EXPERIMENTAL INVESTIGATION ON DETERMINATION OF BOND STRENGTH FOR VARIOUS TYPES OF CONCRETE USED AT SITES

By

Alay Dinesh Shah
(04MCL017)

DEPARTMENT OF CIVIL ENGINEERING
Ahmedabad 382481
May 2006

EXPERIMENTAL INVESTIGATION ON DETERMINATION OF BOND STRENGTH FOR VARIOUS TYPES OF CONCRETE USED AT SITES

Major Project

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Civil Engineering
(Computer Aided Structural Analysis & Design)

By

Alay Dinesh Shah
(04MCL017)

Guide
Shri J.S.Thakur

DEPARTMENT OF CIVIL ENGINEERING
Ahmedabad 382481
May 2006

CERTIFICATE

This is to certify that the Major Project entitled "**Experimental Investigation on Determination of Bond Strength for various types of Concrete used at sites**" submitted by **Mr. Alay Dinesh Shah (04MCL017)**, towards the partial fulfillment of the requirements for the degree of **Master of Technology in Civil Engineering** (**Computer Aided Structural Analysis and Design**) of Nirma University of Science and Technology, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

Shri J.S. Thakur
Guide,
Former Assistant Professor,
Institute of technology,
Nirma University,
Ahmedabad

Dr. G.N. Gandhi
Head,
Department of Civil Engineering,
Institute of Technology,
Nirma University,
Ahmedabad

Dr. H.V. Trivedi
Director,
Institute of Technology,
Nirma University,
Ahmedabad

____
Examiner

____
Examiner

____
Date of Examination

ACKNOWLEDGEMENT

It gives me immense pleasure and happiness to express thanks and profound gratitude to **Shri J.S. Thakur,** for his valuable guidance and continual encouragement throughout the Major project. I am heartily thankful to him for his time to time suggestion and the clarity of the concepts of the topic that helped me a lot during this study.

I am also thankful to **Shri R.V. Shah,** Department of Civil Engineering, Institute of Technology, Nirma University, Ahmedabad for his continuous help and guidance through the project. I would like to extend my thankfulness to **Prof. P.V.Patel** and **Prof. U.V. Dave**, Department of Civil Engineering, Institute of Technology, Nirma University, Ahmedabad for their help through out the project.

I am extremely thankful to **Dr. H.V. Trivedi**, Director, Institute of Technology for his kind support and permission for developing facilities for the project. I would like to convey my special thanks to **Prof. G.N. Patel**, Professor, **Dr. P.H. Shah**, Ex. Head, and **Dr. G.N. Gandhi**, Head, Department of Civil Engineering, Institute of Technology, Nirma University, for their continual kind words of encouragement and motivation throughout the Major Project. I am also thankful to **Shri C.H. Shah,** structural consultant, for his suggestions to improve the quality of work and for providing coating material.

I would like to thank **Shri Sharadbhai Patel**, Estate department, Nirma University, for providing necessary facilities for the experimentation. I am extremely thankful to **Shri C.N. Vasava,** Laboratory Assistant, Strength of materials laboratory, Nirma University, for his help and assistance during testing which helped me to complete this study in time. I am also thankful to **Shri P.N. Raval**, Laboratory Assistant, Concrete technology laboratory, Nirma University for his assistance during testing.

I am thankful to **Shri Sailesh Sonar** and **Shri Amol Popli** FOSROC (I) Pvt. Ltd., for providing Super-plasticizer and technical guidance. I am also thankful to **Shri Sandeep Holey,** Ultratech Cement Limited, for proving cement at the time of shortage in the market.

I would also thankful to all faculty members of Institute of Technology, Nirma University, Ahmedabad for their special attention and suggestions towards the project works.

The blessings of God and my family members makes the way for completion of Major Project. I am very much grateful to them.

The friends, who are always helpful during the testing and motivated me throughout this course, I am thankful to them also.

Alay Dinesh Shah
Roll No.04MCL017

ABSTRACT

The shear stress developed at the interface of concrete and bar is called bond stress. And, with the advancement and development in technologies for the preparation of Concrete and Steel it has become important to investigate the bond strengths of these engineered materials as bond stress mentioned in IS: 456 – 2000 are the same since 1964. But with enormous improvement in the field of concrete and steel these values of bond strength are bound to differ and hence the study of bond strength is essential.

The study of bond strength is important as the flow of forces from concrete to steel and vice-versa takes places depending upon bond values.

Procedures mentioned in IS: 2270 (Part 1)–1967, “Methods of Testing Bond in Reinforced Concrete”, is used to carryout the pull-out test.

The study consists of casting five different grades of concrete i.e. M 20, M 25, M 30, M 35 and M 40 with three different types of concrete mix which were mix with Fibres and Super-plasticizer, mix with Super-plasticizer and Normal mix. With this, three different diameter of reinforcement bar 12 mm, 16 mm and 20 mm and three different type of reinforcement bars namely Mild steel, TMT and TMT Coated were used. Specimens for measuring mechanical properties like compressive, flexural and tensile strength of all these different mix were also cast. In total there were 585 specimens tested. Out of these, 405 specimens were pull-out specimens and the rest 180 specimens were for finding the mechanical property of concrete.

Pull-out test was carried out on 28 days with the loading rate as mentioned in the IS: 2770. From the results so obtained, bond strength and Load-Slip curves for all the specimens were plotted and discussed. Also analytical study was carried out using “SAP 2000” and the results obtained are compared with the experimental results.

From the experimental study, it was found that:

1. Mix with Fibres and Super-plasticizer were able to provide greater bond strength
2. TMT bars were able to provide greater bond strength than the other two materials
3. With the increase in diameter of the bar the bond strength decreases for the same size of specimen.
4. The values of bond strength were on much higher side than the IS: 456-2000 bond stress values.
5. Also it was found that the required development length was largely reduced by considering the values of bond strength obtained from the experimental work.

From the analytical study, it was also found that that with the increase in the diameter of bar the bond strength decreases.

This study encouraged the need for revising the bond strength values mentioned in IS: 456-2000.

CONTENTS

List of Notations

$\bar{x}$	mean strength
Σx	sum of the strength of cubes
N	number of cubes
s or σ	Standard deviation
n	number of observation
x	arithmetic mean
v	coefficient of variation
f_{ck}	characteristic strength
t	A constant, depending on the definition of characteristic strength and is derived from the mathematics of Normal distribution.
ft	Target mean strength
ϕ	Diameter of reinforcement bar
fy	Ultimate yield stress of steel

LIST OF FIGURE

LIST OF TABLES

1. INTRODUCTION

The success of force taking mechanism for any structural RCC member depends upon the efficiency of concrete and steel to transfer stresses across their surfaces. In other words, the better the bond between the steel and concrete the better would be the behavior of the members when subjected to loads. The stress transfer takes place because of the occurrence of adhesion, mechanical resistance and frictional resistance offered by the steel bar.

The numerical values of bond stress are mentioned in IS: 456-2000 and the same are adopted depending upon the grade of concrete while carrying out RC Design. IS: 456-2000 also states that the bond stress values shall be increased by 60% if deformed bar is used in place of plain bar.

The bond values given in IS: 456-2000 has not been revised since years. The bond values that appeared in IS: 456-1964 still appeared on IS: 456 - 2000 though the concrete and steel have undergone huge change in terms of composition, strength etc. over these 40 years.

With the advancement in technology and with better understanding of material, today's concrete has not only remained a mixture of Cement, Sand, Coarse Aggregate, Water but is often blended with materials like flyash, silica fumes, fibres, super-plasticizer, retarders and many other chemicals to modify the properties of concrete. This is done to achieve the required strength, durability and minimize the problems like shrinkage cracks etc. and to make concrete suitable for the condition where it has to perform.

Today structures have become taller, bigger, slender, massive and huge, and this demands high strength concrete and steel. As concrete has undergone smart changes so also has steel. Continuous development in steel has been observed. From plain bars to Cold Twisted deformed bars to High Strength TMT bars.

When these two high strength materials are used in RCC, their bond behavior might not follow the numerical figure obtained 40 years ago, based on technology available at that time. So proper estimation of bond strength can help in avoiding the congestion of steel at the joints, as greater values of bond strength when adopted as compared to the values given in IS: 456-2000 may result into small length of anchorage steel. This would also indirectly result in better placing of concrete at the joints and hence better quality of joints that would perform efficiently during critical loads as compared to joints with lots of steel and honey-combed concrete. The effect of this would also be seen in reducing the cost of the structure considerably.

Thus, the scope of the work is to carry out Pull-Out test as per IS: 2770 (Part I) – 1967 (reaffirmed 1990) on various kinds of concrete like designed normal concrete, concrete prepared with the addition of Super-plasticizer and concrete reinforced with polypropylene fibres and reinforcing the same with plain bars, TMT (Thermo-Mechanically Treated) bars and TMT bars coated with polymer coating and to study the bond stress values of the same. Various load-slip curves are plotted and encouraging conclusions are derived from the same.

After carrying out various pilot tests for designing the concrete mix, fixing the super-plasticizer dosage, etc. as large as 585 samples were cast, to study the bond behavior. The 28th day results were used for studying the bond properties of the samples. The results obtained are quite encouraging and clearly shows the advantage of using TMT bars or advantage of adding a requisite dosage of super-plasticizer and polypropylene fibres in enhancing the bond values.

It is investigated that the results obtained form this experiment would help structural engineers in adopting rational values of bond depending upon the type of concrete and steel used, rather than just adopting the values from IS: 456 - 2000 code.

The outline of the experiment done and the thesis written is mentioned herewith to give an overall idea of the work carried done:

- Chapter 1: This chapter gives the introduction to the thesis, the need for carrying out this experimental work for finding the bond strength for various concrete and steel, scope of the work, the benefits of the findings of this experimental work.

- Chapter 2: This chapter deals with the literature review that was carried out to know the research work undergoing in the field of bond stress and related topics. To get the knowledge about the latest technologies and the inventions that can be incorporated in the project. To study the results and conclusions that other researchers had found and hence to decide the parameters which should be studied like variation of bond strength with respect to the variation in the type of concrete, grade of concrete, type of bars, etc. in the project to make the experiment targeted and most beneficial one.

- Chapter 3: This chapter gives the basic idea about the bond between the concrete and steel. Theoretical concept of bond strength and the development of bond strength due to various forces are discussed at great length. The difference in development of bond strength in plain bars when compared to deformed bars is also discussed in this chapter. This chapter also gives idea about the different types of failure pattern which are likely to be observed during a pull-out of the reinforcement. The calculation of bond strength and the load slip curves are also discussed here. The code and procedures to be followed for carrying out the Pull-Out test to find the bond strength is discussed, the calculations to be carried out and the graphs to be drawn, are also discussed in this chapter.

- Chapter 4: This chapter deals with the advanced materials that modify the properties of concrete. The advanced materials like Super-plasticizer, fibres, varieties of steel like plain bars, TMT bars are also discussed here in this chapter. Coatings that are been applied on the reinforcement bar and are used at the sites are also discussed here. The properties of the advanced materials which are used in this project are also discussed here.

- Chapter 5: This chapter deals with the various aspects of concrete mix design, concrete mix proportioning and different methods of mix designs like BIS recommended method, ACI method and DOE method. Also, design of concrete mix with different methods is carried out for M20, M25 and M30 grade of concrete and the results, so obtained, are also shown here.

- Chapter 6: Here, the pilot tests, that were carried out to optimize the project, are discussed. Pilot tests that were carried out such as mix design for various grade of concrete mix that are to be used in the project, tests for deciding the dosage of super-plasticizer and test carried out to decide whether helical reinforcement is required in the pull-out specimens or not, were discussed in this chapter.

- Chapter 7: This chapter deals with the experimental setup and the work planned for the project. The apparatus required the type of specimens that are to be cast, the fabrication that was carried out and the final setup that was done to perform the out the Pull-Out test is discussed in this chapter. Along with this, the work planned for the project is also discussed here. The work planned consisted of the total amount of casting that was to be carried out which included casting for the various grades of concrete, various type of concrete mix, various types of reinforcement bars and various diameter of reinforcement bars.

- Chapter 8: This chapter deals with the results of the Pull-out test and the observation made. Here, the readings recorded were used to plot the load-slip curves and hence, compare the load-slip curves of various diameters of bars of different concrete mix of similar grade. This chapter also discusses the bond strength of different types of reinforcement bars for various grades of concrete and for all type of concrete mix. Also, the bond strength of various grade of concrete is compared with those of IS: 456-2000. Various types of failure pattern observed are discussed here. The experimental results obtained are compared the analytical results of SAP 2000 in this chapter. This chapter also consists of an exercise that was carried out to compare the development length obtained by considering the bond stress values given in IS:456-2000 and the bond stress values so obtained from the experiment.

- Chapter 9: This chapter deals with the conclusion that was drawn from studying the results that were obtained from the Pull-out test. The future scope of work is also been discussed in this chapter.

2. LITERATURE REVIEW

2.1 INTRODUCTORY REMARK

Bond between steel and concrete in the reinforced concrete structures becomes very important characteristics and its study is immensely necessary. There are several studies available, where various researchers have carried out experiments for the determination of bond strength. This chapter is a compilation of these studies carried out to find the bond properties between steel and concrete.

2.2 EXPERIMENTAL WORK

Researchers from all parts of the world have tried to study this important aspect and have performed rigorous and innovative experiments for determining the bond strength and their findings are discussed here.

For carrying out such experimental work, two most important aspects which are the shape and size of specimens on which Pull-Out test is to be performed and the loading rate that is to be applied during the pull out of the reinforcement bar is discussed below:

2.2.1 SIZE, SHAPE AND DIAMETER OF REINFORCEMENT BAR USED IN PULL-OUT SPECIMENS

Cylinders, beams and cubes of various sizes have been studied by different researchers to find the bond properties.

Homayoun H. Abrishami et. al.[1] have used 150mm x 300mm, 200mm x 300mm and 150mm x 150 mm (diameter x length) size of cylinders to study the bond strength. FIGURE 2.1 shows the cylindrical type of pull-out

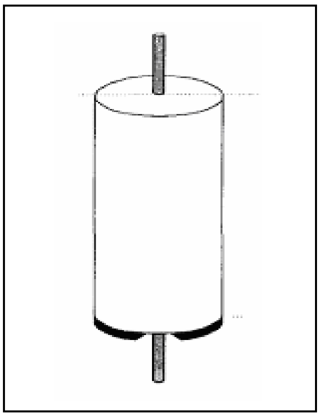


FIGURE 2.1 PULL-OUT SPECIMEN (CYLINDER) [1]

specimen. They had used 25 mm and 30 mm diameter of reinforcement bar having yield strength 400 MPa.

Y.I.Mo et. al. [2] in their experimental study of bond and slip of plain rebars in concrete have used 150mm x 300 mm cylinders. Figure 2.2 shows the experimental set up for carrying out the pull-out test for the cylindrical type of specimen. They had used three types of reinforcement bar which were plain, deformed and zinc coated bars of diameters 12 mm and 16 mm. Even the embedded length was kept as 60 mm and 120 mm.

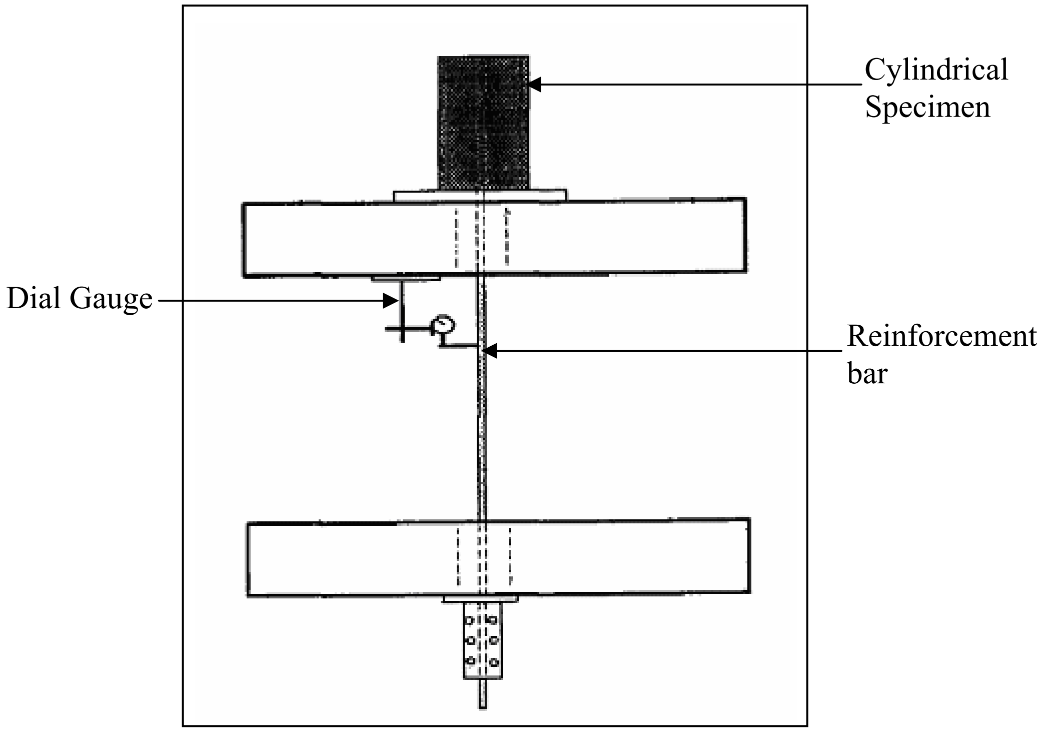


FIGURE 2.2 PULL-OUT SPECIMEN (CYLINDRICAL) SETUP [2]

F. Belaid et. al. [3] have used cubes of 100mm x 100mm x 100mm and cylinders of 110mm x 110mm were cast to study the bond strength. They had used 8 mm diameter of bar.

Roman Okelo et. al. [4] used cubes of 203mm x 203mm x 203mm in size for their experimental work. The experimental setup that was prepared is as shown in FIGURE 2.3. Here the measuring devices used were LVDT’s. They had used both circular and square cross-section of reinforcement bar to study the effect of cross-section of bar on the bond strength.

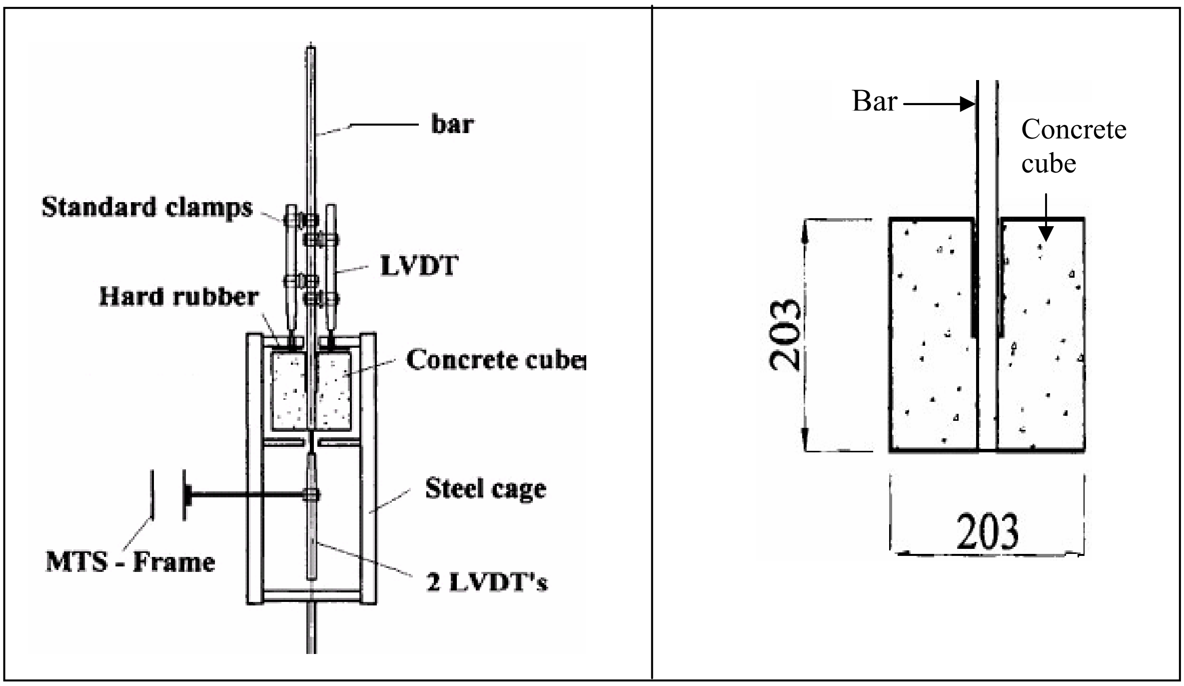


FIGURE 2.3 PULL-OUT SPECIMEN (CUBE) AND ARRANGEMENT OF THE SPECIMEN [4]

M. Harajli et. al. [5] used beam specimens of 1200mm x 200mm x 150mm and 1200mm x 200mm x 200mm for studying the bond strength. In his experiment he had used 16 mm, 25mm and 32 mm diameter of reinforcement bar.

Dirk Weibe et. al. [6] have used specimens of size 100mm x 100mm x 100mm and 80mm x 100mm x 100mm for their experimental work. The specimens are shown in the FIGURE 2.4 where the different position of the reinforcement bar can be observed so as to study the effect of different size of cover. The loading direction and casting direction are also specified in the FIGURE 2.4. They had used 10 mm diameter of reinforcement bar.

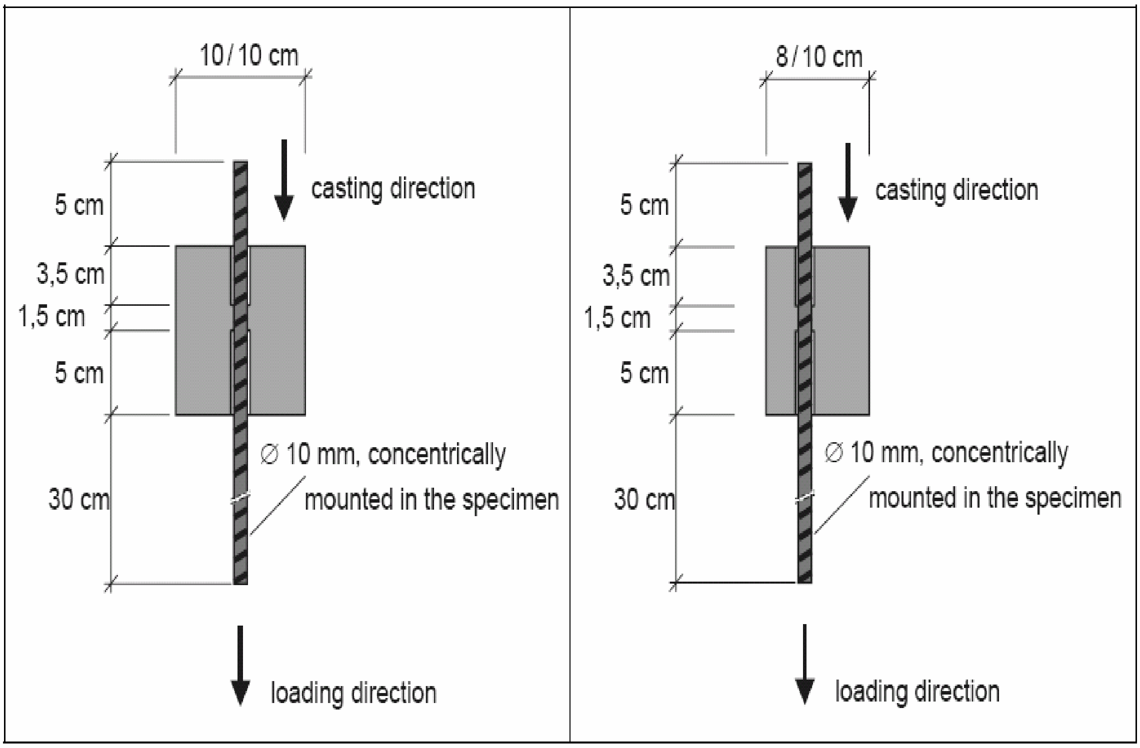


FIGURE 2.4 PULL-OUT SPECIMEN [6]

U.Mayer et. al [7] for their experiments on bond strength used beam specimens of sizes as follows:

i. 200mm x 200mm x 2300mm
ii. 400mm x 400mm x 2500mm
iii. 300mm x 300mm x 2500mm
iv. 400mm x 400mm x 2700mm
v. 300mm x 300mm x 2900mm
vi. 400mm x 400mm x 2900mm.

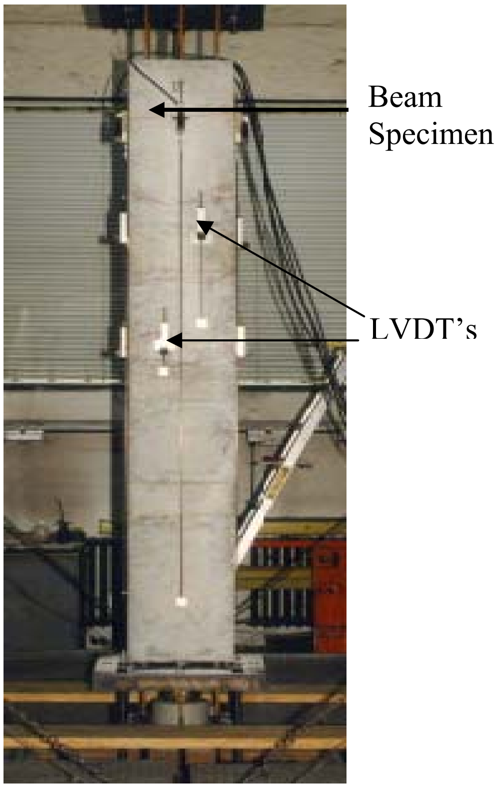


FIGURE 2.5 PULL-OUT SPECIMEN BEAM) [7]

The beam with length 2300 mm had reinforcement of 6 mm diameter while the beams of length 2500 mm was reinforced with 12 mm diameter bars, the beams of length 2700 mm were reinforced with 16 mm diameter reinforcement bars and the beams with 2900 mm length were reinforced with 25 mm diameter reinforcement bars. The experimental setup is as shown in FIGURE 2.5. There were three LVDT's used for recording the readings.

Nguyen Viet Tue et. al. [8] for their study used 200mm x 120mm x 120mm specimen. In their experiment they had used 10 mm, 12 mm, and 14 mm diameter of reinforcement bar.

2.2.2 LOADING RATES

Different researchers have used different experimental setup and different loading rated depending upon the size and shape of the specimen. Although the basic idea remaining the same i.e. to pull out the bar from the specimen.

Y.l.Mo et. al. [2] conducted the Pull-Out test with the setup shown in the FIGURE 2.2. The loading rates used in the experiment were 20, 40 and 60 kN/min.

F. Belaid et. al. [3] conducted the experiments with the loading rate of $0.5d^2$ N/s. where d= diameter of the bar in mm.

Roman Okelo et. al. [4] used the setup as shown in the FIGURE 2.3 and FIGURE 2.6. The load was applied to the specimen at the rate of 0.274 mm/min and hence all the tests were carried out in displacement controlled mode. LVDT's are used as the measuring devices.

M. Harajli et. al. [5] in their experiment applied two symmetrical concentrated loads, the distance between the loads was taken equal to the splice length plus the height of the specimen. The specimens were tested on the universal testing machine.

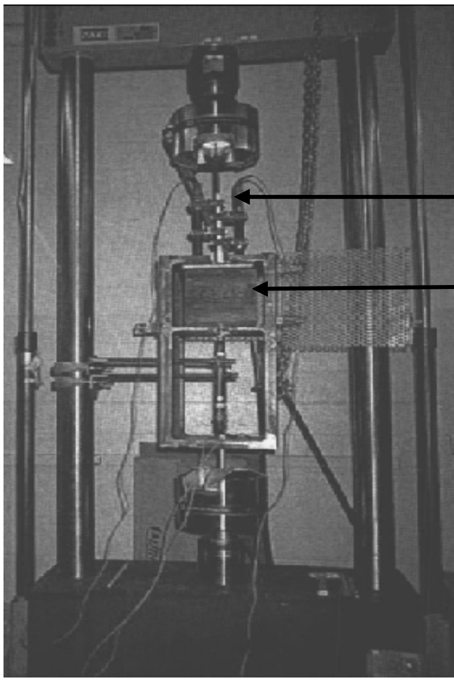


FIGURE 2.6 SETUP OF PULL-OUT TEST SPECIMEN [4]

Dirk Weibe et. al. [6] followed the displacement controlled experiment and the loading rate was kept as 0.005 mm/s.

U.Mayer et. al [7] used the test setup as shown in FIGURE 2.5. Tensile force was applied with the hydraulic jack of capacity 5000 kN. The tests were performed in the displacement controlled mode and the loading rate was 0.01mm/s.

2.2.3 PARAMETERS STUDIED AND FINDINGS

Various kinds of parameters are studied by researchers all around the world. Some of the parameters studied are listed below:

a. Diameter of reinforcement bars
b. Grades of concrete
c. Different types of concrete mix
d. Various types of coatings on reinforcing bars
e. Thickness of coating
f. Different kinds of reinforcement bar
g. Loading rates
h. Development length
i. Size of specimens

Y.l.Mo et. al. [2] studied the effect of bar diameter, bar type, embedded length, concrete strength and loading rate on bond behavior. They found that

- Bond strength of plain rebar was only 28.6% that of deformed rebar.
- The slip at failure was greater for the plain rebars than deformed rebars.
- Increasing the concrete compressive strength was able to improve the bond properties. This is as shown in FIGURE 2.7. Here the compressive strength of P4A12IS, P4B12IS and P4C12IS is 27 MPa, 33 MPa and 60 MPa respectively.
- Also they observed that the bond stress slip curve of plain bar was less than the deformed bar. This is shown in FIGURE 2.7. Here P4A12IS-2 is the plain bar and D4A12IS-2 is for the deformed bar.

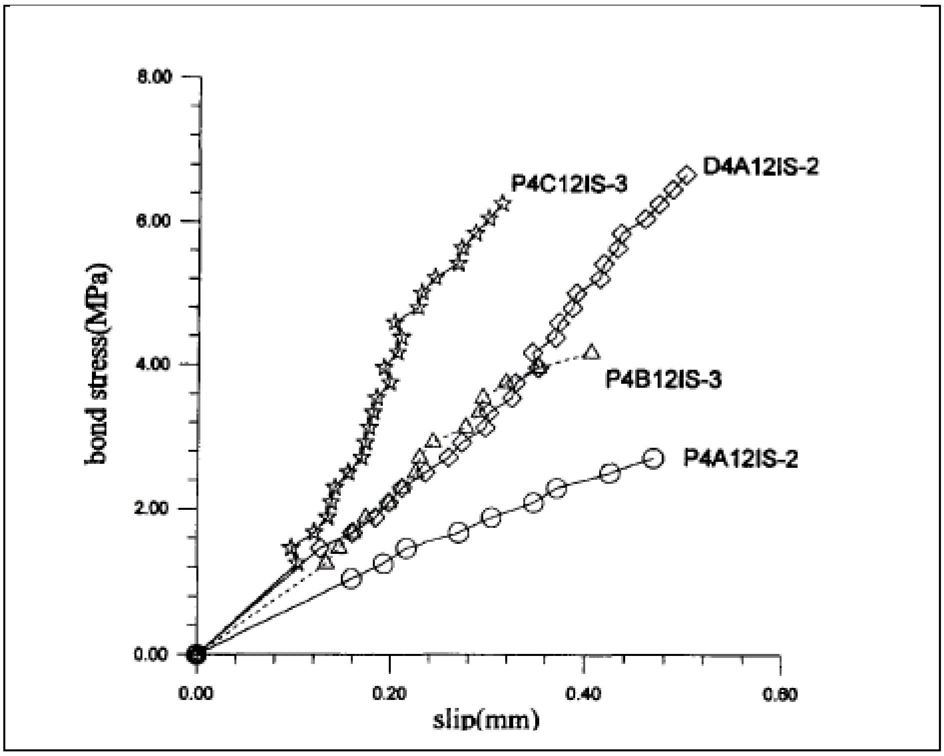


FIGURE 2.7 BOND STRESS-SLIP CURVE [2]

Dirk Weibe et. al. [6] also studied the effect of bar diameter, size of the concrete cover and the loading rate on bond behavior in ultra high strength concrete. They found that the bond behavior of reinforcement in ultra high strength concrete has no negative influence due to the high brittleness of the material. The bond stiffness is increased due to high compressive strength and modulus of elasticity.

Nguyen Viet Tue et. al. [8] studied the effect of the surface condition of steel. They found that the ductility and the bond can be improved by modification of surface condition of the reinforcing steels. They studied the deep ribbed reinforcing steel and found that it shows more ductile bond behavior and the failure of the bond is less brittle as shown in the FIGURE 2.8. It is observed that the bond stress, after reaching its maximum, stays approximately constant up to the doubling of the slip.

Gerald G. Miller et. al. [9] studied the bond behavior of epoxy coated bars and found that epoxy coatings caused reduction in the bond strength, and the reduction becomes significant if the coating thickness is greater than 420 μm.

