JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

COMPARATIVE STUDY ON SHEAR PERFORMANCE OF REINFORCED CONCRETE BEAM BY USING FERROCEMENT COMPOSITE

A Research Submitted to School of Graduate Studies of Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Structural Engineering

By:

EDOSA MEGERSA ABAHARA

July, 2021

Jimma, Ethiopia

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By:

EDOSA MEGERSA ABAHARA

Advisor: Engr. ELMER C. AGON (Asso. Prof)

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DECLARATION

I declare this thesis entitled “COMPARATIVE STUDY ON SHEAR PERFORMANCE OF REINFORCED CONCRETE BEAM BY USING FERROCEMENT COMPOSITE” Using ABAQUS software for simulation is my original work not has been submitted anywhere and presented for the award of degree in any other university.

Submitted by

1. Edosa Megersa	________________	________________
Researcher	Signature	Date

This thesis has been submitted for examination with my approval as university supervisor.

Approved by:

1. Engr. Elmer C. Agon	________________	________________
Main Advisor	Signature	Date
2. Engr. Eden Shukri	________________	________________
Co-Advisor	Signature	Date

ABSTRACT

Reinforced concrete is building material widely used in construction industry in the world. Currently it's also major construction material in Ethiopia at several areas to construct different structures. Beam is one of structural elements constructed by reinforced concrete which is composed of plain concrete, longitudinal reinforcement and shear reinforcement.

In this paper, the effect of steel wire mesh as replacement of shear reinforcement stirrups on reinforced concrete beam was studied. The replacement of wire mesh was equivalent based upon weight with stirrups. Main parameters considered to study was wire mesh change in diameter, spacing, number of wire mesh layers and combination of steel wire mesh with stirrups.

Nonlinear finite element using ABAQUS 6.14 simulation compared with experimental conducted result. The numerical simulation of control beam by finite element have a difference of ultimate load of failure and maximum mid-span displacement when compared with experimental results about 11% and 15% respectively. Depend on control specimen, geometrical cross section for all beam model was 100 mm x150 mm x 1200 mm of width, depth and span length respectively. Total of 29 specimens were modeled respective to their parameters of study.

The results under change of diameter indicate as diameter increases ultimate load of failure increment about 19.8% and 39.59% respectively but as decrease diameter decrement by 4.08% as compared with control specimen. Change in spacing of wire mesh increment ultimate load of failure as spacing close to each other about 19.8% and 4.79% but as spacing increase decrement by 6.6% when compared with control specimen. For parameters conducted under change in wire mesh layers number of wire mesh layers increases failure load capacity about 51.14%, 38.38% and 22.78% respectively as compared with control specimen. In addition to this using combination of wire mesh with stirrups result give increment load carrying capacity about 2.88% and 19.45%. Number of mesh layers for different spacing have maximum shear stress increment about 71%, 50% and 31.41% respectively as compared to control specimen.

Stiffness increment under change steel wire mesh diameter was about 0.8%, 16.94% and 31.05% respectively as compared with control. Ultimate load increases as diameter and layers increase also as close spacing of wire mesh. In Addition to this combination of wire mesh with stirrups increase shear capacity of beam.

Key words: Ferrocement, Shear performance, Reinforced concrete, Welded wire mesh

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ACRONYMS AND SYMBOLS

ACI	American Concrete Institute
CDP	Concrete damage plasticity
FEA	Finite Element Analysis
FEM	Finite Element Method
d	Maximum displacement
mm	Millimeter
NLFE	Non-linear finite element
C3D8R	Plain concrete three dimension eight node reduced integration
RC	Reinforced Concrete
R3D4	Rigid three dimension of four node
SCC	Self compacting cement
S	Stiffness
T3D2	Truss three dimension two node
3D	Three dimension
F	Ultimate load
W	Weight of reinforcement
f_{cm}	Mean compressive strength of 28 days
f_{ctm}	Mean value of axial tensile strength of concrete
VC	Vibrated concrete
E_o	Elastic modulus of undamaged concrete
E_s	Modulus of elasticity for steel
E_{cm}	Young's modulus of elasticity of concrete
ε_{cu}	Nominal ultimate strain
σ_{nom}	Nominal stress
ε_{nom}	Nominal strain
σ_{true}	True stress
ε_{true}	True strain
ε_c	Compressive strain in concrete
ε_{c1}	Compressive strain at Peak compressive stress

ε_t	Tensile strain
ε_t^{pl}	Plastic tensile strain
ε_c^{pl}	Plastic compressive strain
$\varepsilon_c^{in,h}$	Inelastic compression strain
σ_c	Nominal compressive stress
η	Ratio of compression strain at peak load
d_c	Scalar compression damage variable
σ_{cu}	Ultimate compressive strength
u^{el}	Elastic displacement
u^{cr}	Displacement across crack
f_{bo}/f_{co}	Ratio of Equi-biaxial yield stress to Uni-axial yield stress
μ	Viscosity parameter
G_f	Fracture energy of concrete
G_{ch}	Crushing strain
ν	Poisson ratio
Ψ	Dilation angle
V_u	Maximum shear stress
Φ	Diameter of steel and wire
fctm	Mean tensile strength of concrete

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Ferrocement is a composite construction material where closely spaced wire mesh is embedded with mortar [1], [2]. The ACI committee 549 has defined ferrocement as a thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced small diameter wire mesh. Now a days in the world different technology is being developed in the construction industry, one of them are using simple and easily available materials to have a safe and economical building. One of major composed of structural elements are flexural and shear reinforcement. Shear reinforcement need more special attention than flexure failure because its failure not shown any warning. This paper studied on shear performance of reinforced concrete as replacement of shear reinforcement [3]. Replacement of stirrups by ferrocement is mainly for its highly tensile and flexibility strength.

The use of ferrocement was started on early 1848 by Louis Lambot for marine service and 1940 Pier Luigi Nervi modify the concept of using ferrocement with reinforced concrete using layers of wire mesh making material homogenous to resist impact [4]. Ferrocement is an old version of reinforced concrete. Its design is empirical and formal design guide is not yet developed and is mostly used for traditional reinforced concrete [5]. The modeling of wire mesh allows for cracking, yielding and fracturing which is used in tension, yielding and mushing in compression. Application of ferrocement in widely applied in areas of structural components such as: bridge deck, boat, water tank, roofs, retrofitting and silos [1].

This steel wire mesh is also responsible for ferrocement structures to have greater tensile strength and flexibility which was not happened in ordinary concrete structures. It possesses higher tensile strength to weight ratio and a degree of toughness, ductility, durability and cracking resistance considerably greater than those found in other conventional cement based materials [6]. This material may be made from metallic and other suitable materials it was contain discontinuous fibers now a day used combination of steel rod and wire mesh [7].

Generally in order to investigate and understand behavior of ferrocement, diverse natures of analysis have been performed. Effects of wire mesh orientation, number of wire mesh layers, type of wire meshes and influence of cover thickness on behavior of ferrocement and it had been thoroughly investigated. The most common type of reinforcement is steel mesh other materials such as selected organic, natural, or synthetic fibers may be combined with metallic mesh. This research address only the use of steel wire mesh in a hydraulic cement mortar matrix. The material and inter-facial mechanical behaviors are estimated from relevant models found in previous related works or literature.

1.2 Statement of the problem

Now a day's major problem in construction industry are quality and cost of materials especially relative to reinforcement. In addition to this, shear reinforcement was most critical because sudden failure without showing any warning so, its need more attention both in economical and strength. Based on this problem, further material investigation used as shear reinforcement is necessary. Understanding these can help to work on specific aspects of shear capacity of reinforced concrete beam as replacement of wire mesh was done on the basis of their weight with stirrups.

The thesis seen the comparative study on shear performance of reinforced concrete beam by using ferrocement composite. Materials used for shear reinforcement widely steel stirrups in order to minimize shear but now a days it's important to research many other optional materials to be used instead of stirrups to increase shear performance of beam. Thesis investigate shear performance of ferrocement composite in terms of failure load capacity, shear stress, deflection and stiffness using FEA (ABAQUS) software.

The theoretical identification and assumption in the material performance was not exactly precise to actual so, to know real performance of material have to be evaluate under finite element analysis and compare with theoretical explanation therefore researcher seen other materials rather than stirrups by using of ferrocement under change in diameter of wire mesh, spacing, number of wire mesh layers and combination of wire mesh with stirrups for shear resistance.

1.3 Research question

Can reinforced concrete beam using wire mesh as shear reinforcement under change of diameter increase failure load capacity of the beam?

What is the significant effect of steel wire mesh spacing on shear capacity of reinforced concrete beam replacement of shear reinforcement stirrups?

What is the extent wire mesh layers properties play significant role in increasing shear performance of beam?

Can wire mesh combination with stirrups increase shear capacity of reinforced concrete beam as replacement of stirrups?

1.4 Objective of the study

1.4.1 General objective

The general objective of this research was to investigate the shear performance of reinforced concrete beam using ferrocement composite by finite element analysis.

1.4.2 Specific objective

The specific objectives of this paper were:

- To study ultimate load failure capacity of reinforced concrete beam under change diameter of steel wire mesh
- To evaluate shear capacity of reinforced concrete beam by using ferrocement composite under change of wire mesh spacing
- To investigate the effect of wire mesh layers on reinforced concrete beam as replacement of shear reinforcement
- To compare shear performance of reinforced concrete beam combination of wire mesh with stirrups and stirrups alone

1.5 Significance of the study

The main goal of study is to compare the shear performance of reinforced concrete beam by using ferrocement composite. To investigate safe and easily available material replacement for shear reinforcement in RC beam. In addition to this shear failure was suddenly fail and needed skilled labors for arrangement, overcome those problems using optional material instead of stirrups is a better judgment. Ferrocement also molded into any desired shape needed for different geometrical shapes of beam also for reducing shear crack of beam before period of service and increase life span of beam. In addition to this it helps for student to know behavior of ferrocement property and to investigate any other materials which was replacement of shear reinforcement.

The study add knowledge on understanding the analysis of ferrocement as shear reinforcement response of concrete beams using finite element method and the result obtained from this study is helpful for further study and coming researcher.

This research also support to Jimma University as the center of research and also at a national level this thesis provides the most economical and safe shear reinforcement for reinforced concrete beam. Which is indirectly effect on national economic development.

1.6 Scope Limitation of the Study

The research scope focused comparative study on shear capacity of rectangular reinforced concrete beam by using ferrocement composite. In order to investigate shear capacity of RC beam modeling 29 specimens using wire mesh as shear reinforcement under change in diameter of mesh, spacing and number of wire mesh layers and combination of wire mesh with stirrups. All specimens have the same cross section of 100mm width, 150mm depth with 1200mm span length were used. Simulation and analysis were done using ABAQUS software. The comparative study in terms of shear stress, stiffness, maximum mid span deflection and ultimate load of failure.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

The purpose of this thesis is to investigate the shear performance of reinforced concrete beam using ferrocement composite. In this connection, a descriptive literature survey has been done on the earlier works that are appropriate to the present study. Structural engineers are frequently faced with the task of availability of material and its cost in design of structure. Nowadays, using different optional materials which is economical and safe in RC buildings has become an important issue. The summary of this review is presented under the following topics: increase shear performance 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 related to the materials, mechanical properties, load carrying capacity, stiffness, shear stress, deflection and finite element model of the above topics are discussed in this chapter. Literature reviewer conducted to understand current state of knowledge and to investigate whether information from similar applications suitable for adaptation the use with ferrocement composite. The summary of the review is presented in the following manner:

2.1 Relationship between ferrocement and reinforced concrete

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

1. Both ferrocement 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 ferrocement and reinforced concrete are also significant. The main differences are:

1. Compared with reinforced concrete, ferrocement 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, ferrocement has:

i. much better extensibility;

ii. Smaller crack widths,

iii. Higher durability under environmental exposure; and

iv. Better shrinkage crack control.

v. Better impact and punching shear strength [5].

2.2 Description of Previous Research on Section Enlargement

There are different several literature are reviewed in order to achieve the research fruitfulness and acceptable about comparative study on shear performance of reinforced concrete beam by using ferrocement composite. Study shear performance of RC beam using ferrocement to build safe and economical structure. More over how to improve or increase shear performance of a beam is major focused of literature reviewed.

2.3 Ferrocement Used for Different Beam Types

Ferrocement used for different beam types as replacement shear reinforcement and strengthening of existing beam when loss his strength under different problems faced structural members of beam and for increase load carrying capacity.

2.3.1 Study shear behavior under deep beam

In this section experimental, numerical and analytical study to design shear resistance of flanged ferrocement vertical mesh in web. Two group test used I and U beams and total of seven sample. All I beams had the same geometry and reinforcement arrangements but it’s have different strength and shear span to depth ratio. The U shaped in web, flange thickness, reinforcement arrangement, matrix strength and shear span to depth ratio different.

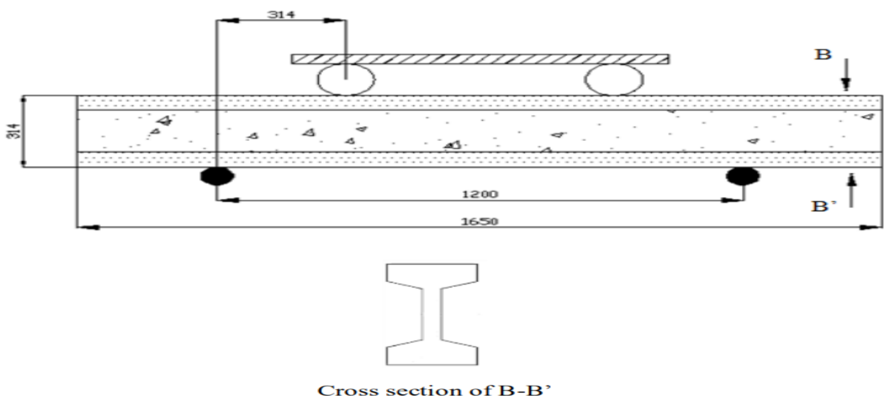


Figure 2.1 Test set up (all in mm) [8]

Table 2.1 Beam specification [8]

Series	No. of layer of wire mesh in the web N_m	Transverse steel ratio %	Longitudinal steel ratio %	Matrix-mix water-cement ratio	Shear span to depth-ratio a/h
U1	2	2.6	2.9	0.55	1
U2	3	3.1	3.5	0.4	1
U3	2	2.6	2.9	0.4	1
U4	2	2.6	2.9	0.4	2
I1	2	0.3	1.37	0.4	1
I2	2	0.3	1.37	0.4	1.34
I3	2	0.3	1.37	0.4	1

Its output show shear failure may occur only when shear span to depth ratio is smaller than 1.5; shear strength may increase by increasing matrix strength, volume fraction mesh, cross sectional area and amount rebar. Main shear failure is diagonal splitting for I beams but U beams is shear failure. Based on result a shear design guide for ferrocement beams was developed [8].

2.3.1.1 Shear and flexural behavior of deep beam

Studied on behavior of ferrocement deep beams under central point load. Specimen used in investigation are 27 rectangular beam with 125 mm width and 250 mm depth but length of beams varied with respect to wire mesh and mortar strength. All specimen cast with cubes of 7.06 cm x 7.06 cm x 7.06 cm to determine compressive strength of mortar.

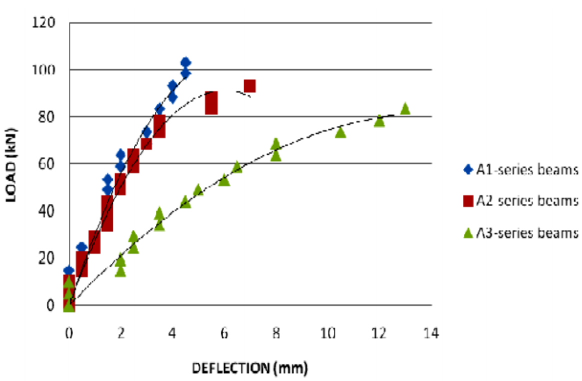
Table 2.2 Detail of test specimens [9]

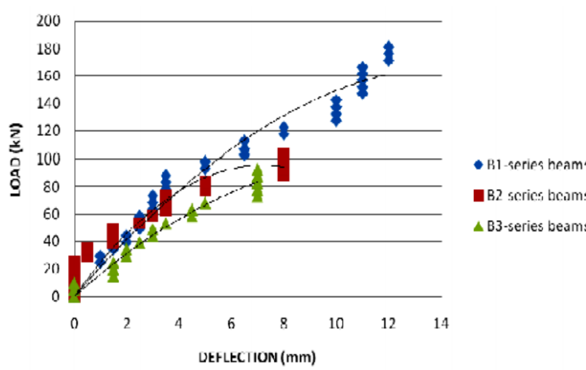
Beam Designation	Parameter to be investigated	shear span to depth ratio a/h	No of layer of wire mesh reinforcement N	Total volume fraction of mesh	Cube compressive strength of mortar f_{cu} Mpa
A1	a/h	0.6	3	1.964	60
A2		0.65	3	1.964	60

A3		7	3	1.964	60
B1	f_{cu}	0.65	3	1.964	85
B2		0.65	3	1.964	60
B3		0.65	3	1.964	40
C1	N	0.65	1	1.816	60
C2		0.65	2	1.883	60
C3		0.65	4	2.026	60

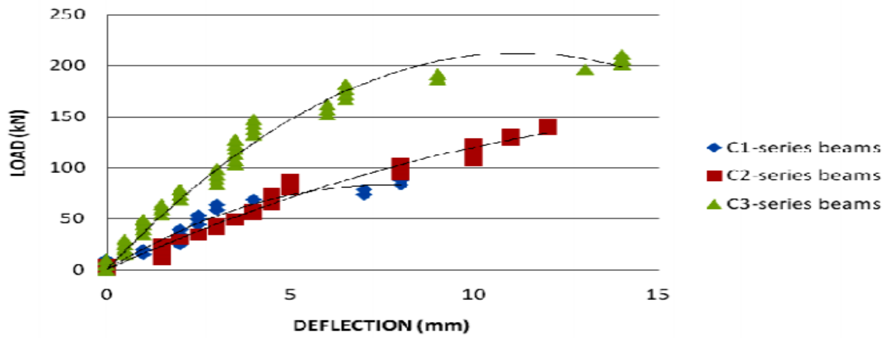
Figure 2.2 Test setup to determine shear and flexure strength [9]

The result from experiment are indicate when shear span to depth ratio decreased, amount of volume fraction and mortar strength increases, diagonal crack strength of ferrocement increase [9].





a) Load deflection behavior of group A   b) Load deflection behavior of group B



c) Load deflection behavior of group C

Figure 2.3 Load deflection behavior of group A, B and C [9]

2.3.2 Shear strength of box section beam

Experimental and analytical study of shear strength of ferrocement composite box section concrete beams. The experimental program have seven box section concrete beams were tested using two-point loading. The experimental program consisted sample dimensions of 100 mm x200 mm and 1800 mm long were cast and tested until failure. It use expanded and welded wire mesh to improve ultimate failure load, shear capacity and deflection respect to beams with control beam [10].

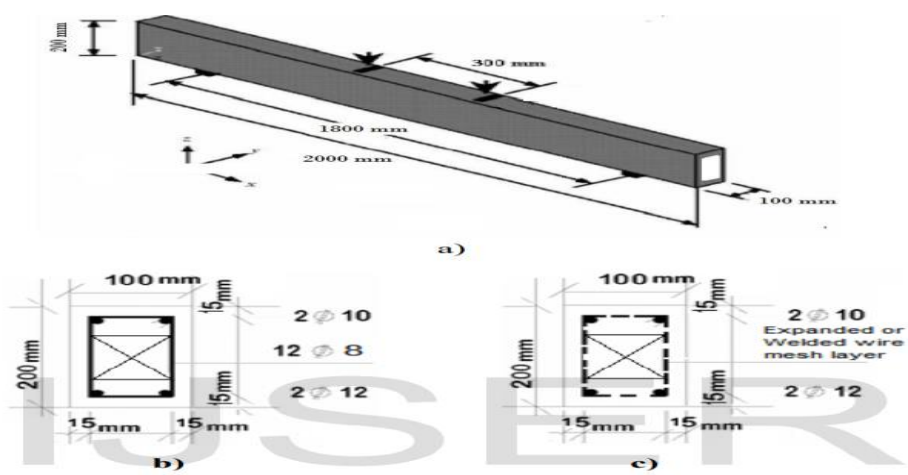


Figure 2.4 a) Beams geometrical shape and reinforcement details, b) control specimen; c) sample of beam with expanded or welded layer mesh [10]

Welded wire mesh high effect in increasing load capacity, deflection, shear stress and crack propagate crack propagation decrease in width and numbers as both wire mesh layers increase for BOX1-1, BOX2-1 and BOX3-1 respectively with enhancement ratio with respect to the control beam of 60.4%, 72.9% and 88.8% respectively in the same manner the expanded wire mesh also increase as follows for BOX1-2, BOX2-2 and BOX3- 2 30.5%, 61.8% and 77.5% respectively.

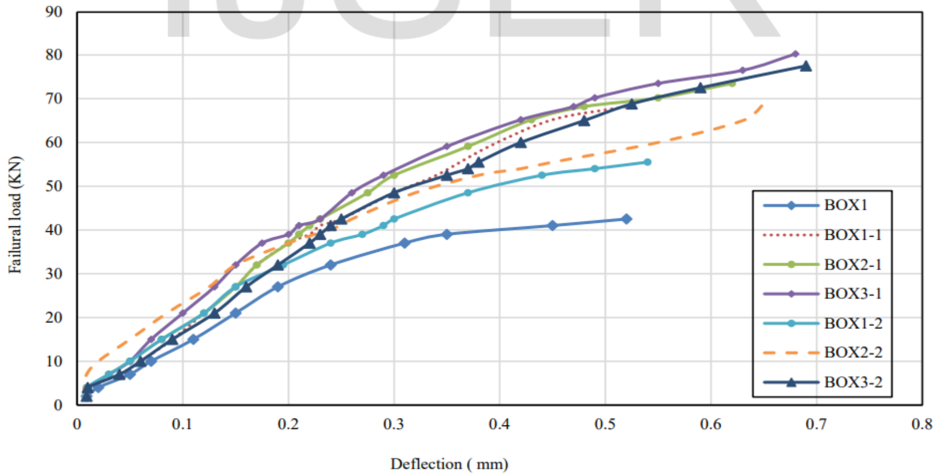


Figure 2.5 Experimental load deflection curve [10]

2.3.2.1 Shear Behavior of Ferrocement Box Beams

Study on shear behavior of ferrocement box beams has been studied by conducting flexure test on 15 beam specimens. Its amount of wire mesh reinforcement in web and in flange of beam and shear span to depth ratio.

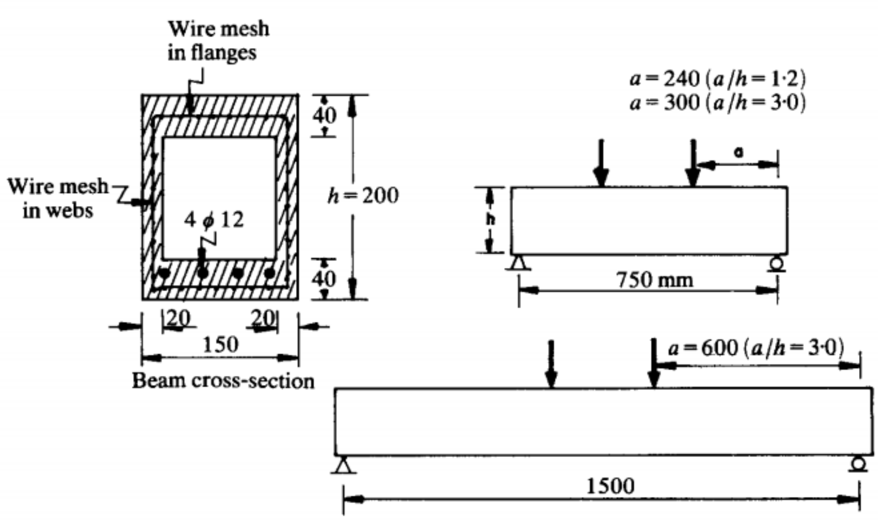


Figure 2.6 Test set-up [11]

The results show that cracking and ultimate shear force increase as wire mesh increase in webs but when wire mesh increase in flanges shear resistance increases and minimize tension cracks in addition to cracking and ultimate shear strength increase as shear span to depth ratio is decreased. Generally shear strength without web reinforcement is below expected the cracking shear strength of ferrocement box [11].

