adhesion is desired. Sikka-Latex is a high quality emulsion that substantially increases the qualities of cement mortar such as: -

- Thin layer patching mortar
- Renders
- Floor screeds
- Concrete repair mortar
- Abrasion resistant linings
- Masonry mortars

Sikka-Latex is generally added to the clean mixing water within the range 1: 1: 1.4. For all applications apart from sprayed on renders as a bonding coat of Sikka-Latex and water (1:1) mixed with fresh cement and sand (1:1) should be brushed into the prepared surface. Subsequently mortar application must be carried out whilst the bonding coat is still wet.

### 4.5.6 Mix Proportion and W/C Ratio

The mix proportion for all RCC work was kept as 1: 2.2: 3.2 (cement: sand: coarse aggregate) and 1:2 mortar ratio was used. As desired, the w/c ratio was kept as low as is 0.25/ 0.3 for mortar and .58 for concrete mix.

CHAPTER 5

# TEST RESULTS AND DISCUSSION

## 5.1 TESTS OF CASE A

In Case A, three RCC Columns specimens were tested for their compressive strength and behavior. These three specimens were tested by applying axial load through universal testing machine of 200-ton capacity. Vertical alignment was ensured to minimize/eliminate any eccentricity. The capping of top and bottom surface of the specimen was done with a thin layer of mortar/plaster of Paris and it was ensured that uniformly distributed load is applied through the steel plates placed at the top and bottom of the column. The load was applied at a slow rate and observations regarding stress-stain were recorded at load increment of 5 ton. Three columns of Case A were labeled as 4C-A 4C-B, 4C-C. The individual observations of these specimens are given in succeeding paras.

### 5.1.1 Specimen 4C-A

This was the first specimen, which was tested. The load was applied at a slow rate and the first visible crack was observed at the load of 12.9 ton (31964 lbs). The first cracks initiated from top right edge and in the middle simultaneously. Soon, these cracks widened quickly and specimen reached its ultimate failure load of 16.6 tons (37184 lbs). The cracks were mostly vertical in nature. The stress-strain readings were recorded at the regular interval of 5 ton. Strains were quite steady in the beginning, but near failure load, increased very rapidly. The observations regarding stress-strain, cracking and failure load are given in Table-4.1. The graphical representation of Case 4C is given in Fig-4.1.

### 5.1.2 Specimen 4C-B

For the second specimen of Case A, the first crack was observed at a load of 9.8 tons (22758 lbs). The cracks initiated at the top, bottom and nearly in the middle of the column simultaneously. The column failed at the load of 12.1 ton (27104 lbs). The cracks widened very slowly and the column remained intact while removing from the testing machine. Specimen 4C-B failed at 12.1 ton load, (4.5 ton lower than specimen 4C-A) which is not significant and could be attributed to difference in workman ship. The stress-strain observations, cracking and failure loads are presented in Table-4.2. The graphical representation of specimen 4C-B is shown in Fig-4.2.

### 5.1.3 Specimen 4C-C

For third specimen of ‘A’ series the first crack was observed at the load of 16.4 ton (36736 lbs). This crack was vertical and initiated in the middle and right bottom edge of the column. The column failed at an ultimate load of 20.2 ton (45248 lbs), which is quite similar to the failure load of specimen 4C-B. The crack growth was quite fast and near failure they joined each other in the middle. The stress-strain observations, details of cracking and failure loads are shown in Table-4.3. The graphical behavior of Case 4C-C is shown in Fig-4.3

### 5.1.4 Analysis of Case A

From the results of all three specimens, it is clear that two specimens of Case A exhibited almost identical behavior and third specimen have less strength which can be due to workmanship, as application of vibrator was difficult in so small columns. The failure loads were generally identical. The average failure load for Case A was calculated as 16.3 ton (36512 lbs). The average stress-strain readings and failure load are presented in Table-4.4. The crack initiation started at about 70 % to 80 % of the failure loads. Major cracks were vertical, however few horizontal cracks were also observed. The cracks widening and propagation was quite fast after their first appearance. The behavior of all three specimens of Case A with respect to the average values are given in Figure-4-37

## 5.2 TESTS OF CASE B

In case B three 4 in circular Columns were treated with one layer of Ferro cement of 15 mm thick having mortar of 1:2 ratio The construction and application of wire mesh is given in Chapter 3. The axial load was applied at slow rate by the universaltesting machine of 200-ton capacity. The capping of top and bottom surface was carried out with thin layer of mortar/plaster of Paris and vertical alignment was adjusted before applying the load. The mortar ratio was kept 1:2 for Ferro cement and the thickness of encasement was kept 15 mm. The thickness of encasement increased a little bit at places because the wrapping of wire mesh around the column was difficult and applying mortar over it was a new experience for the mason. However, it was kept within the limits of 5 mm to 8 mm. This was the first case of Ferro cement, having one wire mesh wrapped inside. All three specimens were named as 4C1-A, 4C1-B 4C1-C and observations were recorded for stress strain, at regular interval of 5 ton. The observations of individual specimens are given in succeeding paras.

### 5.2.1 Specimen 4C1-A

After adjusting the vertical alignment, the load was applied at a steady rate. The first crack was observed at 8.2 ton (18368 lbs). After this first crack, more cracks appeared with regular interval of 4 to 5 ton. The specimen failed at an ultimate load of 28 ton (62720 lbs). Most of the cracks initiated from the top and bottom edges and were diagonal in shape. Near failure these cracks joined in the middle, however the crack growth was quite stable and widening rate was much slower as compared to specimens of Case A. This slow rate of crack growth can be attributed to wire mesh presence inside the encasement, which helped in arresting the cracks during their propagation process. Near failure, small chunks of plaster fell off the specimen from top, but no significant spalling was observed.

The confinement provided by Ferro cement increased the failure load to 28 ton, which is approx 72% higher than the average failure load of control Case A. This was a quite substantial increase in failure load. The specimen was intact and did not break in pieces. The wire mesh inside was in good shape and cracks were not very wide. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.4, and the graphical representation of Case 4C1-A shown in Fig- 4.4.

### 5.2.2 Specimen 4C1-B

The specimen exhibited quite similar failure load to 4C1-A as it failed at an ultimate load of 25.7 ton (57568 lbs). This failure load was about 58% higher than the failure load of control Case A. The initial cracks were minor and did not widen with the application of load. However, near failure, these cracks got prominent and most of them were initiated from the top edge and were diagonal in shape. The wire mesh inside was observed intact, however small spalling of outer layer of mortar cover took place near failure from top. The specimen was still intact while it was removed from the testing machine. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.5, and the graphical representation of case 4C1-B is also shown in Fig-4.5.

