STRUCTURAL BEHAVIOUR EVALUATION OF CORRODED AND NON-CORRODED RCC BEAMS: AN EXPERIMENTAL AND NUMERICAL APPROACH

A

PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degree

of

BACHELOR OF TECHNOLOGY

IN

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Under the supervision

of

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to

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DECLARATION

I hereby declare that the work presented in the Project report entitled **"STRUCTURAL BEHAVIOUR EVALUATION OF CORRODED AND NON-CORRODED RCC BEAMS: AN EXPERIMENTAL AND NUMERICAL APPROACH"** submitted for partial fulfillment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. Saurav**. This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"STRUCTURAL BEHAVIOUR EVALUATION OF CORRODED AND NON-CORRODED RCC BEAMS: AN EXPERIMENTAL AND NUMERICAL APPROACH"** in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Kinley Zam (181652)** and **Pema Yuden (181656)** during a period from August, 2021 to May, 2022 under the supervision of **Dr. Saurav** Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat. The above statement made is correct to the best of our knowledge.

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ABTRACT

Corrosion of reinforcement has been a main cause that results in the deterioration of reinforcements in concrete beams and it is very essential to do the evaluation of structural behavior of the concrete elements in these four areas: compression, tension, flexure and shear. Though there are several ways and techniques that have been suggested, the usage of finite element analysis have been widely used in current years.

In this project, ANSYS software is used to study the structural behavior of corroded and non-corroded reinforced concrete beams by conducting a non-linear finite analysis. SOLID 65 and BEAM188 were two elements assigned for concrete and steel reinforcement respectively. Non-linear material properties were well-defined for each element on the basis of its characteristics. Using the ANSYS software, a beam model has been created. Using the same data a beam was casted with M40 concrete. Its flexural strength will be calculated after 28 days of cure. The beams are designed to be tested under center point loading to find out its ultimate load, deflection corresponding to the loads and crack patterns under the transverse loading.

Comparisons on the deflection, stress, and crack pattern of concrete beam obtained from the ANSYS software and field data were made.

Keywords: ANSYS, Control beam/ Non-corroded, corroded beam, Non-linear finite element

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LIST OF ABBRIEVATION

ACI: American Concrete Institute.

FEA: Finite Element Analysis

FEM: Finite Element Method

FST: Final Setting Time

GUI: Graphical User Interface

HAC: High Alumina Cement

IST: Initial Setting time

LHC: Low Heat Cement

OPC: Ordinary Portland Cement

PPC: Portland Pozzolana Cement

RCC: Reinforced Cement Concrete

RHC: Rapid Hardening Cement

SCC: Stress Corrosion Cracking

SSC: Super Sulphate Cement

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is a building material known for its great strength. It constitute of three made of three main ingredients: cement, water, and aggregates. Concrete has the potential to resist compressive loads but it quite intolerant when it is subjected to tensile forces. A concrete structure in tension fails rather suddenly and without warning.

Generally steel reinforcements are used to enhance the ductility which is the capacity to stretch and deform prior to failure and tensile strength in concrete structures. Reinforced concrete beams are structural elements that are designed to carry transverse external loads. Site engineers must study the structural behaviour of concrete structures to determine the significance of cracks.

1.2 CORROSION IN RC STRUCTURE

Corrosion of reinforcements are one of the main cause of the reinforced concrete structures deteriorating. Steel is not one of the naturally corroding materials and thus it is subjected to corrosion. For corrosion to take place the presence of electrolyte, metallic connection and at least two metals at different energy levels. In case of RC structures the concrete acts as an electrolyte, metallic connection is given by wire ties or the rebar itself.

Corrosion in steel reinforcements used in concrete structure can reduced significantly by keeping adequate concrete cover and using concrete with low permeability and those which are crack free. Chloride is mainly responsible for corrosion as its presence elevates the severity of corrosion attack [5]. Figure 1.1 shows how corrosion attacks the steel in reinforced structures.

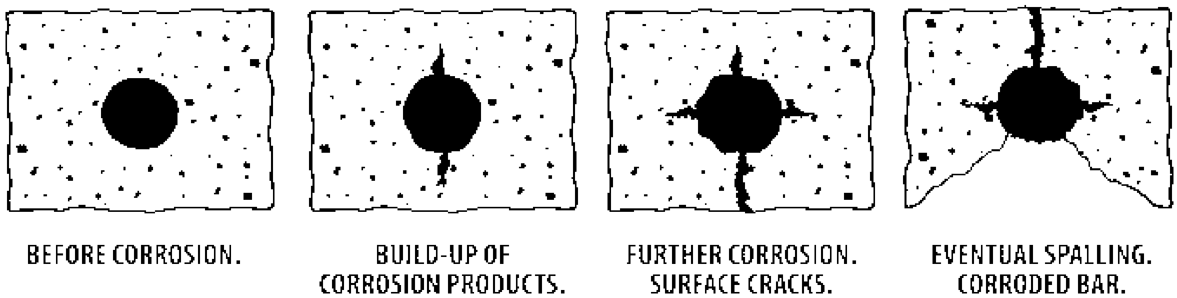

Figure 1.1 Mechanism of Corrosion(Source: The constructor.org[14])

Some examples of constructions that are being harmed by corrosion in reinforcements because of the chloride presence are bridges, structures intended for parking of vehicle, and structures located at the off-shore like piers, dams, docks, and harbor structures [14].

Figure 1.2 Bridges damaged corrosion due to chloride presence(Source:ENG-TIPS.com[12])

A damage of concrete structures happens in different forms like cover cracking, reduced cross-section of rebar, degeneration of bond between reinforcement and concrete.

Diverse methodology have been adopted to analyze the causes of corrosions in reinforced concrete. Among which testing based on experimental process has been broadly used as a way to examine individual elements and the effects of corrosions as it gives realistic responses However this method is expensive and takes a lot of time comparatively.

FEA or FEM has been preferred and used widely as it handles complex geometries and is very fast.

Figure 1.3 Corrosion-of-RC-structure (Source: Ju-Seong, Jung et al [10])

1.3 TYPES OF CORROSION

1. Uniform corrosion

Amongst the types of corrosion, the foremost overwhelming sort of corrosion is uniform corrosion. It is a uniform attack over a material's surface. It’s to the foremost generous that the attacks scope is very simple to decide and following the impact on materials execution is generally simple to evaluate much obliged to the capacity to dependably duplicate and test the wonders. Corrosion of this sort creates rule over a critical locale of a materials surface.

2. Pitting Attack

This sort of corrosion is the most destructive types of corrosion. This is because it is quite a challenge to predict, detect, and describe this type of corrosion. Pitting could be sort of constrained corrosion type where a nearby anode point, or more characteristically, a cathode point, produces a miniature corrosion cell with the normal surface.

Once this process starts leading to hole/cavity development, the corrosion produced appears in various shapes. Most often the pit starts to develop vertically starting from the ground. When the protective oxide coating of the metal structure is punctured or damaged in any way pitting corrosion develops. The non-uniformity in the metal structure is also one of the causes. Pitting is risky as it can cause the structure to fail while only losing a little amount of metal [13].

3. Stress corrosion cracking (SCC)

SCC occurs when tensile tension is combined with a corrosive environment, usually at high temperatures. Stress corrosion is caused by external stress, such as actual tensile pressure on the metal or expansion owing to fast temperature changes. SCC is also generated by residual tensile pressure from the manufacturing process, which includes cold forming, welding, machining, and grinding, among other things. The majority of the surface is normally untouched by stress corrosion, but microscopic cracks develop in the little structure, making the corrosion undetectable [13].

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Many research studies or investigations were done and numerous research have been publish on the evaluation of structural behavior of control and corroded RCC beams using the FEM. These papers really helped in giving more information and helped complete this project. Below are some list of journal and studies that we reviewed while doing this project.

2.2 LISTS OF REVIEW ON LITERATURE

2.2.1 Mohammad Najim Mahmood, Journal of Applied Sciences, Non-linear Analysis of Reinforced Concrete Beams Under Pure Torsion, Volume: 7, Issue: 22, 2007, Page No.: 3524-3529 [2].

A study using ANSYS-V10 was conducted to see if the beams were designed in such a way that they carried the same Torque. It focuses on the effects of beam length or span-to-depth ratio on the strength and performance of rectangular reinforced concrete beams. Figure 2.1 shows the graph showing variation of torque with span of cantilever.

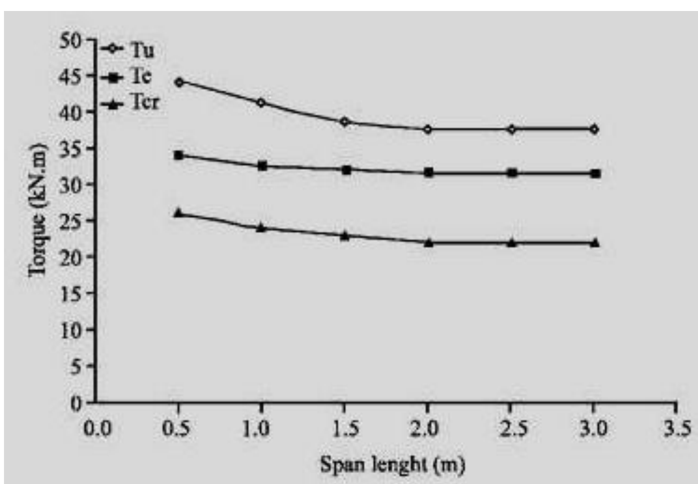

Figure 2.1 Graph showing variation of torque with span of cantilever [2]

To conclude, having cross sectional area and torsional reinforcements persistent for the beams, with more span to depth ratio or equivalent to 4 have the same predefined torsional strength. The drawbacks of this study were that the cross section of the beam and torsional reinforcement were set constant.

Hence calling for a need to conduct further research to inspect the efficacy of all type of the torsional reinforcement of RC beams which are exposed to torsion by altering the ratio of all the types and to forecast which type is more effective. So more effort and experiments needs to be conducted to study the results by changing these constraints.

2.2.2 Aqeel H. Chkheiwer, et al., Nonlinear Finite Element Analysis of Reinforced High Strength Concrete Corbels with and Without Steel Fiber and Shear Reinforcement, Volume 9, September-2018 [11].