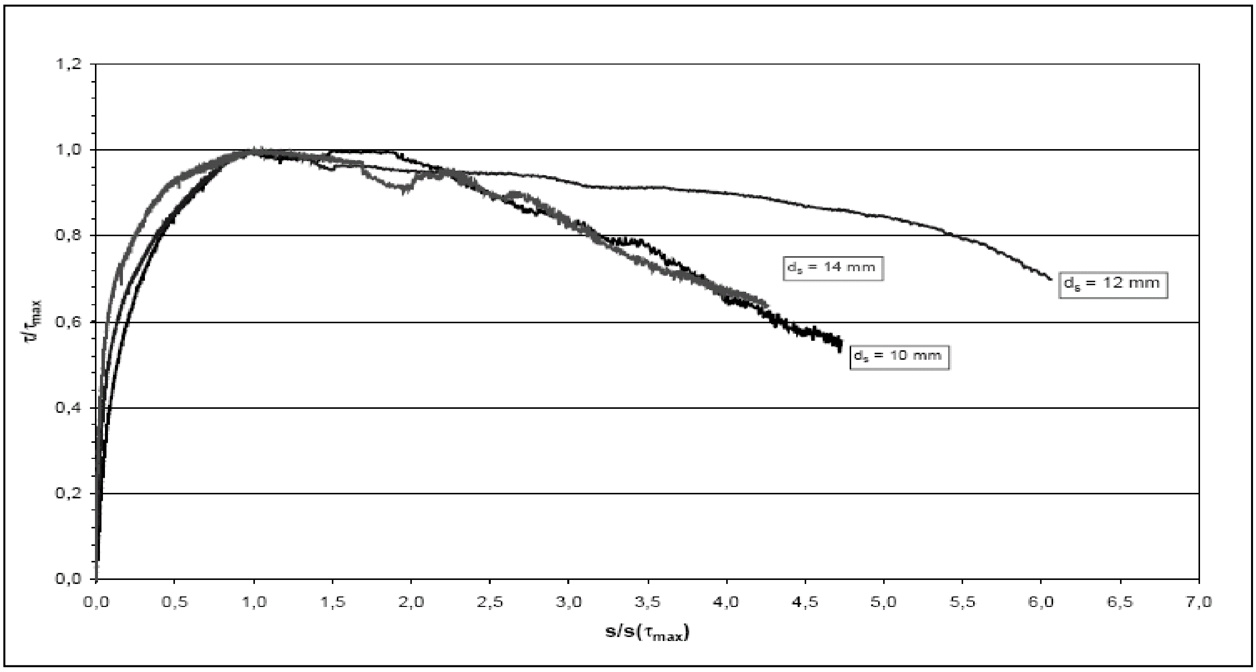


FIGURE 2.8 BOND STRESS-SLIP CURVE [8]

N. Subramanian [10] compared the Indian code provisions IS: 456 – 2000 with the American code provisions. Bond strength is influenced by several factors such as bar diameter, cover of concrete over the bar, spacing of bars, transverse reinforcement, grade and confinement of concrete around the bars, aggregates used in concrete, type of bars and coating applied on bars, if any, for corrosion prevention. In the Indian code on concrete structures which was revised in the year 2000, the provisions regarding development length remained unchanged. Many of the above parameters are not considered in the revised code where as American code considers all these parameters. He suggested the formula given by Darwin et. al. for the Indian code for the development length.

2.3 CONCLUDING REMARKS

Researchers have studied different parameters separately and the work is limited to type of bar with limited concrete grades and for few variations in the diameter of bars. So to make the work more comparative and to study the effect of different parameters simultaneously so as to get the actual idea of bond behavior when various parameters are involved was necessary. And with the innovations of new advanced materials which are very popularly at the sites, finding their bond property has become really important as the bond stress values given in IS: 456-2000 are the ones which were found some 40 years ago when there was no existence of such advanced materials. So advanced materials like Polymer cement coating, Super-plasticizers, fibres etc., which have become really popular these days, their effect on bond strength was required to be studied with other parameters like the effect of diameter of bar, grade of concrete mix, type of concrete mix, effect of using TMT bars instead of plain bars, etc .

3.1 THEORETICAL CONCEPT

The shear stress developed at the interface of bar and concrete is known as bond stress. When a reinforcing bar is embedded in concrete, the concrete adheres to its surfaces and resists any force that tries to cause slippage of bar relative to its surrounding concrete.

One of the basic assumptions in the theory of reinforced concrete is that bond between concrete and steel should be perfect within the elastic limit of steel. This implies that at any level the two materials will deform by identical amounts without slip. It is absolutely necessary to achieve this in practice, as the bond between the two materials is the means of transfer of stresses from one material to another. At the ultimate load, slipping of bar relative to concrete should not cause ultimate failure as long as the bar is not pulled at the ends.

Let us consider a reinforced concrete cantilever AB, as shown in the FIGURE 3.1.

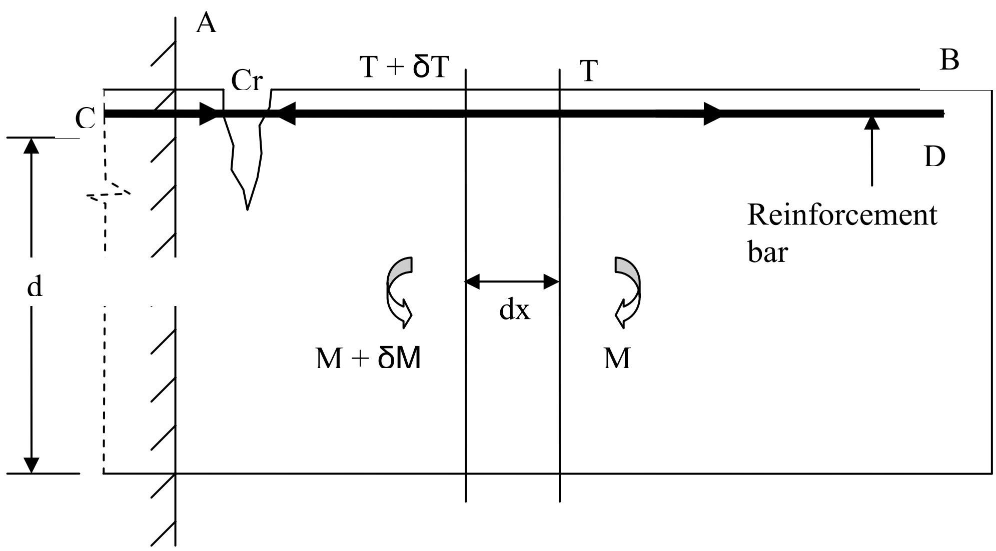


FIGURE 3.1 REINFORCED CONCRETE CANTILEVER AB

Due to the bending moments about A, the concrete will crack as shown in FIGURE 3.1. But if a steel bar is provided across this crack, it will take tension as the crack opens and get stretched. The bar will exert a force horizontally, as shown in fig 3.1, by arrows and will not permit the crack to develop. The steel bar will be stretched only if it is gripped by concrete on either side of the crack. As the steel bars are embedded in concrete at the time of casting, the concrete adheres to its surface and offers a resistance against any slipping of the bar. The greater is the length of the bar CD, the greater is the grip on it and greater is the force that it can exert at the crack Cr, subject to its own strength in tension. Thus, the tension bearing capacity of the reinforcement also depends upon the adhesion between concrete and steel. The steel bar will not be able to exert any pull across a crack near D as it will slip from right side and will not be stretched. But as we go towards C, the grip of concrete on the bar increases and it can bear tension equal to the total bond or the force of grip between the bar and concrete. Similarly, the bar should be sufficiently embedded on the left side to take full tension. Steel bar in a beam can develop tensile forces only if the steel is also strained along with the concrete fibres. This happens only if there is a bond between concrete and the bars. In general, the bending moment in a beam varies from section to section, as shown in FIGURE 3.1 i.e. M to $M+\delta M$ and consequently the tension in the steel bar at each point is different as shown in FIGURE 3.1 i.e. from T to $T+\delta T$ and there is a tendency of the bar to slip over concrete. This tendency is resisted by what is known as BOND or ADHESION between the two materials.

There are three types of resistance offered to slipping of steel bars in concrete namely

i. Pure Adhesion
ii. Frictional resistance
iii. Mechanical resistance

The schematic view of this is shown in FIGURE 3.2

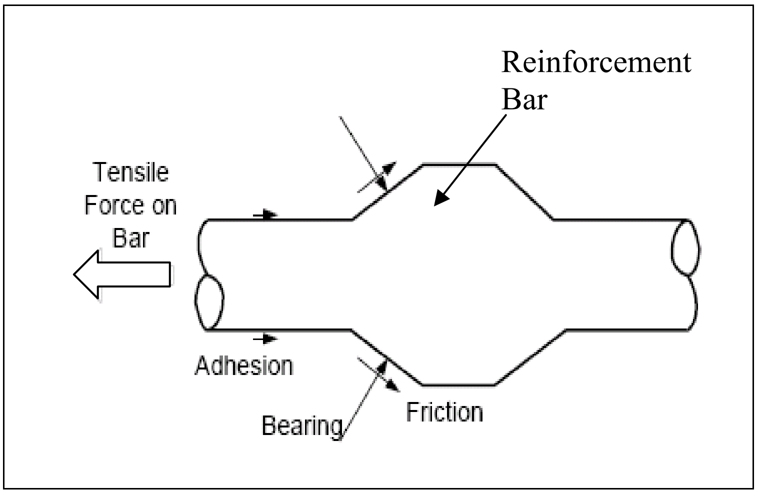


FIGURE 3.2 BOND COMPONENTS [11]

"Pure Adhesion" is due to a gum like property of colloidal material produced in concrete during setting. "Frictional resistance" is due to the property of concrete to shrink while setting and thereby grip steel. So it offers friction to slipping and "Mechanical resistance" is provided by the deforming or undulations on the surface of steel bars.

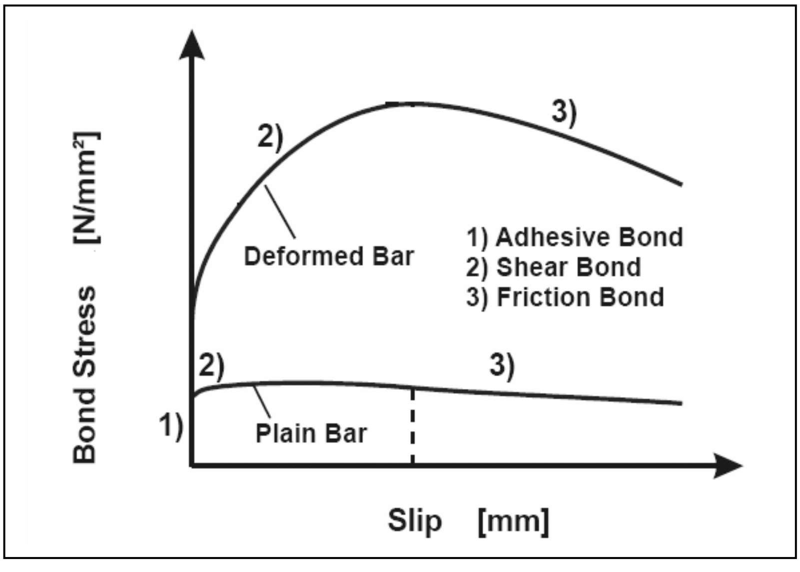


FIGURE 3.3 BOND STRESS - SLIP CURVE [6]

The bond resistance of plain bar is due to the adhesion and friction between concrete and steel. However, even at low tensile stress, adhesion between concrete and steel breaks, causing the slipping of plain bar. After the occurrence of slip, further bond is developed by friction between concrete and steel as shown in FIGURE 3.3. Failure in bond occurs when adhesion and the frictional resistance are overcome and the bar is pulled leaving a round hole in the concrete.

The bond capacity of the deformed bars increases due to mechanical resistance in addition to adhesion and frictional resistance as shown in FIGURE 3.3. When adequate embedment length is provided, bond failure due to pulling of the bar does not occur. The bar will fracture at its loaded end and the surrounding concrete which is subjected to excessive circumferential tensile stress will fail normally splitting. The interacting force between the deformed bar and the surrounding concrete, as shown in figure 3.4, results the splitting of the concrete into two or three segments.

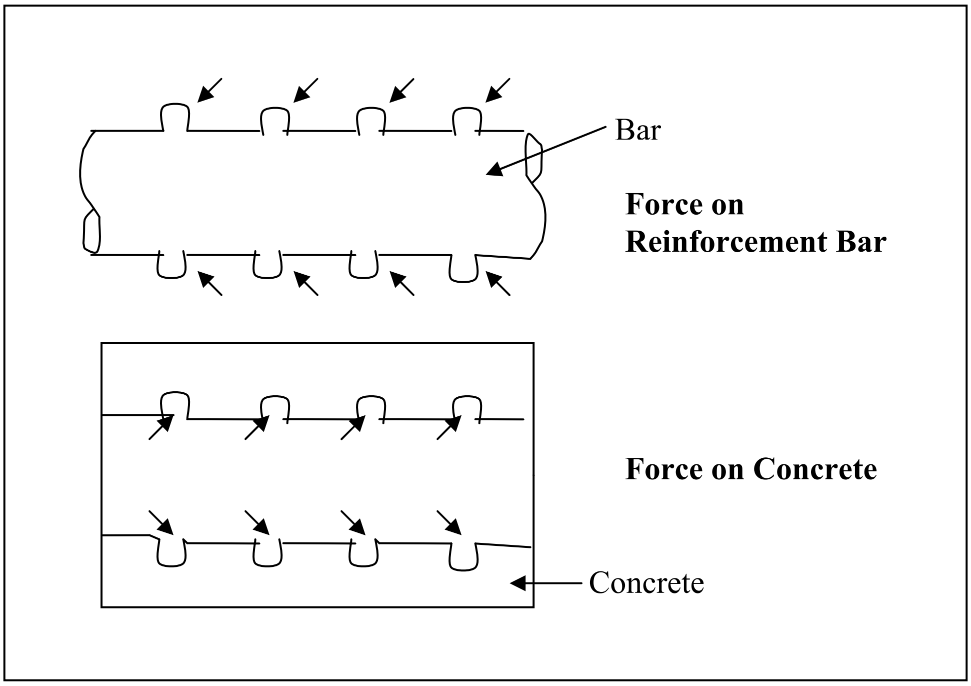


FIGURE 3.4 INTERACTION FORCE IN CONCRETE AND STEEL [12]

The different types of failure that may occur when the bar is pulled out are shown in FIGURE 3.5.

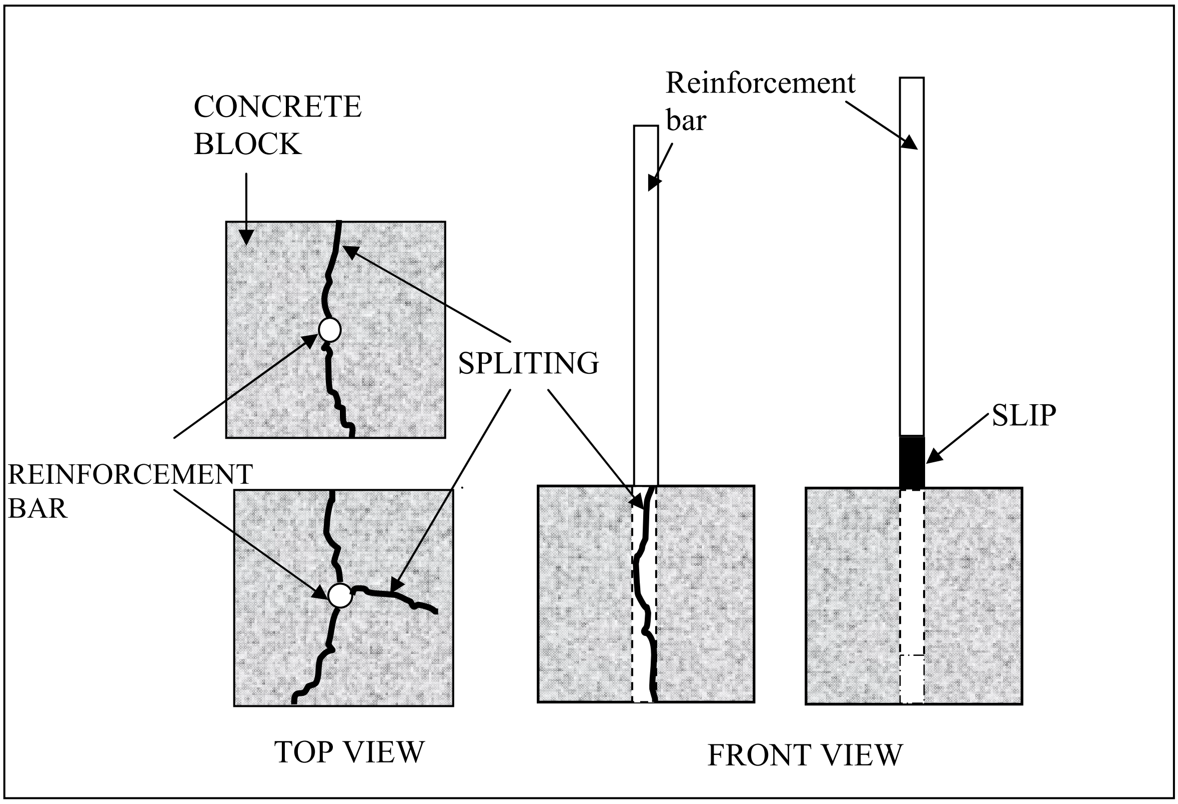


FIGURE 3.5 FAILURE PATTERN

The shear stress developed at the interface of bar and concrete is known as bond stress as defined earlier. It is the force per unit of nominal surface area of a reinforcing bar embedded in the concrete.

If 'P' is the force, l is the length of the embedded bar and its diameter is 'Ø', then

$$\text{Bond strength} = P / (\pi \, \varnothing \, l) \tag{3.1}$$

It had been noted that the bond strength found as above is higher if the length of the embedded bar is smaller. This formula gives an average value of the bond strength over the entire length of the embedment. In Pull-Out test, the maximum bond stress exists near the pulling end and falls to zero at the other end of the embedded bar. FIGURE 3.6 shows the probable distribution of the bond stress along the surface of the embedded portion of the bar.

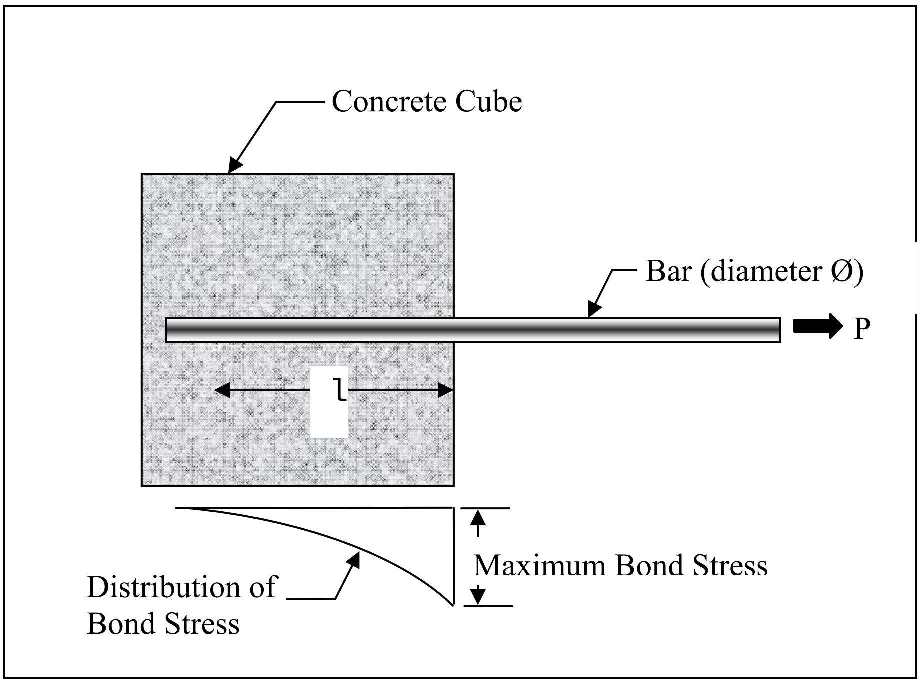


FIGURE 3.6 BOND STRESS VARIATION ALONG THE LENGTH

The Bond Stress values for plain bars given in IS: 456 – 2000 are as tabulated in TABLE 1. for deformed bars these values are increased by 60%.

TABLE 3.1 DESIGN BOND STRESS FOR PLAIN BARS IN TENSION

Grade of Concrete	M 20	M 25	M 30	M 35	M 40 and above
Design bond stress (N/mm^2)	1.2	1.4	1.5	1.7	1.9

The typical LOAD-SLIP curve of Pull-Out test specimen of plain bar and deformed bar is as plotted in FIGURE 3.7. As explained earlier, the curvature of the graphs changes because of the more mechanical resistance available in the deformed bar as compared to the plain bar.

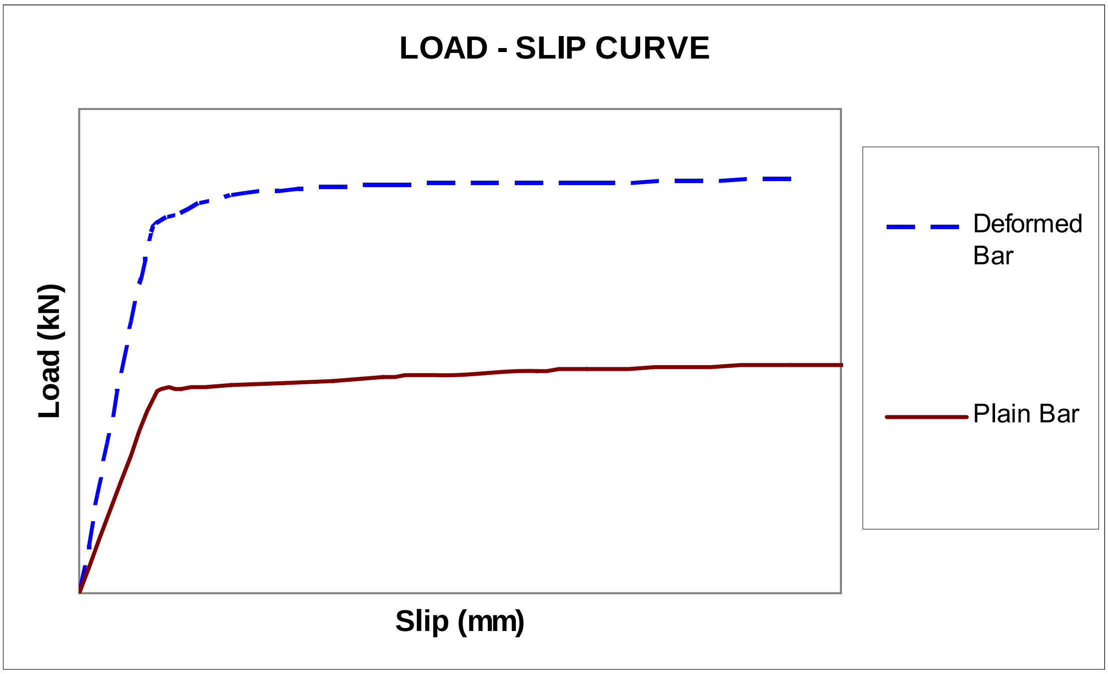


FIGURE 3.7 TYPICAL LOAD-SLIP CURVE

3.2 PULL-OUT TEST

PULL-OUT TEST measures the force required to pull out a previously cast-in situ steel rod. IS: 2770 (Part I) - 1967 (Reaffirmed 1990) "METHODS OF TESTING BOND IN REINFORCED CONCRETE" PULL-OUT TEST.

This part deals with the method for comparison of the bond resistance of different types of reinforcing bars with concrete. The test which is to be carried out is called Pull-Out Test. This method of test is proposed to provide a standardized procedure for comparison of bond characteristics between concrete and different types of reinforcing bars. But it should not be assumed that the average bond stress, calculated from the results of this tests have any direct relation to the permissible bond stress given in IS: 456 - 2000.

One of the basis on which different types of steel can be compared for their bond strength with concrete is, the load at a relative slip of 0.025 mm at the free end of the specimen, in a Pull-out Test.

The logic of measuring the load at 0.025 mm displacement is that, during failure of concrete, till 0.025 mm of slip failure of the RCC may happen in isolation, but after this value is crossed the failure happens because of many other reasons. Thus, more slippage may or may not be accompanied with crushing of concrete or cracking of concrete depending upon type of steel embedded in the concrete. Thus, studying bond stress beyond 0.025mm may not be practically useful.

The apparatus used for testing the specimens prepared is provided with a measuring device for measuring the movement of the reinforcing bar with respect to concrete at both the loaded and unloaded ends of the bar. Dial micrometers are used at both the locations as measuring device. At both the ends dial micrometers graduated to read 0.002 mm and having a range of 25 mm is used. FIGURE 3.8 shows the set-up for Pull out test.
Here,

- Attachment no. 1 is used for resting the dial gauge on the tip of the reinforcement bar at the free end
- Attachment no. 2 is for holding two dial gauges whose tip will rest on the attachment no. 3 which is attached to the reinforcement bar.

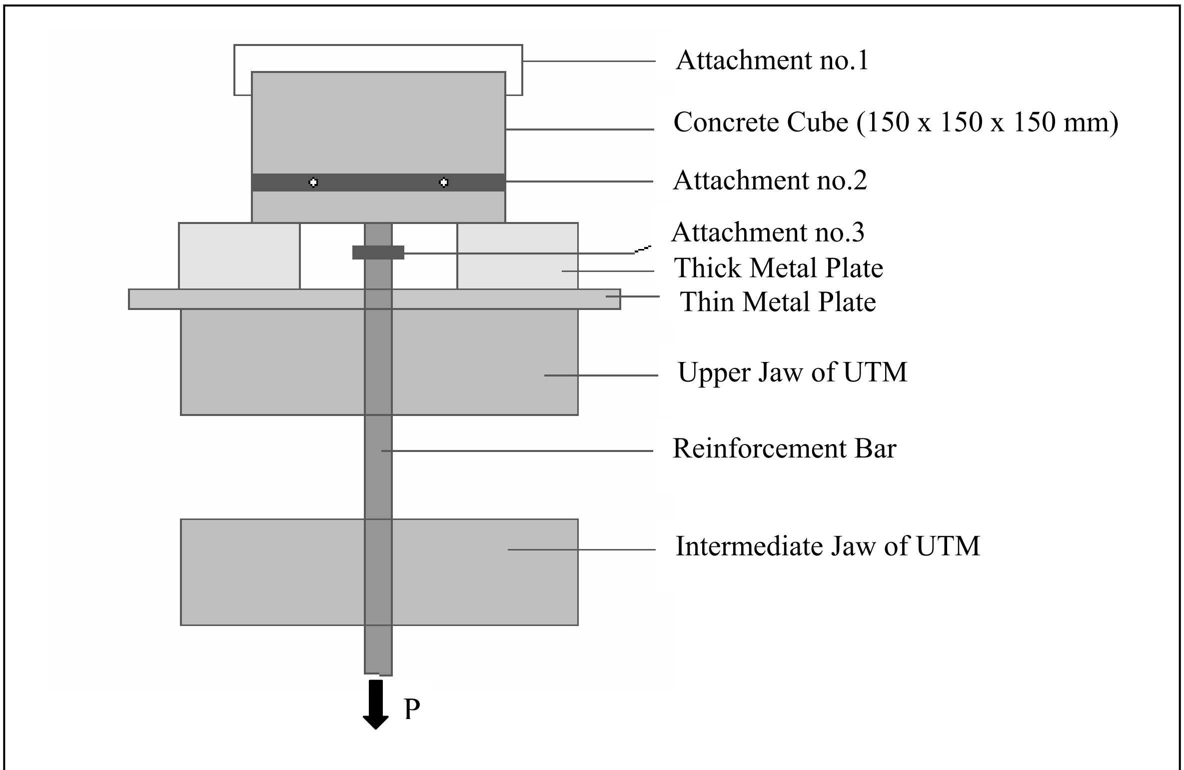


FIGURE 3.8 SETUP FOR PULL-OUT TEST

Three specimens of each variety of concrete and steel has been prepared and tested. The test specimens are to be mounted in a suitable testing machine in such a manner that the bar is pulled axially from the cube. The end of the bar at which the pull is applied is the one that projects from the face of the cube while cast. The loading is to be applied to the reinforcing bar at the rate not greater than 2250 kg/min (230 N/min). The movements between the reinforcing bar and concrete cube, as indicated by the dial micrometers is to be read at a sufficient number of intervals throughout the test to provide at least 15 readings by the time a slip of 0.25 mm has occurred at the loaded end of the bar.

The loading shall be continued and the readings of the movement recorded at appropriate intervals until:

a. The yield point of the reinforcing bars has been reached,
b. The enclosing concrete has failed,
c. A minimum slippage if 2.5 mm has occurred at the loaded end.

For the purpose of comparison the bond resistance of different types of bars, the comparison of bond strength shall be made on the basis of the average bond stress calculated from the loads at a measured slip of 0.025 mm at the free end.

The average bond stress shall be the value obtained for each specimen, by dividing the applied load at the slip specified, by the surface area of the embedded length of the bar; and then taking the average value for the group of each type of bar in the test series.

4. ADVANCE CONSTRUCTION MATERIALS USED FOR MODIFYING THE PROPERTIES OF CONCRETE

4.1 INTRODUCTION

Last 50 years have seen enormous urbanization and accordingly rapid development in infrastructural facilities. Along with this, taller structures, big span bridges, etc. have become the trend in the construction industry. This had demanded better quality of concrete and steel. Innovations are carried out in the field of concrete technology to make concrete more durable, stronger and more versatile material by adding Mineral and Chemical Admixtures and other relevant materials like Fibres, etc. to meet the demand of the quality of construction required these days. Innovations and researches are also going on for making steel more strong and durable and to tackle the problem of rusting, coating materials and other varieties of steel like galvanized steel, etc. have been developed.

A few of these advanced materials have become quite famous at sites and have been used in the experiment are mentioned below:

4.1.1 SUPERPLASTICIZER

Super-plasticizers are the improved version of plasticizers and are also called as High Range Water Reducers. Super-plasticizers are very powerful dispersing agents. Cement being in fine state of division has a tendency to flocculate in wet concrete. These flocculation entraps certain amount of water used in the mix and thereby all the water is not freely available to fluidify the mix. Super-plasticizers get absorbed on the cement particles and the adsorption of charged polymer on the particles of cement creates particle-to-particle repulsive forces which overcome the attractive forces. This repulsive force is called Zeta Potential, which depends on the base, solid content and quantity of Super-plasticizer used. The overall result is that the cement particles are deflocculated and dispersed.

When the cement particles are deflocculated the water trapped inside the flocs gets released and now available to fluidify the mix.

Use of Super-plasticizers permits the reduction of water to the extent up to 30% without reducing workability. Thus allows to make high strength workable concrete. The use of Super-plasticizers is increasing at a very high rate to produce flowing, self leveling, self compacting, high strength and high performance concrete.

As the use of Super-plasticizers have increased it has become very important to investigate its effect on the bond between the concrete and steel. So to study this 'CONPLAST SP430 A1' by 'FOSROC Chemicals (India) Pvt. Ltd.' was used as Super-plasticizer. The product is shown in FIGURE 4.1.

CONPLAST SP430 A1 is based on Sulphonated Napthalene Polymers and is supplied as brown liquid instantly dispersible in water. CONPLAST SP430 A1 has been specially formulated to give high water reductions up to 25% without loss of workability or to produce high quality concrete of reduced permeability.

The properties of CONPLAST SP430 A1 are shown below:

- Specific gravity :1.240 to 1.260 at 27^0 C
- Chloride content : Nil to IS:456
- Air entrainment : <1.5%

FIGURE 4.1 CONPLAST SP430 A1

It can be used with all types of cements except high alumina cement. CONPLAST SP430 A1 is compatible with other types of FOSROC admixtures when added separately to the mix. Site trials should be carried out to optimize dosages.

The use of CONPLAST SP430 A1 helps to produce pumpable concrete. Also it helps to get high strength, high grade concrete M40 and above, by substantial reduction in water resulting in low permeability and high early strength. It is also useful in producing high workability concrete which requires little or no vibration during placing.

The advantages of such Super-plasticizer is improved workability which helps in easier and quicker placing and compaction of concrete. Also it helps in providing high early strength of concrete if water reduction is targeted. It also helps to get improved quality of work with denser, closed textured concrete with reduced porosity and hence more durable. They are also chloride free so they can be safely used in reinforced concrete construction.

CONPLAST SP430 A1 complies with IS: 9103 – 1999, BS: 5075 - Part 3 and ASTM-C-494 Type 'G' as a high range water reducing admixture.

As a guide, the rate of addition is generally in the range of 0.6% to 1.5% by weight of cement (as suggested by FOSROC).

4.1.2 POLYPROPYLENE FIBRES

Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually leading to brittle fracture of the concrete.

FIGURE 4.2 POLYPROPYLENE FIBRES

It has been recognized that the addition of small, closely spaced and uniformly distributed fibres to concrete would act as crack arrester and would substantially improve its static and dynamic properties.

Some of the fibres that could be used are steel fibres, polypropylene, nylons, asbestos, coir, glass and carbon. The use of fibres is now a days becoming very common. So to study the effect of fibres on bond between the concrete and steel has become eminent.

Polypropylene fibres are found to be suitable to increase the impact strength. They possess very high tensile strength, but their low modulus of elasticity and higher elongation do not contribute to flexure strength.

Polypropylene fibres of 12 mm length are as shown in FIGURE 4.2.

To study this effect of fibres on bond polypropylene (12mm length) fibres has been used. The properties of the fibres used are given in the TABLE 4.1.

