EXPERIMENTAL STUDY OF FERROCEMENT AS A RETROFIT/STRENGTHENING MATERIAL FOR MASONRY COLUMNS

Thesis
of
Master of Science

By

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This is to certify that the

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Submitted By

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Dedicated to my loving family

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ABSTRACT

Brick masonry columns are common in low or medium rise masonry buildings. These old masonry buildings / 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 brick masonry 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.

Uniaxial compression tests were performed on three bare masonry columns, three brick columns each, coated with unreinforced plaster of mortar ratio 1:5, 1:2 and a total of nine brick columns (3 for each group) coated with ferrocement having 1, 2 and 3 layers of wire meshes. These nine columns were tied with the help of nails around the column. Another nine columns were tested for the same arrangements except that Sikka-Latex, a bonding agent, was used along with nails to observe the behavior. All the specimens were tested for axial loads using universal testing machine. The observations were made for cracking, failure loads and failure patterns. The study demonstrates that the use of ferrocement coating increases the strength of brick masonry columns significantly.

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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 as a rule, is a very slow process and introduction of new material and production methods often take decades. Pakistan, being an under developed country needs to concentrate on saving her energy and resources. This can be effectively done by introducing new technologies in every field of life. With the ever increasing population growth rate, the need for new construction is in high demand. Apart from new construction, there are many old structures of national and local level existing in Pakistan, which demand immediate repair, or else after some time demolishing and reconstruction of these structures will become imminent. Therefore 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 buildings is enhanced.

Masonry has been used since the time immemorial. In Pakistan we find most of the old structures including some bridges are made of brick masonry columns. These structures have lost their durability as regard to safety due to continuous environmental effects, or these do not fulfill the latest ACI code provisions.

Several studies (Ref 2.5) have been carried out to study the problems related to the distressed buildings 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 finding the ferrocement layers as an economical and effective alternative to these methods. Ferrocement, a thin wall cement mortar reinforced with wire mesh is considered to be a very innovative construction material. Among the potential fields of applications of ferrocement the most recommended use is in the field of rehabilitation and repair of old distressed structures.

1.2 AIM OF PRESENT INVESTIGATION

An endeavor has been made to investigate the suitability of ferrocement 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 ferrocement as a rehabilitation and strengthening material.

Research on ferrocement as a retrofit material has been much inclined towards ordinary reinforced concrete columns and no worthwhile work has been done on rehabilitation of brick masonry columns using this technique. Many old distressed buildings have brick masonry columns and need immediate repairs or rehabilitation. The potential encouraging results from this research work can lead to a viable and economic solution for these distressed structures. Ferrocement, 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.

CHAPTER 2

LITERATURE REVIEW AND CONSTRUCTION PROCEDURES

2.1 HISTORY AND DEVELOPMENT

The history of ferrocement 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 ship building, 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 ferrocement 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.

Ferrocement was also accepted by the Italian Navy Registry and the Italian Navy and thus, a number of crafts were built during World War-II. Nervi also pioneered the architectural use of ferrocement in buildings. He built a small store-house of ferrocement 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, ferrocement was used as one of the structural components.

Despite the evidence that ferrocement 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 ferrocement in developing countries. The panel included personnel experienced in research and application of ferrocement 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 ferrocement 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 ferrocement in a logical and effective manner.

The report of the panel first published in early 1973 has had an immense impact on ferrocement applications. The panel identified ferrocement as an overlooked appropriate technology / material with wide potential applications, specially in developing countries. In early 1977, the American Concrete Institute (ACI) had set up Committee 549 (Ref 2.4) on ferrocement to review the present state-of-art and possibly to formulate a code of practice for this material. The committee found out that ferrocement 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 ferrocement concluded that the definition of ferrocement cannot 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:

“ Ferrocement is a type of thin wall reinforced concrete construction where usually hydraulic cement is reinforced with layers of continuous and relatively small diameter mesh. 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 ferrocement 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.

Ferrocement which is specially 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.

Ferrocement 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 labour intensive, it is relatively inexpensive in developing countries.

2.4 APPLICATIONS OF FERROCEMENT

Ferrocement 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 ferrocement can be divided into following broad categories:-

2.4.1 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 labour. Ferrocement, 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 ferrocement 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 ferrocement as a construction material for housing lies in the variety of shapes which it offers for any structure.

2.4.2 Marine Applications

Ferrocement has been adopted 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 ferrocement and how this thin shell of highly reinforced cement mortar can provide a surprisingly strong, yet simply fabricated boat building material. Ferrocement, 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 ferrocement boat manufacturing units produce annual capacity of 600,000 to 700,000 tonnage. Ferrocement 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, ferrocement boats generally conform to western standards. In Hong Kong, India and Sri Lanka, most of the ferrocement crafts constructed are used as mechanized fishing trawlers while in Korea, these are used as fishing boats. In addition, the South Asian Fisheries Development Centre Philippines, uses ferrocement tanks for prawn brood stock and ferrocement buoys for a floatation system. This is the large scale use of ferrocement for these purposes.

2.4.3 Agricultural Applications

Agriculture provides the necessary base for economic growth in developing countries. The use of ferrocement technology can contribute towards solving some of the production and storage problems of agricultural products. Ferrocement 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 ferrocement technology has shown distinct advantages in building silos of ferrocement. They can be made in situ and /or in prefabricated form. Ferrocement is watertight and with appropriate sealants, it can also be made airtight. In an air tight ferrocement bin, respiration of grain or similar products, quickly removes oxygen from the atmosphere inside and replaces it with carbon dioxide. Any insects and aerobic micro-organisms present, cannot survive to cause damage to the stored products. An underground ferrocement lined storage unit has been developed in Ethiopia to replace the traditional unlined storage pits. The use of ferrocement canal lining prevents seepage loss according to the research on the construction techniques and behavior of ferrocement canal lining undertaken at AIT, Thailand (Ref 2.5).

2.4.4 Water and Sanitation Applications

Ferrocement 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.

Ferrocement water tanks of 20 to 2000 gallon capacity are mass produced in India. In India, Thailand and Indonesia, ferrocement 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. Ferrocement septic tanks are in use in Thailand, India, Indonesia, Philippines and Papua New Guinea, while ferrocement toilet bowls have been developed and constructed in Thailand and Bangladesh (Ref 2.5).