### 5.2.3 Specimen 4C1-C

This specimen also exhibited higher failure load of 27.6 ton (61824 lbs), which is approx 70% higher than the failure load of control Case A. The first crack was observed at 11.7 ton (26208 lbs), which is 50% of its failure load. Initial cracks were minor and did not propagate rapidly. More cracks were observed at the regular interval of 3 to 4 ton, and mostly they were diagonal in shape. These cracks did not widen even at failure and only spalling of outer concrete cover was observed at few places from top and bottom. The wire mesh inside was visible at the places of spalling and looked in perfect shape and no breakage of wire mesh was observed. The bond between the surface of RCC column and Ferro cement encasement was lost at failure and most of the cracks were formed inside the encasement mortar. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.6, and the graphical representation of Case 4C1-C is shown in Fig-4.6

### 5.2.4 Analysis of Case B

The average failure load for Case B was calculated as 27.6 ton (61824 lbs). All the specimens of Case B, showed almost similar results. The specimen 4C1-A failed at 28 ton (62720 lbs) and specimens 4C1-B and 4C1-C failed at the loads of 25.7 ton (57568 lbs) and 27.6 ton (61824 lbs) respectively. Increase in the failure loads was quite significant about 69%. Although the first cracking loads were low, but these could be attributed to existing cracks in the mortar. This observation is validated by the fact that these cracks did not propagate rapidly with the increase in load. The mesh inside was believed to control the cracks propagation, therefore no sudden widening of cracks was observed. The specimens were still intact and could possibly be repaired with grouting or pumping of concrete. The bond between the RCC column and fibrocement encasement was not lost, as only small chunk of outer concrete cover fell off near the failure loads. The wire mesh inside was observed to be in perfect condition and held the column intact. The average stress-strain readings and failure loads are presented in Table-4.16. The graphical representation of all the specimens of Case B, with respect to average values is presented in Figure 4.37.

## 5.3 TESTS OF CASE C

In Case C, three 4 in circular RCC Columns were treated with two layers of Ferro cement coating and were tested for their compression behavior. The specimens were named as 4C2-A 4C2-B 4C2-C and these were aligned vertically before testing in order to eliminate any eccentricity. The total thickness of ferro cement encasement was 25mm. Holding the wire mesh at its location and inserting mortar over and inside the wire mesh was a new experience for the mason. Though, extreme care was taken while wrapping and tightening the wire mesh around the column, still some bulging of wire mesh remained, which required extra mortar thickness to cover it. These specimens were also tested for axial loads through steel plates applied by the universal testing machine of 200-ton capacity. The construction details of the specimens of Case C are given in Chapter 3. With a steady rate, the load was applied and observations were made for stress-strain at the regular interval of 5 ton. The observations for individual specimens are in given succeeding paras.

### 5.3.1 Specimen 4C2-A

The specimen 4C2-A failed at a failure load of 30.8 ton (68992 lbs), which is almost 89% more than the failure load of control Case A. Though it is a significant increase from simple RCC Column, but it is not comparable with the failure load of specimens of Case B, where only one wire mesh was wrapped inside the mortar. It was expected that with the 2 layers of wire mesh wrapped inside, the confinement effects might increase the failure load further. However, the results did not prove better and it could possibly be due to slackness in the wire mesh at places. This problem lead to the premature failure of the specimen due to spalling of plaster. The first crack was observed at 14.6 ton (32704 lbs), but these cracks were minor and did not propagate rapidly with the increase of load. Mostly, cracks were vertical but few horizontal cracks were also observed. One possible reason for such a low cracking loads could be the shrinkage effect of thick mortar cover, varying from 10 mm to 15 mm. These cracks were mostly vertical and of local nature as they did not extend the full length of specimen with increase of load. The mesh inside remained unbroken. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.7, and the graphical representation of Case C is shown in Fig-4.7.

### 5.3.2 Specimen 4C2-B

The specimen 4C2-B, exhibited failure load of 31 ton (69440 lbs), which is almost identical to specimen 4C2-A. The effects of loose wire mesh, its bulging and thicker cover was quite evident in this case. The first cracking load was observed as 12.9 ton (28896 lbs) and like specimen 4C2-A; these cracks were minor and did not propagate with the increase of load. However, spalling of concrete cover took place, which caused premature failure of the specimen. The bond of outer layer of wire mesh was broken from before final failure. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.8, and the graphical representation of Case 4C2-B is shown in Fig-4.8.

### 5.3.3 Specimen 4C2-C

The failure load for specimen 4C2-C was 24.7 ton (55328 lbs). Like other specimens of this group the possible reason for such low failure load could be the loose wire mesh, and thick mortar cover which probably caused the early cracks and premature failure. The first crack was observed at the load of 7.6 ton (17024 lbs), which means that these cracks were pre-existing and became evident with little application of load. These cracks did not extend full length of specimen. Because of bond failure between the mesh and mortar, the composite action could not take place and the failure occurred due to bond failure of encasement and RCC column. The observations regarding the stress-strain, cracking and failure loads are given in Table-4.9, and the graphical representation of Case 4C2-C is shown in Fig-4.9.

### 5.3.4 Analysis of Case C

The average failure load for Case C was calculated as 28.8 ton (64512 lbs), which is not very different from the average failure load of Case B, where only one layer of Ferro cement was applied. The loose wire mesh did not participate in load bearing, as bond between mesh, mortar and RCC Column surface was not strong enough to exhibit composite behavior. The thicker Ferro cement layer spalled off with the increasing load and the bulging of wire mesh also caused premature failure. The average stress-strain readings and failure loads are presented in Table-4.20. The graphical representation of all three specimens of Case C, with respect to average values are presented in Figure 4.37

## 5.4 TESTS OF CASE D

In Case D, three 6in circular RCC Columns specimens were tested for their compressive strength and behavior. These three specimens were tested by applying axial load through universal testing machine of 200-ton capacity. Vertical alignment was ensured to minimize/eliminate any eccentricity. The capping of top and bottom surface of the specimen was done with a thin layer of mortar/plaster of Paris and it was ensured that uniformly distributed load is applied through the steel plates placed at the top and bottom of the column. The load was applied at a slow rate and observations regarding stress-stain were recorded at load increment of 5 ton. Three columns of Case D were labeled as 6C-A 6C-B 6C-C. The individual observations of these specimens are given in succeeding paras.

### 5.4.1 Specimen 6C-A

This was the first specimen, which was tested. The load was applied at a slow rate and the first visible crack was observed at the load of 26.2 ton (58688 lbs). The first cracks initiated from bottom right edge and in the middle simultaneously. Soon, these cracks widened quickly and specimen reached its ultimate failure load of 36.8 tons (82432 lbs). The cracks were mostly vertical in nature. The stress-strain readings were recorded at the regular interval of 5 ton. Strains were quite steady in the beginning, but near failure load, increased very rapidly. The observations regarding stress-strain, cracking and failure load are given in Table-4.10 the graphical representation of Case 6C is given in Fig-4.10.