TABLE 4.1 PROPERTIES OF POLYPROPYLENE FIBRE

Sr. No.	Property	Monofilament Polypropylene Fibre
01	Specific Gravity	0.91
02	Configuration	Circular
03	Diameter (microns)	32
04	Avg. cut length (mm)	12 ± 1
05	Denier	6 ± 0.3
06	Breaking Tenacity (g.p.d)	4.4 ± 0.3
07	Breaking Elongation %	24
08	Ultimate Elongation %	24
09	Melting point ^{0} C	165 - 170
10	Ignition point ^{0} C	-
11	Crimps/cms	Nil
12	Absorption	Nil
13	U.V.Stabilty	Poor
14	Acid & Salt Resistance	High
15	Alkali Resistance	Alkali Proof
16	Bio-degradable	No

17	Dry Dispersion	Excellent in water
18	Wettability	Excellent in water
19	% oil pick up(coating agent)	0.6 - 0.7
20	Thermal Conductivity	Low
21	Electrical Conductivity	Low
22	Young's modulus (GPa)	3.5 – 5
23	Density (t/m^3)	0.9
24	Tensile Strength (MPa)	400 – 700
25	No. of fibres (Million/kg)	15
26	Poisson's ratio	0.29
27	Min. recommended dosage g/m^3 of concrete	910
28	Cost Rs./- for 1 kg	70

4.2 STEEL

Concrete is strong in compression but weak in tension. Therefore reinforcement is needed to resist the tensile stresses resulting from the induced loads.

The steel used in reinforced concrete plays an important role and there has been development of different types of steel to enhance the functions served. For most effective reinforcing action, it is necessary that steel and concrete deform together, i.e., that there should be a sufficiently strong bond between the two materials to ensure that no relative movements of the steel bars and the surrounding concrete occurs. This bond is provided by the relatively large chemical adhesion that develops at the steel-concrete interface, by the natural roughness of the reinforcing steel, and by the closely spaced rib-shaped surface deformations with which the reinforcing bar is furnished in order to provide a high degree of interlocking of the two materials.

Different types of reinforcement used are mild steel, medium tensile steel, hot rolled deformed bars, cold twisted high yield strength deformed (HYSD) steel and hard drawn steel wire fabric.

4.2.1 MILD STEEL

Mild steel bars have been widely used as reinforcement in construction industry. The yield strength of mild steel is 250 N/mm^2 (minimum specified value). Among all kinds of steel, mild steel is the most ductile. Mild steel can be plain or deformed to increase the capacity in bond.

FIGURE 4.3 MILD STEEL

To study the bond strength plain mild steel have been used and its properties are given in TABLE 4.2.

TABLE 4.2 PROPERTIES OF MILD STEEL USED

Type of steel	Diameter (mm)	Ultimate strength (N/mm^2)
Mild Steel	12	466.00
Mild Steel	16	488.33
Mild Steel	20	418.00

4.2.2 TMT

TMT (Thermo-Mechanically Treated) bars are the most commonly used reinforcement bars these days and therefore it has become prime importance to study its effect on bond strength. FIGURE 4.4 shows the TMT bars.

FIGURE 4.4 TMT BARS

Property of TMT bars used is as shown in TABLE 4.3.

TABLE 4.3 PROPERTIES OF TMT BARS USED

Type of steel	Diameter (mm)	Ultimate strength (N/mm^2)
TMT	12	548.50
TMT	16	646.33
TMT	20	678.00

4.3 POLYMER COATING

Corrosion of steel is the major problem in reinforced concrete structures. To over come this, various types of coatings have been developed. The coatings should be strong to withstand fabrication of reinforcement cage, pouring and compaction of concrete. Coatings like epoxy, polymer, etc have been very widely used these days to solve the problem of corrosion.

To study the effect of such coating on the bond strength is very important. 'CICO TAPECRETE P-151' an admixture polymer-cement composite has been used to carry out this study. The picture of CICO Tapecrete P-151 as shown in FIGURE 4.5

FIGURE 4.5 TAPECRETE P - 151

CICO Tapecrete P-151 polymer is an additive polymer cement composite for multipurpose use i.e. water proofing of basements, toilets, sunken portions, roofs, swimming pools, water tank, etc for surface protection, repair, rehabilitation, floor topping, durable and aesthetic exterior finish with cement paints, repairing of concrete and masonry, joining concrete to concrete, etc.

The salient features of CICO Tapecrete are as mentioned below:

- It combines water proofing with tough and hard wearing surfaces. Allows trapped vapors to escape thus preventing peeling.
- It develops excellent bond to most of the building materials.
- It is not effected by Ultra Violet rays and chemicals ranging from mild acid to strong alkalis and is highly durable.
- Bonding aid for new and old concrete / mortar repair and patching of concrete.

The product application needs surface preparation and following steps shall be adopted for preparing the surface:

- The surface should be free from all dust, foreign matters, loose material or any deposit of contaminants.

- All concrete surfaces should be thoroughly prewetted for at least one hour prior to the Tapecrete coating by providing water on the flat surface or by vigorously spraying water on the vertical and inclined surfaces.
- When placing Tapecrete coating, water should be removed so that the surface is only damp. In no case there should be standing water or a shiny wet surface. Depressions may be filled and leveled using Tapecrete cement mortar and for such filler material the mixing ratio is 1 kg cement, 1.5 kg silica sand and 0.5 kg Tapecrete.
- For application on steel the surface should be cleaned properly and should not contain any dust, foreign matters, loose material or any deposit of contaminants. The surface should be free from rust and wire brush may be used to remove the rust so as to prepare the surface for the application of Tapecrete.

Tapecrete polymer is mixed with neat cement in the ratio of 2 kg of cement to 1 kg of Tapecrete. It should be stirred thoroughly until no air bubbles remain in the mix. The mix has to be applied by brush on the prepared surface. Two or more coats are recommended. First coat should be allowed to air dry for 5 – 6 hours before second coat.

5. CONCRETE MIX DESIGN

5.1 INTRODUCTION

One of the aims of studying concrete technology is to design a concrete mix for the particular strength and durability. The design of concrete mix is not a simple task on account of widely varying properties of constituent materials, the condition that is prevailing at the site of work, in particular the exposure condition, and the condition that are demanded for a particular work for which the mix is designed. Design of concrete mix requires complete knowledge of the various properties of these constituent materials, the implications in case of the change on these condition at the site, the impact of the properties of plastic concrete on the hardened concrete and the complicated inter-relationship between the variables. All these make the task of mix design complex and difficult.

The structural engineer stipulates certain minimum strength of the concrete and the concrete technologist designs the concrete mix with the knowledge of materials, site condition and standard of supervision available at the site of work to achieve this minimum strength and durability. Further the site engineer is required to make sure that the concrete is prepared closely following the parameters suggested by the mix designer to achieve the minimum strength specified by the structural engineer.

Mix Design or mix proportioning can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The purpose of designing can be seen from the above definition is two fold. The first object is to achieve the stipulated minimum strength and durability. The second objective is to make the concrete in the most economical manner. Cost wise all the concrete mainly depends on two factors; namely cost of labour and cost of material. Out of which the cost of labour would remain same for both good concrete and bad concrete.

Therefore attention is mainly directed to the cost of materials. Since the cost of cement is many times higher than the other ingredients, attention is mainly directed to the use of as little cement as possible consistent with strength and durability.

5.2 Concrete Mix Proportioning

The mix proportion shall be selected to ensure workability of the fresh concrete and shall have required strength and durability when the concrete is hardened. The determination of the proportions of cement, aggregates and water to attain the required strengths shall be made as follows:

a. By designing the concrete mix such that the concrete shall be called 'Design Mix Concrete'
b. By adopting nominal concrete mix such concrete shall be called 'Nominal Mix Concrete'

Designed Mix Concrete is always preferred to nominal mix. If design mix concrete cannot be used for some reason or the other on the work for grades of M 20 or lower, nominal mixes may be used with the permission of engineer-in-charge, which however is likely to involve higher cement content.

For specifying a particular grade of concrete, following information shall be included:

a. Type of mix, i.e. design mix or nominal mix concrete
b. Grade designation
c. Type of cement
d. Maximum nominal size of aggregate
e. Minimum cement content (for design mix concrete)
f. Maximum water-cement ratio
g. Workability
h. Mix proportion (for nominal mix concrete)
i. Exposure conditions
j. Maximum temperature of concrete at the time of placing
k. Degree of supervision
l. Type of aggregate

m. Maximum cement content
n. Whether an admixture shall or shall not be used and the type of admixture and the condition of use.

5.3 CONCRETE MIX DESIGN ADOPTED

Concrete mix design adopted for the study were

1. Indian standard Recommendation method IS 10262:1982
2. ACI Committee 211 method
3. DOE method

5.3.1 Indian Standard Recommended Method of Mix Design (IS 10262 – 1982)

The bureau of Indian Standards has recommended a procedure for the mix design of concrete based on the experimental work carried out in the national laboratories. The mix design procedure is given in IS 10262 – 1982. The IS recommendation for mix design include the design for nominal concrete mixes (non air entrained) for both medium and high strength concrete.

This method is applicable to both ordinary Portland and Portland pozzolona cements. The final mix proportions selected after trial mixes, may need minor adjustment.

5.3.2 American Concrete Institute Method of Mix Design

This method was published in 1944 by ACI committee 613. In 1954 the method was revised to include, among other modifications, the use of entrained air. In 1970, the method of mix design became responsibility of ACI committee 211 have further updated the method (ACI – 211.1) of 1991. Almost all the multi purpose dams in India built during 1950 have been designed by the prevalent ACI Committee method of mix design.

5.3.3 DOE Method of Mix Design (British Method)

DOE method of concrete mix design was evolved by the Building Research Establishment of Department of Environment (DOE) U.K. DOE method was first published in 1975 and then revised in 1988.This method can be used for concrete containing Fly Ash also.

The details of concrete design by all the method are shown in ANNEX-C. The TABLE 5.1 shows the result of mix design for M20, M25 and M30 mixes obtained from the excel sheet prepared.

Table 5.1 MIX DESIGN

Method	Grade of Mix (MPa)	Water (litres)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
IS	20	23.4	50	68	146
ACI	20	27.5	50	86	152
DOE	20	27.5	50	64	121
IS	25	21.5	50	60	133
ACI	25	20.5	50	57	115
DOE	25	25.0	50	56	109
IS	30	19.1	50	49	115
ACI	30	22.5	50	64	125
DOE	30	22.5	50	47	98

Table 5.2 PROPORTION OF MIX DESIGN

Method	Grade of Mix (MPa)	Water (litres)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
IS	20	0.47	1	1.36	2.92
ACI	20	0.55	1	1.72	3.04
DOE	20	0.55	1	1.28	2.42
IS	25	0.43	1	1.20	2.66
ACI	25	0.41	1	1.14	2.30
DOE	25	0.50	1	1.12	2.18
IS	30	0.38	1	0.98	2.30
ACI	30	0.45	1	1.28	2.50
DOE	30	0.45	1	0.94	1.96

Many trial mixes were tested based on the above results as explained in next chapter, and accordingly mixes were selected for the further work.

6. PILOT TESTS

6.1 INTRODUCTION

This project invited huge amount of casting of samples because of the different parameters which were chosen for study like

- Three selected varieties of concrete
- Three different types of bar
- Three different diameter of bars and
- Five different grades of concrete

Also to decide whether helical reinforcement was to be used in the casting. This is because IS: 2770 (Part I)-1967 states that helical reinforcement should be provided in each pull-out specimen. So to study the effect of helix, pilot testing was to be carried out and this would also help in optimizing the cost of the project as the cost of providing helical reinforcement in each and every specimen of pull-out sample would increase the cost of project to a large extent.

Also, dosage of Super-plasticizer being an important parameter and so to get the optimum dosage of this Super-plasticizer pilot testing was to be carried out.

Three pilot tests were carried out to actually optimize the whole project.
The test carried out consists of the following:

a. Trial mixes for designing concrete mixes M20, M25, M30, M35, and M40 with optimum use of cement.
b. Experiment for determination of optimum dosage of Super-plasticizer using Marsh Cone Test.
c. Experiment for deciding the role of helix.

These pilot tests are explained in the next section briefly.

6.2 Trial mixes carried out for selection of final Mix Proportion

There were 20 different mix proportions were designed and were cast to study the properties of fresh and hardened concrete. Out of these 20 mixes, 15 mix proportions were selected by studying the results of 7 and 28 days. The mix with Super-plasticizer and Fibres were so selected that the slump remained constant and hence resulting in the saving of cement. The mix proportion of the 20 mix cast is as shown in TABLE 6.1. The aim of this experiment was also to optimize the use of cement in the mix designed and hence reducing the overall cost of the project.

TABLE 6.1 MIX PROPORTIONS

MIX No.	INGREDIENTS					RESULTS		
	Cement (kg)	Water (l)	Sand (kg)	Grit (kg)	Kapchi (kg)	SLUMP (mm)	STRENGTH	
							7 days	28 days
1	300	189	595	478	717	75	14.2	-
2	275	172	619	531	797	50	25.8	-
3	275	161	612	488	732	50	22.4	-
4	325	163	615	502	737	60	26.8	-
5	290	138	645	530	775	40	22.4	-
6	350	158	605	495	725	50	22.5	-
7	315	142	645	530	765	40	22.8	-
8	375	150	610	500	730	40	25.2	-
9	365	146	625	505	735	40	33.0	-
10	400	160	560	456	684	38	37.2	-
11	385	154	575	465	395	35	42.7	-
12	300	140	620	465	695	-	23.3	36
13	300	165	595	478	717	-	21.3	35.6
14	300	165	595	478	717	-	21.6	32
15	300	194	560	494	741	100	33.9	41.0
16	325	165	554	488	733	95	32.0	43.7
17	350	175	547	483	724	80	29.6	46.1
18	375	190	541	477	715	135	27.1	42.1
19	400	200	534	471	707	140	29.3	40.0
20	425	196	525	466	698	-	31.6	45.2

There were at least 3 cubes cast of each mix proportion and the compressive strength at 7 and 28 days were found out. Out of these 20 mix proportions, 15 mix proportions were selected for the final casting work. The 15 mix proportions that were selected are shown in Table 6.2.

This exercise helped in getting very good quality control on the 15 mixes selected. Also, it helped in highly optimizing the quantity of cement and workability obtained was also satisfactorily consistent. The final proportions of selected mixes are as shown below:

TABLE 6.2 FINAL MIX PROPORTIONS SELECTED

Sr. NO	Mix	Cement (kg)	Water (l)	Sand (kg)	Grit (kg)	Kapchi (kg)
Normal Mix (N)						
1	M 20	300	189	585	480	720
2	M 25	315	179.55	615	500	735
3	M 30	350	182	605	495	725
4	M 35	390	187.2	605	500	725
5	M 40	400	172	560	456	684
Mix with Super-plasticizer (N+S)						
6	M 20	275	173.25	610	490	735
7	M 25	290	165.3	645	530	775
8	M 30	325	169	640	525	760
9	M 35	375	180	625	505	735
10	M 40	385	165.55	575	465	695
Mix with Super-plasticizer and Fibres (N+S+F)						
11	M 20	275	173.25	610	490	735
12	M 25	290	165.3	645	530	775
13	M 30	325	169	640	525	760
14	M 35	375	180	625	505	735
15	M 40	385	165.55	575	465	695

It can be seen from the above table that Mix with Super-plasticizer contains lesser cement, thus getting dual advantage of lesser cement content and lesser water content without any compensations in strength and workability because of the addition of Super-plasticizer. The results are presented in Annex D.1 and observations on the same are presented in CHAPTER 8.

6.3 Experiment study for obtaining the optimum Dosage of Super-plasticizer

Determination of optimum dosage of Super-plasticizer plays a very important role in making durable and long-lasting concrete. If lesser dosage of Super-plasticizer is added, then it will produce reliable results and the concrete mix will remain harsh. On the other hand, if it is overdosed, it would the retard the initial and final setting times, increase air content and workability. Thus, it becomes very important to determine the optimum dosage of Super-plasticizer to be added in the concrete mix. This is done with the help of Marsh Cone test.

In this experiment, the time taken for mortar with different dosage of Super-plasticizer is measured. The Super-plasticizer selected was 'FOSROC CONPLAST SP430 A1'. Table 6.3 shows the readings of the Marsh Cone Test. Super-plasticizer dosage given in percentage in the TABLE 6.3 is with respect to the weight of cement taken in the mix of mortar. FIGURE 6.1 shows the curve obtained from the test. The optimum dosage is the amount when the curve almost becomes flat. Here it is found that the optimum dosage of Super-plasticizer is 0.4% by weight of cement.

TABLE 6.3 MARSH CONE READINGS

Dosage in %	Time (sec.)
0.1	28.7
0.2	21
0.3	18.4
0.4	17.29
0.5	17.8
0.6	17.9

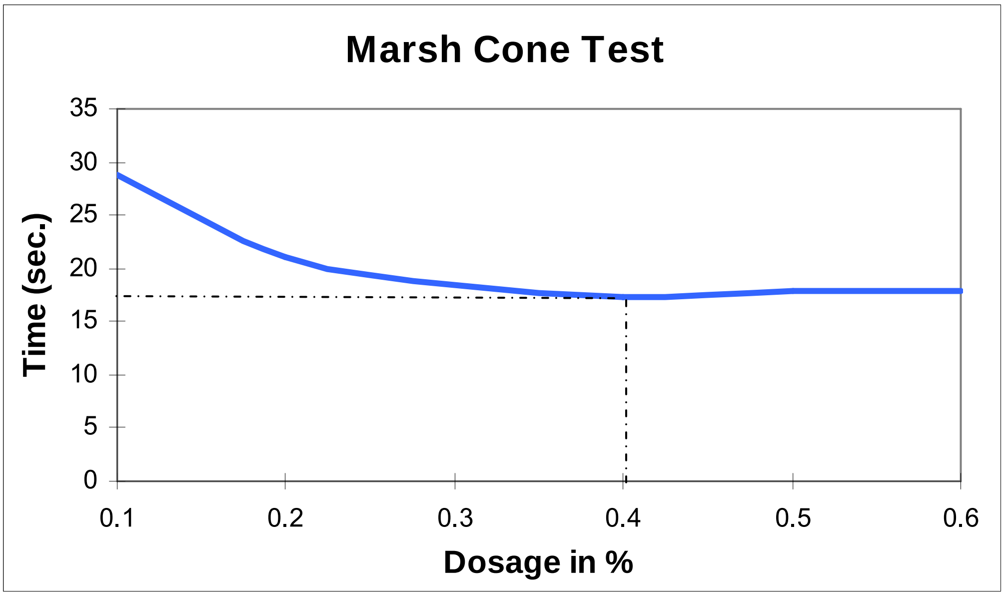


FIGURE 6.1 MARSH CONE TEST

6.4 Experimental study for the requirement to provide helix

According to IS: 2770 (Part-I) – 1967, the pull–out specimen shall be reinforced with a helix of 6 mm diameter plain mild steel bar, such that the outer diameter of the helix is equal to the size of the cube (specimen).

Therefore, to check the role of the helix and to decide whether it is necessary to provide helix in the specimen, 6 cubes were cast. Out of these 6 cubes, in 3 cubes helix was provided and the in other 3 cubes helix was not provided. FIGURE 6.2 shows the specimen with helix.

Pull-out test was carried out and Load-Slip Curves were plotted as shown below in FIGURE 6.3.

FIGURE 6.2 SPECIMEN WITH HELIX

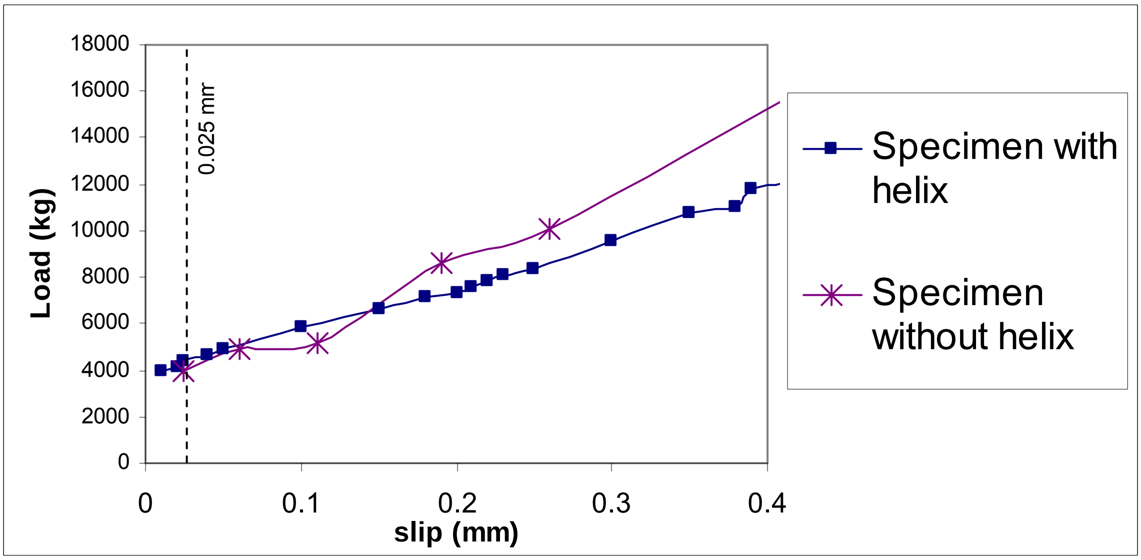


FIGURE 6.3 LOAD SLIP CURVE

TABLE 6.4 READINGS OF PULL OUT TEST

Type of specimen	load @ 0.025mm slip (N)	Bond Strength (N/mm^2)	Type of failure
Specimen with Helix	4169	0.87	Steel
Specimen without Helix	3924	0.82	Concrete

The presence of helix might have helped in the final stage of failure but during the range of study i.e. up to 0.025 mm slip the effect of helix does not help much which is also seen from the FIGURE 6.3 showing the load slip curves and from the TABLE 6.4.

Therefore, in the final casting of specimens the helix was not provided.

7. EXPERIMENTAL SETUP AND WORK PLANNED

7.1 EXPERIMENTAL SETUP

The apparatus required to carry out the Pull-Out test consists of :

- Moulds for Bond test specimen,
- Measuring apparatus i.e. dial micrometer two at the loaded and one at unloaded end of the specimen, and
- Testing machine

The mould for bond test is similar to the mould for casting cubes for the compression test. The inner dimension of the cube should be of 150 mm x 150 mm x 150 mm. The measuring apparatus i.e. dial gauges should be with a least count of 0.0025mm. The testing machine should be of sufficient capacity to carry out the pull-out test and the loading rate should not be more than the one specified in the IS-2770 (Part I)-1967.

The test specimens consist of:

- Concrete cube 150 mm x 150 mm x 150 mm.
- Steel reinforcement bar of approximate one metre length concentrically embedded in the concrete cube as shown in FIGURE 7.1

`

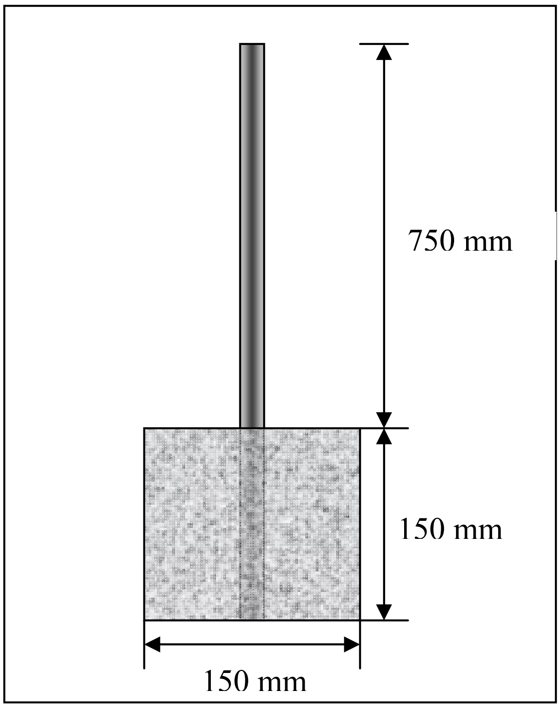


FIGURE 7.1 PULL-OUT SPECIMEN

The schematic diagram of the apparatus for carrying out Pull-Out tests, that is mentioned in IS: 2770 (Part I) - 1967 is as shown in the FIGURE 7.2.

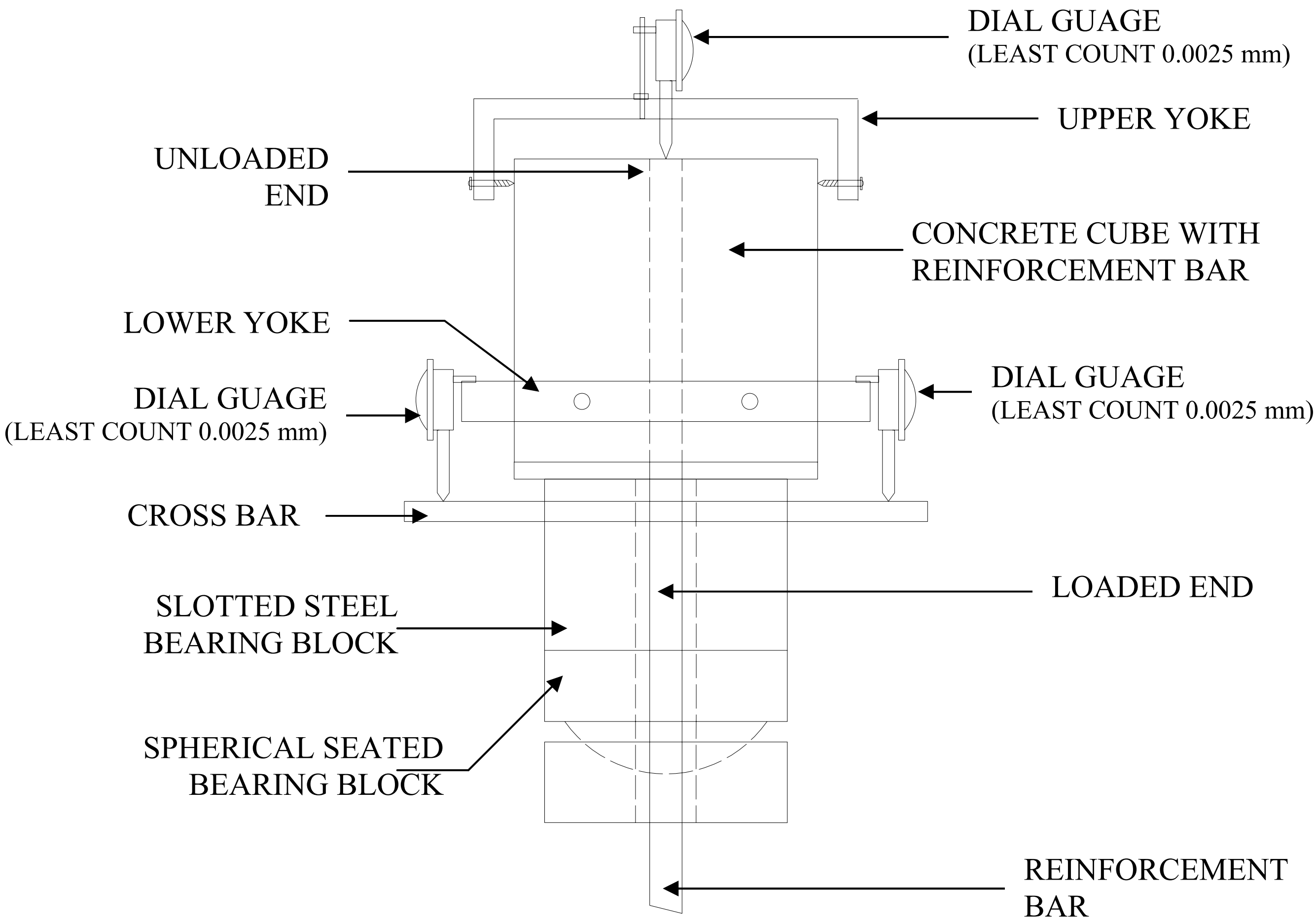


FIGURE 7.2 PULL-OUT APPARATUS AS IN IS: 2770 (PART I) - 1967

Here, dial micrometers are mounted on suitable yokes which are attached to the concrete specimen i.e. cube with set screws. At the unloaded end of the bar, the dial gauge can be adjusted by means of the threaded bolt with which it is attached to the upper yoke. At the loaded end of the bar, adjustment is accomplished by changing the height of the cap screw on the ends of the cross bar on which the stem of the dial micrometer rests. The split ring cross bar is attached to the reinforcing bar through the four screws in the arms of the cross bar. The cross bar rests in the slot machined in the intermediate bearing plate.

Looking to the apparatus suggested by the code, the apparatus that was fabricated with the resources available at the institute is as shown FIGURE 7.3.

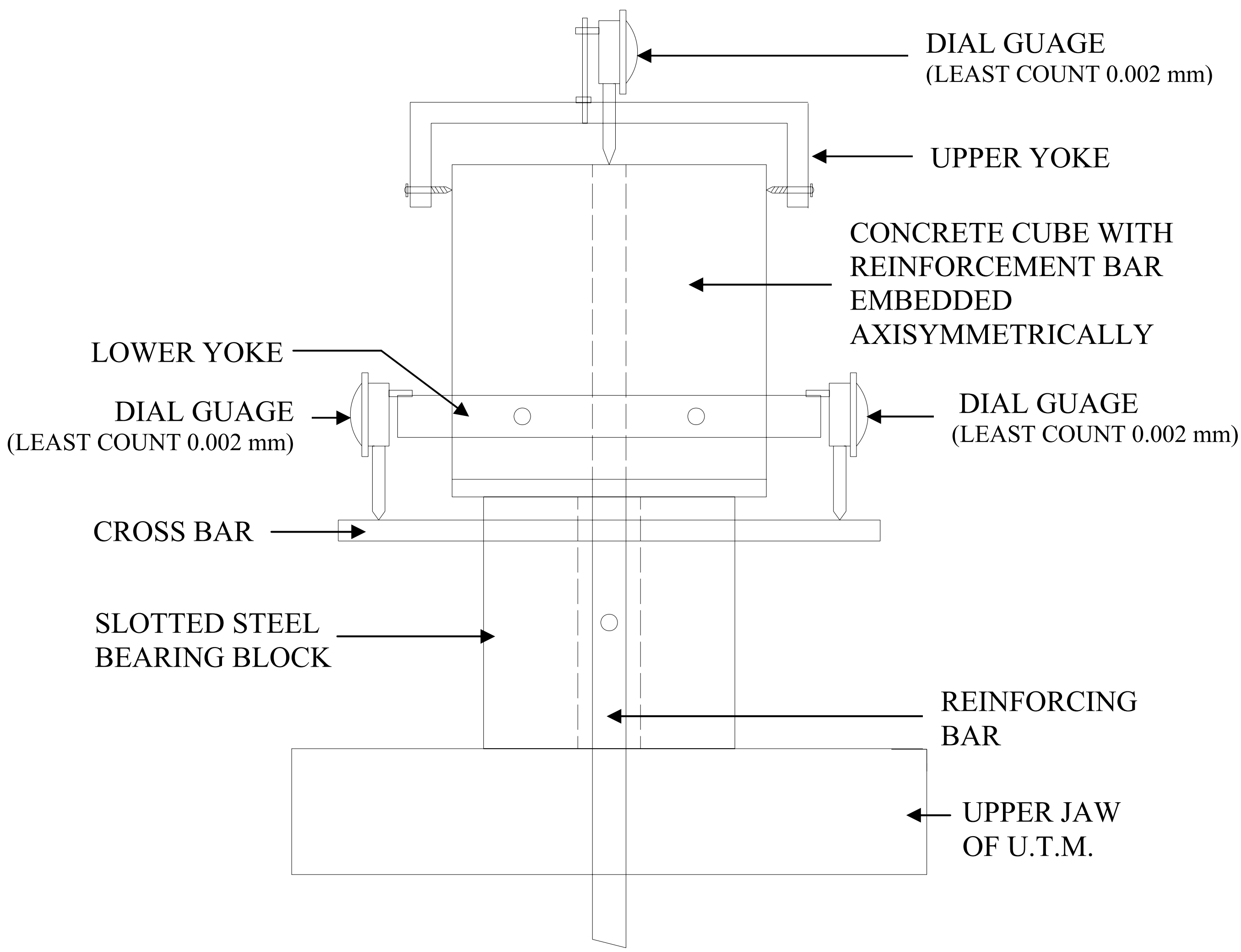


FIGURE 7.3 APPARATUS FABRICATED FOR PULL-OUT TEST

The apparatus fabricated is almost similar to that shown in IS: 2770 (Part I) - 1967. The load is applied by a Universal Testing Machine (U.T.M.) of 40 T capacity.

7.2 TEST PROCEDURE

- The loading rate is kept below 2250 kg/min as per the specification of IS: 2770 (Part I) -1967.
- The movement between the reinforcing bar and the concrete cube, as indicated by the dial micrometers is read at each 0.002 mm interval (which is the least count of the mounted dial gauges).
- The readings of the dial micrometers are recorded at both the loaded and unloaded end of the specimen.
- The loadings is continued and the readings of the micrometer dial gauge is recorded until :
  - The yield point of the reinforcing bar is reached.
  - The enclosing of the concrete has failed
  - A minimum slippage of 2.5 mm has occurred at the loaded end.
- For the purpose of comparison of bond resistance of deformed bars and plain bar, the comparison of the bond strengths is made on the basis of the average bond stress calculated from the loads at a measured slip of 0.025 mm at free end. It is recommended that when comparing plain and deformed bars, the complete load slip curves of both should also be plotted.
- The following details shall be recorded:
  - The crushing strength of the concrete cube at an age corresponding to the age of the specimen at the time of making the pull-out test.
  - The age of the specimen
  - The load at a slip of 0.025 mm at the free end
  - The load at a slip of 0.25 mm at the free end
  - The slips at free and loaded ends at regular intervals of loadings
  - The maximum load at failure and the type of failure.

