ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Investigation of Potential Use of Ferro Cement Jacketing for Strengthening of Reinforced Concrete Column and Construction Methodology

A Thesis in Structural Engineering

By:
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UNDERTAKING

I certify that research work titled “Investigation on Potential Use of Ferro Cement Jacketing for Strengthening of Reinforced Concrete Column and Construction Methodology” is my work. The work has not been presented elsewhere for assessment. Where the material has been used from other sources, it has been appropriately acknowledged/referred.

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ABSTRACT

Strengthening of the existing structures has become a large part of the construction industry. Columns are the firmest structural element in any structure that transfers the entire loads to the foundations. In general, the strengthening of deficient columns is necessary to increase the load-carrying capacity and ductility that can be achieved by external confinement of columns. External confinement can be done by using different materials such as ferro cement, fiber-reinforced polymers, and steel jacketing.

This thesis presents the results of an experimental and numerical study on the capacity of the strengthened reinforced column by ferro cement. Five group tests were conducted, and all sample specimen tests were under static load. The test had three reinforced concrete columns, three cement mortar wrapping reinforced concrete columns, three single layer ferro cement strengthened reinforced concrete columns, three double layers ferro cement strengthened reinforced concrete columns, and three triple layers ferro cement strengthened reinforced concrete columns. All samples tested by applying an axial load.

The experimental data used for validation of the finite element models were developed using the abaqus software package. The validated models used as part of the study was to investigate the effects of material strength, reinforcement geometry and arrangement, and the influence of the axial load. The conclusions from the experiments and the numerical studies are that the number of layers of mesh in the ferro cement had a significant effect on enhancing the maximum axial load capacity of a column and increased its ductility property. The transverse wires in the ferro-mesh provide confinement to the column, and it is very good to use ferro cement material for strengthening a column.

ACKNOWLEDGMENTS

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Ac	Gross cross-sectional area of the matrix section
η	Global factor of reinforcement mesh in the loading direction
A_{mesh}	Total Surface area of reinforcement mesh
A_r	Effective area of reinforcement
As	Cross-section area of tension
A_{sc}	Cross-section area of compression
b	Width of the concrete section
C	Distance from the top surface to the neutral Axis (N.A)
C_m	Compression force of matrix
Cs	Compression force of reinforcement
d	Distance from the top surface to tension
d’	Distance from the top surface to compression
dc	Compression damage variable
d_{si}	Distance from extreme compression to each layer of mash
ds	Tensile damage variable
E	Young’s modules
E_{cm}	Young’s modules of concrete
f'_c	Specific compressive strength of concrete
f_{cm}	Compressive strength
f_{ctm}	Tensile stress of concrete
F	Force
F_c	Maximum load failure
F_{cc}	Force of compression Concrete
F_{sc}	Force of Compression steel bar
F_t	Maximum loading at failure
h	Height of concrete section
I	Second moment of area
M	Bending moment
P	Axial load

P_{bal} Axial load at balance

Po Pure load column

Sr Specific surface

S_{rl} Specific surface in the longitudinal direction

S_{rt} Specific surface in Transverse direction

T_s Tensile force of reinforcement

$V_{composite}$ Composite volume

V_{mesh} Total volume of reinforcement mesh

Vr Volume fraction

V_{rl} Volume fraction in the longitudinal direction

V_{rt} Volume fraction in the transverse direction

CHAPTER ONE

1 INTRODUCTION

1.1 General

Ferro cement is a composite material used to form a thin section; it is composed of mortar and reinforcement like light steel fabrics and meshes. Ferro cement is one of the earliest versions of reinforced concrete; however, it's design has been mostly empirical, and a formal design guide has not been developed as it is being developed more for traditional reinforced concrete.

Ferro cement is a type of thin-wall reinforced concrete commonly constructed of hydraulic cement mortar, reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh can be of metallic or other suitable materials [1].

Various strengthening techniques are available depending on the type and condition of the structure. The selection of the most appropriate method and material is based on the results of structural assessment and detailed structural analysis.

Strengthening can be done in two ways

- Global Strengthening
- Local Strengthening

In global strengthening, the entire structure is strengthened to fulfill the serviceability and ultimate limit state requirements. It involves the analysis and design of the whole structure as per the specifications given in standard codes. Whereas, in local strengthening, only a specific member of the structure is enhanced to resist the required applied load [2].

1.2 Background to the strengthening of structures

The primary reasons for the deterioration of RC structures are cracking (due to incorrectly made construction joints, poor compaction, segregation, poor curing, and high water content) and spalling (due to corrosion in the reinforcement bars accelerated by a lack of adequate cover). The cracks in the concrete may be developed due to the wrong design of the structure or due to the poor quality of materials used. And these cracks will further facilitate internal corrosion of steel reinforcement used in reinforced concrete structural elements, and in course of time deepens up due to an increase in corrosion resulting in peeling of concrete cover or spalling of concrete. Use of proper repairing material and methods on damaged or deteriorated reinforced concrete structures is a necessity not only to serve the intended service life but also assure the safety of buildings.

Strengthening can be done through the following methods: [3]

- Reinforced concrete jackting: it involves the addition of concrete sections
- Jacketing Construction: addition of RC section
- Fiber-reinforced polymers jackting: additional strengthen members
- Steel jacketing construction: additional strengthen members
- Ferro cement jackting

From all the above techniques, jacketing construction is the most preferred method of strengthening. This method involves the following techniques:

I. Jacketing with fiber-reinforced polymers such as aramid fibers, carbon fibers, and glass fiber polymers.

II. Jackting with Reinforced Concrete

III. Jackting with external steel caging techniques

IV. Jakting with ferro cement

In comparison [4] to the above, strengthening with ferro cement jakting is the oldest and cost-effective technique used to enhance the concrete structures. Ferro cement consists of closely spaced and uniformly distributed reinforcement, which provides ductility to the otherwise brittle concrete. This inherent property makes the ferro cement a distinctive composite construction material. The unique properties of ferro cement, such as waterproof, fire-resistant, durability, low self-weight, and crack resistance, make it an ideal material for wide application [5].

1.3 Objectives

1.3.1 General Objectives

This thesis aims to study through experimental and numerical investigation on the effectiveness of ferro cement confinement in strength deficiency column and behavior of ferro cement short columns under axial compression loading.

1.3.2 Specific Objectives

- To investigate the behavior of reinforced concrete columns by jacketing with ferro cement.
- To investigate the contribution of mesh wire in strengthening column using ferro cement.
- To investigate the composite behavior of reinforced concrete column jakting with ferro cement.
- To identify the comparisons of the different types of specimens.

1.4 Statements of the Problems

Reinforced concrete is the commonly used material for the construction of structures designed as per the specifications given in the standard codes to meet the service life. Based on these specifications, the load is taken into account for the design of the various elements of the structure like beams, columns, and slab. During the service life, if the loading conditions change because of shifting the function of the structure, this can result in poor performance of the structural elements for which it was designed earlier. And also, the structures are susceptible to deterioration due to earthquakes, deficiencies of the material used, inadequate design, and faulty construction. Moreover, water pollutants also cause corrosion and develop cracks leading to the failure of structural elements. As the replacement of the damaged structural components is a challenging and cost-intensive process, so the replacement of a particular structural part in the existing structure also creates a risk to the integrity of other connecting members.

1.5 Significance of the Study

Many reinforced concrete structures are deficient in stiffness, ductility, and strength capacity compared to current standards. When a powerful event, such as an earthquake, occurs, un-strengthened, and inadequate concrete members may fail and produce catastrophic results. To overcome this problem, many strengthening and repair methods have been studied, implemented, and have produced a variety of results. Therefore, this research work forms a part of experimental and numerical investigations aimed at developing an efficient and economical method of strengthening existing reinforced concrete structures for enhanced axial load capacity.

1.6 Research Methodology

In this study, mainly reviewing literature, experimental work, and numerical analysis using Abaqus were conducted. A total of fifteen specimens is investigated, among those three columns as control and nine columns as a strengthened column. Strengthening columns are grouped based on the number of layers of wire mesh. Each group has three columns those tested with one, two, and three-layer of mash wire with mortar strengthening column. Afterward, numerical analysis is done with the help of Abaqus for the control and strengthening column. Finally, the result obtained from experimental verse numerical results is plotted, and comparison is made.

1.7 Research Outline

This thesis is divided into the following six chapters:

Chapter 1 Introduction**:** The first chapter gives a general introduction, including the research background, the aim of the thesis, and the outline of the thesis.

Chapter 2 Ferro cement material behavior and applications: The second chapter presents a brief literature review including: the development of ferro cement, a description of the ferro cement constituents and their mechanical behavior, basic mechanical behavior of ferro cement, columns under combination of axial load and bending, strengthened reinforced concrete using ferro cement jacket, and use of FEA in ferro cement modeling.

Chapter 3 Experimental tests: The third chapter presents the experiments in detail, including material property tests of the matrix and reinforcement fabrication of the ferro cement column specimens, design, and construction of the equipment and test details.

Chapter 4 Finite element modeling: The details of the finite element modeling is presented in chapter four. The commercial package abacus was used to establish and validate finite element models against the experimental results.

Chapter 5: Result and discussion: The fifth chapter presents the results of columns tests, which is static loading.

Chapter 6: Conclusion and Recommendation: The last chapter summarizes the main conclusion from work undertaken for this thesis and gives recommendations for research.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 General

The purpose of this thesis is to elaborate on the strengthening or Jacketing the existing structural elements or structures. In this connection, a descriptive literature survey has been done on the earlier works that are appropriate to the present study. The summary of the review is presented under the following topics: Strengthening techniques, finite element modeling, and analysis. Many types of research have been carried out, and a number of studies are available in the literature on the above topics. However, those enquire that is related to the materials, mechanical properties, load carrying capacity, stiffness, ductility, energy absorption capacity, and finite element model of the above topics are discussed in this chapter. The summary of the review is presented in the following manner:

2.2 Ferro cement: Definition and History

Ferro cement is a type of reinforced concrete with embedded mesh layers in cement mortar. The mesh may be metallic or nonmetallic, and mortar composition may vary using advanced concepts of concrete technology. In light of the above definition, ferro cement may be considered as a new technology material as well as a high-performance composite. It can be used as a high-performance material to be used as prefabricated technology. In concrete family and composite materials, ferro cement is the most innovative invention which can conserve resources, save energy, protect the environment, and reduce human effort.

Ferro cement is defined by the American Concrete Institute (ACI) Committee 549R97 in their “State of the Art Report” as: “ferro cement is a type of thin-wall reinforced concrete commonly constructed of hydraulic cement matrix reinforced with closed spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable material. The fineness of the matrix and its composition should be compatible with the opening and tightness of the reinforcing system, and it is meant to encapsulate [1].”

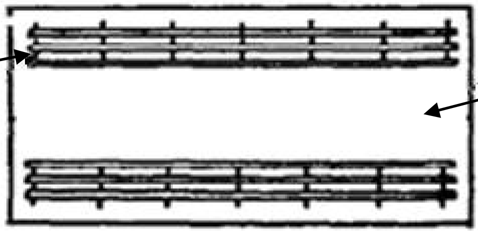

Figure 2-1: Typical meshes used in Ferro cement application *[5]*.

There are many relationships between ferro cement and reinforced concrete, and these are summarized as follows:

1. Both ferro cement and reinforced concrete obey the same principles of mechanics and can be investigated using the same theories.
2. Both can be examined using similar techniques, experimental tests, or numerical simulations.
3. Both can be designed implementing the same philosophy, such as limit state design to satisfy both the ultimate and serviceability limit states.

However, the differences between ferro cement and reinforced concrete are also significant. The main differences are:

1. Compared with reinforced concrete, ferro cement is homogenous and isotropic in two directions.
2. Ferro cement has excellent tensile strength and a high specific surface of reinforcement.
3. Due to the two-dimensional reinforcement of the mesh system, ferro cement has:
   i. much better extensibility;
   ii. smaller crack widths,
   iii. higher durability under environmental exposure; and
   iv. better shrinkage crack control.

Ferro cement was first officially proposed in 1847 by Joseph Louis Lambot in France. It was utilized in the construction of a rowboat using woven wires and matrix. In 1852, a patent was submitted in the name of “ferro cement,” which means “Iron Cement.” In the early 1940s, an Italian architect, Pier Luigi Nervi, resurrected the original ferro cement for the following reason:

‘’The fundamental idea behind the new reinforced concrete material ferro cement is the well-known and elementary fact that concrete can stand large strains, in the neighborhood of the reinforcement and that the magnitude of the strains depends on the distribution and subdivision of the reinforced through the mass of the concrete.” [1]

Professor Nervi established the preliminary characteristics of ferro cement through a series of tests. Nervi claimed the successful use of ferro cement in roofs of buildings and warehouses in addition to its use in boat building. After the second war, Nervi proceeded, following a series of tests, to design and construct several roofs, which remain models of the rational and aesthetic use of ferro cement in structural design. Also, Nervi built a 165-ton motor sail-boat “Irene,” with a ferro cement hull with a thickness of 36 mm [1].

Joseph Louis Lambot is considered the father of ferro cement. He constructed boats, seats, and plant pots in 1855 and patented his innovation with the name of “Ferciment” in France. In 1940’s Pier Luigi Nervi of Italy reinvented ferro cement, he tested ferro cement to discover its characteristics and performed some experiments to recognize advantages of ferro cement. Nervi first used ferro cement in a public structure in 1948 that was an exposition hall at Turin with a 100 m span roof. The roof was constructed using prefabricated panels of ferro cement. In 1953, Nervi used ferro cement for the roof of Milan Fair Building and Flaminio Stadium, Rome. In 1959 Nervi used ferro cement corrugations for construction of cantilever roof. Research Studies on ferro cement behavior started in the late fifties. In 1968, the fisheries department of the USA built boats with ferro cement in Asia, Africa, and Latin America to be used in fishing. In 1972, the US academy of sciences reported potential applications of ferro cement in developing countries. In 1975, the American concrete institute formed committee ACI 549 on ferro cement. The committee issued its first report in 1980. In 1976, the International ferro cement Information Center (IFIC) formed at the Asian Institute of Technology (AIT) Bangkok. In 1979 RILEM formed committee 48 for ferro cement. International Ferro cement Society formed a committee IFS-10-01, which developed the ferro cement model code (FMC) in 2001. A lot of research on ferro cement is going on to develop it as a substitute material for various conventional construction materials such as bricks, stones, timber, steel, concrete. [6]

In the 1960s, ferro cement began to be used in various countries such as the United Kingdom, China, India, Australia, and New Zealand [1].

In 1972, Gordon W. Bigg wrote about the merits of ferro-cement as a small vessel hull material. He attempted to separate fact from fancy to enable the potential designer of its vessels to predict the performance of a ferro cement hull realistically. [7]

After 1972, several academic committees were set up to study the behavior and development of Ferro cement:

- 1972, an Ad Hoc Panel was set up by the USA National Academy of Science.
- 1974, Committee 549 was established by the American Concrete Institute (ACI).
- 1976, an International Ferro cement Information Centre (IFIC) was established at the Asian Institute of Technology, Bangkok, Thailand, and in cooperation with the New Zealand Ferro cement Marine Association (NZFCMA), they published a quarterly journal called, “The Journal of Ferro cement.” Unfortunately, the journal was terminated in 2006. Also, from 1981 until 2012, ten international symposia were held in various parts of the world, Cuba was taken the latest symposia, called FERRO10.
- 1991, the International Ferro cement Society (IFS) was formed to promote the use of ferro cement. In 2001, the Model Code was introduced. The code provides a document that enables civil engineers to study and model their ferro cement designs.
- 2011, the Ferro cement Society (FS) was established in India. The ferro cement group ACI 549 (ACI, 1988) is still the most effective international committee and published a design guide for ferro cement in 1989. This guide is still the most important reference design and is widely used by most designers. In 2000, Professor Antoine Naaman of the university of Michigan produced the first (and to date the only) textbook “Ferro cement and Laminated Cementitious Composites” [8].

2.3 Application of Ferro cement

Ferro cement is a highly versatile construction material that has a potentially wide range of practical applications. Ferro cement can be used to manufacture different shapes of structures around the world. In developing countries, it has been used for housing, sanitation, agriculture, fisheries, water resource projects (e.g., water transportation vessels), and to repair or strengthen old structures. Also, applications of ferro cement were used for boats, water tanks, shell structure, roof, strengthening balcony, and extension room.

In Ethiopia, underground pits are the traditional method of grain storage. It has been found that when the conventional pit is lined with ferro cement and provided with an improved airtight lid, a hermetic storage chamber with desirable resistance to moisture penetration can be achieved [1].