2.4.5 Rural Energy Applications

Biogas and solar energy are two alternate sources of energy for the rural areas in which ferrocement 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 ferrocement which lead to a considerable cost reduction. Ferrocement has also been used as a digester lining where bricks are not economically available. Use of ferrocement biogas digester will promote conservation of timberlands and it will encourage farmers to raise livestock providing additional income to the family.

2.4.6 Miscellaneous Applications

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

2.5 CONSTITUENT MATERIALS

A ferrocement 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. A brief description of the materials used for ferrocement is given below in the succeeding paragraphs.

2.5.1 Reinforcing Mesh

One of the essential components of ferrocement is wire mesh. Different types of wire meshes are available almost everywhere. These generally consist of thin wires, either woven or welded into a mesh, but the main requirement is that 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 ferrocement 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.

2.5.1.1 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 ferrocement 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 is excellent but the problem of rusting in open air limits their use.

2.5.1.2 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.

2.5.1.3 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.

2.5.1.4 Expanded Metal Mesh

This is another type of mesh sometimes used in ferrocement 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.

2.5.1.5 Watson Wire Mesh

This mesh consists of straight high tensile wires and a 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 has 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.

2.5.1.6 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.

2.5.2 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 ferrocement is known as mortar. It is normally made of Portland cement and ordinary silica sand. Cement in the presence of water reacts to form cementitious 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 ferrocement construction.

2.5.2 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 ferrocement 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.

2.5.4 Admixtures

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 (Ref 2.5) in ferrocement 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 ferrocement 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.

2.5.5 Water

The quality of water for the mixing of mortar has vital effect on the resulting hardened ferrocement. 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. Sea water 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.

2.5.6 Coatings

In general, ferrocement 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.

2.5.7 Mortar mix

The reaction of Portland cement and water results in formation of hardened cement paste. The ranges of mix proportions recommended for common ferrocement 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.

2.6 CONSTRUCTION PROCEDURES

Ferrocement construction unlike other sophisticated engineering construction requires minimum skilled labour and it utilizes readily available materials. The basic material required for ferrocement 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 ferrocement construction techniques can easily be acquired and requisite quality control can be achieved using fairly unskilled labour for the fabrication under the supervision of a skilled foreman. The most important advantage of ferrocement is that it can be fabricated into almost any desired shape to meet the user needs.

The four major steps in ferrocement 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.

2.6.1 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 ferrocement varies 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 ungalvanized 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.

2.6.2 Mortar preparation

The proportion of the mix are 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 0.40 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.

2.6.3 Plastering

Plastering is often considered as the most critical phase in the whole ferrocement 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 plaster work. 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 form work 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 (Ref 2.5). 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.

2.6.3.1 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.

2.6.3.2 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.

2.6.3.3 Sectional Plastering

When undertaking the plastering operation of large ferrocement 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.

2.6.3.4 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 troweled for a very smooth finish. If a rough surface for subsequent painting is required, a sponge should be used.

2.6.4 Curing

In order to obtain a good quality hardened mortar, the placing and compaction of the mortar must be followed by curing in a suitable environment during the early stages of hardening. 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 space occupied by water in the fresh cement paste has been filled by the products of hydration of cement. 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 ferrocement structure.

2.6.5 Coatings

Generally the adequately plastered ferrocement structures need no protection unless exposed to severe environmental conditions. The paint work 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 ferrocement 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 ferrocement.
- 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 labour.
- 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 3

SPECIMENS CASTING AND MATERIAL DETAILS

3.1 AIM

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

3.2 RESEARCH METHODOLOGY

Among the available coating procedures, a thin overlay of ferrocement has been suggested for use with unreinforced masonry columns, that require in-plane and out of plane strengthening. This investigation deals with the compressive behavior of masonry columns coated with ferrocement. A total of 27 masonry columns were constructed (Ref Fig 3.1) and treated with different encasement cases. The size of the masonry column was kept as 9 inch x 9 inch x 9 inch. The specimen were divided into 9 groups and for each group three columns were constructed. These specimens were moist cured and air dried in the laboratory for three weeks each (Ref Fig 3.2). The testing was conducted after six weeks for all the specimens. For the identification purpose the nine 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.

3.3 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 (Ref Fig 3.3). 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 was done with the help of two compressometers attached to the specimen with the help of proving rings. One compressometer each was attached on the opposite faces of the specimen to record the vertical strains. The readings were taken at the loading increment of 1 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

3.4 PREPARATION OF SPECIMENS

The experimental investigation was carried out for nine different groups of columns. Each group consisted of three columns and each group was labeled in alphabetic order for identification purpose. The original masonry columns were constructed using mortar ratio of 1: 4. The construction details (Ref Fig 3.4 to 3.10) of each group is given below:-

3.4.1 Case A Simple Brick Masonry Columns

Three simple brick masonry columns were constructed with mortar ratio of 1: 4 , and labeled as A11, A12 and A13. 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 ferrocement encasement.

3.4.2 Case B Simple Plaster Column With Mortar Ratio 1: 5

Simple plaster of 1: 5 ratio was applied on three masonry columns, in order to see the beneficial effects of simple plastering. These columns were labeled as B11, B12 and B13. The mortar ratio 1: 5 is commonly used for plastering. Same observations were made during the testing as for Case A.

3.4.3 Case C Simple Plaster Columns With Mortar Ratio 1 : 2

In case C, columns were coated with rich mix of ratio 1: 2. This case was prepared to evaluate the difference caused by rich mix. Columns were labeled as C11, C12 and C13 and during testing, observations were made for cracking, failure load, cracking pattern and vertical strains.

3.4 .4 Case D Ferrocement Coated Columns With 1 Layer of Wire Mesh

In Case D, three masonry columns were coated with ferrocement encasement having one layer of wire mesh in it. Initially a mortar of 0.2 inch (5 mm) thickness was applied on the specimen and the mesh layer was wrapped around the column and bonded with the help of nails. Three nails each were placed on all four faces of the column. It was ensured that the mesh is wrapped tightly and sticks firmly to the initially applied mortar on the surface of brick column. A cover of 0.2 inch (5 mm) mortar was provided on the outer side of mesh to give it a smooth finish. The mortar ratio 1:2 was used for ferrocement encasement. The columns of Case D were labeled as D11, D12 and D13.