7.3 WORK PLANNED

The work planned for the project can be divided into two aspects:

1. Experimental Study

2. Analytical Study

7.3.1 EXPERIMENTAL STUDY

For carrying out this study there were total 585 specimens that were cast. There were 3 different types of concrete that was cast:

- Normal mix
- Mix with Super-plasticizer
- Mix with Fibres and Super-plasticizer

For each of these mixes there were five different grades of concrete cast as follows:

- M20
- M25
- M30
- M35
- M40

There were 3 different types of reinforcement bars taken for study. They were:

- Mild Steel
- TMT
- TMT coated bars

Also, 3 different diameters of each of there bars were taken for study

- 12 mm
- 16 mm
- 20 mm

For getting the compressive strength 6 cubes of 150mm x 150mm x 150 mm were cast for each variety of mix. For getting flexural and split tensile strength three beams and three cylinders were cast of 100 mm x 100 mm x 500 mm and 150 mm x 300 mm respectively for each variety of mix. TABLE 7.1 below shows the total amount of each type of specimen that was cast.

Table 7.1 TOTAL SPECIMENS FOR PULL-OUT TEST

SR.NO.	NOTATION	GRADE OF CONCRETE	SPECIMENS FOR PULL-OUT EST (nos.)	CUBES (nos.)	CYLINDERS (nos.)	BEAMS (nos.)
1	N^{+}	M 20	27	6	3	3
2	N	M 25	27	6	3	3
3	N	M 30	27	6	3	3
4	N	M 35	27	6	3	3
5	N	M 40	27	6	3	3
6	$N+S^{++}$	M 20	27	6	3	3
7	N+S	M 25	27	6	3	3
8	N+S	M 30	27	6	3	3
9	N+S	M 35	27	6	3	3
10	N+S	M 40	27	6	3	3
11	$N+S+F^{+++}$	M 20	27	6	3	3
12	N+S+F	M 25	27	6	3	3
13	N+S+F	M 30	27	6	3	3
14	N+S+F	M 35	27	6	3	3
15	N+S+F	M 40	27	6	3	3

N^{+} - Normal Mix

$N+S^{++}$ - Mix with Super-plasticizer,

$N+S+F^{+++}$ - Mix with Fibres and Super-plasticizer

7.3.2 ANALYTICAL STUDY

For carrying the analytical study SAP 2000 software was used. Models of Pull-out specimen were prepared of different grade of concrete mix and the yield stress of steel was assigned according to the values given in TABLE 4.2 in CHAPTER 4. The concrete cube was modeled as a solid element and meshing of the solid was carried out to get more accurate results. The reinforcement bar was modeled as a line element. The concrete cube size was given similar to that used for carrying out the pull-out testing i.e. 150 mm x 150 mm x 150 mm. The pull out force was assigned from the results of the experimental study. And the stress pattern was studied. Also, the bond stress found from the experimental study and analytical study was compared. The results of the same are explained in CHAPTER 8.

8. RESULTS AND OBSERVATIONS

8.1 INTRODUCTION

The entire experiment was done with an aim to study the bond strength of various concrete when used as RCC member with different steel. The codal provisions of IS: 2770 (Part 1) – 1967 was followed to perform the experiment. As stated earlier, total of 585 specimens were tested, out of which 405 specimens were Pull-Out specimens and the following readings were recorded

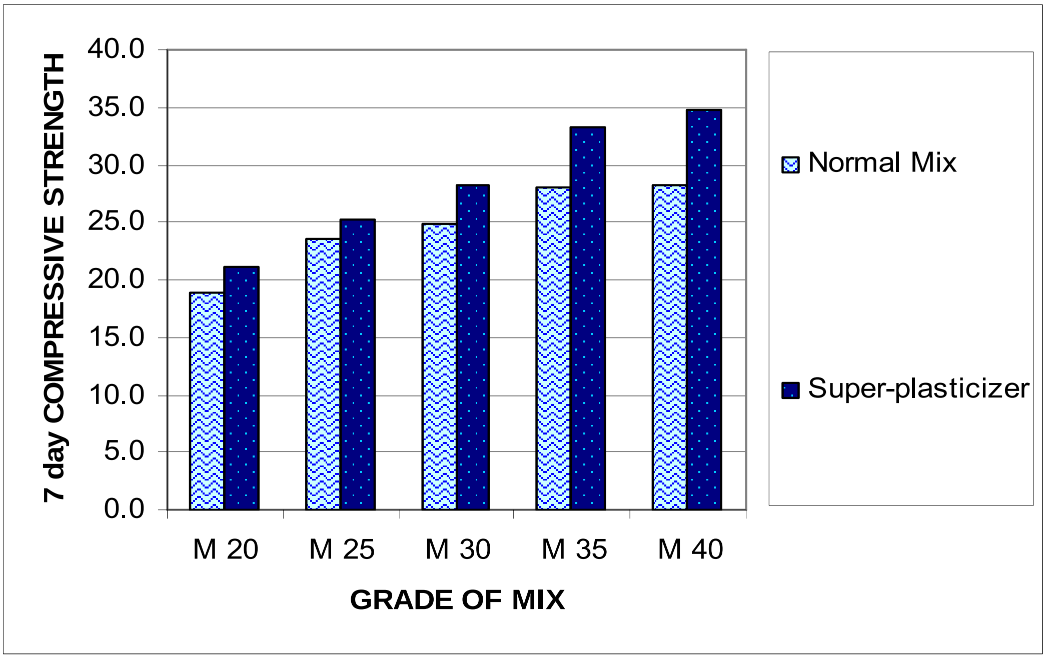
1. Load- Slip curves for all pull-out specimens
2. Pull-Out loads at a slip of 0.025 mm and maximum pull at the time of failure.
3. Type of failure observed.

The summary of the results of Pull-Out test carried out on 405 specimens is given in ANNEX D.2. Also there were 180 samples without reinforcement that were cast to get the properties of concrete. Out of these 180 samples, 90 samples were cubes and were tested on a Compression Testing machine and the results of the same are tabulated in ANNEX D.1. Remaining 90 samples were tested on Universal Testing Machine. Out of these 90 samples, 45 were beam specimens for getting the value of flexural strength and 45 were cylinders tested to get the tensile strength. The results of the beam specimens and column specimens tested are tabulated in ANNEX D.1.

8.2 Physical results

The results of the tests carried out for studying the mechanical properties of mixes designed are presented in ANNEX D.1. Following are the observations made form the results obtained:

1. Addition of Super-plasticizer with decreased quantity of cement and lesser quantity if water content, has resulted in satisfactory results in terms of similar workability and strength achieved, as that of normal mix. Thus, results in saving of cement. This is shown in FIGURE 8.1. Here workability is measured in terms of slump in mm.



Grade of Concrete	**M20**	**M25**	**M30**	**M35**	**M40**
Dosage of cement (Super-plasticizer)	275	290	325	375	385
Dosage of cement (Normal)	300	315	350	390	400
Workability (Super-plasticizer)	95	90	70	60	70
Workability (Normal)	110	80	55	50	50

FIGURE 8.1 COMPRESSIVE STRENGTH

2. Addition of Fibres along with Super-plasticizer though had resulted in slight decrease in workability, but has performed better showing higher values for tensile strength, that is going to aid the bond stress values on positive side.

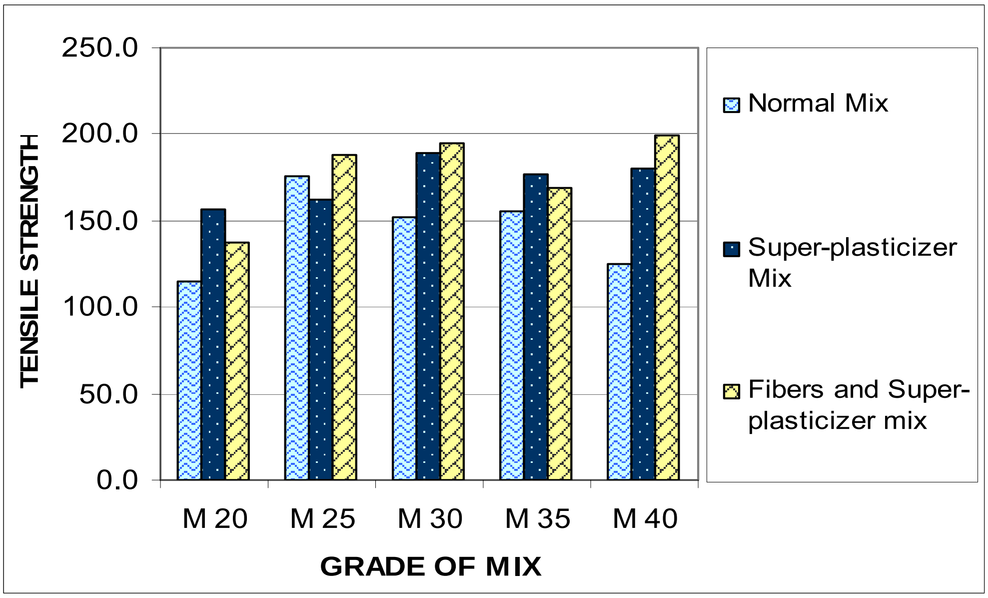


FIGURE 8.2 TENSILE STRENGTH

8.3 LOAD - SLIP CURVES

The Load – slip curves of the pull-out samples were plotted. The load-slip curves of same diameter of bar and same type of steel were compared with different types of mixes which are as follows:

1. Normal mix
2. Mix with Super-plasticizer
3. Mix with Super-plasticizer and Fibres

The Load-Slip curves plotted here shows the load in Kilo Newton (kN) versus the slip in millimeter (mm). The readings recorded from the dial gauge micrometers are in division so to convert it into slip in mm the readings are to be multiplied by 0.002. A few of the load-slip curves are presented herewith to show the general behavior of all concrete and steel.

In all the load-slips curves the following are the notations used:

- F denotes mix with Fibres and Super-plasticizer
- S denotes mix with Super-plasticizer
- N denotes normal mix
- MS denotes Mild Steel
- TMT denotes Thermo-Mechanically Treated bars
- TC denoted TMT coated bars

8.3.1 LOAD-SLIP CURVES OF 12 mm DIAMETER BARS

The load-slip curve shown in FIGURE 8.3, is for 12mm diameter Mild Steel bars anchored into M35 grade concrete cube. The load-slip curve shows that:

- The mix containing fibers is able to take the greatest load about 16 % more than Normal mix in this case.
- Mix with Super-plasticizer is able to take load greater than normal mix but less than mix with fibres and Super-plasticizer, about 7 % more than Normal mix.
- Normal mix is able to take the least load at a specified slip of 0.025mm at the free end.

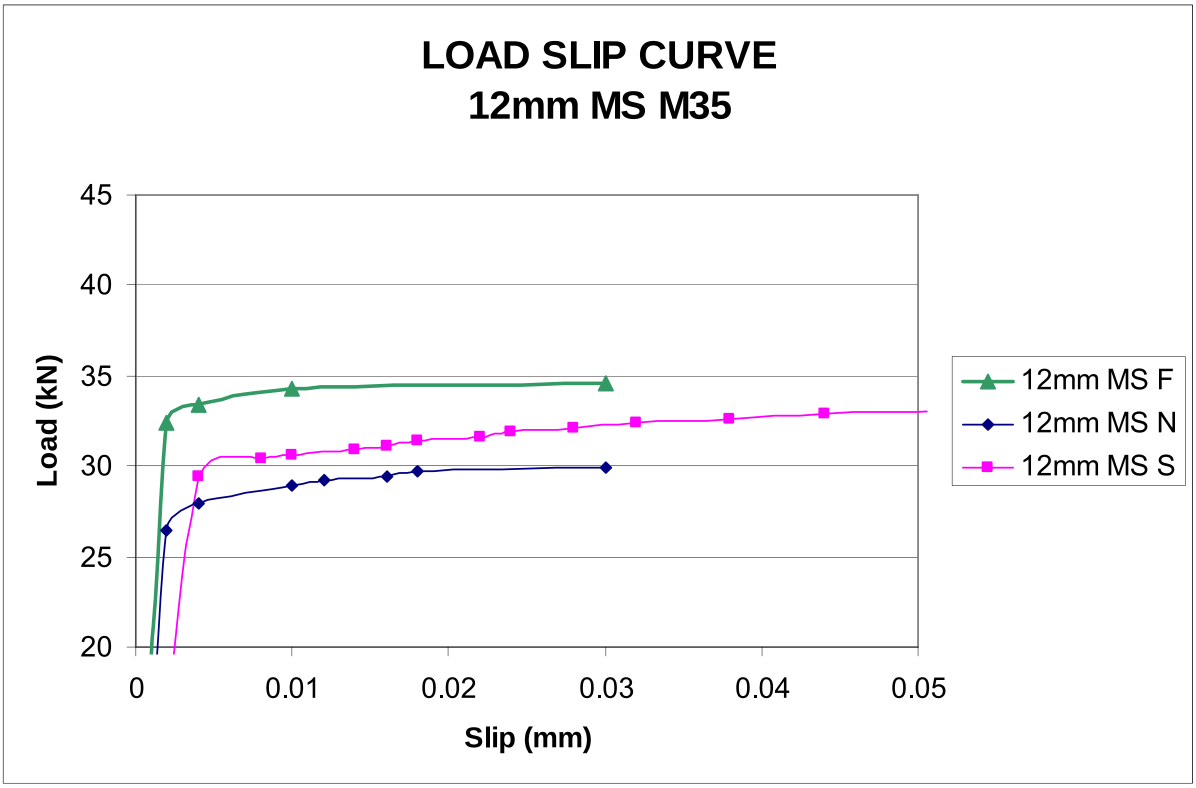


FIGURE 8.3 LOAD-SLIP CURVES OF 12mm MILD STEEL BARS ANCHORED IN M35 GRADE OF CONCRETE CUBE

The load-slip curves of TMT COATED bars are shown in FIGURE 8.4. Here also it is observed that:

- TMT COATED bars with the mix of Fibres and Super-plasticizer is able to take the greatest load about 34 % more than Normal mix in this case.
- Mix with Super-plasticizer develops lesser bond strength then the mix with Fibres and Super-plasticizer about 12 % more than Normal mix in here.
- Normal mix is able to take the least load at specified slip of 0.025 mm at the free end of the specimen.

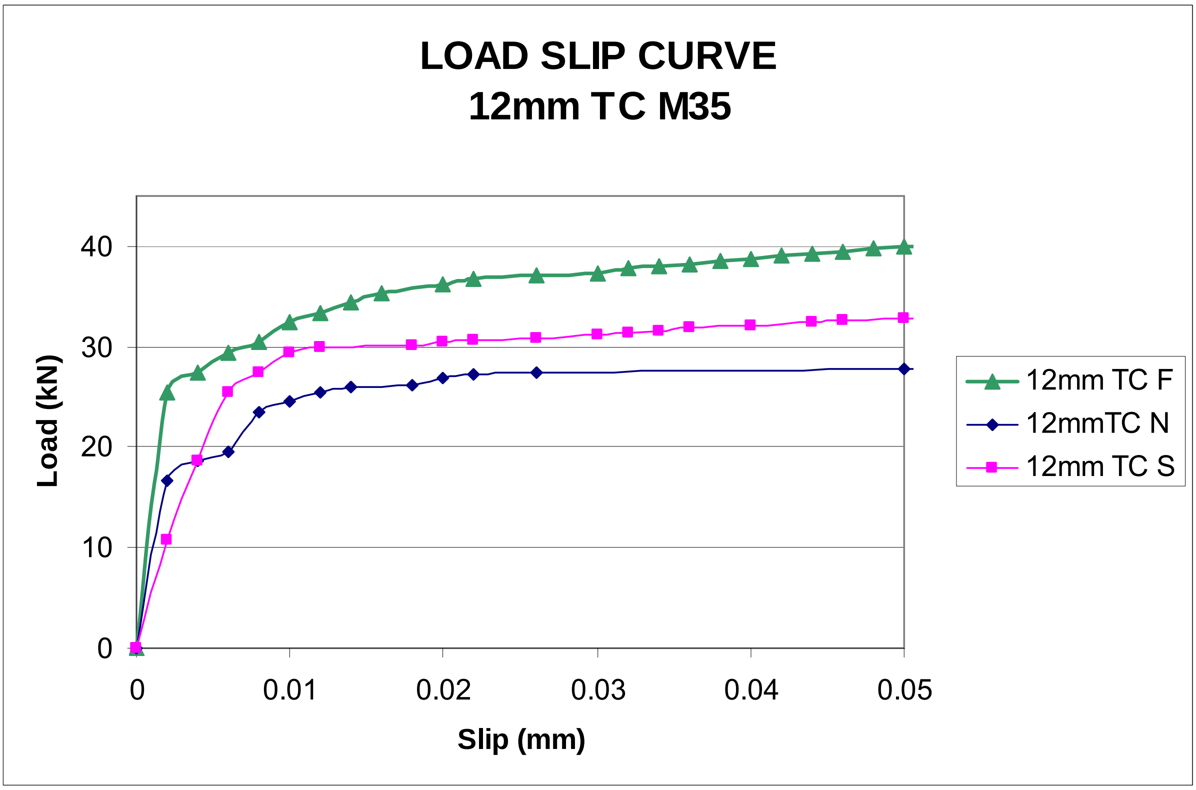


FIGURE 8.4 LOAD-SLIP CURVES OF 12mm TMT COATED BARS ANCHORED IN M35 GRADE OF CONCRETE CUBE

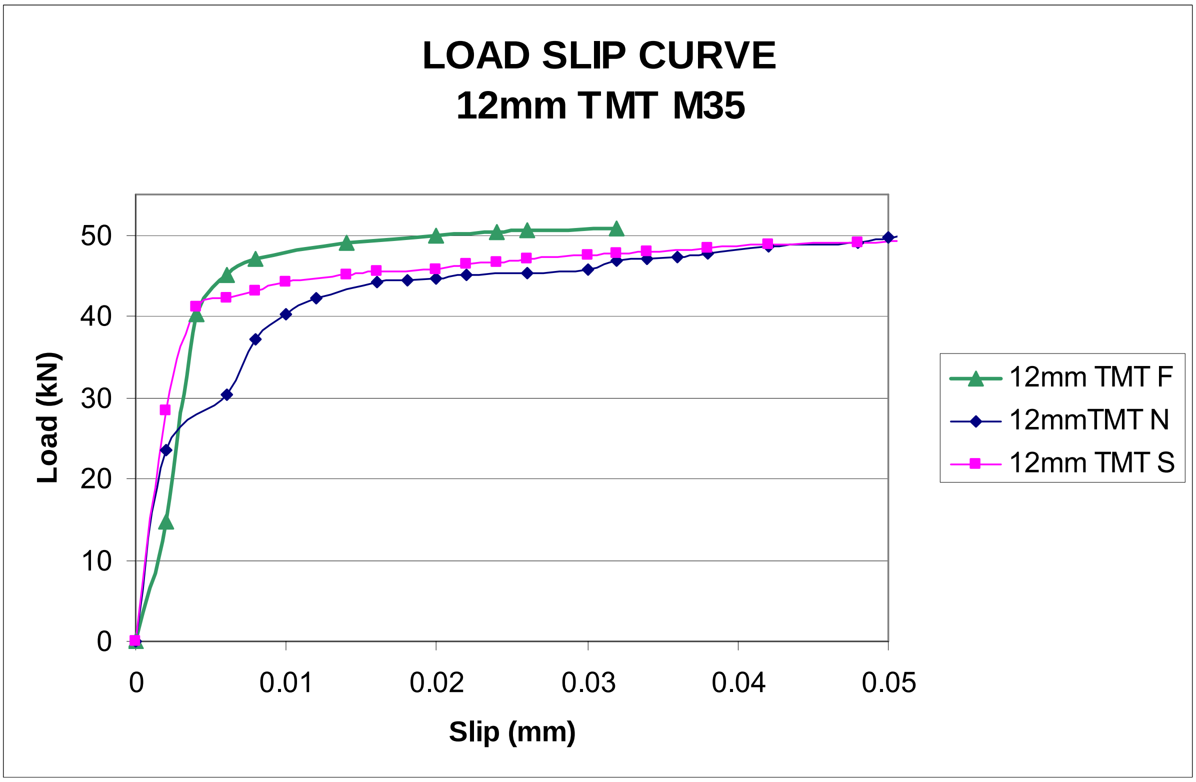


FIGURE 8.5 LOAD-SLIP CURVES OF 12mm TMT BARS ANCHORED IN M35 GRADE OF CONCRETE CUBE.

Load-Slip Curve of TMT bars are as shown in FIGURE 8.5. It is observed that:

- The mix containing Fibres and Super-plasticizer is able to take highest load as it is observed in the Mild Steel bars and TMT Coated bars. They are able to take about 11 % more than Normal mix in this case.
- The mix with Super-plasticizer is able to take a bit lesser load than the mix with Fibres and Super-plasticizer but about 4 % more than Normal mix in here.
- Normal mix is able to take lesser load as compared to the other two mixes at the specified slip of 0.025 mm at the free end of the specimen.

8.3.2 LOAD-SLIP CURVES OF 16 mm DIAMETER BARS

The Load-Slip curve is plotted in the same way as done for 12 mm diameter bars. The graph shown in FIGURE 8.6, 8.7 and 8.8 are the load-slip curves of 16 mm diameter bars for M40 grade of concrete.

The FIGURE 8.6 consists of Load-Slip curve of 16 mm diameter Mild Steel bars of different mix of grade M40.

From the graph it is observed that:

- The bars with mix containing Fibres and Super-plasticizer are able to take more load than the other two mixes at a specified slip of 0.025 mm. The load taken by this is about 84 % greater than the load taken by the Normal mix.
- The bars with Super-plasticizer are able to take about 28 % more load than the Normal mix.
- The bars with Normal mix take the least load.

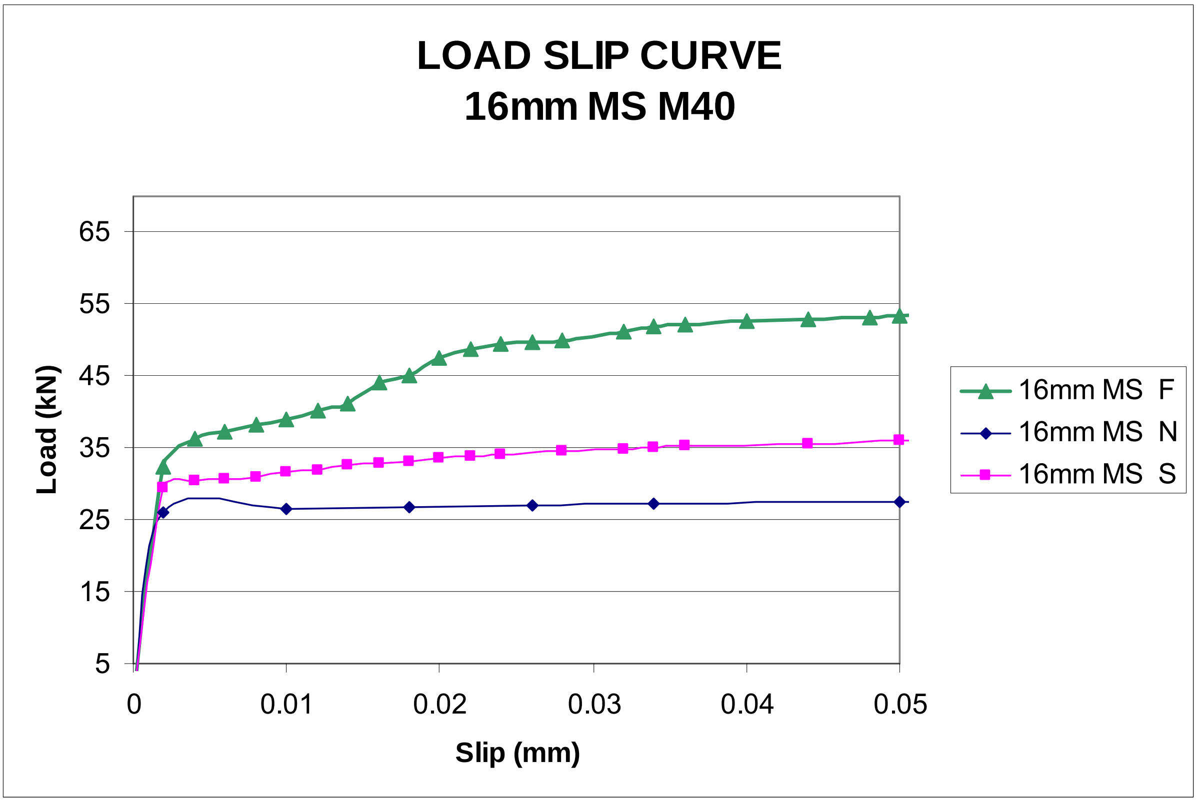


FIGURE 8.6 LOAD-SLIP CURVES OF 16 mm MILD STEEL BARS ANCHORED IN M40 GRADE OF CONCRETE CUBE

FIGURE 8.7 shows the Load-Slip curves of 16 mm TMT COATED bars of grade M40. Here also it is observed that:

- The mix with Fibres and super-plasticizer is able to take greater loads than the other two mixes i.e. about 61 % more load than the other two mixes.
- The mix with Super-plasticizer is also able to take about 40 % greater load than the Normal mix.
- The Normal mix is able to take the least load.

FIGURE 8.8 also shows the Load-Slip curves of 16 mm TMT bars of grade M40. It is seen that the same trend is followed here also i.e. the bars with the mix consisting of Fibres and Super-plasticizer shows greater bond of about 28 % than the other two mixes.

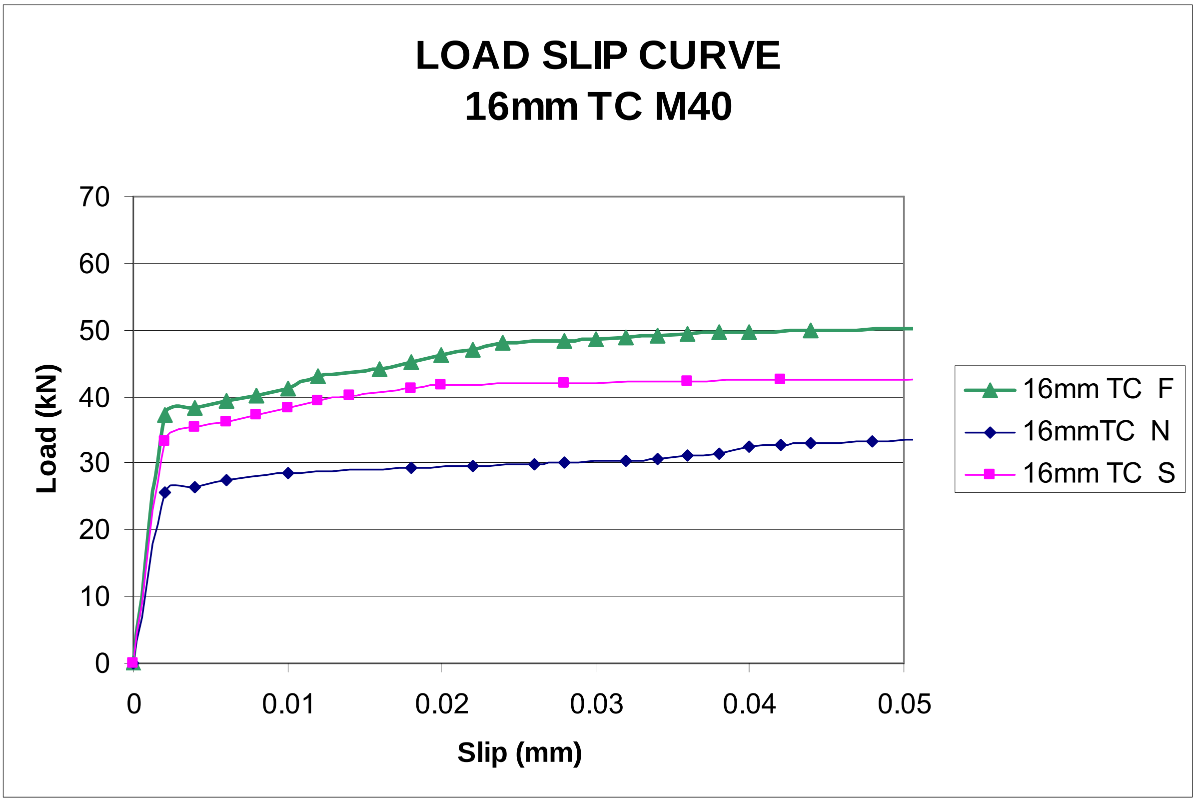


FIGURE 8.7 LOAD-SLIP CURVES OF 16 mm TMT COATED BARS OF GRADE M40

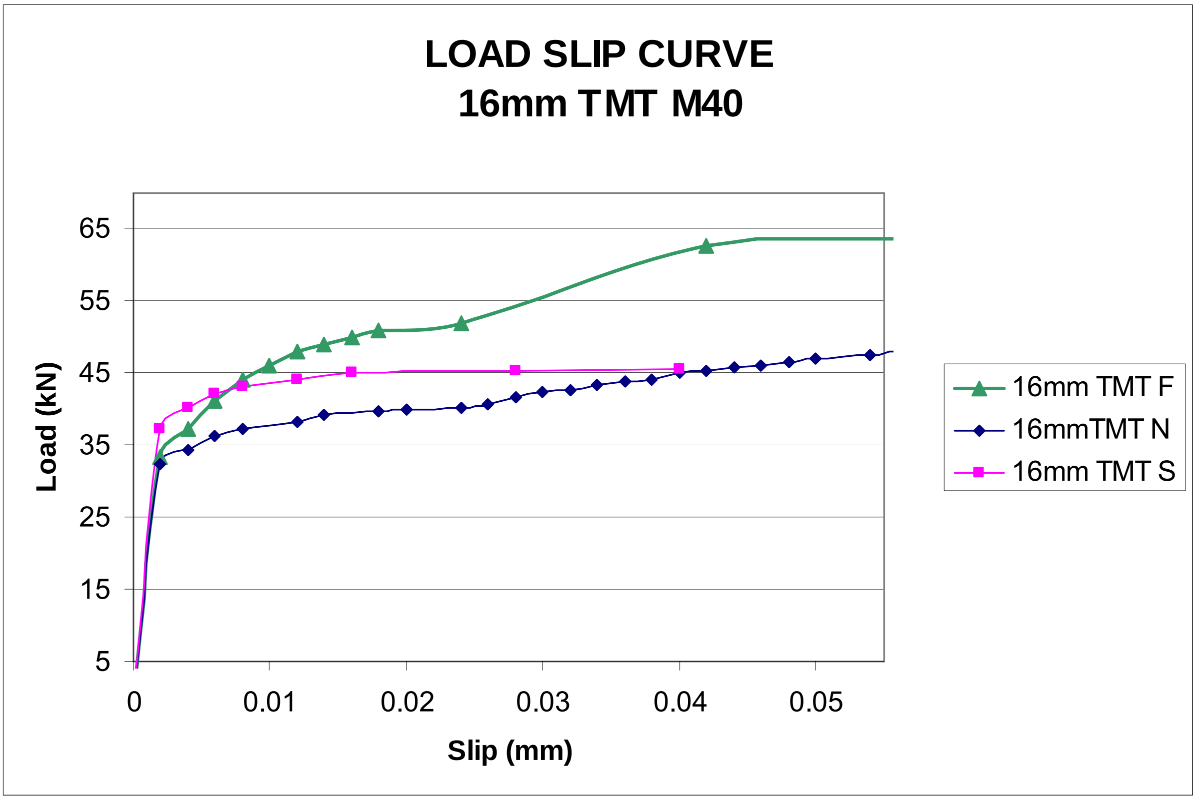


FIGURE 8.8 LOAD-SLIP CURVES OF 16 mm TMT BARS OF GRADE M40

8.3.3 LOAD-SLIP CURVES OF 20 mm DIAMETER BARS:-

FIGURE 8.9, 8.10 and 8.11 shows the Load-Slip curves of the 20 mm diameter bars of grade M40.

Figure 8.9 shows the Load-slip curve of 20 mm diameter Mild Steel bar of all the mixes. From the graph it is observed that:

- The mix with Fibres and Super-plasticizer is able to take about 72 % greater loads than the mix with Super-plasticizer and Normal mix at a specified slip of 0.025 mm at the free end.
- Mix with Super-plasticizer was able to take 53 % greater load than the Normal mix.