Recently, many structures have been built using ferro cement. It has been worked on building a one-story house using precast ferro cement elements in Haiti. In India, it is blossoming, and they have just held a ferro cement conference, on topics such as water tanks and ferro cement houses. In Cuba, many swimming pools have been constructed using ferro cement and some simple dwellings.

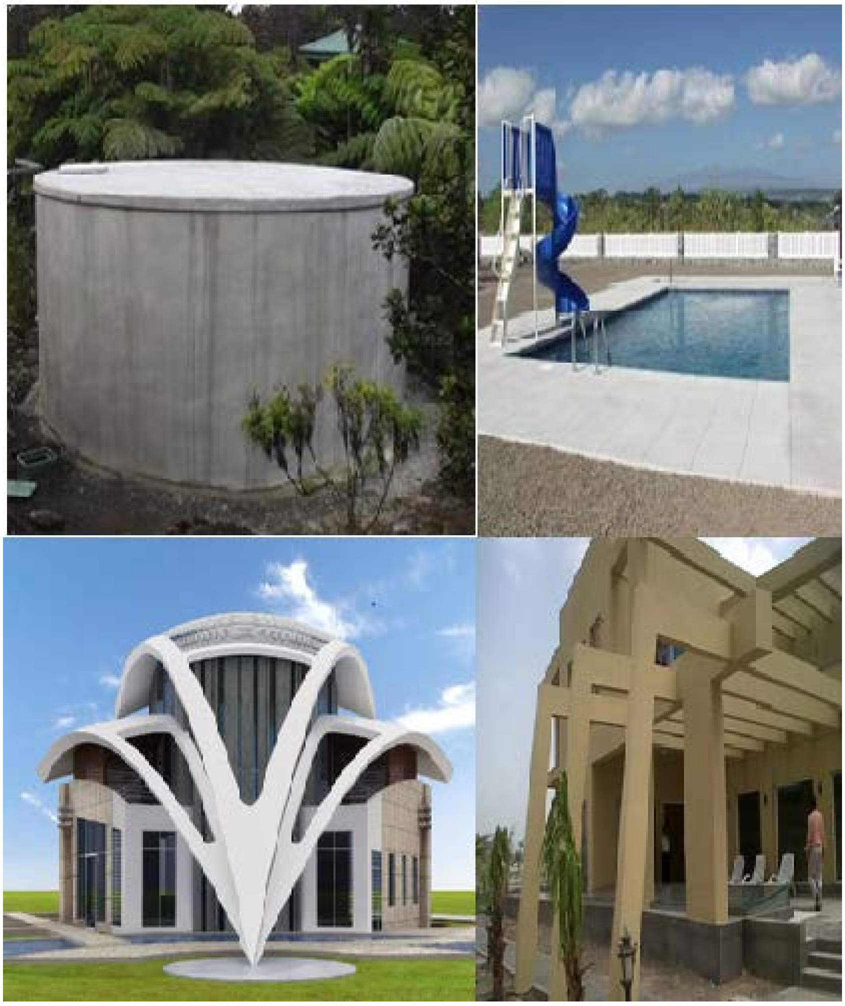

Figure 2-2: Application of Ferro-cement

Durability and maintenance are of great concern in civil engineering structures. To increase the durability of structures, ferro cement is a better option than reinforced concrete and masonry in some circumstances. Reinforced concrete or masonry walls often exhibit distress due to damaged or need Strengthening before the end of their design life following events such as earthquakes or fires. Examples of strengthening structures using ferro cement are presented in a later section.

2.4 Constituent Materials

The main components of ferro cement are the matrix and the reinforcing mesh. It primarily consists of cement, sand, wire meshes, and various admixtures. The main difference between reinforced concrete and Ferro cement is the scale.

Reinforced concrete uses a larger size reinforcing bar as compared to wire/meshes in ferro-cement. Reinforced concrete consists of less volume of the metallic part as compared to that of the ferro-cement. It does not contain large size aggregate as used in reinforced concrete, and only cement mortar is used. Sometimes depending on the requirement, it may consist of large size bars along with wire mesh. The number of layers of wire mesh to be provided depends on the applications for which it is going to be used. Typical cross-sections of ferro-cement are shown in (Figure.2.3) [9]

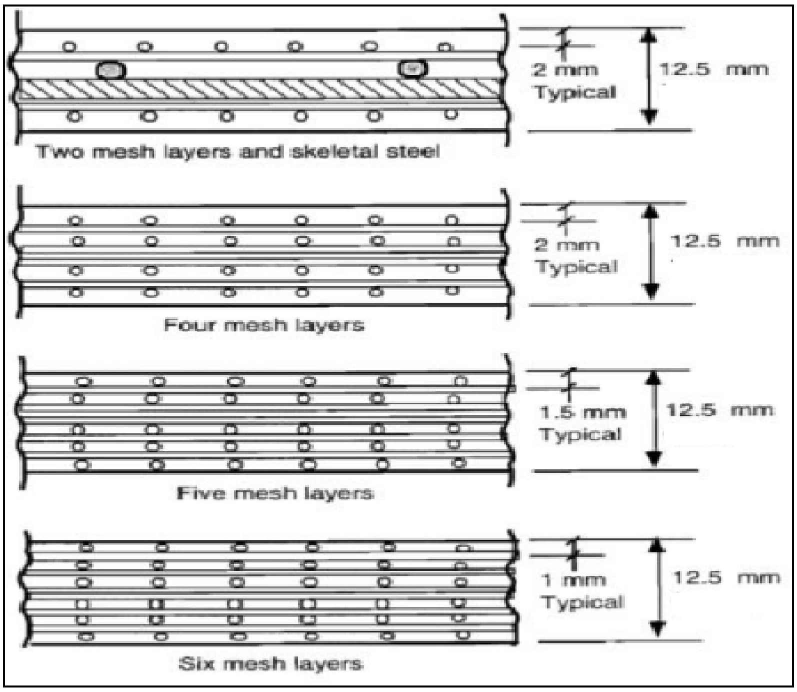

Figure 2-3 :Typical cross sections of Ferro-cement *[5]*

They are described as follows:

2.4.1 Matrix

The matrix is a mixture of cement, well-graded sand, water, and possibly some admixtures such as silica fume and superplasticizer. Similar to concrete, the matrix should have adequate workability, low permeability, and high compressive strength. The water-cement ratio, sand-cement ratio, quality of water, type of cement, and curing conditions in addition to the casting and compaction can influence the mechanical properties of the matrix [1].

2.4.1.1 Cement

Ordinary Portland Cement (OPC) is commonly used. It should be kept fresh, be of uniform consistency, and free of lumps and foreign matter. Moreover, it should be stored in dry conditions for a short duration as possible.

2.4.1.2 Aggregates

Normal-weight fine aggregate is commonly used in the matrix. Aggregates having high hardness, large strength, and containing sharp silica can achieve the best strength results. However, the aggregate should be kept clean, inert, free of organic matter, and deleterious substances and free of silt or clay.

2.4.1.3 Water

The water used in ferro cement should be fresh, clean, and free from organic or harmful solutions. Unclean water may interfere with the setting of cement and will influence the strength or lead to staining on surfaces.

2.4.1.4 Admixtures

An admixture is defined as a material other than water, aggregate, or hydraulic cement, which might be introduced into a batch of ferro cement or matrix, during or immediately before its making. It is used in a matrix to provide up to four benefits, which are reduced water requirement, increased strength, improvement in impermeability, and better durability. The two main categories of admixtures are chemical and mineral admixtures.

Mineral admixtures can reduce energy costs, save raw materials, and improve concrete and matrix properties, such as porosity, strength, permeability, and durability. Various mineral admixtures are now commonly used in cement and concrete production, such as silica-fume and fly ash. Silica-fume has a high content of amorphous silicon dioxide and consists of very fine spherical particles. It is collected by filtering the gases escaping from the furnaces and is used to improve cement properties such as compressive strength, bond strength, and abrasion resistance. Fly ash, or natural pozzolan as pulverized particles, is another admixture added for changing the property of the concrete and matrix. [1]

2.4.2 The property of the matrix

To produce a workable matrix, the weight ratio of sand to cement varies from 1.4 to 2.5, and the ratio of the water to cement is between 0.30 and 0.55. In general, a workable mix can completely penetrate and surround the mesh reinforcement and have acceptable amounts of shrinkage and porosity. Water-reducing admixtures can be used to enhance mix plasticity, especially where admixtures such as superplasticizer are used. Furthermore, the slump of the fresh matrix should not exceed 50 mm. From literature, different moduli have been given for the matrix, for example, the Young's Modulus given may vary from 5 GPa to over 20 GPa, even based on the same sand-cement and water-cement mixtures. As the matrix property varies among these studies, separate experimental studies are carried out to characterize this behavior for the current study. [10]

2.4.2.1 Reinforcement Mesh

The reinforcement should be clean and free from deleterious materials such as dust, rust, paint, oil, or similar substances. A wire mesh with closely spaced wires is the most popular reinforcement used in ferro cement structures. Generally, common wire meshes have square or hexagonal openings. Meshes with square openings are available in the woven or welded form. Other types of reinforcement are also used for some special applications or specific performance or economy, such as expanded metal mesh. Typical types of mesh are shown in Figure (2.4).

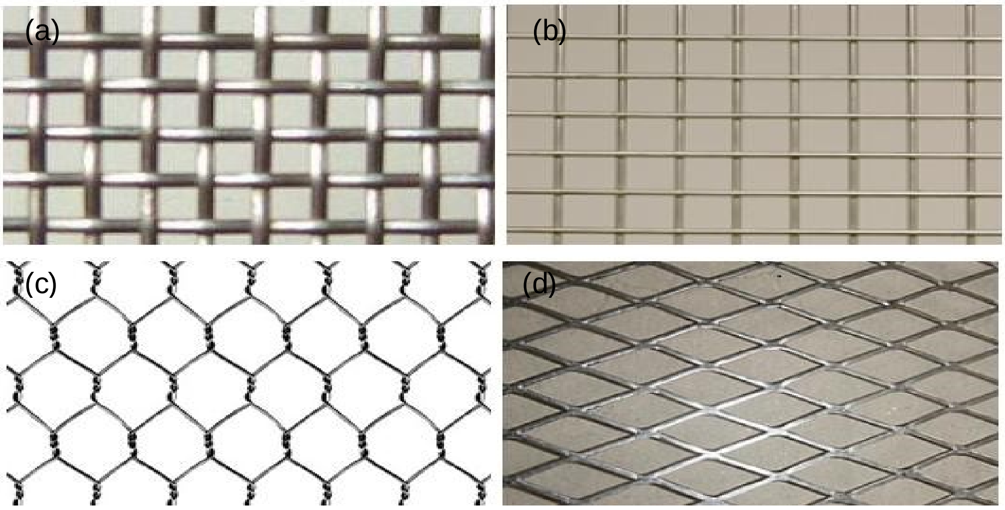

Figure 2-4: Typical types of mesh, (a): (Woven-mesh), (b): (Welded-mesh) (c): (Hexagonal-mesh) (d): (Expanded-mesh) [1]

Woven mesh: As shown in Figure (2.4) (a), the woven mesh is made of longitudinal wires woven crossing transverse wires. There is no welding at the intersections. Based on the tightness of the weave, the thickness of the woven mesh may be up to three wire diameters.

Welded wire mesh: It is produced using longitudinal and transverse wires welded together at the intersections, as illustrated in Figure (2.4) (b). It has a higher stiffness than woven mesh, which is why the welded mesh leads to smaller deflections in the elastic stage. Welded mesh is also more durable, more intrinsically resistant to corrosion, and more stable in structures than woven mesh.

Hexagonal or chicken wire mesh: This mesh is a type of fencing mesh that has hexagonal holes see figure (2.4) (c). It has many different applications, such as animal fencing and fence netting. It is fabricated from cold drawn wire that is woven in hexagonal patterns. As no wires are continuous along any one direction, this type of mesh is more flexible than woven or welded mesh and is generally easier to fabricate and use, especially for curved structures.

Expanded metal mesh: This is formed by slitting thin-gauge steel sheets and extending them perpendicularly to the slits, as shown in figure (2.4) (d). This type of mesh offers approximately equal strength in the normal orientation but is much weaker in the direction in which the expansion took place. It can be used as an alternative to welded mesh, but it is challenging to use in construction involving sharp curves.

2.5 Reinforcement mesh parameters

The unique properties of ferro cement are derived from a relatively large amount of two-way reinforcement. The reinforcement is made up of small elements with a much higher surface area than conventional reinforcement. Therefore, the reinforcement has greater elasticity and cracking resistance, together with narrow uniformly spaced cracks. The thickness of the covering matrix varies from 3 mm to 5 mm, which leads to thin sections. Based on the Ferro cement Model Code (IFS), volume fraction, and specific surface are used to describe the amount of mesh. The volume fraction is the volume ratio of the reinforcement to the volume of ferro cement, which is calculated by [1]

$$V_r = \frac{V_{mesh}}{V_{composite}} * 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 2.1$$

Where:

$V_r = \text{Volume fraction}$

$V_{mesh} = \text{Total volume of reinforcement mesh}$

$V_{composite} = \text{The volume of composite}$

The specific surface is the bonded surface area of reinforcement per unit volume of the ferro cement, which can be calculated as:

$$S_r = \frac{A_{mesh}}{V_{composite}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

Where:

$S_r = \text{Specific surface}$

$A_{mesh} = \text{Total surface area of reinforcement mesh}$

Due to the geometry of the mesh layers, the volume fraction and specific surface in the longitudinal (V_{rl} and S_{rl}) and transverse (V_{rt} and S_{rt}) directions are calculated separately in some cases. It has been suggested that the total specific surface of meshes should be greater than or equal to 0.08 mm^2/mm^3 and that the total volume fraction should be greater than 1.8% (ACI, 1997). It is worth mentioning that the effective area of reinforcement (A_r) is the area in one direction only. It can affect the strength of the ferro cement, especially under uniaxial tensile loading and bending.

$A_r = \eta * V_r * A_c$ ………………………………………………………………………………………………….2.3

where:

A_c =Gross cross-sectional area of the matrix section

η =Global factor of reinforcement mesh in the loading direction

The value of η varies with the mesh orientations. The mesh orientations should be considered in the longitudinal direction (η_l), transverse direction (η_t), or any other angular directions (η_θ). Figure 2-4 shows the direction of reinforcement, and Table 2-1 shows the values of η in longitudinal, transverse, and 45° direction for woven square mesh, welded square, hexagonal, expanded metal, and longitudinal bars.

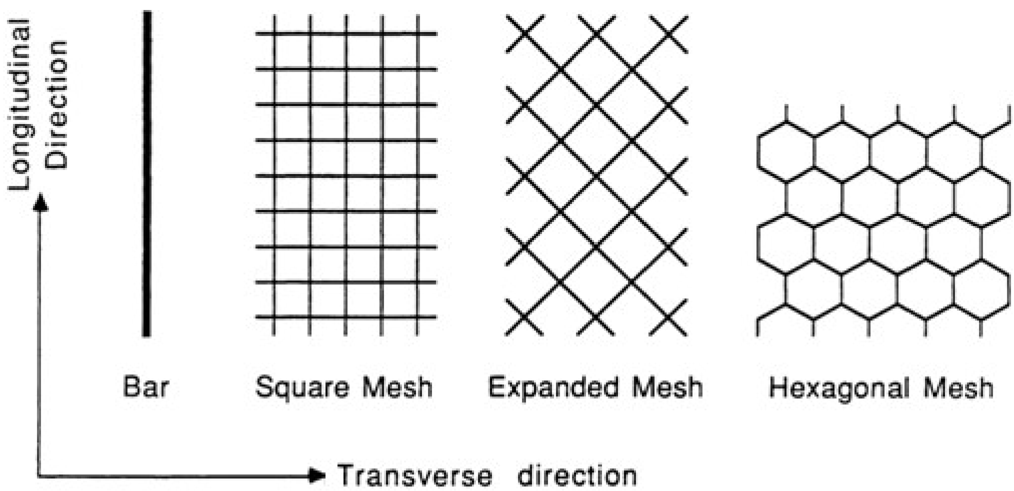

Figure 2-5: Proposed longitudinal and transverse directions of reinforcement mesh *[5]*

Table 2-1: Global efficiency factor(η) of reinforcement in uniaxial tension or bending *[1]* (ACI, 1988)

Mesh type	**Global efficiency factor (η)**		
	Longitudinal (η_l)	**Transverse (η_t)**	**At $\eta_\theta = 45°$**
Woven square mesh	0.5	0.5	0.35
Welded square mesh	0.5	0.5	0.35
Hexagonal mesh	0.45	0.3	0.3
Expanded metal mesh	0.65	0.2	0.3
Longitudinal bars	1	0	0.7

2.6 Behavior of Ferro cement

The four major behavior characteristics of ferro cement elements that should be considered are tension, compression, flexure, and shear.