### 5.4.2 Specimen 6C-B

For the second specimen of Case D, the first crack was observed at a load of 27.6 ton (61824 lbs). The cracks initiated at the top and in the middle of the column simultaneously. The column failed at the load of 34.5 ton (77280 lbs). The cracks widened very slowly and the column remained intact while removing from the testing machine. Specimen 6C-B failed at 34.5ton, which is not significant and could be attributed to difference in workman ship. The stress-strain observations, cracking and failure loads are presented in Table-4.11. The graphical representation of specimen 6C-B is shown in Fig-4.11

### 5.4.3 Specimen 6C-C

For third specimen of 'D' series the first crack was observed at the load of 35.95 ton (80528 lbs). This crack was vertical and initiated in the middle and right TOP edge of the column. The column failed at an ultimate load of 41.8 ton (93632 lbs), which is about 7tons higher than specimen 6C-B. The crack growth was quite fast and near failure they joined each other in the middle. The stress-strain observations, details of cracking and failure loads are shown in Table-4.12 the graphical behavior of Case 6C-C is shown in Fig-4.12

### 5.4.4 Analysis of Case D

From the results of all three specimens, it is clear that all three specimens of Case D exhibited almost identical behavior. The failure loads were generally identical. The average failure load for Case D was calculated as 37.7 ton (84448 lbs). The average stress-strain readings and failure load are presented in Table-. The crack initiation started at about 75 % to 85 % of the failure loads. Major cracks were vertical, however few horizontal cracks were also observed. The cracks widening and propagation was quite fast after their first appearance. The behavior of all three specimens of Case D with respect to the average values are given in Figure-4-37

## 5.5 TESTS OF CASE E

In case E three 6 in circular Columns were treated with one layer of Ferro cement of 15 mm thick having mortar of 1:2 ratio .The construction and application of wire mesh is given in Chapter 3. The axial load was applied at slow rate by the universal testing machine of 200-ton capacity. The capping of top and bottom surface was carried out with thin layer of mortar/plaster of Paris and vertical alignment was adjusted before applying the load. The mortar ratio was kept 1:2 for Ferro cement and the thickness of encasement was kept 15 mm. The thickness of encasement increased a little bit at places because the wrapping of wire mesh around the column was difficult and applying mortar over it was a new experience for the mason. However, it was kept within the limits of 5 mm to 8 mm. This was the first case of Ferro cement, having one wire mesh wrapped inside. All three specimens were named as 6C1-A, 6C1-B 6C1-C and observations were recorded for stress strain, at regular interval of 5 ton. The observations of individual specimens are given in succeeding paras.

### 5.5.1 Specimen 6C1-A

After adjusting the vertical alignment, the load was applied at a steady rate. The first crack was observed at 25.7 ton (57568 lbs). After this first crack, more cracks appeared with regular interval of 4 to 5 ton. The specimen failed at an ultimate load of 49.3 ton (110432 lbs). Most of the cracks initiated from the top and middle and were diagonal in shape. Near failure these cracks joined in the middle, however the crack growth was quite stable and widening rate was much slower as compared to specimens of Case D. This slow rate of crack growth can be attributed to wire mesh presence inside the encasement, which helped in arresting the cracks during their propagation process. Near failure, quite significant plaster fell off the specimen from top.

The confinement provided by Ferro cement increased the failure load to 49.3 ton, which is approx 31% higher than the average failure load of control Case D. This was a quite substantial increase in failure load. The specimen was intact and did not break in pieces. The wire mesh inside was found broken at very limited places and cracks were not very wide.  The observation regarding the stress-strain, cracking and failure loads are given in Table-4.13 and the graphical representation of Case 6C1-A shown in Fig- 4.13.

### 5.5.2 Specimen 6C1-B

The specimen exhibited quite similar failure load to 6C1-A as it failed at an ultimate load of 56.2 ton (125888 lbs). This failure load was about 49% higher than the failure load of control Case D. The initial cracks were minor and did not widen with the application of load. However, near failure, these cracks got prominent and most of them were initiated from the top edge and were diagonal in shape. The wire mesh inside was observed yielded at certain places, and small spalling of outer layer of mortar cover took place near failure from top. The specimen was still intact while it was removed from the testing machine. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.14, and the graphical representation of case 464C1-B is also shown in Fig-4.14.

### 5.5.3 Specimen 6C1-C

This specimen also exhibited higher failure load of 60.1 ton (134624 lbs), which is approx 59.4% higher than the failure load of control Case D. The first crack was observed at 31.6 ton (70784 lbs), which is 52% of its failure load. Initial cracks were minor and did not propagate rapidly. More cracks were observed at the regular interval of 3 to 4 ton, and mostly they were diagonal in shape. These cracks did not widen even at failure and only spalling of outer concrete cover was observed at few places from top and bottom. The wire mesh inside was visible at the places of spalling and looked in perfect shape and no breakage of wire mesh was observed. The bond between the surface of RCC column and Ferro cement encasement was lost at failure and most of the cracks were formed inside the encasement mortar.

The observation regarding the stress-strain, cracking and failure loads are given in Table-4.15 and the graphical representation of Case 6C1-C is shown in Fig-4.15.

### 5.5.4 Analysis of Case E

The average failure load for Case E was calculated as 55.2 ton (123648 lbs). All the specimens of Case E, showed almost similar results. Increase in the failure loads were quite significant about 46%, which is about 23% less than 4 in circular Column with one layer of Ferro cement. Although the first cracking loads were low, but these could be attributed to existing cracks in the mortar. This observation is validated by the fact that these cracks did not propagate rapidly with the increase in load. The mesh inside was believed to control the cracks propagation, therefore no sudden widening of cracks was observed. The bond between the RCC column and Ferro cement encasement was partially broken. The wire mesh inside was observed to be yielded at certain places. The average stress-strain readings and failure loads are presented in Table-4.16. The graphical representation of all the specimens of Case E, with respect to average values is presented in Figure 4.37.

## 5.6 TESTS OF CASE F

In Case F, three 6 in circular RCC Columns were treated with two layers of Ferro cement coating and were tested for their compression behavior. The specimens were named as 6C2-A 6C2-B 6C2-C and these were aligned vertically before testing in order to eliminate any eccentricity. The total thickness of Ferro cement encasement was 25mm. Holding the wire mesh at its location and inserting mortar over and inside the wire mesh was a new experience for the mason. Though, extreme care was taken while wrapping and tightening the wire mesh around the column, for which steel Screws were used, still some bulging of wire mesh remained, which required extra mortar thickness to cover it. These specimens were also tested for axial loads through steel plates applied by the universal testing machine of 200-ton capacity. The construction details of the specimens of Case F are given in Chapter 3. With a steady rate, the load was applied and observations were made for stress-strain at the regular interval of 5 ton. The observations for individual specimens are in given succeeding paras.