The project examines the performance and conduct of high strength reinforced concrete corbels by using an ANSYS program. A hypothetical study was done by the finite element technique and was divided into three series. The series is divided into two parts,

i. The first portion contained 6 specimens for equating with the investigational results. The sorts of concrete with high strength concrete and normal strength concrete are the main constraints of this portion.
ii. The second part of series one contains 6 specimens and examines planned specimen by finite element to check on other factors.

The series II contains 14 high strength reinforced concrete corbels and its main constraints are concrete compressive strength, main reinforcement ratio (ρw), shear reinforcement stress (ρhfyh), and outside depth to the entire depth of corbel (k/h)

Series III is split into two parts:

i. The first part of the series three contains 17 high strength reinforced-concrete corbels for analytical of experimental result, where the key variables of this part are steel fiber content (Vf %), shear span-to-depth ratio (a/d), compressive strength concrete (f′c), main reinforcement ratio (ρw) and shear reinforcement stress (ρhfyh).

ii. The second part contents 8 specimens and analyzes proposed specimen by finite element only to check on other factors.

The variation of concrete from NSC to HSC increases the ultimate shear strength of the corbel specimens about 17.9 and 25.4 % to check out the shear span-to-depth ratio of 0.6 and 20.2% and 35.5% at shear span-to-depth ratio of 0.45. The rise in horizontal reinforced index made the corbels with fc of 60 MPa more energetic than corbels with fc of 40MPa or 50 MPa. When k/h increases from (0.24) to (1.00) the final load also rises by 12.3%. A contrast was done between ACI318-M14, Fatuhi's equation and Truss Model.

The factor of safety against shear failure obtained by using Truss Angle Method increased with increasing the concrete compressive strength, the shear span-to-depth ratio value, and presence or absence horizontal stirrup.

The Truss Angle Method equation is mostly less conservative than the ACI Code equation. The Fatuhi's equation showed a rise in the ultimate shear strength when the fiber content was increased. The value of ultimate shear strength obtained by ACI-code is smaller in value than experimental results obtained.

2.2.3 Nilesh H. Saksena & Prof. P.G.patel, Effects of the circular openings on the behavior of concrete beams without additional reinforcement in opening region using fem method, Vol. IV/ Issue II/April-June, 2013 [5].

In this paper, a 3-D non-linear finite element method is done using ANSYS where the simply reinforced concrete of circular opening having different diameters are kept at different positions to find out the effect of varying proportions on the conduct of the beams. Many different rectangular beams with identical cross-sections with circular openings where used with monotonic loading with two incremental concentrated loads. Total of 7 beam’s models were stimulated to find the load-deflection behavior and then related to solid concrete beam.

The main objective of this paper was to examine the outcome of dissimilar diameters of circular opening on the conduct of concrete beams and position of the opening on the behavior of the beam of circular unreinforced openings on conduct of the concrete beams.

Figure 2.2 show that the simulation processes were done correctly as the Fem result and the experimental result in graph below were almost same.

The beams short of opening were near to the ultimate load obtained from the FEM method. The ultimate load capacity of the RC rectangular section beams is affected by the beams with circular openings at the middle of the length.

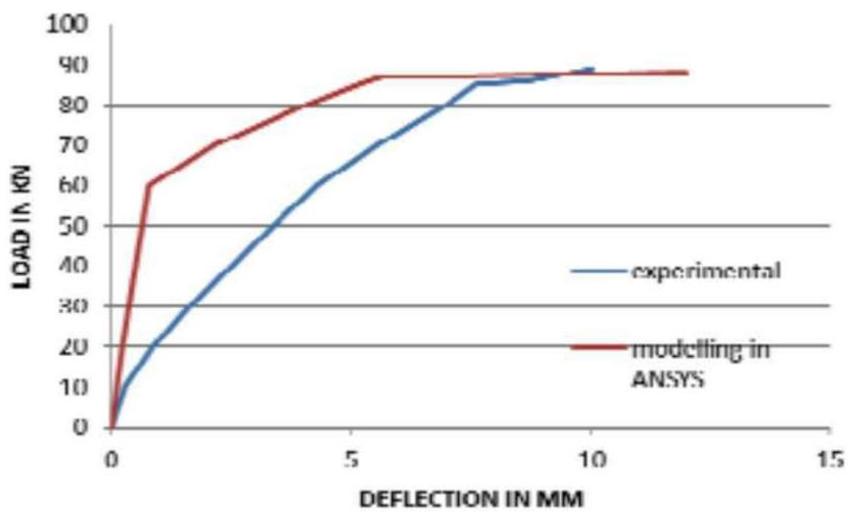

Figure 2.2 Comparison between experimental Results and ANSYS Results for Solid models [5]

Whereas circular opening of diameter of 45% of depth close the back reduced the extreme stack capacity of RC rectangular segment pillars at the slightest 35% compared to solid beams.

2.2.4 V. S. Pawar & P. M. Pawar, Nonlinear Analysis of Reinforced Concrete Column with ANSYS, Volume: 03 Issue: 06 | June-2016 [6].

A non-linear element analysis was done using the ANSYS to examine the reinforced concrete pillars up to the failure. A models with reinforced concrete columns that were exposed to the axial symmetric and eccentric loading were used seeing the regular use of the lab.

Here, the non-linear material structure of concrete were used to examine the ultimate load, load mid span displacement relationship and cracks development. While carrying out the study of the RC columns in, it came out that the outcomes were further subtle to mesh size, constituent's characteristics, load growths, and other parameters.

2.2.5 Antonio F. Barbosa and Gabriel O. Ribeiro, ANALYSIS OF REINFORCED CONCRETE STRUCTURES USING ANSYS NONLINEAR CONCRETE MODEL, 1998 [16]

The paper studies about the useful application of non-linear models to examine the reinforced concrete structures. The main con of this experiment was that it had difficulty in characterizing the materials properties. It was reinforced to inspect the failures in materials which are brittle, applied to the 3-D solid elements in reinforcing bars. Cracking and crushing were determined by the failure surface.

The load deflection curves as shown in figure 2.3 came quite close and similar to the results at the early stage of load history for the analysis conducted. The differences appeared soon after the application of service load.

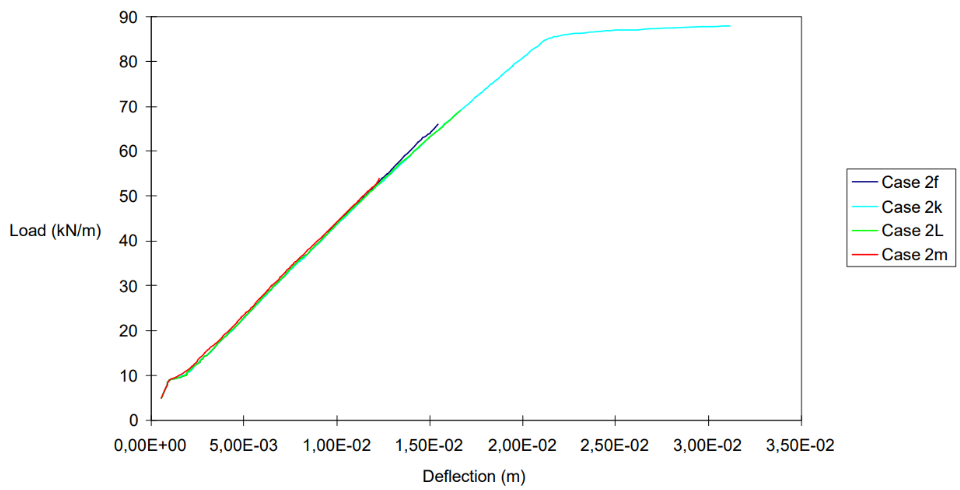

Figure 2.3 Load-deflection curve for models with discrete reinforcement.[16]

Models with the smeared reinforcement had identical response. After the crack opening in initial phase, the models were found to have almost linear path of stiffness lesser than the initial one. Either in discrete or smeared, despite the good concrete elastoplastic model behavior, models combining crushing and plasticity has early and less convergence. However the experimental comparisons are yet to be done.

2.2.6 Shivakumar V Poojar, T. Geetha Kumari, Non Linear Finite Element Analysis of SFRSCC and SFRNCC One Way Simply Supported Slabs in Flexure using ANSYS, Volume: 02 Issue: 04, July-2015 [17]

The steel fiber reinforced self-compacting concrete and steel fiber reinforced cement are subjected to the four point bending load. The software was used to model the slabs. The slabs were used to compare the experimental results with the ultimate loading, load deflection curve as shown in figure 2.4 and load strain behavior of each case.

The ratio of FE to Experimental was shown to be 1 by the comparison results. The results of the experiment were less than predicted in FEM. There was a variation of 11%.

Figure 2.4 shows the load deflection curves of M70 grade cement.

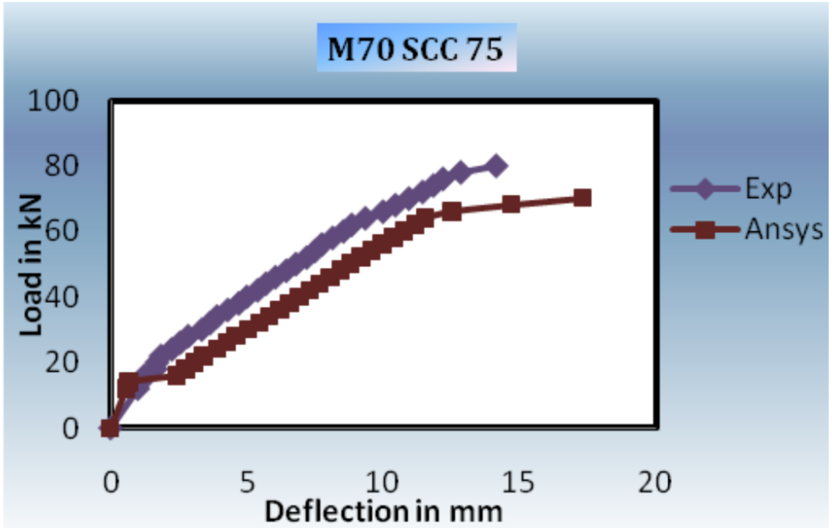

Figure 2.4 Load-Deflection Curves of M70 [17]

2.2.7 A. Gherbi, L. Dahmani, A. Boudjemia, Study on Two Way Reinforced Concrete Slab Using ANSYS with Different Boundary Conditions and Loading, Vol:12, No:12, 2018 [18]

In this paper it focuses on the patterns of failure in the rectangular slab with various edge conditions. Smeared reinforcement was used. The behavior was analyzed under various loading and boundary conditions in terms of fracture form and displacement. Then the results were compared to the experimental results. The other objective of the paper was to show the similarity of crack pattern between the ANSYS and experimental analysis.