2.6.1 Behavior under tension

Usually, the tensile behavior of ferro cement can be classified into three stages.

1. Elastic stage (OA in Figure 2-6): The matrix and reinforcement mesh are assumed to be acting as one with linear elasticity. This is similar to the behavior of reinforced concrete. No cracking occurs in this stage.
2. Elastic-plastic stage (AB in Figure 2-6): Multiple cracks start to form and propagate. In this phase, ferro cement differs from reinforced concrete as uniform fine cracks (less than 100 microns) form rather than the larger cracks found in a reinforced concrete structure.

3. Plastic stage (after point B in Figure 2-6): This is the crack stabilization and opening phase, and is when the ultimate load occurs.

One interesting part of the elastic-plastic stage is that the primary cracks occur randomly at critical sections when the tensile stress exceeds the matrix tensile strength. As the load increases, new cracks may occur in the matrix due to the tensile stress exceeding the matrix tensile strength. To transfer stress between cracks, more cracks will continue to occur at this stage until the stress in the matrix does not exceed the matrix tensile strength again, and the number of cracks in the matrix stabilizes.

An advantage of ferro cement is that there are a substantial reserve strength and ductility after the occurrence of visible cracks. One can decide on appropriate repair and strengthening measures based on visual inspections.

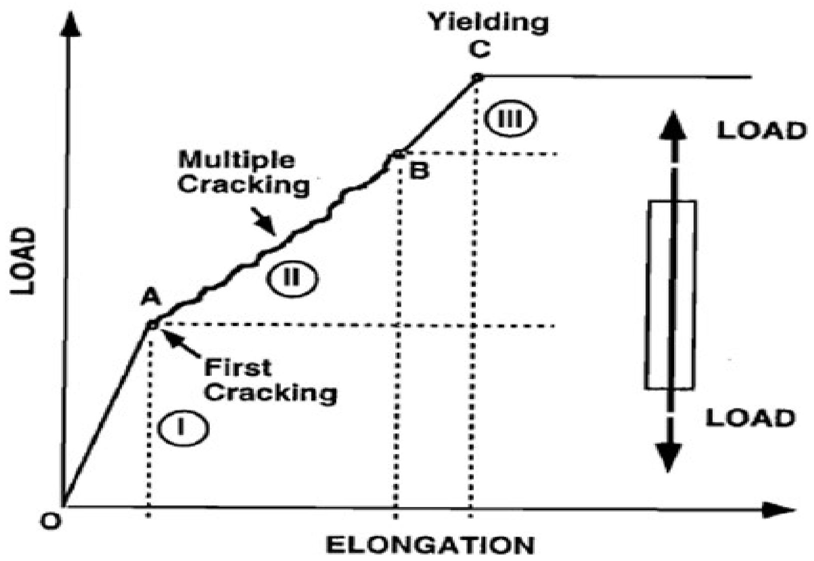

Figure 2-6: Ferro cement under tension [8]

The peak tensile strength is controlled by the reinforcement characteristics, such as strength, volume fraction, and orientation of the wire. Some researches [11] carried out several compression and tension experiments on different types of reinforcement meshes. They concluded that in direct tension tests, the expanded metal is stronger and stiffer than welded mesh. Arif and Kaushik performed load-displacement experiments on welded mesh and woven mesh at 0, 15, 30, 45, 60, 75, and 90-degree orientations. The report shows that the ferro cement with 45° orientation mesh has the lowest loading resistance [11] .

Ferro cement tensile failure can be categorized as a ductile failure, which means the matrix is cracked long before failure and does not contribute to peak strength, so the load capacity, in this case, is independent of the thickness of the specimen. Khandvi and Ramesh analyzed the effect of cover and arrangement of reinforcement on the behavior of ferro cement in tension. The analysis demonstrates that the load is not affected by the arrangement of reinforcement. The tensile strength of the matrix and thickness of the specimens have a significant influence on the first crack strength, but not on the ultimate strength.

2.6.2 Behavior under Compression

Most of the research on the compression behavior of ferro cement was conducted more than three decades ago. In compression, the load-carrying capacity of the matrix strongly influences composite behavior. They reported that the compressive strength of ferro cement mainly depends on the matrix, and it is possible to control and predict this behavior within specified limits. A substantial increase in volume fraction cannot affect compressive strength. [12]

The orientation of the reinforcement has a relatively minor consequence on the direct compressive effect. A ferro cement column, in which meshes are applied in layers in the same plane as the loading plane when the longitudinal wire direction is along the loading direction, the compressive strength may be higher than for other mesh orientations. It has been found that the strength may be increased by shaping mesh like a closed box, and the transverse component of reinforcement has more influence than the longitudinal reinforcement [13].

2.6.3 Behavior under flexure

Ferro cement behavior under flexure is combined behavior in tension and compression and is influenced by matrix strength, mesh type, mesh properties, and mesh orientation. Figure 2-6 shows the flexural behavior of ferro cement, which is similar to tensile behavior. It can be categorized into three stages, the elastic stage, the elastic-plastic stage, and the plastic stage. [14]

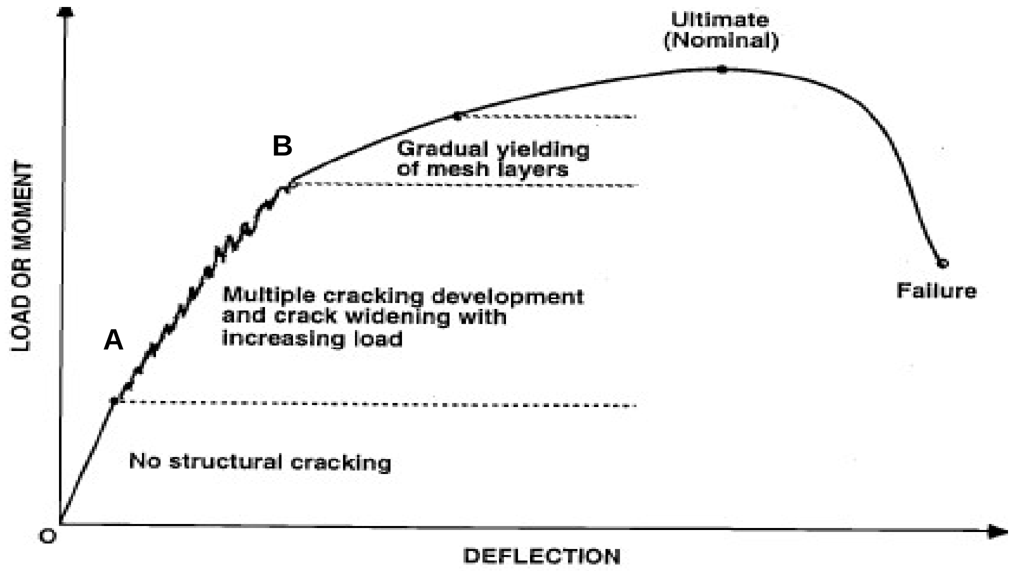

Figure 2-7: Typical load-deflection response of Ferro cement [1]

1) Elastic stage (OA in Figure 2-6): It is the initial portion without structural cracking.
2) Elastic-plastic stage (AB in Figure 2-6): It is also called a multiple cracking stage. This stage sees multiple cracking and cracks widening with increasing load.
3) Plastic stage (After point B in Figure 2-6): The ferro cement starts to yield, and the mesh layer gradually yields, thus achieving the peak load.

The specific surface has less contribution to flexure. This is because the outer most layers mainly control the flexural cracking. According to Naaman, the peak flexural strength was proved to be influenced by the volume fraction and the mesh type. It was found that by increasing the volume fraction, the flexural resistance had a less than directly proportional increase. This is the result of the position of the neutral axis (N.A) changing. As the neutral axis (N.A) position moves upwards, more mesh is in the tension zone, and the peak moment capacity increases. The outer layer has the most influence on the value of the first cracking load. [8]

The orientation of meshes in ferro cement has a considerable effect on the maximum strength. According to ACI 549R97 [1] has reported the weakness of the ferro cement under flexure in different directions; therefore, orientation is important. When the mesh wire direction is along the principal stress direction, the peak flexural strength may achieve maximum value.

2.7 Experimental Studies of Columns under Static Axial Load

2.7.1 Reinforced Concrete Columns

Many researchers have investigated reinforced concrete columns under bending and axial loads. For this thesis, which is primarily concerned with reinforced concrete column jacketing by ferro cement in different layers of mesh wire under static axial load.

In this investigated study the stress of the reinforced concrete members under axial load and biaxial bending by both experimental tests and numerical methods. Tests were carried out on 16 tied reinforced concrete columns with 100 × 100 mm square and 200 × 100 mm rectangular sections under various loading conditions. The angles between the direction of bending and the major principal axis of the cross-section were 0°, 30°, 45° for the square section and 0°, 30°, 45°, 60°, 90° for the rectangular section. Kim and Lee (2000) reported the numerical method was in good agreement for the ultimate loads, the curve of axial loading against lateral deflections. It was also found that the moment method from ACI is conservative in both uniaxial and biaxial bending conditions [15].

In this study they have undertaken 44 experimental tests on reinforced concrete columns subjected to constant axial load and a monotonically increasing lateral force to failure. The aim of this was to gain a greater knowledge of the types of elements and provide data that will be of use in calibrating numerical models and validating simplified methods. The test parameters were concrete strength, axial load level, and longitudinal and transversal reinforcement ratios. The strength and deformation of the columns were studied, and an examination of the simplified calculation methods in Euro code 2 (CEN, 2004a) and ACI 318-08 (ACI, 2008) concluded that both are very conservative [16].

2.7.2 Reinforced Concrete Columns Strengthened using Ferro Cement Jacket

Repairing and strengthening of existing concrete structures has become more common during the last decade due to the increasing knowledge and confidence in the use of advanced repairing materials. Many researchers found that ferro cement jackets can provide effective confinement for reinforced concrete elements, and therefore, it has great potential for use as a strengthening material. The skill required for the fabrication of ferro cement is of a low level and its constituents are usually available locally.

This investigation aims to study the structural behavior of ferro cement plates under flexural loading and the influence of the different variables on the strength and deformation characteristics. The variables studied were the mesh number, strength, opening and distribution, presence of steel bars, and the thickness of the section and the mortar cover. The experimental program included 49 plates, 1000 x 300 mm in dimensions, reinforced with woven type steel wire mesh, and tested under two lines load. The effect of the variables on the crack width was studied quantitatively by comparing the rate of growth of the crack width of the plates. It was found that Ferro cement cracking behavior is characterized by almost a full development of the cracks at relatively early stages of the load (about 30-50% of the ultimate load), and the crack width is smaller and more uniformly distributed than in reinforced concrete.

The mesh number and yield strength influenced the crack width and spacing significantly. There was a limit for the mesh number, after which the enhancement in the cracking performance of the plates slowed down noticeably. Crack width prediction equations were derived from these tests, which showed good correlation, whereas the published crack width formulae largely overestimated or underestimated the measured crack width. The strength and deformation were influenced mainly by the yield strength and fraction volume of reinforcement in the loading direction. The deflection is most likely to exceed the serviceability criteria before the crack width. For a span-deflection ratio of 180, the mean crack width was mostly below 20 microns, and the load was about 15-30% of the ultimate load. A procedure is proposed to analyze ferro cement sections under flexural loading. While the application of reinforced concrete theory to predict the ultimate moment largely underestimated the experimental results, the proposed procedure predicted closely the experimental moment and deflection at first cracking, yielding, and failure of the tested plates [14].

The aim of the study to examine the performance of reinforced concrete beams strengthened by the ferro cement technique. In this experimental investigation, five beams of the rectangular cross-section were cast using C-25 (25 Mpa compressive strength of concrete) normal mix and high strength deformed bars as longitudinal and shear reinforcement. The jacketing on beams were done for two conditions. In one case, the beams were stressed to 70% of the failure load, and then jacketing was done. In the second case, for overloading, the unstressed beams jacketing was done. The results obtained indicate that the increase in ultimate load was 70% in the over-loading case and 45% in the stressed beam, also there was a reduction in rotation and deflection. It was concluded from the experimental investigation that the strengthening of reinforced concrete beams by the Ferro cement technique is practicable and has considerable advantages [17].

Strengthening of reinforced concrete structure improves the load-carrying capacity and extends their service life. To extend the life span of the RC pre-damaged beam, strengthening is required, and this can be effectively achieved using Ferro cement. Ferro cement is a composite material of weld mesh and chicken mesh embedded in a mortar with various volume fractions. It is bonded to the soffit of the beam for strengthening. The main objective of this research work is, to study the flexural behavior of pre-damaged beam with various ferro cement configuration under two-point loading, and to compare the experimental and analytical results of strengthened pre-damaged RC beam for the parameters like first crack load, ultimate load, load carrying capacity, stiffness, and energy dissipation. As a result, indicated that both experimental and analytical showed similar values, and there is strengthening improvement using Ferro cement laminating [18].

In various parts of the world, the behavior of reinforced concrete moment resisting frame structure during recent earthquakes has highlighted the consequences of the poor performance of reinforced concrete beam-column joints. Reinforced concrete beam-column joints in a reinforced concrete moment resisting frame are crucial zones for the transfer of loads, effectively between the connecting beams and columns in the structure. Ferro cement jacketing is mostly used for strengthening damaged structures due to easy availability and durability. In the present work, the effect of wire mesh orientation on the strength parameters of stressed exterior beam-column joints strengthened with ferro cement jackets has been presented. The beam-column joints were stressed to ultimate load and then Strengthened with ferro cement jackets with two different wire mesh orientations. The results show a significant increase in ultimate load-carrying capacity of strengthening beam-column joints using ferro cement jackets with two layers of wire mesh with orientation at L shape and 45 degrees to the longitudinal axis of the joint, varies from 6.70 percent to 22.57 percent along with the increase in the yield load and stiffness of the joint. However, orientation at 45 degrees shows the higher percentage increase in the stiffness and ultimate load carrying capacity followed by L-shape orientations to the joint [19].

In various parts of the world, Reinforced Concrete (RC) structures, even in seismic zones, are still being designed only for gravity loads. Such structures, though performing well under conventional gravity load case, could lead to a questionable structural performance under seismic or wind loads. In most cases, those structures are highly vulnerable to any moderate or a major earthquake. Along with seismic prone zones like the Himalayan region in India, Iran, Turkey, New Zealand, and fault regions in the US, etc., devastations from the earthquake have also been seen at the places believed to be seismically not-so-active. Therefore, in the design of the reinforced concrete beam-column joints against seismic load, it is desirable to limit joint strength degradation until the ductility capacity of the beam reaches the designed capacity. The present work includes experimental investigation to study the structural behavior of Beam-Column Joint by wrapping technique. There are two types of wrapping techniques, type I strengthening & type II strengthening. The study is carried out to analyze the effect of different wrapping techniques on strengthening of RC (reinforced concrete) beam-column Joints using ferro cement. After experimental investigation, observations of type I and type II are better in mechanical properties than control specimen. Type II has better properties than type I [20].

In the present investigation, the effect of the strength of ferro cement jackets for initially damaged exterior RC beam-column joints has been presented. Totally three reinforced concrete BC joints were loaded to ultimate loading designated as control specimens, and then these damaged specimens strengthened using ferro cement jackets.

The wire meshes were provided in the joint region. The experimental observation showed improvement in ultimate load, yield load-carrying capacity with an increase in stiffness of the Ferro cement jacketed joints in comparison to the control joint [21].

An experimental study was conducted on the reduced-scale masonry infilled RC test frame, to investigate its overall performance due to the addition of monolithic RCC strips in the in-filled bays and to jacket the places, where cracks were found. One reinforced concrete (RC) was tested under slow-cyclic lateral loading. The addition of monolithic RCC strips and ferro-cement jacketing improved the damage tolerance, lateral load resisting capacity, stiffness, ductility, and energy dissipation of the frame. Diagonal crushing of brickwork was eliminated by placing monolithic RCC strips in the infill bays [22].

Ferro cement can provide an effective confinement jacket for existed concrete columns and has great potential for use as a strengthening material.