### 5.6.1 Specimen 6C2-A

The specimen 6C2-A failed at a failure load of 57.3 ton (128352 lbs), which is almost 52% more than the failure load of control Case D. Though it is a significant increase from simple RCC Column, but it is not comparable with the failure load of specimens of Case E, where only one wire mesh was wrapped inside the mortar. It was expected that with the 2 layers of wire mesh wrapped inside, the confinement effects might increase the failure load further. However, the results did not prove better and it could possibly be due to slackness in the wire mesh at places and increase in thickness of mortar. This problem leads to the premature bond failure of the specimen, which resulted, into spalling of plaster. The first crack was observed at 24.8 ton (55552 lbs), but these cracks were minor and did not propagate rapidly with the increase of load. Mostly, cracks were vertical but few horizontal cracks were also observed. One possible reason for such low cracking loads could be the shrinkage effect of thick mortar layer, varying from 10 mm to 15 mm. These cracks were mostly vertical and have local nature, as they did not extend the full length of specimen with increase of load. The mesh inside was also found broken loosened at certain places. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.16 and the graphical representation of Case F is shown in Fig-4.16

### 5.6.2 Specimen 6C2-B

The specimen 6C2-B, exhibited failure load of 51.5 ton (115360lbs), which is almost identical to specimen 6C2-A. The effects of loose wire mesh, its bulging and thicker cover was quite evident in this case. The first cracking load was observed as 32.2 ton (72128lbs) and like specimen 6C2-A; these cracks were minor and did not propagate with the increase of load. However, spalling of concrete cover took place from top, which caused premature failure of the specimen. The bond of outer layer of wire mesh was broken well before final failure. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.17, and the graphical representation of Case 64C2-B is shown in Fig-4.17

### 5.6.3 Specimen 6C2-C

The failure load for specimen 6C2-C was 55.6 ton (124320lbs). Like other specimens of this group the possible reason for such low failure load, not contributing the effect of second layer of Ferro cement could be the loose wire mesh, and thick mortar cover which probably caused the early cracks and premature bond failure. The first crack was observed at the load of 35.6 ton (79744 lbs), which means that these cracks were pre-existing and became evident with little application of load. These cracks did not extend full length of specimen. Because of bond failure between the mesh and mortar, the composite action could not take place and the failure occurred due to bond failure of encasement and RCC column. The observations regarding the stress-strain, cracking and failure loads are given in Table-4.18 and the graphical representation of Case 6C2-C is shown in Fig-4.18.

### 5.6.4 Analysis of Case F

The average failure load for Case F was calculated as 54.8 ton (122752 lbs), which is not very different from the average failure load of Case E, where only one layer of Ferro cement was applied. The loose wire mesh did not participate in load bearing, as bond between mesh, mortar and RCC Column surface was not strong enough to exhibit composite behavior. The thicker Ferro cement layer spalled off with the increasing load and the bulging of wire mesh also caused premature failure. The average stress-strain readings and failure loads are presented in Table-4.20. The graphical representation of all three specimens of Case F, with respect to average values are presented in Figure 4.37

## 5.7 TESTS OF CASE G

In Case G, three 4in square RCC Columns specimens were tested for their compressive strength and behavior. These three specimens were tested by applying axial load through universal testing machine of 200-ton capacity. Vertical alignment was ensured to minimize/eliminate any eccentricity. The capping of top and bottom surface of the specimen was done with a thin layer of mortar/plaster of Paris and it was ensured that uniformly distributed load is applied through the steel plates placed at the top and bottom of the column. The load was applied at a slow rate and observations regarding stress-stain were recorded at load increment of 5 ton. Three columns of Case G were labeled as 4S-A, 4S-B, and 4S-C. The individual observations of these specimens are given in succeeding paras.

### 5.7.1 Specimen 4S-A

This was the first specimen, which was tested. The load was applied at a slow rate and the first visible crack was observed at the load of 24.7 ton (55328 lbs). The first cracks initiated from bottom right edge and in the middle simultaneously. Soon, these cracks widened quickly and specimen reached its ultimate failure load of 30.1 tons (67424 lbs). The cracks were mostly vertical in nature. The stress-strain readings were recorded at the regular interval of 5 ton. Strains were quite steady in the beginning, but near failure load, increased very rapidly. The observations regarding stress-strain, cracking and failure load are given in Table-4.19 the graphical representation of Case 4S is given in Fig-4.19.

### 5.7.2 Specimen 4S-B

For the second specimen of Case G, the first crack was observed at a load of 19.2 ton (43008 lbs). The cracks initiated at the top and in the middle of the column simultaneously. The column failed at the load of 24.5 ton (54880lbs). The cracks widened very slowly and the column remained intact while removing from the testing machine. Specimen 4S-B failed at 24.5ton, which is not significant and could be attributed to difference in workman ship. The stress-strain observations, cracking and failure loads are presented in Table-4.20 the graphical representation of specimen 4S-B is shown in Fig-4.20

### 5.7.3 Specimen 4S-C

For third specimen of 'G' series the first crack was observed at the load of 16.4 ton (36736 lbs). This crack was vertical and initiated in the middle and right top edge of the column. The column failed at an ultimate load of 21.7 ton (48608 lbs), which is about 9tons lower than specimen 4S-A. The crack growth was quite fast and near failure they joined each other in the middle. The stress-strain observations, details of cracking and failure loads are shown in Table-4.21 the graphical behavior of Case 4S-C is shown in Fig-4.21

### 5.7.4 Analysis of Case G

From the results of all three specimens, it is clear that two specimens of Case G exhibited almost identical behavior and third specimen has less strength, which can be due to workmanship of small size columns. The average failure load for Case G was calculated as 25.4 ton (56896 lbs). The average stress-strain readings and failure load are presented in Table-. The crack initiation started at about 70 % to 85 % of the failure loads. Major cracks were vertical, however few horizontal cracks were also observed. The cracks widening and propagation was quite fast after their first appearance. The behavior of all three specimens of Case G with respect to the average values are given in Figure-4-37

## 5.8 TESTS OF CASE H

In case H three 4in square Columns were treated with one layer of Ferro cement of 15 mm thick having mortar of 1:2 ratio The construction and application of wire mesh is given in Chapter 3. The axial load was applied at slow rate by the universal testing machine of 200-ton capacity. The capping of top and bottom surface was carried out with thin layer of mortar/plaster of Paris and vertical alignment was adjusted before applying the load. The thickness of encasement increased a little bit at places because the wrapping of wire mesh around the column was difficult and applying mortar over it was a new experience for the mason. However, it was kept within the limits of 5 mm to 8 mm. All three specimens were named as 4S1-A, 4S1-B 4S1-C and observations were recorded for stress strain, at regular interval of 5 ton. The observations of individual specimens are given in succeeding paras.

### 5.8.1 Specimen 4S1-A

After adjusting the vertical alignment, the load was applied at a steady rate. The first crack was observed at 22.1 ton (49504lbs). After this first crack, more cracks appeared with regular interval of 4 to 5 ton. The specimen failed at an ultimate load of 34.1 ton (76384lbs). Most of the cracks initiated from the top and middle and were diagonal in shape. Near failure these cracks joined in the middle, however the crack growth was quite stable and widening rate was much slower as compared to specimens of Case G. This slow rate of crack growth can be attributed to wire mesh presence inside the encasement, which helped in arresting the cracks during their propagation process.

