EXPERIMENTAL INVESTIGATION OF ANCHOR GROUP EFFECTS ON CONCRETE BREAKOUT STRENGTH WITHIN FIBER REINFORCED CONCRETE

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Abstract

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Supervising professor: Dr. Raad Azzawi

This research investigates the effect of anchor groups on concrete breakout strength within steel fiber reinforced concrete (SFRC) under tension load. High strength steel headed studs (F1554 Grade 105) in grouping action were cast-in-place within concrete specimens of different amounts of steel fibers. Four types of concrete mix designs were produced in the lab by using different amounts of steel fibers (0%, 0.5%, 1%, and 1.5%) by volume fraction of the mixture. The physical properties of steel fibers reinforced concrete were calculated through testing of specimens at the Civil Engineering Laboratory Building (CELB). In total, 12 cylinder specimens of 4-inch diameter and 8-inch height for compressive strength, 12 cylinder specimens of 6-inch diameter and 12-inch height for split tensile test, 12 beam specimens of 6*6*20 inch for modulus of rupture and flexural behavior. 4 concrete beams of 54*18*10 inch were cast-in-place with 12 sets of anchor groups were installed and tested after 28 days of curing. Embedment depth and distance between anchors for all group sets are kept constant. The effective embedment depth and the spacing between two anchors in grouping action are specified as per ACI 318-19.

The experiments revealed that the increase of the amount of the steel fiber fraction increases the concrete breakout strength of anchor groups in tension by 43.33%, 73.42%, and 81.1% for 0.5%, 1.0%, and 1.5% volume fraction of steel fibers respectively.

The research shows that the diameter of the concrete failure cone was reduced by increasing steel fibers. The failure angle increased by 14.6%, 48.5%, and 70% for 0.5%, 1.0%, and 1.5%. The concrete breakout strengths for anchor groups were compared with single anchors were tested at the same conditions. The anchors group effect reduces the concrete breakout strength by (19.45%, 16.8%, 15.7%, and 14%) for (0.0, 0.5, 1.0, and 1.5%) steel fiber compared with single anchor. Concrete compressive strength increased by (9.5%, 25.5%, and 17.5%) for (0.5%, 1%, and 1.5%) steel fibers respectively. The split tensile strength increased by (20.5%, 32.63%, and 35.35%) for (0.5%, 1%, and 1.5%) steel fibers and the flexural of concrete increased also by (3.7%, 9.8%, and 16.4%). Finally compare the experimental results of the concrete breakout strength with modified Concrete Capacity Design Method (CCD).

Table of Contents

Acknowledgments ………………………………………………………………………. ii

Abstract ……………………………………………………………………...………………iii

Table of Contents …………………………………………………..………………………v

List of Illustrations ……………………………………………………………..…...………viii

List of Tables ………………………………………………………………..……………..…x

CHAPTER ONE ……..…………………………………………………………………………1

INTRODUCTION………….……….…………………………………….………………1

1.1 Objectives……………………………………………………………………………4

1.2 Research Contribution………………………………………………………………...5

1.3 Outline of Thesis………………………………………………………………………5

CHAPTER TWO..………………………………………………………………………………7

LITERTURE REVIEW…………………………………..………………………………….7

2.1 Previous Research and Design Practices…………………………………………..……7

2..1.1 Concrete Grouping Anchors…….……………………………………………….....7

2..1.2 Steel Fiber Reinforced Concrete (SFRC)……………………… ……………….17

2.2 Advantages vs Disadvantages of Steel Fiber in Concrete…………………………19

CHAPTER THREE……………………………………………………………………………21

EXPERIMENTAL WORKS…………………………………………………………………..21

3.1 Fabrication of Test Specimens……………………….……………………………..21

3.1.1 Design of Formwork specimens……………………………………………………21

3.1.2 Preparing of Formwork…………………………………………………………...23

3.1.3 Material and Mix Design…………………………………………………………….24

3.1.4 Casting of Concrete…………………………………………………………………27

3.2 Test Set-Up ………………..…………………………………………………………30

3.2.1 Cylinder Compression Test…………………………………………………...30

3.2.2 Cylinder Split Tensile Test……………………………………………………. .33
3.2.3 Flexural Beam Test…………………………………………………………………36
3.3 Anchor Groups Pull-out Test……………………..…………………………………38
CHAPTER FOUR…………………………………………………………………………….46
EXPERIMENTAL RESULTS ………………………………………………………………46
4.1 Results of Compression Test………………………………………………………..46
4.1.1 Compression Test Data……………….…………………………………… ……..46
4.1.2 Compression Test Results…………………………………………………………47
4.2 Results of Split Tensile Test…………………………………………………………48
4.2.1 Tensile Test Data……………………………………………………………………48
4.2.2 Tensile Test Results………………………………………………………………...49
4.3 Results of Modulus of Rupture……………………………………………………...50
4.3.1 Modulus of Rupture Test Data……………………………………………………..50
4..3.2 Modulus of Rupture Test Results…………………………………………………51
4.4 Concrete Breakout and Grouping Anchors Test Results……………… …………..53
4.4.1 Concrete Breakout Strength in Tension Data…………………………………….53
4.4.2 Ultimate Tensile Load of Grouping Anchors……………………………………...54
4.4.3 Concrete Breakout Cone, Diameter and Angle of Failure………………………55
4.5 Anchor Groups vs Single Anchors in Tension Test……….……………………...57
4.6 Experiment Summary…………………..…………………………………………60
4.6.1 Experiment data and Results……………………………………………………60
4.7 Discussion of Results…………………………………………………………………...61
4.7.1 Small Specimen Contributions…………………..………………………………61
4.7.2 Anchorage Presumptions and Hypothesis………………………………………..61
CHAPTER FIVE……………………………………………………………………………67
CONCLUSIONS AND RECOMMENDATIONS ……...…………………………… ………..67

5.1 Conclusions……………………………...……………………………………………67

5.2 Research Contribution and Impact.……………………………………………...68

5.3 Recommendations for Further Researches……………..…………………………...69

APPENDIX A.…………………………………………………………………………….70

List of Equations……………………………………………………………………..70

Example……………………………………………………………………………….70

REFERENCES……………………………………………………………………………..71

LIST OF ILLUSTRATION

Figure 1.1 Type of Steel Fiber in This Study………. ………………..……………………3

Figure 2.1 The Concrete Cone Failure and Angle of Failure..…………..…………………10

Figure 2.2 Types of Anchors (Post-installed and Cast-in-place)……………………………14

Figure 2.3 Types of Failure Mods of Anchors in Tension……………...………………….14

Figure 2.4 Two Types of Steel Fiber used in previous Research.……..……………………18

Figure 3.1 Specimen Plan View……………………………………..………………..….21

Figure 3.2 Specimen Section (A-A)………………………………..…………….…….22

Figure 3.3 Specimen Section (B-B)…………..……………………..…………………….22

Figure 3.4 Stages of Timber Formwork Specimens..……………….……………………..23

Figure 3.5 On-Site Concrete Mix…………….……………………..…….………………24

Figure 3.6 Cylindrical and Beam Specimens…..…………………..………………………25

Figure 3.7 Type of Steel Fiber OL 13/0.2……………………………..……………………26

Figure 3.8 SFRC during the Pouring Day and After…….……………..……………………27

Figure 3.9 Slump Test On-Site………………..…………………..………………………28

Figure 3.10 Slump Test for Different Mixtures…….…………………..……………………29

Figure 3.11 Concrete Specimens in the Curing Room……………..…………………….…30

Figure 3.12 Compression Test Set-Up………………..……………..……….…………31

Figure 3.13 Compression Failure vs Different SFRC……………………………….……32

Figure 3.14 Split Tensile Test Set-Up……………..………………..………………………33

Figure 3.15 Split Tensile Failure vs Different SFRC………………………………………34

Figure 3.16 Split Tensile Failure vs Different SFRC….……………..……………………35

Figure 3.17 Flexural Test Set-Up……………………..……………..………………...36

Figure 3.18 Flexural Failure vs Different SFRC………….……………..……………………37

Figure 3.19 Steel Headed Stud (F1554 G105)……...……………..……………………38

Figure 3.20 Pull-out Test Set-Up……………………..……………..……………………39

Figure 3.21 Pull-out Test Set-Up On-site……………………..…………..……….……….40

Figure 3.22 Load Cell…………………………………….……………..……………………40

Figure 3.23 Research Team During the Test Day……….……………..……………………41

Figure 3.24 Concrete Breakout Failure (0.0% SFRC)……..…………..…………….….…42

Figure 3.25 Concrete Breakout Failure (0.5% SFRC)…...……………..……………………43

Figure 3.26 Concrete Breakout Failure (1.0% SFRC)………...………..……………………44

Figure 3.27 Concrete Breakout Failure (1.5% SFRC)………...………..……………………45

Figure 4.1 Average Compressive Strength vs SFRC………………..……………………47

Figure 4.2 Average Tensile Strength vs SFRC ……………………...…..……………………49

Figure 4.3 Average Flexural Strength vs SFRC ……………………..……………………51

Figure 4.4 Summary of Average Strength vs SFRC…………………..……………………53

Figure 4.5 Average Concrete Breakout Strength vs SFRC.………..……………………55

Figure 4.6 Average Cone Diameter vs SFRC….……………………..……………………56

Figure 4.7 Average Angle of failure vs SFRC….……………………..……………………57

Figure 4.8 Concrete Breakout Strength of Anchor Groups and Single Anchor vs SFRC…………………………………………………………….…………………………59

Figure 4.9 Modification Factor (Z) vs SFRC…………………………..……………………64

Figure 4.10 Concrete Breakout Strength (Nominal vs Experimental)..……………………66

LIST OF TABLES

Table 1.1 The Breakdown Structure of The Research……………..……......………………..4

Table 3.1 Mix Properties of The Concrete Mixture….………………..……......…………...…..25

Table 3.2 Properties of Steel Fiber………………………………..……......……………....26

Table 3.3 The Weight of Steel Fiber for Each Percentage..…….……......………………..26

Table 3.4 The Slump Test Value for Different Percentage of Steel Fiber....……….……..29

Table 4.1 Compressive Strength Test Data……………………..……......………………..46

Table 4.2 Split Tensile Strength Test Data ………………..……......…………..…..………..48

Table 4.3 Flexural Strength Test Data ……….………………………..……......……….……..50

Table 4.4 Summary of Strength Results for Different SFRC…….……......………….....…..52

Table 4.5 Concrete Breakout Strength Results for Different SFRC…......………………..…..54

Table 4.6 Concrete Cone Diameters and Angle of Failure Test Data........………...……..56

Table 4.7 Average Concrete Breakout Strength of Anchor Groups vs 2 Single Anchors

………………..……......…………………………………………...……………………..58

Table 4.8 The Steel Fiber Modification factor……………………..……......………………..64

Table 4.9 Concrete Breakout Strength from Experiment and Modified CCD..…….……..65

CHAPTER ONE

INTRODUCTION

In the construction industry, concrete is most used as the foundation for most structures. Concrete foundations transfer the loads from the superstructure to the soil underneath. The concrete is assumed to be a brittle material with low tensile strength thus the brittleness of the material can be reduced by improving the behavior of concrete with the addition of fibers. Using an adequate amount and appropriate shape of steel fibers increases the tensile strength and the ductile behavior of the concrete matrix. In many structural applications, the attachments of the structural elements to the concrete can be transmitted by using of anchorage. So, the concrete anchors serve a unique purpose in structural design and construction. Hence, understanding the behavior of the anchor groups in tension will be studied in this research.

Modern fastening technologies became important in the field of civil and structural engineering. Anchorage in concrete constructions is used in many structures, concrete anchors and headed studs used to connect structural steel members and the concrete member. Concrete anchor connections are a critical component of load transfer between steel and concrete members affecting structural performance. There are various types of failures of anchored connections that can occur under tension, shear, or combined tension-shear loading.

There are two main types of anchors: cast-in-place anchorages, which are installed in structures during the formwork stage and before concrete pouring, and post-installed anchorages, which are placed in hardened concrete. Cast-in-place anchors include several shapes and sizes (Hex headed bolt, hooked J and L bolts, and welded headed stud). Hex headed stud is an anchor typically comes with a small washer and hex nut as specified in ASTM F1554 outlines with different grades but (F1554 G105) was used in this research.

Anchorage in concrete subjected to tension loads may fail due to anchor steel failure, pull-out failure, concrete cone failure. The concrete cone is one of the failure modes of anchors in concrete, loaded by a tensile force. The failure is governed by crack growth in concrete, which forms a typical cone shape having the anchor's axis as the revolution axis. A concrete breakout occurs when the applied load is resisted by the cone of influence greater than the force generated between concrete and steel anchor itself. In the case of a concrete breakout or concrete cone failure of anchor groups, the anchor spacing, effective embedment depth, and the concrete edge distance have a significant influence on the load-bearing capacity of the group. The concrete breakout strength of anchor groups was studied carefully in this research and comparing the results of failure with those obtained from the nominal concrete breakout strength based on the Concrete Capacity Design (CCD) Method as specified in ACI 318-19 and modifying the nominal concrete breakout strength of anchor groups with the modification factor related to the Steel Fiber Reinforced Concrete (SFRC).

Adding the steel fibers to the concrete mix to improve the fracture behavior of concrete. Thus, the brittle matrix of plain concrete (PC) can be improved to a composite material, which is reinforced by randomly oriented short, discontinuous steel fibers of geometry. The steel fiber reinforced concrete shows improved flexural tensile strength of the concrete under the tension load and this is an important factor affected on the concrete breakout strength. Adding steel fibers shows that the cone geometry changed in a way that the cone diameter decreased, and this is due to the increasing in the tensile strength of concrete.

The steel fiber reinforced concrete is a widespread technical solution in civil engineering, due to the advantages that it provides, in terms of economic savings when compared with conventional reinforced concrete. The steel fibers reduce the cracking in concrete due to shrinkage and thermal variations thus improving the durability of concrete structures.

SFRC is a composite material, combining a cementitious matrix with a discontinuous reinforcement, consisting of steel fibers randomly distributed in the matrix. Steel fibers can vary by class of concrete, type of fibers, and their shapes, length, diameter, and surface finish. There are many advantages of using the steel fibers in concrete, for example, increase the tensile strength and the ductility of concrete, reduced the shrinkage cracking and reduced concrete deformations improved the cohesion, and increased the toughness and fatigue strength. The steel fibers used in this study is (DRAMIX) OL 13/20 as shown in Figure (1.1). Using of this type of steel fiber because the one of the objectives of this study is to compare the experimental results of anchor groups with the single anchors obtained from another study by using the same type of steel fiber.

Figure 1.1 Type of Steel Fiber Used in This Study

1.1 **Objectives**

The main objective of this research is to investigate the effect of anchor groups on the concrete breakout strength within steel fiber reinforced concrete under tension load. As well as comparing the concrete breakout strength of anchor groups with single anchors. To meet this objective, four concrete specimens with different amounts of steel fibers were cast-in-place with 12 sets of anchor groups (F1554 Grade 105, steel-headed studs) were produced and tested at the Civil Engineering Laboratory Building (CELB) at the University of Texas in Arlington. Anchor groups were placed before pouring of concrete and all the specimens created from the design mixtures were also tested for their physical properties. Table (1.1) illustrates the breakdown structure of this research.