2.8 FEM in Ferro Cement Research

The finite element method (FEM) is popular for civil engineering applications worldwide. With the power of computer hardware improving dramatically over the last 30 years, the simulation speed has significantly increased, and the use of new elements and finer meshes, plus experience and feedback from experiments, have improved the accuracy of the results, saving engineers both time and money.

Many engineers and researchers use FEM for structural design and analysis. However, for ferro cement structures, FEM is still a new territory; this is because there are only a few people who have conducted simulations on Ferro cement, although the reinforced concrete structure is a major material in construction. [23]

Abaqus to model experiments on strengthened concrete beams under bending. The load-deflection curves from the models closely correlated with the experimental results. Two-dimensional (2D) and three-dimensional (3D) models were developed for comparison with experimental results. It was found that the 3D non-linear models gave the most reliable predictions. Also, the interaction between the matrix and mesh layers was reported to be critical in analyzing behavior, and a perfect bond was found to be appropriate. [24]

The previous literature shows that FEM can be used in studies and can provide acceptable results. Three-dimensional models were reported satisfactory for behavior studies of complex structure. Besides, the 3D model can make parametric studies, especially the effects of geometry and mesh layer numbers, easy to undertake. Consequently, 3D FEM models were used in the simulation studies in this thesis.

2.9 Summary and Conclusions

Based on the literature review in this chapter, it can be seen that has several advantages when compared with reinforced concrete structures, such as it is lightweight, easy to shape, and has a low carbon footprint and smaller crack width. Due to the closely distributed reinforcement throughout its cross-sectional area, shows homogenous properties. Because structures are not within the mainstream of reinforced concrete structures, their development in the last one hundred years has been very slow. However,f erro cement has high potential as a retrofit or strengthening material; for example, Ferro cement jackets can be used on reinforced concrete columns.

The finite element method (FEM) is popular for civil engineering design and analysis. It can quickly predict structural behavior, thus saving money, but its use with new materials does need to been proven, e.g., for ferro cement.

CHAPTER THREE

3 Experimental Tests

3.1 Introduction

This chapter presents the details of the experimental tests reported in this thesis. These include:

- **Material property tests**: Five materials/elements were tested: concrete, matrix, Mortar matrix, 6 mm steel bar, 2.5 mm general steel bar, and 0.8mm welded mesh. The results are used as input values for the Finite Element Model (FEM)
- **Casting the column specimens**: Fifteen columns were cast and tested. All columns were tested using static loads.
- **The equipment setup**: The specimens were tested as vertical cantilevers, with one partialy fix end, and the load applied to the other end.

3.2 Material property tests: concrete and matrix

3.2.1 Experiment preparation

The experimental program included casting, curing, and testing the specimens. The concrete and matrix both contain cement, sand, aggregates, and water as per code ACI (American Concrete institution). The details of the components are given below:

- **Cement:** The cement used was Ordinary Portland Cement (OPC), which was stored under dry conditions so that the cement used in the experiments was fresh and free of lumps and other foreign matter.
- **Fine aggregates:** Normal-weight natural river sand and uncrushed gravel were used in the matrix. The maximum particle size was 2.36 mm, passing through a No. 7 sieve.
- **Coarse aggregates:** The coarse aggregate used was uncrushed gravel with a maximum particle size of 19 mm.
- **Water:** Clean and fresh potable tap water were used throughout, being free of organic matter and acidic material.

The mix ratios for concrete and the matrix were constant for all of the experimental tests.

For the concrete: The proportions of the cement, water, fine and coarse aggregate were: 380kg/m^3, 192.5 kg/m^3, 692.92 kg/m^3 and 1154.4 kg/m^3 respectively, which is based on code provision [25].

For the matrix: The cement and sand were mixed in the ratio of 1:2 by weight, and the water-cement ratio was 0.5 [1].

3.2.2 Sampling

The concrete and matrix test cube were cast in clean molds lubricated with grease oil, to make the demolding easier when the material had hardened. All materials were weighted and well mixed in a blender see Figure (3.1). Then the mixture was poured into the mold (150×150 mm cube mold), and mechanical vibration applied. A vibrating table was used to provide expulsion of air voids and compaction, and the material cover controlled using a handheld float. The specimens were cured in a container up to 28 days, as shown in figure (3.2).

Figure 3-1: Mixer and Matrix mix in the blender

Figure 3-2: Curing of Samples

3.2.3 Specimen tests

3.2.3.1 Compressive test:

The cubes were centered on the lower platen of the testing machine. A constant rate of 0.5 kN/sec loading, the load, and strain recorded. The compressive strength is:

$$f_{cm} = F_c/A_{cy} \quad \text{……………………………………………………………………….3-1}$$

where:

f_{cm} Compressive strength

F_c Maximum load at failure

A_{cy} Cross-sectional area of the cylinder

The value of Young's Modulus (E), and Poisson's ratio (υ) were taking from the code

$$\text{Young's Modulus (E)} = \sigma_y/\varepsilon_y \quad \text{………………………………………………………..3.2}$$

where:

σ_y =The yield stress

$= 0.4\, f_{cm}$

ε_y =The strain at yield stress

$$\text{Poisson's ratio } (\upsilon) = \varepsilon_t/\varepsilon_y \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3,$$

where:

ε_t -The lateral strain at yield stress

Figure 3-3: Compression test

3.2.4 The test results

Typical stress-strain curves for concrete and the matrix under compression are shown in Figures 3-4 and 3-5, and results present in Table 3-1. The average compressive strength of the concrete reached 38.3 N/mm^2, and the compressive strength of the matrix reached 35.02 N/mm^2. The values of Young's Modulus were 31000N/mm^2 and 21000 N/mm^{2,} respectively.

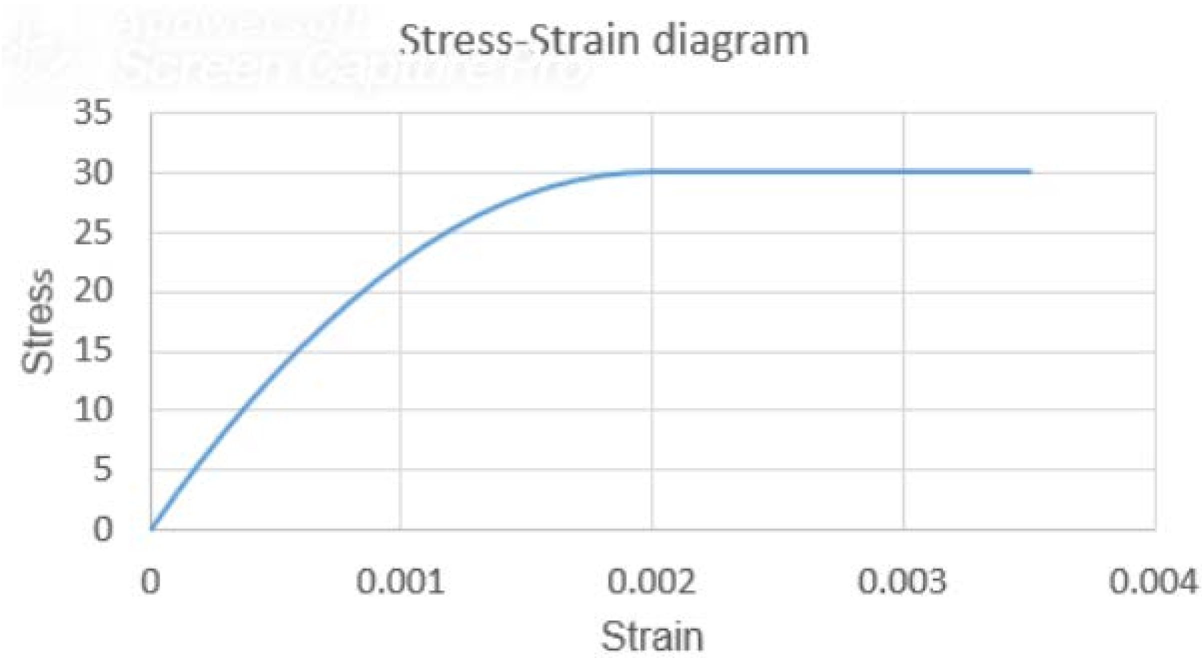

Figure 3-4: Typical concrete cubic compressive test of stress-strain curve [26]

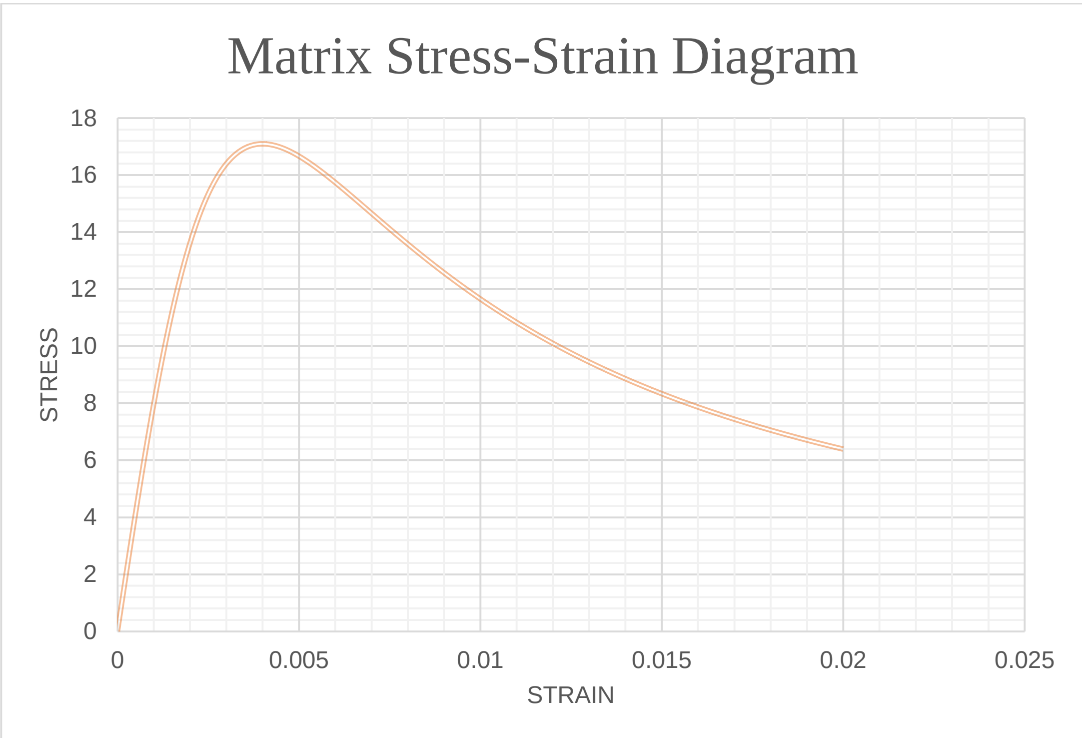

Figure 3-5: Typical matrix(Mortar) cubic compressive test of stress-strain curve(Popovics model for compressive matrix property) [27]

Table 3-1: The material properties of the concrete and the matrix

Material	Compression strength (N/mm^2)	Young's Modulus (N/mm^2)	Poisson's ratio	Tensile stress (N/mm^2)
Concrete	30	31000	0.2	1.8
Matrix	17.1	21000	0.16	-

3.3 Reinforcing material tests

Three different types of reinforcing material were used for the reinforced concrete and ferro cement specimens.

1) 6 mm diameter steel bar
2) 2.5 mm diameter general steel bar
3) Galvanized square welded steel mesh with 0.8 mm wire diameter, 10 mm mesh opening

The material properties were measured using tension tests in a UTM (Universal Tensile Machine) test machine with a capacity of 2500 kN. The tension tests were performed on each sample with a 50 mm gauge to record the results. The tests were carried out with a displacement ratio: 5 mm/min until the specimens cracked. All the specimens were cut in 600 mm lengths.

Figure 3-6: Longitudinal bar test set up

The mechanical properties of the reinforcing materials are presented in Table (3.2). The welded mesh had yield strength 350 N/mm^2 with Young's Modulus 200000 N/mm^2.

Table 3-2: The properties of the reinforcing materials

Reinforcement	Diameter (mm)	Yield Strength (N/mm^2)	Young's Modulus (N/mm^2)
General steel bar	6	460	195000
General steel bar	2.5	460	190000
Weld mesh	0.8	350	175000

3.4 Column Specimens

A sequence of 15 columns was proposed to investigate the effects of reinforcement amount on the static load behavior. Table 3-3 below gives the columns and their designation. Control columns of Cement mortar strengthening reinforced concrete were provided and compared with ferro cement strengthening Reinforced columns with different layers of mesh (which provides a similar area of longitudinal steel) and two layers of mesh to investigate the effect of steel content. Also, control columns that had been overlain with two and three layers of mesh were used to investigate strengthening. The relationships between the fifteen (15) specimens are shown in Figure 3-9.

Table 3-3: Specimen nomination

Number	Naming	Description
1	RCS	Reinforced concrete under static test – Control specimen
2	NWCSS	Reinforced concrete strengthened using mortars cement under static test
3	SWCS	Reinforced concrete strengthened using one layer mesh ferro cement under static test
4	DWCS	Reinforced concrete strengthened using two-layer mesh ferro cement under static test
5	TWCS	Reinforced concrete strengthened using three-layer mesh ferro cement under static test

3.5 Casting

3.5.1 The Reinforced concrete columns (RC)

Fifteen square reinforced concrete columns were cast. The column reinforcement is shown in Figure 3-7, and consisted of four longitudinal 6 mm diameter steel bars and four 2.5 mm diameter steel bar stirrups, with 150 mm spacing in between. All square columns were cast in a horizontal position using steel molds for the formwork, as shown in Figure 3-8. The steel molds were properly oiled on the inner sides for easy removal of the specimens at the time of de-molding. The prepared reinforcement cage was held carefully in the molds. Concrete spacers of 25 mm size were used to maintain a 25 mm concrete cover to the main reinforcement. The concrete was poured in three layers, and compaction of each layer was carried out using a vibrating table to remove air voids. Six concrete cubes were cast at the same time. After 24 hours of casting, all columns and cubes were demolded and cured under plastic sheets so that loss of moisture was avoided.

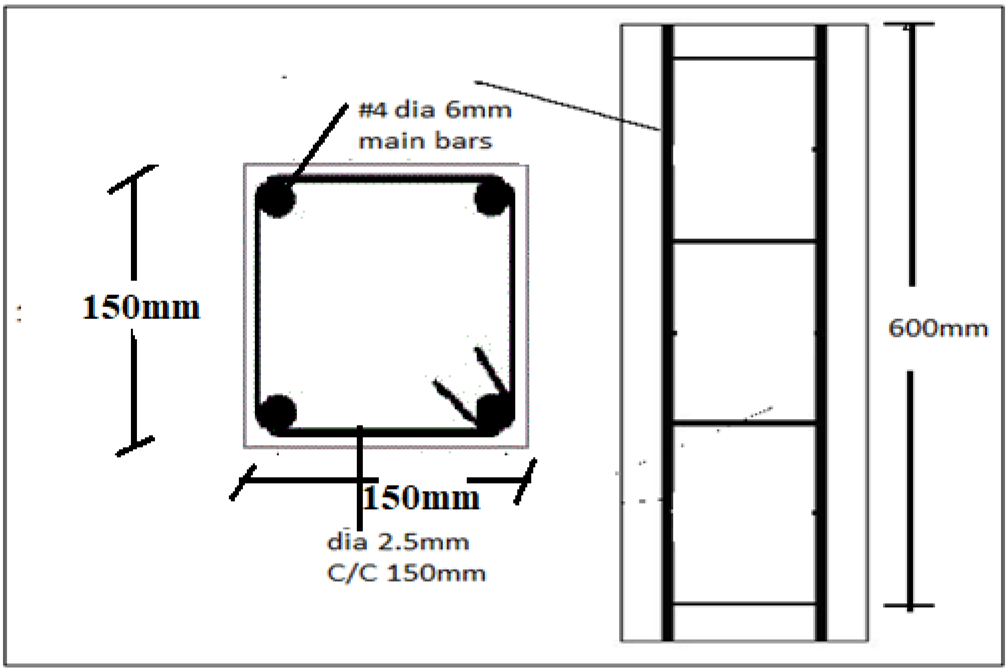

Figure 3-7: Reinforcement arrangement in the concrete column

Figure 3-8 : Reinforcing steel in a Rectangular oiled steel mold

Figure 3-9: The Specimens of controls and Reinforced concrete strengthen by Ferro cement

3.5.3 Reinforced concrete column strengthened using Ferro cement jacket (RFC)

After the concrete attain maximum compressive strength (28 days), The 12 reinforced concrete columns were strengthened by ferro cement jacket using the following technique:

- All strengthening column have chiseled using steel hammer and concrete chisel,
- Put “bohaka’ thin mix cement with water as a binder material
- Apply first coat plastering
- Wrapping a single layer of wire mesh
- Again apply a second coat and wrapping the second layer and the plastering is continued until it fit the vertical alignment.
- Finally, finishing work has conducted.