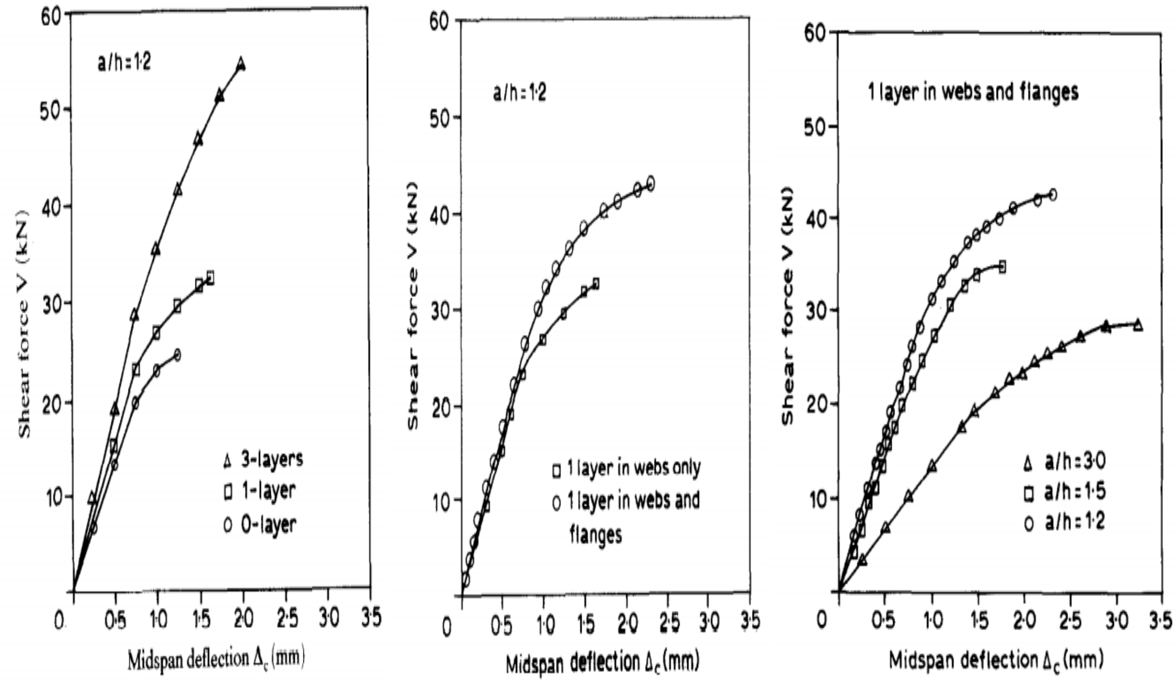


Figure 2.7 Typical V-A c curves for the effect of wire mesh reinforcement in webs, Typical V-A c curves for the effect of wire mesh reinforcement in flanges and Typical V-A c curves for the effect of a/h ratio respectively [11]

2.3.3 Behavior of simple supported beams sing wire meshes as shear Reinforcement

The paper studied behavior of reinforced concrete beams with wire mesh as shear reinforcement. The experiment includes testing of 4 prototype beams under a static loading. Their parameters mainly focused on type of shear reinforcement, which are stirrups, wire mesh, combination of both stirrups and wire mesh as shear reinforcement. The equivalent of wire mesh with stirrups based on weight. The experiment done by two point loading of four sample. The main objective of study is to increase shear performance of beam.

The specimens are designed considering steel bars of 8mm diameter at compression face and two bars of 12mm diameter at tension face. Although to have shear reinforcement beam 6mm stirrup was used. All of the test beams are of the same dimensions (100*150*1200) mm as shown in following figure 2.8.

Specimen ID	Details
B-1	Control beam
B-2	RC beam with stirrups as shear reinforcement
B-3	RC beam with wire mesh and stirrups as shear reinforcement
B-4	RC beam with wire mesh as shear reinforcement

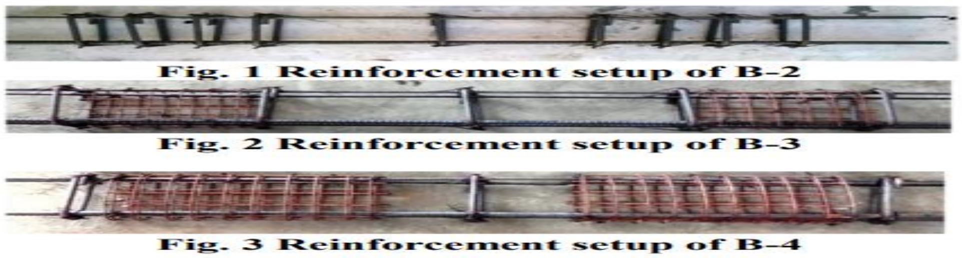


Figure 2.8 with reinforcement details, support locations of loads [3]

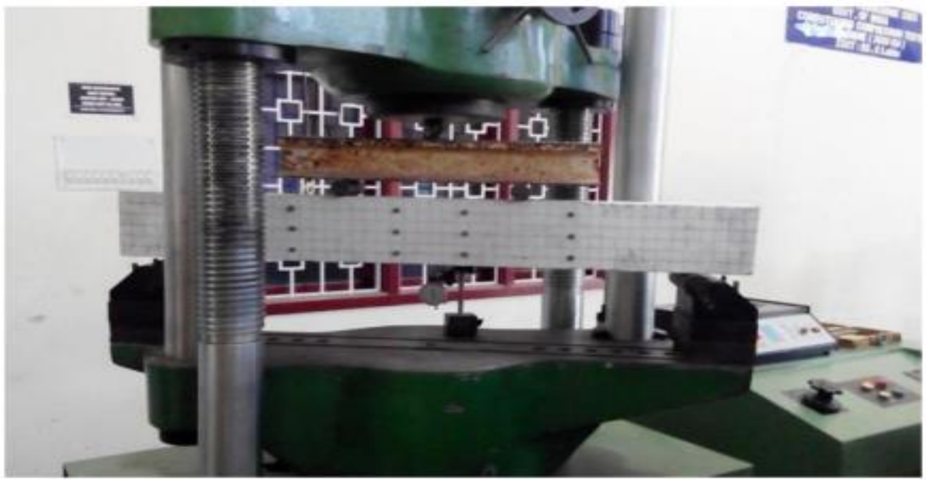


Figure 2.9 Beam test set-up [3]

It is observed that from the experimental data and the corresponding graph that replacement of stirrups by wire mesh alone increase ultimate load carrying capacity from 108.42KN to 110.35KN and for beam stirrups replacement by combination of wire mesh with stirrups to 114.3KN for the deflection corresponding to ultimate load of 110.35KN is 9.8mm as compared to 8.2mm of B-2 at 108.42KN and 7.6mm for ultimate load of 114.3mm of B-4. Therefore, the result shows there is an increase in ultimate loads for B-3 and B-4 comparing with B-2 respectively [3].

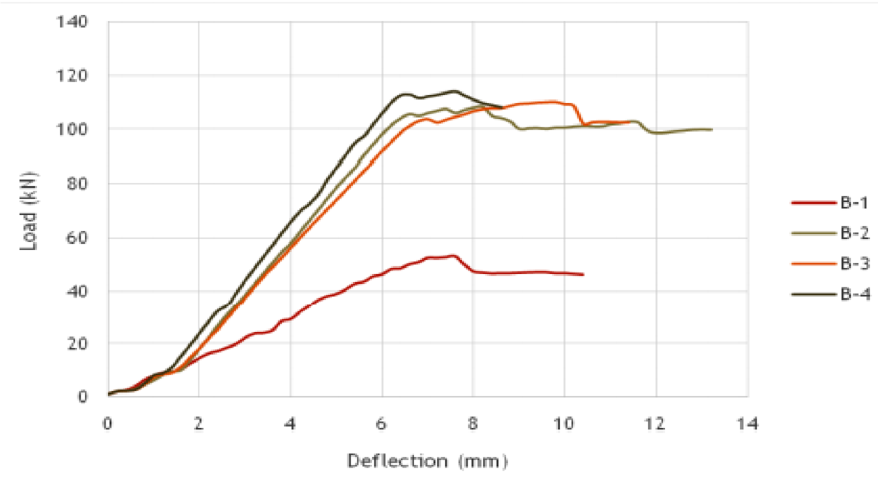


Figure 2.10 Load -Displacement for beams [3]

2.3.3.1 Improving shear strength of beams using ferrocement composite

The paper studied on reinforced concrete beam of two point loading seven sample of beam used for replacement of shear reinforcement stirrups by welded and expanded wire mesh diameter of 0.7mm and 1.25mm thickness respectively. Cross section of beam used for experiment is 150mm width, 150mm depth and 1900mm of span and finally validate by finite element analysis [10].

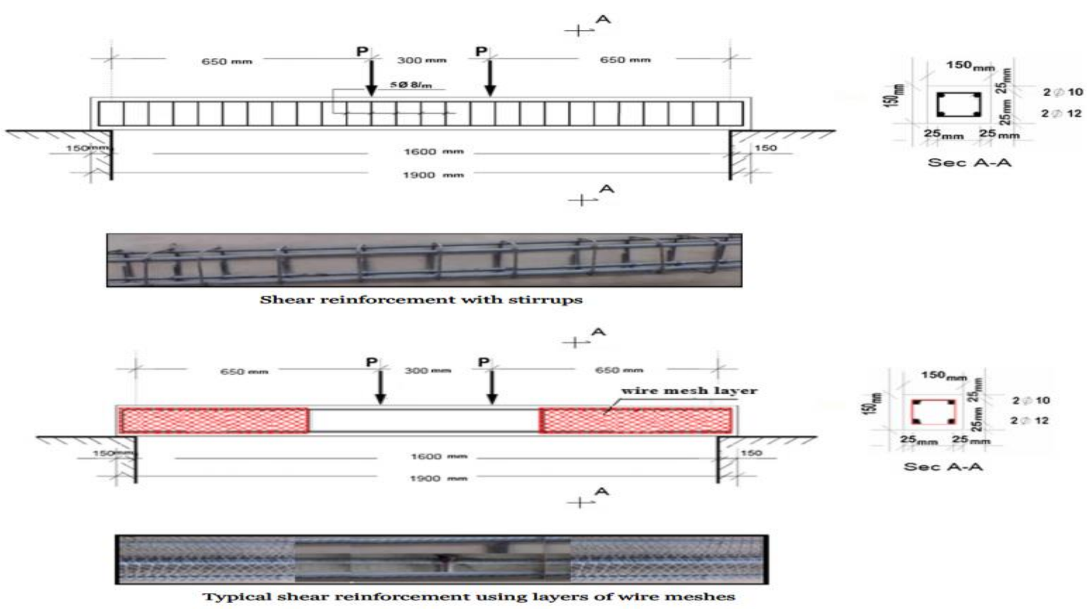


Figure 2.11 Beam geometry and reinforcement detail [10]

Results show that beams with wire mesh as showed smaller cracks when compared with normal shear reinforcement stirrups crack pattern of wire mesh shown in Figure 2.20. Welded wire mesh increases shear performance of beam rather than reference and expanded wire mesh.

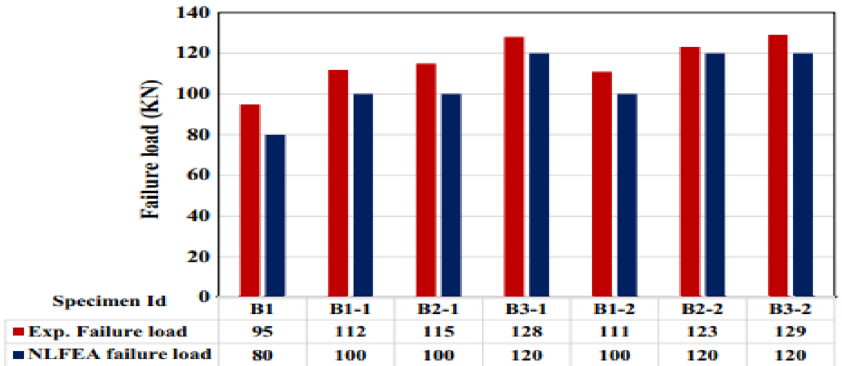


Figure 2.12 Comparison between failure load of experiment and NLFE analysis (KN) [10]

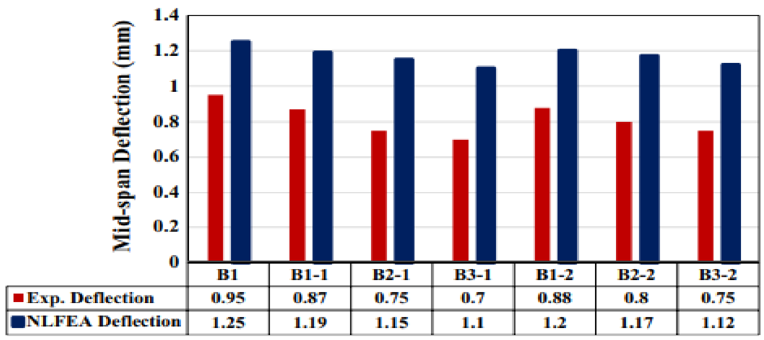


Figure 2.13 Comparison between mid-span deflection of experimental and NLFE analysis [10]

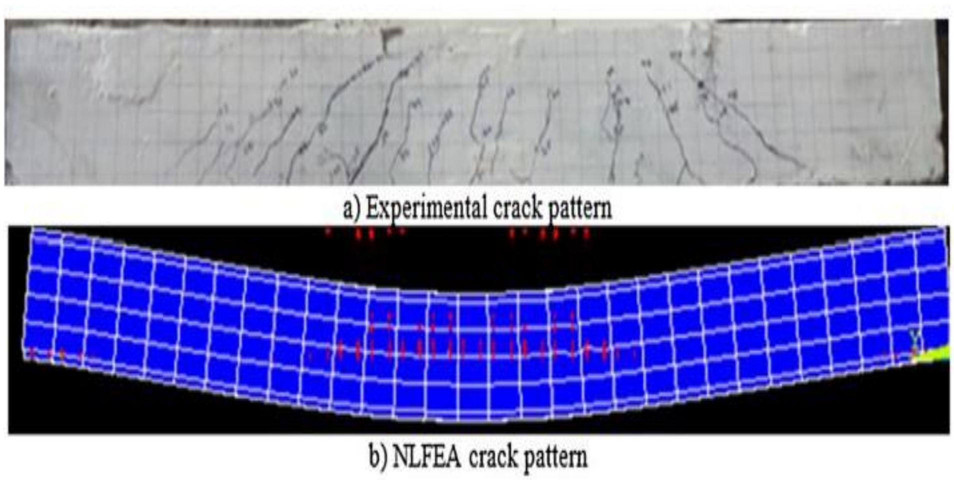


Figure 2.14 Crack pattern of wire mesh beams [10]

2.3.3.2 Shear strength of rectangular simple supported using with micro-concrete

The paper studied with five RC beam of cross section 200 mm length, 200 mm width, 270 mm depth, all specimen are weak in shear one out of five beam are control beam and all other four are strengthen using welded and weaved wire mesh with ferrocement micro-concrete [12].

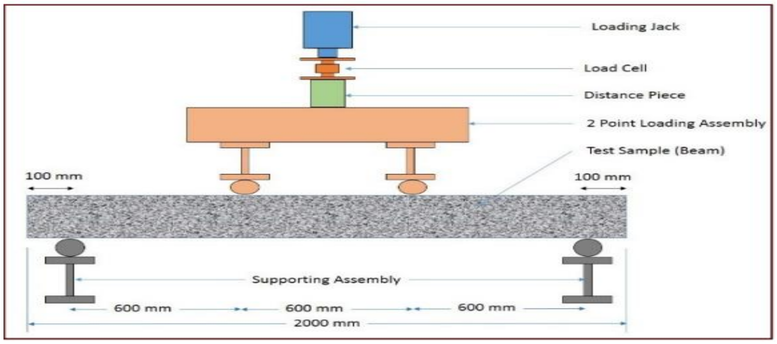


Figure 2.15 Diagrammatical representation of test setup assembly [12]

The result from experimental work indicate strengthening one are better improve performance of beam as compared with control specimen.

2.3.3.2 Structural performance of ferrocement beams reinforced with composite materials

Ultimate load of failure and deflection output discussed according the following Table 2.3 and Figure 2.16 its show that Shear Strengthened Beam using Micro concrete and welded wire-mesh shows better strengthening than all types of strengthening method of maximum ultimate load of failure 155.08KN and minimum deflection at failure load 9.24mm.

Table 2.3 Ultimate load vs deflection [13]

Load(KN)	Beam Designation				
	CB	FC-Weave	FC-Weld	MC-Weave	MC-Weld
Ultimate load (KN)	135.21	137.38	139.32	141.46	155.08
Ultimate Deflection(mm)	15.12	14.44	14.83	12.87	9.24

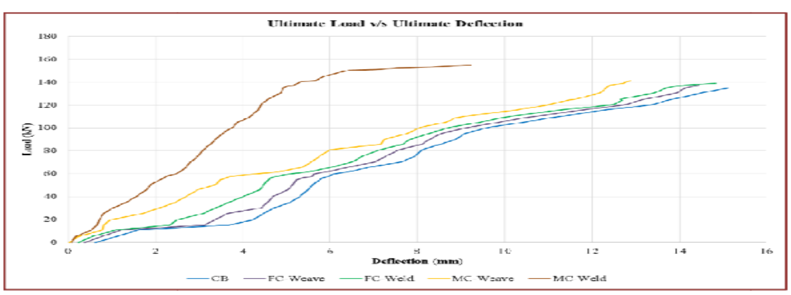


Figure 2.16 Ultimate load v/s Ultimate deflection [13]

The experiment investigate of current work to examine structural behavior reinforced concrete using ferrocement composite materials under three point load till failure. It casted twelve beam specimen having cross section of 120 mm, 200 mm, 1600 mm of beam width, depth and length respectively. The samples used different type of reinforcement; steel bar, wire mesh (welded and expanded) and composite materials fiber glass mess. The studied focused on flexural capacities in terms of strength, ductility, cracking behavior and energy absorption.

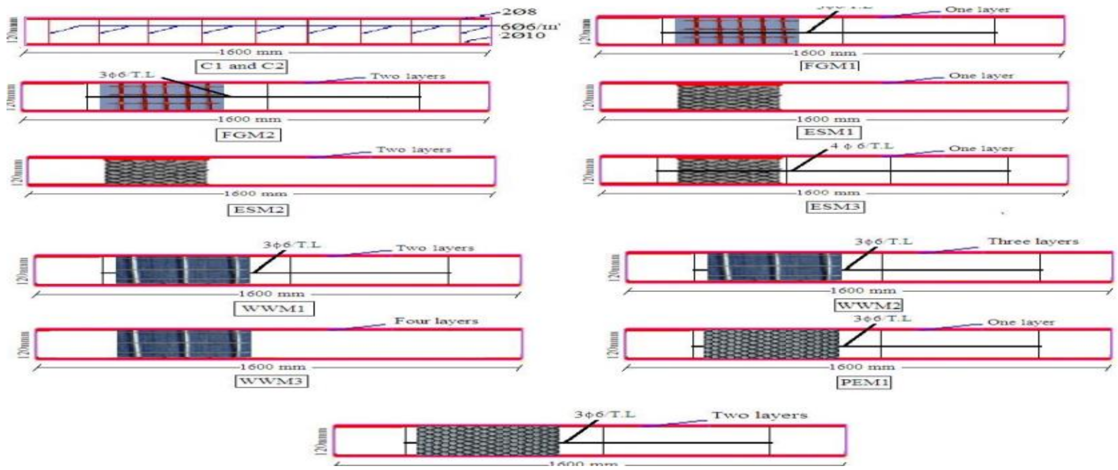


Figure 2.17 Details of test specimens [13]

The results of investigation on experimental test beam with fiber glass smallest first crack load and ultimate load beam with ferrocement of four layers welded wire mesh has better structural performance than other types of strengthening also beam with steel mesh crack width smaller when compared with non-metal meshes [13].

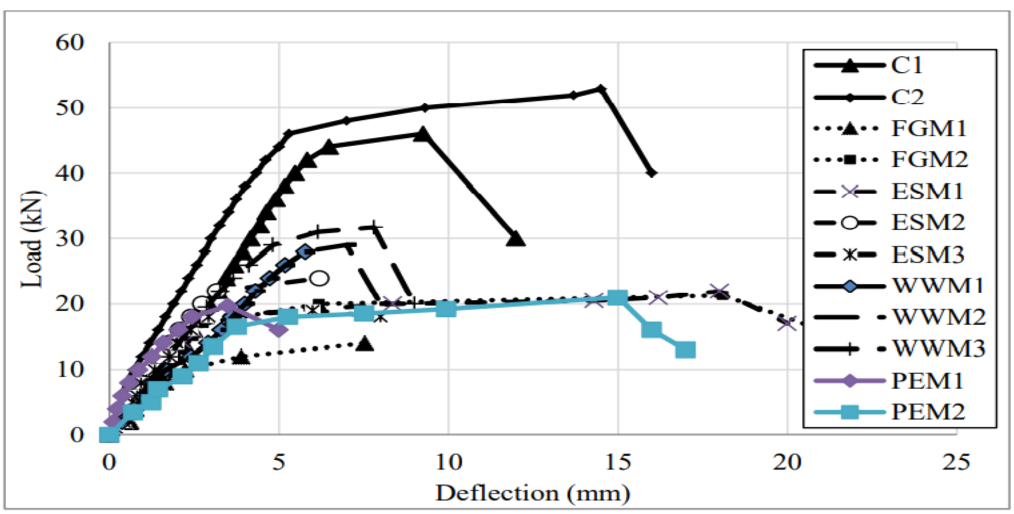


Figure 2.18 Load-deflection curves of all test specimens [13]

2.4 Other Material Replacement of Shear Reinforcement

There are other materials also replacement of shear reinforcement to improve the capacity of shear resistance for reinforced concrete beam.

2.4.1 Shear Performance of Steel Fibrous Concrete Beams

Under this studied experimental of steel fibers shear reinforced by monotonic and cyclic loading. Seven steel-fiber-reinforced concrete beams and control specimen were used for study. By volume fraction of (0.5 % and 0.75%). Test program as shear reinforcement two beams tested monotonically and five beams were tested under cyclic deformation. Hook-ended steel fibers with an aspect ratio equal to 75 were used [14].

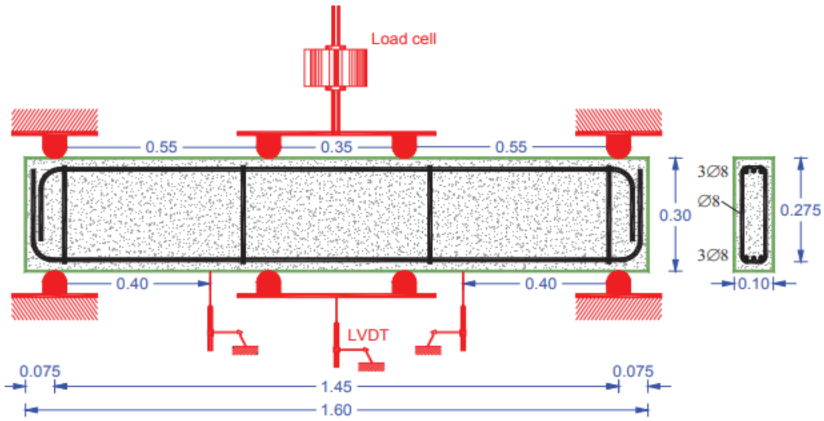


Figure 2.19 Characteristic test setup and steel reinforcement of the tested beams [14]

Results of experimental tested shows that steel-fiber-reinforced beams exhibited increase shear capacity with high shear capacities enhanced energy dissipation or toughness [14].

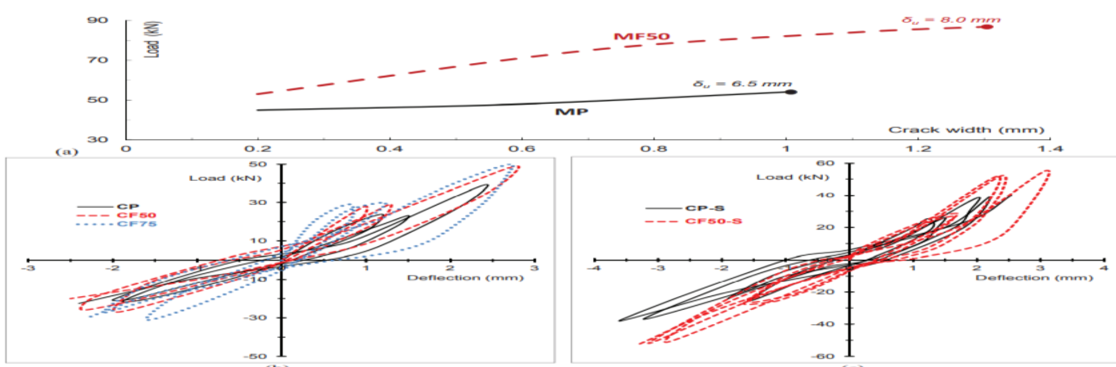


Figure 2.20 Test results [14]

2.4.2 Shear Performance of Steel Fibrous Concrete Beams

Presented of paper on experimental by structural performance of self-compacting concrete (SCC) are limited and this can be identified as one of the barriers to the widespread use and acceptance. Its initially focus on characterize the behavior of bamboo reinforced SCC beams without stirrups. Twelve SCC sample and vibrated concrete (VC) beams tested under four-point loading until ultimate load of failure using shear span to depth ratio for all samples 1.8. Variables of study were beam depth (150mm, 250mm and 275mm) with longitudinal reinforcement percentage of 1.5% and 3 and concrete type SCC and VC [15].