The confinement provided by Ferro cement increased the failure load to 34.1 ton, which is approx 34% higher than the average failure load of control Case G. This was a quite substantial increase in failure load. The specimen was intact and did not break in pieces. The wire mesh was found intact except was loosened at certain places, and cracks were not very wide. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.22 and the graphical representation of Case 4S1-A shown in Fig- 4.22

### 5.8.2 Specimen 4S1-B

The specimen exhibited quite similar failure load to 4S1-A as it failed at an ultimate load of 35.6 ton (79744lbs). This failure load was about 41% higher than the failure load of control Case G. The initial cracks were minor and did not widen with the application of load. However, near failure, these cracks got prominent and most of them were initiated from the top edge and were diagonal in shape. The wire mesh inside was observed yielded at certain places, and small spalling of outer layer of mortar cover took place near failure from top. The specimen was still intact while it was removed from the testing machine. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.23, and the graphical representation of case 4S1-B is also shown in Fig-4.23

### 5.8.3 Specimen 4S1-C

This specimen also exhibited higher failure load of 29.4 ton (65856lbs), which is approx 16% higher than the failure load of control Case G. The first crack was observed at 16.8 ton (37632lbs), which is 57% of its failure load. Initial cracks were minor and did not propagate rapidly. More cracks were observed at the regular interval of 3 to 4 ton, and mostly they were diagonal in shape. These cracks did not widen even at failure and only spalling of outer concrete cover was observed at few places from top and bottom. The wire mesh inside was visible at the places of spalling and looked in perfect shape and no breakage of wire mesh was observed. The bond between the surface of RCC column and Ferro cement encasement was lost at failure and most of the cracks were formed inside the encasement mortar. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.24 and the graphical representation of Case 4S1-C is shown in Fig-4.24

### 5.8.4 Analysis of Case H

The average failure load for Case H was calculated as 33.03 ton (73987 lbs). All the specimens of Case H, showed almost similar results. Increase in the failure loads was quite significant about 30%. Although the first cracking loads were low, but these could be attributed to existing cracks in the mortar. This observation is validated by the fact that these cracks did not propagate rapidly with the increase in load. The mesh inside was believed to control the cracks propagation, therefore no sudden widening of cracks was observed. The bond between the RCC column and Ferro cement encasement was partially broken. The wire mesh inside was observed to be yielded at certain places. The average stress-strain readings and failure loads are presented in Table-4.16. The graphical representation of all the specimens of Case H, with respect to average values is presented in Figure 4.37.

## 5.9 TESTS OF CASE I

In Case I, three 4 in square RCC Columns were treated with two layers of Ferro cement coating and were tested for their compression behavior. The specimens were named as 4S2-A, 4S2-B, 4S2-C, and these were aligned vertically before testing in order to eliminate any eccentricity. The total thickness of Ferro cement encasement was 25mm. Holding the wire mesh at its location and inserting mortar over and inside the wire mesh was a new experience for the mason. Though, extreme care was taken while wrapping and tightening the wire mesh around the column, for which steel Screws were used, still some bulging of wire mesh remained, which required extra mortar thickness to cover it. These specimens were also tested for axial loads through steel plates applied by the universal testing machine of 200-ton capacity. The construction details of the specimens of Case I are given in Chapter 3. With a steady rate, the load was applied and observations were made for stress-strain at the regular interval of 5 ton. The observations for individual specimens are in given succeeding paras.

### 5.9.1 Specimen 4S2-A

The specimen 4S2-A failed at a load of 29.8 ton (66752lbs), which is almost 18% more than the failure load of control Case G. Neither it is a significant increase from simple RCC Column, nor it is comparable with the failure load of specimens of Case H, where only one wire mesh was wrapped inside the mortar. It was expected that with the 2 layers of wire mesh wrapped inside, the confinement effects might increase the failure load further. However, the results did not prove better and it could possibly be due to slackness in the wire mesh at places and increase in thickness of mortar. This problem leads to the premature bond failure of the specimen, which resulted, into spalling of mortar. The first crack was observed at 14.8 ton (33152lbs), but these cracks were minor and did not propagate rapidly with the increase of load. Mostly, cracks were vertical but few horizontal cracks were also observed. One possible reason for such low cracking loads could be the shrinkage effect of thick mortar layer, varying from 10 mm to 15 mm. These cracks were mostly vertical and have local nature, as they did not extend the full length of specimen with increase of load. The mesh inside was also found broken/ loosened at certain places. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.25 and the graphical representation of Case I is shown in Fig-4.25

### 5.9.2 Specimen 4S2-B

The specimen 4S2-B, exhibited failure load of 35.7 ton (79968lbs), which is almost identical to specimen 4S2-A. The effects of loose wire mesh, its bulging and thicker cover was quite evident in this case. The first cracking load was observed as

18.6 ton (41664lbs) and like specimen 4S2-A; these cracks were minor and did not propagate with the increase of load. However, spalling of concrete cover took place from top, which caused premature failure of the specimen. The bond of outer layer of wire mesh was broken well before final failure. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.26, and the graphical representation of Case 4S2-B is shown in Fig-4.26

### 5.9.3 Specimen 4S2-C

The failure load for specimen 4S2-C was 37.8 ton (84672lbs). Like other specimens of this group the possible reason for such low failure load, not contributing the effect of second layer of Ferro cement could be the loose wire mesh, and thick mortar cover which probably caused the early cracks and premature bond failure. The first crack was observed at the load of 22.5 ton (50400lbs), which means that these cracks were pre-existing and became evident with little application of load. These cracks did not extend full length of specimen. Because of bond failure between the mesh and mortar, the composite action could not take place and the failure occurred due to bond failure of encasement and RCC column. The observations regarding the stress-strain, cracking and failure loads are given in Table-4.27 and the graphical representation of Case 4S2-C is shown in Fig-4.27.

### 5.9.4 Analysis of Case I

The average failure load for Case I was calculated as 34.5 ton (77280lbs), which is not very different from the average failure load of Case H, where only one layer of Ferro cement was applied. The loose wire mesh did not participate in load bearing, as bond between mesh, mortar and RCC Column surface was not strong enough to exhibit composite behavior. The thicker Ferro cement layer spalled off with the increasing load and the bulging of wire mesh also caused premature failure. The average stress-strain readings and failure loads are presented in Table-4.20. The graphical representation of all three specimens of Case F, with respect to average values are presented in Figure 4.37

## 5.10 TESTS OF CASE J

In Case J, three 6 in square RCC Columns specimens were tested for their compressive strength and behavior. These three specimens were tested by applying axial load through universal testing machine of 200-ton capacity. Vertical alignment was ensured to minimize/eliminate any eccentricity. The capping of top and bottom surface of the specimen was done with a thin layer of mortar/plaster of Paris and it was ensured that uniformly distributed load is applied through the steel plates placed at the top and bottom of the column. The load was applied at a slow rate and observations regarding stress-stain were recorded at load increment of 5 ton. Three columns of Case J were labeled as 6S-A, 6S-B, and 6S-C. The individual observations of these specimens are given in succeeding paras.