Smeared reinforcement was discovered to be more practical because it does not require explicit modelling like rebar, allowing for a much coarser mesh definition. Finally, as the load was increased, the propagation of cracks in slabs validated the process of yield line formation till the ultimate collapse.

2.2.8 Jigna Jagadish and Lekshmi L, Non Linear Finite Element Analysis of Steel Fiber Reinforced Concrete Beams, Volume 14, Number 12, 2019 [19]

A non- linear finite element approach was used to investigate the conduct of a steel fiber reinforced concrete beam. The strength of reinforced concrete beams was investigated using the proportion of steel in the concrete. Steel fiber reinforced concrete beams were tested for their load carrying capacity. The strength of ten beams with different steel bar proportions were compared to the strength of all the beams.

The beams reinforced with CFRP bar and 4% steel fibre with shear reinforcements were found to have a good load carrying capacity. Load carrying capability improved as the proportion of steel fibre increased. Without shear reinforcement, the ultimate load carrying capacity of a beam reinforced with CFRP bar and 4% steel fibres increases by 21. 53 percent. The beam reinforced with CFRP bar and 4% steel fibres had the lowest deflection and maximum load bearing capability.

2.3 RESEARCH GAPS

Limited literature papers are available on corroded RC beams.

Most papers used high strength concrete of grade M60 and M70

2.4 RESEARCH OBJECTIVES

This paper centers mainly on the workings of control and corroded reinforced beam using FEA to investigate the response and results of control and corroded reinforced RCC beam under the transverse loading.

The objective is to improve computer models for predicting the behaviour of corroded reinforced concrete beams:

i. i. Develop a system for control and corroded reinforced concrete beams using computer modelling.
ii. To study the structural and flexural behavior of non-corroded/corroded beams as analyzed on the basis of data obtained from experiment and ANSYS software

2.4 SCOPE OF THE STUDY

The scope of this project is to use finite element methods to gain a better insight and inspection of the structural behaviour of non-corroded and corroded beams under center point loading. The finite element models were created in order to evaluate their behaviour and ultimate loads. The FEA outcomes were linked to the test datas.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

Methodology covers the methods performed to find out the expected results in any experiment or test performed. In this project we did experimentally as well as in software to find the result and do the comparison between the two results obtained.

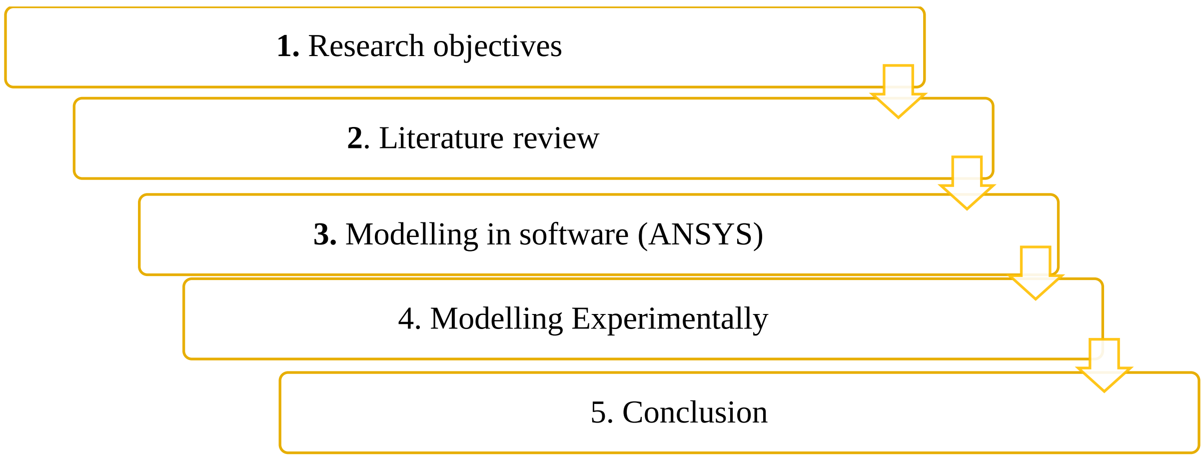

Figure 3.1: Methodology flowchart

Basically there are three methods to solve the engineering problems are they are as follows:-

a. Analytical Method

Analytical methods are applicable only for simple geometries. These types of problems have been solved in our undergraduates' levels. It is quite popular but now days it is not in use much.

b. Experimental Method

It has been widely use due to its real life responses. However it is not used due to its time consuming nature and being expensive.

c. Numerical Method

It is applicable to handle complex geometries that are not been able to solve by the above two method. It is very fast and gives accurate results.

It is further divided in to four types as follows [15]:-

- Boundary Element Method
- Finite Volume Method
- Finite Difference Method
- Finite Element Method

Among which the main focus in will on FEM in this project.

3.2 FINITE ELEMNT METHOD

It is a widely used method for numerically solving differential problems arising in engineering in modelling.

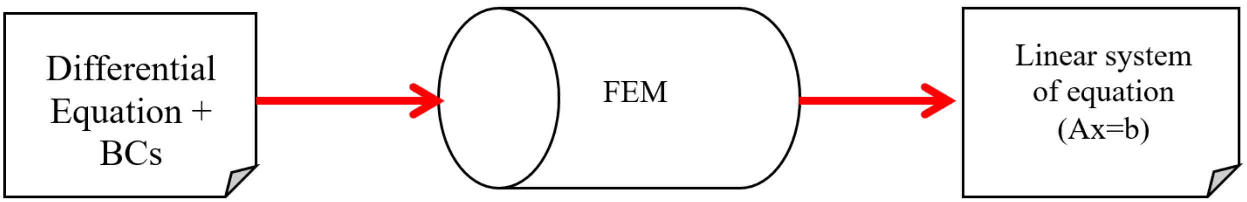

Figure 3.2 FEM solving scheme.(Source: Solid Mechanics Classroom [15])

After getting the, it linear systems of equations are solved using a computer (Ansys).

The main objective of FEM is to find the approximate u(x, y) to the boundary value problem.

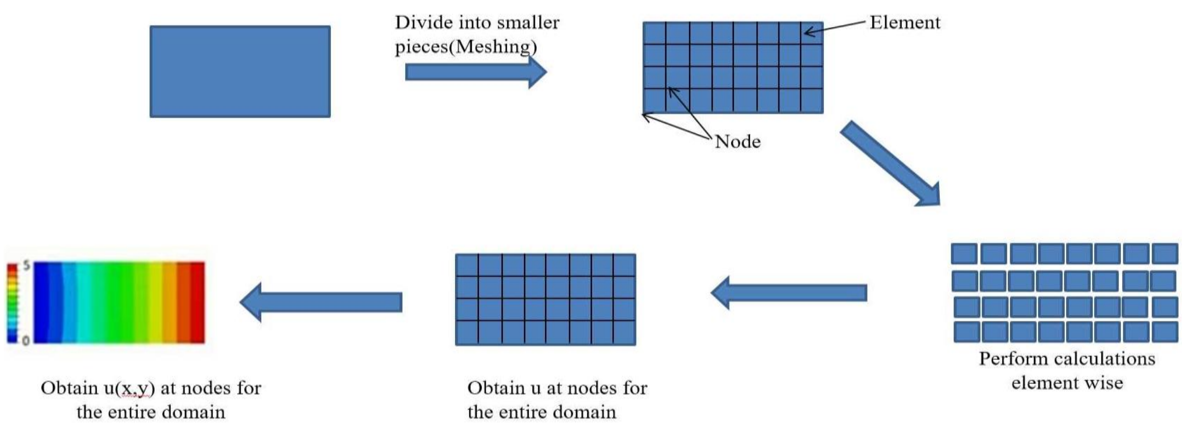

Figure 3.3 Process of FEM (Source: Solid Mechanics Classroom [15])

3.2.1 ADVANTAGES AND LIMITATIONS OF FEM METHOD

3.2.1.1. Advantages of FEM method

- Model complex shaped bodies
- Model is easily refined for accuracy by varying
- Can handle complex loading
- Can include variety non-linear effects
- Boundary conditions are easily incorporated
- It is simple, compact and result-oriented and hence widely used by the engineering community.

3.2.1.2. Limitations of FEM method

- High computational time
- Required better computers and memory units (high storage)
- Required trained and skilled operators
- Need to validated the result
- Output results varies considerably

3.2.1.3. Applications of FEM Method

- In the arenas of Mechanical/ Aerodynamics/ Automobile/Civil
- Heat transmission
- Fluid movement
- Electric and magnetic field
- Biomedical engineering problem

3.3 EXPERIMENTAL STUDIES

Concrete beam of dimension 500mm in length and height and width of 100mm were casted. Four steel flexural reinforcements of diameter 10mm; two in top and two in bottom were used. Shear reinforcement included 8mm diameter 2 legged stirrups were used. The cover of the rebar were set to 20mm in all course. Figure 3.4 shows the reinforcement setup of the beam.

Figure 3.4. Reinforcements in beam

3.3.1 Materials Used

- Cement (Portland Pozzolana Cement)
- Sand (Zone II)
- Coarse aggregate (angular, 20mm)
- Steel reinforcement (8mm and 10mm) of grade Fe500
- Curing tank
- Sodium chloride (NaCl)
- Chemical admixture(Naphthalene plasticizer)
- DC Power supply
- Connection wires

3.3.2 Properties of the Materials used

a) Consistency Test on Cement

This test was conducted to calculate the quantity of water to be included to the cement to induce a glue of standard consistency.

Standard consistency is a steadiness which permits the Vicat plunger of 10 mm diameter to pierce up to a depth of 5mm - 6mm above the bottommost of the Vicat's mould. Vicat's apparatus is used. The normal range of Normal Consistency should be 26%-33%.