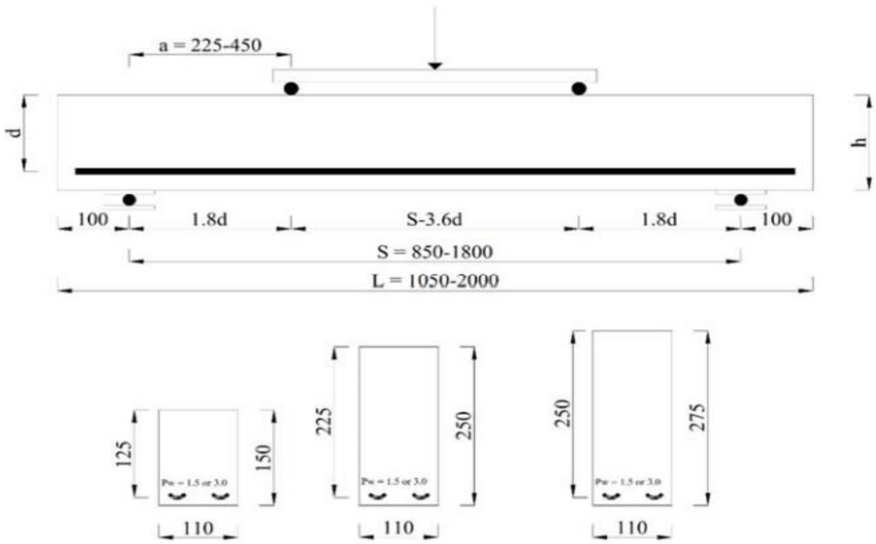


Figure 2.21 Schematic diagram of experimental test setup [15]

The result of experimental output are contribution of bamboo to ultimate shear strength may be quite significant and some higher in SCC than VC beams. Deformation capacities of SCC are higher than VC. Moreover, in order to interpret structurally good design, shear strength results revealed that a simple reduction factor of 2.5 is appropriate, enough, and must be applied to the documented shear supply of standard being considered fact.

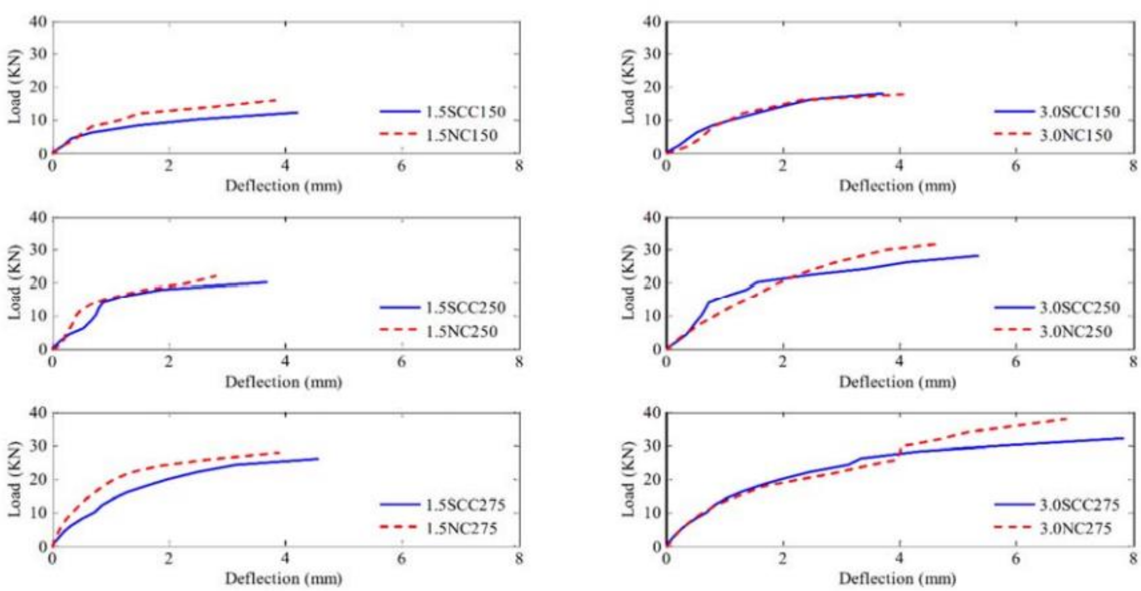


Figure 2.22 Load-deflection behavior [15]

Table 2.4 Experimental response [15]

Beam reference	Load, deflection and energy characteristics						
	First flexure crack		First diagonal crack		Ultimate failure		
	P_f	Δ_f	p_d	Δ_d	P_{ult}	Δ_{ult}	E_{ult}
1.5SCC150	8	1.5	10	2.49	12	4.22	36.34
1.5VC150	10	1.14	12	1.5	16	3.8	43.23
3.0SCC150	10	1.16	14	2.00	18	3.73	45.33
3.0VC150	14	1.8	16	2.28	18	4.05	51.74
1.5SCC250	14	0.89	18	1.9	20	3.7	56.20
1.5VC250	16	1.10	20	2.3	22	2.8	43.71
3.0SCC250	18	1.4	22	2.49	28	5.36	109.61
3.0VC250	20	1.92	26	2.86	32	4.67	96.43
1.5SCC275	20	2.01	24	3.16	26	4.58	85.80
1.5VC275	24	1.83	26	2.65	28	3.88	84.49
3.0SCC275	24	3.13	28	4.35	32	7.85	188.06
3.0VC275	28	4	34	5.18	38	6.84	167.52

The experiment and validation focused on structural shear strengthening due to shear failure is difficult in structural failure because of shear failure is catastrophic failure. This failure appear due to environmental action and loading condition on structure.

2.5 Application of Steel Wire Mesh for Beam Strengthening

Application of ferrocement was in several areas for structural elements and for non-structural elements one.

2.5.1 Response of reinforced concrete beams retrofitted by ferrocement

The experimental works to investigate behavior of beam retrofitting by ferrocement to strength beam by both flexure and shear. Used ten sample of specimen to studied different parameters like shear reinforcement, different diameter of wire mesh for rehabilitation, repair of initially stressed for fixed wire mesh ferrocement. Sample cross section of 140mm wide, 240mm depth and 200mm span. Wire mesh used for experimental work (1.2mm and 2mm) [15].

Table 2.5 Properties of steel mesh wire [15]

Mesh wire size	Yield Stress (Mpa)	Yield Strain	Ultimate Strength (Mpa)	Ultimate Strain
Φ2.2mm	412	0.00281	518	0.0321
Φ1.2mm	405	0.00286	502	0.0329

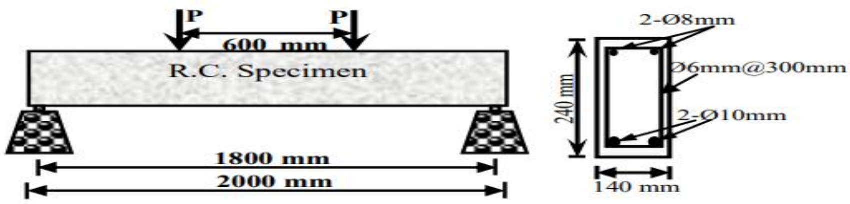


Figure 2.23 Geometry and cross-section laboratory specimens [15]

The results from experimental shows strengthening and repairing of RC beam by ferrocement is acceptable due to increased ultimate load of failure strengthening (69.8-175%) and repairing (50.94-125%) during change diameter of wire mesh also increase ultimate load of failure of beam from (95-175%) without stirrups and (69.8-126.4%) with stirrups.

2.6 Determine Stiffness of Beam

Stiffness of beam calculated [16]

$$S = \frac{F}{d} \quad (2.1)$$

Where:

S stiffness of beam

F ultimate load of failure

d maximum mid span displacement

Weight of reinforcement calculated based on [17], [18]

$$W = D^2/162 * L \quad (2.2)$$

Where: W weight of steel reinforcement

D diameter of reinforcement

CHAPTER THREE

RESEARCH METHODOLOGY

This research is analytical research where the main goal of studied in this paper would mainly focused comparative study on shear performance of reinforced concrete beam using wire mesh with mortar material considering the effects change in diameter of wire mesh, spacing, number of mesh layers and combination of wire mesh with stirrups by using FEA method. This chapter describes the way of developing finite element model that can simulate the shear performance of reinforced concrete beam using ferrocement under static loading. This indicated the approaches and techniques that researcher use collect data and investigate the research problem. The experimental model [1] was adopted as a reference test specimen for finite element modeling by using nonlinear finite element program ABAQUS/CAE 6.14. ABAQUS has the ability to simulate complex structural behavior under loading condition such as tension, compression, shear etc. finite element model needs to be kept as simple as possible. Because of the ferrocement, a large amount of ferromesh. It contains an extensive document of elements that can model virtually all geometrical boundary. The type of elements selected for matrix and ferrocement affect both the accuracy and the time taken for computation.

3.1 Research Design

This research was executed using analytical method conducted under finite element analysis which used to investigate comparative study on shear capacity of reinforced concrete beam by using ferrocement composite conducted under ABAQUS software. Thesis was systematic investigation to find easily available and safe material for structural elements of beam. In other ways it's a process of collecting analyzing and interpreting data to provide a recommendation to the research findings. After organizing collecting literature review of different recent published analysis using ABAQUS software following series step of analysis from creating part up to job analysis and extract result.

3.2 Study Variables

There are two variables discussed in paper those independent and dependent variables. Dependent variable is response of research study which was obtained from independent variables presented under independent variable.

3.2.1 Dependent variable

The effect of steel wire mesh on shear performance of reinforced concrete beam as replacement shear reinforcement stirrups.

3.2.2 Independent variables

The independent variables which will be measured and manipulated to determine its effectiveness and relationship observed phenomenon are listed below.

- Diameter of wire mesh
- Spacing of steel wire mesh
- Number of wire mesh layers
- Combination wire mesh with stirrups

3.3 Specimens Selection

The key parameters for this study were the diameter of wire mesh, spacing of wire mesh, number of wire mesh layers and combination of wire mesh with stirrups. Based on above parameters all beam cross section, 100mmx150mmx1200mm width, depth and span length respectively selected for study. Total number of modeled specimen of beams are 29 samples respective to their different parameters of ferrocement composite. The specimen divided into control specimen which was using stirrups as shear reinforcement and sample modeling based on above parameters.

3.5 Modeling of Reinforced Concrete Beam Using Ferrocement Composite

The modeled was done in order to see the effectiveness of welded wire mesh as replacement of shear reinforcement stirrups. Different parameters used to investigate shear capacity of beam under different behavior of steel wire mesh. Beams cross-sections detail are listed in Table 3.1. Investigation of shear performance of reinforced concrete beam using ferrocement was carried out by using FEA of ABAQUS software.

Table 3.1 Cross section detail of different specimen based on parameters

No	Beam name	B x D (mmxmm)	Longitudinal Reinforcement		Stirrups (mm)	Wire mesh		
			Tension	Compression		Diameter (mm)	Spacing (mm)	Layer
1	CB0	100x150	2Φ12	2Φ8	Φ6 c/c 150	no	no	no
2	WM1	100x150	2Φ12	2Φ8	no	1.5	8x8	1
3	WM2	100x150	2Φ12	2Φ8	no	2	8x8	1
4	WM3	100x150	2Φ12	2Φ8	no	2.5	8x8	1
5	WML1	100x150	2Φ12	2Φ8	no	1.5	8x8	2
6	WML2	100x150	2Φ12	2Φ8	no	2	8x8	2
7	WML3	100x150	2Φ12	2Φ8	no	2.5	8x8	2
8	WME1	100x150	2Φ12	2Φ8	no	1.5	11x11	1
9	WME2	100x150	2Φ12	2Φ8	no	2	11x11	1
10	WME3	100x150	2Φ12	2Φ8	no	2.5	11x11	1
11	WME1L	100x150	2Φ12	2Φ8	no	1.5	11x11	2
12	WME2L2	100x150	2Φ12	2Φ8	no	2	11x11	2
13	WME3L2	100x150	2Φ12	2Φ8	no	2.5	11x11	2
14	WMEL3	100x150	2Φ12	2Φ8	no	2.5	11x11	3
15	WMEL4	100x150	2Φ12	2Φ8	no	2.5	11x11	4
16	WMF1	100x150	2Φ12	2Φ8	no	1.5	15x15	1
17	WMF2	100x150	2Φ12	2Φ8	no	2	15x15	1
18	WMF3	100x150	2Φ12	2Φ8	no	2.5	15x15	1
19	WMFL1	100x150	2Φ12	2Φ8	no	1.5	15x15	2
20	WMFL2	100x150	2Φ12	2Φ8	no	2	15x15	2
21	WMFL3	100x150	2Φ12	2Φ8	no	2.5	15x15	2
22	WMC1	100x150	2Φ12	2Φ8	Φ6 c/c 360	1.5	8x8	1
23	WMC2	100x150	2Φ12	2Φ8	Φ6 c/c 360	2	8x8	1
24	WMC3	100x150	2Φ12	2Φ8	Φ6 c/c 360	2.5	8x8	1
25	WMCE1	100x150	2Φ12	2Φ8	Φ6 c/c 360	1.5	11x11	1
26	WMCE2	100x150	2Φ12	2Φ8	Φ6 c/c 360	2	11x11	1
27	WMCE3	100x150	2Φ12	2Φ8	Φ6 c/c 360	2.5	11x11	1
28	WMCF1	100x150	2Φ12	2Φ8	Φ6 c/c 360	1.5	15x15	1
29	WMCF2	100x150	2Φ12	2Φ8	Φ6 c/c 360	2	15x15	1
30	WMCF3	100x150	2Φ12	2Φ8	Φ6 c/c 360	2.5	15x15	1

3.6 Geometry

Based on the geometry or dimension described in Table 3-1 the parts of a reinforced concrete beam were modeled as described below. All approximate size of part created on windows 3000.

a) Plain concrete beam a rectangular concrete beam was modeled using three-dimensional, deformable and extrusion method.

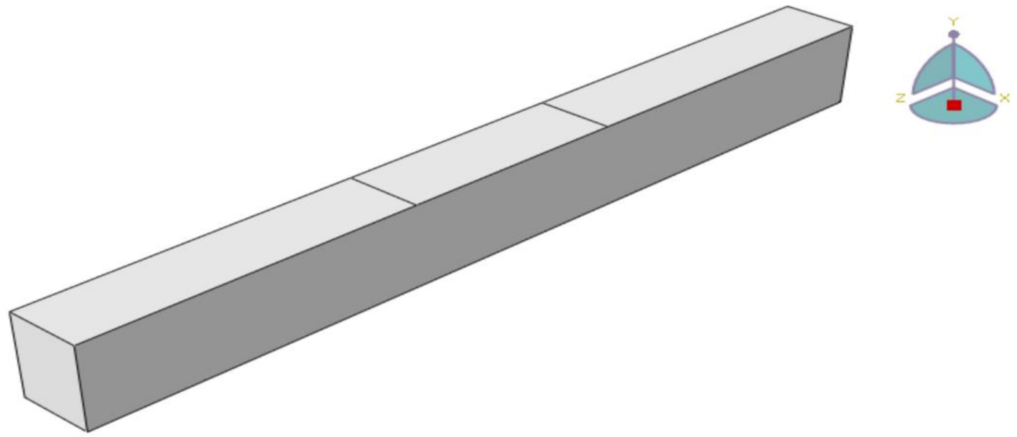


Figure 3.1 Beam cross section

b) Longitudinal reinforcement bar

Lines longitudinal bar was modeled using three-dimensional, deformable and wire planar by using line connected.

Figure 3.2 Longitudinal reinforcement

c) Shear reinforcement

A rectangular closed stirrup was modeled using three-dimensional, deformable and wire planar by line connected.

Figure 3.3 Shear reinforcement

d) Steel wire mesh

Steel wire mesh was modeled using a three-dimensional, deformable and wire manner from a line wire rectangle.

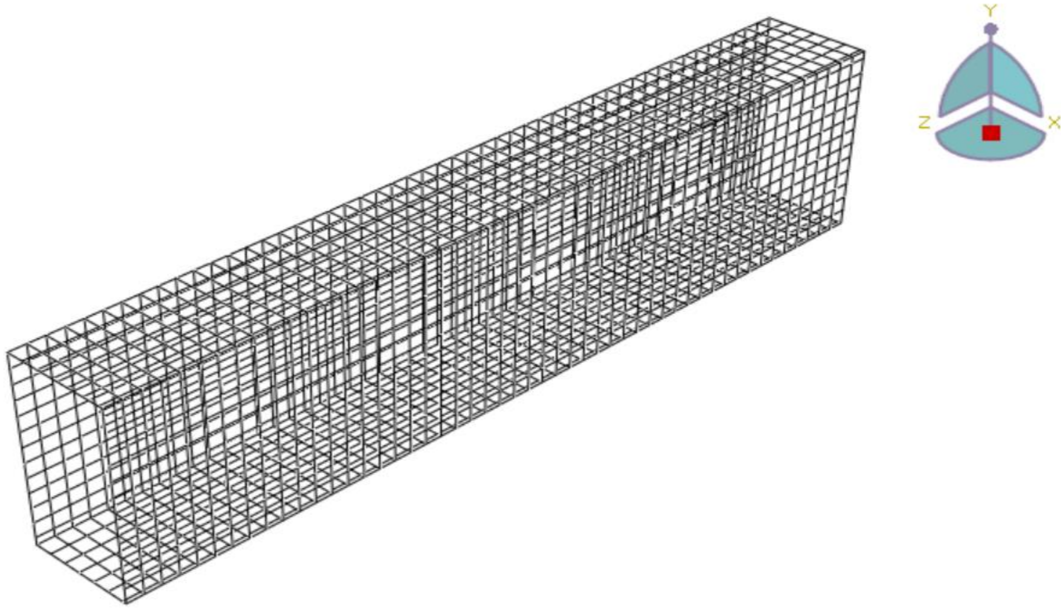


Figure 3.4 Wire mesh

3.7 Material Property

Experimental data of [1], was used for all materials (concrete, reinforcement bar, mortar wire mesh).

Concrete damage plasticity model uses the flow theory of plasticity and damage mechanics to analyze the concrete structure.

The parameters of the concrete damage plasticity model, including damage parameter, strain hardening/softening rules, and other several elements. However, behavior of concrete materials complex, because they have different properties in terms of tension and compression so must include nonlinear stress, strain relation, displacement of hardening/softening parameters. The material property input in Abaqus is in two groups, uniaxial stress-strain curves, and plasticity parameters. These are shown in the following sections:

a) b)

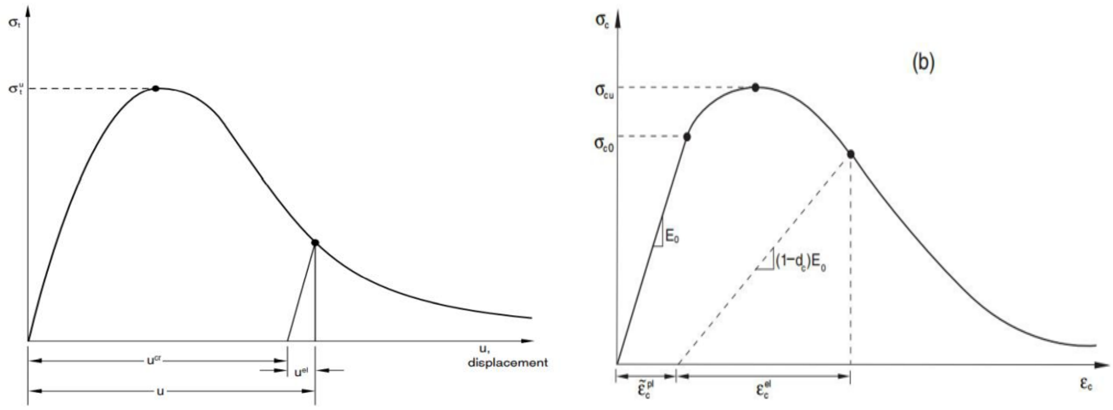


Figure 3.5 Response of concrete uniaxial loading in tension 'a" and compression "b" [17], [18]

$\sigma_c = (1-d_c)\, E_o\, (\varepsilon_c-\varepsilon_c^{pl})$ (3.1)

$\sigma_t = (1-d_t)\, E_o\, (u-u^{el})$ (3.2)

The parameters which were used in this model Abaqus software input for compression discussed as below according to for dilation angle, eccentricity, ratio of compressive biaxial to compressive uniaxial ($\frac{fbo}{fco}$), Constant Kc and viscosity the default value was used [19].

Table 3.2 Input data for the property of concrete plasticity

Modulus of elasticity	31475.81
Poisson ratio (ν)	0.2
Dilation angle (ψ)	36 (default)
Eccentricity	0.1 (default)
f_{bo}/f_{co}	1.16 (default)
Constant K_c	0.6667 (default)
Viscosity	0.0001

3.7.1 Uni-axial compressive strength of concrete

Cubic compressive strength of the concrete which was used in this thesis was M-25. Uniaxial compressive stress-strain diagram for nonlinear analysis was cylindrical compressive strength f_{ck} is 25Mpa. It was derived from Equation which is provided on [20], [21].

In concrete damage plasticity models, the plastic hardening strain in compression $\varepsilon_c^{pl,h}$ played a key role in finding the relation between the damage parameters and the compressive strength of concrete. The relation between σc and εc shown in Figure 3.2 (compressive stress and shortening strain shown as absolute values) for short term uniaxial loading is described by the Expression (3.14):

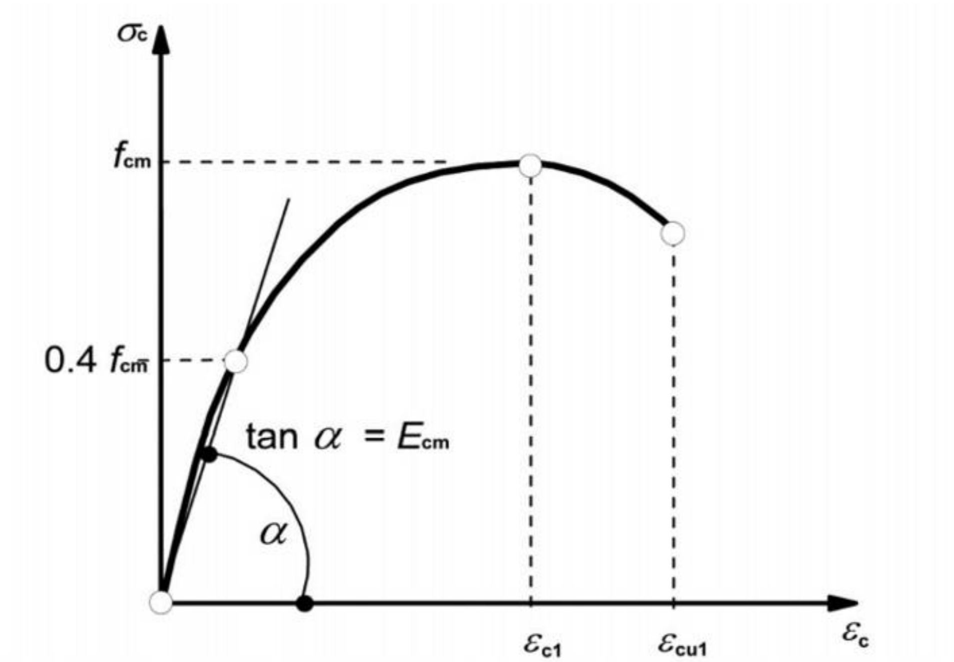


Figure 3.6 Schematic representative of the stress-strain relation of structural analysis (the use 0.4fcm for definition E_{cm} is approximate) [19]

$$\frac{\sigma c}{fcm} = \frac{k\eta - \eta 2}{1 + (k-2)\eta} \qquad (3.3)$$

Where:

$\eta = \varepsilon c / \varepsilon c1$

$0 < (\varepsilon_c) < (\varepsilon_{cu1})$ where ε_{cu1}-nominal ultimate strain

ε_{c1} is strain at peak stress

$k = 1.05\, E_{cm}\, (\frac{\varepsilon c1}{fcm})$

$f_{cm} = f_{ck} + 8$ MPa (3.4)

f_{cm} is mean compressive strength 28 days

E_{cm} is secant modulus of elasticity of concrete

$E_{cm} = 22[\frac{fcm}{10}]^{0.3}$ where f_{cm} (Mpa) (3.5)

$\varepsilon_{c1}(0/00) = 0.7 f_{cm}^{0.31} < 2.8$ (3.6)

$\varepsilon_{c1}(‰) = 2.2$

$\varepsilon_{cu1} = 3.5‰$

It indicates that $0 < |\varepsilon_c| < |\varepsilon_{cu}|$ was in consideration using indicated above explained formula cylindrical strength for each point plotted on the below chart presented in appendix of Table A.1.

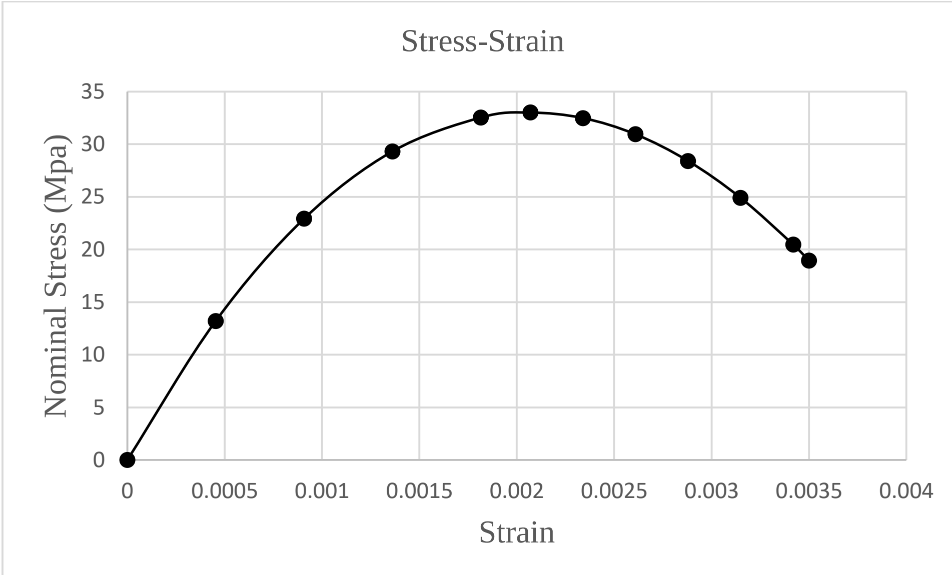


Figure 3.7 Compressive stress-strain curve of concrete at age 28 days

Then input value which was used for ABAQUS as compressive behavior is compressive stress-crushing strain. Crushing strain was calculated by deducting elastic strain from total strain.