Table (1.1) The Breakdown Structure of the research

Concrete Beams Specimens	4 Beams (54"x18"x10") with 12 Sets of Cast-in-place Anchor Groups	3 Sets of Anchor Groups w/o (SFRC 0.0%)
		3 Sets of Anchor Groups with (SFRC 0.5%)
		3 Sets of Anchor Groups with (SFRC 1.0%)
		3 Sets of Anchor Groups with (SFRC 1.5%)
Specimens Testing	4"x8" (12 Cylinders) tested for Compressive Strength	Three cylinders of each mixture tested for (0.0%, 0.5%, 1.0%, and 1.5% SRFC)
	6"x12" (12 Cylinders) tested for Tensile Strength	Three cylinders of each mixture tested for (0.0%, 0.5%, 1.0%, and 1.5% SRFC)
	6"x6"x20" (12 Beams) tested for Flexural Strength	Three beams of each mixture tested for (0.0%, 0.5%, 1.0%, and 1.5% SRFC)

1.2 **Research Contribution**

The importance of this research is how the concrete breakout strength of anchor groups was increased in tension load and decreasing of the cost due to the use of the steel fibers in concrete. Using steel fibers increased the physical properties of the concrete itself like, increasing the compressive strength, tensile strength, and flexural strength. Thus, this research reduces the need for heavy concrete mass required to produce the same anchorage strength comparing with the strength without fibers. Overall, there are two main issues addressed in this research: the economy and providing more safety to the structures. Increase the strength of concrete allows to use of anchors with lower grades and this will lead to a decrease in the cost and no need for a heavy mass of concrete. As well as in many structural applications where the anchorage plays an important part to transfer the loads to the concrete for example (Guardrail in bridges) this will give the designers to consider the additional strength that came from the steel fiber and will allow more factor of safety.

1.3 **Outline of the Thesis**

The study is presented in this thesis through five chapters as follows:

Chapter 1- Introduction: This chapter illustrates the concept of concrete breakout behavior of anchor groups in tension and how the steel fibers influence on the strength.

Chapter 2- Literature Review: This chapter presents the concept of anchor groups, steel fiber reinforced concrete, and covers past researches on the concrete breakout with SFRC.

Chapter 3- Experimental Works: This Chapter covers the design requirements of anchor groups, the design of concrete mix within Steel fibers, and the testing of all specimens.

Chapter 4- Experimental Results: This chapter presents the test results and all the data of the specimens introduced previously.

Chapter 5- Conclusions and Recommendations: This chapter highlights the conclusions and recommendations by the researcher and the proposals for further researches.

CHAPTER TWO

LITERATURE REVIEW

2.1 Previous Research and Design Practices

Anchorage serves an important role in connecting and attaching various components of concrete structures. Anchors can be cast into concrete during placement of concrete. It is essential to understand the behavior of anchorages in SFRC and to validate the applicability of the current study for the design of anchorages for use in structural concrete. however, there are many researches available on the behavior of anchorages in SFRC. This chapter summarizes the work that has been conducted by other researchers on the anchor groups in SFRC and its structural performance and the concrete breakout strength of SFRC.

2.1.1 Concrete Grouping Anchors

A paper by (Tóth et al. 2019), presents the results of experimental investigations on tension and shear loaded steel anchors in normal-strength plain concrete (PC) and in SFRC. The comprehensive test program includes 62 pull-out and shear loading tests on single anchors and anchor groups. The results indicate that the fiber content has a positive effect on the load-displacement behavior of the anchorages, in general. Better utilization of fastening systems can be attained due to the more ductile behavior and due to the crack bridging mechanism of the SFRC. Furthermore, in certain applications and parameter combinations, the ultimate load in case of concrete failure higher in SFRC compared to PC. The performed experimental study includes tension and shear loading tests on both single anchors and on anchor groups to investigate the influence of steel fiber reinforcement on the concrete cone and concrete edge failure loads. Tests were carried out in normal-strength PC and in SFRC using 30 kg/m3 and 50 kg/m3 of steel fibers. Furthermore, centric (e = 0 mm) and eccentric tension tests (e = 60 mm, e = 120 mm) were carried out on anchor groups, composed on a single row of three anchors (1 × 3). Based on the presented new results and the comparison, the applicability of the CCD-Method is shown to be suitable and conservative for anchorages in SFRC. Based on the total number of 129 test results (62 new results, 67 from literature) available for fiber contents 0; 20; 25; 30; 40; 50; 60 and 80 kg/m3, a modification factor γ-fiber for increasing the concrete cone and concrete edge capacity was proposed to be (1.25). The test results on anchor groups in SFRC showed that the anchor group behavior is affected not only by the load-bearing capacity of the anchors and their geometrical arrangement but also by the load displacement behavior of the anchors.

Another paper by (Bokor et al. 2019), addresses the experimental study to investigate the load-displacement behavior of tension loaded anchor group configurations. Furthermore, the work aimed to generate an experimental database on the concrete cone failure of anchor groups under tension loading. The design of only rectangular anchor groups with regularly spaced anchors with a maximum of three anchors in a row is covered by the standards where the group consists of fasteners of the same type and size. Consequently, it is assumed in the design that all anchors within a group exhibit the same axial stiffness. Two different post-installed anchor systems were used during the experiments, namely: (i) Torque-controlled expansion anchor (size M12) and (ii) adhesive anchor with a bond strength of ca. 30–35 MPa (Epoxy mortar + 12.9 threaded rod of size M12 and M16). It was observed that when anchor groups are located near the concrete edge and are loaded eccentrically in tension, it makes a considerable difference whether the eccentricity of the load is away or close the edge. For the tested case, for the same value of load eccentricity, 26% higher loads were reached when the loading was away from the edge. The experiments on anchor groups subjected to biaxial eccentric loads pointed out that the calculated failure loads for anchor groups according to the current regulations of EN1992-4 are rather conservative. The investigations on anchor groups with varying base plate thickness showed the significant influence of the base plate stiffness on the concrete cone capacity and the non-linear load-displacement behavior of anchor groups. Finally, the test results and the investigation of concrete breakout bodies of the diverse anchor group configurations showed that also in the case of complex breakout bodies, a particular projected area of concrete can be attributed to each anchor.

A paper by (Qian et al. 2019), studied the investigation of the tensile capacity for anchor groups of cast-in-place headed anchors with high strength and deep embedment at the different spacing between anchors. Experimental tensile load tests were conducted on 12 reinforced concrete specimens for the anchor groups of cast-in-place headed 42CrMo anchor bolts of 36, 48, and 60 mm in diameter with an identical embedment of 35 times the anchor diameter. The spacing between the anchors of the test specimens varied from 2 to 5 times the outside diameter of the anchor. The construction of a specimen mainly consisted of the procedures of binding steel bars, fixing anchor bolts, supporting wall framework, pouring concrete, and removing template and maintenance. The ready-mixed sulfate resistant concrete with a 28-day 150-mm cubic compressive strength of 25MPa, which was transported from an industrial plant by mobile mixers to the site. The tensile load-displacement curves of the anchor groups, irrespective of the anchor spacing and diameter, followed the same pattern and can be simplified into three typical regions: an initial linear segment, a curvilinear transition, and a final linear sector. The interpreted load-carrying capacity of the elastic limit of an anchor group of cast-in-place headed anchors with high strength and deep embedment in reinforced concrete increased as the anchor spacing increased. All the three anchor bolts of each specimen were pulled out from the concrete column, and even at the applied maximum tensile load, the measured axial steel strains did not exceed the yield strain of 42CrMo alloy steel.

The design recommendations and guidelines regarding anchorage to the concrete are mainly proposed in (ACI 318-19). The design provisions in the ACI standards are generally based on the assumption of a ductile failure mode for cast-in-place anchors; that is, the tensile capacity of the anchor bolt is governed by the tensile yield and fracture of the anchor steel or by the tensile breakout of the concrete in which the anchor is embedded. The average breakout capacity of a headed anchor is determined by the Concrete Capacity Design (CCD) Method, and the breakout strength calculations are based on a model suggested in the Kappa Method. Figure (2.1) shows the concrete cone failure and how to determine the angle of failure (∅).

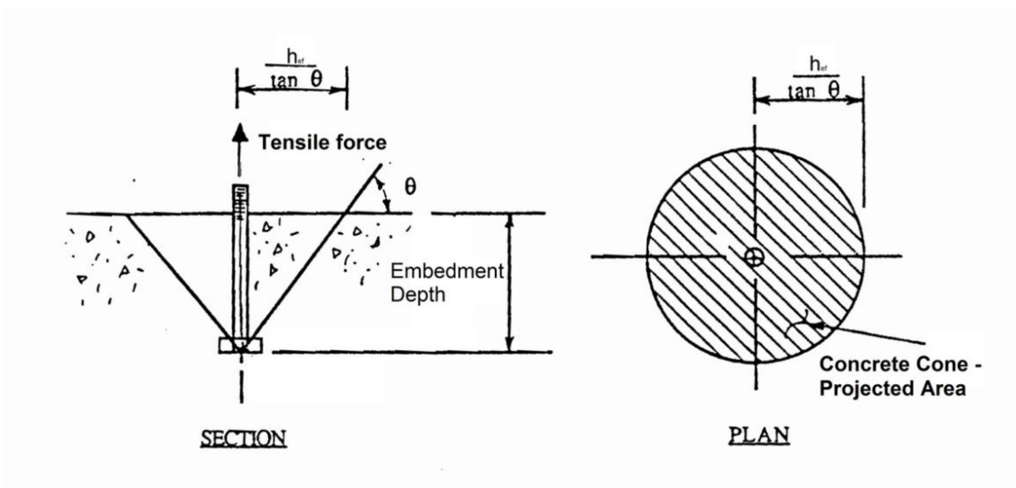


Figure (2.1) The Concrete Cone Failure and Angle of failure

The anchor distance from the concrete-free edge/s and adjacent anchor/s might affect the anchorage capacity and performance (Nilforoush R., 2017). The size effect of the concrete cone failure load is very important to ensure the ductile behavior of anchors (Lee N.H. et al. 2007). Cast-in-place anchors subjected to tension and combined tension and shear interaction, edge conditions, and group effects of cast-in-place anchors should be taken into consideration by examining the concrete failure modes.

According to (ACI 318-19) standard, the minimum center-to-center spacing between anchors should be four times the outside diameter of an anchor to preclude splitting failure of the surrounding concrete. (Klug et al. 2002) performed tension and shear loading tests using expansion anchors, undercut anchors, and bonded anchors in PC and SFRC. The embedment depth of the tested anchors ranged between 50 and 60 mm. No increase in the ultimate load for the tested anchor types was reported and it was concluded that the structural behavior of fastenings is not improved in SFRC (L = 35 mm, wavy steel fiber and L = 50 mm, d = 0.8 mm hooked-end steel fiber) compared to plain concrete. However, in most of the cases, the observed failure mode of the anchors was different from concrete breakout failure and therefore, the beneficial effects of anchoring in SFRC could not be shown. Furthermore, the authors assumed that the fiber orientation might have been parallel to the component surface. Consequently, the amount of fibers, which were intercepting the concrete breakout body, was not sufficient to improve the load-bearing behavior of the fastening system.

(Kurz et al. 2012) investigated the load-bearing behavior of four different fastening systems (bonded anchor, expansion anchor, bonded expansion anchor, concrete screw) under tension loading in PC and in SFRC. The embedment depth of the tested anchors ranged between 65 and 75 mm. The different installation parameters corresponded to the manufacturers' installation instructions. The observed failure modes included pull-out failure, steel failure, and concrete cone failure. However, when the bonded anchor was tested with an embedment depth to anchor diameter ratio of 5.8 (hef/d), the obtained failure mode was concrete cone and the increase in the ultimate load by adding 25 and 60 kg/m3 fiber to the basic mixture was (17 and 23%), respectively. The author concluded that the steel fiber content (L = 60 mm, d = 0.75 mm, hooked-end steel fibers) has no significant influence on the loadbearing and installation behavior of the tested fastening systems.

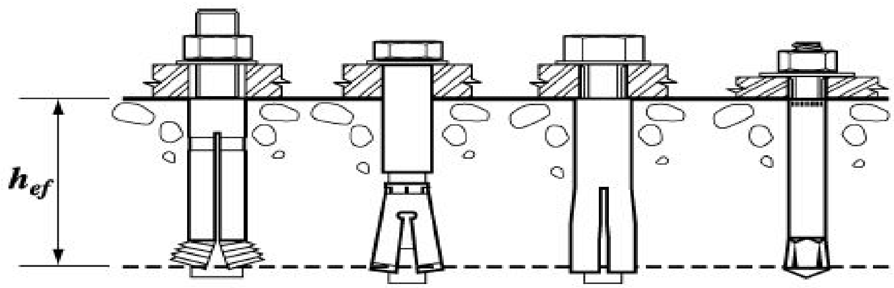
(Nilforoush et al. 2017) investigated the tensile behavior of single cast-in-place anchor bolts (hef = 220 mm, d = 36 mm) in plain and steel fiber-reinforced normal- and high-strength concrete (L = 60 mm, d = 0.92 mm, hooked-end steel fibers) and showed that the addition of 80 kg/m3 steel fibers to the concrete mixture leads to a significant increase (27–43%) in the tensile breakout capacity of headed anchors. The vertical anchor displacement at peak load and the ductility also showed a significant increase compared to the behavior in plain concrete. It was also established by (Nilforoush et al. 2017) that the Concrete Capacity Design (CCD) method underestimates the ultimate resistance of headed anchors in SFRC in case of concrete cone failure.

The ultimate concrete cone capacity of anchors under tension loading and the concrete edge failure of anchors under shear loading may be increased by adding steel fibers into the concrete mix. However, the positive influence of the improved mechanical properties of SFRC can be verified only if concrete related failure modes such as concrete cone failure or concrete edge failure occur. Therefore, the choice and combination of the different installation parameters such as embedment depth, edge distance, anchor diameter, steel strength and bond strength shall be made such that the premature pull-out or steel failure of the anchor can be avoided. If other failure modes than concrete failure such as pull-out, bond failure, steel rupture are decisive, the ultimate load remains unchanged. Therefore, the application of steel fibers may generally be more beneficial for the cast-in-place headed anchors and post-installed adhesive anchors (than the other types of anchors), which are more likely to fail by concrete-related failure modes such as concrete cone breakout, concrete splitting, and concrete edge failures (Toth et al. 2019).

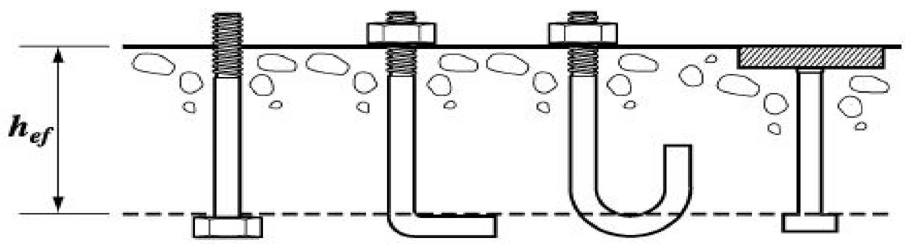
Concrete anchor connections are a critical component of load transfer between steel and concrete members affecting structural performance. Failures of anchored connections can occur under tension, shear, or combined tension-shear loading.