Table 3.1 Test data for consistency of cement

Sl. No	Water Added (ml)	Percentage of water added (%)	Quantity of Cement (g)	Depth of Penetration from the bottom (mm)
1	100	25	400	15
2	116	29	400	10
3	128	32	400	7

The percentage of water content for normal consistency was found to be 32%.

Figure 3.5: Vicat Apparatus for consistency test

b) Initial and Final Setting Time

Setting time is the time when cement paste becomes rigid to withstand a definite pressure.

Initial setting time (IST): the time passed between the minutes that water added to cement to time that the paste begins to lose its plasticity. It is utilized to delay the method of hydration or solidifying.

Final setting time (FST): the time passed between the minutes that the water added to cement, and time when the paste has totally lost its plasticity and has reached enough inflexibility to resist definite pressure. It is used for safe elimination of scaffolding or form.

For the PPC cement the standard IST should not be less than 30 minutes and FST should not be more than 600 minutes. Table 3.2 shows the experimental data obtained for the test.

The amount to of water to be added is calculated as:

$$0.85 \times p \times \frac{Weight\ of\ cement}{100}$$ p is the normal consistency of cement. (P=32%)

Table 3.2 Test data for setting time of cement

Sl.No	Quantity of Cement (g)	Quantity of water (ml)	% of water by weight	Penetration from bottom (mm)	IST (min)	FST (min)
1	400	108.8	32%	6	60	540

After the test the IST was found to be 60 minutes and FST was found to be 540 minutes.

Figure 3.6 (a) Setup for Initial setting time **Figure 3.6 (b)** Setup for Final setting time

c) Soundness of cement

The capability of cement to uphold a same volume is known as soundness of the cement. Le-Chatelier apparatus was used.

The amount of water to be added is calculated as:

$$\frac{0.78 \times P \times Weight\ of\ cement}{100}$$

Table 3.3 Test data for soundness of cement

Sl. No	Weight of the Cement (g)	Water (ml)	Initial Distance (mm)	After 24 hrs. (mm)	After 30 mins of boiling in water bath (mm)
1	100	24.96	7	8	9

This test is done to accelerate the hydration of free lime by application of heat thus discovering the defects in short time. It is also done to minimize the shrinkage if paste.

It is done to confirm that cement does not show any considerable expansion of major importance.

For Ordinary Portland Cement, Rapid Hardening Cement, Low Heat Cement, and Portland Pozzolana Cement consistency is restricted to 10 mm, for High Alumina Cement and Super Sulphate Cement must not surpass soundness of 5mm.

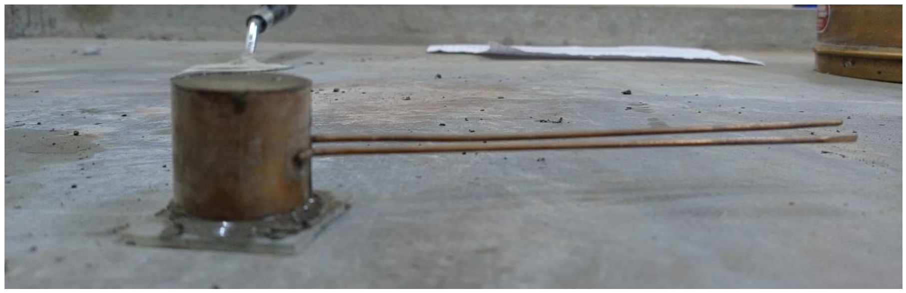

Figure 3.7 Le-chatelier apparatus

Figure 3.7 illustrates soundness test setup. The expansion of the cement obtained is 1mm.

The cement paste is boiled so that any chances to enlarge is raced up and can be noticed.

d) Fineness of the Cement

The degree to which cement is ground to lesser particles is called fineness of cement.

It has a significant part within the hydration and therefore on the rate of gain of strength.

Table 3.4 Test data for fineness of cement

Weight of sample taken in gram (W)	Weight of residue in gram (R)	Percentage of residue $=(\frac{R}{W} \times 100)$
100	1	1%

90 µ sieves are utilized.

The fineness of the cement is 1%.

e) Specific gravity of cement

Specific gravity is the ratio of weight of a given volume of material to the weight of an equal volume of water.

Le Chatelier's flask shown in figure 3.8 is used to determine specific gravity of cement.

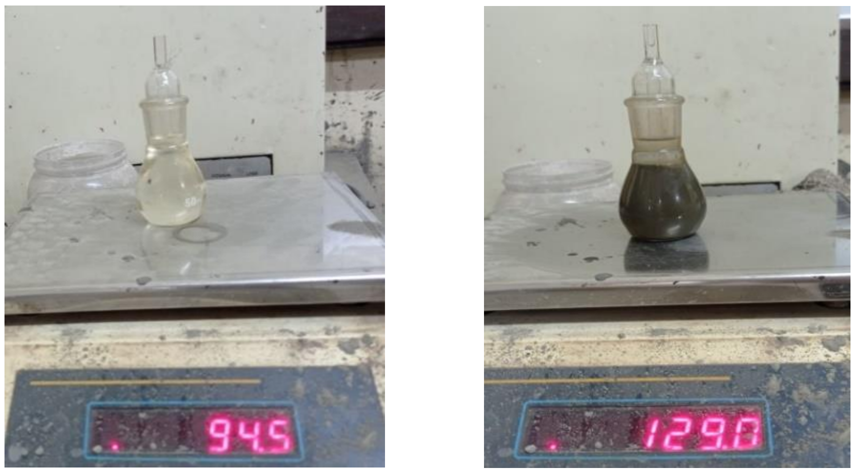

Figure 3.8 Le Chatelier's flask

Table 3.5 Test data for specific gravity of cement

Weight of empty bottle (W_1) :	**40.5 g**
Weight of empty bottle + Water (W_2) :	94.3 g
Weight of bottle + Kerosene (W_3) :	94.5 g
Weight of bottle + Kerosene + Cement (W_4) :	129 g
Weight of cement (W_5) :	50 g

- Specific gravity of kerosene oil = $\frac{W_3-W_1}{W_2-W_1} = \frac{94.5-40.5}{94.3-40.5} = \mathbf{1.004}$
- Specific gravity of cement = $\frac{W_5}{W_5+W_3-W_4} \times 1.004 = \mathbf{3.23}$

f) Compressive strength of Concrete

Compressive strength of a concrete is the determination of the capability of the concrete to withstand the loads applied on it. It is the degree of the strength of the concrete under compression.

The compression strength increases with increase in cement concrete content. It increases with decrease with air and water content. The compressive strength is inversely related to water-cement ratio.

The compressive strength test outcomes are used to find out that the concrete mixture meets the prerequisites of the definite strength in the work determination. The values of compressive strength for cubes tested after various days are shown in Table 3.6

The compressive strength of cement at the end of:-

- 7 days = 26.2 N/mm^2
- 14 days = 36.23 N/mm^2
- 28 days = 45.67 N/mm^2

Table 3.6 Test data for compressive strength

SI. No	No. of days	Sample Details	Compressive strength in (N/mm^2)	Average compressive strength in (N/mm^2)
1	7	Sample 1	25.4	26.2
		Sample 2	26.8	
		Sample 3	26.4	
	14	Sample 1	35.5	36.23
		Sample 2	36.3	
		Sample 3	36.9	
	28	Sample 1	44.8	45.67
		Sample 2	45.4	
		Sample 3	46.8	

Figure 3.9 Concrete Test Cubes

Figure 3.10 Testing cubes under compression test

3.3.3 MIX DESIGN (IS: 10262- 2019) [20]

a. Grade of concrete : M40
b. Compressive strength at 28days : 40MPa
c. Type of Cement : Portland Pozzolana Cement(PPC)
d. Maximum Nominal size : 20 mm
e. Exposure Condition : Severe (for RCC)
f. Workability : 75mm
g. Type of aggregate : Crushed angular aggregate
h. Method of concrete placing : Chute (Non pumpable)
i. Chemical Admixture type : Naphthalene Plasticizer

Test Data for materials

Specific gravity of cement = 3.23

Specific gravity of Coarse Aggregate = 2.78

Specific gravity of Fine Aggregate = 2.65

Specific gravity of Admixture = 1.145

Water absorption: CA= 0.5%

: FA = 1%

i. TARGET STRENGTH FOR MIX PROPORTIONING

$f'_{ck} = f_{ck} + 1.65\,S$

$= 40 + (1.65 \times 5)$

$= 48.25$ MPa

$f'_{ck} = f_{ck} + X$

$= 40 + 6.5$

$= 46.5$ Mpa

Target strength will be 48.25 N/mm^2.

Where,

- f'_{ck} = target average compressive strength at 28 days,
- f_{ck} = characteristic compressive strength at 28 days,
- S = standard deviation, and
- X = factor based on grade of concrete.

ii. **APPROXIMATE AIR CONTENT** = 1% for 20 mm nominal size

iii. **WATER CEMENT RATIO**: 0.36 (corresponding to OPC 43 grade curve is assumed)

iv. **WATER CONTENT:**

- Water content for 75mm slump = $186 + (\frac{3\times186}{100})$ = 191.58 kg

- Since plasticizer is used the water content maybe reduced by: $191.58 \times 0.8 = 153.26$ kg ≈ 153kg

v. CEMENT CONTENT:

- Water cement ratio = 0.36

- Cement content = $\frac{153}{0.36} = 425\text{kg/m}^3$

vi. PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGETE CONTENT:

- Volume of coarse aggregate and fine aggregate is 0.62 for water cement ratio 0.5.