3.4.5 Case E Ferrocement Coated Columns With 2 Layers of Wire Mesh

In Case E, three masonry columns labeled as E11, E12 and E13, were coated with two layers of wire mesh wrapped with the help of nails. Initially, a mortar cover of 5 mm was applied on the surface of brick columns and over that first layer was wrapped tightly and nailed to it. After that a cover of 0.2 inch (5 mm) was given over the first layer and while the mortar was still in green form, second layer was wrapped arround it and nailed to the surface, finally a mortar cover of 0.2 inch (5mm) was provided to give it a smooth finish. The total thickness of encasement was 0.5 to 0.7 inch (15 to 18 mm). The mortar ratio was kept as 1: 2.

3.4.6 Case F Ferrocement Coated Columns With 3 Layers of Wire Mesh

In this case three masonry columns labeled as F11, F12 and F13 were coated with three layers of wire mesh wrapped with nails. Like Case E, a mortar thickness of 0.2 inch (5 mm) was applied on the surface of brick specimens and all three layers were wrapped in the similar manner as stated for Case D and E. A mortar cover of 0.2 inch (5 mm) was applied between and on the outer surface of the specimens. With three meshes wrapped inside and mortar cover of 0.2 inch (5 mm) on either side of mesh, the total thickness of ferrocement encasement became about 0.78 to 0.90 inch (20 to 23 mm). Wrapping and holding three layers of wire mesh was the difficult part of construction. It was done with great care to ensure that minimum cover is provided without letting the cross section of the column extend beyond the desired limits (minimum 5 to 8 mm cover is desired). The mortar ratio for forrerocement encasement was kept as 1: 2.

3.4.7 Case G Ferrocement Coated Columns With 1 Layer of Wire Mesh and Bonded With Sikka-Latex

In Case G, three masonry columns were coated with ferrocement having one layer of wire mesh inside. In addition to nails, a bonding agent “Sikka-Latex” was also used to create better bond between brick masonry and ferrocement coating. All the construction procedures were similar to Case D, except the application of Sikka-Latex. This bonding agent was prepared according to prescribed ratios and applied with the help of simple brush on the rough and dry surface of the brick columns before applying the first initial coat. While Sikka latex was still wet, the initial mortar cover of 0.2 inch (5 mm) was applied over it. Sikka-Latex was also applied between the layers before applying the subsequent mortar cover. The technical details and properties of Sikka latex are given in section 3.5.6. These three columns were labeled as G11, G12 and G13. The mortar ratios for encasement was also kept 1:2.

3.4.8 Case H Ferrocement Coated Columns With 2 Layers of Wire Mesh and Bonded With Sikka-Latex

Case H was similar to case E, except that in case H, bonding agent Sikka-Latex was used to create better bond between masonry column and encasement. All the other constructional procedures were the same as that for Case E. It was considered that a better bond between two materials will enable the column to act as a composite structure and a better in-plane and out of plane action will occur. The columns of Case H were labeled as H11, H12 and H13.

3.4.9 Case I Ferrocement Coated Columns With 3 Layers of Wire Mesh and Bonded With Sikka-Latex

Case I was similar to Case F, except the application of bonding agent Sikka-Latex in addition to nails for better bond between masonry columns and ferrocement encasement. The columns of Case I were labeled as I11, I12 and I13.

3.5 TESTING OF MATERIAL

Ferrocement 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, ferrocement 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 ferrocement 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.

3.5.1 Fine Aggregate

. Normal weight sand is the most common aggregate used in ferrocement. 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 (Ref Table-3.2). 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. These result suggests that the sand was well graded (SW).

3.5.2 Bricks

All the bricks were obtained from one source and test was carried out to determine the average compressive strength and water absorption characteristics. The mean compressive strength of bricks was found as 1616 psi and water absorption was noted as 19 % (Ref to Table-3.3).

3.5.3 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 rupture load was found as 24 kg (52.8 lbs). Similarly, the value of yield strength and ultimate strength were observed as 33528.8 psi and 50287.7 psi respectively.

3.5.4 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 sea water, 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-3.4.

3.5.5 Nails

Normal steel nails were used to tie the wire mesh around the masonry column.

3.5.6 Bonding Agent, Sikka Latex

Sikka-Latex was used in some 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.

3.5.7 Mix Proportion and W/C Ratio

The mix proportion for all masonry work was kept as 1:4 (cement : sand) and for all coatings less Case B, for simple plaster and ferrocement a ratio of 1: 2 was used. The mix proportion for Case-B was kept as 1: 5 for plastering, where simple plastering was done over the masonry columns. As desired, the w/c ratio was kept as low as is 0.25/ 0.3.

LIST OF OPS ROOM ACCESSORIES

S/No	Item	Qty	Remarks
1.	Monitor Samsung DT 15 HM DN 825 175 Z (incl CPU 50x Mare, Key Board, Mouse & 3x leads)	1 each	
2.	Monitor Samsung DT 15 HMDN 5251189 Y (incl CPU Model no. 5508, Key Board, Mouse & 3x leads)	1 each	
3.	Paper Shredder Model T-22 X	01	
4.	Printer Color (incl 1x Sup & 1x Power lead)	01	
5.	BPS Panasonic (CD Remote Control,, 3x leads & adjusting plate)	1 each	
6.	UPS (incl 2x battery & 1x trolley)	01	
7.	Scanner (1x lead power sup)	01	
8.	Video Camera (1x battery)	01	
9.	Magnabyte (Remote Control & ax power sup lead)	01	
10.	Camera YASHICA	01	
11.	Zib Deliver (incl 3x leads & Manual)	01	
12.	Camera SONY (1x power sup lead & Manual)	01	

CHAPTER 4

TEST RESULTS AND DISCUSSION

4.1 TESTS OF CASE A

In Case A, three brick masonry 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 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 1 ton. Three columns of Case A, were labeled as A11, A12 and A13. The individual observations of these specimens are given in succeeding paras.

4.1.1 Specimen A11

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 8.5 ton (19040 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 13.95 ton (31248 lbs). The cracks were mostly vertical in nature and through the mortar joints. The stress-strain readings were recorded at the regular interval of 1 ton. Strains were quite steady in the beginning, but near failure load, increased very rapidly.

While removing from the testing machine the specimen broke in pieces. The observations regarding stress-strain, cracking and failure load are given in Table-4.1. The graphical representation of Case A11 is given in Fig-4.1.