The anchorage systems' load-transfer mechanisms are typically identified as mechanical interlock, friction or bond, and the tensile and shear capacities of these fastening systems are based on various geometrical and material factors such as concrete strength, steel strength, number of anchor rods, effective embedment depth of the rods, rod diameter, and influence of an edge effect. Note that the use of the anchors is only optimal when the design considers not only the load direction as tension, shear, or a combination of tension and shear but also the failure modes (Eligehausen et al. 2012).

There is a large variety of anchors currently available to facilitate attachment to concrete structures. However, they can be broadly divided into two main categories according to the load transfer mechanism namely, cast-in and post-installed mechanical anchors, and bonded anchors. The working principle of cast-in and post-installed mechanical anchors is to transfer the tensile load into the concrete at the anchor head by bearing and/or friction. Bonded anchors, on the other hand, transfer the load through the adhesive layer along the entire bonded length to the concrete. Cast-in anchors that are installed in the formwork before casting the concrete provide enhanced anchorage properties. However, as they are non-adjustable, care should be taken in their location. In contrast, the use of post-installed anchors (expansion and undercut anchors) allows greater flexibility in attachments to concrete as they can be installed in a hole drilled in hardened concrete at almost any desired location (A.F. Ashour et al. 2004) as shown in Figure (2.2). Depending on the concrete strength, the embedment depth, the edge distance, and the steel strength of the anchor, cast-in and post-installed mechanical anchors loaded in tension exhibit different failure modes. Generally, five failure modes were experimentally identified (Steel Failure, Pullout Failure, Concrete Breakout Failure, Side Face Blowout Failure, and Concrete Splitting Failure) as specified in (ACI 318-19) as shown in Figure (2.3).



(a) Post-installed anchors



(b) Cast-in-place anchors

Figure (2.2) Types of Anchors (Post-Installed and Cast-In-Place)

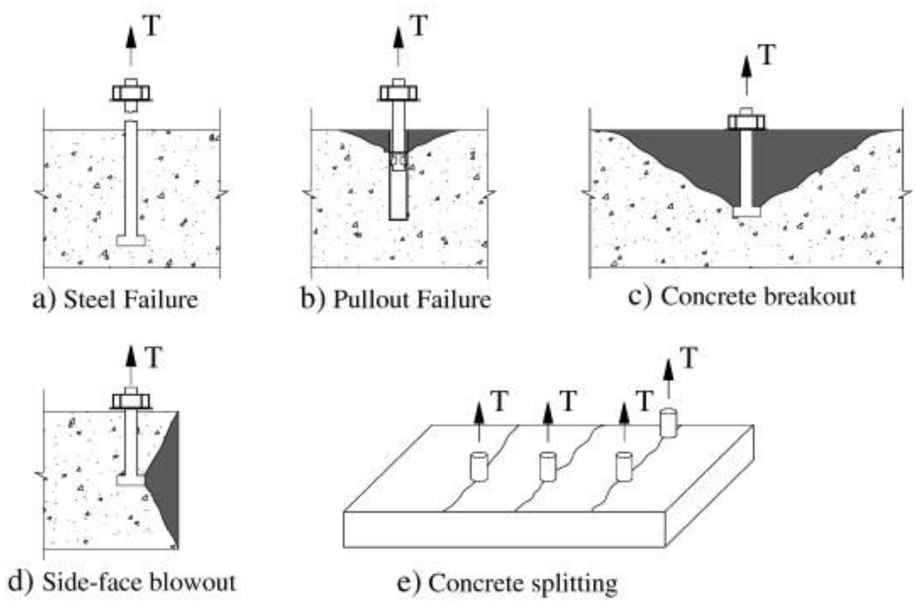


Figure (2.3) Types of Failure Mods of Anchors in Tension

Research by (AlTaan et al. 2012) studied the tensile behavior and strength of cast-in-place short-headed anchor bolts embedded in both normal concrete (NC) and steel fiber reinforced concrete (SFRC). Four volume fractions (vf =0.4%, 0.8%, 1.2%, and 1.6%), two aspect ratios (lf / df =19.63, 36.33), three-bolt diameters (db =8, 10, 12mm), and four embedment depths (hef =25, 37.5, 50, 62.5mm) were used. More than (108) specimens were tested under monotonic tensile loading. Only (90) specimens were failed by large concrete failure cone exceeding the dimensions of the specimen and the cone breaks into pieces in most cases (concrete failure), while the other specimens were failed by yielding or fracture of the bolts (steel failure). Test results showed that breakout capacity (Pu) of the anchors was significantly enhanced by the addition of steel fibers to concrete and the size of the failure cone in (SFRC) specimens were smaller than the size of failure cones in (NC). The researcher concluded that the angle of the cone ranged between (20-33°) for (SFRC), the failure of the samples having different volume fractions is the same as that for normal concrete, but the concrete failure cone was smaller compared with the cone size in normal concrete. As well as the Addition of steel fibers to concrete improves the compressive strength to some extent and the tensile strength to a greater extent. the increase in the compressive strength was (8, 11, 16, 19%) for (vf =0.4, 0.8, 1.2, 1.6%) respectively, and the corresponding increase in the splitting tensile strength was (16, 22, 27, 31%). Finally, the breakout capacity of headed anchor bolts embedded in concrete increased almost linearly with the volume fraction of the added steel fibers by up to 32%. The increase in the breakout capacity was found to be more for short fibers than for long fibers and the volume of the failure concrete cone for headed bolts embedded in fibrous concrete is less than that for headed bolts embedded in plain or unreinforced concrete.

A recent research done by (Karthik Vidyaranya 2019), investigates the effects of steel fibers on the concrete breakout of the cast-in-place headed stud anchors in tension. High strength anchors (F1554 G105) is used in the study for varying steel fiber dosage of (0.0, 0.5, and 1.0%) by volume fraction of concrete. four beam specimens (54”x16”x10”) with 3 headed studs (Single anchors no grouping action provided) in each beam were produced with the concrete mixture of (4000 psi) compressive strength, 4”x8” cylinders for compressive strength, 6”x12” cylinders for split tensile strength and 6”x6”x20” beams for the flexural test were created and tested for the physical properties of steel fiber reinforced concrete were calculated through various tests at the Civil Engineering Laboratory Building at the University of Texas at Arlington. The breakout strength of concrete in tension increased by (77% for 0.5% SFRC) and (107% for 1.0% SFRC) comparing with the concrete breakout strength of plain concrete (PC). Concrete Capacity Design Method (CCD) as specified in ACI 318-14 is modified to predict the concrete breakout capacity of the cast-in-place anchors. Finally, it is found that the diameter of concrete cone failure reduced as the dosage of steel fibers increased and the failure of angle increased as the dosage increased.

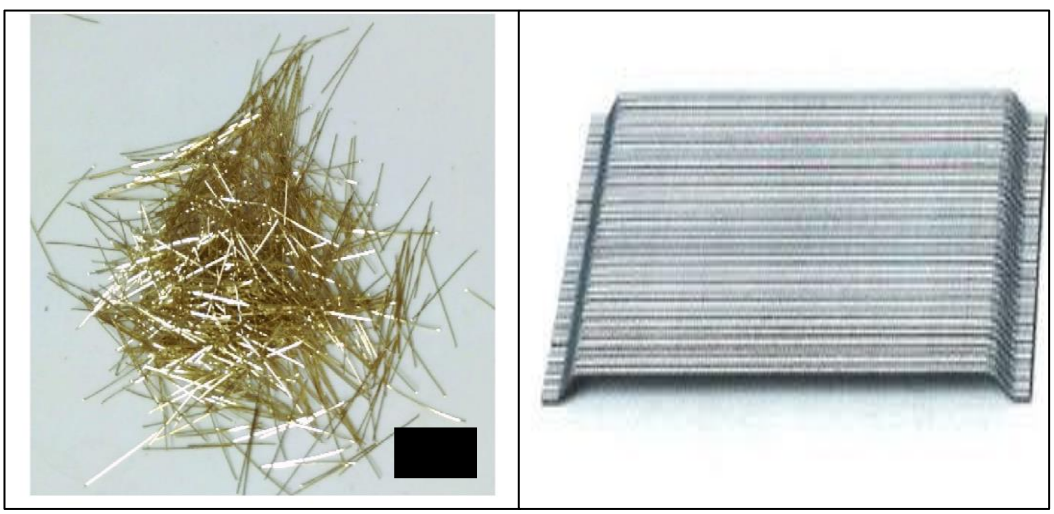
By reviewing the previous studies it is clear that the addition of steel fibers to the concrete mix leads to better mechanical and physical concrete properties including but not limiting to, higher fracture energy, reduced crack widths, increased the durability and increasing of the compressive strength to some extent and the tensile strength to a greater extent. Furthermore, the applicability of using the Concrete Capacity Design Method (CCD) to predict the concrete breakout strength of concrete within steel fibers under tension load and calculating the failure of the angle of concrete.

2.1.2 Steel Fiber Reinforced Concrete (SFRC)

Steel Fiber Reinforced Concrete (SFRC) is increasingly used in the construction of civil structures. (SFRC) is a composite material, combining a cementitious matrix with a discontinuous reinforcement, consisting of steel fibers randomly distributed in the matrix. SFRC is increasingly being adopted for the production of in-situ and prefabricated concrete structures as: auxiliary reinforcement for temporary load cases, partial substitution of conventional reinforcement, and total replacement of conventional reinforcement in elements in overall compression (M. di Prisco et al., 2004). The use of steel fibers for structural applications, as partial or total replacement of conventional reinforcement bars has become a popular solution for the construction of concrete infrastructure, due to its overall good durability and mechanical performance in statically indeterminate structures, e.g. by promoting the formation of several smaller cracks of greater tortuosity instead of few larger cracks (B. De Rivaz, 2010). However, the total replacement of conventional steel reinforcement is still controversial, especially when the long-term durability of SFRC under severe exposure conditions is addressed (E.S Bernard, 2004).

Steel fiber reinforced concrete is classified as a fiber reinforced composite. Fiber concrete can vary by class of concrete, type of fibers, and its shape, length, diameter, and surface finish (Katzer J. et al. 2012). For building structures such as floors, foundations of buildings or tunnel linings, it is often more favorable to use fiber reinforced concrete than conventional reinforced concrete or conventional concrete. Reinforcing the concrete by means of fibers increases the tensile strength of the concrete and the ductility (Kurihara N. et al. 2000). Other advantages of fiber reinforced concrete are reduced shrinkage cracking and reduced concrete deformations, increased toughness and fatigue strength, improved cohesion (Sucharda O. et al. 2018).

A paper by (Marcalikove et al. 2019), studied the mechanical properties of two types of Steel Fibers for reinforced concrete. In both cases, the same concrete mixture is used. The Steel Fibers used differ in shape. The first one is short and straight fiber and the second one is 3D steel fiber. Steel Fiber Reinforced Concrete was prepared at a dosage of 40 and 75 kg steel fibers/m3. The experiment includes determination of strengths, concretely compressive strength, a three-point flexural test, and a Splitting Tensile Strength test. Tests of steel fiber reinforced concrete include determination of compressive strength on cubes a typical size of 150 x 150 x 150 mm. Testing compressive strength on cubes is always perpendicular to the filling direction. Other tests included in the experimental program include splitting tensile strength tests. Two variants were chosen: perpendicular to the filling direction and parallel to the filling direction. Figure (2.4) shows the two types of steel fiber used in previous research.



Dramix® OL 13/20 Dramix® 3D 55/30BG

Figure (2.4) Two Types of Steel Fiber used in Previous research

Compressive strength testing included three samples for each variant. In total, 12 tests were performed. In the case of a 75 kg/m3 wire dosing variant, the compressive strength was higher. Compressive strength for 40 kg/m3 fibers was 36.4 MPa for Dramix OL13/20 and 38.5 MPa for Dramix 3D 55/30BG. In the case of Dramix OL13/20 fibers, the difference in the dosage of 40 and 75 kg/m3 was minimal. Flexural strengths were 3.1 MPa. A noticeable difference can be observed for Dramix 3D 55/30BG fibers. In this case, the strengths were 2.8 and 4 MPa. The flexural strengths with Dramix OL13/20 fiber were 4.7 and 5 MPa. For Dramix 3D 55/30BG fibers, the flexural strengths were 4.3 and 5 MPa. However, the stronger effect of the fibers is in the case of flexural strength and fracture energy.

In conclusion, to optimize structural design of steel fiber reinforced concrete members, it is essential to know their mechanical and fracture properties. It is worthwhile that these properties have to be evaluated on standard specimens and with standard recommendations. Different types of specimens, experimental test procedures and parameters have been proposed to analyze the post-cracking behavior in tension and toughness properties. From the previous studies it is clearly that the steel fibers have a positive impact once added to the concrete.

2.2 Advantages vs Disadvantages of Steel Fiber in concrete

The advantages by using of steel fibers in concrete can be summarized as following:

1. Increasing the compressive strength.
2. Increasing the tensile strength and the flexural strength as well.
3. High durability.
4. Reducing the shrinkage cracking in concrete.
5. Reducing the concrete deformations.
6. Increasing the toughness and fatigue strength.
7. Improving the cohesion.
8. More Ductility of the concrete.

Disadvantages can be summarized as following:

1. Reducing the workability of concrete.
2. Using of SFRC requires more accurate configuration as opposed to normal concrete.
3. Fiber-reinforced concrete tends to be more expensive than ordinary concrete.
4. Fiber-reinforced concrete is heavier than non-fiber concrete.
5. SFRC is difficult to self-mix. Generally, a contractor will mix and pour or spray this type of concrete.
6. Fibers in concrete make concrete very harsh and it is difficult to handle and pose problems during placement.
7. Fibers may get concentrated at few places which is not ideal and in turn results in poor quality of concrete.

CHAPTER THREE

EXPERIMENTAL WORKS

3.1 **Fabrication of Test Specimens**

3.1.1 **Design of Formwork Specimens**

Four types of specimens were prepared according to the test to be performed: Compression test, Spilt Tensile Test, Modulus of Rapture, and finally the anchor groups tension test. Four types of formwork specimens were designed according to the specifications of ACI 318-19. The size of the formwork beam is 54x18x10 inch ensures the anchor groups are satisfied. For the anchor groups pullout test, the formwork beams sizes were more than the specifications of ACI 318-19 to ensure that the edge distances and the spacing between two anchors in one set of tests are satisfied. This large size of beam ensures enough housing for the 3 sets of anchors group in one beam and allows to set up the hydraulic arm on the beam and distribute the compressive force back into the beam outside of the influence area of the anchors group. The effective embedment depth of the anchors group is (2.5 inch) and the spacing between two anchors is (5 inch) as per specifications of ACI 318-19 Chapter 17. See Figure 3.1, Figure 3.2, and Figure 3.3.