Table 3.3 Stress-crushing strain input

σ_c (Mpa)	e_{in}
13.19997	0
22.91777	0.000179
29.31187	0.00043
32.53125	0.000781
33	0.001021
32.48076	0.001307
30.94104	0.001626
28.40714	0.001977
24.90446	0.002358
20.45754	0.002769
18.94994	0.002898

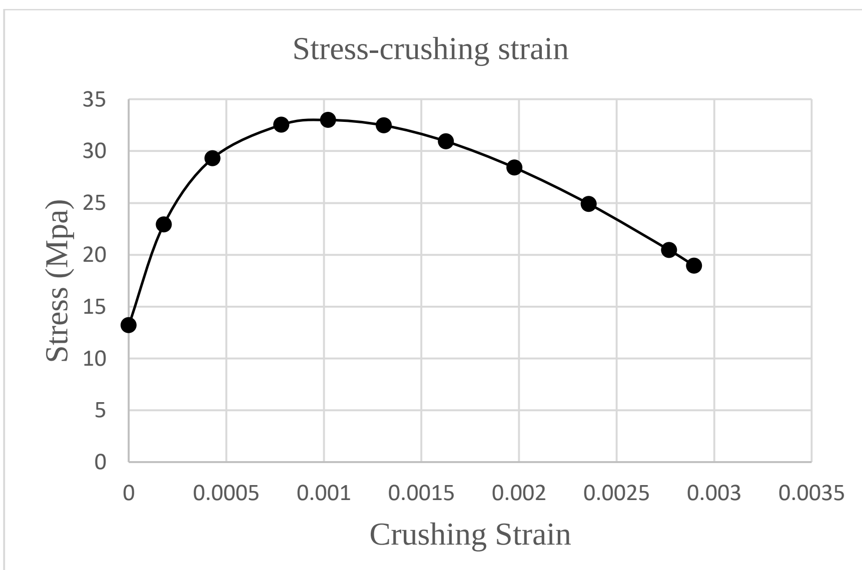


Figure 3.8 Stress-crushing strain curve

3.7.1.2 Concrete compressive damage parameter

Damage variable equation were developed based on [25] methodology proposed. The equation is given as follows according to Euro code. The equation is developed from given as follows according to [22].

Inelastic hardening strain in compression, $\varepsilon_c^{in,h}$ was derived as follows:

$$\varepsilon_c^{in,h} = \varepsilon_c - \frac{\sigma c}{Eo} \quad (3.7)$$

Where:

$\varepsilon_c^{in,h}$ is inelastic compression strain

ε_c is compressive strain

σ_c is nominal compressive stress

E_o is modulus of elasticity

Concrete behavior which was defined by effective parameters, including damage in compression and damage in tension. Compression damage (dc) was based on inelastic hardening strain in compression $\varepsilon_c^{in,h}$ that controlled the unloading curve slope. Given that dc increased with respect to an increase in $\varepsilon_c^{in,h}$, it could be expressed as follows:

$$d_c = 1- \frac{\sigma c}{\sigma cu} \quad (3.8)$$

d_c is scalar compression damage variable

σ_{cu} is ultimate Compressive strength

Using these equation damage variables were determined as follows. And also, the compressive damage variable versus crushing strain (inelastic strain) was plotted as below.

Table 3.4 Concrete compressive damage input

d_c	e_{in}
0	0
0	0.000179
0	0.00043
0	0.000781
0	0.001021
0.015734	0.001307
0.062393	0.001626
0.139177	0.001977
0.245319	0.002358
0.380074	0.002769
0.425759	0.002898

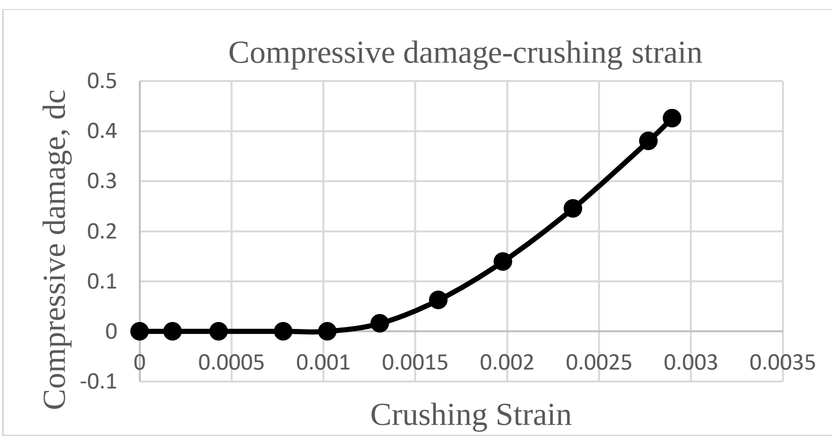


Figure 3.9 Concrete compressive damage versus crushing strain input

3.7.2 Uniaxial Tensile Behavior

In concrete damage plasticity models, the plastic hardening strain in tension u^{cr} was derived (see Figure 3.10 as follows:

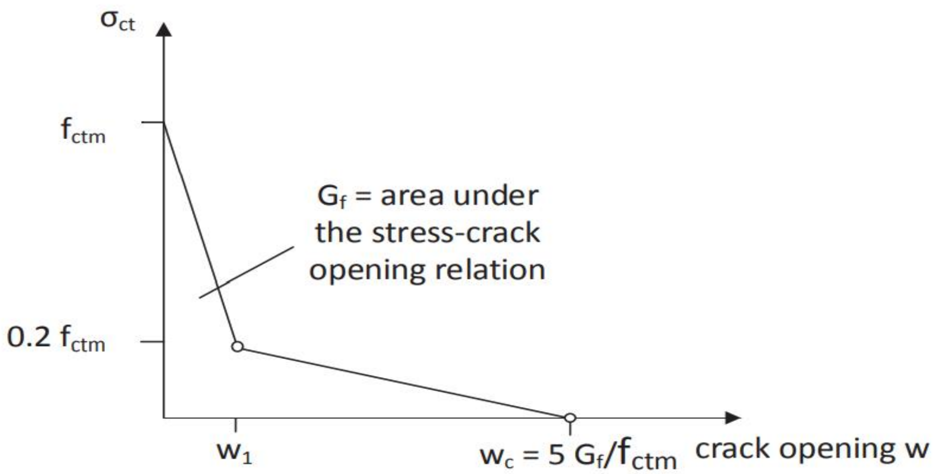


Figure 3.10 Stress-Crack opening relation for uniaxial tension [23]

For tensile behavior, the equation which is developed by [23], were used. The tensile stress σ_{ct} crack opening (w), maximum crack opening w_c ($\sigma_{ct} = 0$) and tensile strength of f_{ctm}.

$\sigma_{ct} = f_{ctm}\,(1 - 0.8\,\frac{w}{w1})$ for $w < w_1$ 3.9

$\sigma_{ct} = f_{ctm}\,(0.25 - 0.05\,\frac{w}{w1})$ for $w_1 < w < w_c$ 3.10

Where:

f_{ctm} $0.3(f_{cm} - 8)^{2/3}$ tensile strength in N/mm^2

w crack opening in mm

$w_c = \frac{5\,Gf}{fctm}$

$w_1 = \frac{Gf}{fctm}$

$G_f = 73 f_{cm}^{0.18}$

Finally After taking into account the assumption of relation in descending segment of the tensile stress-displacement curve, the displacement can be obtained in terms of the crack opening from the following kinematic relation [24].

$u^{cr} = u - u^{el}$ 3.11

Where:

u^{cr} displacement across crack

Table 3.5 Input value of tensile stress and cracking displacement

σ_t (Mpa)	U^{cr}
2.564964	0
2.183294	0.01
1.801624	0.02
1.419953	0.03
1.038283	0.04
0.656613	0.05
0.512993	0.053763
0.47426	0.07
0.450406	0.08
0.426551	0.09
0.402697	0.1
0.378843	0.11
0.354988	0.12
0.331134	0.13
0.30728	0.14
0.283425	0.15
0.259571	0.16
0.235716	0.17
0.211862	0.18
0.188008	0.19
0.164153	0.2
0.140299	0.21
0.116444	0.22
0.09259	0.23
0.068736	0.24
0.044881	0.25

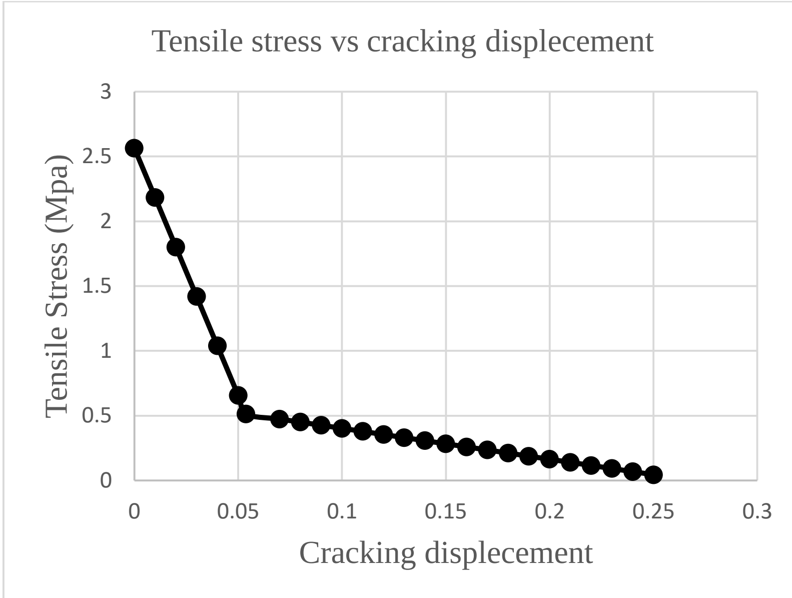


Figure 3.11 Tensile stress vs cracking strain diagram

3.7.2.1 Tensile damage variables

Damage of concrete under tensile behavior was determined as following section equation crack displacement relationship according to [25].

$$d_t = 1- \frac{\sigma t}{\sigma to} \qquad 3.12$$

Where:

d_t scalar tension damage

$$u_t^{pl} = u_t^{ck} - \frac{dt}{1-dt}\left(\frac{\sigma t}{Ec}\right) \qquad 3.13$$

The tensile damage variables were computed are plotted as seen in below section of table 3.6.

Table 3.6 Tension damage variables

dt	U^{cr}
0	0
0.1488	0.01
0.297	0.02
0.446	0.03
0.595	0.04
0.744	0.05
0.8	0.0537
0.815	0.07
0.824	0.08
0.833	0.09
0.843	0.1
0.8523	0.11
0.8616	0.12
0.8709	0.13
0.8802	0.14
0.8895	0.15
0.8988	0.16
0.9081	0.17
0.9174	0.18
0.9267	0.19
0.936	0.2
0.9453	0.21
0.9546	0.22
0.9639	0.23
0.9732	0.24
0.9825	0.25

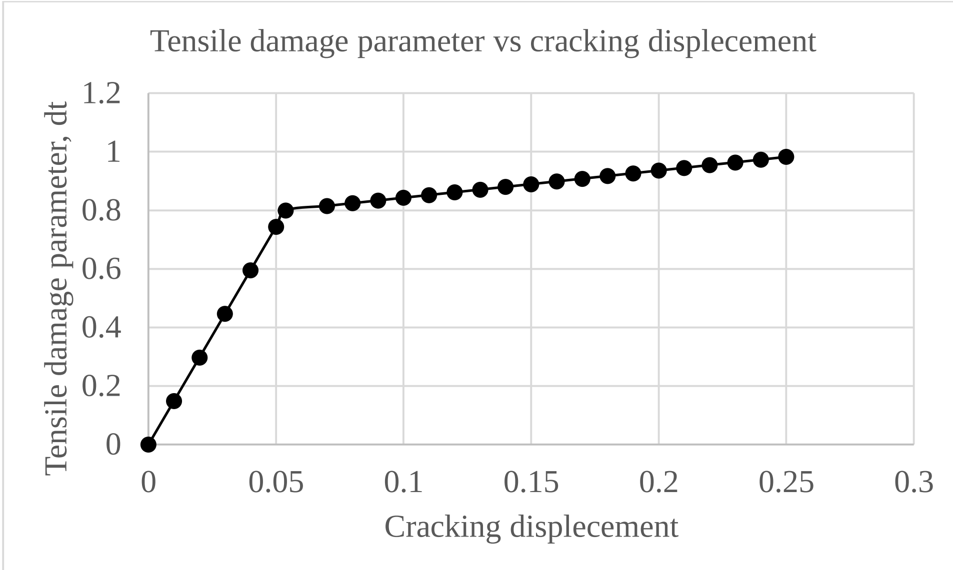


Figure 3.12 Tensile damage parameters vs cracking displacement diagram

3.7.3 Properties of reinforcement bar and ferrocement materials

For all steel reinforcement and wire mesh use density of 7850 Kg/m^3 and Poisson ratio of 0.3 is used for software input [26], [27].

3.7.3.1 Reinforcement bar

Reinforcement and wire mesh used in this study is taken from reference experimental data study by [3]. Steel was Φ12, Φ8 used for longitudinal reinforcement for tension and compression respectively, Φ6 c/c 150mm bar used for shear reinforcement and welded wire mesh of different spacing and diameter. The mechanical properties each material indicated below Table 3.7.

Table 3.7 Mechanical reinforcement bar

Bar and wire mesh size (mm)	Yield Stress (Mpa)	Ultimate Strength (Mpa)
Φ12	500	540
Φ8	500	540
Φ6	500	540
Φ_{mesh} 1.25, 2, 2.5	400	600

a) The curve was straight linear up to yield point or elastic stage
b) Ultimate point or peak point the slope of the tangent is horizontal which is zero
c) The strain hardening point was taken as the beginning point of the in elastic curve. For tensile longitudinal use Φ8, Φ12 and Φ6 for transverse, using above calculated nominal stress and strain.

Based on above formula the tabulated results calculated for nominal stress of reinforcement and wire mesh tabulated below section of Table 3.8 and Table 3.9.

Table 3.8 Nominal stress and strain of steel reinforcement bar

σ (Mpa)	ε
0	0
100	0.000476
200	0.000952
300	0.001429
400	0.001905
425	0.002024
450	0.00215
475	0.002392
500	0.004381
504.5	0.005626
509	0.007598
513.5	0.010717
518	0.015634
522.5	0.023365
527	0.03548
531.5	0.054398
536	0.083836
540.5	0.12948
545	0.2

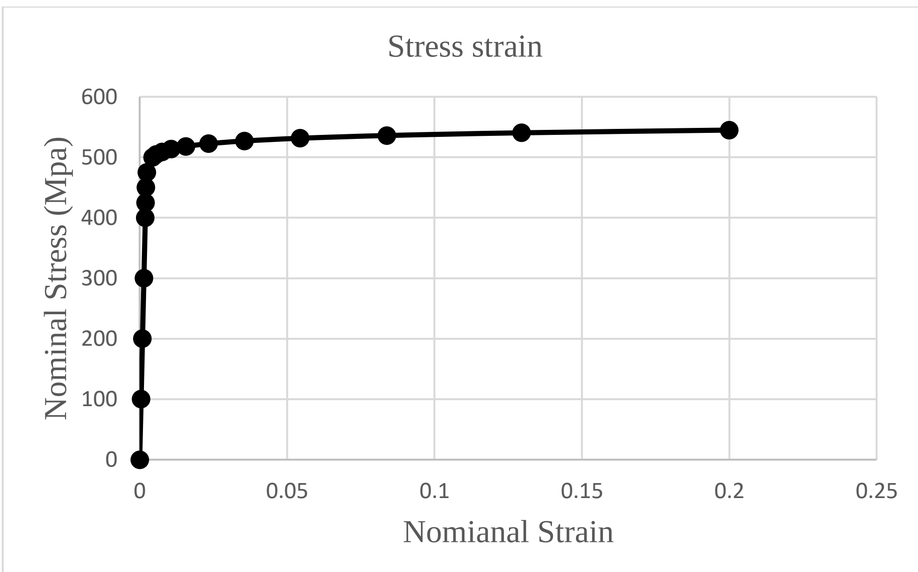


Figure 3.13 Nominal stress vs strain of reinforcement

For wire mesh ferrocement depend on yield stress and ultimate strength of wire mesh nominal stress tabulated below.

Table 3.9 Nominal stress and strain of steel wire mesh

σ (Mpa)	ε
0	0
80	0.0004
160	0.0008
240	0.001206
320	0.00176
340	0.002018
360	0.002407
380	0.003019
400	0.004
420	0.005575
440	0.008083
460	0.012031
480	0.018154
500	0.027509
520	0.041587
540	0.062468
560	0.093013
580	0.137112
600	0.2

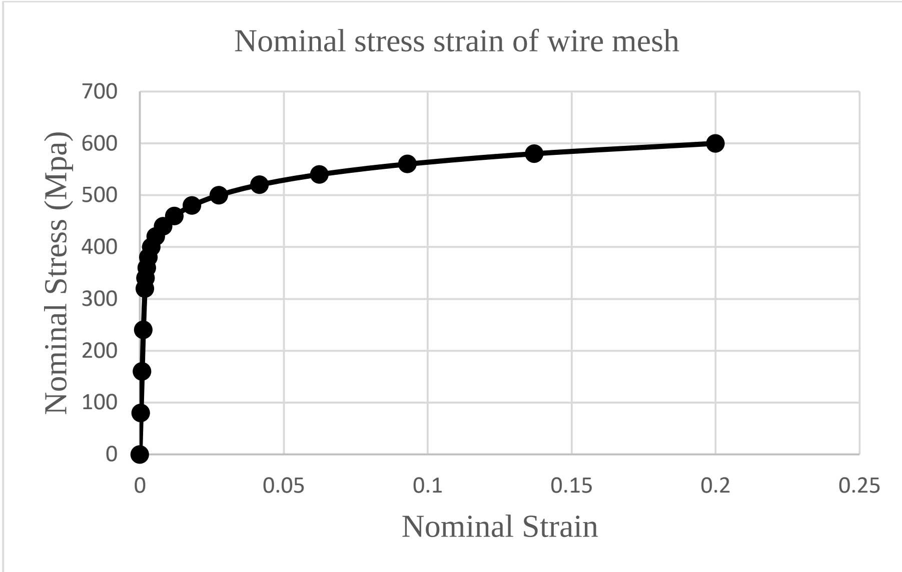


Figure 3.14 Nominal stress vs strain of reinforcement

Nominal stress-strain value cannot be used as input data for ABAQUS but from nominal stress strain we derive equation for true stress strain using logarithmic plastic strain [28].

$$\sigma_{true} = \sigma_{nom}\,(1+\varepsilon_{nom}) \qquad 3.14$$

$$\varepsilon_{true} = \ln\,(1+\varepsilon_{nom}) - \frac{\sigma}{E} \qquad 3.15$$

Where:

σ_{true} True stress

ε_{true} True strain

σ_{nom} Nominal stress

ε_{nom} Nominal strain

E Modulus of elasticity for steel

So, using above equation the nominal stress strain converted to true stress strain and tabulated as below then used as input for ABAQUS for both reinforcement and steel wire mesh.

Table 3.10 Input data true stress and plastic of steel reinforcement

σ_{true} (Mpa)	ε_{true}
502.1905	0
507.3384	0.001239
512.8676	0.003198
519.003	0.006288
526.0984	0.011142
534.7083	0.018725
545.698	0.030494
560.4128	0.048599
580.9363	0.076136
610.484	0.117386
654	0.17795

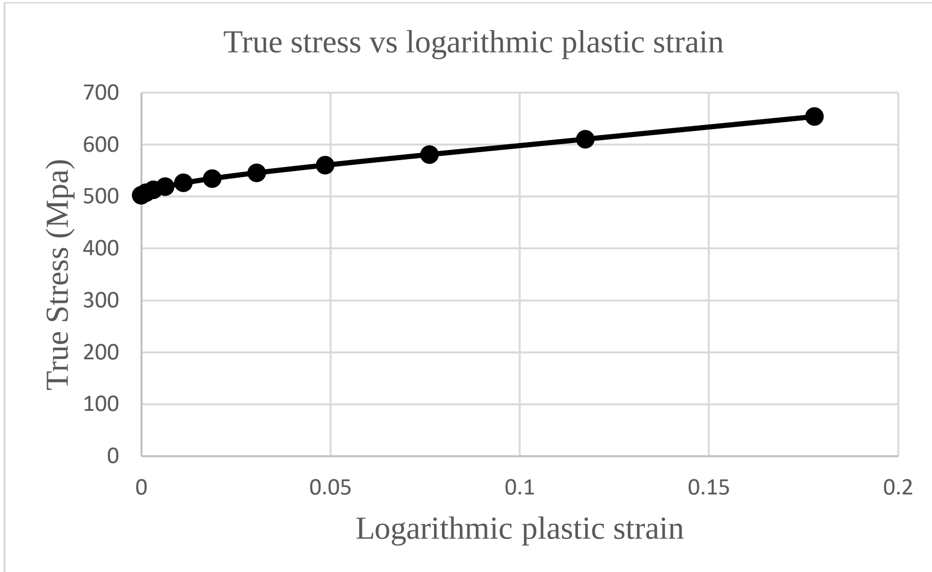


Figure 3.15 True stress vs logarithmic plastic strain

Abaqus input for steel wire mesh true stress vs logarithmic plastic strain also plotted as following

Table 3.11 Input data for true stress and plastic strain of steel wire mesh

σ_{true} (Mpa)	ε_{true}
401.6	0
422.3413	0.001567
443.5566	0.004059
465.5343	0.007967
488.7141	0.013999
513.7545	0.023145
541.6254	0.036754
573.7328	0.056603
612.0872	0.084946
659.5251	0.1245
720	0.17833

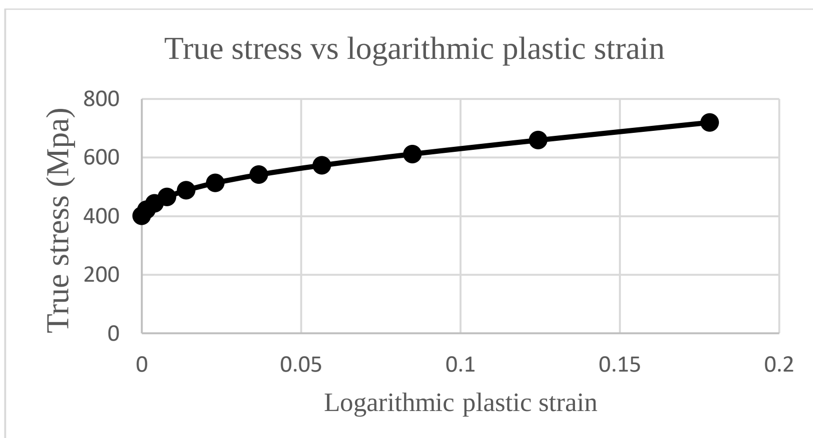


Figure 3.16 True stress vs logarithmic plastic strain input

3.8 Assembly of Parts and Interaction

Assembly and interaction are the major steps challenging in ABAQUS because it made error on analysis so, interaction must be within appropriate which agreement with surface or node. Its need special attention to be fixed proportion position and for the interaction between two parts.

3.8.1 Assembly of parts

An assembly is a collection of positioned part instances. In ABAQUS software, part instance was created at first step of simulation started which described in section 3.6 of this chapter then define property and input value for each material after that assemble of the parts within relative position under assemble tree instance dependent (mesh on part). Assemble for study of shear performance of RC beam using ferrocement as described in the following Figure 3.17.

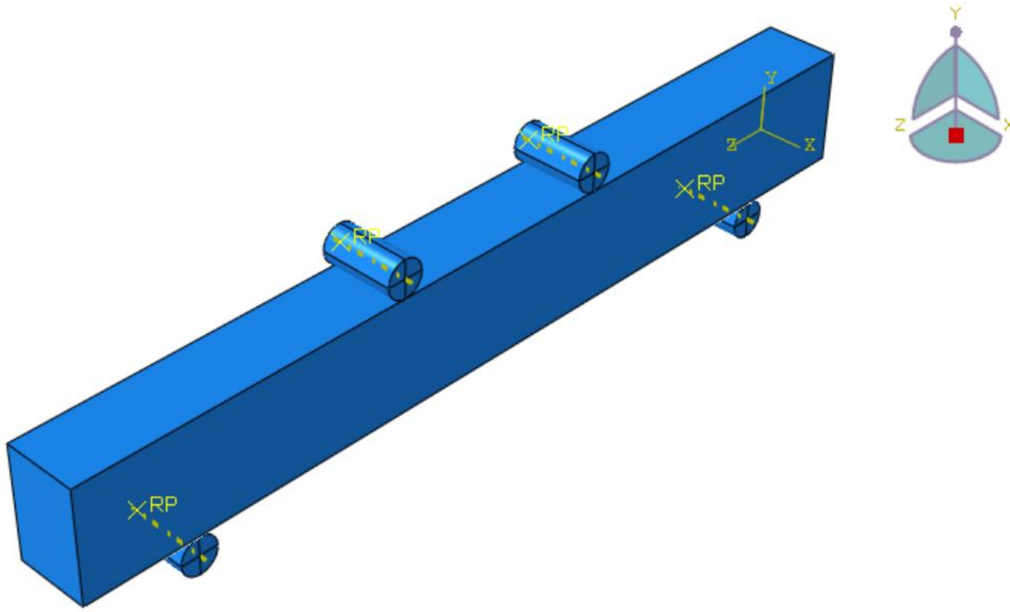


Figure 3.17 Assembled model of beam section

3.8.2 Interaction of parts

When considering reinforced materials to ensure contact between elements of different linking methods are available. Two types of constraints were selected in this thesis for interaction between different parts of beam element; the embedded region which all truss member embedded in 3D stress of concrete beam; Constraint and "Tie" when the rigid plate loading and support interacted with beam this interaction used node contact method. The master surface beam should be applied to the stronger material compared with the material using the slave surface support/loading plate.