4.1.2 Specimen A12

For the second specimen of Case A, the first crack was observed at a load of 11.25 ton (25200 lbs). The cracks initiated at the top, bottom and nearly in the middle of the column simultaneously. The column failed at the load of 15.47 ton (34675 lbs). The cracks widened quite quickly and the column broke in pieces while removing from the testing machine. Specimen A12 failed at 15.47 ton load, (1.5 ton higher than specimen A11) 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 A12 is shown in Fig-4.1.

4.1.3 Specimen A13

For third specimen of 'A' series the first crack was observed at the load of 10.2 ton (22848 lbs). This crack was vertical and initiated in the middle and right bottom edge of the column. The column failed at a ultimate load of 15.6 ton (34944 lbs), which is quite similar to the failure load of specimen A12. The crack growth was quite fast and near failure they joined each other in the middle. Most of the cracks were through the mortar joints, however quite a number of bricks were also found broken. The stress-strain observations, details of cracking and failure loads are shown in Table-4.3. The graphical behavior of Case A13 is shown in Fig-4.1.

4.1.4 Analysis of Case A

From the results of all three specimens, it is clear that all three specimens of Case A exhibited almost identical behavior. The failure loads were generally identical. The average failure load for Case A was calculated as 15.0 ton (33622.5 lbs). The average stress-strain readings and failure load are presented in Table-4.4. The crack initiation started at about 60 % to 70 % of the failure loads. Major cracks were vertical, however few horizontal cracks were also observed. The vertical cracks passed through the joints and bricks, while horizontal cracks were through joints only. 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-4.1.

4.2 TESTS OF CASE B

In Case B, three masonry columns (B11, B12, B13) were coated with simple mortar of ratio 1:5. Like Case A, all specimens of Case B were tested under axial load applied through same universal testing machine of 200 ton. The capping at the top and bottom of the columns was done with great care to eliminate any eccentricity. It was ensured that load is applied gradually and is uniformly distributed. The mortar ratio of 1:5 is commonly used for plastering, so these specimens were coated with simple plaster to observe its effects. The thickness of encasement was kept 5 mm around the columns. The load was applied at slow rate and stress-strain observations were recorded at regular interval of 1 ton. The observations for individual specimens are given in succeeding paras.

4.2.1 Specimen B11

The first crack was observed at the load of 14.6 ton (32704 lbs), and the column failed at an ultimate load of 21.95 ton (49168 lbs). The first crack initiated at 66 % of ultimate load, which is somewhat similar to Case A. The cracks initiated from the edges and were mostly diagonal in nature. They widened rapidly and near failure spalling of concrete took place. The failure load of 21.95 ton shows an increase of approx 46% as compared to the average failure load of Case A (control specimens). The observations taken for stress strain, cracking and failure loads are presented in the Table 4.5. The graphical representation of B11 is shown in Fig- 4.2.

4.2.2 Specimen B12

The load for the first visible crack was 11.05 ton (24752 lbs). This column failed at an ultimate load of 21.3 ton (47712 lbs), which is quite similar to first specimen of Case B. The cracks initiated at the edges and propagated diagonally, however a main vertical crack opened in the middle and passed through the brick joints. These cracks widened rapidly and near ultimate load spalling took place (Ref Fig 4.12). The observations taken for stress–strain, cracking and failure loads are presented in the Table 4.6. The graphical representation of B12 is shown in Fig-4.2.

4.2.3 Specimen B13

The cracking load for this specimen was 10.75 ton (24080 lbs). The column ultimately failed at 19.2 ton, which is about 13% lower than the previous two specimens of Case B. This could be attributed to poor workmanship. The cracks, mostly vertical in nature, initiated from the top and bottom simultaneously. These cracks passed through the brick joints and near ultimate loads joined in the middle. The spalling of concrete also took place at failure (Ref Fig- 4.13). The observations taken for stress–strain, cracking and failure loads are presented in the Table 4.7. The graphical representation of B12 is shown in Fig- 4.2.

4.2.4 Analysis of Case B

The results of all specimens of Case B, clearly suggest that simple mortar ratio of 1:5 can increase the failure loads upto 38%. However, it has no effect on cracks and their growth as the crack growth is as rapid as in Case A. The cracks generally started at about 60% of failure loads. The average failure load of Case B was calculated as 20.8 ton (46629 lbs). Spalling was observed in all the specimens near ultimate load. The average stress-strain readings and failure load are presented in Table-4.8. The graphical representation of all three specimens of Case B, with respect to the average values are shown in Figure 4.2.

4.3 TESTS OF CASE C

In Case C, three brick masonry columns (C11, C12, C13) were coated with rich mortar of 1:2 ratio. These specimens were prepared to study the effects of rich mix. The construction and application method was same as of Case B. The capping at the top and bottom surface of the specimens was carried out with a thin layer of mortar. Before applying load, vertical alignment was set to ensure that uniformly distributed load is applied through the universal testing machine. The thickness of encasement was kept 5 mm around the columns. The load was applied at a slow rate and observations were recorded for stress-strain, at regular interval of 1 ton. The observations of individual specimens are given in succeeding paras.

4.3.1 Specimen C11

The first specimen of Case C, exhibited higher failure load as compared to previous two cases and it failed at 25 ton (56000). This is approx 66% higher than the controlled specimen of brick masonry. Comparing with the results of Case B, where mortar had ratio as 1:5, the failure load capacity of Case C11 increased by approx 20%. This is a worthwhile increase which was achieved by just changing the mortar ratio from 1:5 to 1:2. The first crack appeared at the load of 14.25 ton (31920 lbs), which is about 57% of its failure load. These cracks initiated at the top and bottom edges of the specimen, however a major vertical crack appeared in the middle and widened through the central brick joint. The growth of cracks was relatively stable as compared to Case A and Case B. The column broke in pieces while it was removed from the testing machine. The observation taken for stress–strain, cracking and failure loads are presented in the Table 4.9. The graphical representation of C11 is shown in Fig- 4.3.