In each, three RC (reinforced concrete) columns are strengthened by one-layer mesh ferro cement, two-layer mesh ferro cement, and three-layers ferro cement. Figure 3-

10 shows the pattern of one, two, and three-layers mesh around the reinforced concrete.

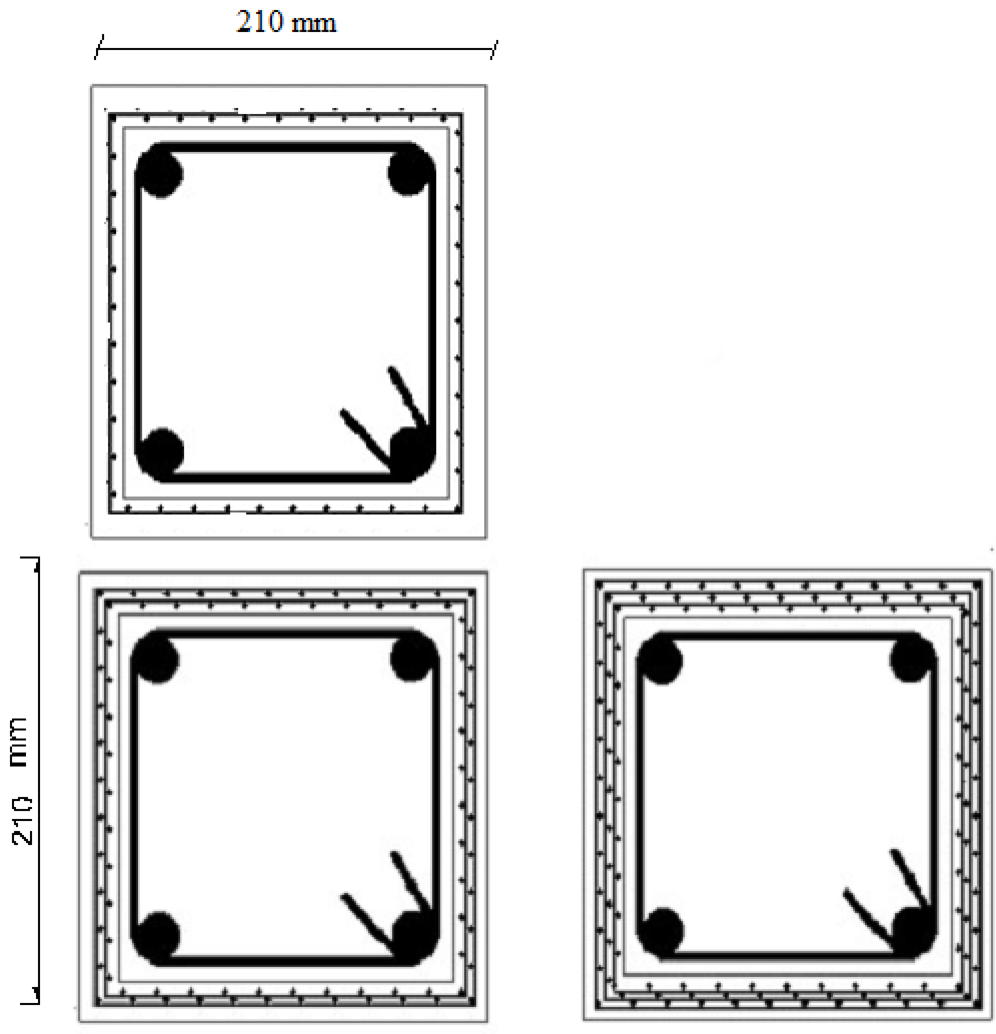

Figure 3-10: The pattern of reinforced concrete strengthened with 1, 2 and 3 layers' mesh

The fresh matrix was cast in accordingly, where the cement to sand ratio was 1:2, and the water to cement ratio 0.5. After finishing each coat of plastering, the enclosed 1,2 and 3 layers welded mesh were wrapped over the square concrete column (Figure 3-10). Then a steel trowel was used and force applied to ensure full penetration of the matrix into the mesh. The final dimensions of the column were 210 × 210 mm. A steel float was used to make the surface of the ferro cement flat. During the plastering process, the tape was used to ensure each size was close to 210 mm. Figure 3-11 shows the preparation of strengthened columns. The strengthened reinforced concrete columns procedure and after finishing curing are shown in Figure 3-13 and 14. The outer ferro cement jacket was not formed in a mold; hence, the outer surfaces of the specimens were coarse.

Figure 3-11: Preparation for strengthening : (a) Measuring, Cutting (b) chiseled specimen to create rough surface (c) put “buhaka” thin mix cement with water (d) mash wire and Put the square mesh on

Figure 3-12: Strengthening procedure (a) applying first coat (b) wrapping mesh wire (C) keeping horizontal and vertical alignment (d) finishing

Figure 3-13: Curing the strengthened column

3.6 The Experimental Rig

3.6.1 The Methodology

The specimens were tested under monotonically increasing concentrated load applied at the top with the universal test machine of capacity 2000KN. Both control and jacketing specimen are tested until failure. Figure 3-15 shows a schematic plot of the experimental programmer with the arrow indicating the axial load.

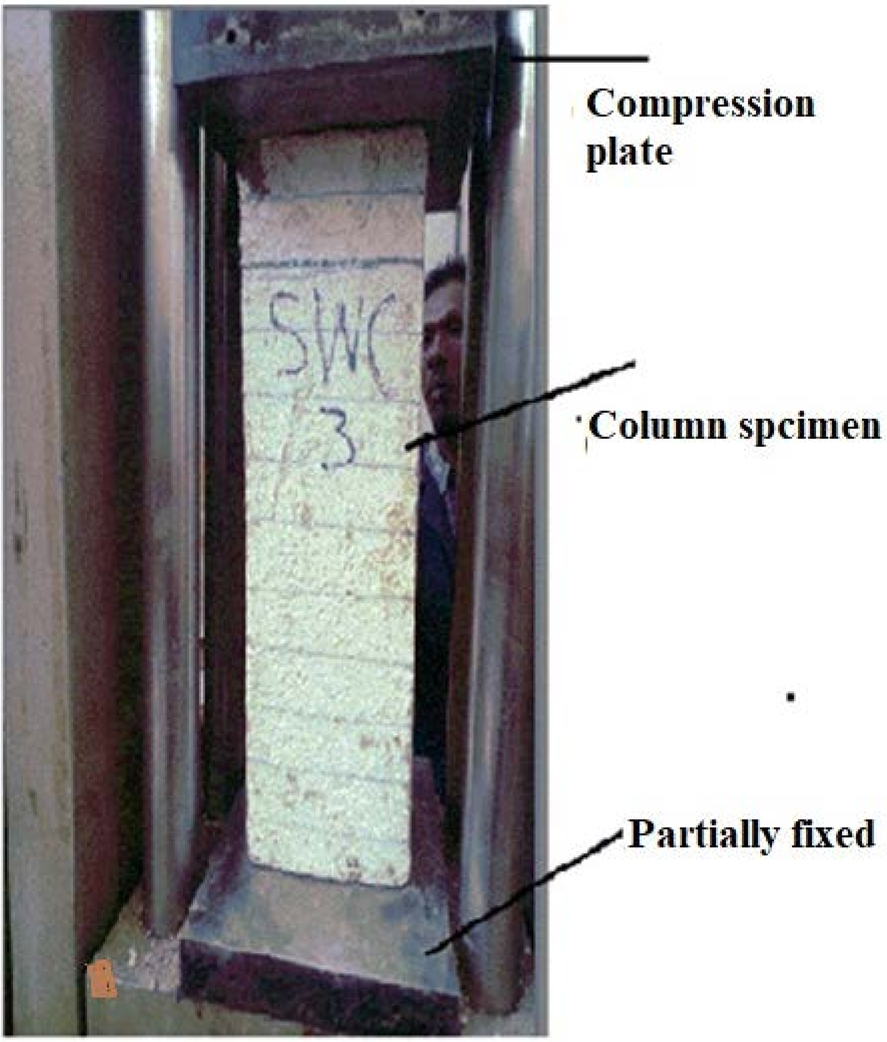

Figure 3-14: The column test layout.

CHAPTER FOUR

4 FINITE ELEMENT MODELING

4.1 Introduction

Conducting column tests on ferro cement structures is time-consuming and expensive. To avoid these problems, Abaqus , a commercial FEM package, has been used by researchers to study the behavior of reinforced concrete structures. Due to the similarity of ferro cement and reinforced concrete, and based on the available literature, Abaqus has been used by the author in the present study.

Abaqus has the ability to simulate complex structural behavior under different loading conditions, such as tension, compression, shear, etc. Complex detailed models require significant computational resources. Ideally, the finite element model needs to be kept as simple as possible. Because of the nature of the reinforcement in ferro cement, a large amount of ferro-mesh, including connections, needs to be built into each model. If a complete three-dimensional (3D) solid model is chosen for the ferro-mesh, the model sizes and computational time will increase dramatically, which is undesirable for research purposes. Also, a 3D-solid detailed model is not needed to capture the behavior that is required in this study. Hence, a 3D non-linear FE truss model was chosen for the ferro-mesh.

Compared to the welded mesh, the matrix requires less element refinement. Also, in ferro cement structures, the performance of the matrix influences the initial cracking and ultimate strength in compression. So a 3D non-linear finite element analysis approach is adopted for the ferro-matrix to provide a simulation that is more detailed and to provide more accurate results. The type of elements selected for matrix and ferro-mesh affect both the accuracy and the time taken for the computation.

4.2 Element Type

4.2.1 Solid Element: Concrete and Matrix

In the Abaqus (2009) element library, there are different types of elements, for example, hexahedron (brick), shell, triangular prism. etc. The most commonly used element for concrete studies is the three-dimensional brick elements, is shown in Figure 4-1. C3D8 and C3D8R are the two main types of brick elements.

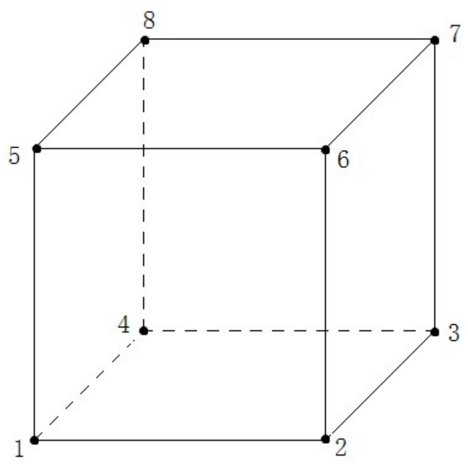

Figure 4-1: The three dimensional brick elements

C3D8: is a fully integrated linear hexahedral element, which contains eight Gauss points. The main advantage of this element type is its accuracy. The disadvantage is for flexural dominated structures. Shear locking phenomenon is commonly associated with this element type, especially for the elements bent, the finer element mesh could be solving this problem with a longer time to simulate.

C3D8R: is an eight-node reduced-integration brick element, which has one Gauss point at the center. Due to insufficient stiffness, the spurious singularity may occur. It is possible for the elements to be distorted so that the strains calculated at the integration point are all zero, which leads to uncontrolled distortion of the mesh. To control this, an artificial stiffness method and artificial damping method in the Abaqus code is proposed. For this thesis, the element used for concrete and the matrix was C3D8R. Using C3D8R underestimates the failure load slightly, but it is less time consuming, and good results are obtained by adopting fine meshes.

4.2.2 Truss element: steel bar, stirrup and welded mesh

The reinforcement materials, including flat bars, stirrups, and the welded mesh, are modeled using the T3D2 truss elements. These are two-node three-dimensional straight truss elements.

4.3 Concrete damaged plasticity model

The concrete damaged plasticity (CDP) model is capable of capturing the behavior of concrete and quasi-brittle materials. The inelastic behavior of concrete can be incorporated using isotropic damage elasticity in combination with the isotropic tension and the compression plasticity. The model considers the degradation of the elastic stiffness due to tensile and compressive plastic straining. The material property input in Abaqus is in two groups, uniaxial stress-strain curves, and plasticity parameters. These are shown in the following sections:

4.3.1 Euro code 2 concrete material model:

Figure 4-2 shows the relationship between stress and strain for concrete under uniaxial compression, the mathematical expression of which is given in Eq (4-1).

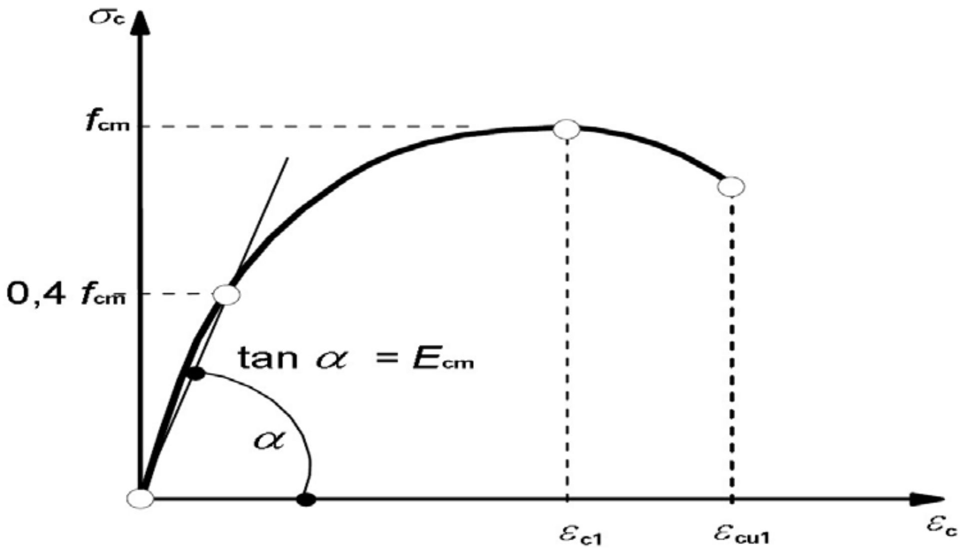

Figure 4-2: The stress-strain curve for concrete under uniaxial compression *[26]*

where:

f_{cm} = Concrete cylinder compressive strength

ε_{c1} = Compressive strain at peak stress, $0007 f_{cm0.31} < 0.0028$

ε_{cu1} = Ultimate strain, 0035 for $f_{cm} < 58$ Mpa

E_{cm} = Young's modulus of concrete, $22(0.1 f_{cm})$^0.3

The equation of this curve is:

$$\frac{\sigma_c}{f_{cm}} = \frac{k\eta - \eta^2}{1 + (k-2)\eta} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. 4.1$$

Where:

$\eta = \text{Ratio of compression strain with strain at peak load}, \dfrac{\varepsilon_c}{\varepsilon_{c1}}$

$k = 1.05 \dfrac{E_{cm}}{f_{cm}}$

Figure (4.2) shows the use of the previous equation Eq (4.1) to simulate the experimental data, which predicted the property of concrete.

4.4 Contact

When considering reinforced materials to ensure physical contact, different linking methods are available. Two types of constraints were selected in this thesis; the embedded region constraint and the “Tie” constraint.

4.4.1 Embedded region

Reinforcement in concrete structures is typically provided by rebar. Usually, the rebars are defined as one-dimensional wire truss elements, and the reinforcement can be defined in Abaqus using a single wire. The concrete behavior is independent of the reinforcement behavior, so the interaction between concrete and reinforcement, the embedded bond (perfect bond), is defined in this study to simulate load transfer between concrete and reinforcement. In addition, the welded mesh was also embedded in the matrix structure.

4.4.2 Tie constraint

When concrete columns are strengthened using ferro cement material, the constraint between the concrete surface and the matrix surface was chosen to be a “Tie” constraint in Abaqus . To use this constraint, some basic rules must be followed. In principle, the master surface should be applied to the stronger material compared with the material using the slave surface. Therefore, the concrete surface can be defined as the master face, whereas the matrix surface should be the slave face during the whole simulation.