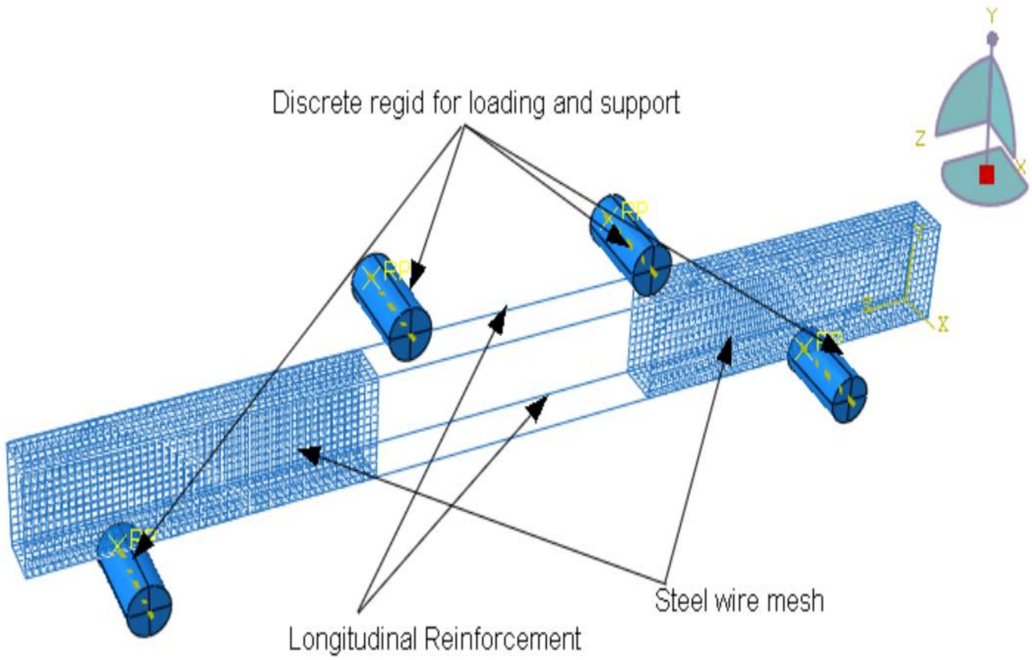


Figure 3.18 Assembly of each part on their position

3.9 Step of Analysis

In first part, instance created initial step was available then after assembly step was created next to property defined. For that step created static general was selected. Static general method includes both material non-linearity and geometrical nonlinearity effects of subsequent steps. It was capable to analysis static loading. Using bulk viscosity of 0.0001. Finally, then edit field output and check history.

3.10 Boundary Conditions and Load Application

This stage also complex stage where fix every boundary condition for needed parts and applied load using plate of loading at appropriate position.

3.10.1 Boundary conditions

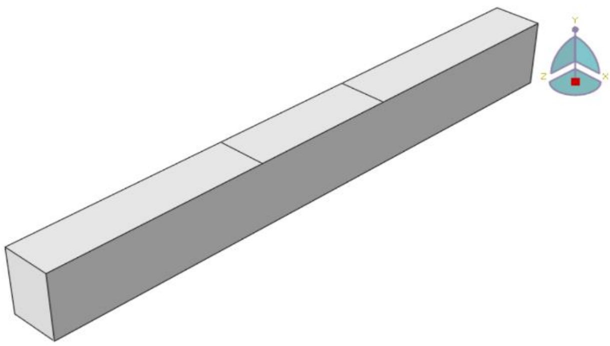
The boundary conditions of beams support plates at the bottom sides within of column constrained under initial category mechanical selected symmetry/Antisymmetry/Encastre pin-end conditions support in both side longitudinal directions of column. Bottom of loading plate surface fix in U_1 and U_3 direction to avoid movement in x and z direction in addition to that castrated support plate at reference point along longitudinal direction to resist movement in all direction. The coupling interactions provide a constraint between a reference node and the nodes on a surface.

3.10.2 Load application

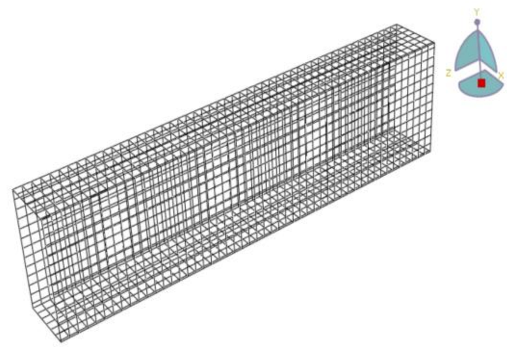
Load application used in the numerical simulations were from experimental validation displacement control method was adopted for static loading of four-point bending used. The beams were modeled under step category of mechanical selected displacement/rotation to apply loads at reference point which distributed along all nodes of loading plate as being horizontal, with both side having the pin-end condition and the other experiencing the applied load.

3.11 Detail Description of Elements of Beam in ABAQUS

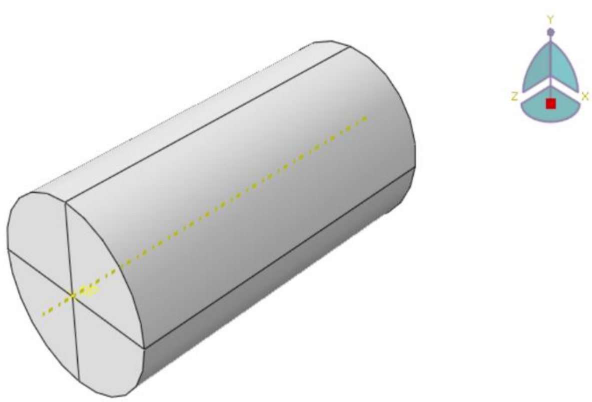
The reinforcement of reinforced concrete, reinforced ferrocement, plate of loading/support and element of beam in Abaqus simulation as the following shown in Figures 3.19.



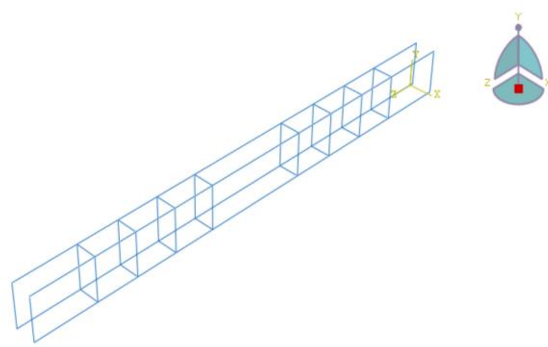
Concrete beam



Truss steel wire mesh



Rigid plate of loading/support



Truss longitudinal and shear reinforcement

Figure 3.19 All parts used in Abaqus

3.12 Finite Element Mesh Size

The size of the mesh used in the finite element method (FEM) can affect the results accuracy and analysis distorted on the members if not properly meshed.

3.12.1 Mesh size

Different mesh size analysis is done until analysis is confirmed with experimental in addition to that using a finer-mesh can give more accurate results but its take long time computation of the model. To find the effective mesh size for each elements of modeling 30mm mesh size which was closest and agree with experimental value selected. Dependent instance were selected for mesh Figure 3.20 shows the mesh size for the matrix structures.

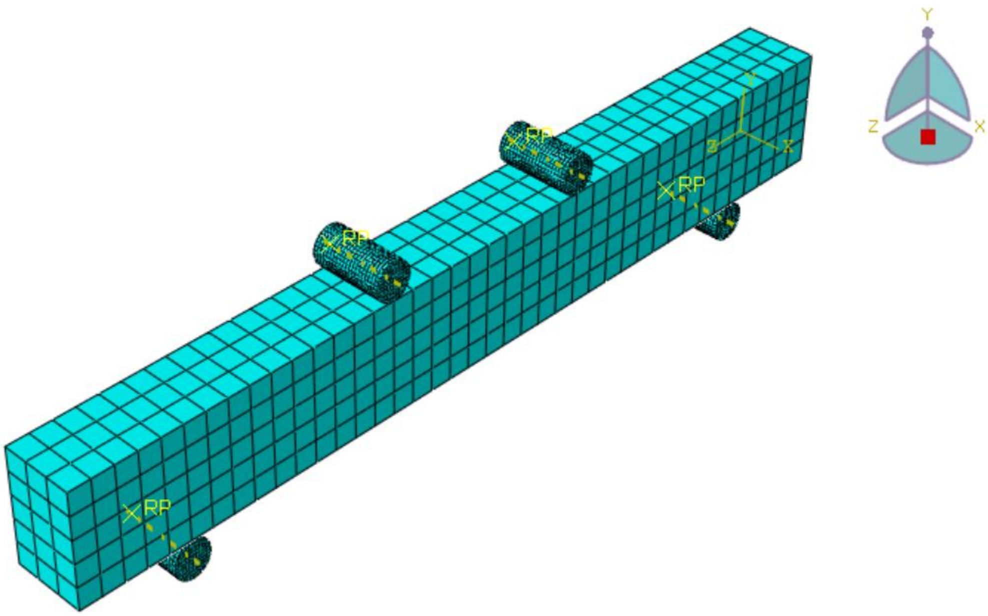


Figure 3.20 Mesh size for the matrix structures

3.12.2 Element type

Concrete and matrix in the Abaqus (2014) element library, there are different types of elements, for example, hexahedron (brick), shell, triangular prism and others. The most commonly used element for concrete studies is the three-dimensional brick elements. C3D8R for plain concrete thesis meshing used in beam. T3D2 for truss element: The reinforcement materials, including flat bars, stirrups, and the welded mesh, are modeled using the T3D2 truss elements also R3D4 for rigid discrete of loading and support plate.

3.13 Job

Finally, job was created after meshing elements under this category check data for analysis then submitted for simulation finally in visualization module tree load versus displacement result extract and presented in Appendix C. Ultimate load of failure and its corresponding displacement and maximum shear stress was taken computation of parameter.

CHAPTER FOUR

RESULTS AND DISCUSSION

Experimental investigation beam tests using ferrocement need long period of time and expensive cost along with sophisticated equipment. To overcome these problems using commercially available ABAQUS 6.14-5 software package has been used by researchers to study comparative shear performance of reinforced concrete beam using ferrocement composite.

The objective of finite element method is discretization structural elements into number of finite elements they link at finite number of nodes. ABAQUS simulate every internal element structure under different loading condition include compression, tension, shear and others. Investigation of overall research study results presented under this chapter based on different way of explanation which was analysis conducted by nonlinear finite element analysis ABAQUS software.

4.2 Comparison of Finite Element Simulation with Experimental Results

The main objective of this research was after validate the experimental study with finite element analysis further study based on different parameters. Therefore, the experimental presented below section was chosen for further study on steel wire mesh as replacement of shear reinforcement stirrups. Behavior of Reinforced Concrete Beam with Wire Mesh as Shear Reinforcement which was investigated by [1] was selected as reference from experimental study.

4.2.1 Reference sample for experiment

Reference of this thesis presented paper on behavior of reinforced concrete beam with wire mesh as shear reinforcement was used as reference experimental conducting. The experimental specimen modeled for replacement of stirrups by wire mesh was chosen for this thesis as reference. Every geometrical element detail was given as below section.

4.2.1.1 Detail of geometry

The cross-section of beam was 100mmx150mmx1200mm width, depth and span respectively.

Longitudinal reinforcement: 2Φ12 for tension, 2Φ8 for compression and shear reinforcement Φ6 150mm c/c was used [3].

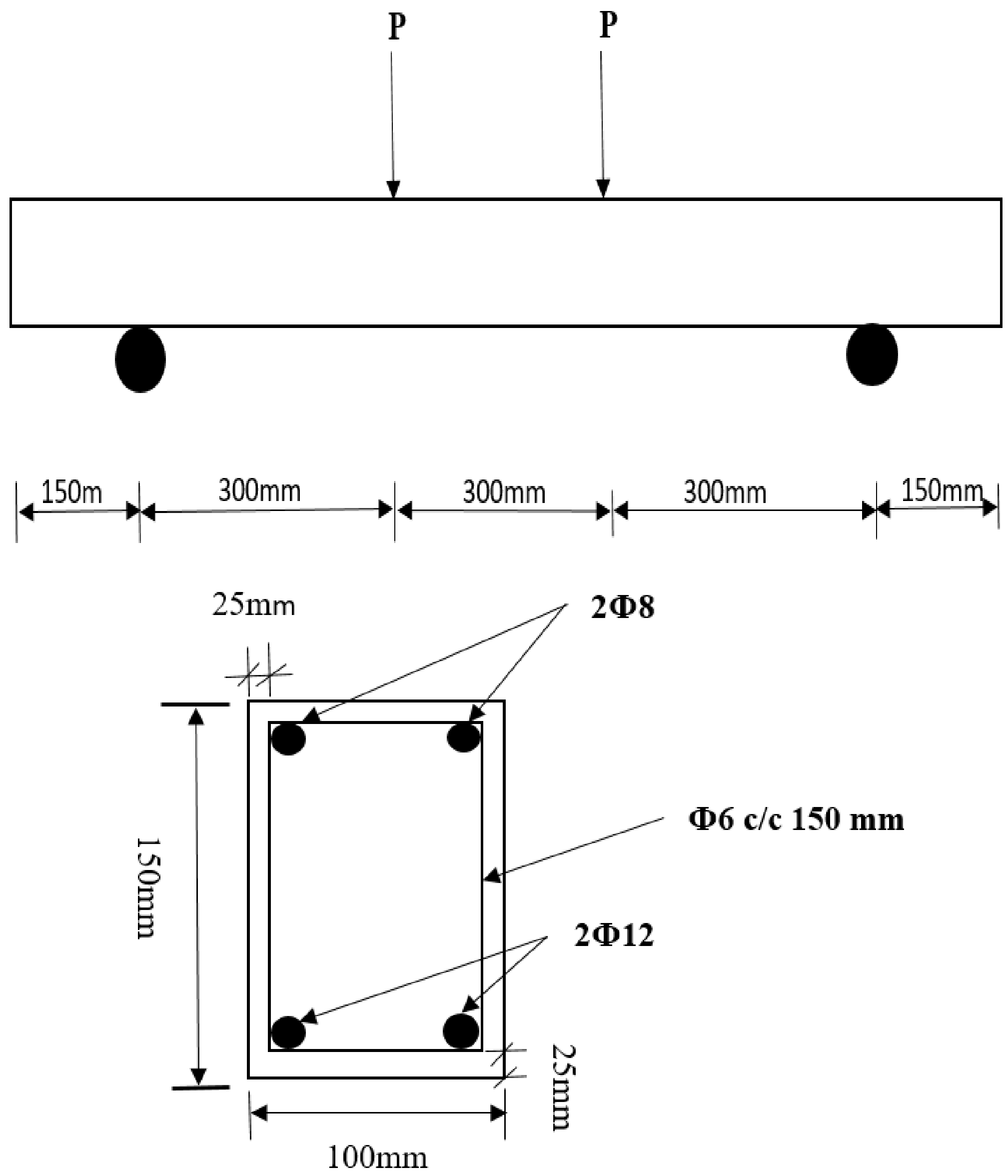


Figure 4.1 Cross section of longitudinal and transverse detail of experimental control beam

The beam span length was 1.2m length which shear reinforcement replacement by wire mesh.

4.3 Experiment Description

Experimental conducted according to explained in above section of geometrical expression and materials used in below section of Table 4.1. Study of experimental investigation was obtained from reference literature to be make validate before going to detail study about material behavior on shear capacity of reinforced concrete beam.

Table 4.1 Experimental test used materials

Specimen Type	Longitudinal tension reinforcement	Longitudinal compression reinforcement	Shear reinforcement	Concrete (Mpa)
Experimental	12 Phi	8 Phi	6 Phi	25

4.4 Finite Element Simulation

The experimental study discussed as previous section in research methodology standing from experimental results thesis simulation done based on presented material and geometrical cross section of beam in order to consume time, energy and resources. In addition to this finite element analysis modified mesh size, viscosity, and incrimination of speed load condition presented in Table 4.2. The model results presented in terms of ultimate load failure vs Mid-span displacement.

Table 4. 2 Finite element simulation description for control

Elements	Mesh size	Viscosity	Speed (m/s)
CB0	30	0.0001	0.01

Based on above description standards discussed in Table 4.2 modeling of all finite element was carried out. Result of control specimen by finite elements conducted through try and error of mesh size until finite elements agree with result of experimental analysis.

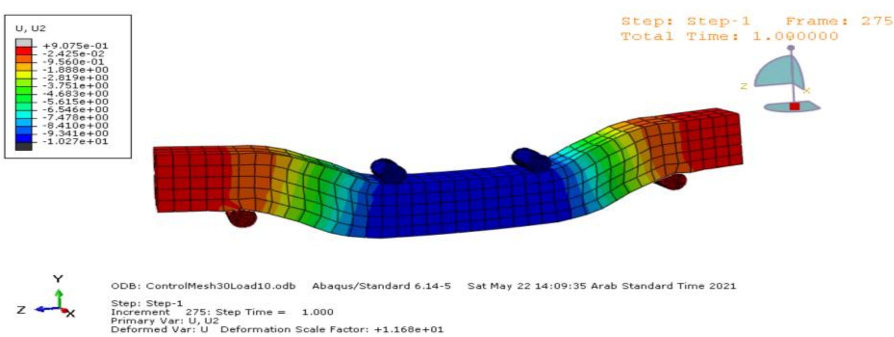


Figure 4.2 Failure mode of control beam at maximum failure load

Finally experiment results and finite element analysis results compared with each other. It must be closed numerically by ultimate load failure and mid span displacement in order to model other specimen based on variables used in thesis.

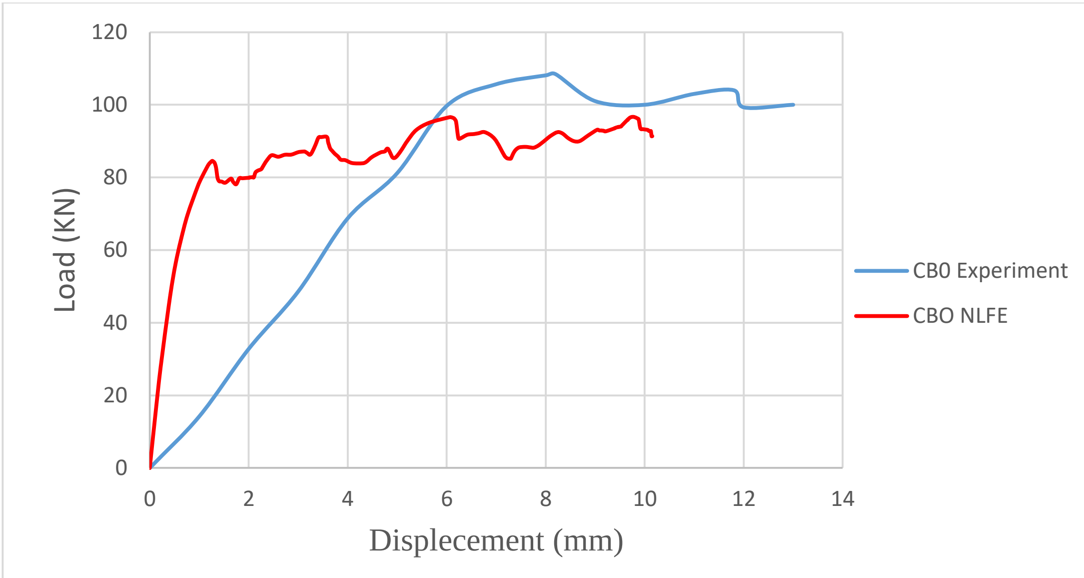


Figure 4.3 Comparison of failure load vs mid-span displacement curve of experiment with NLFE

Crack pattern of analytical and experimental are discussed as following section Figure 4.4.

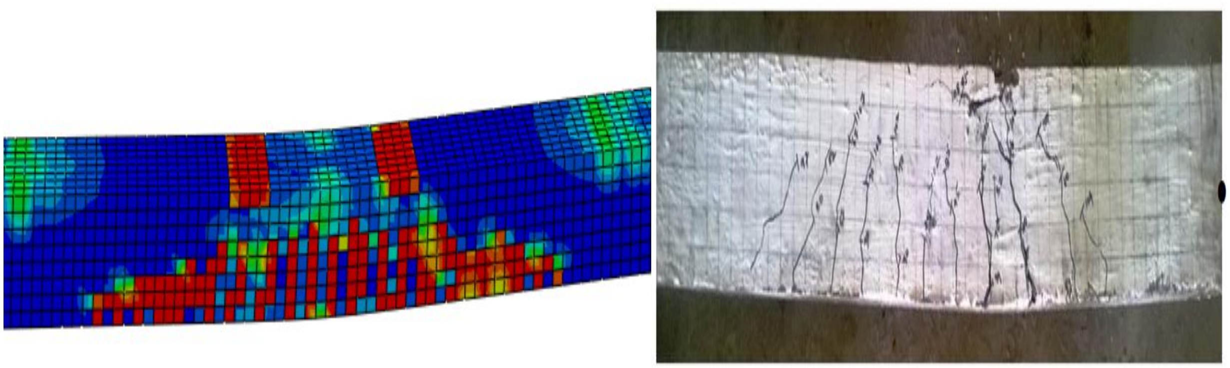


Figure 4 4 Comparison of crack pattern experimental and finite element analysis

The comparison of experimental and finite element analysis in tabular form was discussed as below table 4.3 section.

Table 4.3 Experimental and finite element comparison summary

Category	Experimental Results		Finite element Results		Variation in Percent	
Element	Load	Displacement (mm)	Load (mm)	Displacement (mm)	Failure load Variation (%)	Mid-span displacement Variation (%)
CB0	108.42	8.2	96.67	9.7	11	15

4.4.1 Effects of selected parameters on the shear performance of reinforced concrete

As discussed in Section 3.3.1 parameters affect the shear performance of reinforced concrete beam using ferrocement. These parameters are change in diameter of wire mesh, change in space of steel wire mesh, change number of steel wire mesh layers, and combination of wire mesh with stirrups.

4.4.1.1 Effects of change in diameter of wire mesh to study shear performance RC beam

In this study all specimen of sample modeled with the same element of mesh size, boundary condition, loading condition under four-point bending by static loading but used different diameter of wire mesh in computation of finite element discretization.

Failure load performance versus Maximum mid-span deflection of the beam under change of wire mesh diameter of (WM1, WM2, and WM3). In this study computation shear performance of reinforced concrete beam as replacement with steel wire mesh of different diameters used for study was 1.5mm, 2mm and 2.5mm under this change to investigate the behavior of shear performance significant effect.

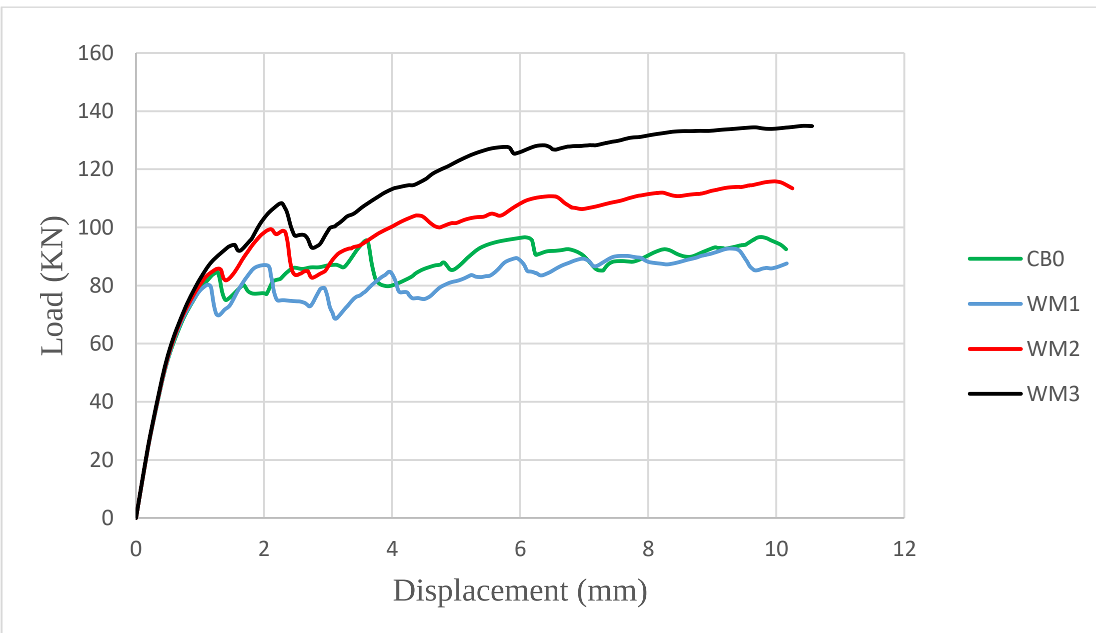


Figure 4.5 Ultimate load of failure vs mid-span displacement of RC beam using steel wire mesh as shear reinforcement under change in diameter

As presented in section above of Figure 4.5 are the ultimate loads of failure for chosen sample specimen under the change in diameter of steel wire mesh with 1.5mm, 2mm and 2.5mm. To investigate ultimate load of failure when compared with control specimen. The variation of ultimate load between CB0 and WM2 was 19.14 KN or 19.8% increments ultimate load of failure capacity. Using steel wire mesh of WM2 and WM3 have load carrying capacity variation due to change in diameter of steel wire mesh from 115.81KN to 134.94 KN load carrying capacity increment about 39.59% as compared to CB0. However, when diameter of wire mesh decreased between WM1 and WM2 ultimate load carrying capacity was decreased from 115.81KN to 92.73 or by 4.08 % when compared with CB0.