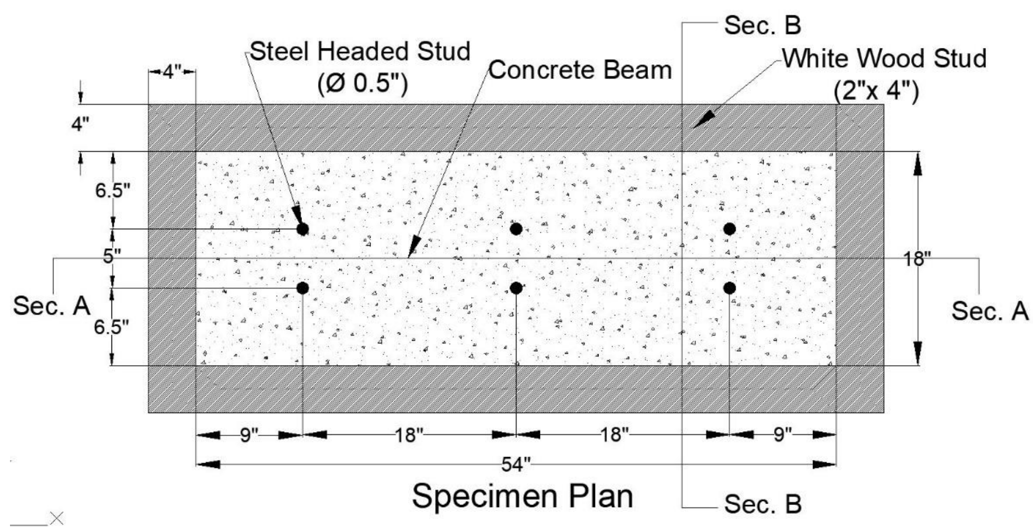


Figure 3.1 Specimen Plan View

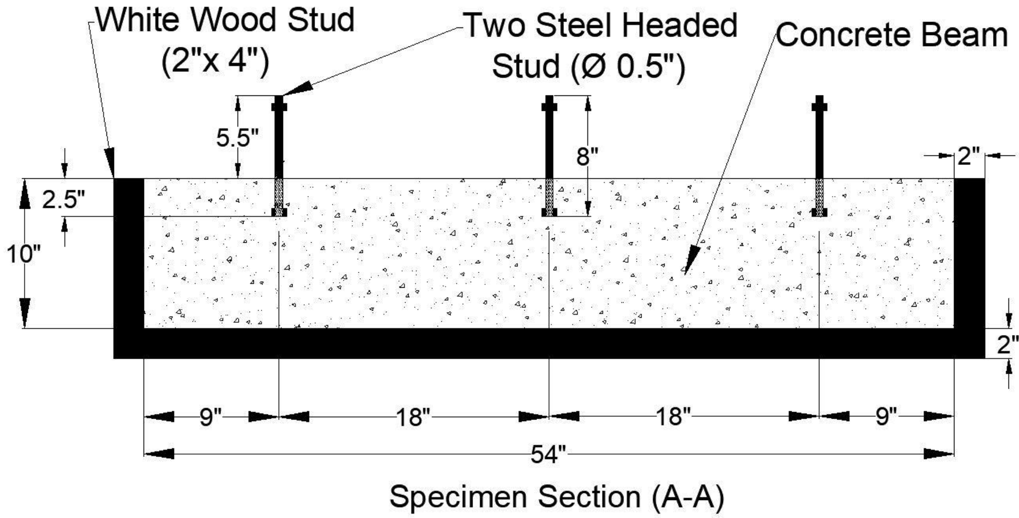


Figure 3.2 Specimen Section (A-A)

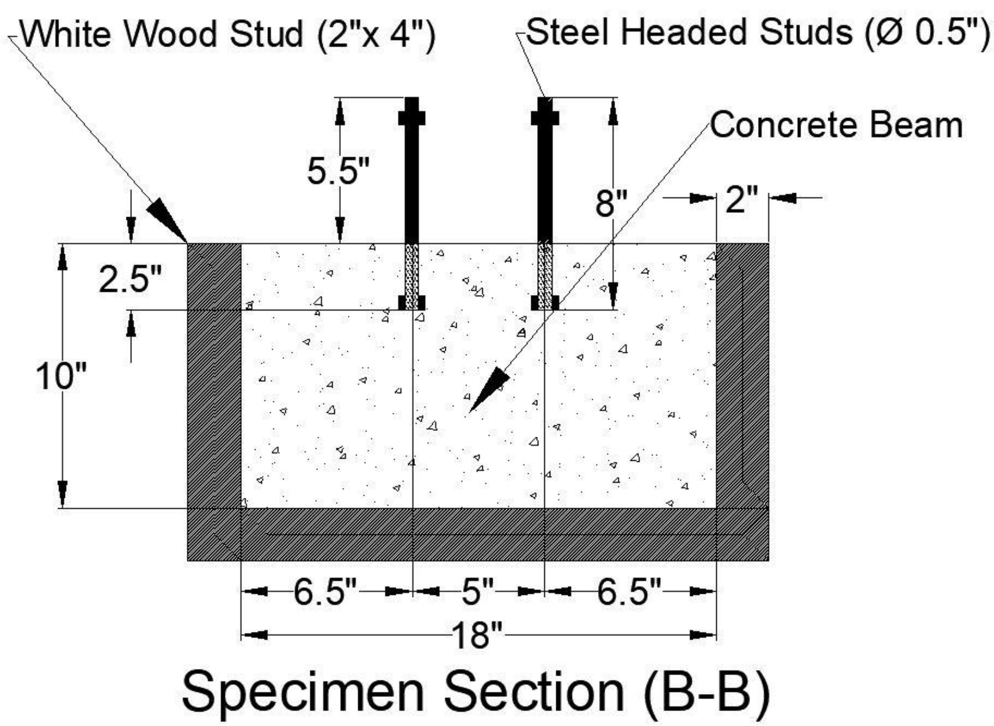


Figure 3.3 Specimen Section (B-B)

3.1.2 **Preparing of Formwork**

Timber formwork specimens were constructed for 4 concrete beams and illustrated in Figure (3.4). Preparing of a typical white wood section (2”x4”) as per the design of the formwork specimen. A Typical (2”x4”) wood section was cut and nailed together to create the formwork specimen. As well as (1/2”) plywood was cut and nailed to the sides of all the frame. Additional (1/2”) plywood was nailed to the exterior faces of the frame to ensure that the pressures from the concrete beam during the pouring stage will not affect the created frame. The interior panels of the formwork frame are oiled up to prevent any sticking between the frame and the poured concrete by using WD-40.

Figure 3.4 Stages of Timber Formwork Specimens

3.1.3 **Material and Mix Design**

The experimental study aims to understand the material's behavior and the action of the anchor groups under the tensile test. The concrete and steel fiber are the main materials used in this test; the concrete itself is a composite material that its constituents contain cement, aggregate, and water. The concrete mixture was prepared from the cement, sand, gravel, and adding of water. The concrete was mixed by mixers available at the CELB lab, Figure (3.5) shows the on-site concrete mix. The plain concrete (PC) is designed for a target compressive strength of (4000 psi), Table (3.1) illustrate the mix proportions of the concrete mixture.

Figure 3.5 On-Site Concrete Mix

For each batch, cylindrical specimens (4”x8” and 6”x12”) and beams (6”x6”x20”) were cast and tested after 28 days of curing to determine the compressive strength, split tensile strength, and flexural strength of the concrete. Figure (3.6) shows the cylindrical specimens and beams as well.

Figure 3.6 Cylindrical and beam specimens

Table (3.1) Mix Proportions of the Concrete Mixture

Component	Density (Ibs/cf.)	Weight (Ibs)	Volume (cf.)
Portland Cement II	196	771.2	3.93
Coarse Aggregate	161	1413	8.78
Fine Aggregate	176	1974.4	11.22
Water	62.4	380	6.1
Air	-		0.6
Concrete Mix Total		4538.6	30.63

The experiment was conducted to give sight into the real material behavior of the steel fiber reinforced concrete and the type of concrete breakout strength under the ultimate tensile load applied to the anchor groups. The straight steel fibers are used in this study, according to previous studies and recommendations of industrial companies that the weight fraction of steel fibers will vary from (0.5% - 2.0%). The type of steel fiber used in this study is (Dramix), Figure (3.7) shows the type of steel fiber, and Table (3.2) illustrate the properties of the steel fiber as well.

Figure 3.7 Type of Steel Fiber OL 13/0.21

Table (3.2) Properties of Steel Fiber

Type of Fiber	Length mm (in)	Diameter mm (in)	Aspect Ratio (L/D)	Tensile Strength N/mm2 (ib/in2)
Bright, High Carbon, wire/ straight	13 (0.51)	0.21 (0.0083)	13/0.21	2750 (398853.8)

The SFRC the same proportions are used with different amount of steel fibers; the addition of steel fiber is according to the percentage of steel fiber required multiplied by the total volume in (Ibs). Table (3.3) illustrates the weight of steel fiber for each concrete beam.

Table (3.3) The Weight of Steel Fiber for Each Percentage

0.0 % Steel Fiber	0.5 % Steel Fiber	1.0 % Steel Fiber	1.5 % Steel Fiber
Plain Concrete	**5.7 Ibs**	**11.4 Ibs**	**17.2 Ibs**

3.1.4 Casting of Concrete

The formworks and the small specimens are prepared by spraying the inside faces with WD-40, the WD-40 acts as a concrete releasing agent and prevents the sticking between the formwork and the poured concrete. The concrete was mixed by using of the mixers available at the CELB, the following steps are made to produce the concrete:

1- Adding of the coarse aggregate to the concrete mixer.
2- Adding of the fine aggregate to the mixture.
3- Adding of the Portland cement to the mixture and let the mix around 2-3 minutes.
4- Adding water gradually to the mixture to the appropriate amount base on the designed w/c ratio to obtain good workability.
5- In the case of SFRC, the steel fibers added (% by weight of concrete) before adding the water to allow the proper distribution of the fibers in the mixture. Figure (3.8) shows the concrete during the pouring stage and after that.

Figure 3.8 SFRC During the Pouring Day and After

The slump test was performed according to the ASTM C143 (Standard Test Method for Slump of Hydraulic-Cement Concrete). The slump value demonstrates the workability of the concrete. To measure the slump; the standard 8” base, 4” top, and 12” height slump cone was used. The slump cone is used on the steel base plate and the concrete is poured inside the cone for three layers. For each layer, the concrete is tamped with steel rod 24 times. When the cone is filled with concrete the top surface is made to be smooth. Then starting of lifting the cone within 5 seconds and the distance from the top of the cone to the top of poured concrete is the slump value. Figure (3.9) shows the slump test on-site.

Figure 3.9 Slump Test On-Site

It was discovered that with the same w/c ratio for all the concrete mixtures the slump value is changing. With the addition of steel fibers, the consistency of the mix was influenced hence the slump value decreases. The slump was decreasing as the percentage of the steel fibers increased and the workability of the SFRC was less than the plain concrete due to these reasons. This effect was more visible with the addition of a higher percentage of fibers, Table (3.4) illustrates the slump test values for a different amount of steel fiber, and Figure (3.10) shows the slump test for different mixtures.

Table (3.4) The Slump Test Value for Different percentage of Steel Fiber

Mixture	**PC (0.0% SF)**	**0.5% SF**	**1.0% SF**	**1.5% SF**
Slump Value	**8**	**6**	**5**	**4**

(0.0 % Steel Fiber)

(1.0 % Steel fiber)

Figure 3.10 Slump Test for Different Mixtures

After 24 hours the concrete specimens were de-molded, and the specimens were labeled with the type of concrete and cured inside the curing room with specific temperature to the date of the test (after 28 days). Figure (3.11) shows the concrete specimens in the curing room.

Figure 3.11 Concrete Specimens in the Curing Room

3.2 **Test Set-Up**

All tests were conducted on the testing floor of the Civil Engineering Laboratory Building at the University of Texas at Arlington. In this section, the cylinder compression test, split tensile test, flexural test, and finally, the anchor groups pull out the test are discussed for each one of these tests.

3.2.1 Cylinder Compression Test

The concrete cylinders (4"x8") are tested under a uniaxial compression load by using the (500 kips) compression machine based on the ASTM C39. The standard procedure the compression test was performed. The concrete specimens were loaded at a loading rate of (440 Ib/sec) (35 psi) and the ultimate load was recorded. Figure (3.12) shows the images of the compression test set-up and the instrumentation.

Figure 3.12 Compression Test Set-Up

After completing the concrete cylinder’s compression test it was clear that the compressive strength was increased by increasing the fraction of steel fibers. Increasing of the compressive strength from SFRC (0%) to SFRC (0.5%) is noticeable while the increase in strength from (0%) SFRC to (1.5%) SFRC is less than and this is because of increasing the air voids between the concrete and the steel fiber. Figure (3.13) shows the concrete cylinders compression failure for different types of SFRC.

(0.0 % SFRC)

(0.5 % SFRC)

(1.0 % SFRC)

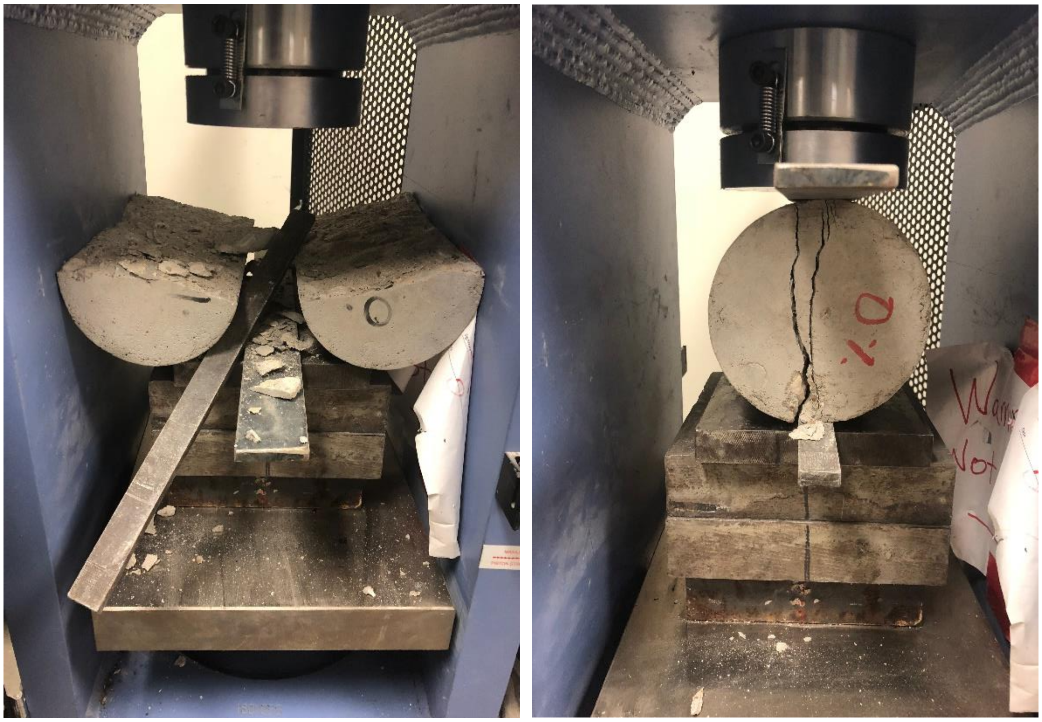
(1.5 % SFRC)

Figure 3.13 Compression Failure vs different SFRC

3.2.2 **Cylinder Split Tensile Test**

The concrete cylinders (6”x12”) are tested by using the (500 kips) compression machine based on the ASTM C496. The specimen was tested according to the standard procedure. In this test, the load was applied across the concrete cylinders and the specimens were loaded at an approximate loading rate of (500-700 Ib/sec) (150 psi/min) until the concrete specimens develop a tension crack along their diameter. The ultimate load due to the triaxial compression force is used in determining the split tensile strength, Figure (3.14) shows the tensile test set-up and the instrumentation. After completing this test, it was notified that the split tensile strength increased by increasing the fraction of the steel fibers and the increase for the strength from (0%-0.5%) has been more pronounced. The behavior of (1% SFRC and 1.5% SFRC) is more similar in the terms of strength. See Figure (3.15) and (3.16) shows the specimen's tensile failure for different types of SFRC.