4.5 Boundary conditions and load application

The boundary conditions and load application used in the numerical simulations were identical to those used in the experiments in Chapter 3. The columns were modeled as being horizontal, with one side having the partially pin-end condition and the other experiencing the applied load. The boundary and loading conditions are shown in Figure 3-14. Reference Points (RP) were introduced in the simulations from the Abaqus toolset, which defines reference points that are used in constraints and connectors. The coupling interactions provide a constraint between a reference node and the nodes on a surface. The following shows the detail.

4.6 Detail description of reinforcement in ABAQUS

The reinforcement of reinforced concrete (RC) and reinforced ferro cemente (RFC) in Abaqus simulation is precisely the same position and amount as experimental specimens, shown in Figures (4.5) and (4.6).

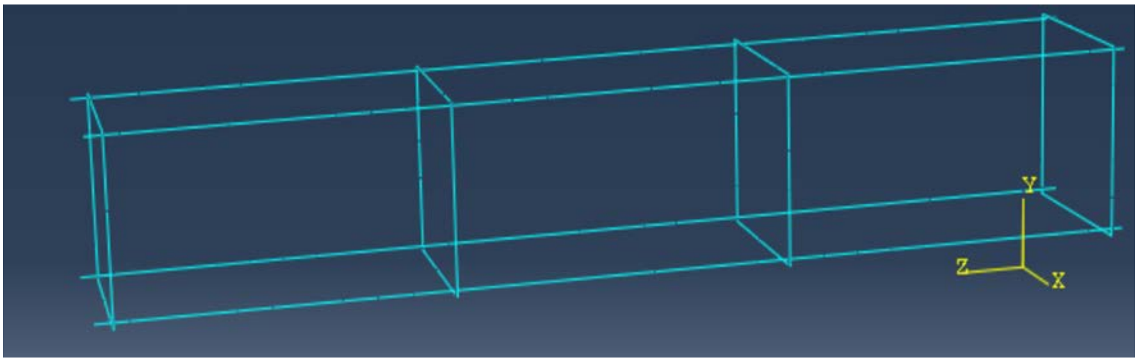

Figure 4-3: Arrangement of reinforcement for unstrengthen column

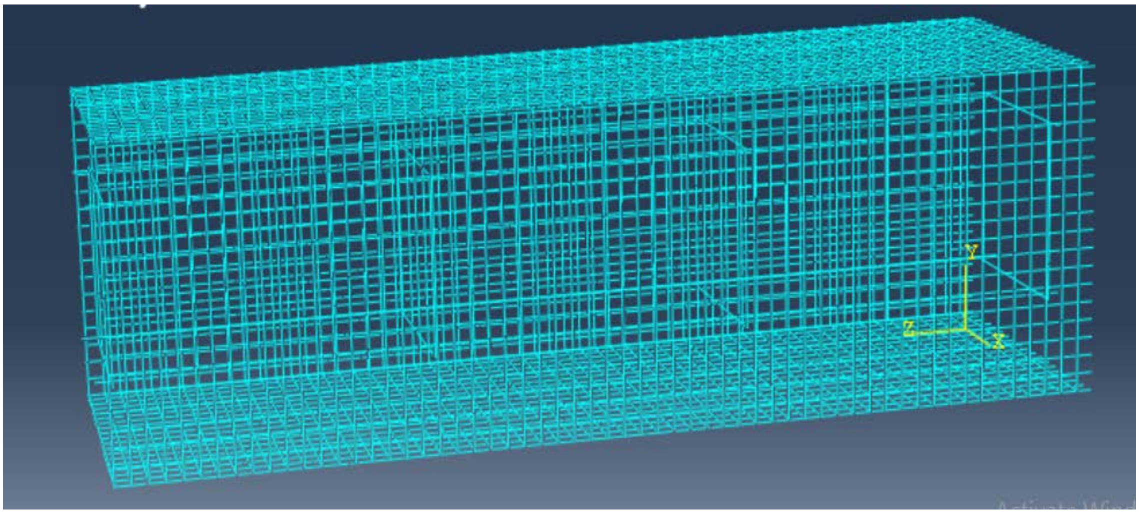

Figure 4-4:Arregment of reinforcement(mesh wire) for strengthen column

4.7 Finite element mesh size

The size of the mesh used in the finite element method (FEM) can affect the results. Although using a finer-mesh can produce more accurate results, a major disadvantage is that a large amount of computational resources is required. To find the most efficient mesh size, It has been conducting diffrenete mash size, From those trial the 20mm mesh size was selected. Figure (4.7) shows the mesh size for the matrix structures.

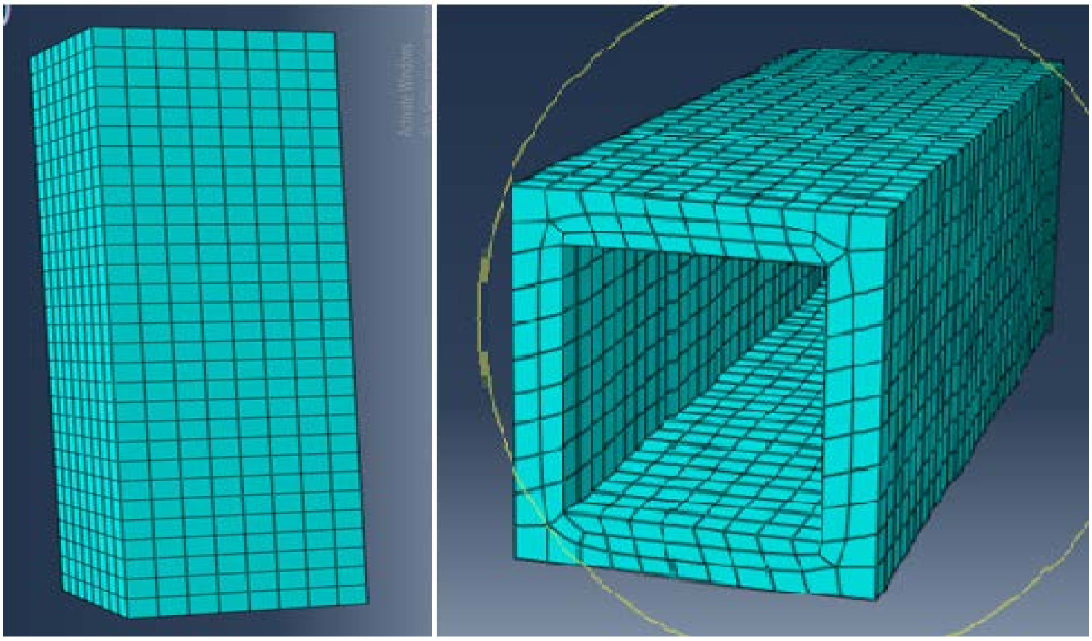

Figure 4-5: The mesh size for the matrix (mesh size 20 mm)

CHAPTER FIVE

5. RESULTS and DISCUSSIONS

5.1 Introduction

In the experimental tests, it is hard to measure the strain variation. Hence, using strain failure as a damage criterion for a structure is extremely difficult. However, the finite element model can clearly show the strain variation of the structure under loading. Moreover, in addition to their high cost, the tests are incredibly time-consuming since the concrete or Ferro cement needs at least 28 days to dry. Therefore, it is challenging to conduct an extensive range of experiments.

The test results are presented in this chapter. The behavior of the specimens during the laboratory experiment is discussed. The effects of a varying number of layers of mesh wire (ferro cement) on the strengthening columns are elaborated in this chapter.

5.2 Control Column

The axial load capacity for the three control column is taken. The column behaves in a ductile manner and gives a large deflection before the final failure. This is the typical behavior of an under-reinforced RC member. The difference between the three specimens is rather small, and the mean value also indicated in the figure (5.1) and Table (5.1).

5.3 Strengthening Column

The axial load capacity for the individual ferro cement strengthened Column in sequence MWCS, SWCS, DWCS, and TWCS is shown in Fig.5.1 and Table 5.1. The results from all column sample types in each series are close, which indicates that the strengthening was conducted similarly. The mean value can be used to represent each series.

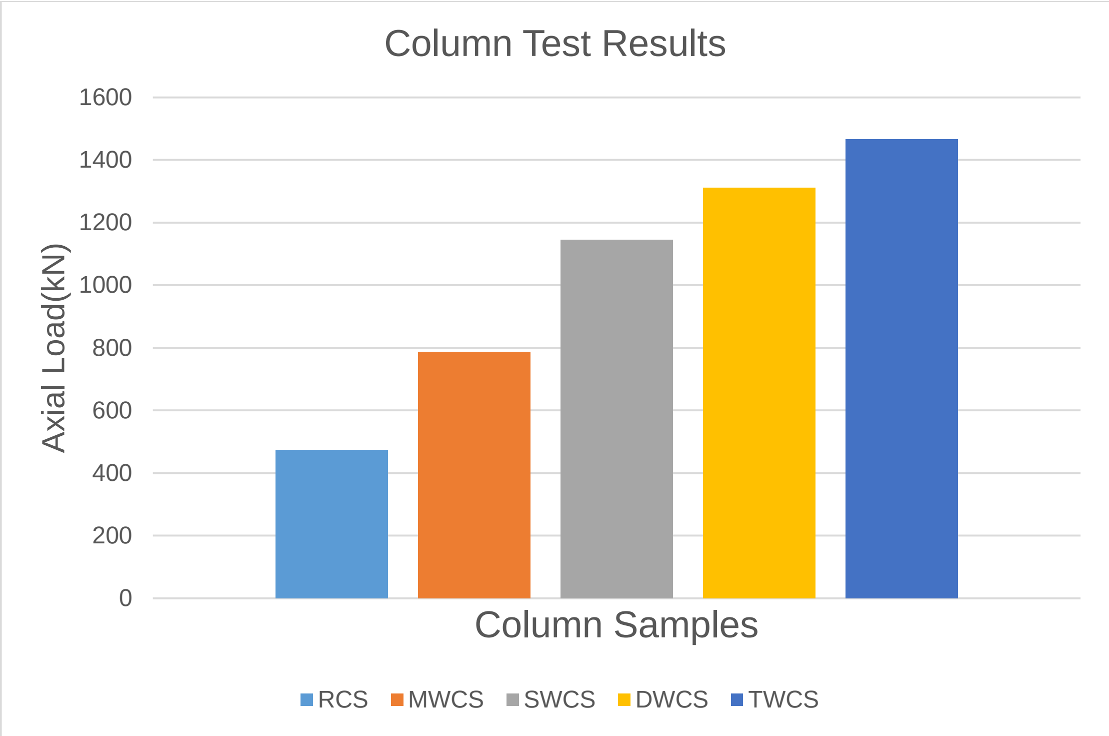

Figure 5-1: Experimental Test Results

Table 5-1:Detailing Experimental Test Results

Sample	Load from Experimental test	Average	Cross section area (mm2)	Pressure (kPa)	Stresses (MPa)	Average	Diffrence with respect to MWCS(%)	Diffrence with respect to RCS (%)
RCS1	562.5		0.0225	25000	25			
RCS2	576.07		0.0225	25603.11	25.6031			
RCS3	573.3	573.523	0.0225	25480	25.48	25.36104	0	0
MWCS1	923.87		0.0441	20949.43	20.9494			
MWCS2	941.5		0.0441	21349.21	21.3492			
MWCS3	936.06	933.81	0.0441	21225.85	21.2259	21.17483	0	0
SWCS1	1210.4		0.0441	27446.71	27.4467			
SWCS2	1297.07		0.0441	29412.02	29.412			
SWCS3	1234.7	1214.057	0.0441	27997.73	27.9977	28.28549	133.58071	111.531273
DWCS1	1311.01		0.0441	29728.12	29.7281			
DWCS2	1321.2		0.0441	29959.18	29.9592			
DWCS3	1298.05	1310.087	0.0441	29434.24	29.4342	29.70718	140.29478	117.137089
TWCS1	1456.42		0.0441	33025.4	33.0254			
TWCS2	1469.51		0.0441	33322.22	33.3222			
TWCS3	1472.89	1466.27	0.0441	33398.87	33.3989	33.24883	157.02052	131.102006

5.3.1 Ultimate Load Carrying Capacity

Experimental test and simulations results show that the ultimate load-carrying capacity of different types of ferro cement jacketed columns is higher than that of conventional Reinforced concrete column control and Mortar wrapping control column. The ultimate load-carrying capacity of SWCS, DWSC, and TWSC types column specimens have a higher value than RCS and MWSC type column specimens. The observed average incremental ultimate load for all column type is given in Table (5.2) and (5.3)

Table 5-2 : Experimental Increment Results

Sample	Load from Experimental Test(kN)	Average	Percentage of Load Resistance Capacity with respects to MWSC (%)
MWCS	923.87	933.81	0
	941.5		
	936.06		
SWCS	1210.4	1214.057	30.01%
	1297.07		
	1234.7		
DWCS	1311.01	1310.087	40.29%
	1321.2		
	1298.05		
TWCS	1456.42	1466.27	57.02%
	1469.51		
	1472.89		

Table 5-3: FEA Incremental Results

Sample	Load from FEA (kN)	Percentage of Load Resistance Capacitywith respect to RCS	Percentage of Load Resistance Capacity with respects to MWSC (%)
RCS	783.63	0	0
MWCS	1380.66	76.19%	0
SWCS	1696.937	116.55%	22.91%
DWCS	1766.347	125.40%	27.93%
TWCS	1934.21	146.82%	40.09%

5.3.2 Deflection Response from FEA

Similar ultimate axial load, all jacketed specimens show higher ultimate axial deflection, i.e., axial ductility than benchmark specimen. Table 5.2 shows the average ultimate axial deflection of all tested specimens. It is clear from the table, and type TWCS shows the highest value of deflection. The typical load-deflection curve of each type of tested specimen is shown in figure 5.2. It is clear from the curve; all jacketed specimens are more ductile than the non-jacketed specimen. In the case of jacketed specimens, type DWCS and type SWCS are more ductile than type MWCS AND RCS**.**