- For water cement ratio of 0.36, the volume of coarse aggregate is = 0.62 + 0.028 = 0.648

- Volume of fine aggregate is = 1- 0.648 = 0.352

vii. **MIX CALCULATIONS [20]**:

a) Total Volume = 1 m^3

b) Volume of entrapped air in wet concrete = 0.01m^3

c) Volume of cement = $\frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{1}{1000} = \frac{428}{3.23\times1000} = 0.133\ m^3$

d) Volume of water = $\frac{\text{Mass of water}}{\text{Specific gravity of water}} \times \frac{1}{1000} = \frac{153.26}{1000} = 0.153\ m^3$

e) Volume of chemical admixture (super plasticizer) @ 1.0 percent by mass of cementitious material:

$$= \frac{\text{Mass of the chemical admixture}}{\text{Specific gravity of admixture}} \times \frac{1}{1000} = \frac{4.25}{1.145 \times 1000} = 0.0037m^3$$

f) Volume of all in aggregate = [(a-b)-(c+d+e)] :

= [(1-0.01) – (0.133 + 0.155 + 0.0037)]

= 0.6983 m^3

g) Mass of coarse aggregate = f × Volume of coarse aggregate × Specific gravity of coarse aggregate × 1 000:

= 0.6983 × 0.648 × 2.78 × 1 000 = 1257.95 kg ≈ 1258 kg

h) Mass of fine aggregate = f × volume of fine aggregate × Specific gravity of fine aggregate × 1 000:

= 0.6983 × 0.352 × 2.65× 1000

= 651.37 kg ≈ 652 kg

Mix Proportioning

- Cement = 425 kg/m^3
- Water = 1.53 *l*
- Fine aggregate (SSD) = 652 kg/m^3
- Coarse aggregate (SSD) = 1258 kg/m^3
- Admixture = 4.25 kg/m^3
- Free water-cement ratio = 0.36

Mix Ratio = 1: 1.53: 2.96

Total volume of concrete needed for beam:

$$V_1 = 2\times10^7 \text{ mm}^3 \text{ or } 0.02 \text{ m}^3$$

Figure 3.11 Beams

Dimension of the test cubes (100 × 100 × 100) mm^3

Total volume of concrete needed for cubes:

$$V_2 = 9000000\ mm^3 \text{ or } 0.009\ m^3$$

Figure 3.12 Test Cubes

- Total volume of concrete required = $V_1 + V_2$ = $0.029\ m^3$
- 15% of 0.029= $0.00435\ m^3$

• Volume of concrete = 0.029 + 0.00435

= 0.03035 m^3

Hence the amounts of materials required are:

- Cement = 12.89 kg
- Water = 4.6 *l*
- Fine aggregate = 19.78 kg
- Coarse aggregate = 38.18 kg
- Admixture = 0.13 *l* or 130 *ml*

3.3.4 Construction of Accelerated Corrosion test setup

The Galvano static method is used for creating an accelerated corrosion where it involves continuous passing of DC current to the deformed beams to accelerate the corrosion. The specimens were submerged in to the tank to accelerate galvanic corrosion as shown in figure 3.13 The beam was immersed horizontally in the tank of 3% of salt solution. The steel rod was immersed in to the electrolytic tank and was connected with negative output while deformed bar were connected to positive output. A current supply of voltage 15V was supplied to the tank.

The course of the current obliged the beams to be anode and the steel rod to be cathode [1].

The current induced to the tank was checked on daily base for 8 days. Figure 3.13 shows the accelerated corrosion setup.

Figure 3.13. Accelerating Corrosion Setup

Figure 3.14 DC current supply Machine

3.4 MODELING OF THE BEAM IN SOFTWARE (ANSYS)

3.3.1 Elements used in Ansys

Table 3.7 Element types for Working Model

Material Type	ANSYS Element
Concrete	SOLID65
Steel Reinforcement	BEAM 188

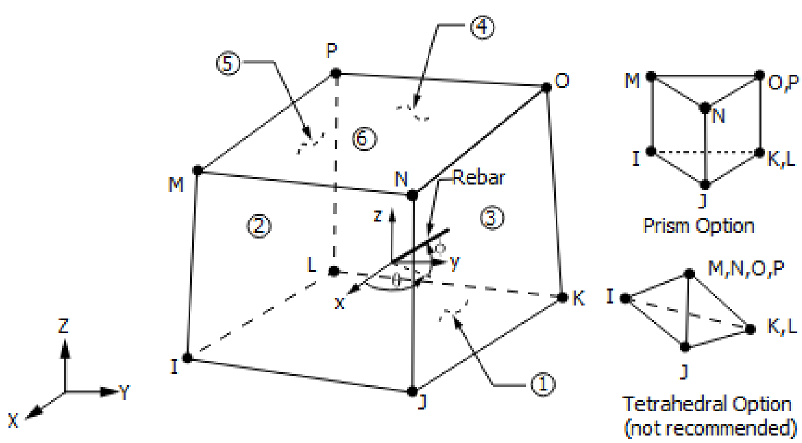

Figure 3.15 Solid 65 elements(Source: Innovative infrastructure solution [24])

a. Element used for concrete

SOLID65 can be used with or without reinforcing bars. The solid can crack in tension and crush in compression. For example, in concrete applications, the element's solid capacity can be used to represent the concrete, while the rebar capability can be utilized to model reinforcing behavior. Each of the eight elements has three degrees of freedom: translations in the nodal x, y, and Z directions.

The concrete element resembles a 3-D structural solid, but it has particular cracking and crushing characteristics. The consideration of nonlinear material properties is the most essential component of this part. The concrete has the ability to crack (in three orthogonal directions), crush, deform plastically, and creep. The rebar can be twisted and compressed, but not sheared. Plastic deformation and creep are also possible. For a more accurate result while using the SOLID65 elements, it is recommended to use rectangular mesh. The mesh was therefore setup in a way where the elements created would be rectangles or squares [24].

b. Element used for rebar and stirrup

BEAM188 is used for rebar and stirrups in the modelling process. It has been specified that the BEAM188 element be used for analyzing beam structures that are slender to fairly stubby/thick. Timoshenko beam theory which includes shear-deformation effects is used to create the element [24]. The element permits deformation of both restricted and unrestricted cross-sections.

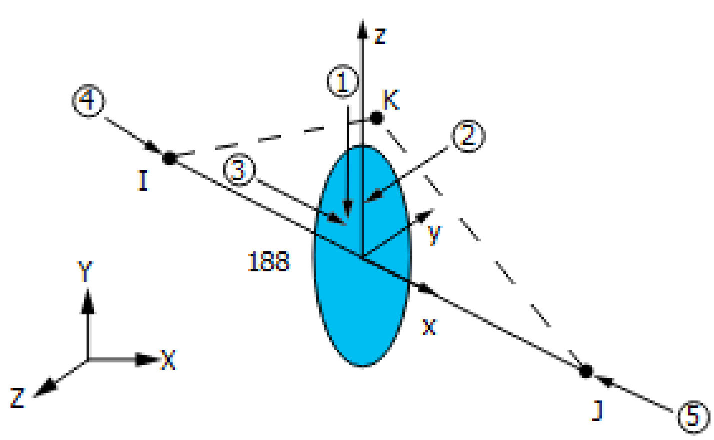

Fig. 3.16 Beam 188 element(Source: Innovative infrastructure solution [24])

c. Material Models

Different sorts of material characteristics are included in the ANSYS models. The linear elastic tension stiffening relationship is used to represent cracking and the stress-strain graph. In this model, we assumed and took values for various parameters from previously conducted tests. The open shear transfer coefficient of concrete is 0.2[9] whereas the closed shear transfer coefficient is 0.9 [9]. The multilinear isotropic stress-strain graph was obtained from the following formulas [1]:

1. $$f = \frac{E_c e}{1+(\frac{e}{e_0})^2}$$

2. $$e_0 = \frac{2f_{ck}}{E_c}$$

3.

4. $$E_c = \frac{f}{e}$$

Where,

f- Stress of at any strain e (n/mm^2)

e- Strain at stress f

e_0 - Strain at the ultimate compressive strength F_{ck}

The resulting multilinear isotropic hardening stress-strain curve for concrete us shown in figure 3.17.

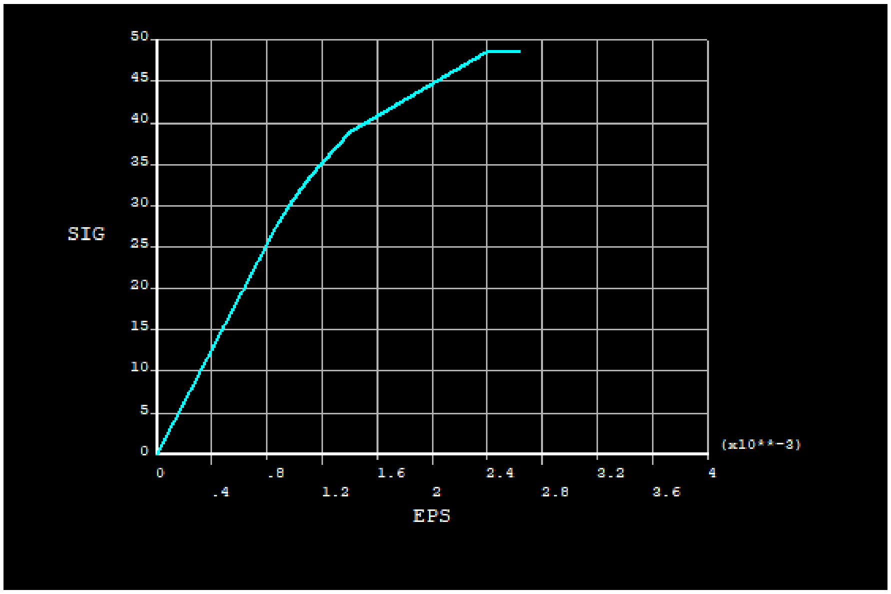

Figure 3.17 Multilinear stress-strain isotropic hardening curve for concrete.

3.3.2 Modelling Non-Corroded or Control Beam

The FEA study includes modeling of the concrete beams with proper dimensions and properties. The beam is modelled as volume with 500 mm long in length and cross section area of 100mm × 100mm as shown in Figure 3.18.