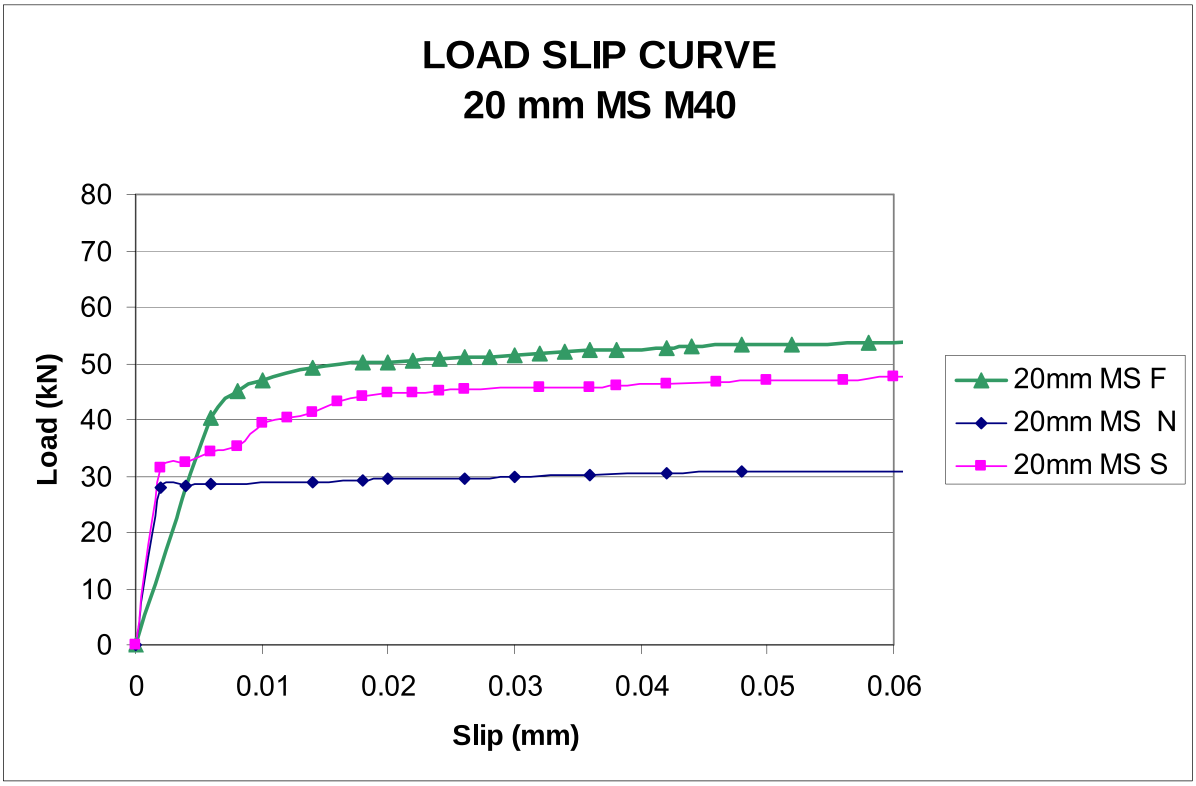


FIGURE 8.9 LOAD-SLIP CURVES OF 20 mm MILD STEEL BARS OF GRADE M40

FIGURE 8.10 shows the Load-Slip curves of 20 mm TMT COATED bars of M40 grade. The same trend is also followed here as in the case of 20 mm Mild Steel bars. The mix with Fibres and Super-plasticizer are able to tale 75 % more load than Normal mix and the mix with only Super-plasticizer are able to take 45 % more load than the Normal mix.

FIGURE 8.11 presents the Load-Slip curves of 20 mm TMT bars of M40 grade and here also it is observed that:

- The bars with mix containing Fibres and Super-plasticizer are able to take 22 % greater loads than the mix with Super-plasticizer and Normal mix.
- The mix with Super-plasticizer are able to take 6% more load than Normal mix at the specified slip of 0.025 mm at the free end of the specimen.
- Here also it is observed that the Normal mix is able to take the least load as seen all the previous graphs.

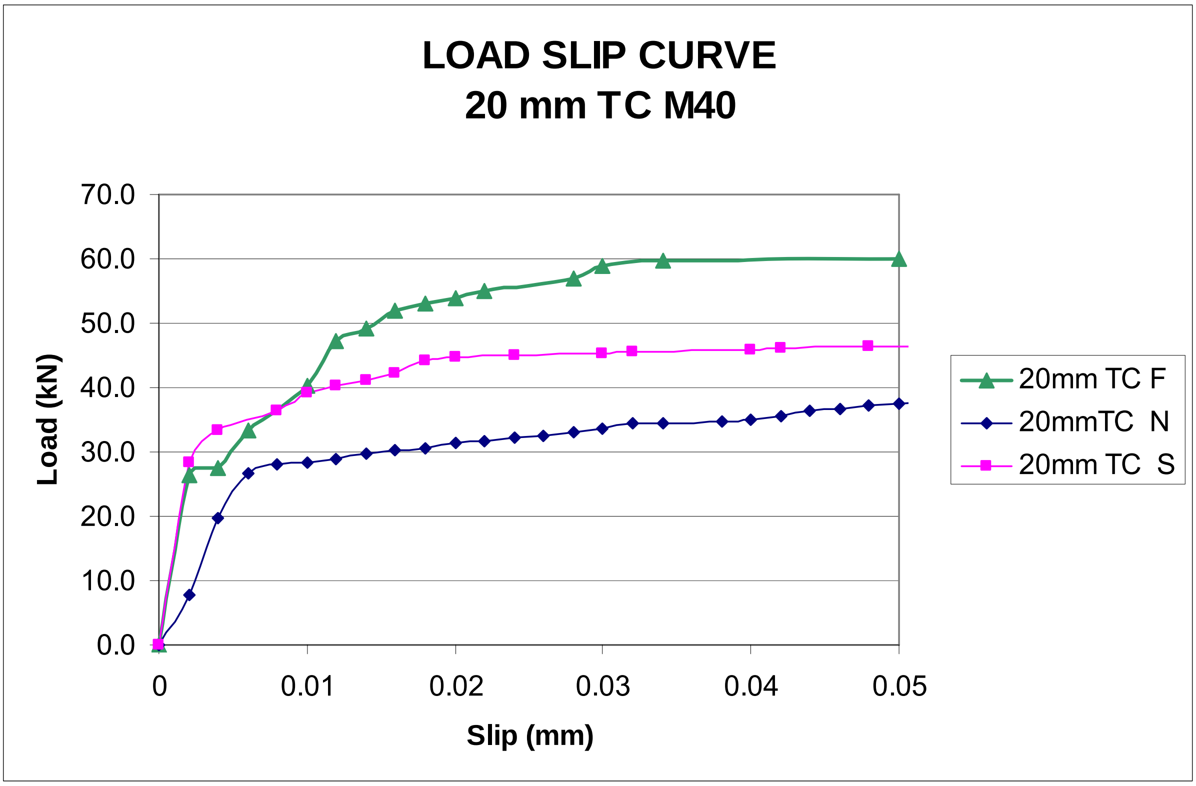


FIGURE 8.10 LOAD-SLIP CURVES OF 20 mm TMT COATED BARS OF GRADE M40

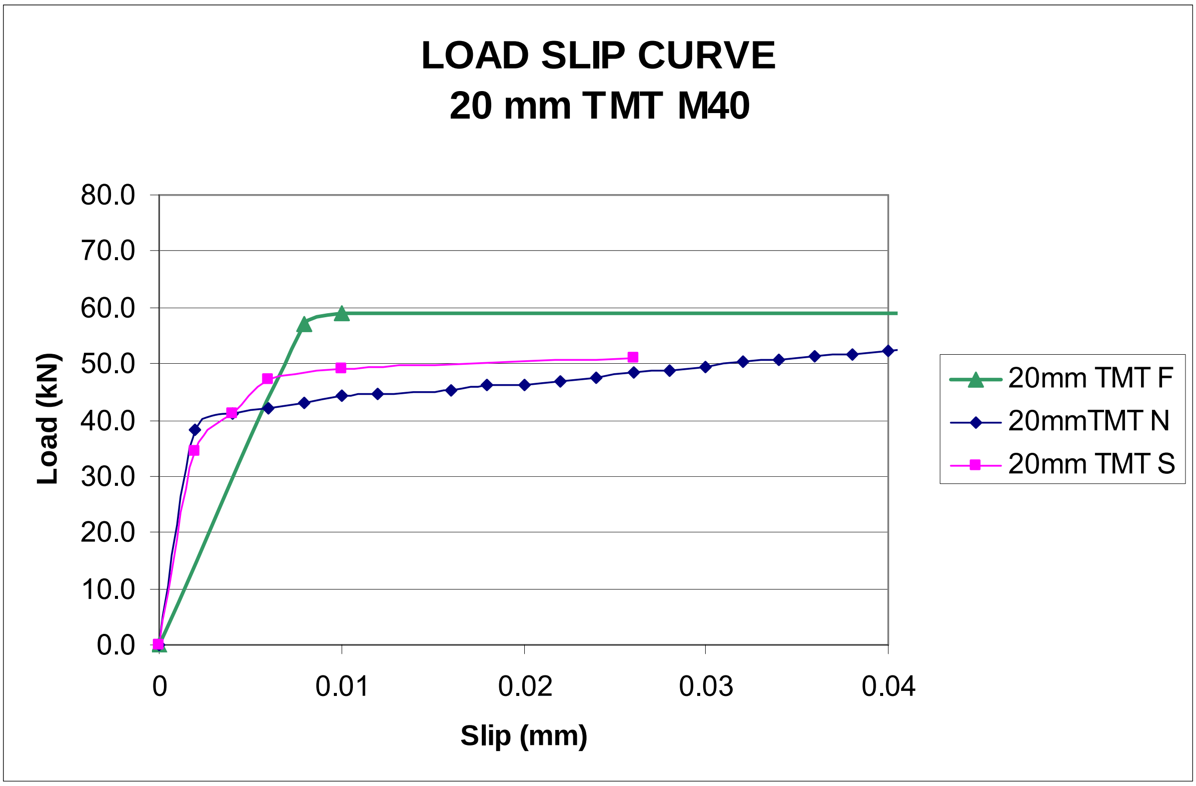


FIGURE 8.11 LOAD-SLIP CURVES OF 20 mm TMT BARS OF GRADE M40

From all the load slip curves general observation that can be made is that:

- Mix consisting of Fibres shows greater bond strength than the one with Super-plasticizer and Normal mix.

  The reason for this is that the presence of fibres prevents cracks to expand which occur during loading. It embraces the concrete and hence delays its failure.

- The mix with Super-plasticizer shows increase in bond strength than the Normal mix.

  This may be due to use of Super-plasticizer, dense, close textured, durable concrete is produced and also the dispersion of cement particles is greatly improved which may result in better bond strength.

- It is also observed that the pattern of the curve remains almost similar for all the diameter of bar and for all the type of concrete mixes that were cast.

8.4 COMPARISON OF BOND STRENGTH OF MILD STEEL, TMT AND TMT COATED BARS

To study the effect of variation in bond strength when using Mild steel bars, TMT bars and TMT Coated bars graphs were prepared. The graphs were prepared with X-axis showing the variation in the grade of the mix and Y-axis representing the bond strength.

FIGURE 8.12 shows the variation in bond strength with different grade of mix while using three different types of steel bars namely

- Mild steel bars
- TMT bars
- TMT Coated bars

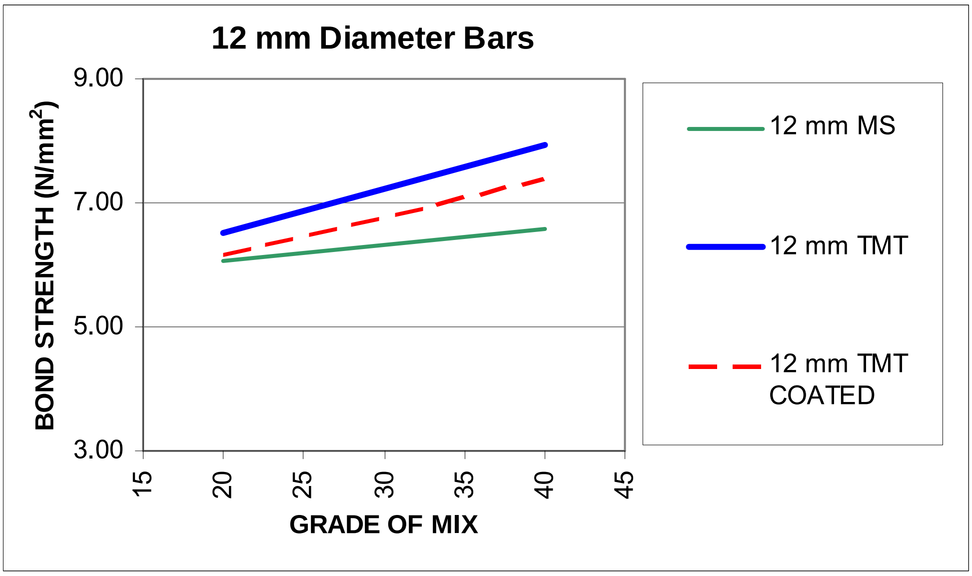


FIGURE 8.12 VARIATIONS IN BOND STRENGTH FOR 12 mm DIAMETER BAR AND NORMAL MIX

It is observed from the graph in FIGURE 8.12 that the:

- Mild Steel bars possess the least bond strength.
- TMT Coated bars have a lesser bond strength when compared to TMT bars.
- TMT bars provide greater bond strength than the other two bars.
- Also it is observed from the graph that for all the type of steel bond strength increases with the increase in the grade of mix.

Such Graphs were also prepared for 16mm diameter bars and 20 mm diameter bars and are shown in FIGURE 8.13 and FIGURE 8.14 respectively.

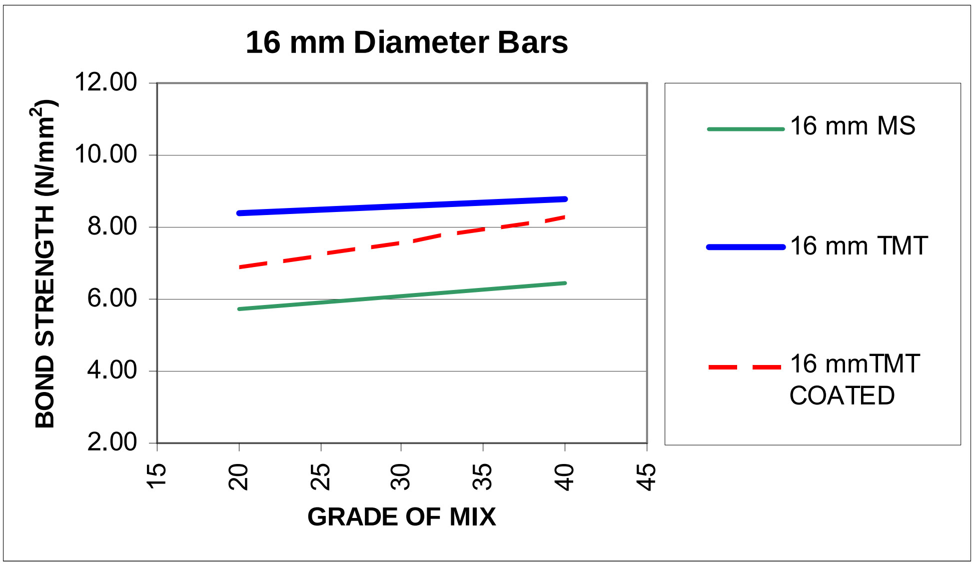


FIGURE 8.13 VARIATIONS IN BOND STRENGTH FOR 16 mm DIAMETER BAR AND NORMAL MIX.

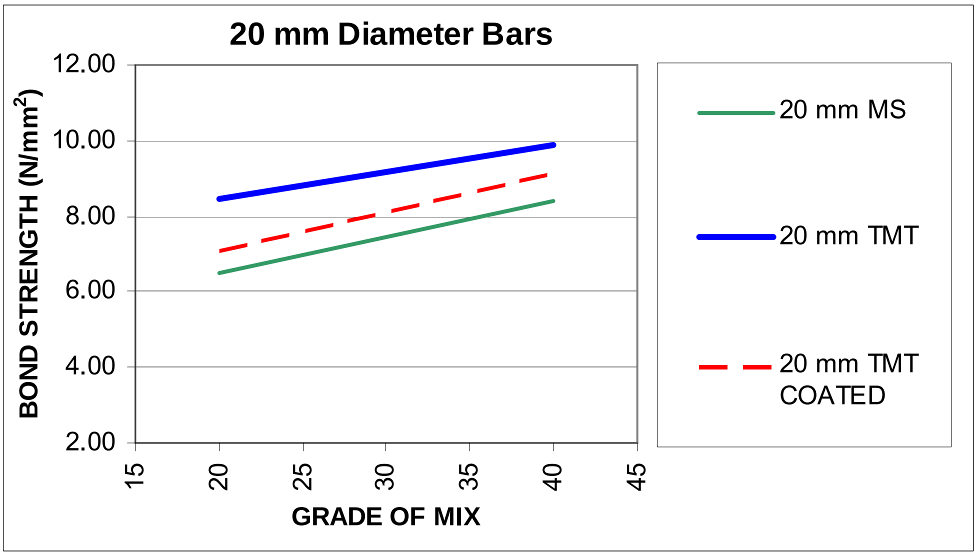


FIGURE 8.14 VARIATIONS IN BOND STRENGTH FOR 20 mm DIAMETER BAR AND NORMAL MIX.

From the graph in FIGURE 8.13 it is observed that:

- The bond strength of TMT bars is the greatest followed by TMT COATED bars and Mild Steel bars which are having the least bond strength.

- It is observed from the trend lines that the bond strength increases with the increase in grade of the mix.

From the graph in FIGURE 8.14 similar kind of observation can be drawn that:

- TMT bars shows greatest bond strength
- Mild Steel bars shows the least bond strength
- The bond strength increases with the increase in the grade of the mix.

To study the variation of bond strength with the grade of concrete and the effect of different type of steel in detail, graphs for the other two mixes were also prepared. The graphs for:

- 12 mm
- 16 mm
- 20 mm

diameter bars in mix containing Super-plasticizer are shown in FIGURE 8.15, FIGURE 8.16 and FIGURE 8.17 respectively.

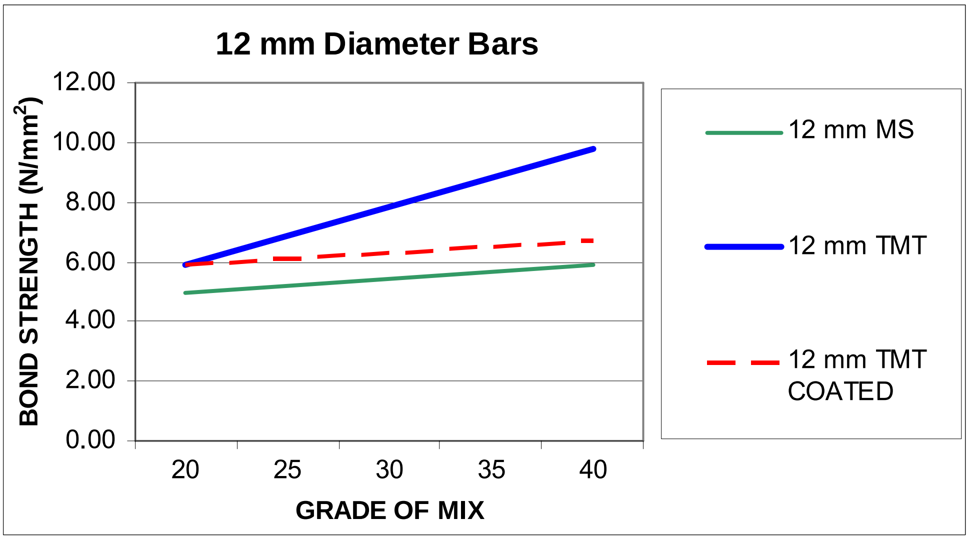


FIGURE 8.15 VARIATIONS IN BOND STRENGTH FOR 12 mm DIAMETER BAR AND MIX WITH SUPER-PLASTICIZER.

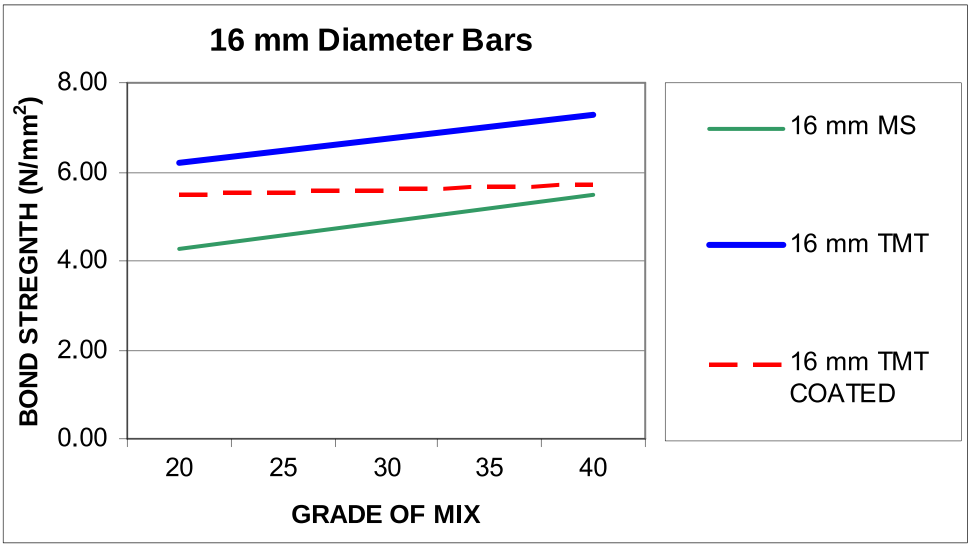


FIGURE 8.16 VARIATIONS IN BOND STRENGTH FOR 16 mm DIAMETER BAR AND MIX WITH SUPER-PLASTICIZER.

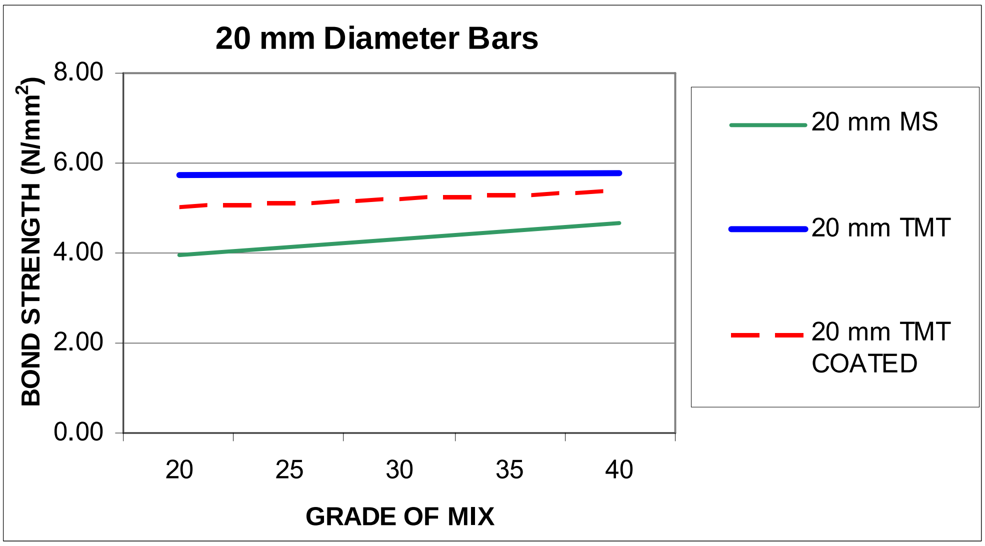


FIGURE 8.17 VARIATIONS IN BOND STRENGTH FOR 20 mm DIAMETER BAR AND MIX WITH SUPER-PLASTICIZER.

The graph in FIGURE 8.15 shows the variation in bond strength with the change in grade of the mix containing Super-plasticizer of 12 mm diameter bars. Here also it is observed that:

- TMT bars show greatest bond strength followed by TMT COATED bars followed by Mild Steel bars.
- With the increase in grade of concrete the bond strength also increases.

Graph in Figure 8.16 for 16 mm diameter bars and graph in FIGURE 8.17 for 20 mm diameter bars also shows the same behavior as that of 12 mm diameter bars (FIGURE 8.13) and similar observations can be made.

Graph in FIGURE 8.18, FIGURE 8.19 and FIGURE 8.20 shows the variation of bond strength with grade for the mix containing Fibres and Super-plasticizer.

Graph in FIGURE 8.18 shows the variation of bond strength with the grade of mix for 12 mm diameter bars.

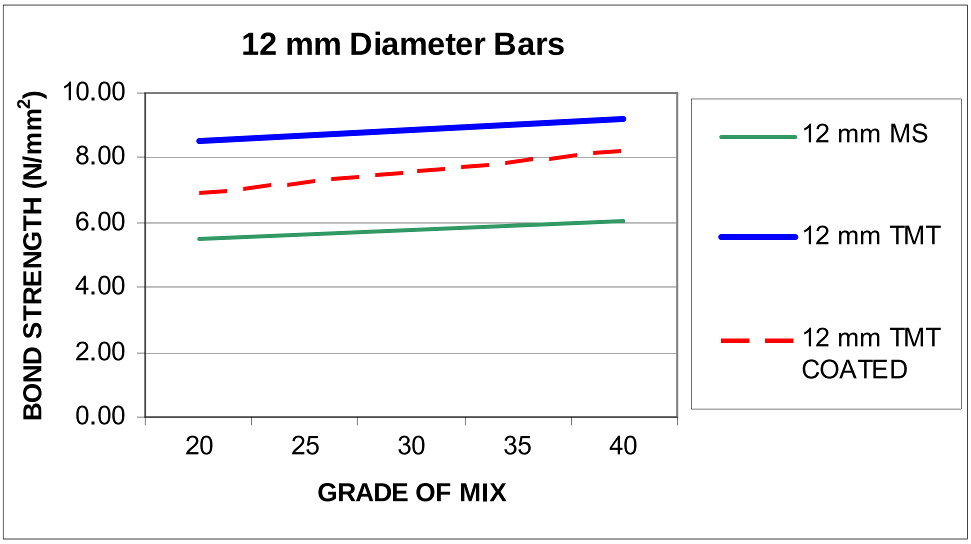


FIGURE 8.18 VARIATIONS IN BOND STRENGTH FOR 12 mm DIAMETER BAR AND MIX WITH FIBRES AND SUPER-PLASTICIZER.

Graph in FIGURE 8.18 also shows that:

- Bond strength of TMT bar is higher than the TMT COATED BARS and Mild steel bars showing the least bond strength among the three.
- Also it is seen from the trend line that the bond strength increases with the increase in grade of the mix.

Similar observation can also be made in the graph of FIGURE 8.19 showing variation in bond strength with the increase in grade for 16 mm diameter bars and in the graph of FIGURE 8.20 for 20 mm diameter bars.

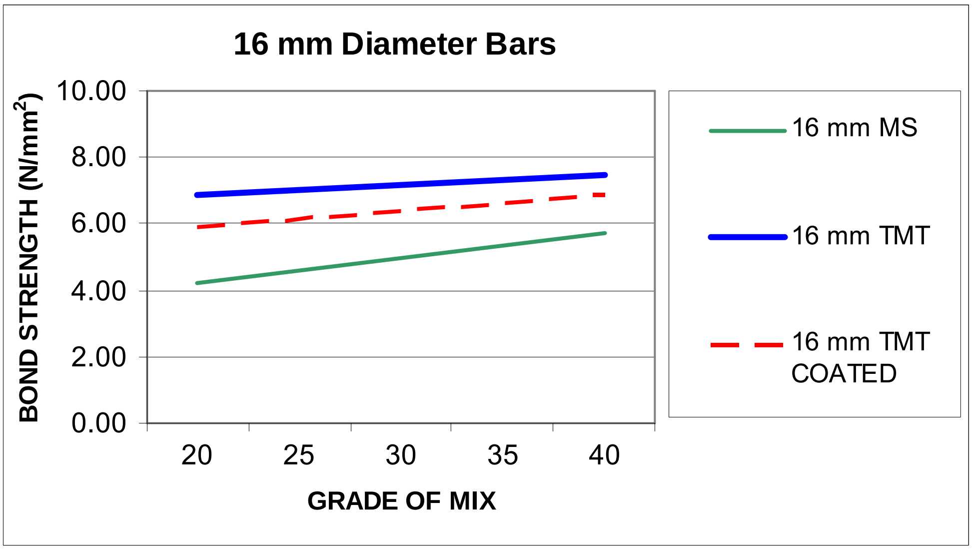


FIGURE 8.19 VARIATIONS IN BOND STRENGTH FOR 16 mm DIAMETER BAR AND MIX WITH FIBRES AND SUPER-PLASTICIZER.

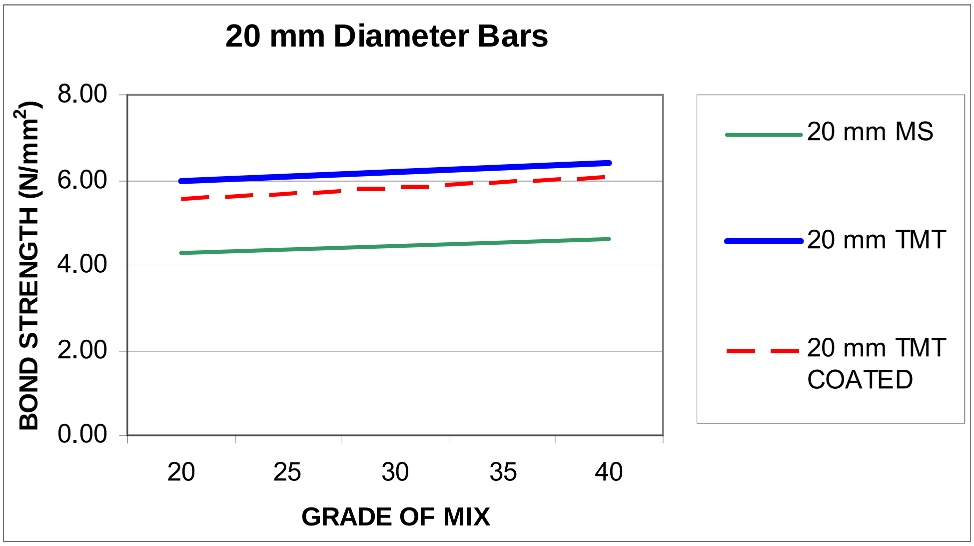


FIGURE 8.20 VARIATIONS IN BOND STRENGTH FOR 20 mm DIAMETER BAR AND MIX WITH FIBRES AND SUPER-PLASTICIZER.

From the graph shown in the FIGURE 8.12 to FIGURE 8.20 general observation that can be made is that:

- There is an increase in the bond strength with the increase in the grade of mix, about 10 % to 60 % increase when grade of concrete changes from M 20 to M 40, depending upon the type of reinforcement bar.

  As grade of mix increases the bond strength increases this is because to produce higher grade of concrete cement content is increased which being the main binding material and hence results in higher bond strength. As the cement increases the mix is able to develop greater adhesion and frictional resistance and due to which the bond strength increases with the increase in the grade of concrete as explained in CHAPTER 3.

- TMT bars show the highest bond strength when compared to the other two bars TMT Coated and Mild steel bars. And Mild steel bars show the least bond strength. TMT bars shows about 25 % to 60 % more bond strength than mild steel bars where as, TMT Coated bars shows 15 % to 35 % greater bond strength

  The reason for this is that TMT bars being deformed bars, having ribs provide mechanical resistance in addition to the adhesion and frictional resistance which help in the increasing in the bond capacity. TMT COATED bars also have the ribs but the mechanical resistance offered by these types of bars reduces due to the application of coatings which decreases the depth of ribs and hence results in less mechanical resistance than TMT bars. Bond capacity in Mild steel is only contributed by because of adhesion resistance and frictional resistance and hence its bond strength is lowest when compared with TMT Coated and TMT bars as discussed in CHAPTER 3.1.

8.5 EFFECT OF DIAMETER OF BAR ON BOND STRENGTH

To study the effect of the diameter of bar on the bond strength graphs were prepared for all the diameter of bars for all the grades of mixes and for all the type of concrete mix. Some of them are shown here to get the idea about the effect of diameter of bar on bond strength. FIGURE 8.21 shows the variation of bond strength for 12 mm diameter bars in Normal mix of grade M40.

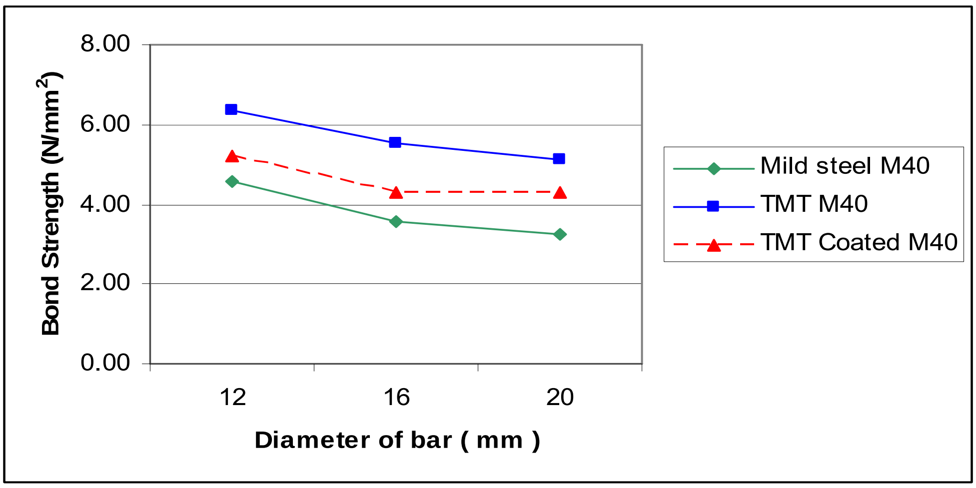


FIGURE 8.21 VARIATIONS IN BOND STRENGTH WITH DIAMETER OF REINFORCEMENT BAR (FOR M40 GRADE, NORMAL MIX)

It is observed that the bond strength reduces as the diameter of bar increases. It is seen that the bond strength reduces about 20 % to 40 % when bar diameter increases from 12 mm to 20 mm.

FIGURE 8.22 shows the variation in bond strength for Super-plasticizer mix of grade M25. Here also it is observed that the bond strength reduces with the increase in the diameter of bar. The decrease in the bond strength with the increase in the diameter of bar from 12 mm to 20 mm is found to be 26 % to 53 %.

FIGURE 8.23 shows the variation of bond strength for mix with Fibres and Super-plasticizer of grade M30 with the variation in diameter of reinforcement bar. It is observed that there is about 29 % to 35 % when the bar diameter increases from 12 mm to 20 mm.