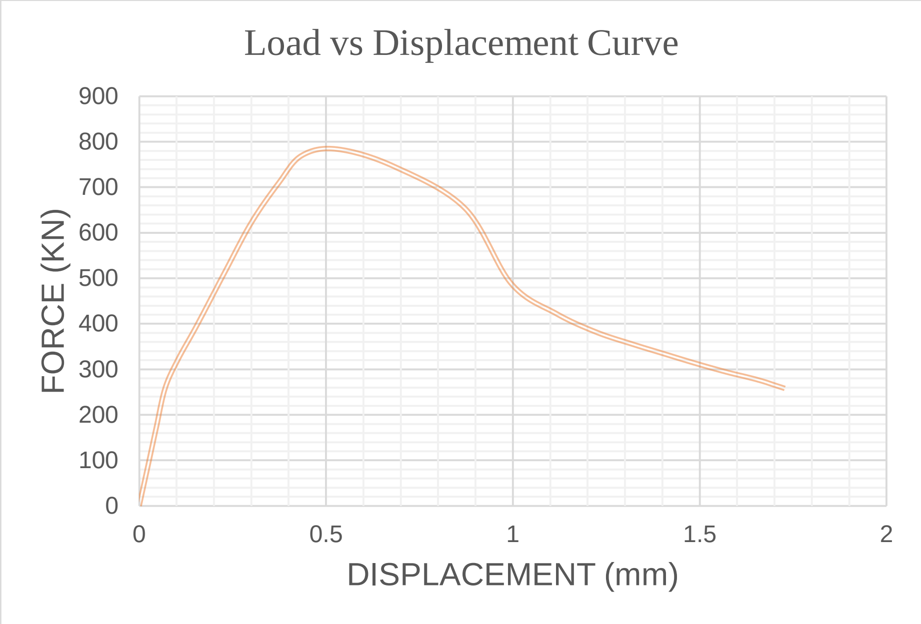

Figure 5-2: Reinforced Column Sample Deflection Response Curve

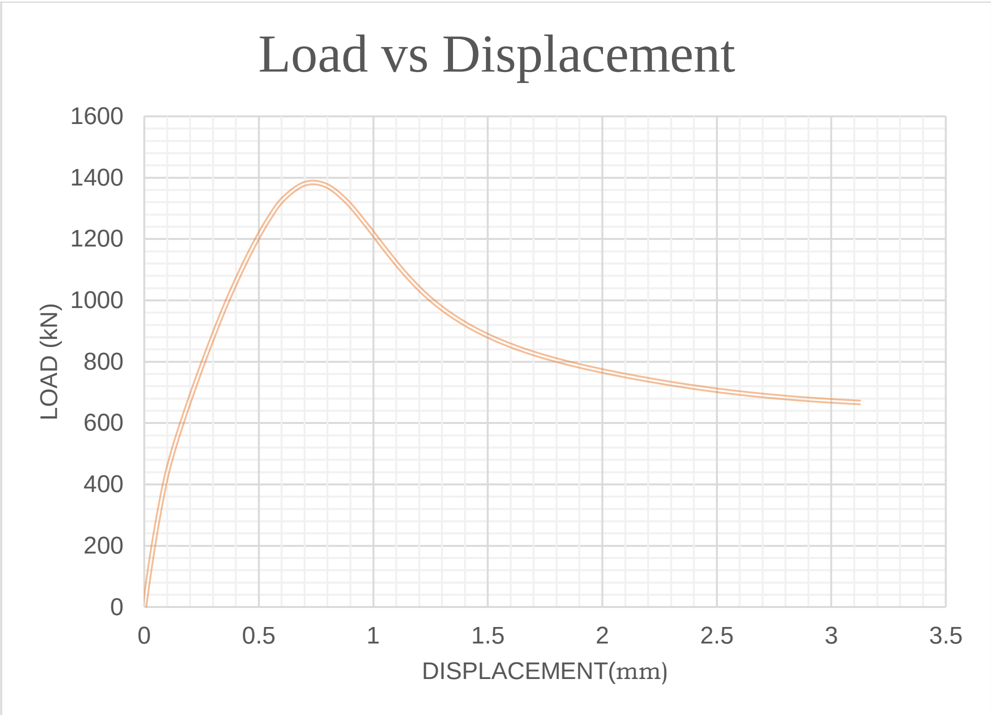

Figure 5-3 : Mortar wrapping Column Sample Deflection Response Curve

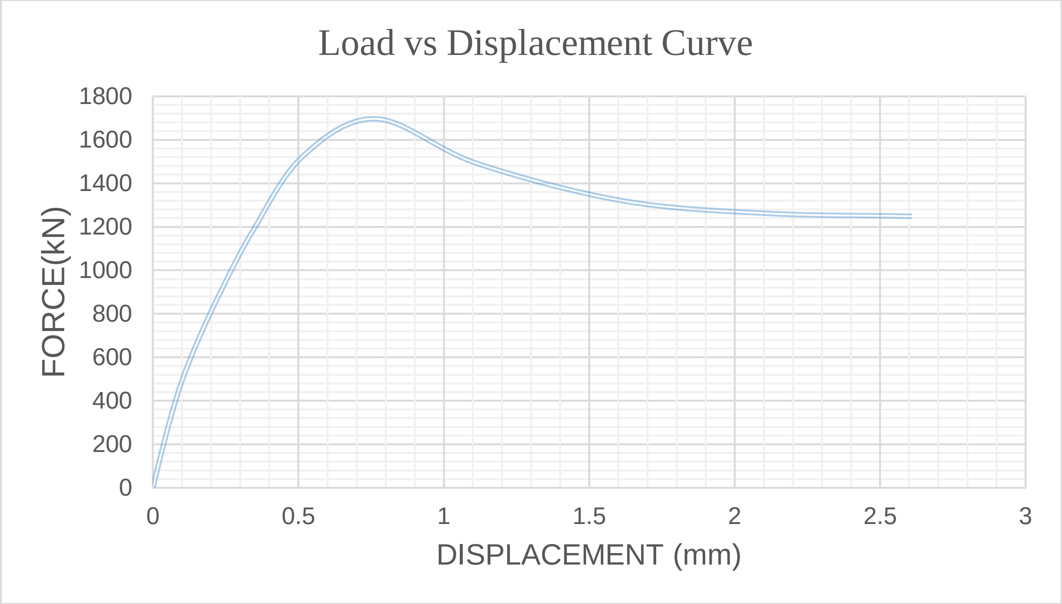

Figure 5-4:Single Wrapping Column Sample Deflection Response Curve

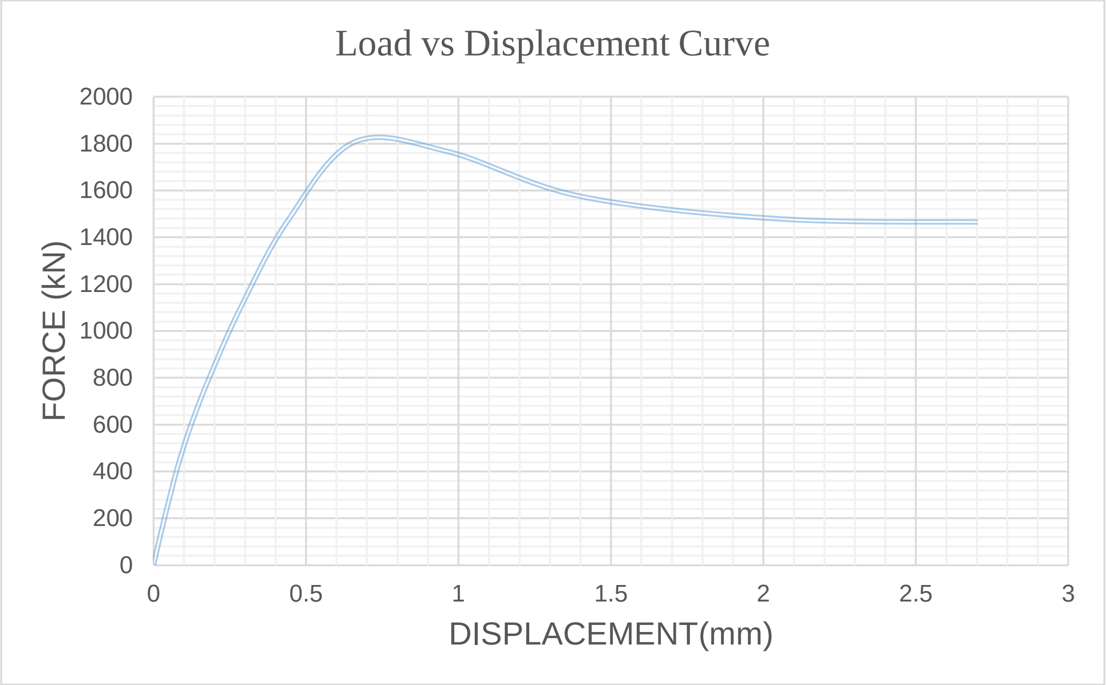

Figure 5-5: Double Wrapping Column Sample Deflection Response Curve

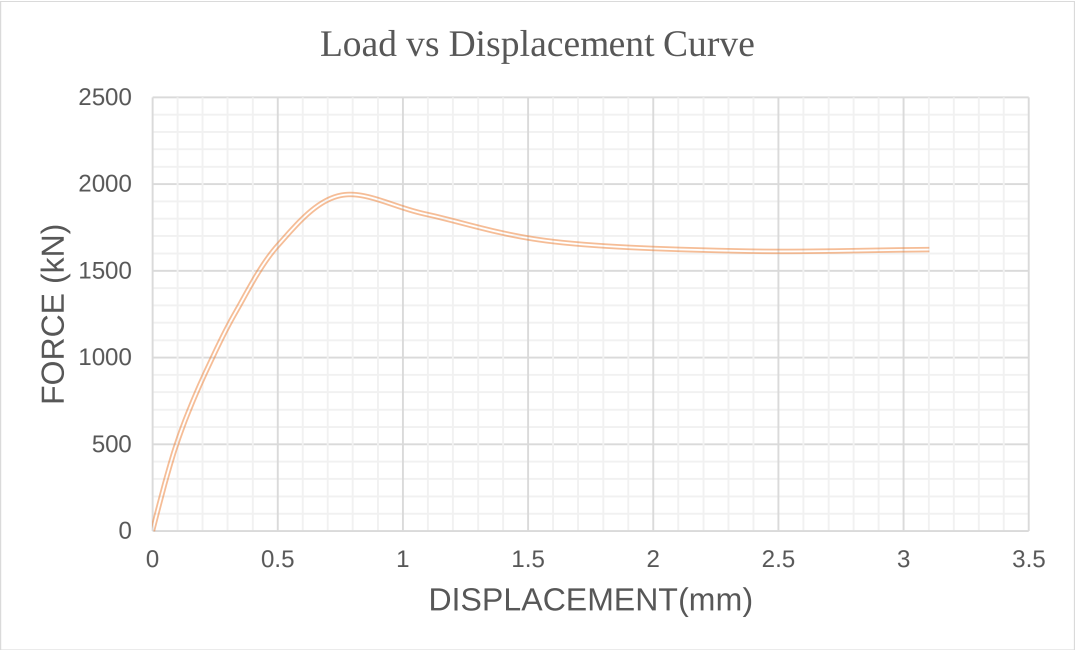

Figure 5-6: Triple Wrapping Column Sample Deflection Response Curve

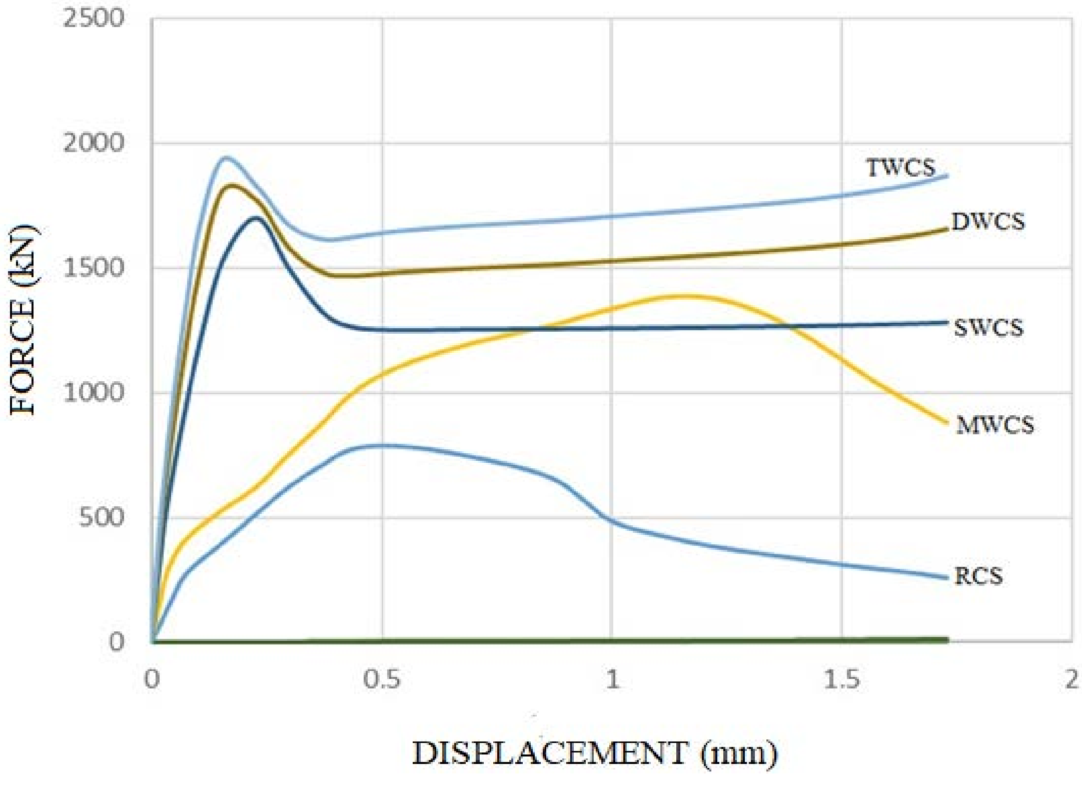

Figure 5-7: All Columns Sample Deflection Response Curve

5.3.3 Failure Pattern

The typical failure pattern of tested columns is shown in figure 5.8. It is seen that the non-jacketed column starts to fail by crushing of concrete at the point of application of load. On the other hand, all jacketed columns begin to fail from the ferro cement jacket. In the case of jacketed column specimen, cracking occurs at both the corner and the middle of each face. Crack width at both the edge and the center of the face in this type are almost similar.

Figure 5-8:Typical failure pattern for MWCS

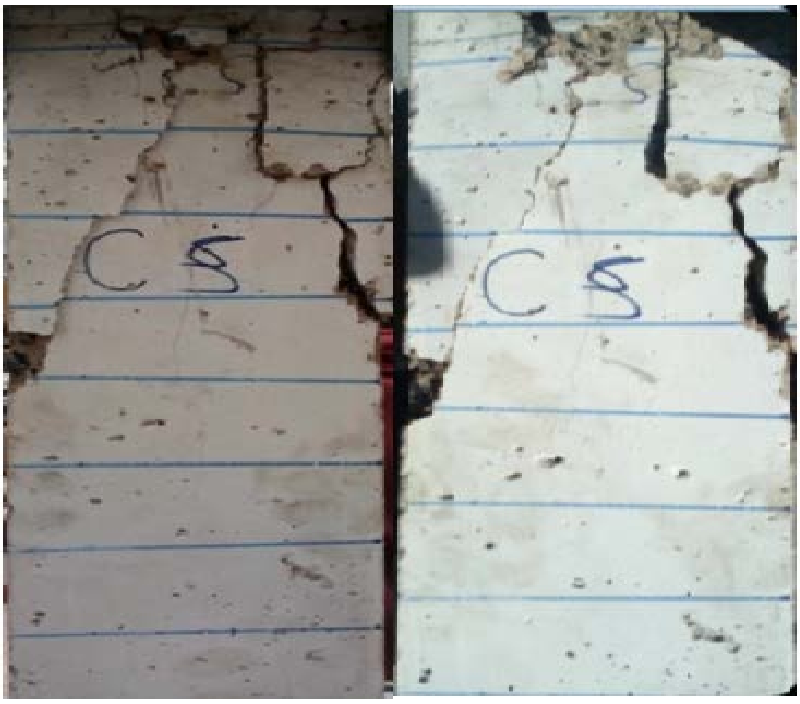

Figure 5-9: **Typical failure pattern RCS**

Figure 5-10:**Typical failure pattern SWCS**

Figure 5-11:Typical failure pattern DWCS

Figure 5-12: **Typical failure pattern TWSC**

5.3.4 Verification of FEM with experiments

Verification of the FEM results using the experimental results is given in the following sections. A good load increment agreement was found between the FEM results and the experimental results, as described in the following sections, especially in the ascending stages and peak loads for all numerical simulations, but with slight differences in the descending part. Three groups of FEM results are compared with the experiment results:

a) Reinforced concrete column (RCS)
b) Mortar strengthening columns without mash wire (MWCS)
c) Reinforced concrete columns strengthened using a Ferro cement jacket (SWCS, DWCS, TWSC)

5.3.5 Compared with Experimental Tests Axial load with FEM

A comparison between the FEM analysis results and the experimental results for RC is shown in Figure 5-13. The values and deviations are presented in Table (5.4). The deviation is calculated using Eq (5.1);

$$\text{Deviation} = \frac{\text{FEM} - \text{Test}}{\text{Test}} \times 100\% \quad \text{.....5-1}$$

Table 5-4: Diffrence between Expiremental and FEA Incremental Results

Name of Sample	Type	Peak load (kN)	Deviation
RCS	Test	573	
	FEM	783	36.635%
MWCS	Test	933.54	31.53%
	FEM	1227.66	
SWCS	Test	1214.057	39.77%
	FEM	1696.937	
DWCS	Test	1310.087	
	FEM	1766.34	39.77%
TWCS	Test	1446.27	
	FEM	1934.21	31.91%