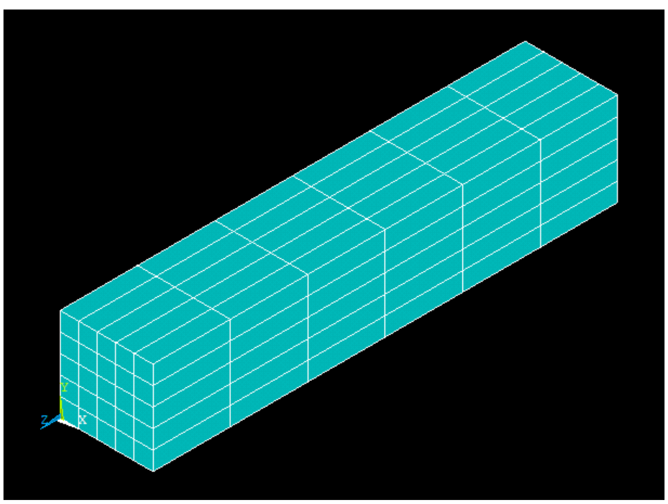

Figure 3.18 Finite Element Model and Mesh

The flexural and shear reinforcements were created using Beam188 elements. The reinforcement's bars of 10 mm diameter of 4 numbers were used and for stirrups 8mm diameter of 4 numbers were used throughout the beams. Figure 3.19 shows the rebar shares the same nodes at points and intersects the shear stirrups.

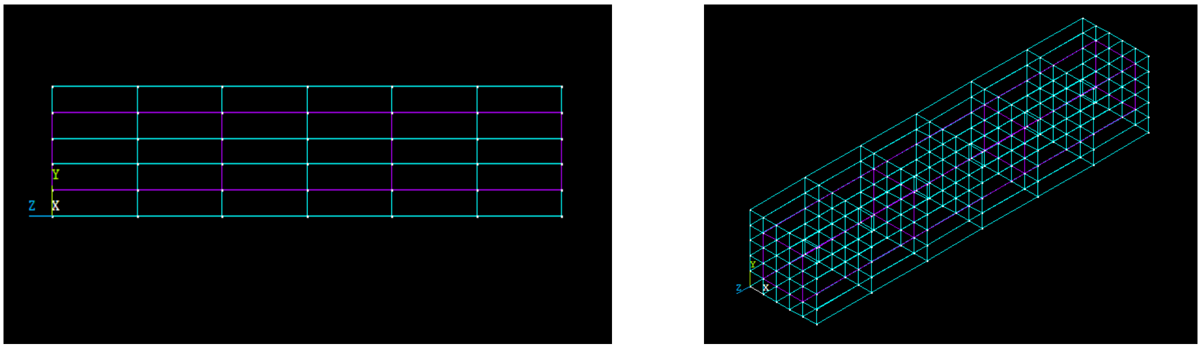

Figure 3.19 Reinforcement Configuration of Control Beam

3.3.3 Modelling Corroded Beam

One of the main causes of the decline of reinforced concrete structures is the corrosive nature of the reinforcement. This phenomenon can result in rebar area reduction, cracking, and concrete scaling. The most evident outcome of rebar corrosion is area reduction of rebar [13]. Carbonate corrosion occurs uniformly in concrete, whereas chloride corrosion causes localized corrosion known as pitting.

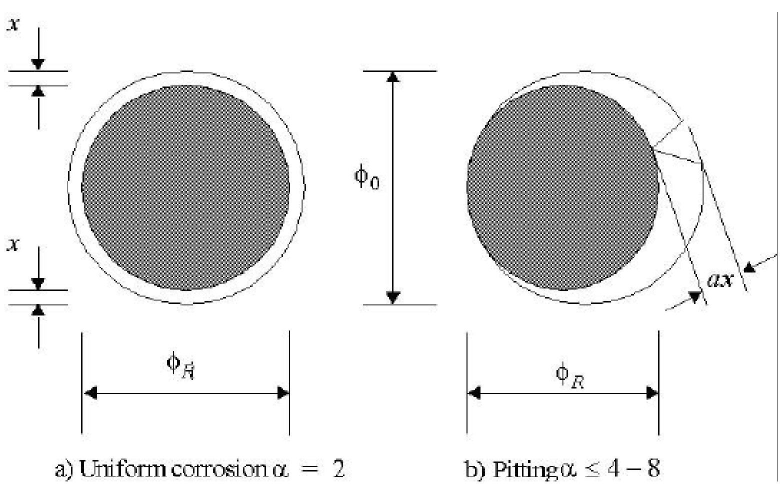

Fig.3.20 Residual steel bar cross section(Source: Research Gate [13])

In this paper the corrosion was assumed to be uniform, hence the coefficient of corrosion is taken as 2. In case of pitting corrosion the coefficient can be taken in between 4-8. The finite element model for corroded beam is modelled the same way as the control beam which is the calibration model. But the bar diameter is reduced in the corroded beam. The diameter of remaining cross section area of the uniformly corroded tensile reinforcement can be calculated as shown [13] as (Figure 3.20 a):

$$\boldsymbol{D_{res} = \varphi_0 - \alpha x}$$

Where,

D_{res} - Residual bar diameter

φ_0 - Initial bar diameter (control beam)

α - Coefficient depending on the type of attack

x - Corrosion penetration.

The compressive strength of the corroded beams was only about 70 % of the strength of the reference beams according to the findings in previously published papers. Hence the compressive strength of the corroded beam was taken 48.25Mpa.

The model of the corroded reinforced concrete beam is similar to the calibration model but the difference is the cross-sectional area. The cross-sectional areas were reduced due to the corrosion due to reinforcement. From the calculation of uniform corrosion the reinforcements used were 8mm diameter bars and 6mm diameter stirrups. Following figure 3.21 shows the reinforcement configuration of the corroded beam.

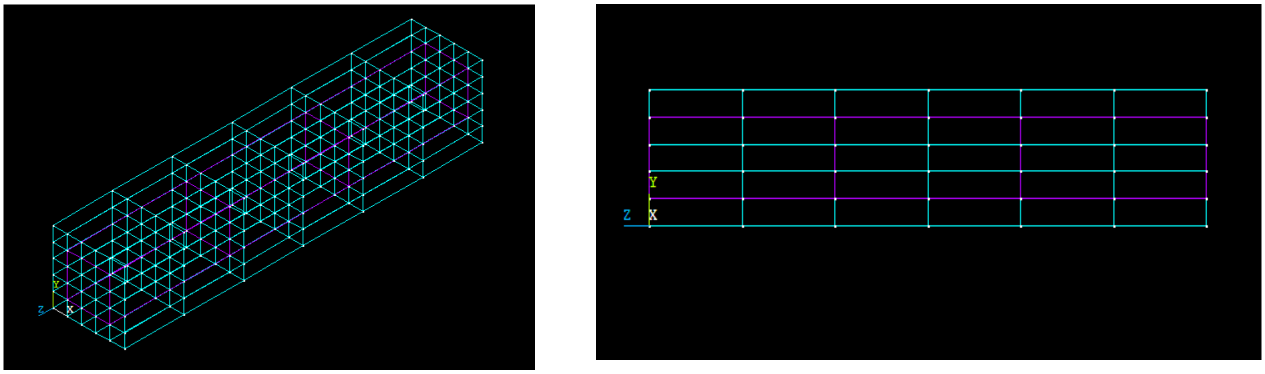

Figure 3.21 Reinforcement Configuration of Corroded Beam

3.3.4 Boundary Conditions and Loads

In the model, the supports are modelled as a roller support on one end and hinged support on the other end. The model can be constraint to get a unique solution. The force P of 68.5kN is applied on the nodes for non-corroded beam and a force of 48.7kN for corroded beam.

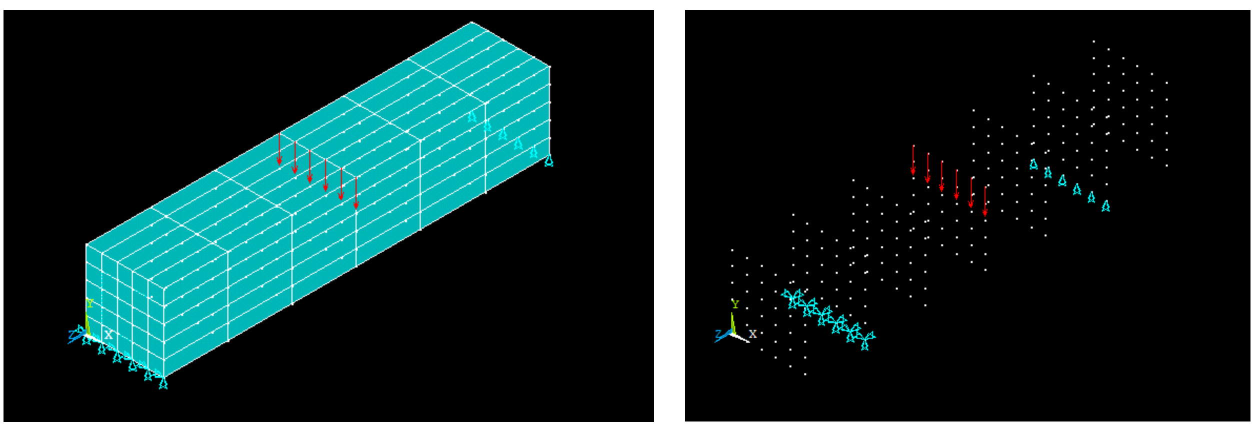

Figure 3.22. Loading and Boundary Conditions

CHAPTER 4

RESULT

4.1 GENERAL

This chapter contains the results obtained after performing analysis in software and performing experimentally. The different results and factors obtained from the different procedures and methodology are all presented in this chapter.

The purpose of this project is to compare the results of the FE model and the experimental beam to confirm that the elements, real constants, material characteristics, and convergence criteria are all required to represent the response of the members of the various components that were compared.

4.2 EXPERIMENTAL STUDIES RESULTS

4.2.1 Control Beam or Non-corroded Beam

i. Flexural strength

The beam was casted and kept for 24hours and then was demoulded. After demoulding the beam was kept for 28 days in curing tank. After 28 days of curing, the beam was kept under centre point loading to check the flexural strength to determine the stress, strain, deflection curves and ultimate flexural strength.

All beams (control and corroded beam) were tested under centre point loading under monotonic increasing load up to failure. Following figure 4.1 shows the load test setup.
The ultimate load came to be 68.5kN with maximum displacement of 6.4mm. The cracks initially started at the constant moment region and then started to verge outwards. Figure 4.3 shows the crack pattern of the control beam.
The graph shown in Figure 4.3 shows the Load vs. Displacement curve.

Figure 4.1 Load test setup

Figure 4.2 Experimental Crack Pattern of Control beam.