4.3.2 Specimen C12

The failure load observed for specimen C12 was 25.3 ton (56672 lbs), which is quite similar to the specimen C11. This result further proved the credibility and benefits of using rich mix for plastering. The increase percentage of failure loads are similar to specimen C11. The first crack was observed at 12.6 ton (28224 lbs), which is approx 50% of failure load. This indicates that cracking load limit decreases with increasing failure loads. Mostly the cracks were vertical and started from the top and bottom edges and near failure joined in the middle. These cracks passed through the brick joints in the middle, and widened at very fast rate near failure load (Ref Fig-4.14). The spalling of concrete cover started near failure load and the specimen also broke while being removed after the testing. The observations taken for stress-strain, cracking and failure loads are presented in the Table 4.10. The graphical representation of C12 is shown in Fig-4.3.

4.3.3 Specimen C13

This column failed at an ultimate load of 25.7 ton (57568 lbs), which is almost identical to other two specimens of Case C. The first crack was observed at 9.7 ton (21728 lbs), which is 38% of failure load. After the first crack, the subsequent cracks occurred at regular intervals of 3 to 4 ton, until the specimen failed. The crack growth was a bit stable as compared to Case A and Case B. The spalling of concrete cover took place near maximum load. However, with the first cracks appearing at lower loads, it shows that the design loads governed by cracking would be lower than the failure loads. One possible reason for such lower cracking loads could be the shrinkage being caused by rich mix. The specimen C13 broke in pieces while it was being removed from testing machine. The observations taken for stress–strain, cracking and failure loads are presented in the Table 4.11. The graphical representation of C13 is shown in Fig-4.3.

4.3.4 Analysis of Case C

As expected, the specimens of Case C exhibited fairly good results in terms of higher failure loads. The average failure load was calculated as 25.33 ton (56746.5 lbs). This clearly shows a worthwhile increase of about 70% from the average failure load of controlled specimens of Case A. Also a 40% increase of failure load was observed from Case B, where mortar ratio 1:5 was used. This proves that the mix ratio used for the plastering also plays a significant role in strengthening the brick columns. However, the first cracking loads were observed at about 50% of the failure load, which is lower than the specimen of Case A and B. The possible reason for these lower cracking loads could be the shrinkage caused by rich mix. The bond between bricks and mortar was lost near failure loads as spalling was observed in all the specimens. The average stress-strain readings and failure load are presented in Table-4.12. The graphical representation of all three specimens of Case C, with respect to average values are presented in Figure 4.3.

4.4 TESTS OF CASE D

In Case D, three brick columns were covered with one layer of ferrocement wire mesh and covered with 5 mm mortar of 1 : 2 ratio. The construction and application of the 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 and vertical alignment was adjusted before applying the load. The mortar ratio was kept 1:2 for ferrocement and the thickness of encasement was kept 10 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 ferrocement, having one wire mesh wrapped inside. All three specimens were named as D11, D12, D13 and observations were recorded for stress strain, at regular interval of 1 ton. The observations of individual specimens are given in succeeding paras.

4.4.1 Specimen D11

After adjusting the vertical alignment, the load was applied at a steady rate. The first crack was observed at 4.75 ton (10640 lbs). After this first crack, more cracks appeared with regular interval of 4 to 5 ton. The specimen failed at an ultimate load of 30.2 ton (67648 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, B and C. 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, but no significant spalling was observed.

The confinement provided by ferrocement increased the failure load to 30 ton, which is approx 100% higher than the average failure load of control Case A. The increase from the failure load of Case B and C is approx 45% and 20% respectively. This was a quite substantial increase in failure load. The specimen was intact and did not break in pieces like Case A and B. The wire mesh inside was in good shape and cracks were not very wide. It was observed that this column could be repaired with grouting process. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.13, and the graphical representation of Case D11 shown in Fig- 4.4.

4.4.2 Specimen D12

The specimen exhibited quite high failure load as it failed at an ultimate load of 38.45 ton (86128 lbs). This was a significant increase in failure load as compared to all the previous specimens. This failure load was about 156% higher than the failure load of control Case A and 84% and 52% higher than the failure load of Case B and C respectively. 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 bottom edge and were diagonal in shape (Ref Fig-4.15). The wire mesh inside was observed intact, however small spalling of outer layer of mortar cover took place near failure. The specimen was still intact while it was removed from the testing machine. It was observed that this column could be repaired by grouting or pumping of concrete. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.14, and the graphical representation of case D12 is also shown in Fig-4.4.

4.4.3 Specimen D13

This specimen also exhibited higher failure load of 36.55 ton (81872 lbs), which is approx 144% higher than the failure load of control Case A. Similarly it is significantly higher than the failure loads of Case B and C. The first crack was observed at 18.25 ton (40880 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. 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 brick column and ferrocement encasement was lost at failure and most of the cracks were formed inside the encasement mortar. The column was intact and could possibly be repaired with grouting or pumping of concrete. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.15, and the graphical representation of Case D13 is shown in Fig-4.4.

4.4.4 Analysis of Case D

The average failure load for Case D was calculated as 35.06 ton (78549.5 lbs). All the specimens of Case D, showed different results. The specimen D11 failed at 30.2 ton (67648 lbs) and specimens D12 and D13 failed at the loads of 38.45 ton (86128 lbs) and 36.55 ton (81872 lbs) respectively. These different failure loads are indicative of the workmanship problems of ferrocement. Though, ferrocement does not require any special technique or skill, still it is not very common practice in the country, so masons find it a bit difficult to work with wire mesh and mortar simultaneously. Nevertheless, increase in the failure loads were significant. 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 brick column and ferrocement 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 D, with respect to average values are presented in Figure 4.4.

4.5 TESTS OF CASE E

In Case E, three ferrocement coated brick masonry columns were tested for their compression behavior. The specimens were named as E11, E12, E13 and these were aligned vertically before testing in order to eliminate any eccentricity. The total thickness of ferrocement encasement varied from 15 mm to 20 mm. 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 E 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 1 ton. The observations for individual specimens are in given succeeding paras.

4.5.1 Specimen E11

The specimen E11 failed at a failure load of 30.55 ton (68432 lbs), which is almost 100% more than the failure load of control Case A. Though it is a significant increase from simple brick masonry, but it is not comparable with the failure load of specimens of Case D, 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 (Ref Fig-4.16). The first crack was observed at 5.75 ton (12880 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 5 mm to 8 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-4.17, and the graphical representation of Case E11 is shown in Fig-4.5.