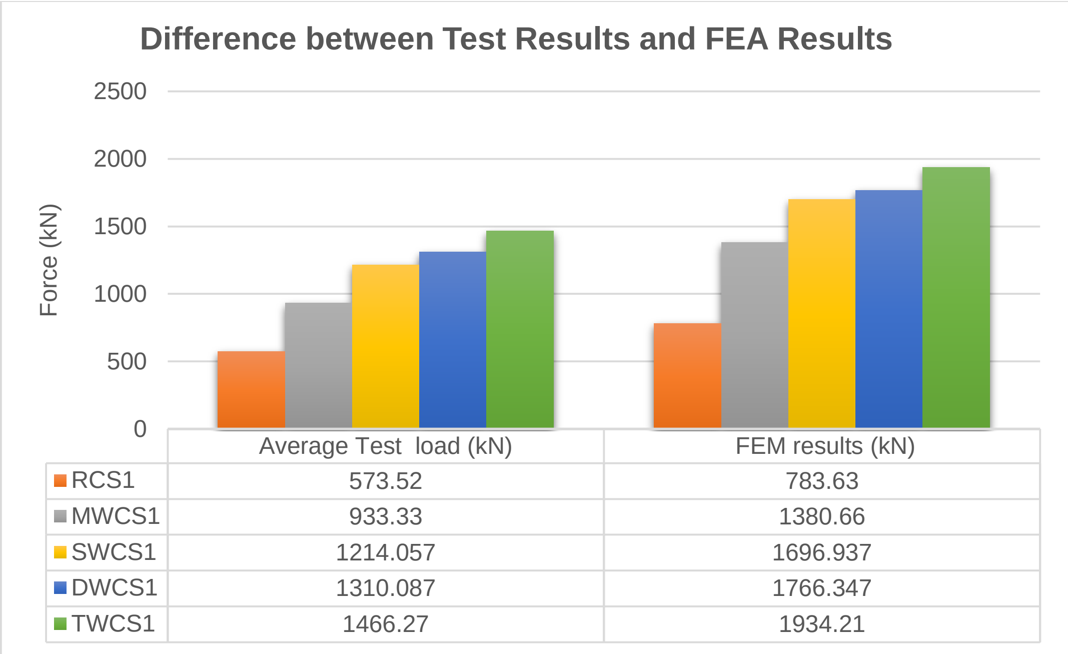

Figure 5-133: Difference between Experimental and FEA Results

5.3.6 Deformation Ductility Results

The value of column deformation ductility is calculated as the ratio of deformation at the failure to deformation at yield. The energy balance method was used to create an idealized bi-linear curve, the effective yield being at the turning point of the bi-linear curve. The load-displacement diagram in Figure 5-14 shows the definition of the deformation ductility, and this is given in Eq 5-2. There are two loads of particular interest, namely the peak load and 85% post-peak.

$$The\ \mathrm{deformation\ ductility}(\mu_\Delta) = \frac{\Delta_u}{\Delta_{y1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots.5.2$$

Where

μ_Δ = deformation ductility

Δ_U=displacement of the column in the descending branch corresponding to 0.85 of the maximum load

$\Delta_{y1=}$ Effective yielding displacement

$$The\ \mathrm{deformation\ ductility}(\mu_\Delta) = \frac{0.925}{0.35} = 2.64$$

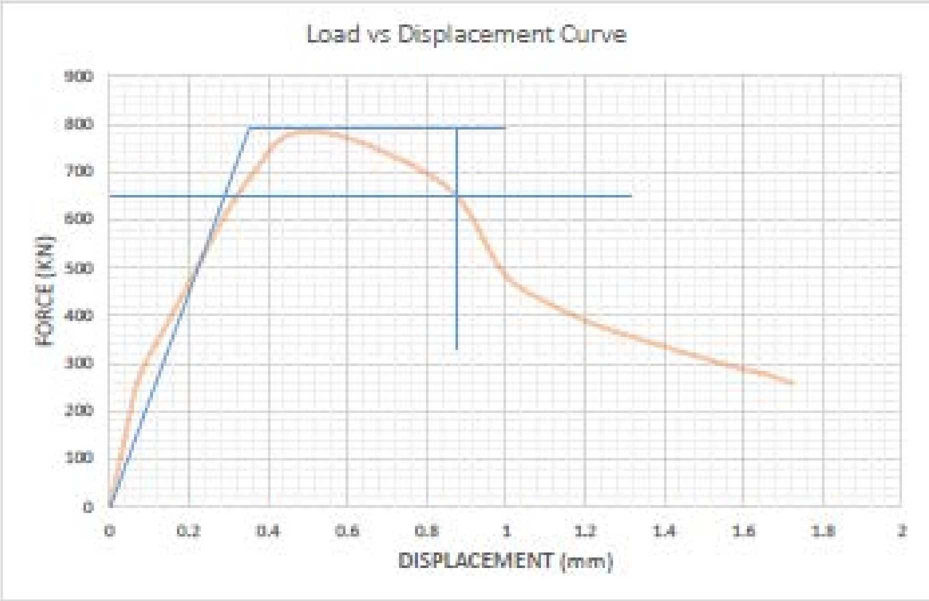

Figure 5-14: The bi-linear idealization curve (RCS)

Table 5-5: Deformation Ductility FEA Results

Name	Type	Peak load (kN)	Effective dis-placement (mm)	Ultimate dis-placement (mm)	Deformation ductility
RCS	**Test**	573	0.35	0.925	2.64
	FEM	783			
MWCS	**Test**	933.54	0.5	1.1	2.2
	FEM	1227.66			
SWCS	**Test**	1214.057	0.5	1.15	2.3
	FEM	1696.937			
DWCS	**Test**	1310.087	0.5	1.7	3.4
	FEM	1766.34			
TWCS	**Test**	1446.27	0.5	2	4.0
	FEM	1934.21			

5.4 Conclusion

In this study, a finite element model, using the commercial package Abaqus, was used to simulate the behavior of ferro cement columns. The results from the experimental work were validated using the FEM, and the behavior of ferro cement or the strengthened columns were expected. The concrete damaged plasticity model was used for this thesis. The Axial load resistance capacity of the simulations had difference with that of the experimental tests as described the previous topice. There are several reasons for the differences between the experimental data and the finite element analysis.

- The embedded interaction used for the FEM is too perfect for simulating the realistic cases as bond-slip may occur.
- The material properties cannot be perfectly input in Abaqus , especially for the tensile property of the concrete or matrix.

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a summary of the main findings of this study and recommends several further studies. Conclusions are drawn from the results and observations of the experimental work and the finite element analysis (FEA) presented in this thesis.

6.1 Conclusion

As the study result indicated, there was a good enhancement in the performance of all wrapping columns. As stated in the literature reviews, the degree of enhancement was directly related to the number of layers of wire mesh wrapping around columns. Based on the experimental work, finite element analysis result, and visual observation, the following conclusions are made. The strengthened of columns wrapping by one layer, two layers, and three-layer welded mesh wire of square specimens give around 30%, 40%, and 57%, enhancement respectively, when compared with the ferro cement column without mesh wire.

For final specimen of ferro cement columns, significant enhancement in peak displacement and ductility were observed in specimens wrapping by mesh wire. Especially while increasing the number of wire mesh layer shows an enhancement in peak displacement and ductility than the control specimen. Therefore, it can be concluded that,

- The ferro cement material can be used for structural use, repairing work, strengthening structures,
    - Simple to apply, no need for high skilled labors
    - It is economical to use for most communities.
    - Create a job opportunity for many professions
    - Ferro cement confinement increases the ultimate load-carrying capacity of columns.
    - It has the ability to deform in a ductile manner
- Experiments and FEA showed that strengthening could increase axial load resistance capacity of the column.
- The axial capacity of the strengthened columns was improved by more than 40% by applying the ferro cement.

- The layers of the wire mesh were found to have a significant effect, mainly where three coats were applied. There was a more significant strengthening effect with better ductility capacity.
- Relatively easy for construction and handling can be used effectively for strengthening RC columns that require an increase in axial capacity.
- The increment in load resistance capacity of the specimen in experimental and finite element analysis results were almost similar.
- The failure modes observed in the strengthening of columns were as the steel reinforcement yields; it was followed by rupture of ferro cement.

6.2 Recommendation

This study highlighted the behavior of square columns under axial load. Due to financial and time constraints, only 15 static tests were performed, and the following points can be recommended for further research.

- Investigating lateral load scenario for reinforced concrete columns.
- Investigating reinforced concrete column strengthening by Ferro cement under cyclic load
- Examining more experimental tests by considering different types of structureral members, shape and dimensions column, such as circular or slender columns.
- Investigating by considering different types of mesh (such as woven mesh) of ferro cement also needs to be considered.
- Investigation of mechanical properties of ferro cement material.

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ANNEX ONE

Construction Methodology

A good repair improves the function and performance of structures, restores and increases its strength and stiffness, enhances the appearance of the concrete surface, provides water tightness, and prevents the ingress of the aggressive species to the steel surface durability.

The Ferro cement construction is done as the following bellows

- Breaking open the damaged spalled cover or the affected zone or the cover of RCC elements (such as beams or columns) with the help of a chisel and hammer
- Select appropriate material like sand mash wire, cement, and water
- Exposing the original reinforcing bars and scraping of corrosive layers of reinforcement and applying anti-corrosive paints (if any) or cutting and replacing the corroded reinforcement
- Roughening the concrete surface, and placing chicken and/or galvanized wire/ weld mesh in position and the mesh should get fixed/ embedded to the original slab/beam/column reinforcement. Use skeletal reinforcement, if required. Ferro cement membrane protective layer can be carried out. In this, layers of closely spaced wires can be used on to the RCC surfaces to prevent crack widening
- Applying cement mortar on the reinforcing wire-mesh by hand or through spraying (similar to grouting/ shotcrete methods The cement matrix is in the proportion of about 1:2 and has admixtures which reduce shrinkage and develop early high strength. The matrix is vibrated locally using light vibrating tools.
- Provide necessary curing for 28 days

ANNEX TWO

Reinforced Mash Parameter Requirement's

Reinforced Mash Parameter					
Vmash	Vtl+VtT	Vmash = both horizontal and Transversal reinforcement			
Vcomposite	12960000	mm3	Vcom = Total Composite volume		
Vr	(Vmash/Vcomp)*100		Vmash=VtL+VtT		
diameter of mash (mm)	0.8		Vmash for RC	68,197.69	
Types	Vtl (mm3)	VtT (mm3)	Total V mash		
SWCS	21900	19830	109927.692		
DWCS	21900	19830	129757.692		
TWCS	21900	19830	149587.692		
Vr single	0.8482075	Should not be less than 1.8% it is not ok			
Vr Double	1.001216759	Should not be less than 1.8% it is not ok			
Vr Triple	1.154226019	Should not be less than 1.8% it is not ok			
		According to 549R-97			
Sr single	0.042410375	0.08mm2/mm3 it is not ok			
Sr Double	0.050060838	0.08mm2/mm3 it is not ok			
Sr Triple	0.057711301	0.08mm2/mm3 it is not ok			
Note: According to the above calculation the reinforcement (mesh wire) provided not satsfied the minimum requirments, But still it improved load resistance capacity of column.					

ANNEX THREE

Concrete Mix Design

Construction Works Bule Hora university		
Concrete Mix Design Class - 30		
Purpose :-	Research	24/6/2018

1.0 Summary of requirements in specification .

1.1 Regarding to the concrete characteristics prescribed by the specifications, those basic data are summarized in the

Table 1/1 as follows:

Table 1/1: Summary of requirements

Parameter	*Description*	*Referrence*
Type of cement	Ordinary Portland Cement	Dangote
Cement content kg/m^3	380	Initial Quantity
Water/Cement Ratio	0.492	ACI 211.1 Table A1.5.3.4(a)
Compressive Strength (N/mr	30	Conteract Specification
Standard deviation	8.5 N/mm^2	ACI-318 M,02 (Table-5.3.2.2)
Slump Required	25 - 75	ACI 211.1 Table A1.5.3.1

2. All quality tests for aggregates for Aggregates are calculated in the laboratory at Mega ~ Moyal Road project and are considerd for this mix design.

3. Flakiness index for coarse Aggregate is

4. The concrete is non air entrained

5. The mix design method adopted is The American Concrete Institute, ACI manual 211-1-97

6. Source of materials

6.1 Dangote , Ordinary Portland Cement

6.2 Stone Dust (Fine Aggregate) , Finchwha

6.3 Coarse Aggregate, Finchwha

6.4 Water from Compound

7. Laboraory Designe Data

Table 7/1: Test data for the Aggregates to be used in the mix proportioning

Description	*Unit*	*Value*
Enterapped air	%	0.0
Bulk Specific gravity for coarse aggregate,19mm (ssd	gm/cm^3	2.669
Bulk Specific gravity for stone dust (ssd)	gm/cm^3	2.645
Fineeness Modulus for stone dust	%	3.080
Specific gravity for OPC cement	gm/cm^3	3.150
Water Absorption for coarse aggregate,19mm mm	%	0.480
Water Absorption for Stone dust	%	0.910
Natural Moisture Content for Stone dust (NMC)	%	0.740
Natural Moisture Content for coarse aggregate,19mm	%	0.100
Oven dried rodded unit weight for coarse aggregaates	Kg/m^3	1549
Oven dried loose unit weight for Stone dust	Kg/m^3	1618
Oven dried loose unit weight for coarse aggregaates,	Kg/m^3	1416

8.0 Targat Mean Strength								
	Fc+s							
	Where :-	S : Standard Deviation		*8.5*				
	TMS=	39	(N/mm^2)					
**** **The cube target Mean Strangth after**						**39**	**(N/mm2)**	
From this value , the 7 days strength result will be calculated as 67%of the 28days mean strength, ie.=							26	(N/mm^2)
From this value , the 3 days strength result will be calculated as 40%of the 28days mean strength, ie.=							15	(N/mm^2)
9. Dry mass of coarse aggregate Determination								
The quantity of corse aggregate estimated from ACI211-1-23 table A-1.5.3.6 for afineness modulus of fine aggregate,								
3.09 and nominalsize of coarse aggregate 19mm indicates 0.60m3, therfore,the required dry mass for coarse aggregate								
will be calculated as								
= Over dried Rodded Unit Weight for coarse aggregate *						0.60	m^3	
929.4	kg							
10. Mixing Water Determination (Excluding Absorbed Water)								
From ACI211-1-97 table A1.5.3.4 (a) water cement Ratio is taken as 0.5 and at the same time from the project specification								
table 8404-1, the 28days cube compressive strength is estimated to be 39 Mpa, and 380kg cement is taken for one m^3 Concrete mix,								
Hence the quantity of mixing water will be =				187	kg/m3			
11. Fine Aggregate (Ston dust) Mass determination								
From ACI211-23 table A1.5.7.1, the of a cubic meter of non air entrained concrete made with aggregate h								
19mm is extrapolated to			2345	kg/m3	rsted	2350	Kg/m3	
**** The given masses are :								
			Kg	187				
			Kg	380.0				
			Kg	929.4	ntersted of coa. agg		1150	Kg/m3
	Total mass of ingredients		Kg	2350				
	The mass of Fine Aggregate Stone Dust		Kg	**633.0**				
12. Volume of fine aggregate (River Sand) for one metric cube of concrete								
			M^3	0.187				
			M^3	0.121				
			M^3	0.431				
			%	0.000				
			M^3	0.738				
			M^3	**0.262**				
13. Based on estimated concrete mass Kg .						**%**	**age**	
			Kg/m^3	187.0		7.8		
			Kg/m^3	380.0		15.8		
			Kg/m^3	691.8		28.7		
	Mass of coarse aggregate,19mm		Kg/m^3	1150.0		47.7		
			%/m^3	0.0		0.0		
			Kg/m^3	2408.7		100.0		

14. Absorbed water dose not become part of the mixing water & must be excluded from the					
*Water Absorption					
Water Absorbed in Stone Dust	6.3				
Water Absorbed in coarse aggregate,19mm "	5.5				
Total quantity of water absorbed by both of aggregates "	11.8				
Notural moisture content:					
Stone Dust (kg)	5.1				
coarse aggregate,19mm	1.2				
Total	6.3				
** Net water to be added with the mixing water (kg)	-5.5				
There fore the quantity of materials required for one meter cube of concrete are:					
Water	192.5				
Cement	380.0				
Stone Dust	692.9				
Coarse aggregate,19mm	1154.4				
Air entrained	0.0				
Total quantity of	2420				
aboratory triyal bath weight is scale down to		0.03	m^3		
Water	5.20				
Cement	10.26				
Fine river sand	18.71				
Coarse aggregate 19mm	31.17				
*During mixing in Lab we added			gm of additional water= Nil		

ANNEX FOUR

Analytical Study

		Axial Load calculation of RC column						
fc	30	mPa						
fyd	460	mPa						
b	150	mm						
h	150	mm						
Ac	22500	mm2						
Rebar	6	dia mm						
No of bar	4	pcs						
As	113.09	mm2						
Po=(0.567*fc*Ac)+(0.87 *As*fyd)				Reinforced concrete design Euro code 2				
Po	427983.618	427.9836	kN					
	727021.4	727.0214	kN					
RC column		427.98	kN					
Axial Load calculation of RC column Strengthening by Ferro cement								
Strengthening section	b'		210	mm				
Strengthening section	h'		210	mm				
	Ag	44100	mm2					
	d	0.8	mm					
	Astl	36.69	mm2					
	AstT	30	mm2					
	As	66.69	mm2					
Po=(0.85*fm*Ac)+(As*fyd)								
Po	629.932	kN						
MWCS	630	kN						
SWCS	1057.91562	kN						
DWCS	1084.91562	kN						
TWCS	1111.91562	kN						