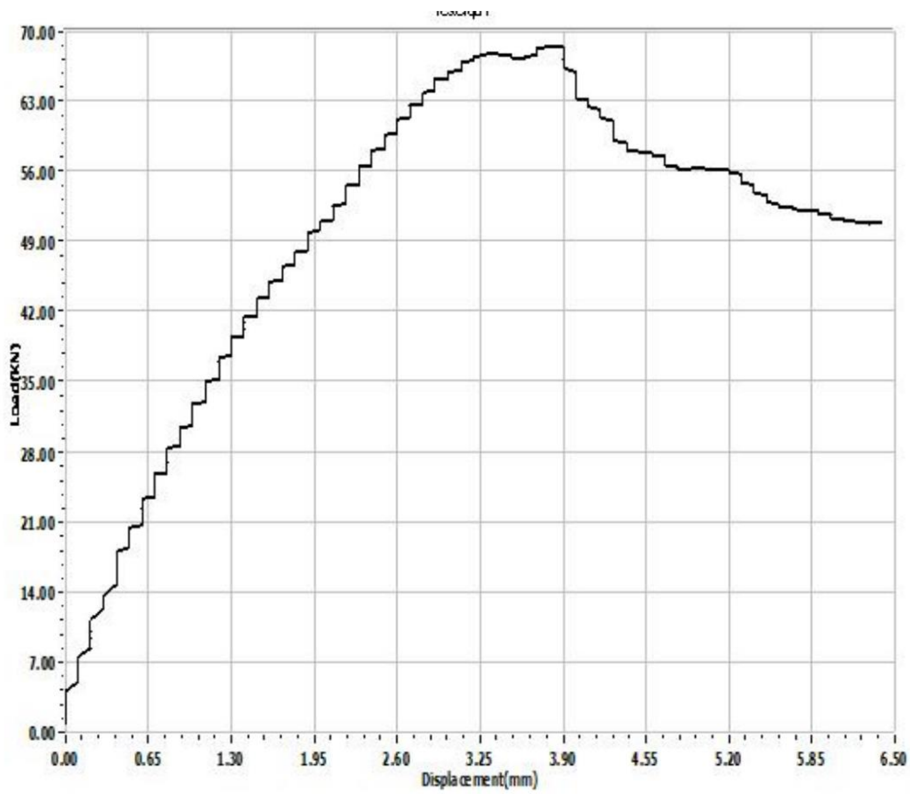

Figure 4.3 Load Vs. Displacement Curve for control beam.

The initial cracking of the beam corresponds to the load of 5kN that created the first cracks around the constant moment region and is the flexural crack. The cracking increases as the load increased. The cracking of beam begins outward towards the support and finally at the load of 68.5kN the beam cracked.

4.2.2 Corroded Beam

After 28 days of curing, the beam was kept under the acceleration corrosion tank for 8 days to accelerate the corrosion in the beam. After 8 days keeping in the tank the corrosion was checked using half-cell potential testing equipment. The Figure 4.4 shows the half-cell potential testing equipment.

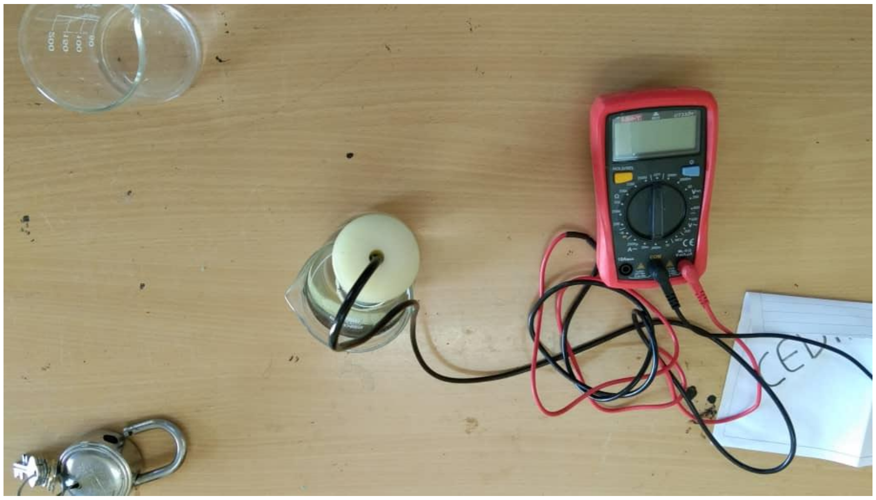

Figure 4.4 Half-cell potential testing equipment.

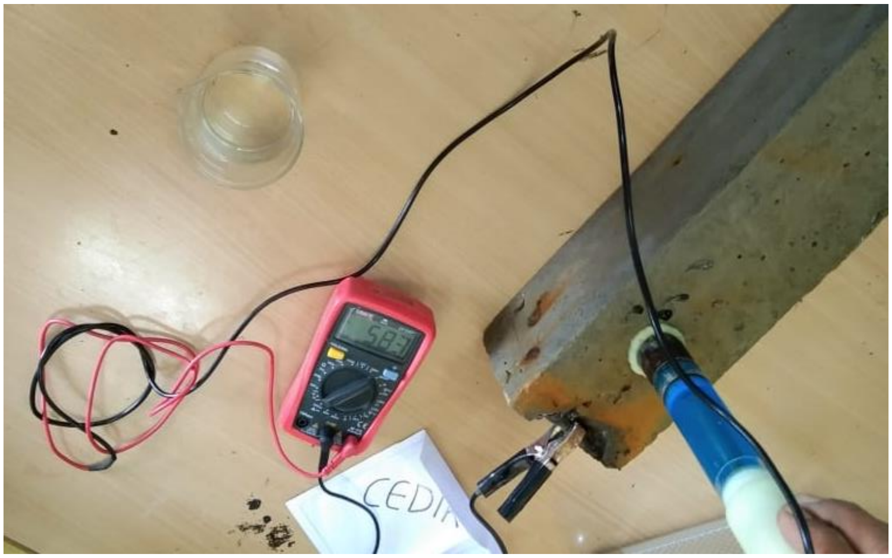

Figure 4.5 Half-cell potential test setup.

Table 4.1 shows the values or percentage of corrosion produced on the beam after 8 days of keeping it in the accelerated corrosion setup.

Table. 4.1 Percentage of Corrosion

Sl.No	Distance (mm)	Corrosion Percentage (%)
1	0	52.4
2	10	55.9
3	20	59.3
4	30	59.8
5	40	60.3
6	50	64.2

For the corroded beam, the first crack was formed around the constant moment region extended upward and out toward the support region. Figure 4.6 shows the cracking pattern of the corroded beam.

Figure 4.6 Experimental Crack pattern of Corroded Beam

The first crack occurred at the load of 1.5KN with displacement of 0.1mm. The ultimate load failure occurred at 48.7KN with maximum displacement of 5.10mm.

Figure 4.7 shows the Load vs. Displacement curve of Corroded beam.

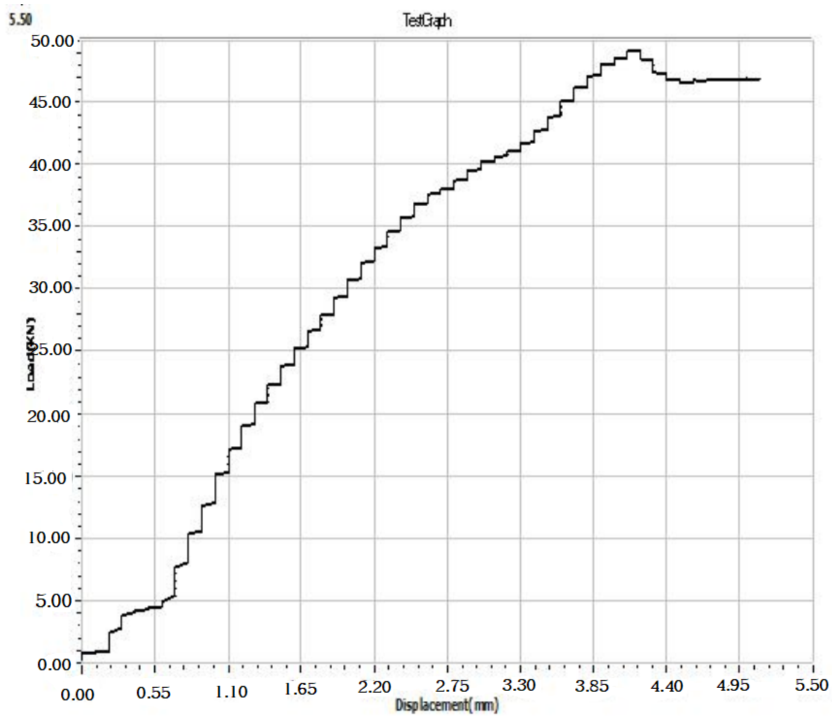

Figure 4.7 Load vs. Displacement curve of Corroded beam

4.3 RESULTS FROM ANSYS

4.3.1 Non-corroded beam

The cracking patterns in the beam were obtained from the Cracking/Crushing plot option. In the region, comparisons were made to endure stress. The concrete beam was analyzed before the cracks were made. The cracking of the beam in the FE model corresponds to 7.4 kN. The flexural crack occurs in the constant moment region.

The crack pattern can be seen in the Figure 4.8.

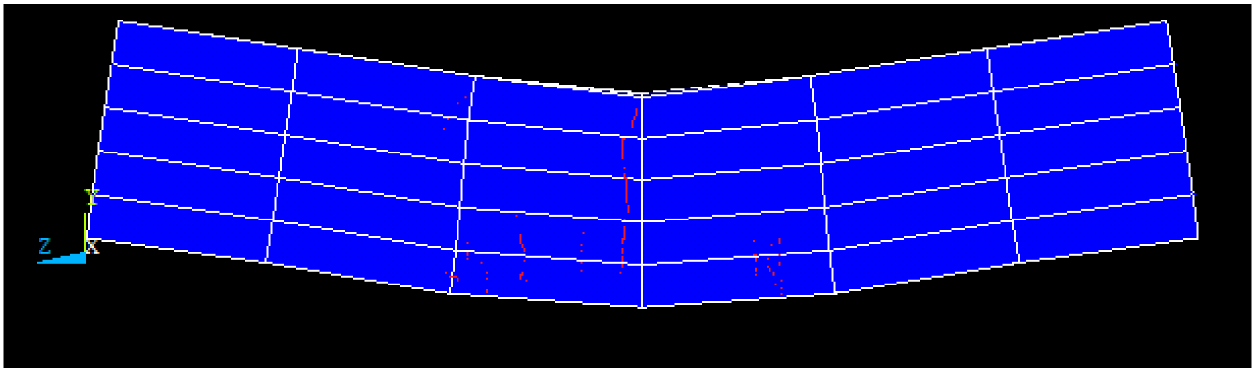

Figure 4.8 Crack pattern for control beam

The crack was formed at 143.5sec after applying the center point load of 7.4 kN.