4.5.2 Specimen E12

The specimen E12, exhibited even lower failure load of 25.35 ton (56784 lbs), which is surely not the true result of this kind of encased column. The effects of loose wire mesh, its bulging and thicker cover were quite evident in this case. The first cracking load was observed as 8.6 ton (19264 lbs) and like specimen E11, 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 outer layer of wire mesh was intact alongwith the overall column after failure. It was observed that a repair was possible with the help of grouting. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.18, and the graphical representation of Case E12 is shown in Fig-4.5.

4.5.3 Specimen E13

The failure load for specimen E13 was 27.75 ton (62160 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 4.6 ton (10304 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 brick column. The observations regarding the stress-strain, cracking and failure loads are given in Table-4.19, and the graphical representation of Case E12 is shown in Fig-4.5.

4.5.4 Analysis of Case E

The average failure load for Case E was calculated as 27.88 ton (62458.50 lbs), which is not very different from the average failure load of Case C, where simple plaster of 1:2 was applied. The loose wire mesh did not participate in load bearing as bond between mesh, mortar and brick surface was not strong enough to exhibit composite behavior. The thicker plaster cover 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 E, with respect to average values are presented in Figure 4.5.

4.6 TESTS OF CASE F

In Case F, three brick masonry columns were coated with ferrocement having three layers of wire mesh wrapped inside. These specimens were named as F11, F12 and F13. The construction procedure of these specimens is given in Chapter 3. The wrapping of three wire mesh layers and application of mortar cover within the prescribed limits of 5 mm to 8 mm was a difficult task. The total thickness of encasement varied between 20 mm to 25 mm, however at places more thickness was required to cover the bulging wire mesh. The capping at the top and bottom surface of specimen was done with a thin layer of mortar and columns were aligned vertically before applying the axial load. The strain readings towards the end of maximum loads were quite erratic and the probable reason for that was the use of smaller steel plates (size of steel plates was 9 inch by 9 inch i.e. equal to the size of original brick column) being used for the application of load. These smaller plates caused punching effects at the ends. However, for all other cases, plate of bigger size was used. The loads were applied at the steady rate and observations were made for stress-strain, cracking and failure loads. The individual observations of Case F are given in succeeding paras.

4.6.1 Specimen F11

This specimen failed at the load of 30.25 ton (67760 lbs). The problem of loose wire mesh, specially the outer layers, caused premature failure of the specimen. The first crack was observed at 13.25 ton (67760 lbs), which is approx 46% of failure load. The subsequent growth of these cracks was quite stable and mostly the cracks initiated near edges, specially in the region of brick column surface and encasement joint. It was observed that near failure, the surface cracks between brick column and ferrocement encasement got widened, thus indicating bond failure. Therefore, because of this bond failure between brick column surface and ferrocement encasement, composite behavior could not develop and the specimen failed at 30.25 ton. The spalling of outer concrete cover was observed, however the wire mesh inside was intact and in good shape. The repair work seemed possible with the grouting. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.21, and the graphical representation of Case F11 is also in Fig- 4.6.

4.6.2 Specimen F12

The specimen failed at the load of 29.15 ton (65296 lbs). The first crack was observed at 17.65 ton (39536 lbs). The crack growth was stable/gradual and mostly cracks initiated from the bottom edge and were vertical. At failure load a major wide crack was observed at the joint of brick column surface and encasement, indicating bond failure (Ref-Fig 4.17). The composite behavior did not take place in this case as well, and spalling of outer layer of concrete was observed near failure. The wire mesh inside was intact. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.22, and the graphical representation of Case F12 is shown in Fig-4.6.

4.6.3 Specimen F13

This specimen exhibited even lower failure load of 28.25 ton (63280 lbs). The first crack was observed at 14.6 ton (32704 lbs), which is approx 50% of its failure load. The cracking pattern observed in this case also suggested that an in plane and out of plane composite behavior between brick column and ferrocement encasement could not take place. The bond was lost between brick column and encasement, therefore the specimen failed with hardly any confinement effects of ferrocement. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.23, and the graphical representation of Case F12 is shown in Fig-4.6.

4.6.4 Analysis of Case F

The average failure load calculated for Case F was 29.25 ton (65445.35 lbs). The use of smaller steel plates caused punching effects, which are quite visible in the graphic representation. After analysis of all these specimens, it was quite evident that for a proper composite behavior of ferrocement coated columns, the bond between brick column surface and wire mesh layers has to be very strong. In case of poor bond, the application of load causes the original column to take load independently without any contribution from the ferrocement. The average stress-strain readings and failure loads are presented in Table-4.24. The graphical representation of all these specimen of Case F with respect to average values are shown in Figure 4.6.

4.7 TESTS OF CASE G

In Case G, three brick masonry columns were coated with ferrocement having one layer of wire mesh wrapped inside. But in this case, a bonding agent called Sikka-Latex was used in addition to nails for the better bond between brick column surface and ferrocement casing. The procedure of construction and application of Sikka-Latex is given in Chapter 3. The capping at the top and bottom surface was carried out with a thin layer of mortar and vertical alignment was adjusted before applying the load. The thickness of the ferrocement encasement was kept 10 mm. All three specimens were named as G11, G12, G13 and observations were recorded for stress-strain, at the regular interval of 1 ton. The observations of individual specimens are given in succeeding paras.

4.7.1 Specimen G11

This specimen failed at the load of 33.7 ton (75488 lbs), which is approximately 125% more than the failure load of control Case A. This result is comparable to the average failure load of Case D, where one layer of wire mesh was used and bonded with the help of nails only. This is indicative of the fact that no significant benefit is achieved in terms of failure load capacity with the application of Sikka-Latex. The first crack was observed at 6.5 ton (14896 lbs), which was at lower loads, but the crack growth was very stable and these cracks did not widen too much even at failure. The application of Sikka-Latex was helpful in keeping the encasement intact as no spalling of outer concrete cover occurred. The whole specimen was intact at failure and mesh inside was not visible anywhere. Most of the cracks were small in size and had a somewhat jagged appearance. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.25, and the graphical representation of Case G11 is shown in Fig-4.7.

4.7.2 Specimen G12

This specimen failed at 39.15 ton (87696 lbs), which is approximately 160% more than the control Case A. It is even more than the failure load of all specimens of Case D. This is indicative of the fact that with proper wrapping of wire mesh and good workmanship in application of bonding agent, the results can be higher/encouraging than what was achieved in the previous cases. The first crack was observed at 10.25 ton (22960 lbs). The growth of these cracks was very slow and most of them were of local nature as they did not propagate beyond 7 to 8 inches. Maximum cracks initiated from the middle and made jagged appearance. Few vertical cracks initiated from the bottom but did not propagate. No spalling was observed and the entire specimen was intact with the wire mesh. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.26, and the graphical representation of Case G12 is shown in Fig-4.7.