### 5.10.1 Specimen 6S-A

This was the first specimen 6 in square Columns series that was tested. The load was applied at a slow rate and the first visible crack was observed at the load of 63.2 ton (141568lbs). The first cracks initiated from top right edge. Soon, these cracks widened quickly and specimen reached its ultimate failure load of 79 tons (176960 lbs). The cracks were mostly vertical in nature. The stress-strain readings were recorded at the regular interval of 5 ton. Strains were quite steady in the beginning, but near failure load, increased very rapidly. The observations regarding stress-strain, cracking and failure load are given in Table-4.28 the graphical representation of Case 6S is given in Fig-4.28.

### 5.10.2 Specimen 6S-B

For the second specimen of Case J, the first crack was observed at a load of 65 ton (145600lbs). The cracks initiated at the top and in the middle of the column simultaneously. The column failed at the load of 78 ton (174720lbs). The cracks widened very slowly and the column remained intact while removing from the testing machine. The stress-strain observations, cracking and failure loads are presented in Table-4.29 the graphical representation of specimen 6S-B is shown in Fig-4.29

### 5.10.3 Specimen 6S-C

For third specimen of ‘J’ series the first crack was observed at the load of 63.5 ton (142240lbs). This crack was vertical and initiated in the middle and right top edge of the column. The column failed at an ultimate load of 76.6 ton (171584lbs), The crack growth was quite fast and near failure they joined each other in the middle. The stress-strain observations, details of cracking and failure loads are shown in Table-4.30 the graphical behavior of Case 6S-C is shown in Fig-4.30

### 5.10.4 Analysis of Case G

From the results of all three specimens, it is clear that all three specimens of Case J exhibited almost identical behavior The average failure load for Case J was calculated as 77.8 ton (174272lbs). The average stress-strain readings and failure load are presented in Table-. The crack initiation started at about 75 % to 85 % of the failure loads. Major cracks were vertical, however few horizontal cracks were also observed. The cracks widening and propagation was quite fast after their first appearance. The behavior of all three specimens of Case J with respect to the average values are given in Figure-4-37

## 5.11 TESTS OF CASE K

In case K three 6in square Columns were treated with one layer of Ferro cement of 15 mm thick having mortar of 1:2 ratio .The construction and application of wire mesh is given in Chapter 3. The axial load was applied at slow rate by the universal testing machine of 200-ton capacity. The capping of top and bottom surface was carried out with thin layer of mortar/plaster of Paris and vertical alignment was adjusted before applying the load. The thickness of encasement increased a little bit at places because the wrapping of wire mesh around the column was difficult and applying mortar over it was a new experience. However, it was kept within the limits of 5 mm to 8 mm. All three specimens were named as 6S1-A, 6S1-B 6S1-C and observations were recorded for stress strain, at regular interval of 5 ton. The observations of individual specimens are given in succeeding paras.

### 5.11.1 Specimen 6S1-A

After adjusting the vertical alignment, the load was applied at a steady rate. The first crack was observed at 14.01 ton (31392lbs). After this first crack, more cracks appeared with regular interval of 4 to 5 ton. The specimen failed at an ultimate load of 68.1 ton (153216lbs). Most of the cracks initiated from the top and bottom edges and were diagonal in shape. The crack growth was quite stable and widening rate was much slower as compared to specimens of Case J. This slow rate of crack growth can be attributed to wire mesh presence inside the encasement, which helped in arresting the cracks during their propagation process.

The confinement did not improve strength at all, Rather about 12% strength was decreased because of drilling for screws and chipping actions. . The specimen was intact and did not break in pieces. The wire mesh was found broken at no of places. The bond between Ferro cement layer and surface of RCC column was broken well before it reaches its ultimate design strength, and mortar started spalling from top and bottom. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.31 and the graphical representation of Case 6S1-A shown in Fig- 4.31

### 5.11.2 Specimen 6S1-B

The specimen exhibited quite similar failure load to 6S1-A as it failed at an ultimate load of 67.1 ton (150304lbs). This failure load was about 13% lower than the failure load of control Case J. The initial cracks were minor and did not widen with the application of load. However, near failure, these cracks got prominent and most of them were initiated from the top edge and were diagonal in shape. The wire mesh inside was observed yielded at certain places, and huge spalling of outer layer of mortar cover took place near failure from top. The specimen was still intact while it was removed from the testing machine. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.32, and the graphical representation of case 6S1-B is also shown in Fig-4.32.

### 5.11.3 Specimen 6S1-C

This specimen also exhibited failure load of 71.8 ton (160382lbs), which is approx 7% lower than the failure load of control Case J. The first crack was observed at 47 ton (105952lbs), which is 66% of its failure load. Initial cracks were minor and did not propagate rapidly. More cracks were observed at the regular interval of 5 to 7 ton, and mostly they were diagonal in shape. These cracks widened from top edge and big spalling of Ferro cement layer started from top edge. The wire mesh which was quite visible through cracks was also broken at no of places and the bond between RCC Column and Ferro cement layer was completely broken well before it reaches its ultimate strength. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.33 and the graphical representation of Case 6S1-C is shown in Fig-4.33.

### 5.11.4 Analysis of Case K

The average failure load for Case K was calculated as 69.1 ton (154784 lbs). All the specimens of Case K, showed almost similar results. There wasn't any Increase in the failure loads, however about 12% decrease in strength was observed due to screwing and chipping actions. Although the first cracking loads were low, but these could be attributed to existing cracks in the mortar. This observation is validated by the fact that these cracks did not propagate rapidly with the increase in load except from top edge. The mesh inside was believed to control the cracks propagation, therefore no sudden widening of cracks was observed. The bond between the RCC column and Ferro cement encasement was completely broken from top edge. The wire mesh inside was observed to be yield at no of places. The average stress-strain readings and failure loads are presented in Table-4.16. The graphical representation of all the specimens of Case K, with respect to average values is presented in Figure 4.37.

## 5.12 TESTS OF CASE M

In case M three 6 in square Columns were treated with two layers of Ferro cement of 25 mm thick having mortar of 1:2 ratio .The construction and application of wire mesh is given in Chapter 3. The axial load was applied at slow rate by the universal testing machine of 200-ton capacity. The capping of top and bottom surface was carried out with thin layer of mortar/plaster of Paris and vertical alignment was adjusted before applying the load. The thickness of encasement increased a little bit at places because the wrapping of wire mesh around the column was difficult and applying mortar over it was a new experience. However, it was kept within the limits of 5 mm to 8 mm. All three specimens were named as 6S2-A, 6S2-B 6S2-C and observations were recorded for stress strain, at regular interval of 5 ton. The observations of individual specimens are given in succeeding paras.