As more load was applied on the beam, the cracking occurred. When the load was increased, the beam began cracking towards the support.

4.3.2 Corroded beam

To model the corroded beam, the diameters of the steel for reinforcements were calculated from the formula mention earlier. The corrosion coefficient was taken as 2 since uniform corrosion was considered. Penetration value of corrosion was assumed as 1mm after much reference from other papers. Table 4.2 shows the parameters of the beam.

Table 4.2 Diameter of cross section of steel reinforcements

Type	Diameter in control beam(mm)	Diameter in corroded beam(mm)
Top rebar	10	8
Bottom rebar	10	8
Stirrups	8	6

Figure 4.9 shows FE Crack Pattern due to the uniform corrosion in the beam. The initiation of corrosion is likely to occur at the stirrup reinforcements that has minimum concrete cover.

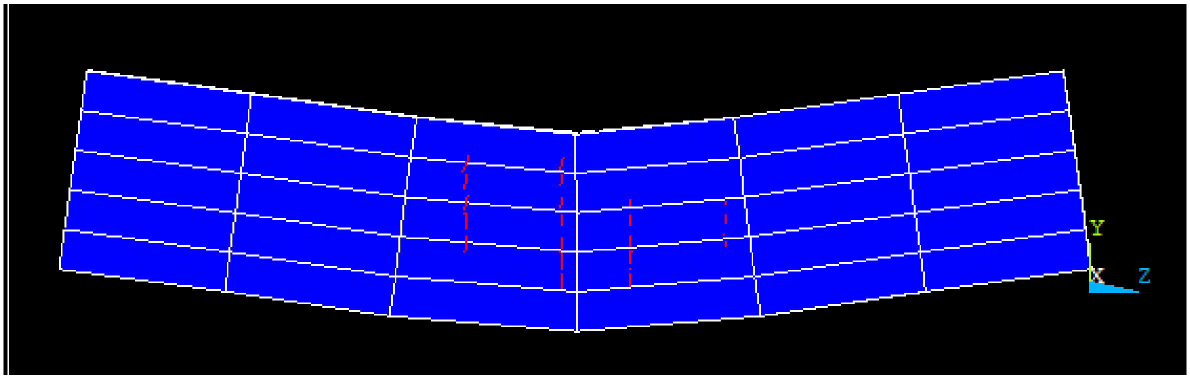

Figure 4.9 FE Crack Pattern for Corroded Beam

The cracks first appeared at the constant moment region and then extended upward and outward. The initial cracking in concrete is related to the load. 2.8 kN. as more loads were applied to beam, cracking occurred in the non- linear region of the response. The cracking lines increased in size.

4.4 CURVES COMPAIRSONS BETWEEN EXIPERMENTAL AND ANSYS RESULTS.

4.4.1 Comparisons of result obtained in Control beams

In the control beam the ultimate load as obtained from the experimental procedure was 68.5kN with maximum displacement of 6.5 mm. The initial crack started appearing at a load of 5kN corresponding to a deflection of 2 mm.

The result obtained from ANSYS, the initial crack appeared at a load of 7.4kN. Figure 4.10 shows the comparison of plot of load vs. displacement between the FE method and experimental data.

As seen, the data converged well and the difference were just insignificant.

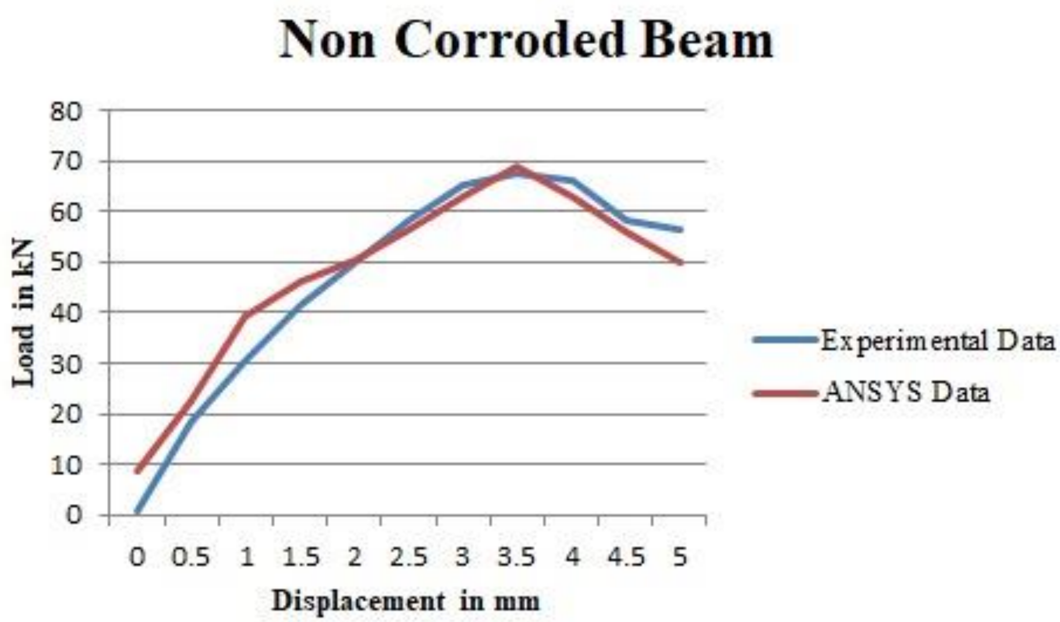

Figure 4.10 Comparison of Load Vs. Displacement curve between Experimental and ANSYS data for Control Beam

4.4.2 Comparison of results obtained in corroded beam

In the corroded beam the ultimate load as obtained from the experimental procedure was 48.7kN with the displacement of 5.1 mm. The initial crack started appearing at a load of 1.5kN corresponding to a deflection of 0.1 mm. From the result obtained from ANSYS, the initial crack appeared at a load of 2.8kN.

Figure 4.11 shows the comparison of plot of load vs. displacement between the FE method and experimental data. As seen, the response from both method converged well and the difference were just insignificant.

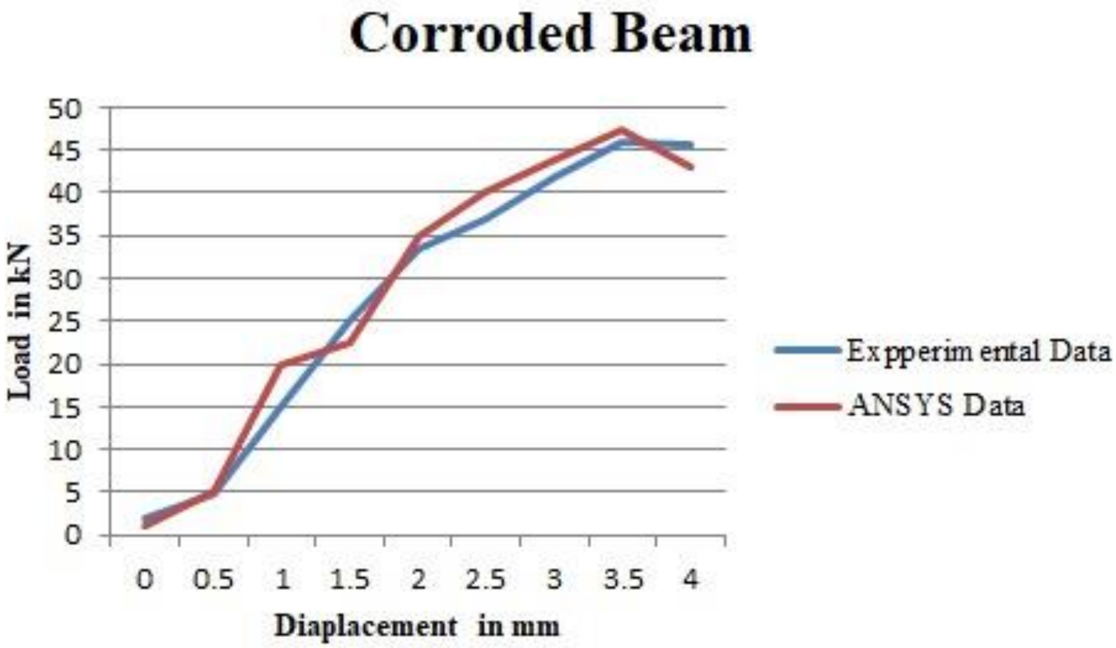

Figure 4.11 Comparison of Load Vs. Displacement curve between Experimental and ANSYS data for Corroded Beam

CHAPTER FIVE

CONCLUSION

5.1 General

The results of the project's debates and conclusions are contained in this chapter. There are conclusions drawn from the examination of the control reinforced concrete beam.

5.2 Conclusions

The control and corroded beams were assessed using the finite element method. The data was used to calibrate a reinforced concrete beam model, which predicted initial cracking and flexural failure.

The results of the experiment were then compared to the beam. The experimental findings were compared to a model of a non-corroded reinforced concrete beam.

The conclusions drawn from the project are as follows:

- The data obtained from the experimental reinforced concrete beam was closer to the data obtained from the finite element model.
- FEA accurately simulates the reinforced concrete beam's failure mechanism and predicts the failure load. It was quite near to the experimental failure load.
- The reduction in the reinforcement due to the corrosion plays a significant role in determination of flexural strength.
- The failure load or the ultimate load applied to the model in ANSYS is very close to the experimental values.
- The entire load-displacement results produced was quite similar to the experimental results. Therefore it’s comparable and boost the confidence to use ANSYS to develop model and run the program.

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