4.7.2 Specimen G13

This specimen failed at 36.25 ton (81200 lbs), which is approximately 142% more than the failure load of Case A. No significant increase in load capacity was observed as compared to the similar Case D (without Sikka-Latex). However, use of

Sikka-Latex was helpful in keeping the specimen intact, as no spalling of concrete occurred. The cracks were mostly vertical and small in size and did not extend through the entire length of the column (Ref Fig-4.18). It was observed that after failure the specimen could be repaired with suitable grouting procedures. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.27, and the graphical representation of Case G13 is shown in Fig-4.7.

4.7.3 Analysis of Case G

The average failure load was calculated as 36.36 ton (81461.56 lbs), which is significantly higher than the failure load of the controlled Case A. Although the use of Sikka-Latex did not help in increasing the failure load capacity but it was effective in controlling the spalling of concrete cover. No spalling was observed in all specimens and the cracks were also localized as they did not propagate much. The cracks were mostly diagonal and horizontal and made jagged appearance in the middle. The average stress-strain readings, cracking and failure loads are presented in Table 4.28. The graphical representation of all three specimens of Case G with respect to the average values are shown in Figure 4.7.

4.8 TESTS OF CASE H

Case H consisted of three brick masonry columns encased with ferrocement having 2 wire mesh layers wrapped and bonded with the nails and Sikka-Latex. The details about its construction and application of Sikka-Latex are given in Chapter 3. These specimens were named as H11, H12, H13 and load was applied at a steady rate through universal testing machine of 200 ton capacity. The observations were recorded for stress-strain at the regular interval of 1 ton. The observations of individual specimens are given in succeeding paras.

4.8.1 Specimen H11

This specimen exhibited lower failure load of 28.55 ton (63952 lbs), which is approximately 91% higher than failure load of control Case A. But nevertheless, it was less than the failure load of Case D and G. The cracking started at 4.25 ton, which was in the early stages of load application. The crack growth was quite stable in the beginning but near failure, bond appeared to be lost between two wire mesh layers and brick column. This bond failure lead to the low failure load of this specimen. The cracks appeared to widen at the brick surface and encasement joints. The mesh inside was intact and no spalling was observed. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.29, and the graphical representation of Case H11 is shown in Fig-4.8.

4.8.2 Specimen H12

This specimen failed at 36 ton (80640 lbs), which is 140% higher than the failure load of Case A. It is about 26% higher than the failure load of specimen H11. This clearly indicates that if the wire mesh is wrapped properly and good bond is maintained, these higher failure loads can be achieved. The cracks initiated from the bottom edges and they were few in number and mostly vertical. It was observed that the thickness of the mortar cover played an important part in controlling the crack propagation and maintaining the bond between the layers of wire mesh and between the brick surface. The minimum thickness of 5mm was difficult to maintain, especially when more wire meshes were to be wrapped. No spalling was observed and overall specimen was intact with wire mesh inside (Ref-Fig 4.19). This specimen could possibly be repaired with the grouting procedures. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.30, and the graphical representation of case H12 is shown in Fig-4.8.

4.8.3 Specimen H13

This specimen exhibited lower failure load of 25.25 ton (56560 lbs). This was most probably due to bond failure. The extra mortar cover applied to cover the two layers of mesh lead to early initiation of cracks and bond failure between the two layers. Most of the cracks were vertical and at the location of layer joints. The application of Sikka-Latex was effective only in maintaining bond between brick column and first mortar layer, the subsequent mortar layers lost the bond near failure. The possible reason for this bond failure was the extra mortar applied for covering the meshes. The observation regarding the stress-strain, cracking and failure load are given in Table-4.31, and the graphical representation of Case H13 is shown in Fig-4.8.

4.8.4 Analysis of Case H

This group had same arrangements of encasements as of Case E. The only difference was that in Case E, only nails were used for the bonding, whereas in this case, a bonding agent called Sikka-Latex was also used along with nails. However, the average failure load for Case H was 29.93 ton (67050 lbs), which is not much different from the failure load of Case E (27.88 ton). But comparing the individual specimens of Case E, where none of them exhibited failure load more than 30 ton, where as in Case H, failure load as high as 36 ton (80640 lbs) was noted. This indicates that lower failure loads of case H were primarily due to poor workmanship in handling the wire mesh and mortar together. This could be overcome with little practice and experience. However, the use of Sikka-Latex appeared to be effective only in maintaining bond between brick surface and first mortar layer of 5 mm. The subsequent mortar layers appeared to form early cracks and at failure load the bond between them was lost. The addition of wire mesh did not make much difference in achieving higher failure loads, unless bond between them is maintained. The average stress-strain readings and failure load are presented in Table-4.32. The graphical representation of all three specimens of Case H with respect to the average values are shown in Figure 4.8.

4.9 TESTS OF CASE I

The specimens for Case I were prepared with three layers of wire meshes wrapped inside the mortar. This encasement was bonded with the nails and the bonding agent Sikka-Latex. The specimens of Case I were named as I11, I12, I13 and in the similar manner subjected to axial load through universal testing machine of 200 ton capacity. The capping at the top and bottom, and vertical alignment were carried out before applying the load. The Case F and I both have the 3 wire meshes inside, but in Case I, Sikka-Latex was also used in addition to nails. The observations recorded for the individual specimens are given succeeding paras.

4.9.1 Specimen I11

This specimen failed at 36.9 ton (82656 lbs), which is approximately 146% higher than the failure load of control Case A. It was observed that bond between the brick surface and encasement was fairly good and this lead to higher failure load. There was no spalling of concrete cover and overall the specimen was intact at failure. This difference of failure load of Case F and I, reveals the effectiveness of Sikka-Latex for keeping the specimen intact. However, with three layers of meshes, the thickness of mortar was varying and this excessive thickness lead to the initiation of early cracks. The workmanship problems were also exposed when near failure bond between outer layers of meshes were lost at joints. In this case cracks initiated from the bottom and top edges and were vertical in shape. These cracks widened with the application of load, and just before the failure the outer layer of specimen seemed to have lost the bond. Therefore, composite action of all three layers of mesh could not be maintained. However, increase in the failure load was significant. The bond between the initial 2 inner layers and brick column was successful and the final cracks were observed through the center of brick column. The wire mesh inside was intact and the column could possibly be repaired with grouting. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.33, and the graphical representation of Case I11 is shown in Fig-4.9.