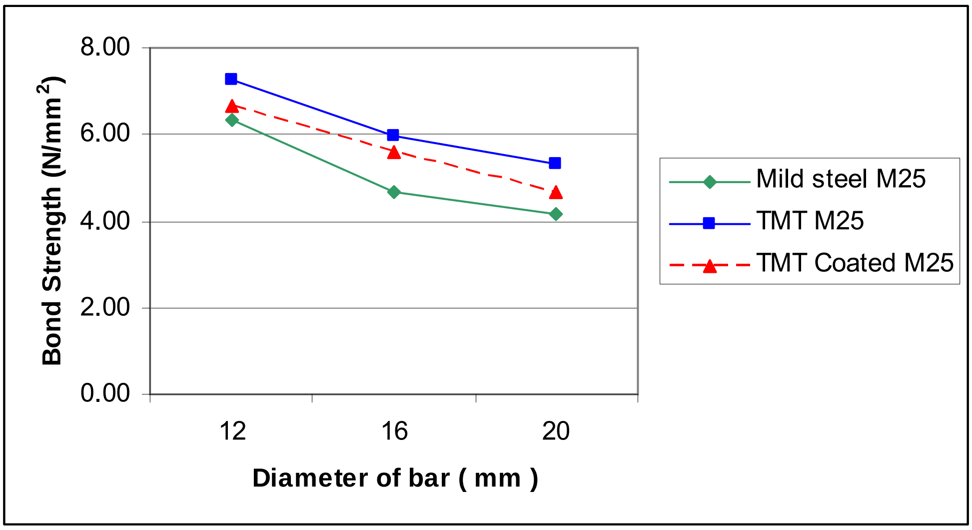


FIGURE 8.22 VARIATIONS IN BOND STRENGTH WITH DIAMETER OF REINFORCEMENT BAR (FOR M25 GRADE, MIX WITH SUPER-PLASTICIZER)

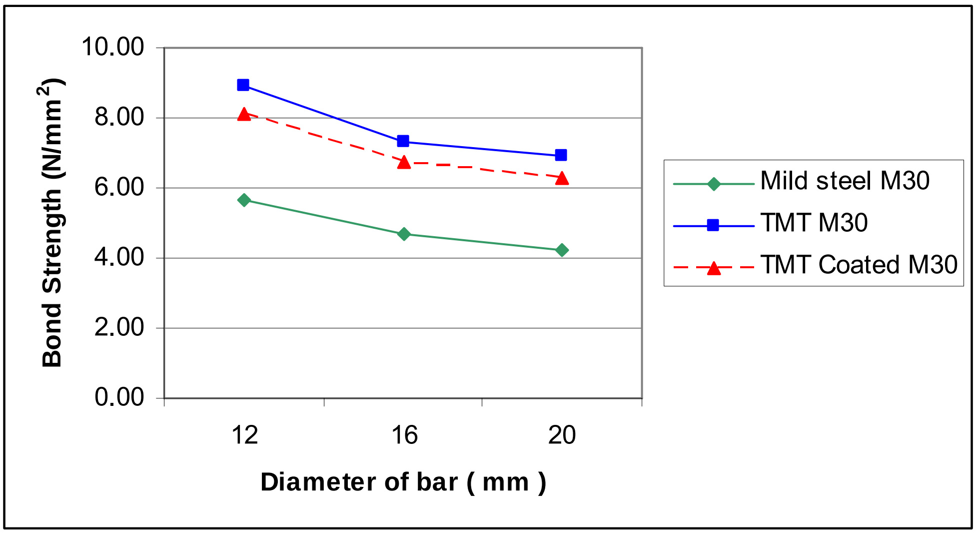


FIGURE 8.23 VARIATIONS IN BOND STRENGTH WITH DIAMETER OF REINFORCEMENT BAR (FOR M30 GRADE, MIX WITH FIBRES AND SUPER-PLASTICIZER)

The variation in the bond strength with the variation in diameter of reinforcement bar is also studied further using analytical model which is discussed in SECTION 8.8 of this CHAPTER 8.

8.6 COMPARISON OF BOND STRENGTH

The graph in FIGURE 8.24 shows the variation of bond strength for all the different type of mix and also variation with the grade of concrete. Here the values of bond strength are also compared with those mentioned in IS:456 – 2000.

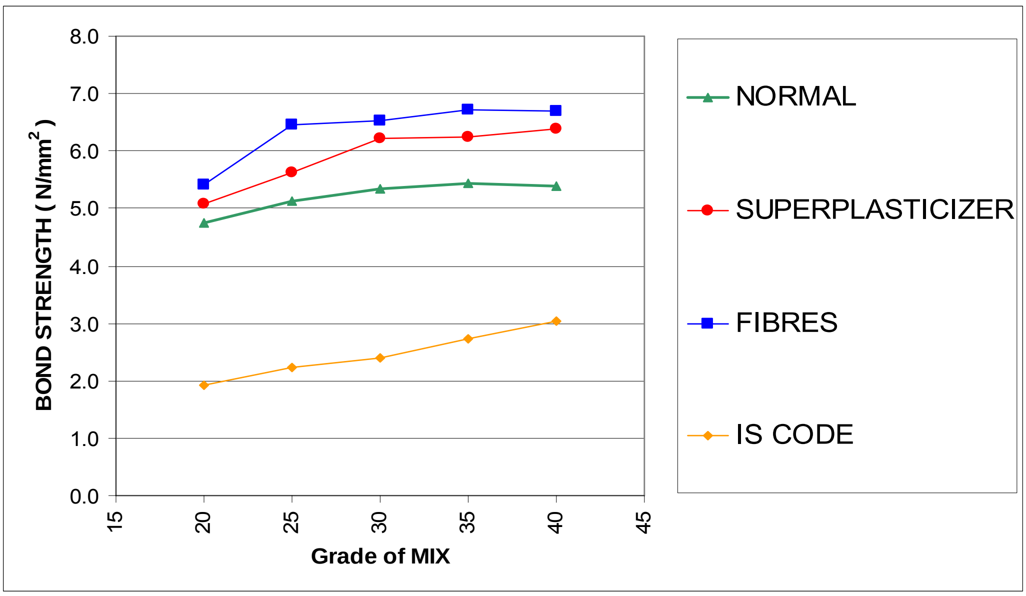


FIGURE 8.24 VARIATIONS IN BOND STRENGTH

The values of bond strength shown in FIGURE 8.24 are the average value of all the diameter of bars for a particular mix. This is done so as to compare the results of bond strength with IS code, as IS code does not have different values of bond strength for different diameter of bars.

It is observed that:

- The mix with Fibres have 15% to 26% more bond strength when compared to Normal mix and 5% to 15% higher bond strength when compared to mix with Super-plasticizer.
- Mix with Super-plasticizer shows 7% to 18% higher bond strength then Normal mix.
- Bond strength of mix with Fibres shows 120% to 190% greater bond strength compared to bond stress values given in IS:456 - 2000
- Mix with Super-plasticizer shows 110% to 165% greater bond strength when compared to bond stress values given in IS: 456 – 2000.
- Normal mix shows 77% to 147% more bond strength when compared to the bond stress values given in IS: 456 - 2000.
- Considering that the Factor of Safety taken in the code as 2 then also the values of bond strength would turn around to be much lower than found from the experimental study.

  After considering this Factor of Safety i.e. 2, the bond values of Fibre mixed concrete about 45 greater than the IS values and the values of mix with Super-plasticizer are about 33% greater than IS values and normal mix shows 23% greater values than IS Code.

To get more idea about the extent to which the values of bond strength varies with respect to IS Code values refer to FIGURE 8.25.

Also it can be observed from the FIGURE 8.24 that the pattern of curve for all the type of mix is almost similar to that of IS Code.

To get the idea about the trend followed by these mixes and IS code values a graph showing trend line is plotted as shown in FIGURE 8.26.

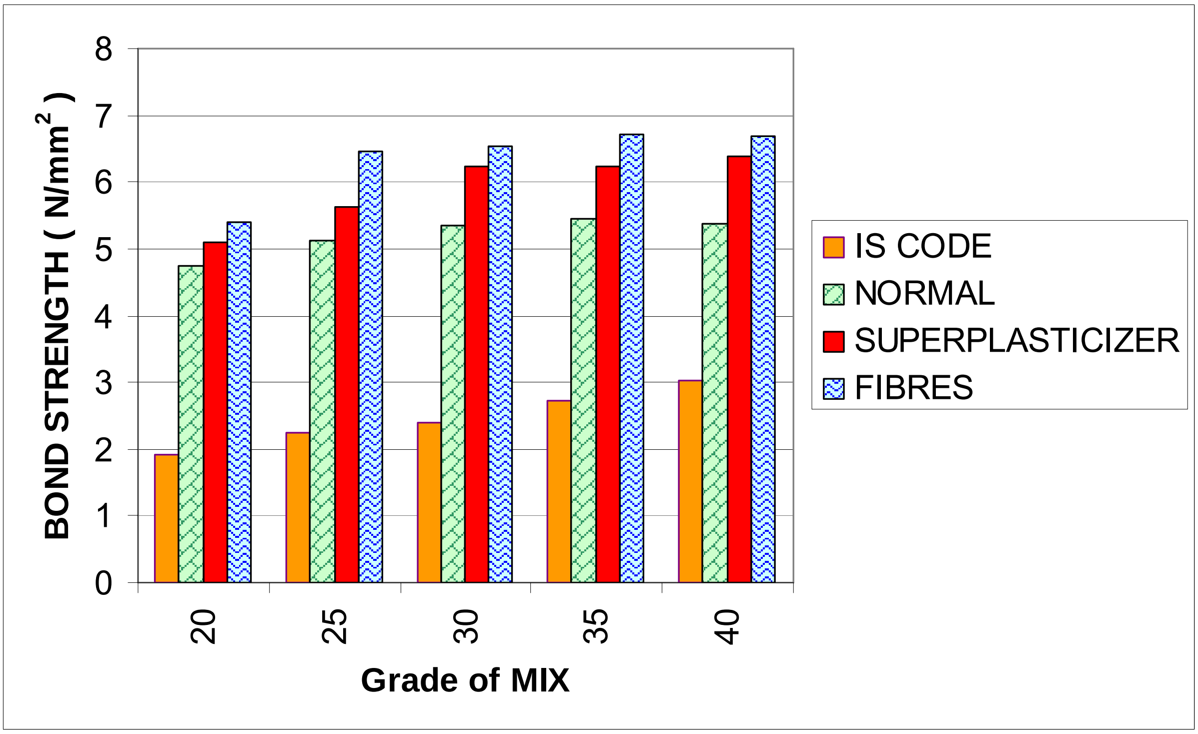


FIGURE 8.25 VARIATIONS IN BOND STRENGTH WITH RESPECT TO IS CODE

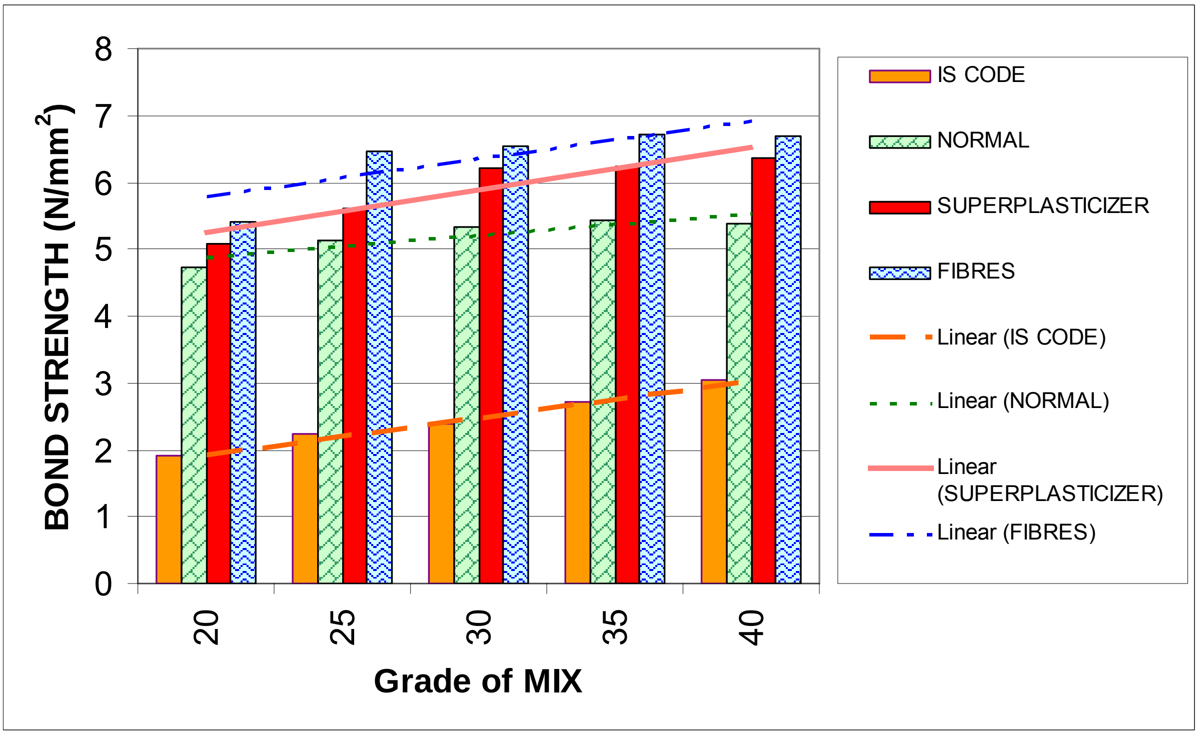


FIGURE 8.26 TREND LINE FOR VARIATION OF BOND STRENGTH OF DIFFERENT MIX AND IS CODE VALUES

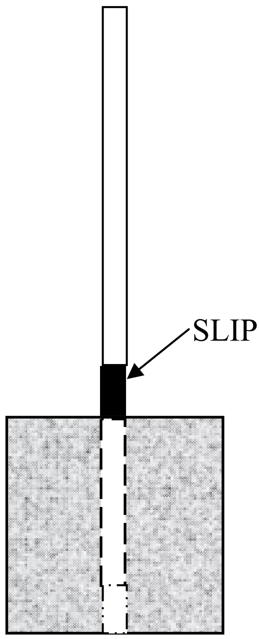
8.7 FAILURE PATTERN

It was observed that in Mild steel the failure occurred due to slip, the steel rod was just pull out leaving a hole in the concrete. Where as in TMT bars mostly splitting of concrete was observed and in some case for 12 mm diameter bars slipping of steel was seen. TMT COATED bars also the failure was similar to TMT bars but here due to the presence of coating the slipping kind of failure was also observed in many cases including in 16 mm diameter bars.

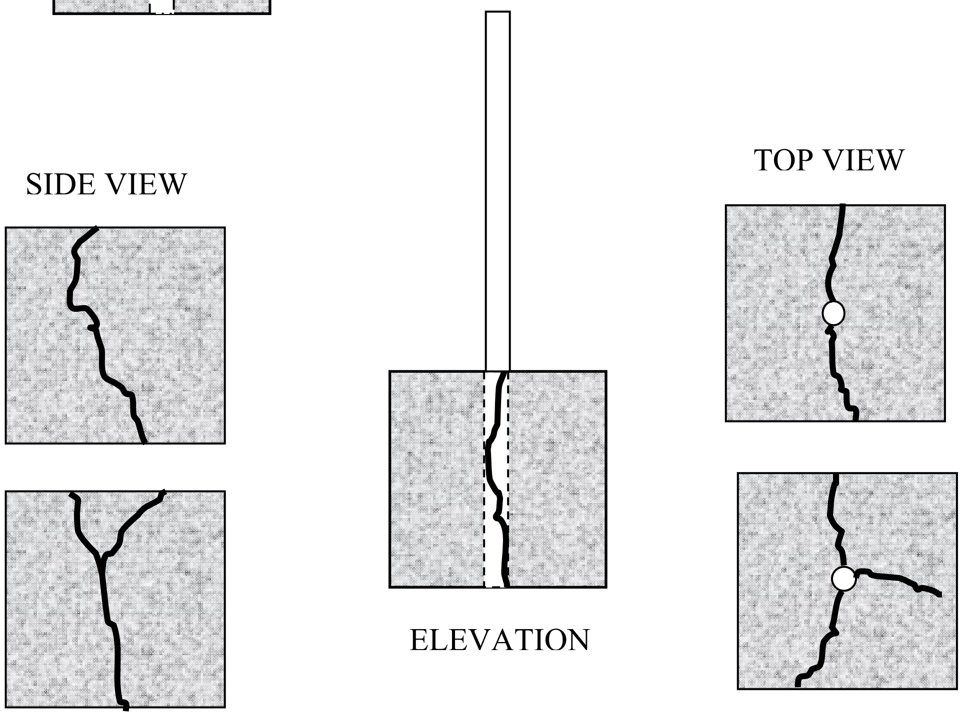
It was observed that the coating that was applied did not stick to the concrete surfaces during the pull-out or the splitting type of the failure. Only the coating which was there on the tip of the ribs got removed due to the pull out of the reinforcement where in the other parts of the bar the coating remained in adhesion with the reinforcement bar.

This can be observed in the FIGURE 8.27 shown below:

FIGURE 8.27 TMT COATED BAR AFTER PULL-OUT TEST



- The figure here shows slipping of the bar from the concrete



- The figure here shows splitting of concrete.
- Some of the failure patterns are shown below.

FIGURE 8.28 FAILURE PATTERNS

THE FIGURE 8.28 shows the various failure pattern observed during the experiment and the pictures taken are show in the ANNEX E.

8.8 COMPARISON OF SAP MODEL AND EXPERIMENTAL RESULTS

To further study the results obtained from the experiment, models of the pullout sample were prepared on SAP 8.11 software.

Modeling was carried out by taking the concrete cube as solid element of size 150 mm x 150 mm x 150 mm and then it was meshed so that 1 solid element was divided into 16 solid elements each of size 37.5 mm x 37.5 mm x 37.5 mm as shown in FIGURE 8.29. The steel bar was modeled as a line element and ultimate yield stress of steel was taken as 466 N/mm^2. Concrete was given the property of M20 grade i.e. modulus of elasticity of concrete was taken as 22360 N/mm^2 (i.e. 5000 $\sqrt{f_{ck}}$)

The pull-out force was applied on the steel in global Z-direction and then analysis was done. For 12 mm diameter bar the load was given as 30 kN, for 16 mm diameter bar the load was given as 40 kN and for 20 mm diameter bar the load was given as 50 kN, based on the experimental results obtained from M 20 grade of concrete.

The results show that as the diameter of bar increases, the bond strength decreases which was also observed in the experiments carried out. This trend matches with that obtained from the experimental work.

Also the stress pattern was similar to theoretical concept as shown in FIGURE 3.6 of CHAPTER 3.

The results of the SAP analysis are as shown in the figures below. In FIGURE 8.29, 8.32 and 8.35 the deformed shape of the specimen with reinforcement bar of diameter 12 mm, 16 mm, and 20 mm can be observed respectively. FIGURE 8.30, 8.33 and 8.36 shows the shear stress pattern of the whole specimen reinforced with 12 mm, 16 mm, and 20 mm diameter bar respectively, where as, FIGURE 8.31, 8.34 and 8.37 shear stress distribution near the reinforcement bar for 12 mm, 16 mm and 20 mm diameter bar can be observed.