### 5.12.1 Specimen 6S2-A

After adjusting the vertical alignment, the load was applied at a steady rate. The first crack was observed at 52 ton (116704lbs). After this first crack, more cracks appeared with regular interval of 4 to 5 ton. The specimen failed at an ultimate load of 75.5 ton (169120lbs). Most of the cracks initiated from the top and bottom edges and were diagonal in shape. The crack growth was quite stable and widening rate was much slower as compared to specimens of Case J. This slow rate of crack growth can be attributed to wire mesh presence inside the encasement, which helped in arresting the cracks during their propagation process.

The confinement did not improve strength at all. The specimen was intact and did not break in pieces. The wire mesh was found broken at no of places. The bond between Ferro cement layer and surface of RCC column was broken well before it reaches its ultimate design strength, and mortar started spalling from top edge. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.34 and the graphical representation of Case 6S2-A shown in Fig- 4.34.

### 5.12.2 Specimen 6S2-B

The specimen exhibited about 9 ton less quite similar failure load to 6S2-A, which can be attributed to workmanship, as it failed at an ultimate load of 66.1 ton (148064bs). This failure load was about 15% lower than the failure load of control Case J. The initial cracks were minor and did not widen with the application of load. However, near failure, these cracks got prominent and most of them were initiated from the top edge and were diagonal in shape. The wire mesh inside was observed yielded at certain places, and huge spalling of outer layer of mortar cover took place near failure from top. The specimen was still intact while it was removed from the testing machine. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.35, and the graphical representation of case 6S2-B is also shown in Fig-4.35.

### 5.12.3 Specimen 6S2-C

This specimen also exhibited failure load of 77.1 ton (172704lbs), which is approx equal to failure load of control Case J. The first crack was observed at 55 ton (123648lbs), which is 71% of its failure load. Initial cracks were minor and did not propagate rapidly. More cracks were observed at the regular interval of 5 to 7 ton, and mostly they were diagonal in shape. These cracks widened from top edge and big spalling of Ferro cement layer started from top edge. The wire mesh which was quite visible through cracks was also broken at no of places and the bond between RCC Column and Ferro cement layer was completely broken well before it reaches its ultimate strength. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.36 and the graphical representation of Case 6S2-C is shown in Fig-4.36.

**5.12.4 Analysis of Case M**

The average failure load for Case M was calculated as 72.9 ton (163296 lbs). All the specimens of Case M showed almost similar results except 6S2-B, which was about 9 ton, less due to workmanship. There wasn't any Increase in the failure loads, however about 6% decrease in strength was observed due to screwing and chipping actions. Although the first cracking loads were low, but these could be attributed to existing cracks in the mortar. This observation is validated by the fact that these cracks did not propagate rapidly with the increase in load except from top edge. The mesh inside was believed to control the cracks propagation, therefore no sudden widening of cracks was observed.  The bond between the RCC column and Ferro cement encasement was completely broken from top edge. The wire mesh inside was observed to be yield at no of places. The average stress-strain readings and failure loads are presented in Table-4.16. The graphical representation of all the specimens of Case K, with respect to average values is presented in Figure 4.37.

## 5.13 ANALYSIS OF EXPERIMENTAL RESULTS

The ultimate failure loads and cracking loads of all specimens are presented in Table 4.37. The stress-strain curves based on the average readings of all the cases are shown in Figure 4.37. From the summary of these results, it can be seen that the load carrying capacity of ferrocement coated specimens increased significantly as compared to the load carrying capacity of simple RCC columns, The strength increase in Circular Columns is more than Square Columns. At the same time %age increase in strength due to application of Ferro cement is decreased as the design strength of normal RCC Column increases. It was observed that a significant increase in failure load capacity was achieved with one layer of wire mesh as compared to failure load capacity of 2 layers of wire meshes. The probable reason for this low failure load capacity with 2 layers of wire meshes was due to either the bond failure between the core and casing or the bond failure between the two parallel layers of meshes.

From the results and observations it appears that most likely the failure of coated columns was initiated by the failure of casing due to the combined action of bending moment and the tensile forces in the cross-sectional plane. It was observed that in most of the cases, vertical cracks occurred, which are the indicators of tensile stresses in the casting. It was also observed that columns subjected to compression, tries to increase its lateral dimensions due to Poison's effect. Both casing and core expand latterly, however the casing is restrained from lateral expansion by horizontal strands of wire mesh. The core applies an outward pressure on casing, which subjects the core towards inward confining pressure. The outward pressure by core will cause bending moment as well as tension in the casing. If the bond between casing and core is perfect, the two will try to act together, and some of the bending and tensile stresses of the casing will be shared by the core. Therefore, for a good composite structural action between casing and core, the bond should be maintained till failure. In most of the cases, specially with two layers of wire meshes, it was observed that the bond between core and casing or bond between two parallel layers of wire meshes was not maintained till failure and a local failure occurred due to separation of core and casing or bulging of outer layer.

The load at which the first visible cracks were observed varied over a wide range. For simple RCC specimens these cracks occurred between 70% to 85% of failure loads. For ferrocement coated columns these initial cracks were observed at the early stages of loading. The probable reason for such a low cracking loads for ferrocement coated specimens was the thickness of mortar cover . The excessive mortar thickness applied to cover the bulging mesh layers caused premature cracks. Therefore, designed loads as governed by cracking would be much lower than failure loads. However, the crack growth in the ferrocement coated specimen was stable and these cracks did not widen rapidly as in case of simple RCC specimens.

**Chapter 6**

# COMPARISON OF USE OF FERROCEMENT LAMINATIONS WITH OTHER REPAIR TECHNIQUES

## 6.1 GENERAL

The astronomical increase in the cost of construction has forced the engineers to look for economical and better method for the repair of damaged or distressed structures. A wide range of rehabilitation schemes is used for a variety of structures to under take the rehabilitation. In the recent years Ferro cement is used more and more in the field of rehabilitation and re strengthening of structures.

Ferro cement is an ideal material for rehabilitation and 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 and low cost of construction.

The rehabilitation of structural elements employing Ferro cement is relatively a new aspect of its use. It is now well established that Ferro cement is when used for infrastructure rehabilitation has inherent and unique advantages. Ferro cement possesses a degree of toughness, ductility, durability, strength & crack resistance that is considerably greater than that found in other forms of concrete construction. All these properties achieved within a thickness of about 1-inch (25-mm).

It should be noted that repair using Ferro cement can be the only method, which can be successfully applied, in a wide spectrum of structural types covering essentially all the terrestrial as well as marine applications, while the other forms of rehabilitation methods may be suitable only for a certain types of structures.

An important aspect of Ferro cement which given it distinct advantage over reinforced concrete in certain situations, is its enhanced resistance to cracking which is due to the closely spaced small diameter reinforcement. Enhanced crack resistance combined with high toughness. The ability to be cast into any shape, its rapid constructions with no heavy machinery involved, small additional weight it imposes, and low cost of construction makes it an ideal choice for rehabilitation and re strengthening of the structures.