4.9.2 Specimen I12

This specimen exhibited failure load of 36.2 ton (81088 lbs), which is quite similar to Case I11. The overall behavior in terms of crack growth and subsequently the bonding of third layer near failure was similar to Case I11. No spalling was observed in specimen I12. It was noticed that the cracks could be repaired with the concrete grouting procedure. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.34, and the graphical representation of Case I11 is shown in Fig-4.9.

4.9.3 Specimen I13

The specimen I13 exhibited a bit higher failure load of 37.5 tons (84000 lbs). The small increase in failure load could be attributed to the better workmanship. The cracking pattern was similar to other two specimens of this group. The cracks initiated from the top and bottom edges and were vertical in shape. However, it was observed that these cracks were not in line with each other and did not extend to the entire length of the specimen. The cracks initiation started at the early stages of load application and first crack was observed at 8 tons (17920 lbs). This could be due to mortar layers provided to cover the wrapped wire mesh. The subsequent growth of cracks was stable and no spalling was observed at failure. Only the third layer of wire mesh seemed to have lost the bond. The composite action of all three layers could not take place at the failure loads. The observation regarding the stress-strain, cracking and failure loads are given in Table-4.35, and the graphical representation of Case I13 is shown in Fig-4.9.

4.9.4 Analysis of Case I

Average failure load for Case I was 36.86 tons(82582.50lbs), which is approx 145% more than the failure load of control Case A. However, comparing with the failure loads of Case D and G, (35.06 tons and 36.36tons respectively), it is observed that addition of two extra layers did not make any significant contribution to the failure loads. Additional two layers caused problem in wrapping procedure and additional mortar thickness was to be applied for covering the bulging wire mesh. The additional thickness caused problem in creating the perfect bond between the ferrocement layers. The crack initiation started early due to the extra mortar cover. Therefore, it is worth mentioning that unless the proper mortar thickness is applied (which is difficult to achieve while handling the wire mesh and mortar together), a perfect bond cannot be achieved even with the help of bonding agent. The real benefit of additional layers of wire meshes and bonding agents can only be achieved if the mortar thickness is kept between the prescribed limits of 5 mm to 8 mm. The average stress-strain readings and failure loads are presented in Table-4.36. The graphical representation of all three specimens of Case I, with respect to the average values are shown in Figure 4.9.

4.10 ANALYSIS OF EXPERIMENTAL RESULTS

The ultimate failure loads and cracking loads of all specimens are presented in Table 4.37. The stress-strain curves and trend lines based on the average readings of all the cases are shown in Figures 4.10 and Figure 4.11 respectively. From the summary of these results, it can be seen that the load carrying capacity of ferrocement coated brick specimens increased significantly as compared to the load carrying capacity of simple brick masonry columns and unreinforced plastered columns. 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 and 3 layers of wire meshes. The probable reason for this low failure load capacity with 2 and 3 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 obsì¥Á 7

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ill 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 and three 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 brick masonry specimen and unreinforced plastered specimen these cracks occurred between 60% to 75% 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 varying from 5 to 8 mm. 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 brick masonry and simple plastered specimen.

The stress-strain curves and trend lines drawn for all nine cases show higher slopes for ferrocement encased specimen than for simple brick masonry or unreinforced plastered specimen, thus indicating greater stiffness of ferrocement coated specimen.

The use of bonding agent Sikka-Latex did not show any significant improvement in failure load capacity, however, it helped in controlling the spalling of mortar. Therefore, in most of the specimens treated with Sikka-Latex , it was observed that the specimen were intact at failures without any spalling of concrete and a possibility of repairing these specimen with the grouting procedures seemed viable.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

An experimental study has been carried out on the composite behavior of masonry columns coated with ferrocement (with 1, 2 and 3 layers of wire meshes). The following conclusions are drawn :-

- The application of the ferrocement coating on bare masonry columns enhances the compressive strength quite significantly. Ferrocement specimens having one layer of wire mesh wrapped inside showed an increase in failure load up to 160% as compared to controlled specimen of Case A (simple brick masonry columns).
- The use of 2 and 3 layers of wire meshes did not improve the load bearing capacity unless the bond between these extra layers and the casing and core is maintained till failure.
- The thickness of mortar cover should be maintained as 3-5 mm between each layer. The excessive mortar thickness applied to cover the bulging wire mesh leads to premature cracking and spalling near failure.
- Premature failure can occur if the wire mesh is not wrapped properly and mortar does not penetrate into it fully.
- The cracking resistance and stable crack growth machanism of bare masonry columns is improved quite significantly due to the provision of ferrocement coating. Although the initial cracking loads in ferrocement coated specimens

are quite low but the subsequent growth and widening was much controlled as compared to brick masonry specimens.

- An appreciable increase of load carrying capacity of brick masonry columns due to the application of 2 different ratios of mortar was observed. The brick columns coated with 1:5 ratio showed an increase of 35% where as the specimen coated with rich mortar ratio of 1:2 showed 66% increase in failure load.
- The failure of brick masonry columns and columns coated with un- reinforced plaster is very sudden and cracks widen rapidly after their formation leading to a brittle failure of the structure.
- The use of Sikka-Latex as a bonding agent does not help in improving the load carrying capacity however it is effective in controlling the spalling of concrete cover.

5.2 RECOMMANDATIONS

- Ferrocement coating should be applied and tested on brick walls.
- Effective bonding measures should be adopted to evaluate the effectiveness of more layers of wire mesh.
- Different types and sizes of wire meshes should be tested with ferrocement.
- Bearing of top and bottom of brick columns should also be done with ferrocement to evaluate improved behavior.
- Use of different admixtures like Rice Husk and Pozzalana etc should be tested to observe the better bond behavior and workability.
- A comparison should be carried out between ferrocement coated columns and RCC columns to evaluate the strength and cost.

- Same experiment should be repeated to confirm the results.
- Behavior of plastered and RCC columns should also be studied under hostile environments.

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