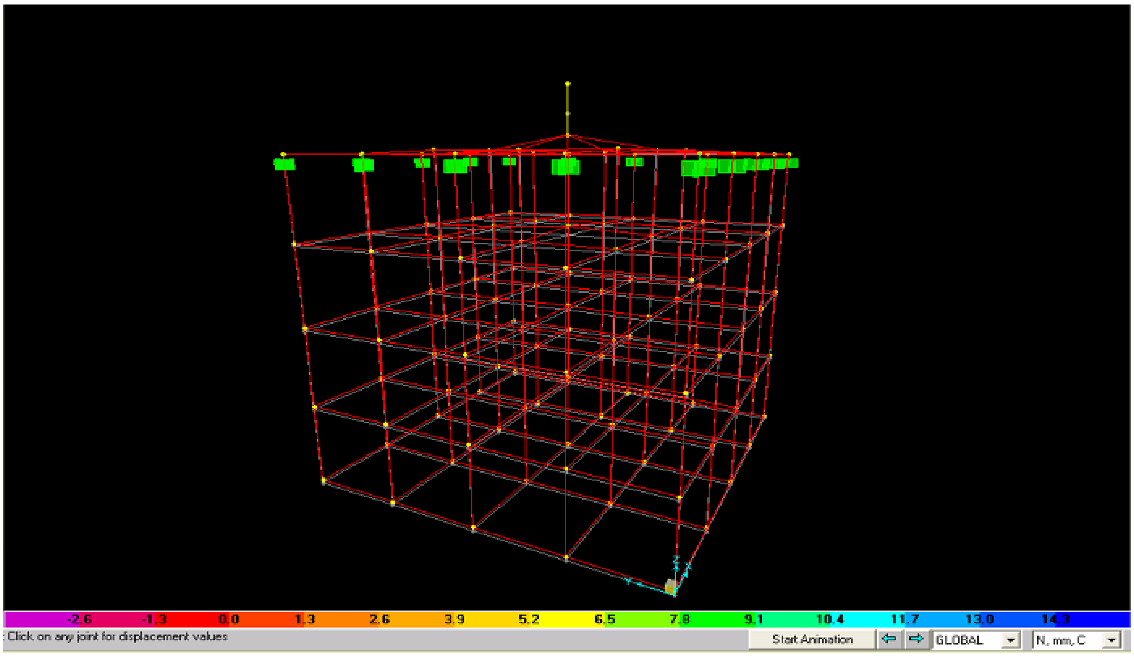


FIGURE 8.29 DEFORMED SHAPE FOR 12 mm DIAMETER BAR

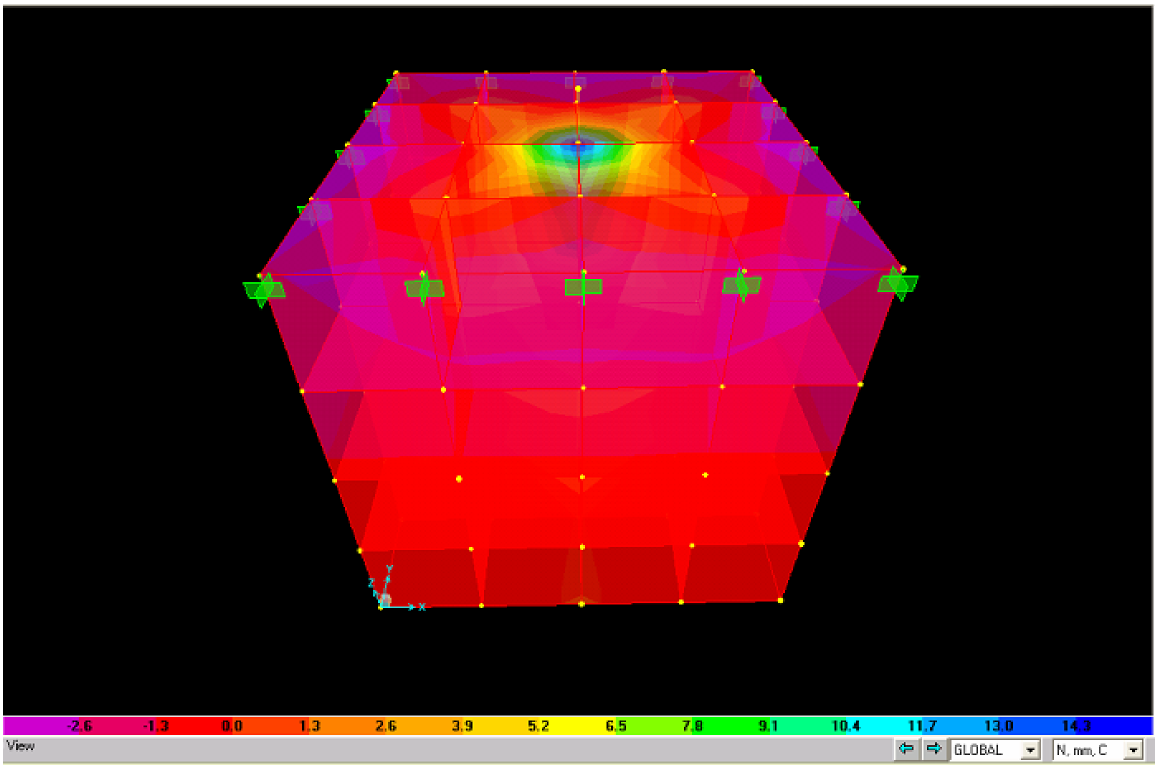


FIGURE 8.30 STRESS DIAGRAM FOR 12 mm DIAMETER BAR

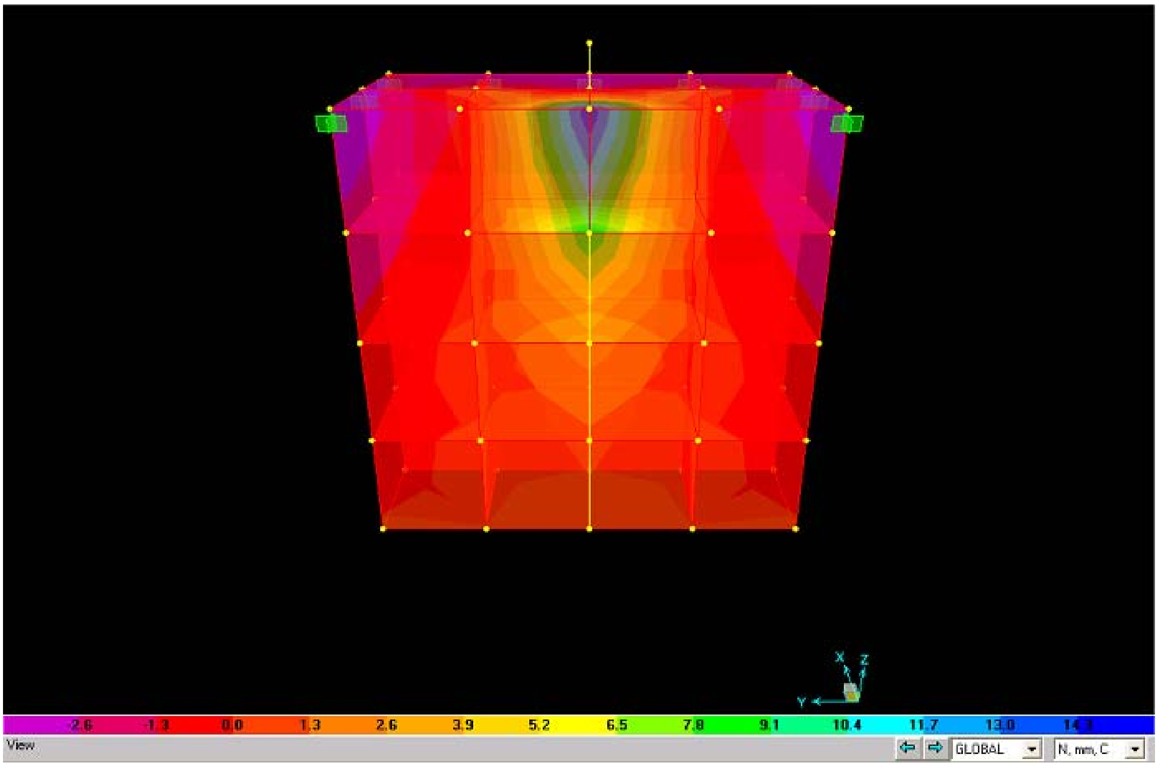


FIGURE 8.31 STRESS DIAGRAM AT HALF SECTION FOR 12 mm DIAMETER BAR

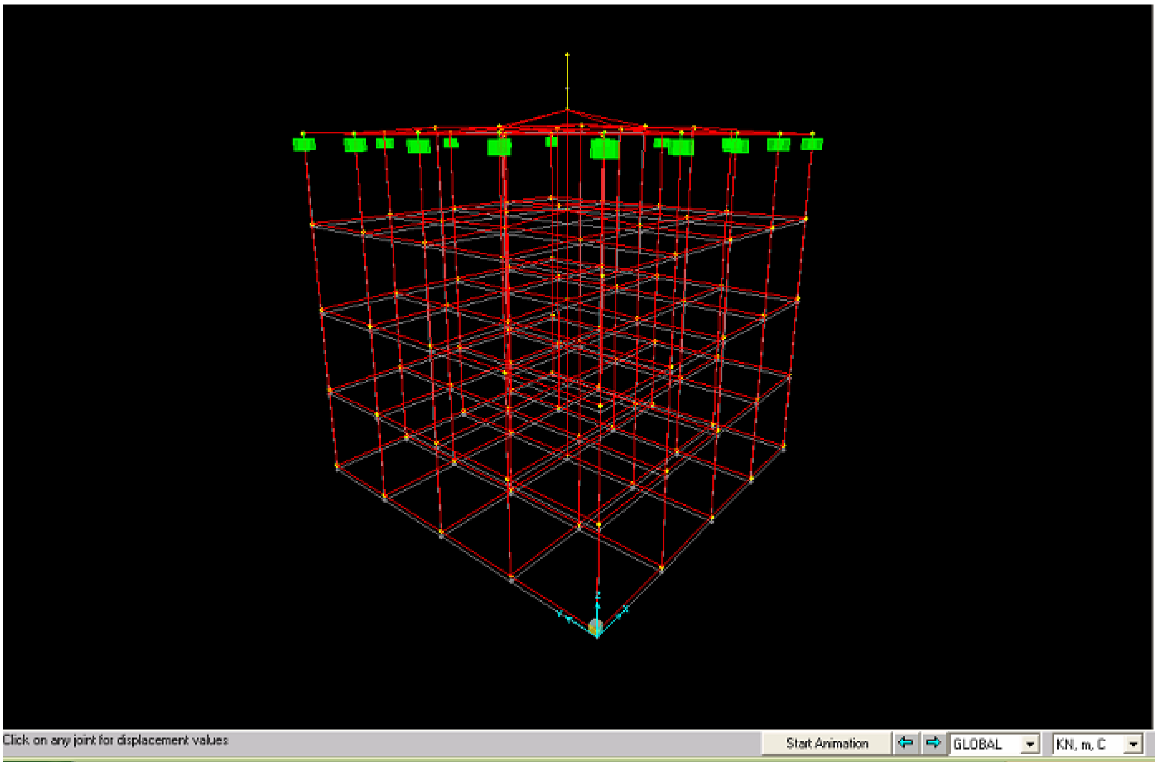


FIGURE 8.32 DEFORMED SHAPE FOR 16 mm DIAMETER BAR

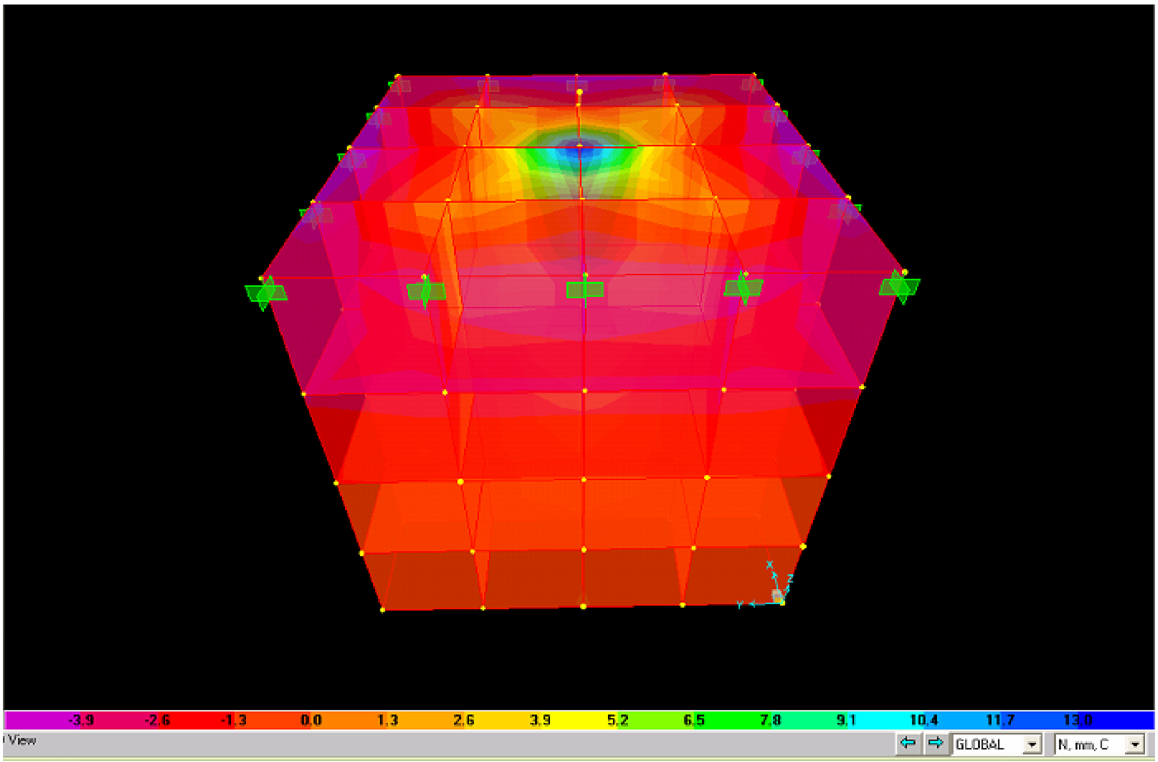


FIGURE 8.33 STRESS DIAGRAM FOR 16 mm DIAMETER BAR

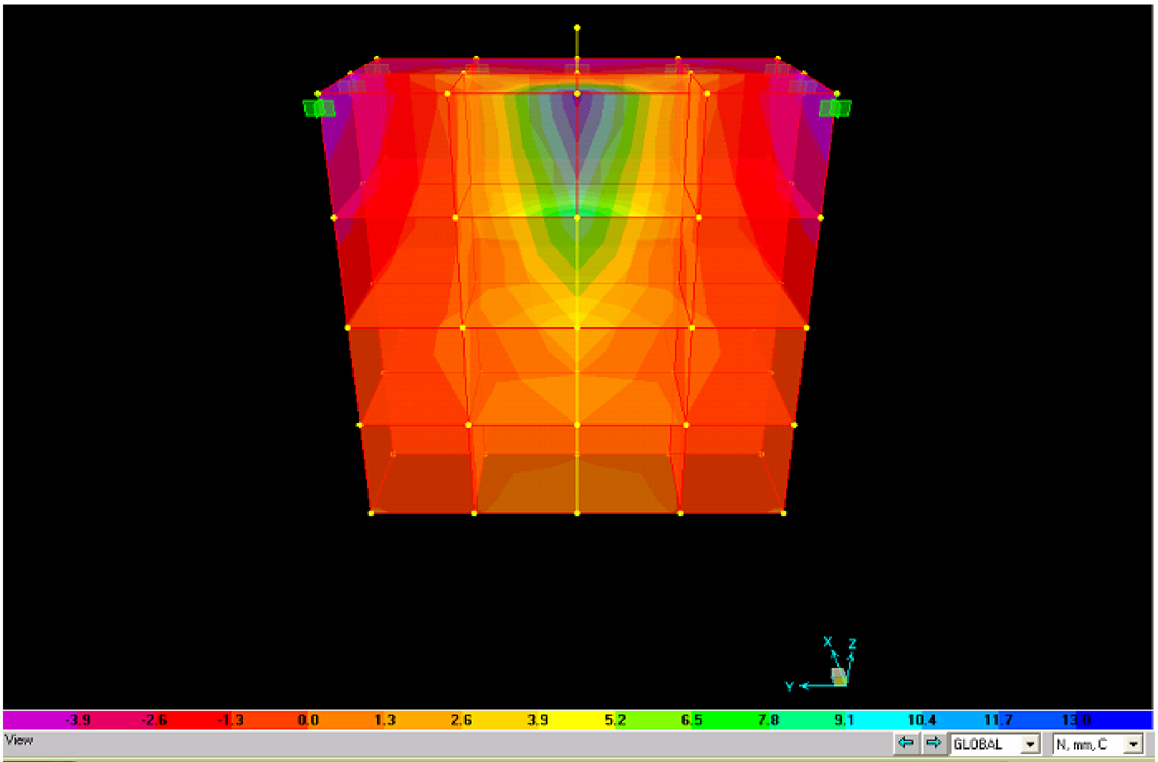


FIGURE 8.34 STRESS DIAGRAM AT HALF SECTION FOR 16 mm DIAMETER BAR

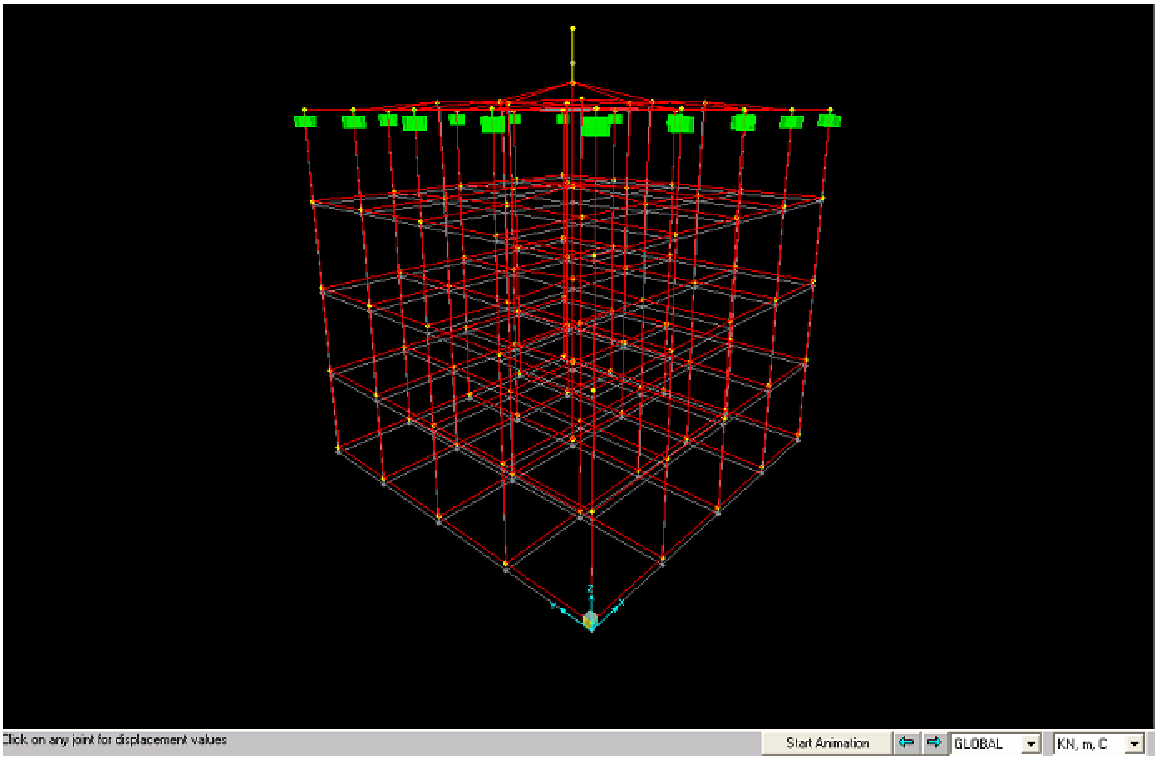


FIGURE 8.35 DEFORMED SHAPE FOR 20 mm DIAMETER BAR

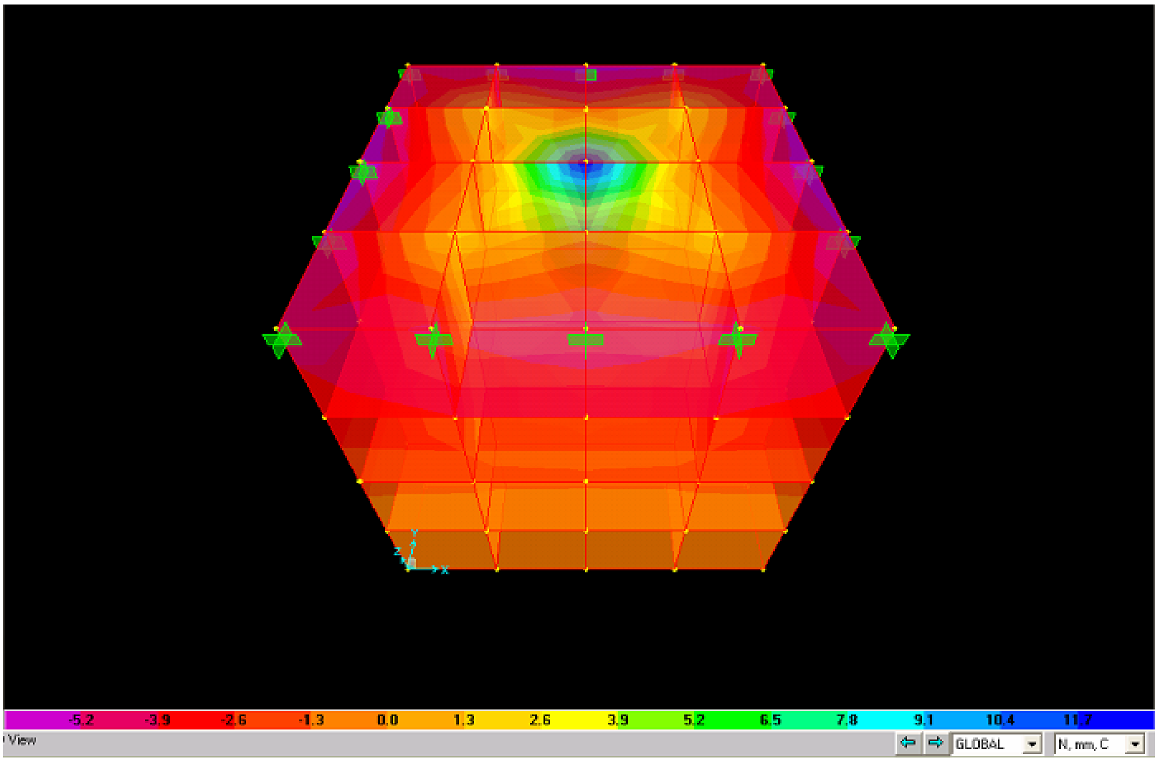


FIGURE 8.36 STRESS DIAGRAM FOR 20 mm DIAMETER BAR

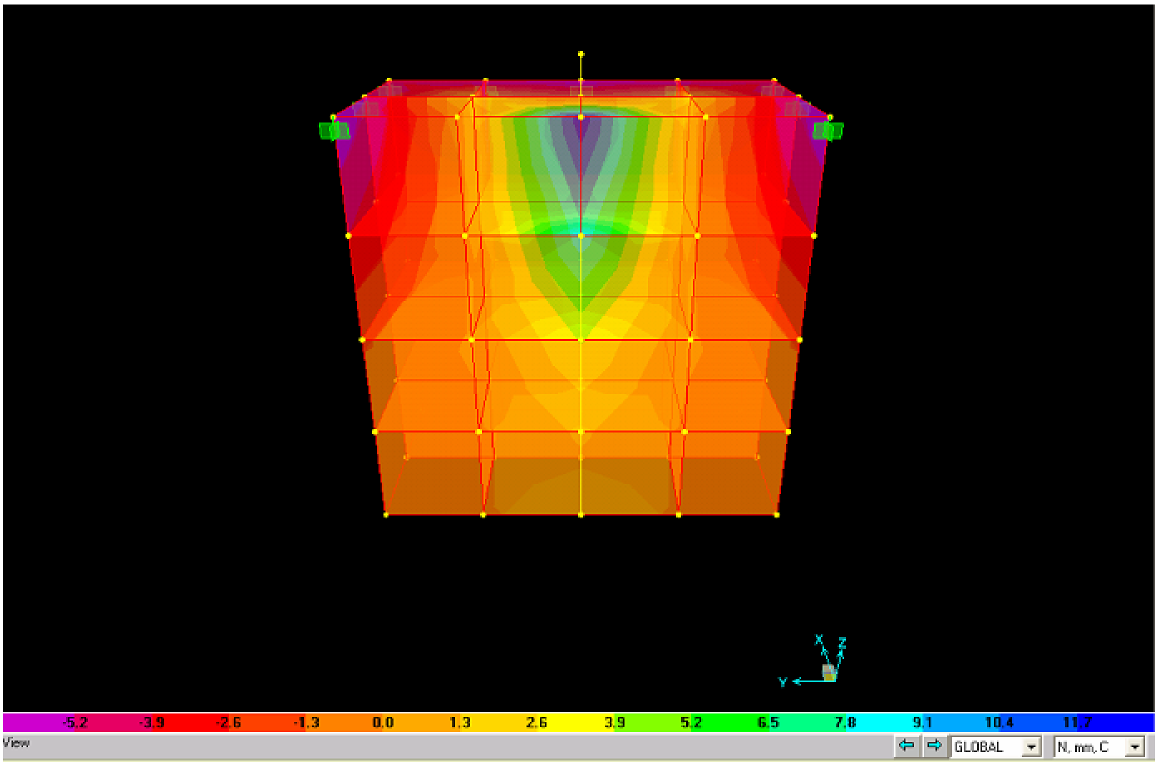


FIGURE 8.37 STRESS DIAGRAM AT HALF SECTION FOR 20 mm DIAMETER BAR

The bond strength found from the analytical model for M 20 grade of concrete is compared with the bond strength values found from the experimental work for M 20 grade of Normal mix. This is tabulated in TABLE 8.1. It shows the bond stress values for plain bars of diameter 12 mm, 16 mm, and 20 mm for Normal mix of M20 grade.

TABLE 8.1 BOND STRESS VALUES

Bar diameter	**Analytical result** (N/mm^2)	**Experimental result** (N/mm^2)
12 mm	14.3	6.16
16 mm	13.0	4.34
20 mm	11.7	4.06

It can be seen that the observation that was made earlier in this chapter that with the increase in diameter of the reinforcing bar the bond strength decreases, similar observation can also be drawn from this analytical model though the values so found form the analytical model are on the higher side as compared to the experimental values.

8.7 DEVELOPMENT LENGTH

After calculating the bond strength for all the specimens development length was calculated and the same were compared with the values given in IS:456 – 2000.

For comparing the values obtained from the experimental work carried out with the IS code values Factor of Safety of 2 was applied to the bond stress values found form the experimental.

Equation 3.1 given in CHAPTER 3.1 has been used to calculate the development length. For bars in compression the values of bond stress shall be increased by 25 %.

Table 8.2 shows the development length so found from the experimental work and from IS code for bars in tension.

TABLE 8.2 DEVELOPMENT LENGTHS

Tension										
fy (N/mm^2)	Experimental values (in terms of ϕ)					IS code values (in terms of ϕ)				
	M 20	M 25	M 30	M 35	M 40	M 20	M 25	M 30	M 35	M 40
250	21.4	19.0	18.0	17.7	17.7	28.3	24.3	22.7	20.0	17.9
415	22.2	19.7	18.7	18.4	18.3	29.4	25.2	23.5	20.7	18.6
500	26.8	23.7	22.5	22.2	22.1	35.4	30.3	28.3	25.0	22.4

ϕ - Diameter of the bar.

The % saving in steel that can be made if the experimental values of development length are used rather than the code value is tabulated below in TABLE 8.3.

TABLE 8.3 PERCENTAGE SAVING IN STEEL

fy (N/mm^2) \ Grade	M 20	M 25	M 30	M 35	M 40
250	24.37	21.88	20.44	11.25	1.15
415	24.37	21.88	20.44	11.25	1.15
500	24.37	21.88	20.44	11.25	1.15

The values shown in TABLE 8.3 are in terms of percentage.

From the TABLE 8.3, it can be observed that the percentage of steel that can be saved is about 38 % to 53 % which will result in considerable reduction in cost and also help in avoiding congestion of steel at joints which led to the poor quality of finish accompanied with honey-combing.

9. CONCLUSION

9.1 CONCLUSION

After testing the specimens and studying the results and observation the following conclusion can be made:

1. The mix with Fibres and Super-plasticizer gives more bond strength than the other two mixes i.e. mix with Super-plasticizer and Normal mix for all the diameter of bars and for all the grade of concrete mix.
2. The mix with Super-plasticizer shows greater bond strength than the Normal mix.
3. TMT bars develop more bond strength than TMT Coated bars and Mild Steel bars for all the type of concrete mix and for all the grades of concrete. Coating when applied to the TMT bars cause reduction in the bond strength.
4. Mild steel bars develop the least bond strength when compared to the other bars i.e. TMT and TMT Coated bars.
5. With the increase in diameter of bar the bond strength decreases for all the type of bar and for all the grade and mix of concrete.
6. Average bond strength of mix with Fibres and Super-plasticizer is more than the other two mixes and are also much more than the bond stress values given in IS: 456 – 2000.
7. The failure pattern of TMT and TMT Coated bars were found similar. The failure pattern of Mild steel bars was different. In Mild steel bars slip occurred and there was no failure in concrete seen where as in case of TMT bars and TMT Coated bars mostly splitting of concrete cube was observed.
8. The required development length is almost half then that calculated from the codal provisions of IS: 456 – 2000.

Hence, it is recommended that the IS code values of bond strength should be changed and should incorporate the advances that have taken place in the field of concrete and steel.

9.2 FUTURE SCOPE OF WORK

The work can be further extended as suggested below:

9.2.1 EXPERIMENTAL WORK

1. Pull-Out test was carried out only for cube specimens according to IS: 2770 (Part I) – 1967, so it should also be carried out using code of other countries for pull-out specimens like cylinders and beams of various sizes as the other parts of IS: 2770 for specimens like cylinders and beams are not available till date. So recommendations can be made for other parts of IS: 2770.
2. Pull-Out test was only performed for cube specimens of size 150 mm x 150mm x 150 mm. The results should also be checked for other sizes mentioned in the code.
3. Pull-Out test was performed using bars of diameter 12 mm, 16 mm and 20 mm only. The effect of other diameter bars on the bond strength can also be studied.
4. Only the effect of advanced materials like Super-plasticizer, Fibres (polypropylene), TMT bars and polymer coating on bond strength are studied here. So the effect of other advanced materials like other chemical and mineral admixtures and other advanced type of reinforcement bars like Fibre Reinforced Plastic rebars, galvanized rebars, etc on bond strength can be studied to further extend the work.
5. Bond strength for High-strength concrete i.e. grade of concrete above M 40 can also be studied as IS: 456 – 2000 gives the same bond strength values for all grade of concrete of M 40 and above which might not be true.

9.2.1 ANALYTICAL WORK

1. Only linear analysis was carried out for finding the bond stress. Non linear analysis should be carried out to get more accurate results.
2. Concrete grade of M 20 was only studied using SAP, so the other grades of concrete can also be studied.

3. The results found from SAP 2000 can be checked with software's like ANSYS and other sophisticated softwares.
4. Bar diameter of 12 mm, 16 mm, and 20 mm are only studied. Other diameter of bars can also be studied.
5. Only plain reinforcement bars were studied using SAP 2000. Other bars like TMT bars can also be incorporated in this study.
6. Only Normal concrete mix was studied here. Other mixes like mix with Super-plasticizer, Fibres can also be studied.
7. Only the size and shape of the specimen taken for experimental work i.e. cube of 150 mm x 150 mm x 150 mm was studied. Other shapes like cylinders and beams can also be studied.
8. In this study effect of meshing size over the results of bond strength can be incorporated.

This Annex consists of tables that were referred to for carrying out the mix design.

Table 1: Values of k or T

% of results below f_{ck}	k or t
50	0
16	1
10	1.28
5	1.65
2.5	1.96
10	2.33
0.5	2.58
0.0	infinity

Table 2: Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for different Exposure with Weight Aggregates if 20 mm Nominal Maximum Size.

Table 2						
exposure	**plain concrete**			**reinforced concrete**		
	minimum cement content	maximum free water cement ratio	minimum grade of concrete	minimum cement content kg/m^3	maximum free water cement ratio	minimum grade of concrete
mild	220	0.6	-	300	0.55	M20
moderate	240	0.6	M15	300	0.5	M25
severe	250	0.5	M20	320	0.45	M30
very severe	260	0.45	M20	340	0.45	M35
extreme	280	0.4	M25	360	0.4	M40

Table 3: Assumed Standard Deviation.

Grade of Concrete	M10 , M15	M20 , M25	M30 and above
Standard deviation	3.5	4.0	5.0

Table 4: Appropriate Entrapped Air Content

Nominal Maximum Size of Aggregate (mm)	Entrapped Air, as Percent of volume of Concrete
10	3
20	2
40	1

Table 5: **Approximate Amount of Water and Sand Content.**
w/c = .60,workability = .80CF,upto M35

Table 5		
Maximum size of aggregate (mm)	Water Content per m^3 of concrete(kg)	Sand per % of tot. agg.by abs. vol.
10	208	40
20	186	35
40	165	30

Table 6: Approximate Sand and Water Contents per Cubic Meter of Concrete.
w/c = .35, workability = .80CF, above M35

Maximum Size Of Aggregate (mm)	Water Content Per Cubic Metre Of Concrete (kg)	Sand As Percent of Total Aggregate By Absolute Volume
10	200	28
20	180	25

Table 7: Adjustment of Values in Water content and sand Percentage for other Conditions

Table 7		
change in condition	adjustments required in	
	water content	% sand in total aggregate
for sand confirming to grading zone 1,zone 3,zone 4	0	+1.5 % for zone 1
		-1.5 % for zone 3
		-3.0 % for zone 4
Increase / decrease in the values of CF by 0.1	± 3 %	0
Each 0.05 increase or decrease in the water cement ratio	0	± 1 %
For round aggregate	- 15 kg	-7%

Table 8: Adjustment in minimum content in cement content for aggregates other than 20 mm nominal maximum size.

Table 8	
Nominal Max. Aggregate Size	Adjustment in Minimum Cement Contents
10	+ 40
20	0
40	-30

Table 9: Vol. of Dry - rodded Coarse Aggregate per unit volume of Concrete

Table 18				
max. Size of	**fineness modulus of sand**			
aggregate (mm)	2.4	2.6	2.8	3
10	0.5	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.6
25	0.71	0.69	0.67	0.65
40	0.76	0.74	0.72	0.7
50	0.78	0.76	0.74	0.72
70	0.81	0.79	0.77	0.75
150	0.87	0.85	0.83	0.81

Table 10: Relationship between Water-Cement Ratio and Compressive Strength Of Concrete

Table 10		
compressive Strength At 28 days	**water cement ratio by weight**	
kgf/cm^2	**non Air entrained**	**Air entrained**
450	0.38	-
400	0.43	-
350	0.48	0.4
300	0.55	0.46
250	0.62	0.53
200	0.7	0.61
150	0.8	0.71

Table 11: Approximate Mixing Water (kg/m3 of Concrete) Requirements For Different Slumps and Maximum Sizes of Aggregates.

Table 11								
	non air entrained concrete							
slump (mm)	maximum size of aggregates in mm							
	10	12.5	20	25	40	50	70	150
30 - 50	205	200	185	180	160	155	145	125
80 - 100	225	215	200	195	175	170	160	140
150 - 180	240	230	210	205	185	180	170	-
approx. amt of entrained air %	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air entrained concrete							
slump (mm)	maximum size of aggregates in mm							
	10	12.5	20	25	40	50	70	150
30 - 50	180	175	165	160	145	140	135	120
80 - 100	200	190	180	175	160	155	150	135
150 - 180	215	205	190	185	170	165	160	-
Rec. avg. tot. air %	88	7	6	5	4.5	4	3.5	3

Table 12: Approximate compressive strength with water cement ratio 0.5

Table 12					
type of cement	type of aggregate	compressive strength (N / mm^2) (age)			
		3	7	28	91
OPC/ sulphate resisting P C	uncrushed	18	27	40	48
	crushed	23	33	47	55
RHPC	uncrushed	25	34	46	53
	crushed	30	10	53	60

Table 13: Approximate water content (kg/m^3) required to give various levels of Workability.

Table 13					
Max. Size of Aggregetes	**type of aggregate**	**slump values (mm)**			
		0-10	**10-30**	**30-60**	**60-180**
10	uncrushed	150	180	205	225
	crushed	180	205	230	250
20	uncrushed	135	160	180	195
	crushed	170	190	210	225
30	uncrushed	115	140	160	175
	crushed	155	175	190	205

The common terminologies that are used in Mix design are listed below:

(a) Mean strength:

This is the average strength obtained by dividing the sum of strength of all the cubes to the number of cubes.

$$\bar{X} = \frac{\Sigma x}{n}$$

Where $\bar{x}$ = mean strength
Σx = sum of the strength of cubes.
n = number of cubes.

(b) Variance:

This is the measure of variability or difference between any single observed data from the mean strength.

(c) Standard deviation:

This is the root mean square deviation of all the results. This is denoted by s or σ. Numerically it can be expressed as,

$$s \text{ or } \sigma = \sqrt{\frac{\Sigma(X-x)^2}{n-1}}$$

Where s or σ = Standard deviation,
n = number of observation
X = particular value of observation
x = arithmetic mean.

(d) Coefficient of variation:

It is an alternative method of expressing the variation of results. It is non-dimensional measure of variation obtained by dividing the standard deviation by the arithmetic mean and is expressed as:

$$v = (\sigma / \bar{x}) \times 100$$

Where v = coefficient of variation.

(e) Characteristic strength (fck):

Cube results follow the normal distribution, hence there is always possibility that some results may fall below the specified strength. It means that the value of the strength of the material below which not more than 5 percent of the test results are expected to fall.

% of results below f_{ck}	k
50	0
16	1
10	1.28
5	1.65
2.5	1.96
10	2.33
0.5	2.58
0.0	infinity

Table 1: Values of k

(f) Target mean strength (ft):

It is necessary to design the mix to have a target mean strength which is greater than the characteristic strength by a suitable margin, as the inherent variability of concrete strength during production is well known.

$f_t = f_{ck} + t \times s$

Where f_{ck} = characteristic strength

t =a constant, depending on the definition of characteristic strength and is derived from the mathematics of Normal distribution.

s = standard deviation.

Mix design was carried out on the Excel sheet prepared by three different methods which are:

1. BIS Method
2. ACI Method
3. DOE Method

Mix design for M20 grade of mix by all the three methods are given below:

C.1 BIS METHOD (M 20 GRADE)

Mix Design BIS Recommendations for Concrete.							
Characteristic compressive strength required :-					20	MPa	
Maximum Size of Aggregate :-			20	mm			
Degree of workability		0.95	compaction factor				
type of exposure :-		Mild					
Grade of cement used :-			43				
Sp.Gravity of cement =			3.15				
Sp.Gravity of CA =			2.6				
Sp.Gravity of FA =			2.6				
Sand Zone	:-	2					
water absorption :		CA	0.5				
		FA	1				
Free Moisture :-		CA	0				
		FA	2				
	k =	1.65					
	σ =	4					
Target Mean Strength :-							
	f_t =	$f_{ck} + k\sigma$	=	26.6	MPa		
water Cement Ratio:-							
	From Graph W/C =		0.485				
	From **Table 3** W/C =		0.55				
selecting Minimum Water Cement Ratio :-				0.485			
Selection Of Water And Sand Content **From Table 4** :-							
Water Content :-		186					
Sand Content :-		35					
Change in Condition		(From **Table 5**)		Water Content		% Sand in Total aggregate	
increase/Decrease in W/C Ratio =			0.115	0		-2.3	%
Inc./Dec. in compaction factor =			0.15	4.5	%	0	
Sand confirming to Zone 1,3,4			III	0		-1.5	%
rounded Aggregate		NO		0		0	%
Total				4.5	%	-3.8	%
				0	Kg/m^3		

Required Sand Content As Percentage Of Total Aggregate By Absolute Volume =				31.2	%
Requires Water Content =		194.37	Kg/m^3		
Cement Content =	400.76	Kg/m^3			
from **Table 3** =	300	Kg/m^3			
Therefore Selecting the maximum value =		400.76	Kg/m^3		
if the maximum Size of Aggregate is other than 20 mm then the change in cement content =			400.76	Kg/m^3	
Volume of Entrapped Air =		2	%		

FA =	534	Kg/m^3
CA =	1178	Kg/m^3

Mix Proportion			
Water	Cement	FA	CA
194.37	401	534	1178
0.48	1	1.33	2.94
For Bag of cement of		50	Kg

Cement=	50	Kg
sand =	66.5	Kg
CA =	147	Kg
Water :-	24	liters
reductions or additions		

extra water to be assed for the absorption in case of CA =	0.735	liters	FA =	0.665
water to be deducted for the free moisture content % in FA =	-1.33	liters	CA =	0

Actual Quantity of water =	23.4	liters
Actual Quantity Of FA =	67.83	kg
Actual Quantity of CA =	146.265	kg

Water	Cement	FA	CA
23.4	50	67.83	146.265
0.47	1	1.36	2.93

C.2 ACI METHOD (M 20 GRADE)

Mix Design BY ACI Method					
Concrete Type :-	Non-Air entrained				
Characteristic compressive strength required :-			20	MPa	(28 days strength)
Maximum Size of Aggregate :-		20	mm		
Degree of workability	0.95	compaction factor	(refer Table 1)		
slump referring to **Table 1** =		75-100			
type of exposure :-	Mild				
Grade of cement used :-		43			

	specific gravity	Bulk density Kg/m3	fineness modulus
Cement	3.15	1450	-
C A	2.6	1700	6.5
F A	2.6	1650	2.5
Sand Zone	3		
k =	1.65		
σ =	4		

bulk volume of dry rodded coarse aggregate per cubic meter of concrete from **Table 2** =	0.65	m^3
Dry mass of coarse aggregate per m^3 of concrete =	1105	kg/m^3
Target Mean strength Ft =	26.6	MPa

equivalent cylindrical strength = 80 % of equivalent cube strength (Assumed)

so equivalent cylindrical strength =	21.28	MPa
	212.8	kgf/cm^2

refer Table 5

compressive strength	**water cement ratio**
250	0.62
200	0.7
212.8	**0.67952**

water cement ratio value from **Table 6** =	0.55	
selecting the minimum of the two values =	0.55	water cement ratio by weight
water content per cubic meter of concrete from workability consideration =	200	kg/m^3

refer **Table 7**

cement content =	363.6364	kg/m^3
from **Table 6** according to durability req. minimum cement content required =	300	kg/m^3
Adopting the higher value		
adopting cement content =	363.64	kg/m^3
amount of entrained air (referring to **Table 7)** =	2	%

Absolute volumes of mix ingredients per cubic meter of concrete are

cement	0.115441	m^3
water	0.2	m^3
C.A.	0.425	m^3
Ent. Air	0.02	m^3
F.A	0.24	m^3
Mass Of F.A =	624	kg/m^3

finally mix proportion by mass per m^3 of concrete

Water	Cement	FA	CA
200	363.6364	624	1105
0.55	1	1.716	3.04

for 1 bag of cement

Water	Cement	FA	CA
27.5	50	85.8	152
litres	kg	kg	kg

Water	Cement	FA	kapchi	grit	kapchi / grit ratio	
27.5	50	85.8	101.34	50.66	kapchi	grit
litres	kg	kg	kg	kg	2	1

C.3 DOE METHOD (M 20 GRADE)

Mix Design BY **DOE Method**

Characteristic compressive strength required :-	20	MPa	(28 days strength)
Maximum Size of Aggregate :-	20 mm	crushed	aggregate
Degree of workability	0.95	compaction fator	(refer Table 1)

slump refering to **Table 1 =**			75-100
type of exposure :-		Mild	
Type of cement :-		OPC	
Grade of cement used :-			43
	specific gravity	Bulk density Kg/m3	fineness modulus
Cement	3.15	1450	-
C A	2.6	1700	6.5
F A	2.6	1650	2.5
Sand Zone	3		
Table 4	k =	1.65	
Table 3	σ =	4	

compresive strength from the **Table 2** =	47	N/mm^2
Target Mean strength Ft =	26.6	MPa
value obtained from curve of water cement ratio =	0.727	
max. value given in **Table 5** =	0.55	
final Water Cement Ratio =	0.55	
Approx. water content refering to **Table 6 =**	225	kg/m^3
cement content =	409.09	kg/m^3
From **Table 5** maximun cement content =	300	kg/m^3
Final cement content =	409.09	kg/m^3
from the curve of estimated wet density of fully compacted concrete we get the estimated wet density of fully compacted concrete =	2340	kg/m^3
total aggregate content =	1509.605	kg/m^3

from the curves of recommended proportions of F.A. for Graging Zones 1,2,3 and 4

we get the proportion of saturated surface dry F.A =	31.5	and	38	%
selecting the average proportion of F.A =	34.75	%		
fine aggregate content =	524.59	kg/m^3		
C.A content =	985.02	kg/m^3		

finally mix proportion by mass per m^3 of concrete

Water	Cement	FA	CA
225	409.09	524.59	985.02
0.55	1	1.283	2.41

for 1 bag of cement

Water	Cement	FA	CA
27.5	50	64.15	120.5
litres	kg	kg	kg

Water	Cement	FA	kapchi	grit	kapchi / grit ratio	
27.5	50	64.15	80.34	40.16	kapchi	grit
litres	kg	kg	kg	kg	2	1

ANNEX – D.1 COMPRESSIVE, FLEXURAL AND SPLIT TENSILE STRENGTH OF CONCRETE

COMPRESSIVE STRENGTH OF CUBES

Grade of mix	Mix A*		Mix B**		Mix C***	
	7 days strength	28 days strength	7 days strength	28 days strength	7 days strength	28 days strength
M 20	19.0	27.7	21.2	34.8	24.6	24.4
M 25	23.6	32.9	25.2	35.4	28.9	27.2
M 30	24.9	33.2	28.3	40.1	28.6	26.0
M 35	28.0	40.0	33.3	32.6	35.4	25.1
M 40	28.3	41.9	34.8	33.4	38.4	32.6

A* - Normal mix
B** - Mix with Super-plasticizer
C*** - Mix with Fibres and Super-plasticizer

FLEXURAL STRENGTH OF BEAMS (AT 28 DAYS)

Grade of mix	Mix A*	Mix B**	Mix C***
M 20	10.1	9.6	8.3
M 25	9.9	11.1	11.1
M 30	10.2	10.9	11.4
M 35	10.0	11.3	10.3
M 40	12.3	10.2	10.5

A* - Normal mix
B** - Mix with Super-plasticizer
C*** - Mix with Fibres and Super-plasticizer

SLPIT TENSILE STRENGTH OF CYLINDERS (AT 28 DAYS)

Grade of mix	Mix A*	Mix B**	Mix C***
M 20	115.2	156.2	137.4
M 25	175.5	162.6	188.4
M 30	152.4	189.7	194.9
M 35	155.8	176.9	169.0
M 40	125.6	180.1	199.3

A* - Normal mix
B** - Mix with Super-plasticizer
C*** - Mix with Fibres and Super-plasticizer

ANNEX – D.2 SUMMARY OF THE PULL-OUT SPECIMEN TESTED

The summary of the Pull-Out test carried out on the specimens are listed below:

SR.No.	Type of Mix	Grade	Type of Bar	Dia. Of Bar (mm)	Max. Load (kN)	Load @ 0.025mm slip (kN)	Type of failure
1	N^{+}	M20	Mild Steel	12	35.3	33.8	Slip
2	N	M 20	Mild Steel	12	36.8	36.8	Slip
3	N	M 20	Mild Steel	12	35.8	35.8	Slip
4	N	M 20	Mild Steel	16	30.9	30.4	Slip
5	N	M 20	Mild Steel	16	34.8	32.9	Slip
6	N	M 20	Mild Steel	16	36.3	34.8	Slip
7	N	M 20	Mild Steel	20	41.7	40.2	Concrete
8	N	M 20	Mild Steel	20	35.8	35.3	Slip
9	N	M20	Mild Steel	20	41.2	39.2	Slip
10	N	M 20	TMT	12	49.5	49.5	Concrete
11	N	M 20	TMT	12	44.6	43.7	Concrete
12	N	M 20	TMT	12	49.5	35.3	Concrete
13	N	M 20	TMT	16	49.1	47.6	Concrete
14	N	M 20	TMT	16	47.6	46.6	Concrete
15	N	M 20	TMT	16	45.6	45.1	Concrete
16	N	M 20	TMT	20	48.1	48.1	Concrete
17	N	M 20	TMT	20	55.9	49.1	Concrete
18	N	M 20	TMT	20	48.1	48.1	Concrete
19	N	M 20	TMT Coated	12	40.7	36.8	Concrete
20	N	M 20	TMT Coated	12	38.7	34.3	Concrete
21	N	M 20	TMT Coated	12	47.1	40.7	Concrete
22	N	M 20	TMT Coated	16	42.2	37.8	Concrete
23	N	M 20	TMT Coated	16	51.0	46.1	Concrete
24	N	M 20	TMT Coated	16	52.0	49.1	Concrete
25	N	M 20	TMT Coated	20	50.5	48.6	Concrete
26	N	M 20	TMT Coated	20	38.3	31.9	Concrete
27	N	M 20	TMT Coated	20	47.1	45.6	Concrete
28	N	M 25	Mild Steel	12	31.9	31.9	Slip
29	N	M 25	Mild Steel	12	40.2	39.2	Slip
30	N	M 25	Mild Steel	12	34.8	34.8	Slip
31	N	M 25	Mild Steel	16	33.1	32.6	Slip
32	N	M 25	Mild Steel	16	38.3	37.0	Slip
33	N	M 25	Mild Steel	16	41.2		Slip
34	N	M 25	Mild Steel	20	47.6	46.8	Slip
35	N	M 25	Mild Steel	20	41.4	34.8	Slip
36	N	M 25	Mild Steel	20	45.6	43.9	Slip
37	N	M 25	TMT	12	39.5	35.3	Concrete
38	N	M 25	TMT	12	53.7	52.7	Concrete

39	N	M 25	TMT	12	40.5	42.9	Slip
40	N	M 25	TMT	16	68.7	61.8	Concrete
41	N	M 25	TMT	16	47.8	47.3	Concrete
42	N	M 25	TMT	16	48.3	48.3	Concrete

SR.No.	Type of Mix	Grade	Type of Bar	Dia. Of Bar (mm)	Max. Load (kN)	Load @ 0.025mm slip (kN)	Type of failure
43	N	M 25	TMT	20	49.5	48.3	Concrete
44	N	M 25	TMT	20	62.8	-	Concrete
45	N	M 25	TMT	20	50.0	46.8	Concrete
46	N	M 25	TMT Coated	12	42.4	41.0	Concrete
47	N	M 25	TMT Coated	12	49.8	48.1	Concrete
48	N	M 25	TMT Coated	12	58.4	37.5	Concrete
49	N	M 25	TMT Coated	16	40.5	36.8	Slip
50	N	M 25	TMT Coated	16	55.7	50.5	Concrete
51	N	M 25	TMT Coated	16	73.3	66.5	Concrete
52	N	M 25	TMT Coated	20	51.5	49.5	Concrete
53	N	M 25	TMT Coated	20	57.1	51.3	Concrete
54	N	M 25	TMT Coated	20	50.8	48.8	Concrete
55	N	M 30	Mild Steel	12	62.8	30.2	Slip
56	N	M 30	Mild Steel	12	32.1	29.9	Slip
57	N	M 30	Mild Steel	12	33.8	33.8	Slip
58	N	M 30	Mild Steel	16	33.6	28.7	Slip
59	N	M 30	Mild Steel	16	35.3	33.4	Slip
60	N	M 30	Mild Steel	16	26.0	25.5	Slip
61	N	M 30	Mild Steel	20	49.1	45.9	Slip
62	N	M 30	Mild Steel	20	38.0	23.3	Slip
63	N	M 30	Mild Steel	20	32.1	29.4	Slip
64	N	M 30	TMT	12	37.8	36.8	Slip
65	N	M 30	TMT	12	50.8	28.2	Slip
66	N	M 30	TMT	12	56.9	47.3	Concrete
67	N	M 30	TMT	16	53.5	53.5	Concrete
68	N	M 30	TMT	16	44.9	44.6	Concrete
69	N	M 30	TMT	16	53.2	51.0	Concrete
70	N	M 30	TMT	20	47.1	47.1	Concrete
71	N	M 30	TMT	20	51.5	50.5	Concrete
72	N	M 30	TMT	20	50.5	50.5	Concrete
73	N	M 30	TMT Coated	12	45.1	38.0	Concrete
74	N	M 30	TMT Coated	12	47.6	39.7	Concrete
75	N	M 30	TMT Coated	12	56.4	35.8	Concrete
76	N	M 30	TMT Coated	16	63.3	36.5	Concrete
77	N	M 30	TMT Coated	16	55.4	48.8	Concrete
78	N	M 30	TMT Coated	16	62.8	46.6	Concrete
79	N	M 30	TMT Coated	20	72.1	54.4	Concrete
80	N	M 30	TMT Coated	20	69.2	55.9	Concrete
81	N	M 30	TMT Coated	20	65.2	54.4	Slip
82	N	M 35	Mild Steel	12	34.6	34.1	Concrete
83	N	M 35	Mild Steel	12	36.5	36.1	Slip
84	N	M 35	Mild Steel	12	29.9	29.9	Slip
85	N	M 35	Mild Steel	16	48.3	43.2	Slip
86	N	M 35	Mild Steel	16	29.9	-	Slip
87	N	M 35	Mild Steel	16		-	Slip

88	N	M 35	Mild Steel	20	39.5	36.1	Slip

SR.No.	Type of Mix	Grade	Type of Bar	Dia. Of Bar (mm)	Max. Load (kN)	Load @ 0.025mm slip (kN)	Type of failure
89	N	M 35	Mild Steel	20	46.1	42.2	Slip
90	N	M 35	Mild Steel	20	42.4	42.2	Slip
91	N	M 35	TMT	12	59.4	59.1	Steel
92	N	M 35	TMT	12	59.1	45.4	Steel
93	N	M 35	TMT	12	60.8	51.0	Slip
94	N	M 35	TMT	16	57.6	58.4	Concrete
95	N	M 35	TMT	16	75.0	72.8	Concrete
96	N	M 35	TMT	16	69.7	69.4	Concrete
97	N	M 35	TMT	20	58.6	58.6	Concrete
98	N	M 35	TMT	20	63.3	63.3	Concrete
99	N	M 35	TMT	20	65.7	65.7	Concrete
100	N	M 35	TMT Coated	12	57.4	27.5	Slip
101	N	M 35	TMT Coated	12	57.4	29.4	Slip
102	N	M 35	TMT Coated	12	52.7	30.9	Slip
103	N	M 35	TMT Coated	16	54.7	35.8	Concrete
104	N	M 35	TMT Coated	16	48.3	38.5	Concrete
105	N	M 35	TMT Coated	16	60.3	44.9	Concrete
106	N	M 35	TMT Coated	20	38.3	38.3	Concrete
107	N	M 35	TMT Coated	20	50.5	48.6	Concrete
108	N	M 35	TMT Coated	20	55.9	54.0	Concrete
109	N	M 40	Mild Steel	12	39.2	38.3	Slip
110	N	M 40	Mild Steel	12	35.3	30.7	Slip
111	N	M 40	Mild Steel	12	31.1	25.8	Slip
112	N	M 40	Mild Steel	16	41.4	35.6	Slip
113	N	M 40	Mild Steel	16	35.8	31.4	Slip
114	N	M 40	Mild Steel	16	28.2	27.0	Slip
115	N	M 40	Mild Steel	20	33.1	31.9	Slip
116	N	M 40	Mild Steel	20	33.4	30.7	Slip
117	N	M 40	Mild Steel	20	32.4	29.4	Slip
118	N	M 40	TMT	12	54.0	-	Concrete
119	N	M 40	TMT	12	43.7	29.7	Concrete
120	N	M 40	TMT	12	50.5	42.4	Concrete
121	N	M 40	TMT	16	43.9	43.4	Concrete
122	N	M 40	TMT	16	50.0	40.2	Concrete
123	N	M 40	TMT	16	34.3	34.1	Concrete
124	N	M 40	TMT	20	49.8	49.1	Concrete
125	N	M 40	TMT	20	59.1	57.6	Concrete
126	N	M 40	TMT	20	71.9	47.6	Concrete
127	N	M 40	TMT Coated	12	43.7	25.8	Concrete
128	N	M 40	TMT Coated	12	48.1	22.3	Concrete
129	N	M 40	TMT Coated	12	58.6	29.4	Concrete
130	N	M 40	TMT Coated	16	58.6	32.4	Slip
131	N	M 40	TMT Coated	16	61.3	29.7	Slip
132	N	M 40	TMT Coated	16	54.7	28.2	Slip
133	N	M 40	TMT Coated	20	43.7	42.2	Concrete

134	N	M 40	TMT Coated	20	58.1	32.1	Concrete

SR.No.	Type of Mix	Grade	Type of Bar	Dia. Of Bar (mm)	Max. Load (kN)	Load @ 0.025mm slip (kN)	Type of failure
135	N	M 40	TMT Coated	20	56.4	47.3	Concrete
136	S[++]	M 20	Mild Steel	12	24.0	23.8	Slip
137	S	M 20	Mild Steel	12	24.8	28.9	Slip
138	S	M 20	Mild Steel	12	29.9	24.5	Slip
139	S	M 20	Mild Steel	16	26.7	26.2	Slip
140	S	M 20	Mild Steel	16	39.7	37.3	Slip
141	S	M 20	Mild Steel	16	47.8	42.7	Slip
142	S	M 20	Mild Steel	20	39.5	39.0	Slip
143	S	M 20	Mild Steel	20	48.8	44.1	Slip
144	S	M20	Mild Steel	20	32.4	31.4	Slip
145	S	M 20	TMT	12	43.9	25.8	Concrete
146	S	M 20	TMT	12	36.8	19.4	Concrete
147	S	M 20	TMT	12	43.7	30.9	Slip
148	S	M 20	TMT	16	45.6	44.6	Concrete
149	S	M 20	TMT	16	53.5	53.2	Concrete
150	S	M 20	TMT	16	42.9	42.7	Concrete
151	S	M 20	TMT	20	49.1	48.8	Concrete
152	S	M 20	TMT	20	67.4	67.2	Concrete
153	S	M 20	TMT	20	54.4	53.5	Concrete
154	S	M 20	TMT Coated	12	39.5	36.1	Concrete
155	S	M 20	TMT Coated	12	56.7	33.4	Slip
156	S	M 20	TMT Coated	12	41.9	22.8	Concrete
157	S	M 20	TMT Coated	16	48.6	46.1	Concrete
158	S	M 20	TMT Coated	16	45.6	42.4	Concrete
159	S	M 20	TMT Coated	16	43.9	40.7	Concrete
160	S	M 20	TMT Coated	20	55.4	48.1	Concrete
161	S	M 20	TMT Coated	20	43.7	41.9	Concrete
162	S	M 20	TMT Coated	20	59.1	59.1	Concrete
163	S	M 25	Mild Steel	12	37.3	35.6	Slip
164	S	M 25	Mild Steel	12	38.3	37.8	Slip
165	S	M 25	Mild Steel	12	37.0	36.1	Slip
166	S	M 25	Mild Steel	16	39.0	35.8	Slip
167	S	M 25	Mild Steel	16	39.0	34.6	Slip
168	S	M 25	Mild Steel	16	28.2	27.0	Slip
169	S	M 25	Mild Steel	20	39.5	39.5	Slip
170	S	M 25	Mild Steel	20	42.7	38.7	Slip
171	S	M 25	Mild Steel	20	47.6	44.9	Slip
172	S	M 25	TMT	12	41.2	41.0	Concrete
173	S	M 25	TMT	12	45.6	-	Concrete
174	S	M 25	TMT	12	36.5	36.1	Concrete
175	S	M 25	TMT	16	41.7	41.4	Concrete
176	S	M 25	TMT	16	45.6	45.4	Concrete
177	S	M 25	TMT	16	49.1	48.1	Concrete
178	S	M 25	TMT	20	32.6	32.6	Concrete
179	S	M 25	TMT	20	46.4	45.6	Concrete

180	S	M 25	TMT	20	54.2	54.2	Concrete

SR.No.	Type of Mix	Grade	Type of Bar	Dia. Of Bar (mm)	Max. Load (kN)	Load @ 0.025mm slip (kN)	Type of failure
181	S	M 25	TMT Coated	12	43.9	37.3	Concrete
182	S	M 25	TMT Coated	12	45.6	38.0	Concrete
183	S	M 25	TMT Coated	12	50.3	31.1	Slip
184	S	M 25	TMT Coated	16	51.3	44.1	Concrete
185	S	M 25	TMT Coated	16	48.1	41.7	Concrete
186	S	M 25	TMT Coated	16	48.8	40.5	Concrete
187	S	M 25	TMT Coated	20	54.0	-	Concrete
188	S	M 25	TMT Coated	20	50.8	44.1	Concrete
189	S	M 25	TMT Coated	20	52.0	43.9	Concrete
190	S	M 30	Mild Steel	12	29.4	28.4	Slip
191	S	M 30	Mild Steel	12	30.9	30.4	Slip
192	S	M 30	Mild Steel	12	31.6	31.4	Slip
193	S	M 30	Mild Steel	16	44.4	42.4	Slip
194	S	M 30	Mild Steel	16	40.0	39.5	Slip
195	S	M 30	Mild Steel	16	49.1	47.1	Slip
196	S	M 30	Mild Steel	20	49.5	44.1	Slip
197	S	M 30	Mild Steel	20	54.7	53.5	Slip
198	S	M 30	Mild Steel	20	51.7	51.7	Slip
199	S	M 30	TMT	12	50.3	50.3	Concrete
200	S	M 30	TMT	12	44.6	44.4	Concrete
201	S	M 30	TMT	12	45.4	45.4	Concrete
202	S	M 30	TMT	16	53.5	53.2	Concrete
203	S	M 30	TMT	16	59.4	58.1	Concrete
204	S	M 30	TMT	16	43.9	26.5	Concrete
205	S	M 30	TMT	20	59.8	59.6	Concrete
206	S	M 30	TMT	20	53.0	53.0	Concrete
207	S	M 30	TMT	20	55.4	55.4	Concrete
208	S	M 30	TMT Coated	12	45.4	38.3	Concrete
209	S	M 30	TMT Coated	12	56.7	46.8	Slip
210	S	M 30	TMT Coated	12	54.7	37.8	Slip
211	S	M 30	TMT Coated	16	40.0	39.7	Concrete
212	S	M 30	TMT Coated	16	49.1	41.2	Concrete
213	S	M 30	TMT Coated	16	41.2	39.0	Concrete
214	S	M 30	TMT Coated	20	57.4	48.8	Concrete
215	S	M 30	TMT Coated	20	50.5	55.7	Concrete
216	S	M 30	TMT Coated	20	48.3	47.8	Concrete
217	S	M 35	Mild Steel	12	32.1	30.4	Slip
218	S	M 35	Mild Steel	12	34.1	31.9	Slip
219	S	M 35	Mild Steel	12	-	-	Slip
220	S	M 35	Mild Steel	16	33.8	30.4	Slip
221	S	M 35	Mild Steel	16	40.0	33.4	Slip
222	S	M 35	Mild Steel	16	41.2	39.5	Slip
223	S	M 35	Mild Steel	20	48.6	42.2	Slip
224	S	M 35	Mild Steel	20	33.4	30.9	Slip
225	S	M 35	Mild Steel	20	44.6	40.2	Slip

SR.No.	Type of Mix	Grade	Type of Bar	Dia. Of Bar (mm)	Max. Load (kN)	Load @ 0.025mm slip (kN)	Type of failure
226	S	M 35	TMT	12	52.7	51.7	Concrete
227	S	M 35	TMT	12	59.1	57.4	Concrete
228	S	M 35	TMT	12	51.3	46.6	Concrete
229	S	M 35	TMT	16	51.5	50.8	Concrete
230	S	M 35	TMT	16	57.4	55.7	Concrete
231	S	M 35	TMT	16	58.1	56.4	Concrete
232	S	M 35	TMT	20	49.3	49.1	Concrete
233	S	M 35	TMT	20	52.0	51.7	Concrete
234	S	M 35	TMT	20	40.2	-	Concrete
235	S	M 35	TMT Coated	12	56.4	43.2	Slip
236	S	M 35	TMT Coated	12	48.1	27.0	Slip
237	S	M 35	TMT Coated	12	43.7	30.9	Slip
238	S	M 35	TMT Coated	16	41.0	40.0	Concrete
239	S	M 35	TMT Coated	16	43.9	35.6	Concrete
240	S	M 35	TMT Coated	16	46.8	38.3	Concrete
241	S	M 35	TMT Coated	20	43.4	21.1	Concrete
242	S	M 35	TMT Coated	20	54.2	14.5	Concrete
243	S	M 35	TMT Coated	20	45.9	40.0	Concrete
244	S	M 40	Mild Steel	12	32.9	32.9	Slip
245	S	M 40	Mild Steel	12	37.3	37.0	Slip
246	S	M 40	Mild Steel	12	36.3	36.3	Slip
247	S	M 40	Mild Steel	16	50.0	48.1	Slip
248	S	M 40	Mild Steel	16	49.8	48.8	Slip
249	S	M 40	Mild Steel	16	38.7	34.1	Slip
250	S	M 40	Mild Steel	20	44.6	44.6	Slip
251	S	M 40	Mild Steel	20	49.3	45.1	Slip
252	S	M 40	Mild Steel	20	47.1	47.1	Slip
253	S	M 40	TMT	12	55.7	54.0	Concrete
254	S	M 40	TMT	12	54.4	50.0	Concrete
255	S	M 40	TMT	12	40.2	48.8	Concrete
256	S	M 40	TMT	16	53.2	53.0	Concrete
257	S	M 40	TMT	16	46.1	46.1	Concrete
258	S	M 40	TMT	16	45.6	45.4	Concrete
259	S	M 40	TMT	20	46.4	46.4	Concrete
260	S	M 40	TMT	20	56.7	56.2	Concrete
261	S	M 40	TMT	20	57.6	57.4	Concrete
262	S	M 40	TMT Coated	12	47.6	34.3	Concrete
263	S	M 40	TMT Coated	12	57.6	29.2	Slip
264	S	M 40	TMT Coated	12	44.6	31.4	Concrete
265	S	M 40	TMT Coated	16	59.6	49.1	Concrete
266	S	M 40	TMT Coated	16	49.1	45.6	Concrete
267	S	M 40	TMT Coated	16	42.7	41.9	Concrete
268	S	M 40	TMT Coated	20	54.2	49.3	Concrete
269	S	M 40	TMT Coated	20	70.1	63.0	Concrete
270	S	M 40	TMT Coated	20	58.9	55.9	Concrete

271	SF^{+++}	M20	Mild Steel	12	40.0	40.0	Slip
272	SF	M 20	Mild Steel	12	39.0	38.0	Slip

SR.No.	Type of Mix	Grade	Type of Bar	Dia. Of Bar (mm)	Max. Load (kN)	Load @ 0.025mm slip (kN)	Type of failure
273	SF	M20	Mild Steel	12	30.7	30.7	Slip
274	SF	M 20	Mild Steel	16	39.7	39.2	Slip
275	SF	M 20	Mild Steel	16	28.2	28.2	Slip
276	SF	M 20	Mild Steel	16	37.8	34.1	Slip
277	SF	M 20	Mild Steel	20	48.8	48.3	Slip
278	SF	M 20	Mild Steel	20	34.1	34.1	Slip
279	SF	M 20	Mild Steel	20	38.0	38.0	Slip
280	SF	M 20	TMT	12	42.7	42.7	Concrete
281	SF	M20	TMT	12	39.0	39.0	Concrete
282	SF	M 20	TMT	12	60.3	56.4	Slip
283	SF	M 20	TMT	16	39.0	38.7	Concrete
284	SF	M 20	TMT	16	58.1	32.9	Concrete
285	SF	M20	TMT	16	41.9	35.1	Concrete
286	SF	M 20	TMT	20	51.0	51.0	Concrete
287	SF	M 20	TMT	20	47.6	47.6	Concrete
288	SF	M 20	TMT	20	47.6	47.6	Concrete
289	SF	M 20	TMT Coated	12	46.4	32.6	Concrete
290	SF	M 20	TMT Coated	12	45.9	35.6	Concrete
291	SF	M 20	TMT Coated	12	36.5	25.8	Slip
292	SF	M 20	TMT Coated	16	36.8	36.5	Concrete
293	SF	M20	TMT Coated	16	41.0	39.2	Concrete
294	SF	M 20	TMT Coated	16	52.0	37.3	Concrete
295	SF	M 20	TMT Coated	20	46.6	44.9	Concrete
296	SF	M 20	TMT Coated	20	39.5	39.2	Concrete
297	SF	M20	TMT Coated	20	51.7	49.1	Concrete
298	SF	M 25	Mild Steel	12	34.8	34.8	Slip
299	SF	M 25	Mild Steel	12	28.9	28.0	Slip
300	SF	M 25	Mild Steel	12	36.8	36.8	Slip
301	SF	M 25	Mild Steel	16	51.7	48.3	Slip
302	SF	M 25	Mild Steel	16	38.5	35.6	Slip
303	SF	M 25	Mild Steel	16	59.6	56.9	Slip
304	SF	M 25	Mild Steel	20	45.1	40.5	Slip
305	SF	M 25	Mild Steel	20	42.4	42.2	Slip
306	SF	M 25	Mild Steel	20	57.9	52.0	Slip
307	SF	M 25	TMT	12	57.9	49.8	Slip
308	SF	M 25	TMT	12	60.6	60.1	Concrete
309	SF	M 25	TMT	12	53.5	49.3	Concrete
310	SF	M 25	TMT	16	69.9	69.9	Concrete
311	SF	M 25	TMT	16	59.6	59.6	Concrete
312	SF	M 25	TMT	16	49.8	-	Concrete
313	SF	M 25	TMT	20	61.8	61.8	Concrete
314	SF	M 25	TMT	20	65.7	65.7	Concrete
315	SF	M 25	TMT	20	53.2	53.2	Concrete
316	SF	M 25	TMT Coated	12	54.7	34.8	Slip
317	SF	M 25	TMT Coated	12	49.3	48.3	Concrete

318	SF	M 25	TMT Coated	12	46.4	41.0	Concrete

SR.No.	Type of Mix	Grade	Type of Bar	Dia. Of Bar (mm)	Max. Load (kN)	Load @ 0.025mm slip (kN)	Type of failure
319	SF	M 25	TMT Coated	16	52.5	47.3	Concrete
320	SF	M 25	TMT Coated	16	53.2	53.2	Concrete
321	SF	M 25	TMT Coated	16	54.2	51.7	Concrete
322	SF	M 25	TMT Coated	20	58.4	55.9	Concrete
323	SF	M 25	TMT Coated	20	64.0	63.5	Concrete
324	SF	M 25	TMT Coated	20	56.2	53.7	Concrete
325	SF	M 30	Mild Steel	12	32.6	30.9	Slip
326	SF	M 30	Mild Steel	12	42.2	39.5	Slip
327	SF	M 30	Mild Steel	12	26.0	26.0	Slip
328	SF	M 30	Mild Steel	16	48.6	44.6	Slip
329	SF	M 30	Mild Steel	16	30.7	28.0	Slip
330	SF	M 30	Mild Steel	16	36.3	33.8	Slip
331	SF	M 30	Mild Steel	20	54.7	52.0	Slip
332	SF	M 30	Mild Steel	20	32.6	31.9	Slip
333	SF	M 30	Mild Steel	20	35.6	35.3	Slip
334	SF	M 30	TMT	12	54.0	54.0	Concrete
335	SF	M 30	TMT	12	53.0	52.2	Concrete
336	SF	M 30	TMT	12	48.1	45.4	Concrete
337	SF	M 30	TMT	16	54.4	54.2	Concrete
338	SF	M 30	TMT	16	55.9	55.9	Concrete
339	SF	M 30	TMT	16	67.7	67.4	Concrete
340	SF	M 30	TMT	20	63.3	62.3	Concrete
341	SF	M 30	TMT	20	73.8	68.7	Concrete
342	SF	M 30	TMT	20	64.0	63.8	Concrete
343	SF	M 30	TMT Coated	12	60.1	47.6	Concrete
344	SF	M 30	TMT Coated	12	47.8	46.1	Concrete
345	SF	M 30	TMT Coated	12	47.8	43.7	Concrete
346	SF	M 30	TMT Coated	16	50.3	48.6	Concrete
347	SF	M 30	TMT Coated	16	69.2	53.0	Concrete
348	SF	M 30	TMT Coated	16	47.3	45.6	Concrete
349	SF	M 30	TMT Coated	20	64.3	64.0	Concrete
350	SF	M 30	TMT Coated	20	43.2	43.2	Concrete
351	SF	M 30	TMT Coated	20	54.7	54.7	Concrete
352	SF	M 35	Mild Steel	12	33.1	32.4	Slip
353	SF	M 35	Mild Steel	12	34.6	34.6	Slip
354	SF	M 35	Mild Steel	12	32.6	30.2	Slip
355	SF	M 35	Mild Steel	16	44.1	40.2	Slip
356	SF	M 35	Mild Steel	16	32.1	31.6	Slip
357	SF	M 35	Mild Steel	16	40.7	40.0	Slip
358	SF	M 35	Mild Steel	20	48.8	38.7	Slip
359	SF	M 35	Mild Steel	20	37.3	37.3	Slip
360	SF	M 35	Mild Steel	20	48.3	48.3	Slip
361	SF	M 35	TMT	12	45.4	43.9	Concrete
362	SF	M 35	TMT	12	47.1	46.8	Concrete
363	SF	M 35	TMT	12	50.8	50.3	Concrete
364	SF	M 35	TMT	16	53.5	52.0	Concrete

SR.No.	Type of Mix	Grade	Type of Bar	Dia. Of Bar (mm)	Max. Load (kN)	Load @ 0.025mm slip (kN)	Type of failure
365	SF	M 35	TMT	16	48.3	48.3	Concrete
366	SF	M 35	TMT	16	58.1	57.9	Concrete
367	SF	M 35	TMT	20	66.5	66.5	Concrete
368	SF	M 35	TMT	20	50.8	50.8	Concrete
369	SF	M 35	TMT	20	51.5	51.5	Concrete
370	SF	M 35	TMT Coated	12	46.8	37.0	Concrete
371	SF	M 35	TMT Coated	12	48.6	44.1	Concrete
372	SF	M 35	TMT Coated	12	53.5	44.1	Concrete
373	SF	M 35	TMT Coated	16	60.6	60.6	Concrete
374	SF	M 35	TMT Coated	16	67.2	59.1	Concrete
375	SF	M 35	TMT Coated	16	59.4	52.0	Concrete
376	SF	M 35	TMT Coated	20	59.1	56.9	Concrete
377	SF	M 35	TMT Coated	20	59.6	57.9	Concrete
378	SF	M 35	TMT Coated	20	47.3	47.1	Concrete
379	SF	M 40	Mild Steel	12	40.7	40.7	Slip
380	SF	M 40	Mild Steel	12	23.5	23.5	Slip
381	SF	M 40	Mild Steel	12	41.2	41.0	Slip
382	SF	M 40	Mild Steel	16	58.1	49.5	Slip
383	SF	M 40	Mild Steel	16	48.3	44.6	Slip
384	SF	M 40	Mild Steel	16	48.1	45.1	Slip
385	SF	M 40	Mild Steel	20	48.3	47.1	Slip
386	SF	M 40	Mild Steel	20	54.7	50.8	Slip
387	SF	M 40	Mild Steel	20	54.2	50.0	Slip
388	SF	M 40	TMT	12	50.0	50.0	Concrete
389	SF	M 40	TMT	12	57.6	57.4	Concrete
390	SF	M 40	TMT	12	53.5	48.3	Concrete
391	SF	M 40	TMT	16	52.5	52.0	Concrete
392	SF	M 40	TMT	16	56.7	53.0	Concrete
393	SF	M 40	TMT	16	63.8	58.9	Concrete
394	SF	M 40	TMT	20	58.9	55.9	Concrete
395	SF	M 40	TMT	20	51.5	51.0	Concrete
396	SF	M 40	TMT	20	59.1	59.1	Concrete
397	SF	M 40	TMT Coated	12	50.3	29.2	Slip
398	SF	M 40	TMT Coated	12	56.2	31.6	Slip
399	SF	M 40	TMT Coated	12	52.7	46.4	Concrete
400	SF	M 40	TMT Coated	16	55.4	48.1	Concrete
401	SF	M 40	TMT Coated	16	54.2	41.9	Concrete
402	SF	M 40	TMT Coated	16	62.3	47.1	Concrete
403	SF	M 40	TMT Coated	20	51.0	38.3	Concrete
404	SF	M 40	TMT Coated	20	60.1	54.9	Concrete
405	SF	M 40	TMT Coated	20	66.0	38.7	Concrete

N^{+} – Normal Mix
S^{++} – Mix with Super-plasticizer
SF^{+++} – Mix with Fibres and Super-plasticizer

There were three types of failure pattern observed:

1. Slip of reinforcement bar
2. Splitting of concrete
3. Failure of reinforcement bar

E.1 SLIP OF REINFORCEMENT BAR

16 mm MILD STEEL

20 mm MILD STEEL

12 mm TMT BAR

12 mm TMT COATED

E.2 SPLITTING OF CONCRETE CUBE

The different types of cracks observed are shown below:

12 mm TMT

12 mm TMT Coated

CRACK PATTERN

12 mm TMT

12 mm TMT Coated

16 mm TMT   16 mm TMT

In some specimens splitting of concrete occurred as shown below:

20 mm TMT Coated   20 mm TMT Coated

20 mm TMT

The condition of the TMT Coated bar after failure of concrete is as shown below:

16 mm TMT Coated bar

20 mm TMT Coated bar

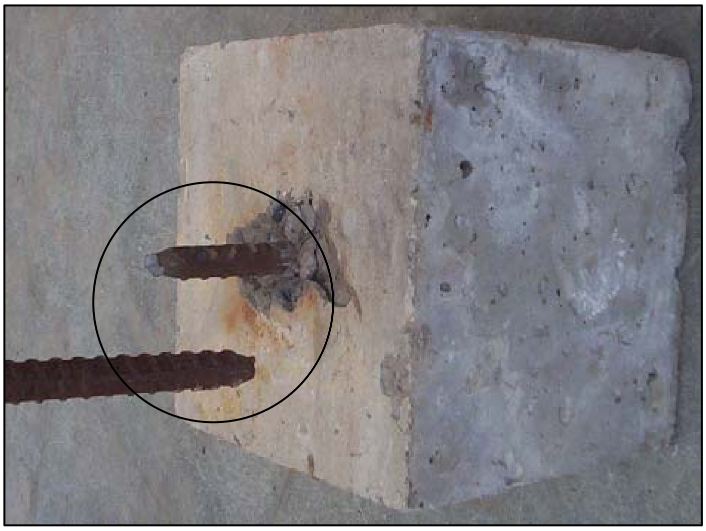
20 mm TMT Coated bar.

E.3 FAILURE OF REINFORCEMENT BAR

In only two specimens the failure of steel had occurred whose pictures are shown below:

12 mm TMT

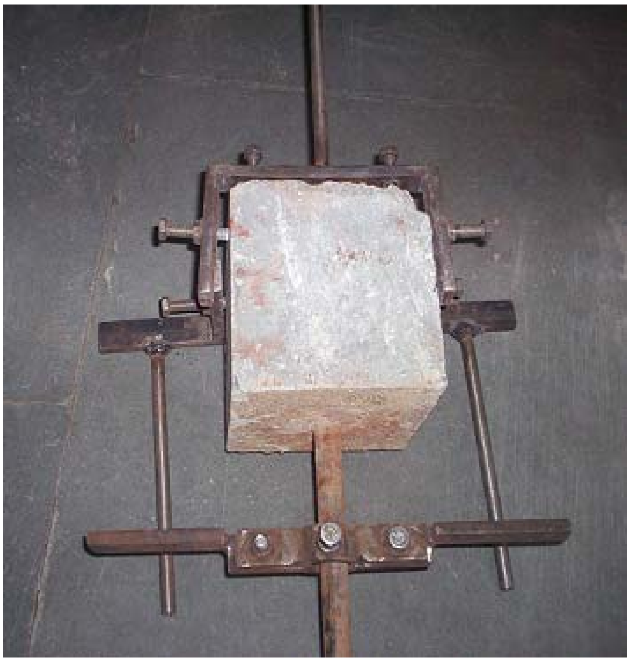
12 mm TMT



The pictures here show the casting work carried that was out.

Pictures below show the test for workability of fresh concrete.

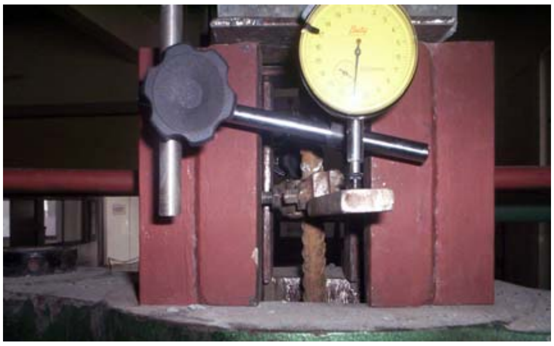
The picture above shows the curing of the pull out specimens

The picture above shows the fabrication carried out for the experiment.

The picture below shows the UTM machine on which testing was carried out.

The picture below shows the arrangement made while performing the test.



The photographs shows the specimens that were tested.