Table 4.4 Results of beam with wire mesh change in diameter

Specimen	Failure load (KN)	Mid-span displacement(mm)	Max shear stress (Mpa)	Stiffness (KN/mm)
CB0	96.67	9.74	9.01	9.92
WM1	92.73	9.27	8.25	10
WM2	115.81	9.99	11.25	11.6
WM3	134.94	10.46	13.92	13

Table 4.5 Relative values of wire mesh change in diameter results with control

Specimen	$P_{ult}/P_{ult.}r_{ef}$ (%)	$\Delta_{ult}/\Delta_{ult.}r_{ef}$ (%)	$V_u/V_{u.}r_{ef}$ (%)	$S_{tiffness}/S_{tiff.}r_{ef}$ (%)
CB0	100	100	100	100
WM1	95.92	95.17	91.56	100.81
WM2	119.8	102.57	124.86	116.93
WM3	139.59	107.39	154.5	131.05

Shear stress of beam as diameter of steel wire mesh show WM2 and WM3 of increment of about 24.86% and 54.5% but the WM1 shear stress decrement by 8.44% because small diameter. In addition to this stiffness of the beam for WM1, WM2 and WM3 increment of 0.8%, 16.94% and 31.05% respectively under change wire mesh diameter.

From finite element analysis based on change in diameter parameter ultimate load of failure versus displacement is shown below section. The results of change in diameter of wire mesh also expressed in the chart form to easily understand ultimate load of failure.

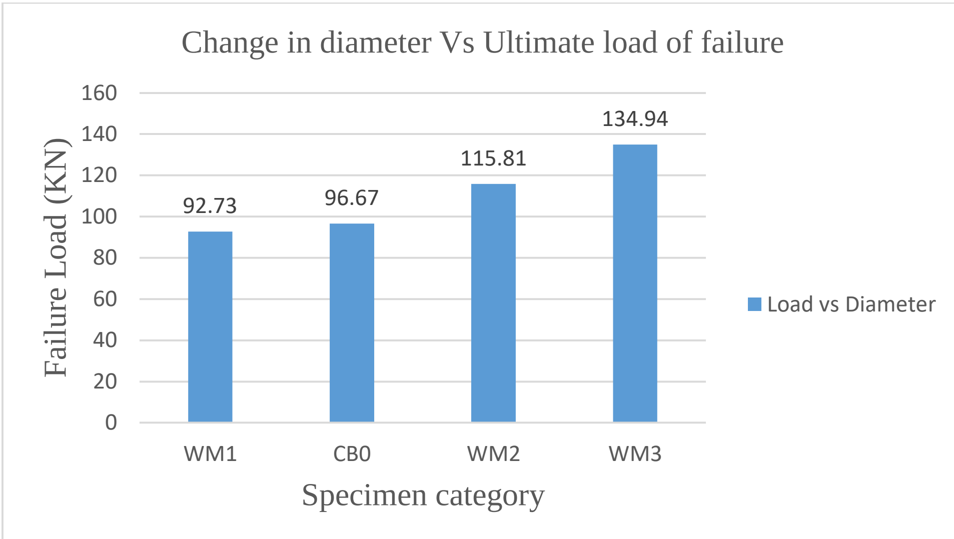


Figure 4.6 Change of wire mesh in diameter vs failure load of each specimen

From Abaqus output maximum shear stress versus diameter of wire mesh express in chart form presented to below section Figure 4.7 and maximum response in Figure 4.8.

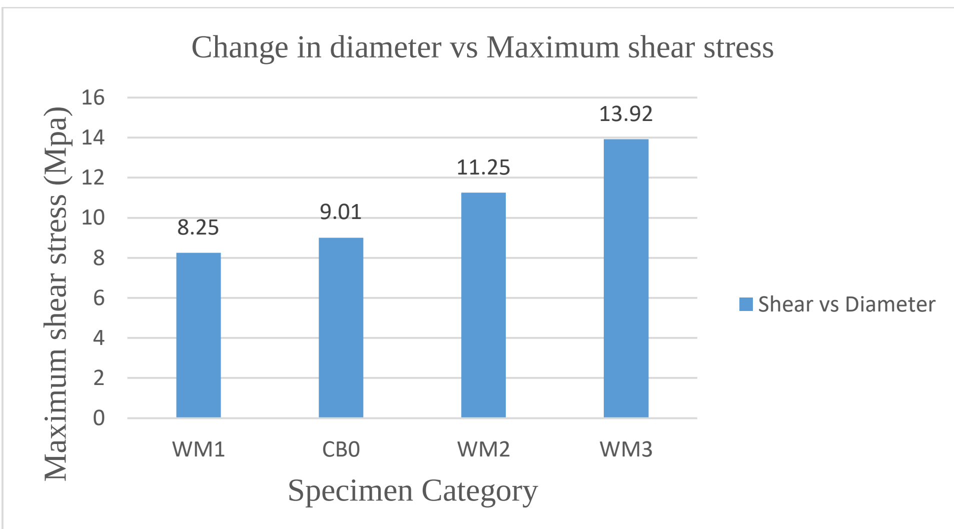


Figure 4.7 Change of wire mesh in diameter vs maximum shear stress of each specimen

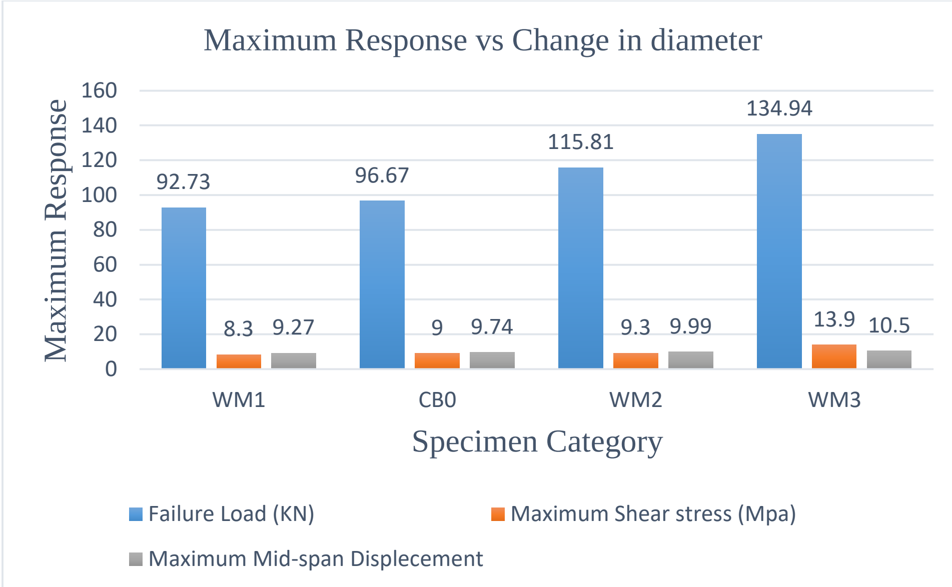


Figure 4.8 Change in diameter vs maximum response in case of change in diameter

Similarly under similar case for different spacing of wire mesh change in diameter ultimate load versus displacement discussed for WME1, WME2 and WME3 in graph and chart description.

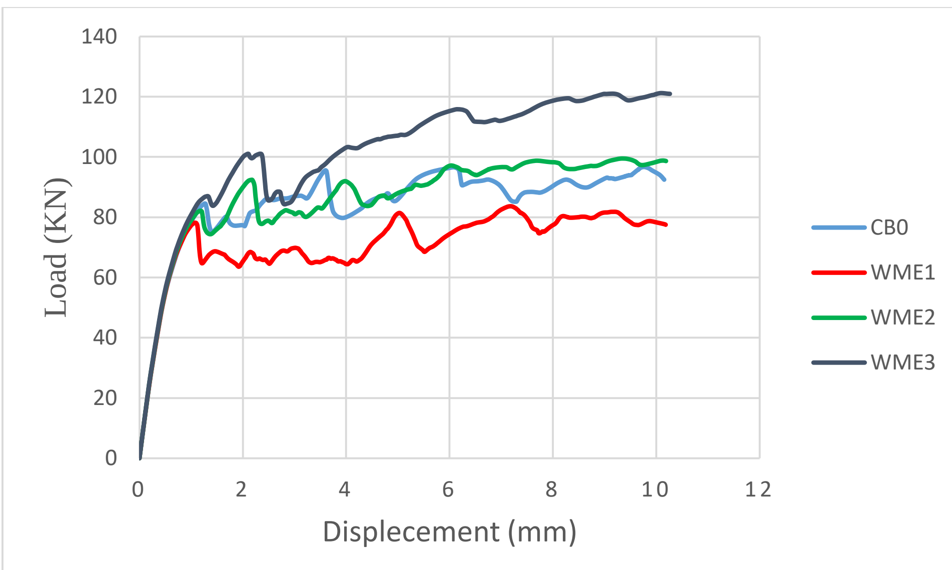


Figure 4.9 Ultimate load of failure vs mid-span displacement of RC beam using steel wire mesh as shear reinforcement under change in diameter

Ultimate load of failure increases for WME2 and WME3 about 4.79% and 26.68% but for WME1 decrement by 13.48% as compared to control specimen. Failure load WME2 compared with WME3 its increase from 101.3 KN to 122.46 KN or 20.89 % but with WME1 is decreased by 17.66 KN or 17.43%.

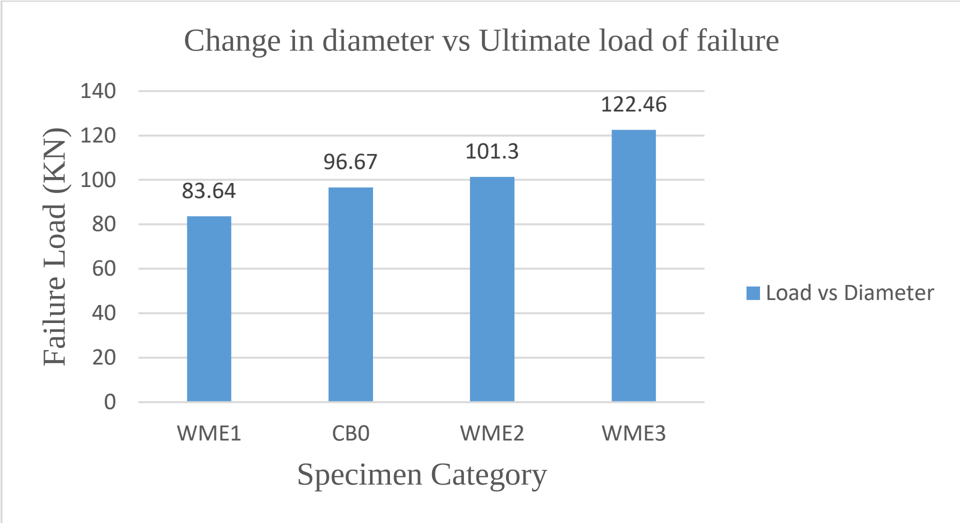


Figure 4.10 Change of wire mesh in diameter vs failure load of each specimen

4.4.1.2 Effects of change in spacing of steel wire mesh to study shear performance RC beam

In Chapter Three of this paper as discussed in variable section one study parameter for this thesis was change in spacing of steel wire mesh under similar condition of finite element analysis. The wire mesh spacing used for study are 8mmx8mm, 11mmx11mm and 15mmx15mm with the same diameters under CB0 specimen. The results presented in the Figure 4.11 and Table 4.6.

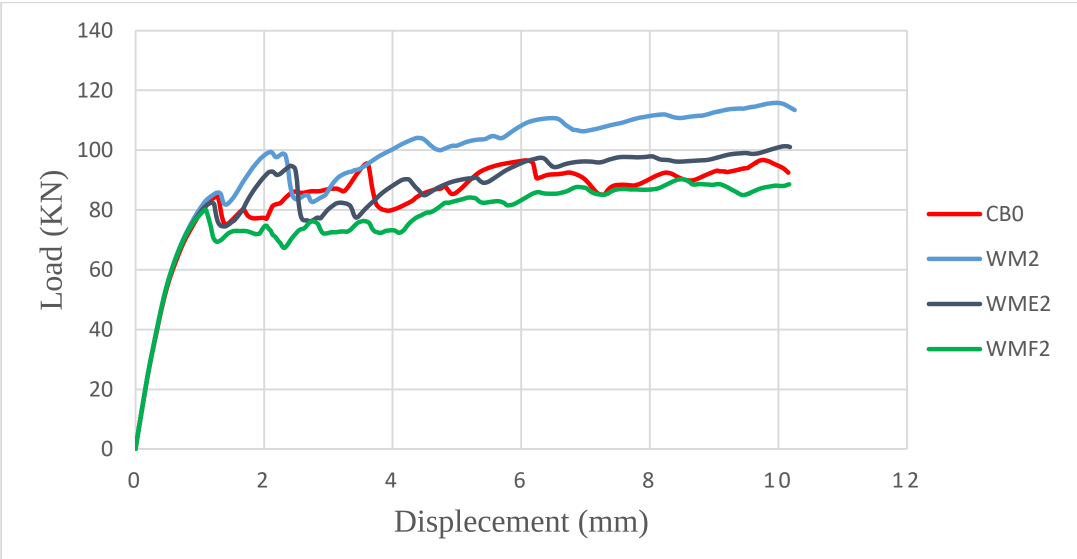


Figure 4.11 Ultimate load of failure vs mid-span displacement of wire mesh replacement shear reinforcement under change in spacing of steel wire mesh

Spacing of wire mesh shown in Figure 4.10, beam with the same diameter and difference in spacing (WM2) was indicated ultimate failure load capacity increased from 96.67 KN to 115.81 KN or 19.8 % as compared with (CB0). In addition to that WME2 ultimate failure load carrying capacity of increased to 101.3 KN or 4.79 % when compared to control specimen. Similarly, the comparison of WMF2 with control specimen decrement ultimate load failure capacity to 90.29 or by 6.6 %. As spacing of wire mesh replacement shear reinforcement stirrups changed maximum shear stress and stiffness capacity detail discussed in the following section.

Table 4.6 Results of beam with wire mesh change in spacing

Specimen	Failure load (KN)	Mid-span displacement(mm)	Max shear stress (Mpa)	Stiffness (KN/mm)
CB0	96.67	9.74	9.01	9.92
WM2	115.81	9.99	11.25	11.6
WME2	101.3	10.08	9.56	10.05
WMF2	90.29	8.5	8.83	10.62

As discussed in Table 4.6 present the results of maximum shear stress and stiffness under change of steel wire mesh spacing. Computation of relative values is presented in below Table 4.7.

Table 4.7 Relative values of wire mesh change in spacing results with control

Specimen	$P_{ult}/P_{ult.ref}$ (%)	$\Delta_{ult}/\Delta_{ult.ref}$ (%)	$V_u/V_{u.ref}$ (%)	$S_{tiffness}/S_{tiff.ref}$ (%)
CB0	100	100	100	100
WM2	119.8	102.57	124.86	116.94
WME2	104.79	103.49	106.1	101.31
WMF2	93.4	87.27	98	107

In the case of spacing of wire mesh change shear stress of beam of WM2 and WME2 increment about 24.86% and 6.1% respectively. Under similar way WMF2 decrement about 2%. Stiffness beam of WM2, WME2 and WMF2 increment about 16.94%, 1.31% and 7.06% respectively.

The study of change of spacing of wire mesh versus ultimate load of failure is shown in the section below Figure 4.12. Change in spacing of wire mesh for different specimen presented in next section explained in chart forms clearly show ultimate load of failure versus spacing effect.

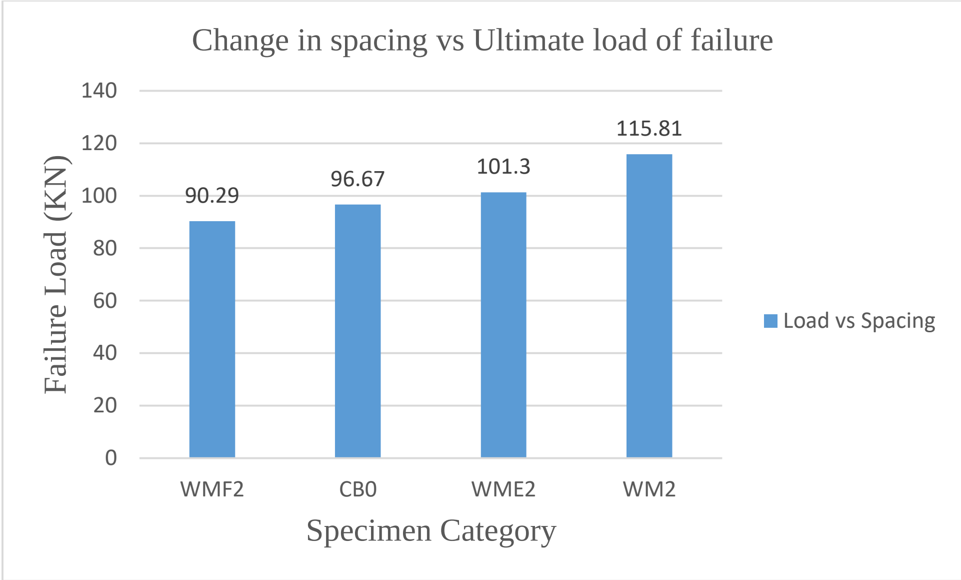


Figure 4.12 Change in spacing vs ultimate load of failure of specimen

Based on spacing parameter of study Abaqus result of maximum shear stress versus spacing of wire mesh which presented as following chart of Figure 4.13.

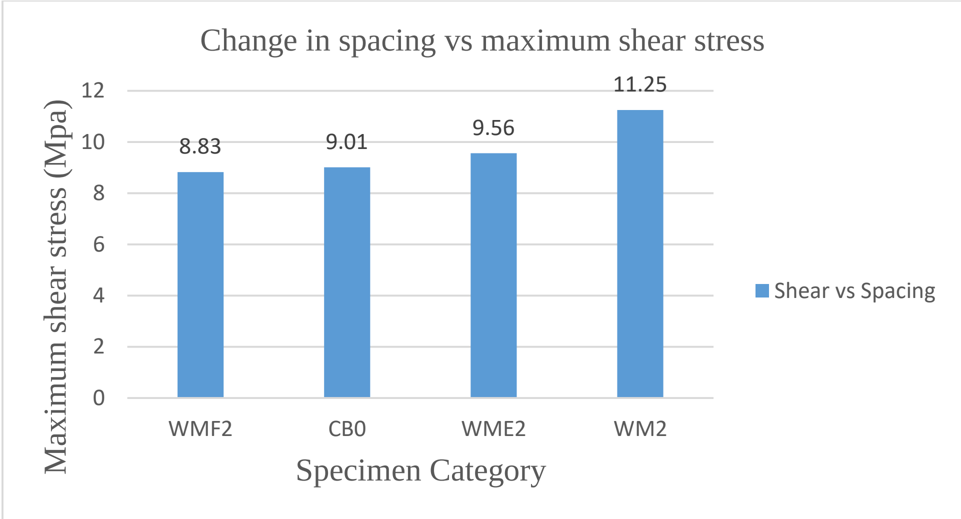


Figure 4.13 Change in spacing vs Maximum shear stress of specimen

In addition to this maximum response of study in paper is discussed in below regression chart form in section of Figure 4.14

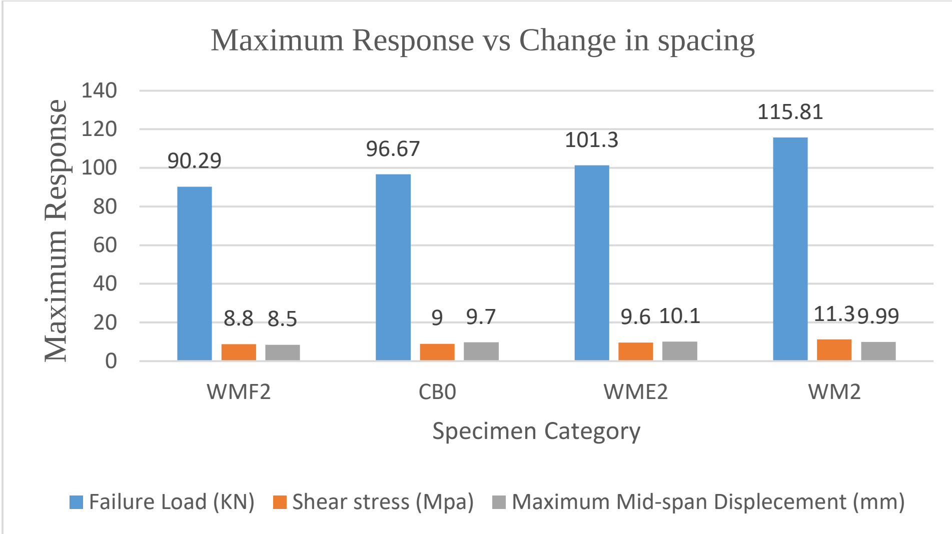


Figure 4.14 Change in spacing vs Response in case of spacing change

4.4.1.3 Effects of change in layers of steel wire mesh to study shear performance RC beam

In this thesis steel wire mesh layer is one of study parameters presented to study the comparison of single layer mesh specimen with two-layer specimen under the same diameter and spacing. In addition to this finite element analysis under the same loading condition, boundary condition, mesh and geometrical properties to investigate their shear performance of beam is determined.

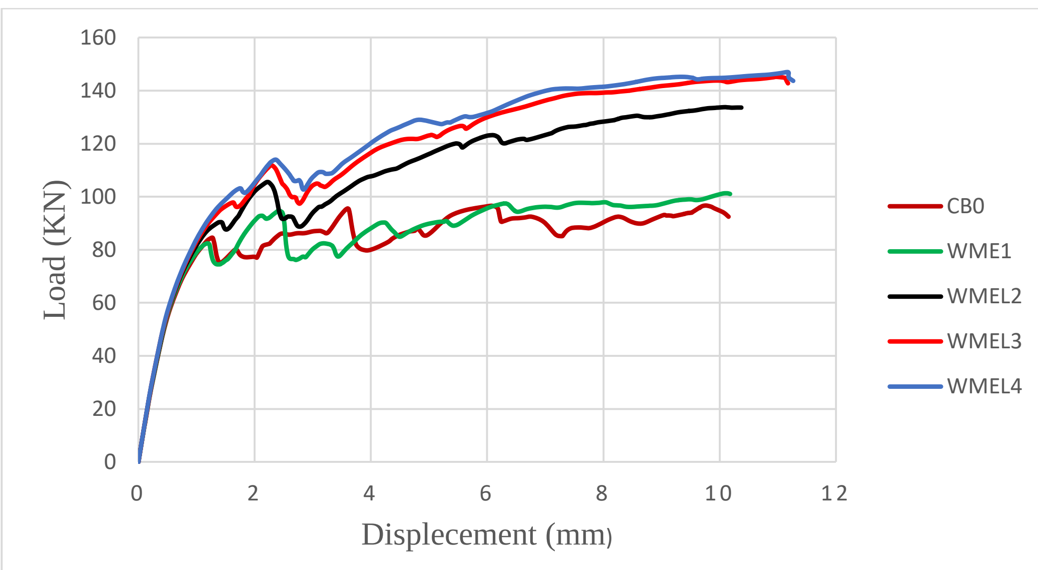


Figure 4.15 Ultimate load of failure vs mid-span displacement of steel wire mesh replacement of shear reinforcement stirrups under change in number of wire mesh layers

Figure 4.15 shows the failure load under the change of wire mesh layers. The results of ultimate load capacity of WMEL2, WMEL3 and WMEL4 increment about 38.38%, 50.2% and 52.04% as compared with control specimen.

Table 4.8 Results of beam with wire mesh change number of layers

Specimen	Failure load (KN)	Mid-span displacement(mm)	Max shear stress (Mpa)	Stiffness (KN/mm)
CB0	96.67	9.74	9.01	9.92
WME1	101.3	10.1	9.56	10
WMEL2	133.8	10.1	13.53	13.23
WMEL3	145.2	10.8	15.53	13.44
WMEL4	146.98	10.2	15.74	14.41

Table 4.9 presented the results of change number of wire mesh layers calculate relative values of load, shear stress and stiffness are presented in section below.

Table 4.9 Relative values of wire mesh change in number of layers result with control

Specimen	$P_{ult}/P_{ult.}r_{ef}$ (%)	$\Delta_{ult}/\Delta_{ult.}r_{ef}$ (%)	$V_u/V_{u.}r_{ef}$ (%)	$S_{tiffness}/S_{tiff.}r_{ef}$ (%)
CB0	100	100	100	100
WME1	104.8	103.7	106.1	100.1
WMEL2	138.4	103.7	150.2	133.4
WMEL3	150.2	110.47	172.4	135.5
WMEL4	152	110.88	174.7	145.26

Change number of wire mesh also have effect on shear stress beam of WMEL2 and WMEL3 and WMEL4 increment about 50.2% and 72.4% and 74.7% respectively. Similarly, stiffness increment about 33.37, 35.48% and 45.26.