For many repairs and renovation programs of civil engineering structure, the suitability of Ferro cement is because of the following reasons,

(1) Better cracking behavior

(2) Capability of improving some of the mechanical properties of the treated structures.

(3) Ability to withstand thermal changes very efficiently

(4) Imposition of little additional dead load requiring no adjustment of the supporting structures.

(5) Ability to withstand thermal changes very efficiently.

(6) Ability of achieving waters proofing without providing any surface treatment.

(7) Readily available constituent materials.

(8) No need for special equipment.

(9) Ability to be used in repair program with no distortion or downgrading of the architectural concept of the structures.

(10) Flexibility of further modification

## 6.2 **HOUSING APPLICATIONS.**

Ferro cement has been extensively used in the areas of housing application for the rehabilitation of distressed elements due to overloading, fire damaged beams and columns and general repairs to the deteriorating structures. Following are the various applications of the use of Ferro cement in the area of housing.

### 6.2.1 Rehabilitation of Distressed Beams: -

Beams subjected to aggressive environment, excessive load, improper workmanship and materials, etc. may be in the state of distress and may need to be rehabilitated to improve their service performance to satisfactory level.

### 6.2.2 Repair of Fire Damaged Structural Elements: -

Structures may be subjected to excessively high temperature during the event of a fire. Ferro cement laminates can be used using special repairing techniques.

### 6.2.3 Rehabilitation of Domes and Arches: -

The ability of Ferro cement to fit into curved surfaces makes it an ideal for the rehabilitation of domes and dwells. An example of such rehabilitation is the restoration of domes in the Windmill Theater in the UK.

## 6.3 WATER STORAGE TANKS:

### 6.3.1 **Rehabilitation of Steel tanks:**

Steel water storage tanks are widely used in every part of the world for various purposes especially in the area of housing to provide water for drinking and daily consumption. One predominant problem associated with steel tanks is that of corrosion.

Trikha et. Al. reports the process of repair of damaged steel water tanks using Ferro cement. The process consists of using the existing steel tank as a formwork while a new Ferro cement inner lining is provided to hold water.

## 6.4 **SANITARY STRUCTURE: -**

### 6.4.1 Sewers Relining: -

The process of sanitary sewer relining using Ferro cement to rehabilitate the sewer has already gained wide acceptance wide acceptance in the United Kingdom. In the sewer application it is important to pay attention to the type and porosity of the mortar matrix used. The cement used for mortar should be sulphate resistant.

The acceptance of Ferro cement as a repair material for sewers is largely due to its relative cheapness, flexibility of shape and the fact that it utilizes conventional materials.

### 6.5 Marine Application: -

The use of Ferro cement for the construction and repairs of boats and trawlers has a long history. In fact, the most successful and convincing application of Ferro cement has been in construction/ repairs of boats.

### 6.6 MISCELLANEOUS APPLICATIONS: -

#### 6.6.1 Swimming Pools: -

Ferro cement laminates are popular for the repair of swimming pools because of their excellent crack resisting properties.

#### 6.6.2 Car Repair: -

An unusual, rather interesting repair process for the body of a 30-years-old car damaged by corrosion was reported. Repair was done by patchwork using Ferro cement replacing the corroded portions of the front mudguard of the car.

Chapter 7

# Conclusions and Recommendations

## 7.1 Conclusions.

With the scope of investigation reported in this study on use of Ferro cement as a retrofit material for RCC columns, the following conclusions may be drawn.

- %Age increase in strength after application of Ferro cement layer is greater for circular columns than square columns.
- %Age increase in strength is more for columns having less design strength than having higher strength.
- The use of 2nd layer of Ferro cement did not improve the load bearing capacity unless the bond between this extra layer and the casing and core is maintained till failure.
- There has been upto 12% decrease in actual capacity of RCC columns because of drilling for screws and chipping for proper bonding etc.
- %Age increase in strength after application of Ferro cement layer decreases as the size of columns increases.
- The effect of Ferro cement layer was nil for 6 in square columns, because the bond between the Ferro cement jacket and column core was broken well before the column reaches its design strength and difference between strength of wire mesh /Ferro cement layer and

design capacity of columns was much more as compared to the other sizes of columns.

- The thickness of mortar cover have significant effect on behavior of Ferro cement jacket, it should be maintained 5 –8 mm between each layer .The excessive mortar thickness applied to cover the bulging of wire mesh leads to premature cracking and spalling near failure.
- Fixing of wire mesh have significant effect on ultimate strength, premature failure can occur if wire mesh not properly fixed and mortar not penetrated in it fully, particularly in case of square columns.
- The cracking resistance and stable crack growth mechanism of bare RCC columns is improved quite significantly due to provision of Ferro cement coating.
- The initial cracking loads in Ferro cement coated specimens are low but subsequent growth and widening was controlled as compared to simple RCC columns.
- The effect of Ferro cement layer would becomes nil for circular column having its design strength of 80-tons Or more and for square columns having its design of 78 tons or more.

- **Strains**

  - Columns start yielding at about 85% of ultimate strength.
  - Yielding to failure behavior is almost similar.
  - After failure the stress-strain curve followed the path with steep slope, Which shows that the load carrying capacity is reducing and strains are enlarging at a slow rate.
  - Generally the circular columns without Ferro cement offered more ductility than square columns.
  - After applying one layer of Ferro cement the square columns offered more strain than circular columns, as strength was also increased.
  - The behavior of columns referring $2^{nd}$ layer of Ferro cement was not constant.

## 7.2 Recommendations

- The strength of wire mesh used for Ferro cement coating should be compatible with design strength of RCC columns.
- Use of Ferro cement as a retrofit material should preferably be used only for circular columns.
- If required to be used for square columns special techniques should be adopted for fixing of wire mesh jacket, because it remains loose between edges.

- Clamps instead of screws should be used for fixing of Ferro cement jacket.
- As almost all the columns started failing from the top, extra tightening arrangements should be made at the top and bottom.
- Size and type of wire mesh should be used compatible with design strength of column.
- Full scale testing of the specimens should be carried out for the columns required to be strengthened/retrofitted.
- Square wire mesh should also be tested by wraping it around the specimen in longitudinal direction.
- Ferrocement should also be incorporated in new construction.
- Since ferrocement increases the durability of the structure, it should be used to strengthen the structures facing durability problems e.g. buildings at Pannu Aqil cantonment and coastal area structures.

## 7.3 **Conclusion**

To conclude I would say that ferrocement is a cheaper way of retrofitting the existing damaged/weakened columns. The thickness of wire mesh need to be further investigated for its effectiveness, as for the columns having less designed strength its use is safe but for heavy columns it use need to be further investigated. Different types of wire meshes can be used for research in future for heavy columns to find out their effectiveness. Also the circular columns proved to be more effective than square ones as the wrapping of wire mesh is easy for circular columns.