Figure 3.14 Split Tensile Test Set-Up



(0.0 % SFRC)

(0.5 % SFRC)

Figure 3.15 Split Tensile Failure vs different SFRC

(1.0 % SFRC)

(1.5 % SFRC)

Figure 3.16 Split Tensile Failure vs different SFRC

3.2.3 **Flexural Beam Test**

Another indirect method of testing and evaluating the tensile strength of the concrete. The (6”x6”x20”) beams are tested based on the ASTM C78, the standard test method for the flexural strength of concrete. The test was (4-points) bending test and the clear span was set to (18”) and the upper bearer distance was set to (6”) from the center of the clear span. The concrete beams were loaded at an approximate loading rate of (100 Ib/sec) and the ultimate load was recorded to determine the modulus of rapture. Figure (3.17) shows the flexural test set-up and instrumentation.

Figure 3.17 Flexural Test Set-Up

The results show that the flexural strength for the concrete beams is increasing proportionally by the increase of the steel fibers. It was clear that the increase of steel fibers leads to the highest flexural strength. One of the most important factors that can be concluded from this test is the tensile capacity of the concrete beams. Figure (3.18) shows the flexural failure for different types of SFRC.

(0.0 % SFRC)

(0.5 % SFRC)

(1.0 % SFRC)

(1.5 % SFRC)

Figure 3.18 Flexural Failure vs different SFRC

3.3 **Anchor Groups Pull-out Test**

The testing of steel headed studs (BLK F1554 GRADE 105 ROD, 3” THREAD EACH) were performed at the CELB Building. The anchor groups were 8” length and 3” threaded and they were embedded 2.5” in the concrete beam. The three sets of anchor groups were placed at 18” between them and the distance between two anchors (5”) to provide grouping action as per the specifications of ACI 318-19, Ch.17. The edge distances are (9” and 6”) from each side according to the specifications of ACI 318-19 Ch.17. The anchor groups were placed in the wooden frame before the day of pouring by using (2”x4”) which was nailed to the frame and holes were drilled based on the requirements. Finally, the anchor groups were placed by using nuts (BLK A194-2H HVY HX NUT) as well as placed nuts on the other side of anchor groups which would be embedded in the concrete beam. Figure (3.19) shows the steel headed stud with the nuts.

Figure 3.19 Steel Headed Stud (F1554 G105)

The anchor groups were tested in accordance with ASTM E488 (Standard Test Methods for Strength of Anchors in Concrete Elements). The anchor groups were all tested individually set by set by placing a set-up which includes (steel frame, hydraulic ram, load cell, small steel plate, and extension steel rod). This set-up was used on all the anchor groups. The test set-up includes the following steps, Figure (3.20) and Figure (3.21) shows the test set-up:

1- Steel Frame: The reaction frame consisted of one steel plate (1” thickness) and four steel rod legs (9.5” height) and it supports the hydraulic ram.
2- Hydraulic Ram: Connected to the Hydraulic machine to pull-out the anchor groups.
3- Load cell: Records the tensile force applied to the anchor groups. The tensile force on the anchor groups would then be increased and controlled manually until the concrete failed. Figure (3.22) shows the load cell used in this test.
4- Extension Rod: Load was applied to the anchor groups through steel plate (1” thickness) and connected by the (1” Diameter)x(36” long high) strength steel rod running through load cell at the top of the ram.

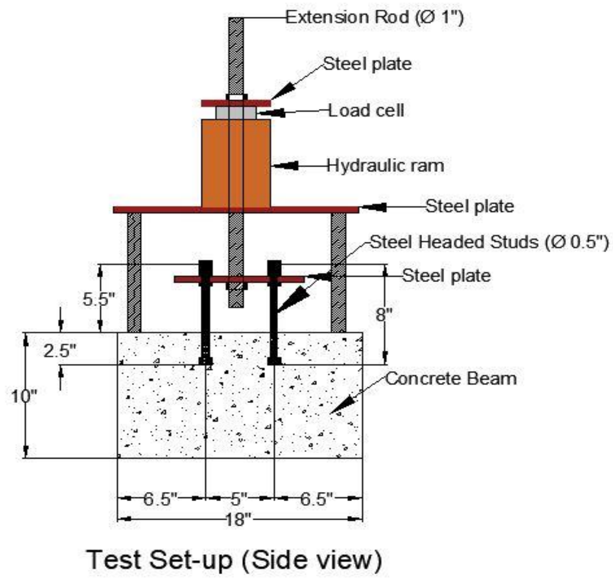


Figure 3.20 Pull-Out Test Set-Up

Figure 3.21 Pull-Out Test Set-Up (On-Site)

Figure 3.22 Load Cell

Figure (3.23) shows the research team at the CELB Building during the testing day.

Figure 3.23 Research Team during the test day

After the anchor groups had been tested and pulled out the ultimate tensile load applied on the anchor groups was recorded and the breakout/cracked area around the anchor groups was monitored and registered. Figures (3.24) to (3.27) show the concrete breakout and the anchor group's failure for different SFRC.

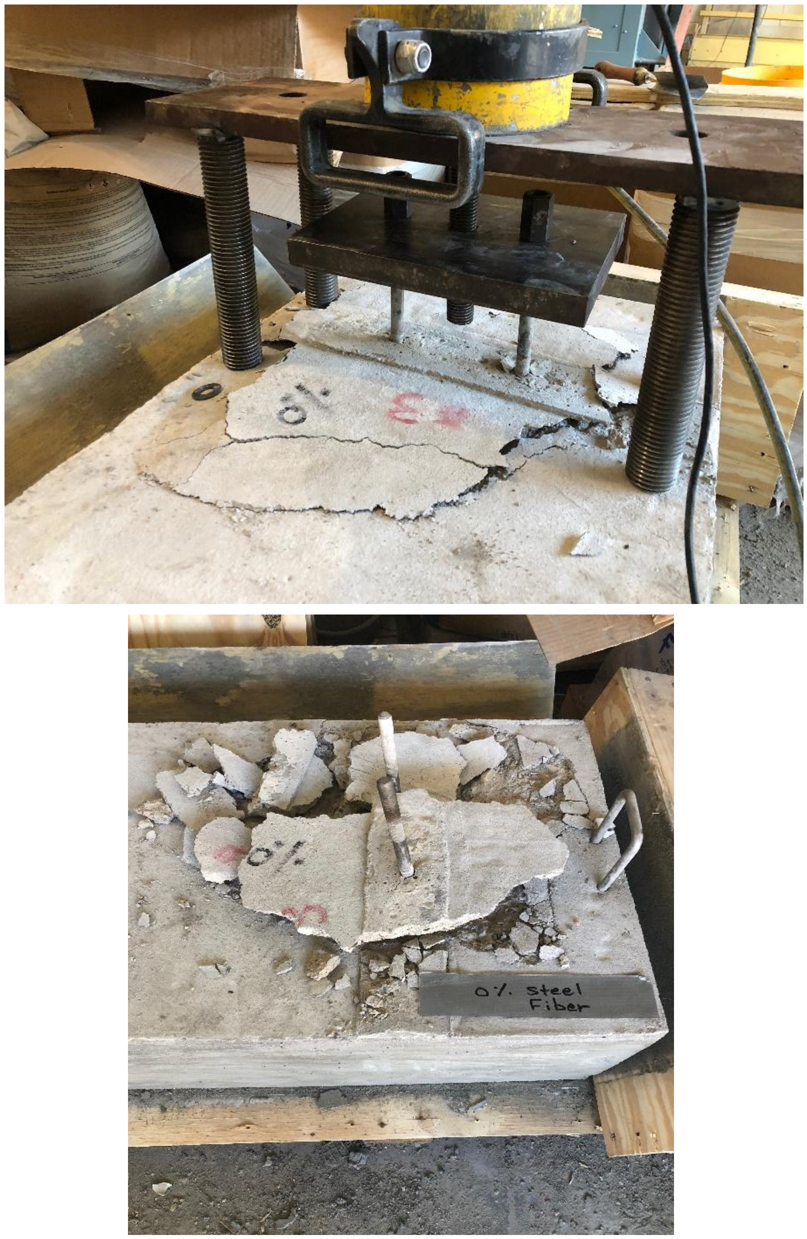


Figure 3.24 Concrete Breakout Failure (0.0% SFRC)

Figure 3.25 Concrete Breakout Failure (0.5% SFRC)

Figure 3.26 Concrete Breakout Failure (1.0% SFRC)

Figure 3.27 Concrete Breakout Failure (1.5% SFRC)

CHAPTER FOUR

EXPERIMENTAL RESULTS

4.1 **Results of Compression Test**

4.1.1 **Compression Test Data**

The compressive strength (fc`) was determined by using the following equation:

Fc` = P/ ($\pi r2$) (psi)

Where: (P) is the applied ultimate load in (Ibs)

(r) is the radius of the cylinder (2”). Table (4.1) illustrates the compression test results.

Table (4.1) Compressive Strength Test Data

Concrete Mix	Specimen No.	Ultimate Load (Ibs)	compressive Strength (psi)	Mean	Standard Deviation	C.V %	Average Strength (psi)
PC (0.0%)	1	53170	4231	4223.67	165.12	3.91	4224
	2	55100	4385				
	3	50950	4055				
SFRC (0.5%)	1	58870	4685	4624.67	58.14	1.26	4625
	2	58040	4620				
	3	57420	4569				
SFRC (1.0%)	1	68890	5482	5300.33	160.65	3.03	5300
	2	65050	5177				
	3	65870	5242				
SFRC (1.5%)	1	63060	5019	4961.67	60.18	1.21	4962
	2	61560	4899				
	3	62410	4967				

- C.V %: Coefficient of Variation

4.1.2 Compression Test Results

From the compressive strength values, the compressive strength has an increasing trend with the increase of a fraction of steel fibers in concrete. The increasing in the average strength from (0.0% SFRC-0.5%SFRC) is around (9.5%) and the increasing from (0.0%-1.0% SFRC) is around (25.5%) while the increasing from (0.0%-1.5%) is around (17.5%). This could be attributed to the air content of the concrete, which many researchers believe that the air content increases with the increase of the steel fibers volume fraction. Figure (4.1) shows the average compressive strength for different SFRC. The coefficient of variation (C.V%) is (1.21% - 3.91%) within the limits of ASTM C39 which is (7.8%).

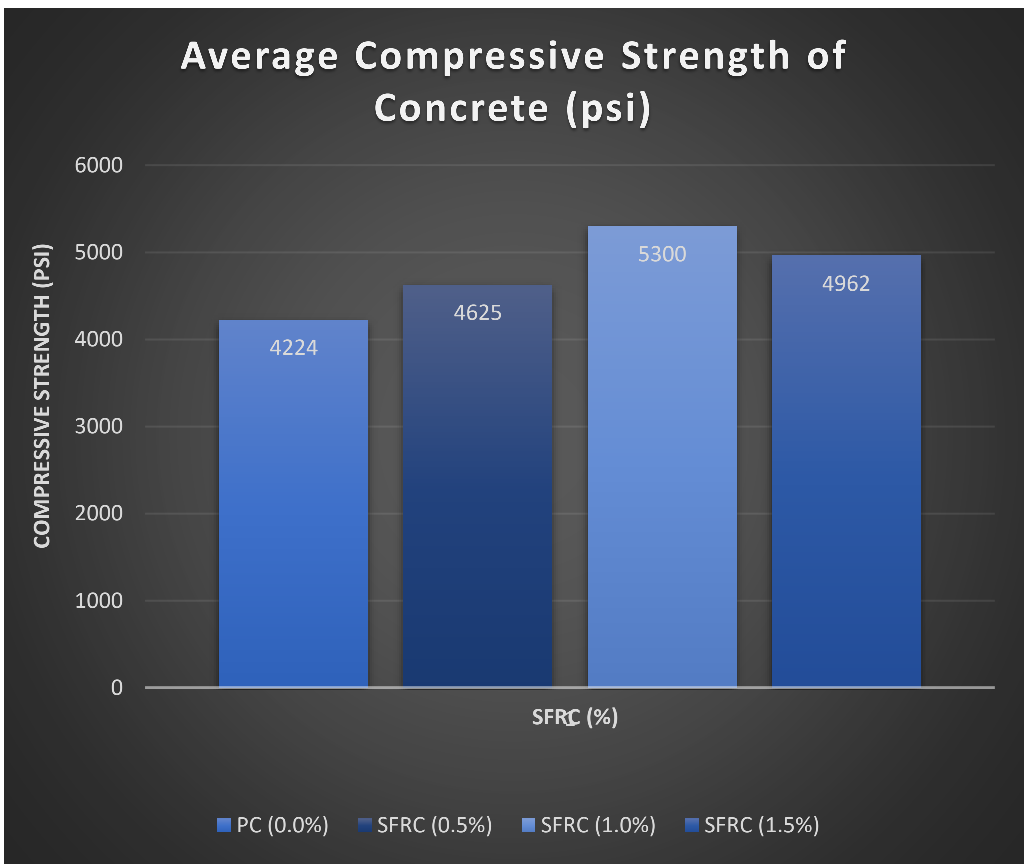


Figure 4.1 Average Compressive Strength vs SFRC

4.2 **Results of Split Tensile Test**

4.2.1 **Tensile Test Data**

The split tensile strength (Ft) was determined by using of the following equation:

$$Ft = 2P/\ (\pi LD)\ (psi)$$

Where: (P) is the applied ultimate load in (Ibs)

(L) is the length of the cylinder (12”).

(D) is the diameter of the cylinder (6”). Table (4.2) illustrates the tensile strength test results.