ABAQUS output of change in number of wire mesh layers presented as following section in chart form in Figure 4.16.

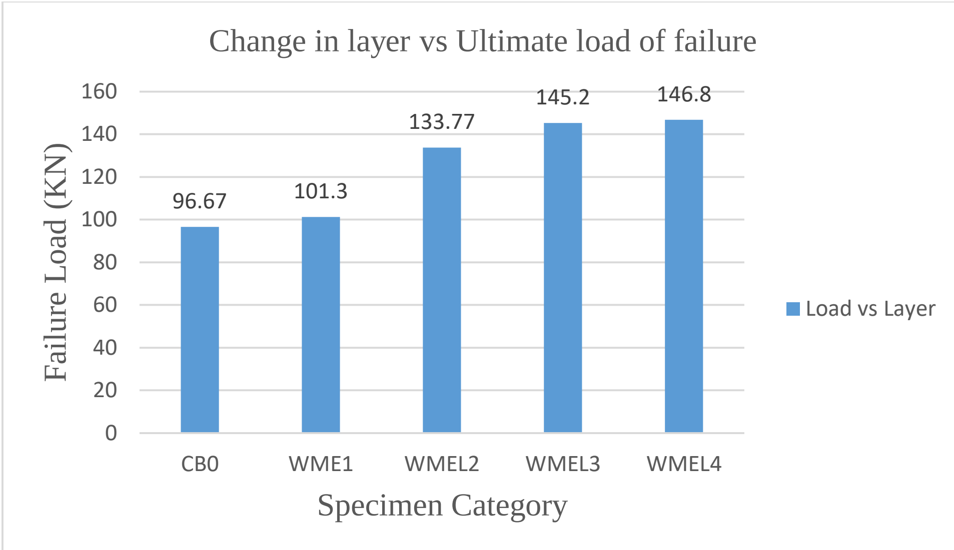


Figure 4.16 Change in number of wire mesh layers vs ultimate load of failure of specimen

In thesis under change of wire mesh spacing maximum shear stress versus number of wire mesh layers presented regression form as follows:

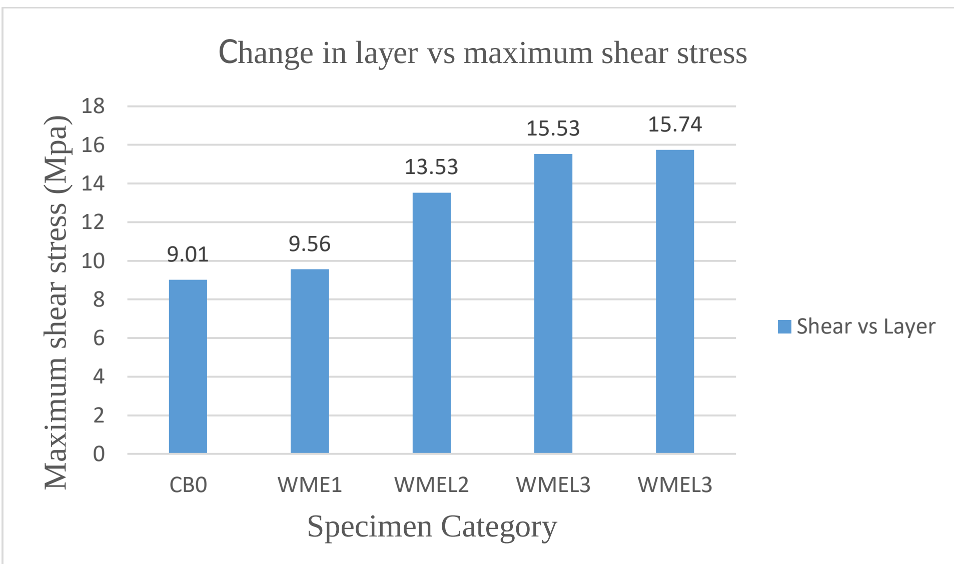


Figure 4.17 Change in number of wire mesh layers vs Maximum shear stress of specimen

For maximum response versus change number of wire mesh layers presented in below section of Figure 4.18 in chart form.

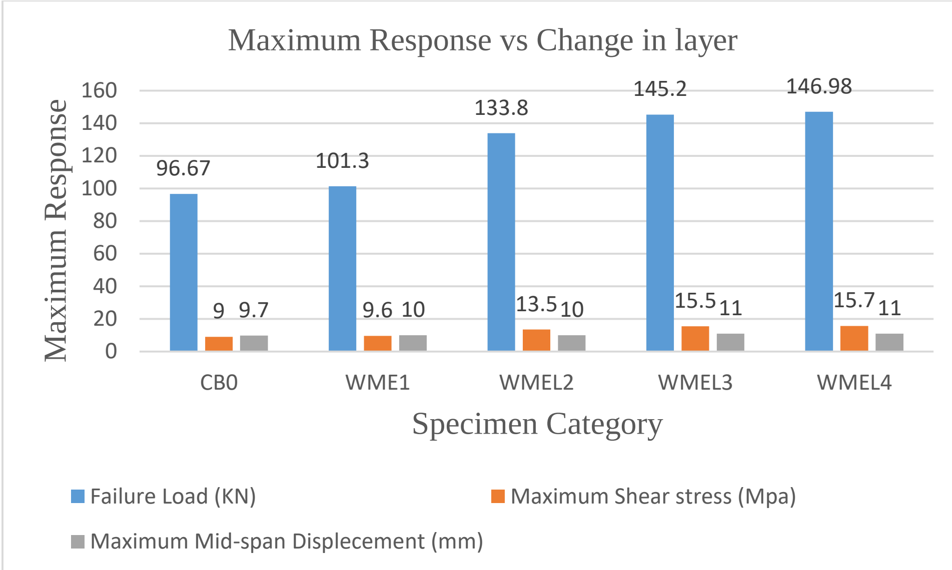


Figure 4.18 Change in number of layers vs Maximum Response due to change of mesh layer

4.4.1.4 Effects of combination wire mesh with stirrups to study shear performance of RC beam

Studying the combination of steel wire mesh with stirrups is also one of the major objectives of this paper which focuses on comparing the shear performance of steel wire mesh as replacement of stirrups. For this parameter simulation conducting under similar finite element condition but change combination of wire mesh used with shear reinforcement stirrups. The results of ultimate load of failure versus displacement shown in Figure 4.19.

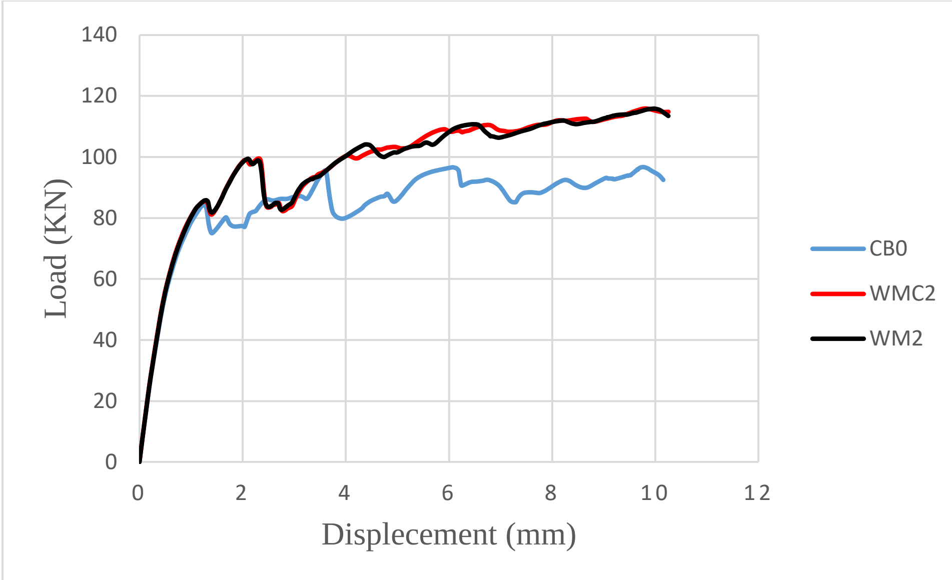


Figure 4.19 Ultimate load of failure vs mid-span displacement of shear reinforcement stirrups replacement by combination of wire mesh with stirrups

Simulation results shows ultimate load carrying capacity between CB0 and WM2 increased from 96.67 KN to 115.51 KN which is 19.8 % and WMC2 increased about 19.49% as compared with CB0.

Table 4.10 Results of beam combination of wire mesh with stirrups

Specimen	Failure load (KN)	Mid-span displacement(mm)	Max shear stress (Mpa)	Stiffness (KN/mm)
CB0	96.67	9.74	9.01	9.92
WMC2	115.51	9.93	11.16	11.6
WM2	115.81	9.94	11.25	11.65

Table 4.10 presents the results of combination of wire mesh with stirrups and the calculated relative values of shear stress, failure load and stiffness are shown in Table 4.11.

Table 4.11 Relative values of wire mesh combination with stirrups result with control

Specimen	$P_{ult}/P_{ult.ref}$ (%)	$\Delta_{ult}/\Delta_{ult.ref}$ (%)	$V_u/V_{u.ref}$ (%)	$S_{tiffness}/S_{tiff.ref}$ (%)
CB0	100	100	100	100
WMC2	119.49	101.95	123.86	117.23
WM2	119.8	9.94	124.86	117.44

Shear reinforcement used with the combination of wire mesh and stirrups shear stress of WMC2 and WM2 increased about 23.86% and 24.86% respectively. For the same study, stiffness of WMC2 and WM2 increased about 17.23% and 16.94% respectively.

Under this category results presented in above section of Table 4.10 based on those results ultimate failure load versus combination of wire mesh with stirrups is shown by chart form in Figure 4.20.

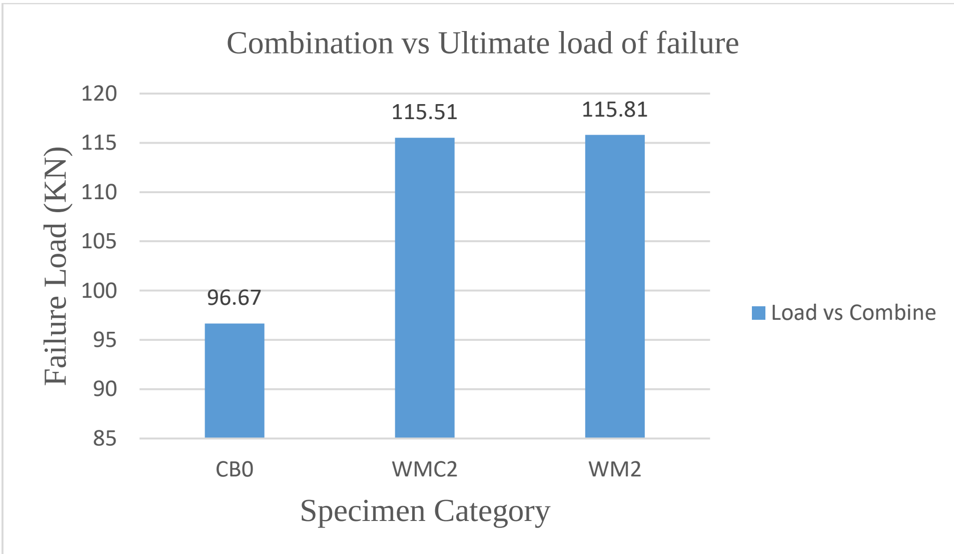


Figure 4.20 Change in combination of wire mesh with stirrups vs load of failure of specimen

From ABAQUS result under combination of wire mesh with stirrups as shear reinforcement maximum shear stress of RC beam plot in below chart of Figure 4.21.

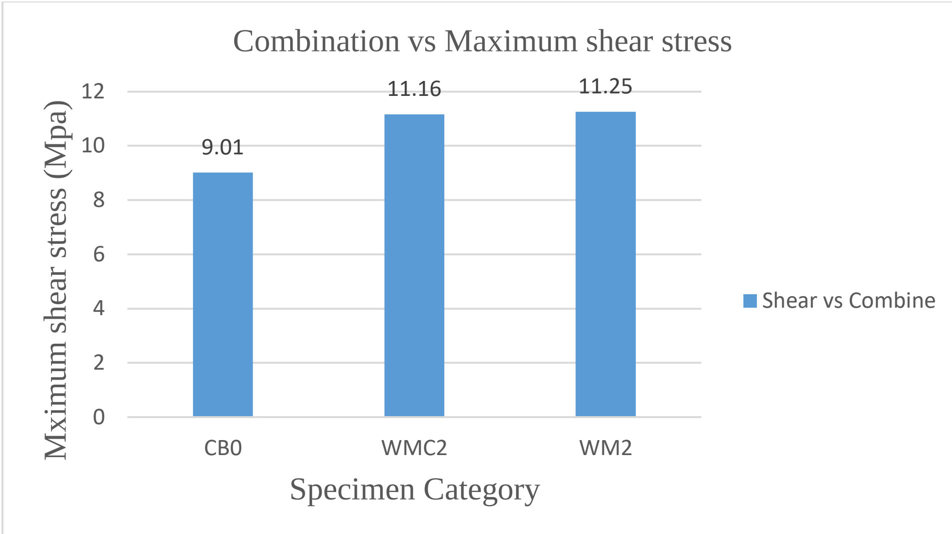


Figure 4.21 Change in combination of wire with stirrups vs maximum shear stress of specimen

Similarly the maximum response versus wire mesh combination with stirrups replacement of shear reinforcement in reinforced concrete beam study based on this parameters presented as the following section of Figure 4.22.

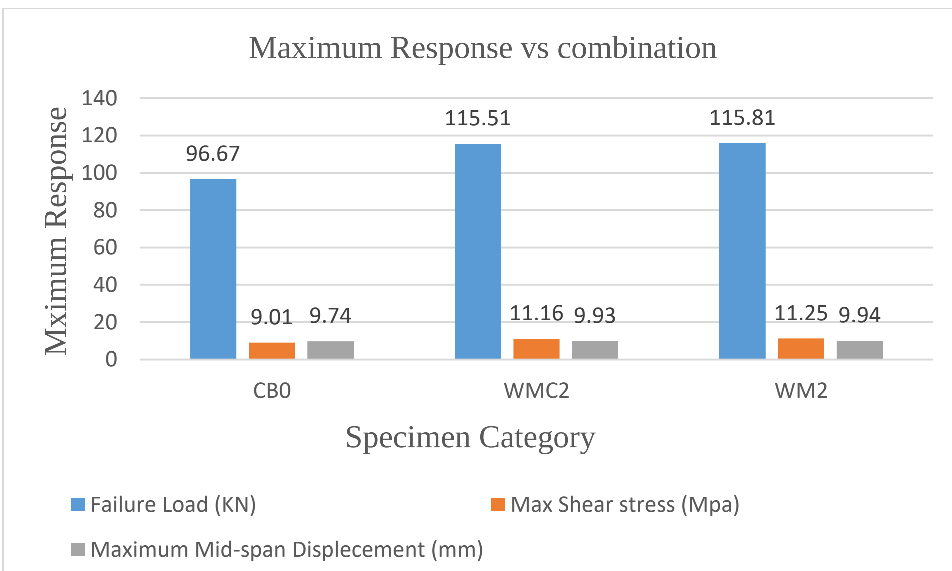


Figure 4.22 Change in combination of mesh with stirrups vs Maximum response of specimen

In addition to this, when layers increase with diameter of wire mesh show great variation of result as compared to the result presented for other parameters. The results are presented in below section Figure 4.23.

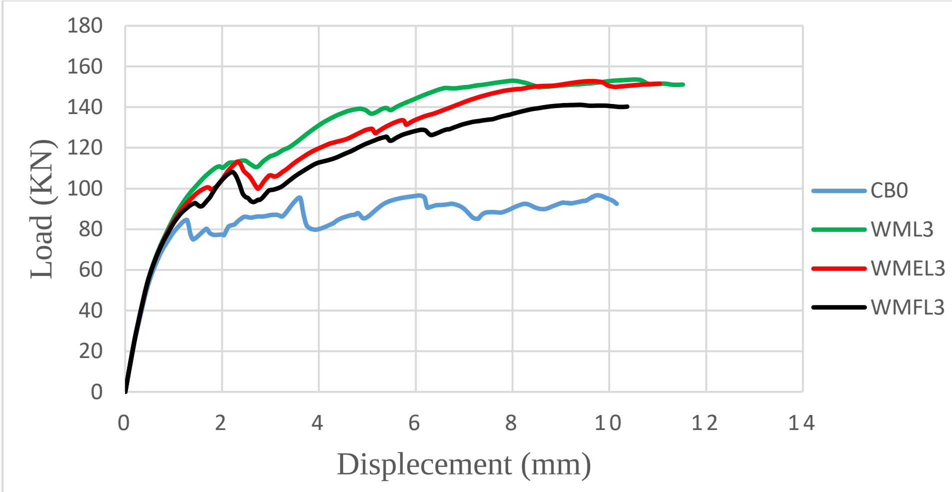


Figure 4.23 Change in number of wire mesh layers and diameter vs ultimate load of failure

Simulation results shows ultimate load carrying capacity between CB0 and WML2, WMEL2 and WMFL2 increased from 96.67 KN to 146.11 KN or 51.14 %, 133.77 or 38.38% and 118.69 or 22.79% respectively as compared with control specimen (CB0).

Table 4.12 Results of wire mesh change in diameter and layers compared with control

Specimen	Failure load (KN)	Mid-span displacement(mm)	Max shear stress (Mpa)	Stiffness (KN/mm)
CB0	96.67	9.74	9.01	9.92
WML3	153.57	10.57	16.81	14.55
WMEL3	152.81	9.65	16.08	15.84
WMFL3	141.15	9.37	14.06	15.06

Based Table 4.13 presents results of calculate relative values with change diameter and layers.

Table 4.13 Relative values when diameter and layers change compared with results of control

Specimen	$P_{ult}/P_{ult.ref}$ (%)	$\Delta_{ult}/\Delta_{ult.ref}$ (%)	$V_u/V_{u.ref}$ (%)	$S_{tiffness}/S_{tiff.ref}$ (%)
CB0	100	100	100	100
WML3	158.86	108.52	186.57	146.67
WMEL3	158.07	99.07	178.47	159.68
WMFL3	146.01	96.2	156.05	151.81

As number of wire mesh layers and diameter increment shear stress of beam WML3, WMEL3 and WMFL3 about 86.57%, 78.47% and 56.05% respectively. Stiffness for similar manner WML3, WMEL3 and WMFL3 about 46.67%, 59.68% and 51.81% respectively.

Under this case show effect of diameter and layers change on steel wire mesh as replacement of shear reinforcement to investigate shear capacity of reinforced concrete beam behavior discussed following section chart Figure 4.24.

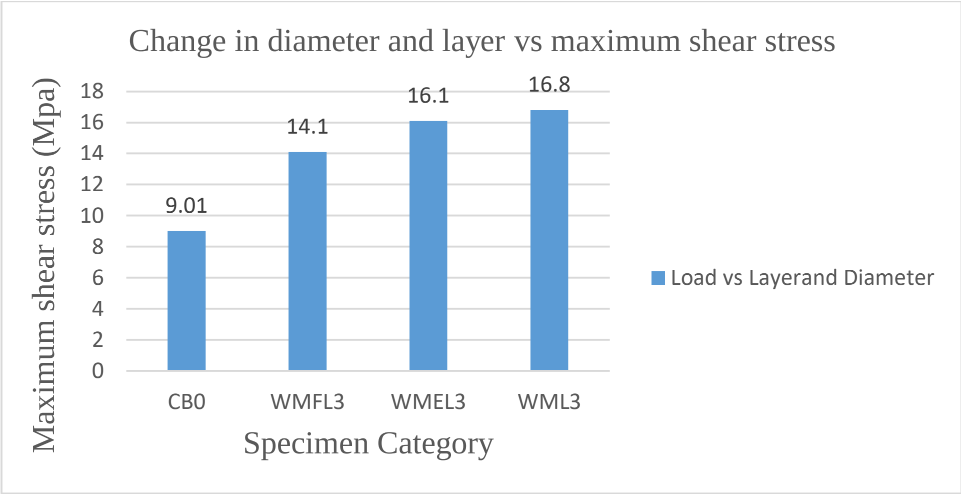


Figure 4.24 Change in number of wire mesh layers and diameter vs maximum shear stress

From ABAQUS result maximum response vs diameter and layers chart was discussed as following section Figure 4.25

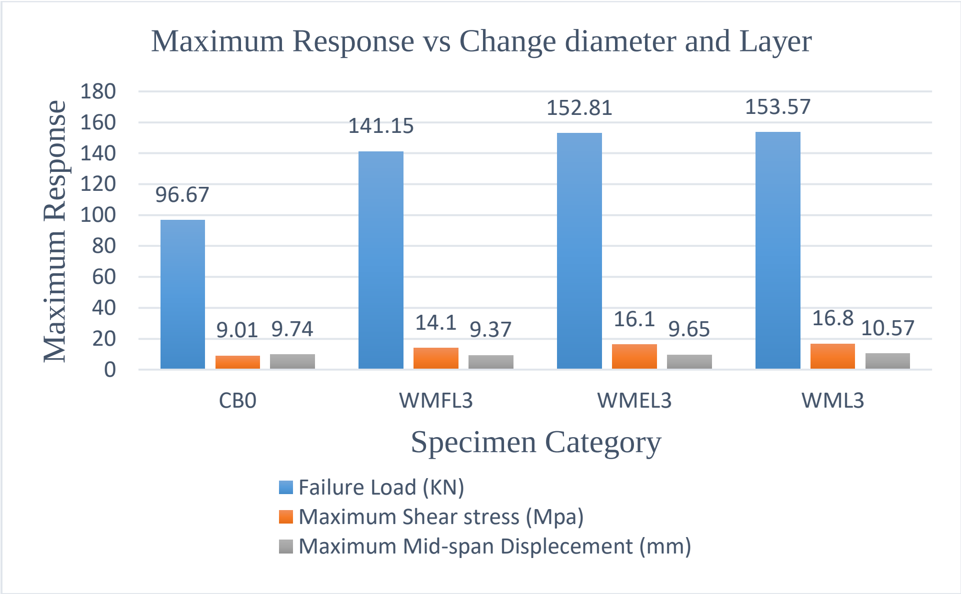


Figure 4.25 Change in number of wire mesh layers and diameter vs Maximum response

4.5 Limitation of parameters considering in study

Under change of different parameters studied in paper there are limitation of shear performance increment as wire mesh replacement of shear reinforcement stirrups. Changed parameters was increase diameter of wire mesh, close spacing of wire mesh, increase number of wire mesh layers and combination of wire mesh with stirrups. These parameters increase shear capacity have been limitation was studied in the below section of table 4.14.

Table 4.14 Limitation of study parameters

Spacing (mm)	Layers	Diameter (mm)	Ultimate load (KN)	Displacement (mm)
11x11	3	2	145.18	10.98
11x11	4	2	146.19	11.17
6x6	1	2	130.28	10.37
4x4	1	2	148.02	11.02
3x3	1	2	153.52	10.02
2x2	1	2	42.92	10.51
11x11	1	4	149.74	11.18
11x11	1	5	154.72	11.85
11x11	1	6	165.26	4.75

Based on results presented in above table number of wire mesh layers was limited to 3 layers. It's not have significant effect on shear performance of reinforced concrete beam as increase more than three layers. Number of wire mesh of 3 and 4 layers have the difference ultimate load of failure about 0.69% the difference have been close to null between two layers. Similarly spacing of wire mesh also decrease ultimate load capacity of reinforced concrete beam as closing spacing of wire mesh less than 3mmx3mm spacing. Spacing of 2mmx2mm results decrement ultimate load capacity about 55.6% and 72.04% as compared to control specimen and 3mmx3mm spacing of wire mesh respectively. In addition to this the change diameter of wire mesh as diameters of wire mesh increased ultimate load capacity of reinforced concrete have not been decreased even till diameter of wire mesh equal with shear reinforcement stirrups.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This chapter presents summary of main result findings of this paper and recommends for further study in future investigation related to this thesis.

A nonlinear 3D finite element was developed to study shear performance of reinforced concrete beam using ferrocement under static load condition. This experimental program conducted by [1] chosen in previous section. Modeling using software (ABAQUS/static general) have different steps of modeling considering geometry, material properties, mesh size, element section, boundary condition, and step of simulation. In previous experimental paper shear reinforcement stirrups used to resist effect of shear. For this study twenty-seven sample were modeled depending on wire mesh diameter, spacing, layers and combination of steel wire mesh with stirrups to study replacement of shear reinforcement stirrups by steel wire mesh. As detail discussed in result and discussion, the following conclusion are drawn:

- ✓ The result of conducted experimental ultimate load of failure (108.42 KN) comparison with finite element analysis (96.67) KN using ABAQUS 6.14 their difference was 11%.
- ✓ Using steel wire mesh as shear reinforcement change of diameter has play significant role to increase load failure capacity of WME2 and WME3 of 2mm and 2.5mm diameter of mesh respectively about 4.8%, 26.68% but WME1 small diameter 1.5mm wire mesh decrement of 13.47% as compared with control beam.
- ✓ Spacing of steel wire mesh has effect on reinforced concrete beam using ferrocement as spacing of mesh was closed to each other increases failure load capacity of WM2 and WME2 about 19.8% and 4.79% respectively but in case of WMF2 decrement about 6.6% as compared with control beam.
- ✓ As studied in this paper when increase number of wire mesh layers ultimate load capacity of WMEL2, WMEL3 and WMEL4 of spacing 11mmx11mm with two, three and four layers increment about 38.38%, 50.2% and 52.04% respectively when compared with CB0. In addition to this improve shear stress and stiffness of RC beam than shear

reinforcement stirrups. For this study number of wire mesh layers more than three layers no significant effect on shear performance of reinforced concrete.