Table (4.2) Split Tensile Strength Test data

Concrete Mix	Specimen No.	Ultimate Load (Ibs)	Tensile Strength (psi)	Mean	Standard Deviation	C.V %	Average Strength (psi)
PC (0.0%)	1	38760	343	331.33	12.5	3.77	331
	2	31990	283				
	3	41620	368				
SFRC (0.5%)	1	44650	395	399	10.58	2.65	399
	2	44150	391				
	3	46400	411				
SFRC (1.0%)	1	49530	438	439	2.65	0.60	439
	2	49980	442				
	3	49340	437				
SFRC (1.5%)	1	51040	452	448.33	8.14	1.82	448
	2	49620	439				
	3	51280	454				

4.2.2 **Tensile Test Results**

From the tensile strength values, it is evident that the split strength of the concrete is increased with the same trend as the concrete compressive strength but considering slight differences. The increase for tensile strength from (0.0%-0.5% SFRC) is around (20.5%) and the increasing of strength from (0.0%-1.0% SFRC) is around (32.63%) while the increasing of tensile strength from (0.0%-1.5% SFRC) about (35.35%). The behavior of (1% and 1.5% SFRC) is more similar in terms of strength. Overall, it is important how the steel fibers affect the failure of the concrete. Figure (4.2) shows the average tensile strength for different SFRC. The coefficient of variation (C.V%) is (0.6% - 3.77%) within the limits of ASTM C496 which is (5.0%).

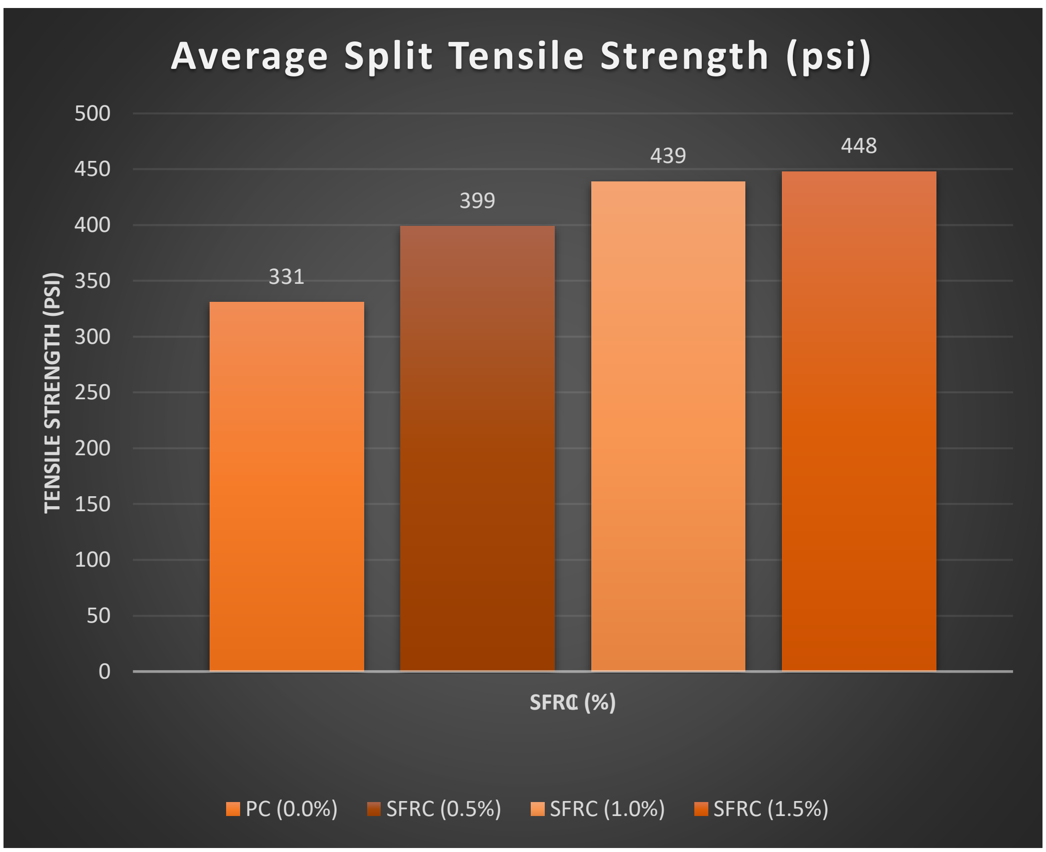


Figure 4.2 Average Tensile Strength vs SFRC

4.3 **Results of Modulus of Rupture**

4.3.1 **Modulus of Rupture Test Data**

The flexural strength (Fr) was determined by using the following equation:

$$Fr = PL/\ (BD2)\ (psi)$$

Where: (P) is the applied ultimate load in (Ibs)

(L) is the length of the beam specimen, clear span from c/c of support (18").

(D) is the depth of the beam (6").

(B) is the width of the beam (6"). Table (4.3) illustrates the flexural strength test results.

Table (4.3) Flexural Strength Test data

Concrete Mix	Specimen No.	Ultimate Load (Ibs)	Flexural Strength (psi)	Mean	Standard Deviation	C.V %	Average Strength (psi)
PC (0.0%)	1	5960	497	512	14.11	2.76	512
	2	6297	525				
	3	6168	514				
SFRC (0.5%)	1	6446	537	531	14	2.64	531
	2	6184	515				
	3	6495	541				
SFRC (1.0%)	1	6746	563	562	17.52	3.12	562
	2	6946	579				
	3	6523	544				
SFRC (1.5%)	1	7280	607	595.67	12.06	2.02	596
	2	7167	597				
	3	6992	583				

4.3.2 **Modulus of Rupture Test Results**

The average flexural strength results clearly show that the flexural strength increases proportionally with the increase of the steel fibers. The increasing of steel fibers for (0.5%, 1.0% and 1.5% SFRC) lead to increase the flexural strength by (3.7%, 9.8% and 16.4%) respectively. It is clear that the behavior of (1% and 1.5% SFRC) is close in the matter of flexural strength. Overall, with (1% and 1.5% SFRC) will give flexural strength about (2-4 times) of Strength of plain concrete and this will give higher strength capacity for the concrete under loading. Figure (4.3) shows the average flexural strength for different SFRC.

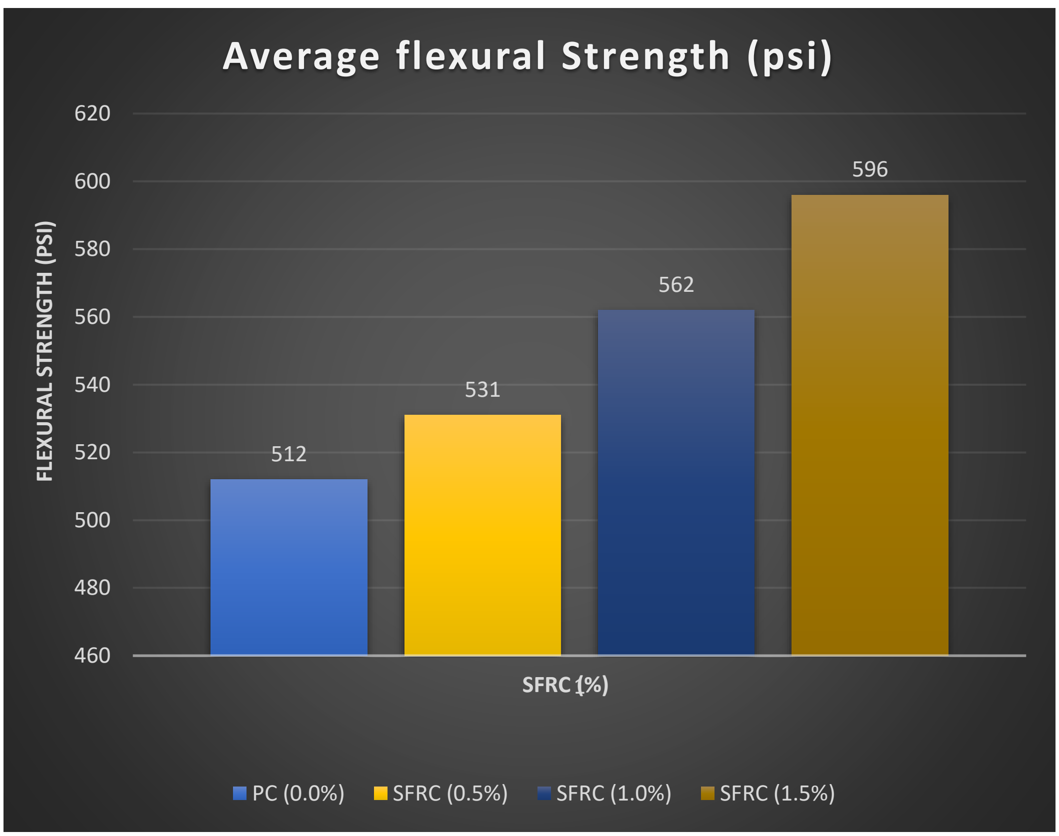


Figure 4.3 Average Flexural Strength vs SFRC

The ratio between modulus of rupture and the split tensile strength is almost the same for all mixtures. It is clearly that plain concrete has the highest ratio comparing with others and the (0.5% SFRC) and (1.0% SFRC) is the same in the ratios. Table (4.4) illustrates the summary of all strength results and Figure (4.4) shows the summary of the average strength for different SFRC.

Table (4.4) Summary of the Strength Results for Different SFRC

Type of Test	PC (0.0% SFRC)	0.5% SFRC	1.0% SFRC	1.5% SFRC
Average Compressive Strength (psi)	4224	4625	5300	4962
Increasing %		9.5	25.5	17.5
Average Tensile Strength (psi)	331	399	439	448
Increasing %		20.5	32.63	35.35
Average Flexural Strength (psi)	512	531	562	596
Increasing %		3.7	9.8	16.4
Modulus of Rupture/Split Ratio	1.55	1.28	1.28	1.33

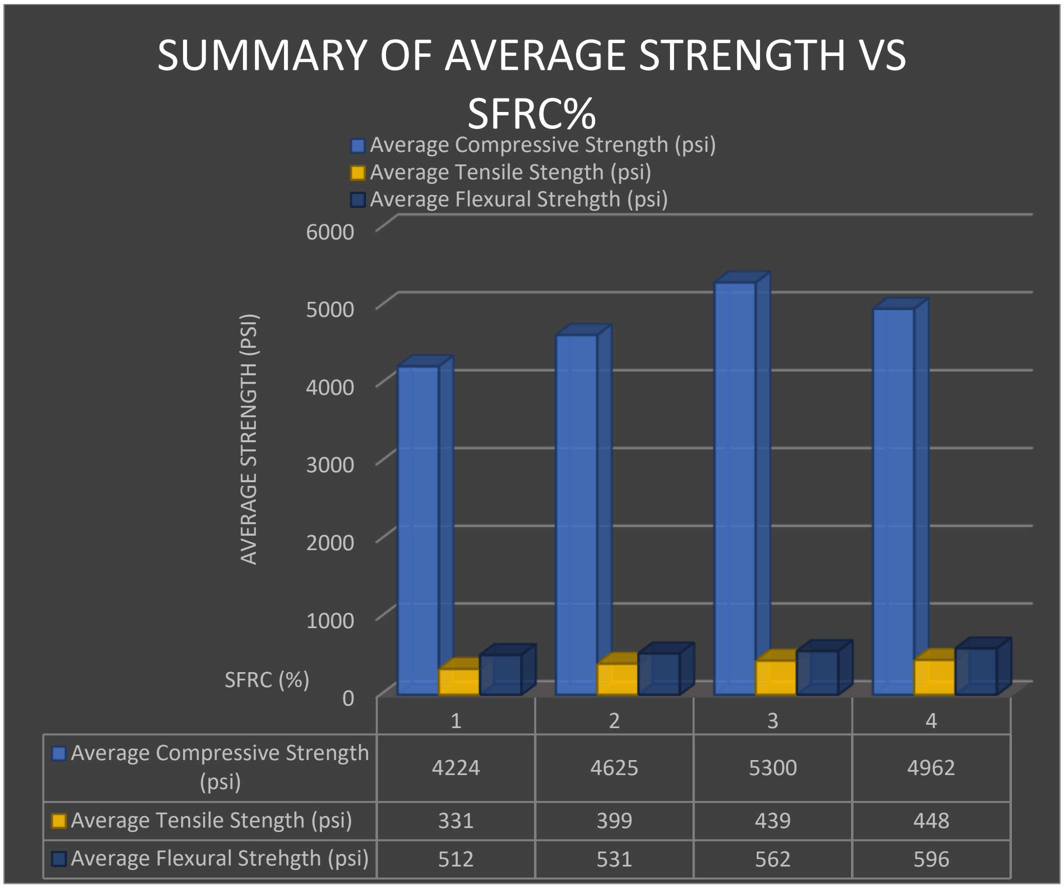


Figure 4.4 Summary of Average Strength vs SFRC

4.4 **Concrete Breakout and Anchor Groups Test Results**

4.4.1 **Concrete Breakout Strength in Tension Data**

After the anchor groups had been successfully tested and the tensile load applied the ultimate tensile load was recorded and the breakout/cracked area around the anchor groups was registered. Table (4.5) illustrates the concrete breakout strength in tension tests for different SFRC.

Table (4.5) Concrete Breakout Strength Test Results for Different SFRC

Concrete Mix	Anchor Groups No.	Concrete Breakout Strength (lbs)	Average Strength (lbs)
PC (0.0%)	1	8926	9334
	2	9762	
	3	9314	
SFRC (0.5%)	1	12745	13379
	2	13832	
	3	13560	
SFRC (1.0%)	1	16652	16187
	2	15581	
	3	16329	
SFRC (1.5%)	1	16548	16901
	2	17121	
	3	17033	

4.4.2 **Ultimate Tensile Load of Anchor Groups**

From the average concrete breakout strength of the anchor group's values, it is clear that the breakout strength of concrete increases by increasing the fraction of the steel fibers in concrete. the increasing in strength from (0.0%-0.5% SFRC) is around 43.3% and the increasing from (0.0%-1.0% SFRC) is around 73.42% while the increasing from (0.0%-1.5% SFRC) is around 81.1%. overall, the increase in concrete breakout strength for (1.0% and 1.5% SFRC) is more similar in the trend of the breakout strength. Figure (4.5) shows the average concrete breakout strength for different SFRC.

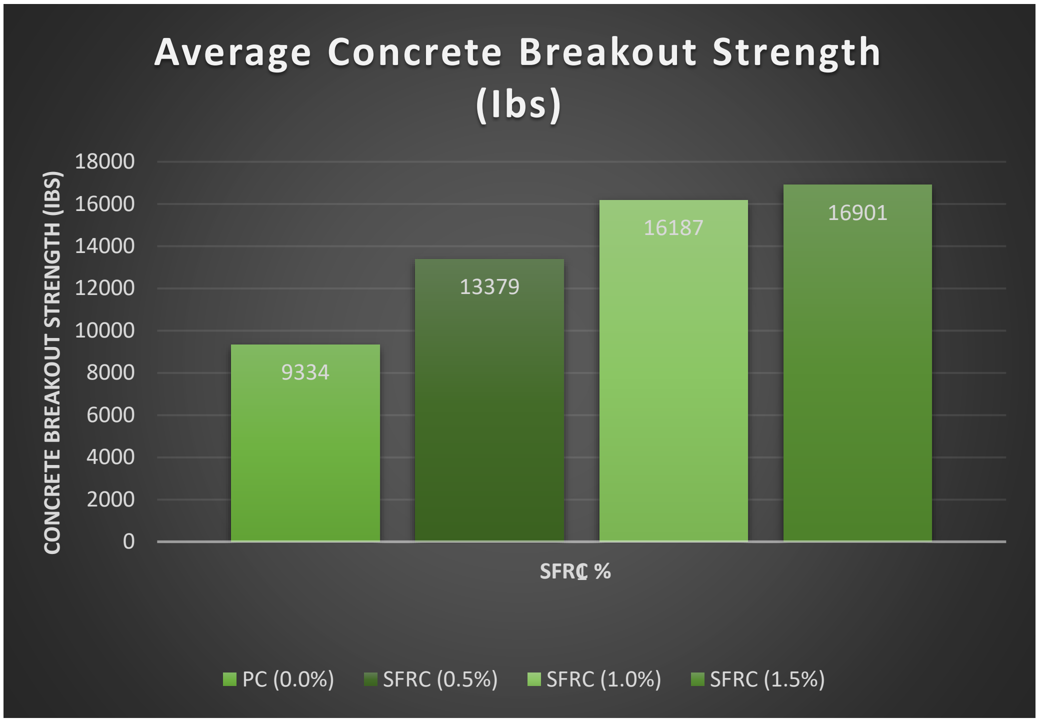


Figure 4.5 Average Concrete Breakout Strength vs SFRC

4.4.3 **Concrete Failure Cone, Diameter and Angle of Failure**

After the tensile testing for all the anchor groups the diameters of the concrete breakout cones for each set of anchors were recorded. The angle of failure (Ø) was determined by using the following equation:

$$Ø = \arctan (Y/(D/2)) \text{ in (Degrees)}$$

Where: (Y) is the effective embedment depth in (2.5in)

(D) is the breakout diameter measured after test in (in). Table (4.6) illustrates the concrete cone diameters and the angle of failures for different SFRC. Figure (4.6) shows the average cone diameters for different SFRC and Figure (4.7) shows the average angle of failure for different SFRC.

Table (4.6) Concrete Cone Diameters and Angle of Failure Test Data

Concrete Mix	Anchor Groups No.	Failure Cone Diameter (in)	Average (in)	The angle of Failure (Degree)	Average (Degree)
PC (0.0%)	1	15.3	15.2	25.89	26.1
	2	15.8		24.84	
	3	14.6		27.5	
SFRC (0.5%)	1	12.8	13.7	32.66	29.9
	2	13.9		29.32	
	3	14.5		27.8	
SFRC (1.0%)	1	10.2	11.23	43.87	38.75
	2	11.4		37.99	
	3	12.1		35.2	
SFRC (1.5%)	1	9.8	10.1	46.2	44.4
	2	10.5		42.3	
	3	10		45	

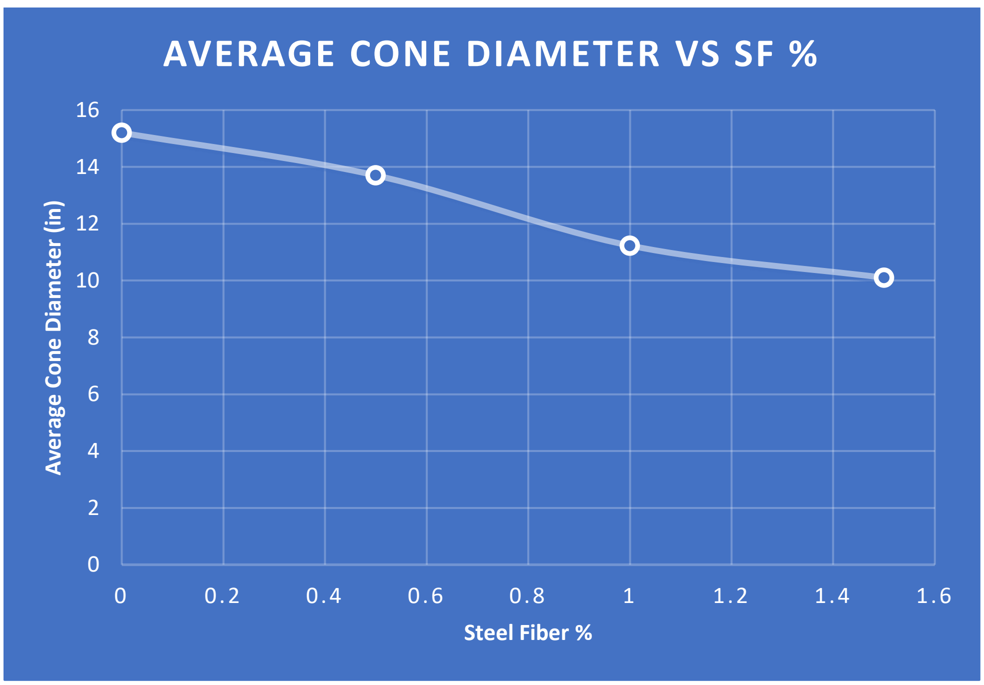


Figure 4.6 Average Cone Diameters vs SFRC

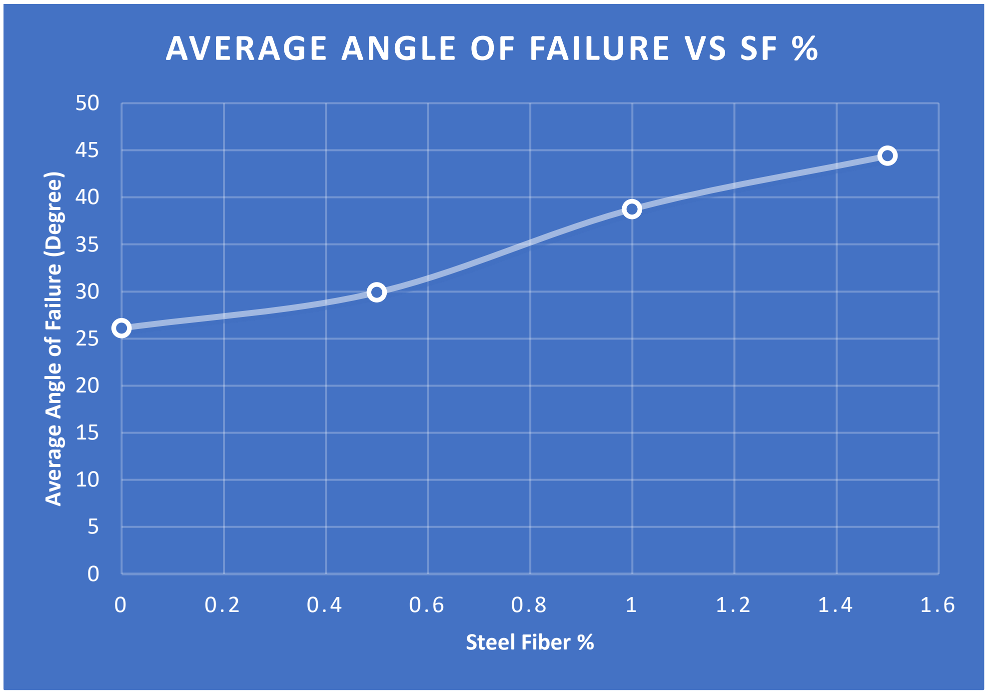


Figure 4.7 Average Angle of Failure vs SFRC

4.5 **Grouping Anchors vs Single Anchors in Tension Test**

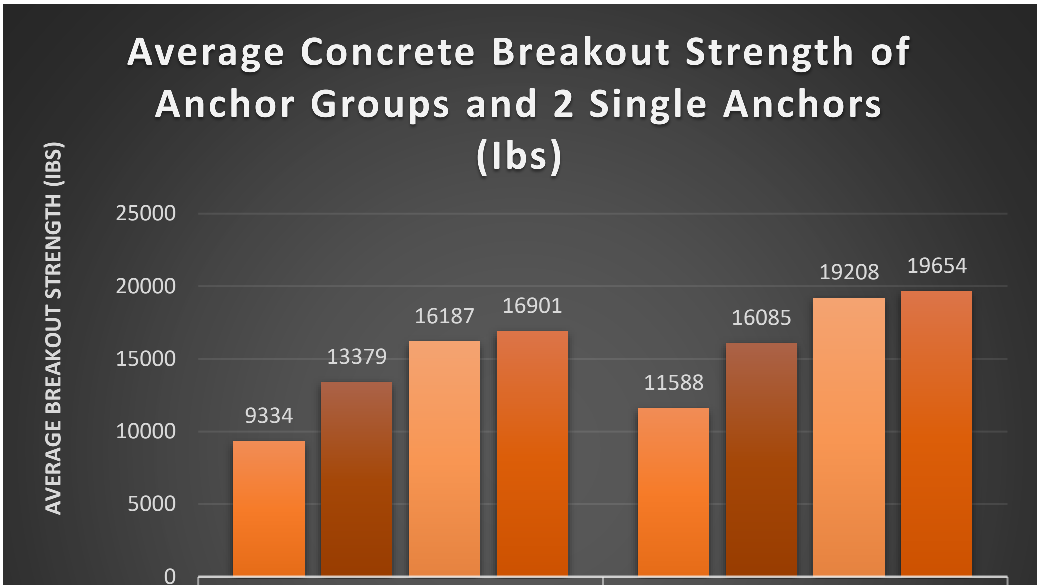
In this section the comparison between the results of experimental investigations on concrete breakout strength of cast-in-place steel anchor groups within Steel Fiber Reinforced Concrete (SFRC) under tension load with the results obtained from another researcher (Karthik Vidyaranya. 2019) who produced and studied the breakout strength for single anchors under the same conditions and specifications. The concrete break strength of anchor groups increased by increasing the steel fibers but there is a difference in the average concrete breakout strength between the two studies. The differences in the concrete breakout strength of anchor groups compared with two single anchors will be reduced by increasing of steel fibers in concrete. the differences for (0.0%, 0.5%, 1.0%, and 1.5% SFRC) is around (19.45%, 16.8, 15.7, and 14%) respectively and this is because of the interaction of the stresses from the grouping action. Overall, increasing the steel fibers in concrete will lead to better results as illustrated in Table (4.7).

Table (4.7) Average Concrete Breakout Strength of Anchor Groups vs 2 Single Anchors

Concrete Mix	Average Concrete Breakout Strength of Anchor Groups (Ibs) With Grouping effect	Average Concrete Breakout Strength of 2 Single Anchors (Ibs)*without Grouping effect	Grouping effect factor
PC (0.0%)	9334	11588	0.81
SFRC (0.5%)	13379	16085	0.83
SFRC (1.0%)	16187	19208	0.84
SFRC (1.5%)	16901	19654	0.86

(*) The values obtained from Reference No. 16

The study confirms the beneficial effects of steel fiber reinforcement in concrete structures. The addition of steel fibers to the concrete mix leads to better mechanical and physical concrete proprieties, including higher fracture energy, and reduced the width of the crack and thus leads to an increase in the concrete breakout strength of anchors in both studies. Finally, it is clear that from the previous table that using of the anchor groups instead of two single anchors will not give the same values of the concrete breakout strength and it is clear that the values of concrete breakout strength of anchor groups always less than the values for two single anchors but there is a positive effect by increasing of the steel fibers. Overall, the two studies proved that the concrete breakout strength of anchor groups will not be twice of concrete breakout strength of 2 single anchors. Figure (4.8) shows the results of the concrete breakout strength of anchor groups and two single anchors with different SFRC.



	1	2
PC (0.0%)	9334	11588
SFRC (0.5%)	13379	16085
SFRC (1.0%)	16187	19208
SFRC (1.5%)	16901	19654

Figure 4.8 Concrete Breakout Strength of Anchor Groups and 2 Single Anchors vs SFRC

4.6 **Experiment Summary**

4.6.1 **Experiment Data and Results**

From the material, tests were conducted and constructed during this research. It was evident that the use of the steel fibers had a great effect on the performance of the plain concrete on all mechanical aspects of the concrete compressive strength, split tensile strength, flexural strength, and finally on the concrete breakout strength of anchor groups. In general, the increasing of the steel fibers from (0.0%-1.5%) showed better performance but the increasing of (1.5% SFRC) showed slight differences and in some tests showed the negative impact as in the compressive strength where the compressive strength decreased for (1.5% SFRC). As well as the concrete behaves as more ductile materials with a higher amount of the steel fibers, and this is clearly shown under the split tensile and flexural tests by giving the concrete more capacity under these loads. The optimum value of the steel fibers is suggested to be (1.0%) as it affects mechanical performance greatly. On the other hand, it should be noted that the increase in the amount of steel fibers decreases the consistency and workability of the concrete which can be undesirable. Therefore, the using of additives to enhance workability would be essential. In conclusion, using (1.0% SFRC) by the volume fraction of the concrete is satisfactory.

4.7 **Discussion of Results**

4.7.1 **Small Specimen Contributions**

Observing and reviewing all the data and test results conducted from this study show that the concrete by itself in nature is a brittle material and weak in tension. Adding of the steel fibers to the concrete changes the tensile and flexural strength of concrete without any introduction of rebars. The addition of the steel fiber introduces a great tensile and flexural strength to the concrete due to the bond between fibers and concrete. Therefore, the increase in the fiber fraction increased compressive, tensile, and flexural strength. The concrete mixture in this study was designed for compressive strength of (4000 psi) but adding steel fibers increased the compressive strength as expected. As well as the tensile strength increased, and this gave the concrete more ductility and to prevent sudden failure and this will give more factors of safety. On the other hand, the concrete breakout strength of anchor groups increased by increasing steel fibers.

4.7.2 **Anchorage Presumptions and Hypothesis**

This section provides the design requirements for anchor groups in concrete used to transmit test loads using tension and covers the concrete breakout failure mode and calculations of the nominal breakout strength as specified in (ACI 318-19) as follows:

1- Anchor group effects shall be considered wherever two or more anchors have spacing less than the critical spacing (3x effective embedment depth of anchors), in this study the embedment depth is (2.5”) so (3x2.5”=7.5”). The spacing in this study was (5”).

2- The minimum edge distances are (6x diameter of an anchor), in this case, the diameter of the anchor is (0.5”) so (6x0.5” =3”). The edge distances from all sides is (6.5” and 9”) respectively.

3- Critical edge distance is more than (2 – 2.5 x embedment depth of anchors) so (2.5 x 2.5" = 6.25"). The critical edge distances selected to be (6.5" > 6.25") to be on the safe side.

4- The effective embedment depth of anchors shall not exceed greater of (2/3 x member thickness and member thickness – 4) so (2/3 x 10" member thickness= 6.67" and 10"-4" = 6"). In this study, the embedment depth of anchors is (2.5" < 6").

There are various types of steel and concrete failure modes for anchor groups as follows:

1- Steel strength of anchor groups in tension.

2- Pullout strength cast-in anchors in tension.

3- Concrete side-face blowout strength of headed anchors in tension.

4- Concrete breakout strength of anchor groups in tension and this is the case in this study.