- ✓ Ultimate load of failure capacity increase when combination of wire mesh with stirrups used as shear reinforcement of WMC2, WMCE2 and WMCF2 of similar diameter about 19.49%, 2.4% and decrease 6.1 % when compared with control beam.
- ✓ Shear stress of steel wire mesh increases as number of mesh layers increases for WML3, WMEL3 and WMFL3 diameter 2.5mm and two layers about 86.52%, 78.47% and 56.05% respectively when compared with control beam.
- ✓ Stiffness increases as diameter of steel wire mesh change for WM1, WM2 and WM3 about 0.8%, 16.94% and 31.05% respectively as compared with control beam.
- ✓ Ultimate load capacity increase as diameter of wire mesh increases. It's not exactly show optimum diameter increment limit. Number of mesh layers increases failure load capacity till three mesh layers more than this no effect on beam. Spacing of wire mesh increases ultimate load of failure when close spacing of wire mesh till 3mmx3mm but mesh size of 2mmx2mm spacing decrement load carrying capacity but this size not applicable so, based on aggregate size we provide wire mesh size above 3mmx3mm mesh spacing.

5.2 Recommendation

As studied in the paper different parameters of wire mesh show effect on shear performance of beam, the following recommendation are forwarded in order to better findings and made strong current presented thesis.

The following recommendations are proposed for further study:

- ➢ Investigate by considering other different types of wire mesh such as expanded, woven, and hexagonal/chicken wire mesh.
- ➢ Use steel wire mesh for other structural elements of column by replacing lateral tie for sufficient ductility, resist shear failure and buckling of longitudinal reinforcement.
- ➢ Application of wire mesh as shear reinforcement have higher ultimate load of failure, shear stress and stiffness. So I recommend to use steel wire mesh as shear reinforcement for different structural elements of beam.
- ➢ Extend further study steel wire mesh effects on flexural strength of reinforced concrete beam.

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APPENDIX

Appendix A: Mechanical Properties of Material used as Input

Table A-1 Input data for the property of Concrete plasticity

Modulus of elasticity	31475.81
Poisson ratio	0.2
Dilation angle	36 (default)
Eccentricity	0.1 (default)
f_b/f_c	1.16 (default)
Constant K_c	0.6667 (default)
Viscosity	0.0001

Table A-2 Input data for compressive behavior of concrete behavior

31475.81			ec	η	σ	eel	ein	dc	ein	σ	ein	dc	ein
fcm (Mpa)	33				fc								
Ecm (Gpa)	31.47581		0.000454	0.219272	13.19997	0.000419	0	0	0	13.19997	0	0	0
ec1	2.069366		0.000908	0.438544	22.91777	0.000728	0.000179	0	0.000179	22.91777	0.000179	0	0.000179
ecu	0.0035		0.001361	0.657816	29.31187	0.000931	0.00043	0	0.00043	29.31187	0.00043	0	0.00043
eta	ec/ec1		0.001815	0.877088	32.53125	0.001034	0.000781	0	0.000781	32.53125	0.000781	0	0.000781
			0.002069	1	33	0.001048	0.001021	0	0.001021	33	0.001021	0	0.001021
k	2.072476		0.002339	1.130475	32.48076	0.001032	0.001307	0.015734	0.001291	32.48076	0.001307	0.015734	0.001307
k-2	0.072476		0.002609	1.260949	30.94104	0.000983	0.001626	0.062393	0.001561	30.94104	0.001626	0.062393	0.001626
			0.002879	1.391424	28.40714	0.000903	0.001977	0.139177	0.001831	28.40714	0.001977	0.139177	0.001977
			0.003149	1.521899	24.90446	0.000791	0.002358	0.245319	0.002101	24.90446	0.002358	0.245319	0.002358
			0.003419	1.652374	20.45754	0.00065	0.002769	0.380074	0.002371	20.45754	0.002769	0.380074	0.002769
fck (Mpa)	25		0.0035	1.691339	18.94994	0.000602	0.002898	0.425759	0.002452	18.94994	0.002898	0.425759	0.002898

Table A-3 Input data for tensile behavior of concrete behavior

fctm (Mpa	2.564964								
GF (N/m)	137.9								
w1 (mm)	0.053763				Tensile behavior				
wc (mm)	0.268815								
0.2fctm	0.512993								
		w	f	dt	yield stres	displacem	dt	displacem	epl
		0	2.564964	0	2.564964	0	0	0	0
		0.01	2.183294	0.148801	2.183294	0.01	0.148801	0.01	0.009986
		0.02	1.801624	0.297603	1.801624	0.02	0.297603	0.02	0.019965
		0.03	1.419953	0.446404	1.419953	0.03	0.446404	0.03	0.029934
		0.04	1.038283	0.595206	1.038283	0.04	0.595206	0.04	0.03988
		0.05	0.656613	0.744007	0.656613	0.05	0.744007	0.05	0.049763
		0.053763	0.512993	0.8	0.512993	0.053763	0.8	0.053763	0.053437
		0.07	0.47426	0.815101	0.47426	0.07	0.815101	0.07	0.069641
		0.08	0.450406	0.824401	0.450406	0.08	0.824401	0.08	0.079617
		0.09	0.426551	0.833701	0.426551	0.09	0.833701	0.09	0.089591
		0.1	0.402697	0.843001	0.402697	0.1	0.843001	0.1	0.099562
		0.11	0.378843	0.852301	0.378843	0.11	0.852301	0.11	0.10953
		0.12	0.354988	0.861601	0.354988	0.12	0.861601	0.12	0.119493
		0.13	0.331134	0.870901	0.331134	0.13	0.870901	0.13	0.12945
		0.14	0.30728	0.880201	0.30728	0.14	0.880201	0.14	0.139401
		0.15	0.283425	0.889501	0.283425	0.15	0.889501	0.15	0.149344
		0.16	0.259571	0.898801	0.259571	0.16	0.898801	0.16	0.159276
		0.17	0.235716	0.908101	0.235716	0.17	0.908101	0.17	0.169195
		0.18	0.211862	0.917402	0.211862	0.18	0.917402	0.18	0.179095
		0.19	0.188008	0.926702	0.188008	0.19	0.926702	0.19	0.18897
		0.2	0.164153	0.936002	0.164153	0.2	0.936002	0.2	0.198808
		0.21	0.140299	0.945302	0.140299	0.21	0.945302	0.21	0.208592
		0.22	0.116444	0.954602	0.116444	0.22	0.954602	0.22	0.218286
		0.23	0.09259	0.963902	0.09259	0.23	0.963902	0.23	0.227824
		0.24	0.068736	0.973202	0.068736	0.24	0.973202	0.24	0.237041
		0.25	0.044881	0.982502	0.044881	0.25	0.982502	0.25	0.245424

Appendix B: Output for Different finite Element Analysis

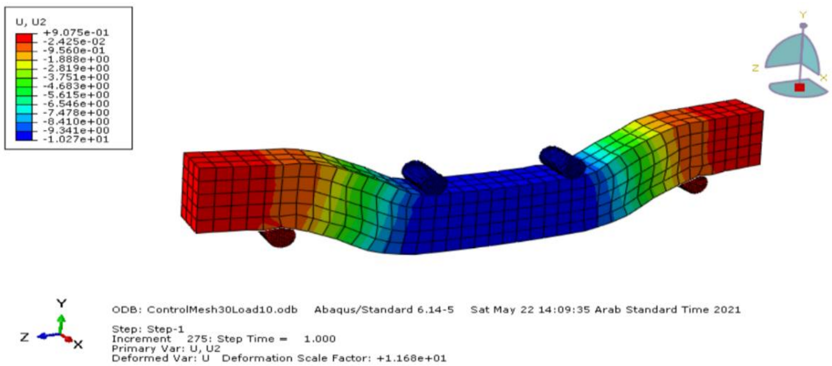


Figure B-1 Maximum deformation at failure load

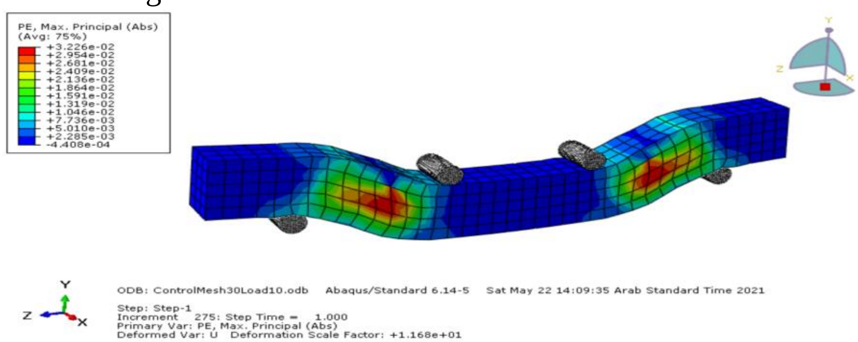


Figure B-2 Cracking pattern in shear

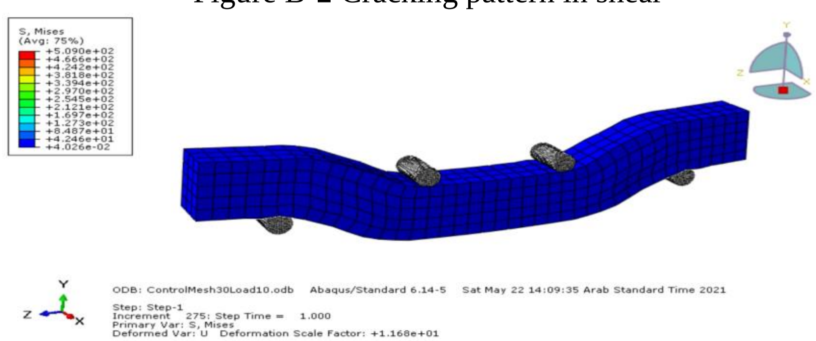


Figure B-3 Stress invariants of beam CB0

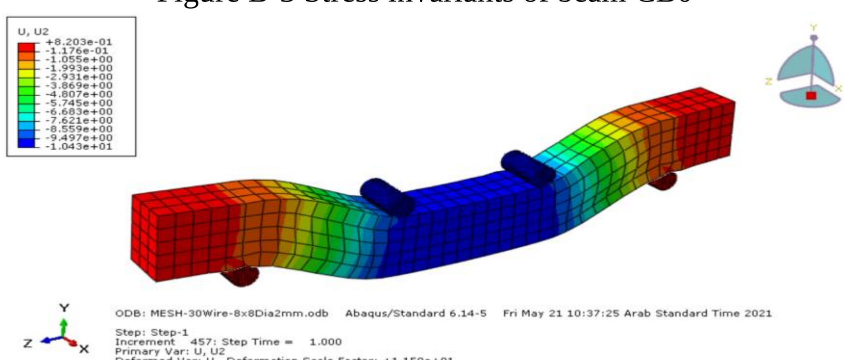


Figure B-4 Maximum deformation of increase shear capacity of beam (WM2)

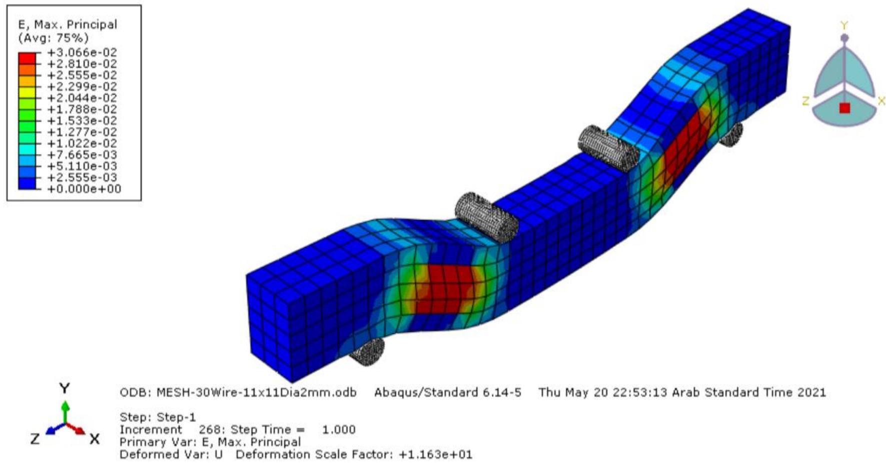


Figure B-5 Cracking pattern of shear (WME2)

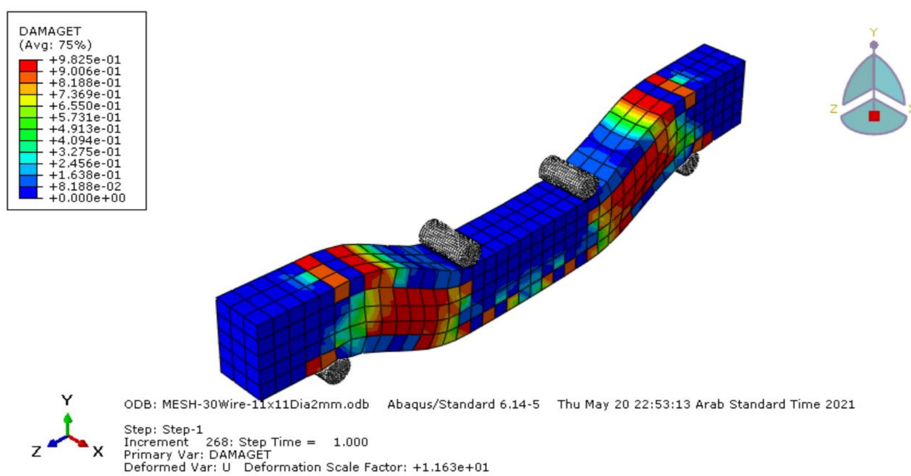
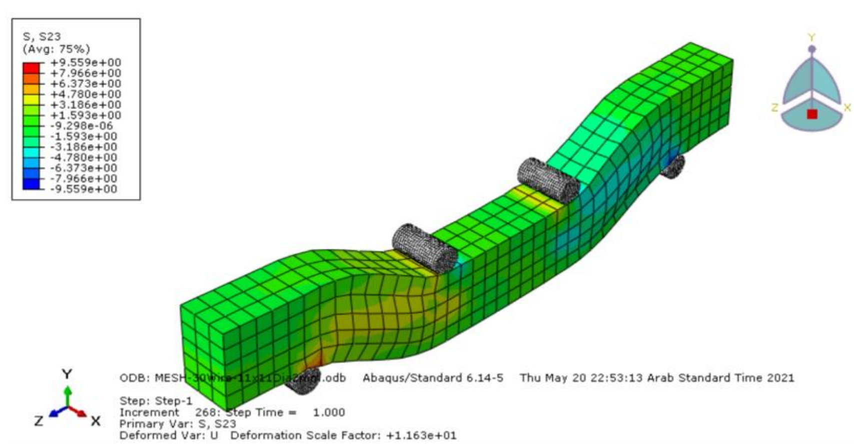


Figure B-6 shear damage (WME2)



B-7 maximum shear stress WME2

Appendix C: Ultimate load failure capacity versus mid-span deflection result

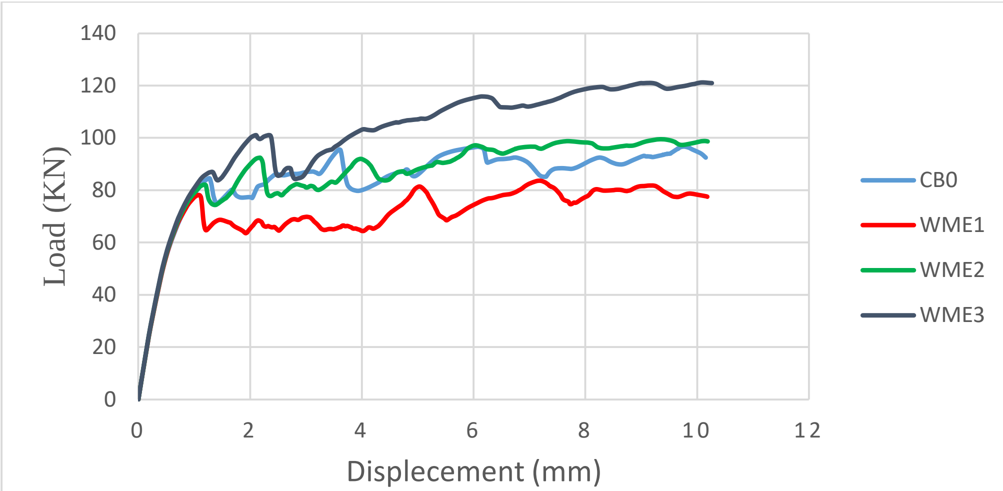


Figure C-1 Ultimate load carrying capacity vs Mid-span displacement diagram under change in diameter (CB0, WME1, WME2 and WME3)

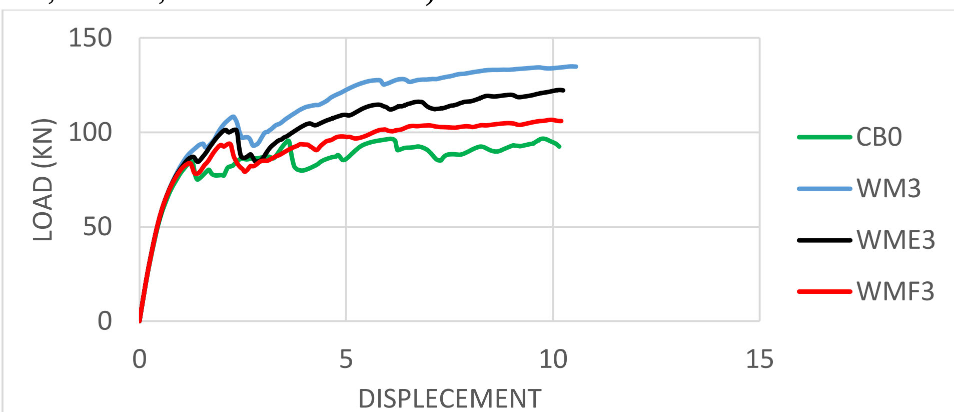


Figure C-2 Ultimate failure load capacity vs mid-span deflection diagram under change in spacing (CB0, WM3, WME3 and WMF3)

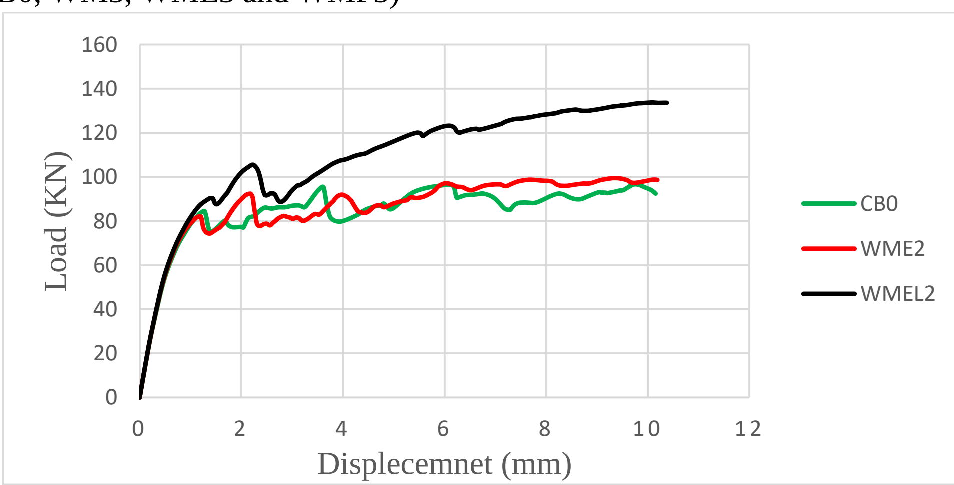


Figure C-3 Ultimate failure load capacity vs mid-span deflection diagram under change in number of layers (CB0, WME2 and WMEL2)

Appendix D: Calculate Equivalent of Wire Mesh and Stirrups Using Weight

Sample of calculation is explained below section other calculations in excel presented in tabular form.
Diameter of stirrups = 6mm

Diameter of wire = 2mm

$As = \pi d^2/4$

For stirrups

$\pi * d^2/4$ *no bar = $\pi * 6^2/4*8$=226.16mm^2

For steel wire mesh

$\pi * 2^2/4$ = 3.14mm^2

To find number of mesh make Equivalent area of both

$\pi * 6^2/4$ *8 = * $\pi * 2^2/4$ no of mesh in transverse direction

226.16mm^2 = 3.14mm^2* no of wire mesh

No of mesh = $\frac{226.16\ mm^2}{3.14\ mm^2}$ = 72.03 take 72 no of wire mesh

L_{Beam} = 1200 mm

The effect of shear on the beam at $\frac{L}{3}$ span from face of support

Therefore $\frac{1200}{3}$ = 400 mm one side for longitudinal

Again for transverse direction of length 2(100) + 2(50) + 2(50) = 400mm

Calculate Weight for single steel = $\frac{D^2}{162} * L$

Stirrups = $6^2/162$ = 0.222

Wire mesh = $2^2/162$= 0.0247

Total weight of steel = $D^2/162*n_b$ (mesh)*L

For stirrups = 0.222*8*400 = 710.4 Kg

For steel wire mesh = 0.0247*72*400 = 711.36 Kg

Weight per area = $\frac{W}{As*Nb(mesh)}$

Stirrups = $\frac{710.4}{28.27*8}$ = 3.14 $\frac{\text{Kg}}{m2}$

Steel wire mesh = $\frac{711.36}{3.14*72}$ = 3.15 $\frac{\text{Kg}}{\text{m2}}$

Spacing of mesh = $\frac{\text{L}}{\text{Nb(mesh)}}$

S = $\frac{400}{72*0.5}$ = 11.11mm take 11mm

Finally take spacing of wire mesh 11mmx11mm as reference

Table D-1 Weight calculation for wire mesh alone

	EQUIVALENT WEIGHT CALCULATION MESH ALONE					
Sample	Diameter (mm)	No mesh	Length(mm	Layers	Weight (Kg)	W/A(Kg/mm2)
WM1	1.5	102	400	1	566.6666667	3.145395927
WM2	2	102	400	1	1007.407407	3.145395927
WM3	2.5	102	400	1	1574.074074	3.145395927
WME1	1.5	78	400	1	433.3333333	3.145395927
WME2	2	78	400	1	770.3703704	3.145395927
WME3	2.5	78	400	1	1203.703704	3.145395927
WMF1	1.5	58	400	1	322.2222222	3.145395927
WMF2	2	58	400	1	572.8395062	3.145395927
WMF3	2.5	58	400	1	895.0617284	3.145395927
WML1	1.5	102	400	2	1133.333333	6.290791853
WML2	2	102	400	2	2014.814815	6.290791853
WML3	2.5	102	400	2	3148.148148	6.290791853
WMEL1	1.5	78	400	2	866.6666667	6.290791853
WMEL2	2	78	400	2	1540.740741	6.290791853
WMEL3	2.5	78	400	2	2407.407407	6.290791853
WMFL1	1.5	58	400	2	644.4444444	6.290791853
WMFL2	2	58	400	2	1145.679012	6.290791853
WMFL3	2.5	58	400	2	1790.123457	6.290791853
Stirrup	6	150	400	1	711.1111111	3.145395927

Similarly for combination of wire mesh with stirrups weight calculated as following tabulated as following section Table D-2.

Table D-2 Weight calculation for combination of wire mesh with stirrups

COMBINATION WIRE MESH & STIRRUPS								
Sample	Diameter (mm)	No mesh	Length(mm	Layer	Weight	Mesh (W/A)	Stirrups(W/A)	Total(Kg/mm2)
Stirrup	6	3	400	1	266.6667		3.1442833	3.1442833
WMC1	1.5	102	400	1	566.6667	3.14539593	3.1442833	3.144839613
WMC2	2	102	400	1	1007.407	3.14539593	3.1442833	3.144839613
WMC3	2.5	102	400	1	1574.074	3.14539593	3.1442833	3.144839613
WMCE1	1.5	78	400	1	433.3333	3.14539593	3.1442833	3.144839613
WMCE2	2	78	400	1	770.3704	3.14539593	3.1442833	3.144839613
WMCE3	2.5	78	400	1	1203.704	3.14539593	3.1442833	3.144839613
WMCF1	1.5	58	400	1	322.2222	3.14539593	3.1442833	3.144839613
WMCF2	2	58	400	1	572.8395	3.14539593	3.1442833	3.144839613
WMCF3	2.5	58	400	1	895.0617	3.14539593	3.1442833	3.144839613

Appendix E: Description of Beam Sample

Table E-1 Description of sample of study

No	Beam name	Beam description
1	CB0	Control Beam
2	WM	Wire mesh spacing of Eight
3	WML	Wire mesh spacing of Eight with number of layers
4	WME	Wire mesh spacing of Eleven
5	WMEL	Wire mesh spacing of Eleven with number layers
6	WMF	Wire mesh spacing of Fifteen
7	WMFL	Wire mesh spacing of fifteen with number of layers
8	CWS	Wire mesh spacing of Eight combination with stirrup
9	CWSE	Wire mesh spacing of Eleven combination with stirrup
10	CWSF	Wire mesh spacing of fifteen combination with stirrup