The nominal concrete breakout strength in tension of a group of anchors (**N_{cbg}**) shall not exceed the following as per the design specifications of (ACI 318-19).

$N_{cbg} = (A_{Nc}/A_{Nco}) \times \Psi_{ec,N}\, \Psi_{ed,N}\, \Psi_{c,N}\, \Psi_{cp,N} * \Psi_{ga} * N_b$

Where:

N_{cbg}: The nominal concrete breakout strength of a group of anchors.

A_{Nc}: The total projected concrete failure area of group of anchors that shall be approximated based on the geometrical failure figure.

A_{Nco}: The projected concrete failure area of a single anchor with an edge distance equal to or greater than (1.5 hef), where (hef; effective embedment depth of anchor). In case of grouping anchors, the ($A_{Nc} < A_{Nco}$***n**, where **n**; No. of anchors in one group).

$\Psi_{ec,N}$: Modification factor for anchor groups loaded eccentrically in tension and shall not be taken greater than (1.0). In this study assumed to be (1.0), no eccentricity.

$\Psi_{ed,N}$: Modification factor for edge effects for anchor groups loaded in tension. For (Ca, min >1.5 hef, then $\Psi_{ed,N}$ = 1.0). In this case ($\Psi_{ed,N}$ = 1).

$\Psi_{c,N}$: Modification factor for no cracking at service load levels and in case of cracking at service load levels, $\Psi_{c,N}$ shall be taken as (1.0). In this case (**$\Psi_{c,N}$ =1.25**) because ($ft<fr$) indicates no cracking at service load levels.

$\Psi_{cp,N}$: Modification factor for post-installed anchors designed for uncracked concrete. For cast-in anchors, $\Psi_{cp,N}$ shall be taken as (1.0).

Ψ_{ga}: Modification factor for anchor groups in steel fiber reinforced concrete. (Ψ_{ga} = 1.25) for (0.0% SFRC) and (Ψ_{ga} = 1.3, 1.34, and 1.36) for (0.5, 1.0 and 1.5% SFRC).

N_b: Basic concrete breakout strength in tension of a single anchor in cracked concrete (Ib), shall not exceed the following as specified in (ACI 318-19, Ch.17).

$N_b = K_c * \lambda_a * \sqrt{fc`} * (hef)^{1.5}$

Where:

K_c =24 for cast-in anchors and 17 for post-installed anchors. In this study (**K_c = 24**).

λ_a : Modification Factor for lightweight concrete shall be taken as (1.0 λ) for cast-in anchors. The value of (λ) shall be based on the composition of the aggregate in the concrete mixture as specified in (ACI 318-19, Ch.17), (λ) for normal weight concrete is (1), (λ) for all light weight concrete is (0.75), and (λ) for sand-lightweight concrete is (0.85). in this study the value of (**λ_a =1**).

**fc`**: The compressive strength of the concrete, based on the design mix in this study (fc`=4000 psi).

h_{ef}: The effective embedment depth of the anchor groups, in this study (**h_{ef} = 2.5”**).

By using the Concrete Capacity Design Method (CCD) specified in the (ACI 318-19) with modification of the equation based on the steel fiber factor and anchor groups factor obtained from this experimental then will obtained the following equation:

$$N_b = K_c * \lambda_a * \sqrt{fc`} * (hef)^{1.5} * (1+Z\ \sqrt{fc`}\ )$$

Where:

Z: Modification factor for percentage of steel fiber in concrete as shown in table (4.8).

Table (4.8) The Steel Fiber Modification Factor

Percentage of Steel Fiber (%)	(Z) Factor
0	0
0.5	0.0025
1	0.0075
1.5	0.01

By using the following equation calculate any value in between the tabulated values:

$$Z = -0.0067(x)^3 + 0.015\,(x)^2 - 0.0008(x) - 7^{e-16}$$

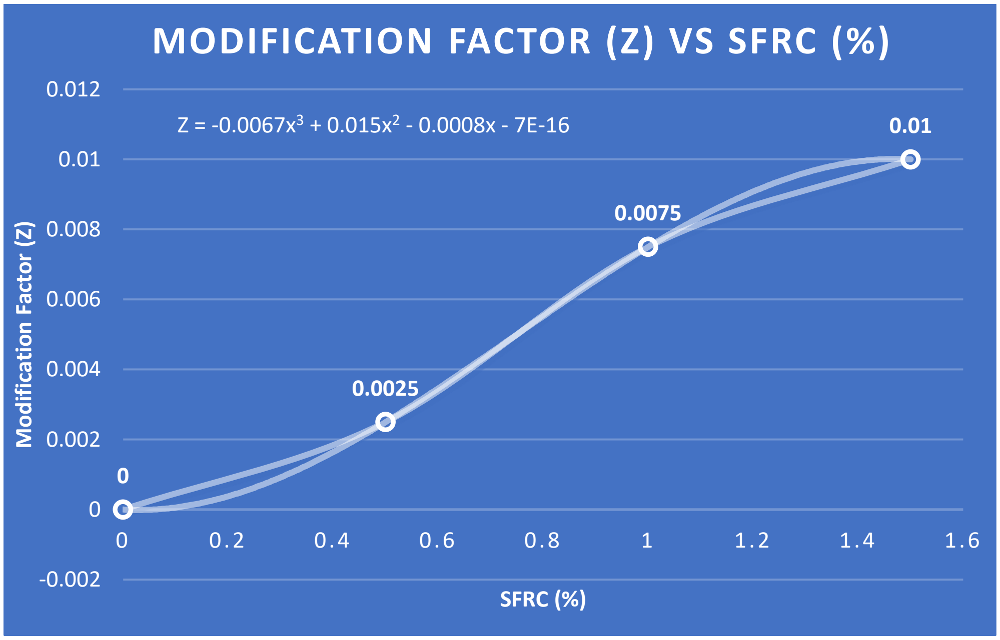


Figure 4.9 Modification Factor (Z) vs SFRC (%)

By using the previous equations and the modification factors the following calculations were obtained as shown in table (4.9).

Table (4.9) Concrete Breakout Strength from Experiment and Modified CCD

Percentage of Steel Fiber (%)	0.00%	0.50%	1.00%	1.50%
Concrete Breakout Strength (Ibs) Experimental	9334	13379	16187	16901
Nominal Concrete Breakout Strength in Tension (Ibs), Ncbg	9780	13310	16536	17493

The selection of the modification factor (Z) is related to the percentage changes (either increasing or decreasing) of the compressive strength of concrete from (0.0%-1.5% SFRC). As well as the selection of the anchor groups factor (Ψga) is related to the flexural and split ratio of the concrete and the differences between the concrete breakout strength of anchor groups with the concrete breakout strength of single anchors from another study by using of the same specifications.

The modified (CCD) method equation predicts the nominal concrete breakout strength in tension of anchor groups within the experimental values with slight differences from (0.5%-4%) thus giving reliable results either (increasing or decreasing). Figure (4.10) shows the concrete breakout strength of the experiment and nominal results. The modified (CCD) method equation based on the results that obtained from this study.

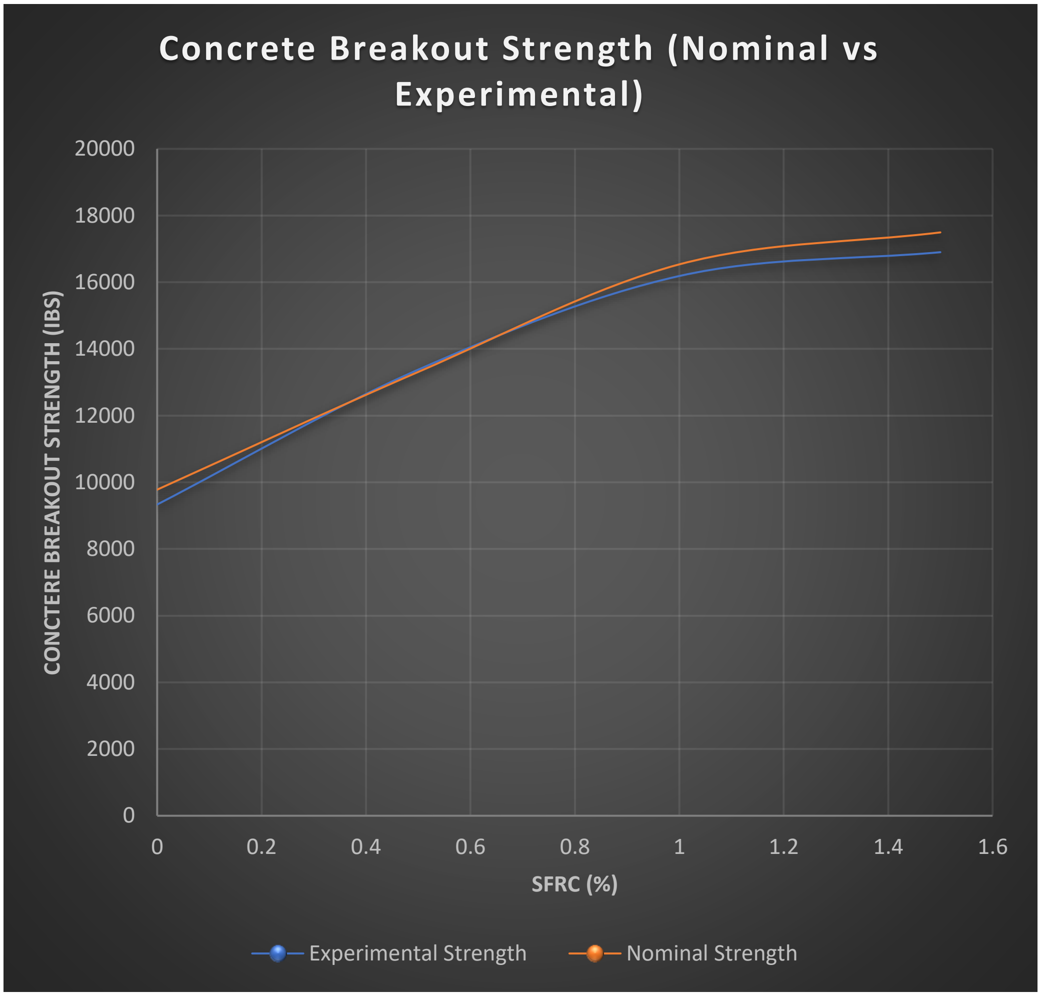


Figure 4.10 Concrete Breakout Strength (Nominal vs Experiment)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1- Increase steel fibers will improve the concrete breakout strength of anchor groups by (43%, 73%, and 81%) for (0.5%, 1.0%, and 1.5% SFRC) comparing with (0.0% SFRC) respectively.

2- The grouping effect of anchors decreased the concrete breakout strength by (19.45%, 16.8%, 15.7%, and 14%) for (0.0%, 0.5%, 1.0%, and 1.5% SFRC) respectively compared with single anchors.

3- The compressive strength of concrete was increased by (9.5%, 25.5%, and 17.5%) for (0.5%, 1.0%, and 1.5% SFRC) respectively. The high amount of steel fibers may increase the air content and decrease the bond between steel fiber and the concrete itself thus reduces the compressive strength for (1.5% SFRC).

4- Increase steel fibers will decrease the diameter of concrete failure cone.

5- The angle of failure of anchor groups increased by (14.6%, 48.5%, and 70%) for (0.5%, 1.0%, and 1.5% SFRC) comparing with (0.0% SFRC).

6- Increase the split tensile strength by (20.5%, 32.63%, and 35.35%) and increase the modulus of rupture by (3.7%, 9.8%, and 16.4%) for (0.5%, 1.0%, and 1.5% SFRC) comparing with (0.0% SFRC) respectively.

7- The ratio between modulus of rupture and the tensile strength is (55% for 0.0% SFRC) and (30% for 0.5%, 1.0%, and 1.5% SFRC). The plain concrete has the highest ratio comparing with others.

8- The concrete breakout strength of anchor groups in tension is related to the concrete tensile strength thus led the researcher to evaluate the modification factor of steel fibers (Z) based on that.

9- Increasing the amount of steel fibers leads to an increase in the ductility of the concrete and prevents the sudden failure in concrete under tension.

5.2 **Research Contribution and Impact**

1- It is recommended to use this application of SFRC for signpost foundations, traffic signal foundations, and the guardrails on the bridges and highways.

2- Providing the new relationships between the nominal concrete breakout strength and the experiment breakout strength.

3- Reducing the size of foundations for many structural applications due to the improvement of the concrete compressive strength and the breakout in tension.

4- Using of the SFRC in pavement reduces the shrinkage, cracking, and the thermal expansion thus reducing the cost of construction.

5- Increasing of the steel fibers within the diameter of the failure cone where anchor groups are to be used and this will lead to an increase in the concrete breakout strength under tension test.

6- Using of the SFRC in many structural applications as mentioned previously will give more factors of safety during the life of construction due to the increase of the concrete properties.

7- Using of hex headed studs led to increasing the concrete breakout strength and this particularly helpful in the bridges.

5.3 **Recommendations for Further Researches**

1- Developing of finite element model for cast-in-place anchor groups under pure tension.
2- Investigation of the ultimate tensile load on cast-in-place and post-installed anchor groups.
3- Studying the effects of different types of steel fibers in concrete.
4- Investigation of the behavior of the concrete breakout strength of anchor groups for varying effective embedment depths.
5- Investigation of the differences between the cast-in-place with post-installed anchor groups for a different amount of steel fibers.
6- Studying the anchor groups action for varying diameters and embedment depths.
7- Testing of anchor groups behaviors when subjected to impact loading.

APPENDIX

LIST OF EQUATIONS

1- Ncbg = (ANc/ANco) x Ψec,N Ψed,N Ψc,N Ψcp,N * (Nb* Ψga) (Ibs)

2- Nb = Kc*ƛa* $\sqrt{fc`}$ * $(hef)^{1.5}$ (Ibs)

3- Nb = Kc*ƛa* $\sqrt{fc`}$ * $(hef)^{1.5}$ * (1+Z $\sqrt{fc`}$) (Ibs)

4- $Z = -0.0067(x)^3 + 0.015\ (x)^2 - 0.0008(x) - 7^{e-16}$

5- Fc`= P/($\pi r2$) (psi)

6- Ft= 2P/(πLD) (psi)

7- Fr= PL/$(BD2)$ (psi)

Example of the nominal concrete breakout strength in tension of a group of anchors (**Ncbg**).

For Modification factor (Z=0.0025) and this is for (0.5% SFRC).

N_b = K_c*ƛa* $\sqrt{fc`}$ * $(hef)^{1.5}$ * (1+Z $\sqrt{fc`}$)

N_b =24*1* $\sqrt{5331}$ * $(2.5)^{1.5}$ * (1+0.0025 $\sqrt{f5331}$)= 8191.1 Ib

N_b*Ψ_{ga} = 8191.1 *1.3 = 10648.4 Ib

N_{cbg} = 10648 * $\Psi_{c,N}$ = 10648 * 1.25 = 13310 Ibs

N_{cbg} = 13310 Ibs < N_{cbg} (Experiment) = 13379 Ibs O.K

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