

EXPERIMENTAL INVESTIGATION OF CONCRETE BREAKOUT STRENGTH OF
ANCHOR IN TENSION WITHIN FIBER REINFORCED CONCRETE

By

KARTHIK KONDAJJI VIDYARANYA

Presented to the Faculty of the Graduate School of
The University of Texas at Arlington in Fulfillment
of the Requirements for the Degree of

Master of Science in Civil Engineering

THE UNIVERSITY OF TEXAS AT ARLINGTON

MAY 2019

Arlington, Texas

Supervising committee:

Dr. Raad Azzawi, Supervising professor

Dr. Shih-Ho Chao

Dr. Seyed Mohsen Shahandashti

Table of Contents	
List of Figures.....	v
List of Tables.....	vii
Acknowledgment.....	ix
Abstract.....	1
1 INTRODUCTION.....	3
1.1 Objectives.....	5
1.2 Research Contribution.....	5
1.3 Outline of Thesis.....	6
2 LITERATURE REVIEW.....	7
2.1 Previous Research and Accepted Design Practices.....	7
2.1.1 Anchoring to Concrete.....	7
2.1.2 Fiber Reinforced Concrete.....	15
3 EXPERIMENT PROGRAMS.....	17
3.1 Fabrication of Test Specimens.....	17
3.1.1 Design of Test Specimen Formwork.....	17
3.1.2 Construction of Formwork.....	19
3.1.3 Concrete Pouring.....	19
3.2 Test Set-up and procedure.....	23
3.2.1 Compression, Tensile and Flexure Testing.....	23
3.2.2 Anchor Testing.....	29
4.1 Compression Test Results.....	33
4.1.1 Concrete Compression Test Results Data.....	33
4.1.2 Concrete Compression Test Results.....	33
4.2 Split Tensile Test Results.....	34
4.2.1 Concrete Split Tensile Test Data.....	34
4.2.2 Split Tensile Test Results.....	34
4.3 Modulus of Rupture Test Results.....	35
4.3.1 Modulus of Rupture of Concrete Test Results Data.....	35
4.3.2 Modulus of Rupture of Concrete Test Results.....	35
4.4 Concrete Breakout Test Results.....	36
4.4.1 Concrete Breakout Strength in Tensile Data.....	36

4.4.2	Ultimate Tensile Load of Concrete Graphs	37
4.4.3	Concrete Breakout Cone Diameter and Failure Angle Data	38
4.4.4	Concrete Breakout Diameter and Failure angle Graphs.....	38
4.5	Project Summary	39
4.5.1	Experiment and Results.....	39
4.6	Results Discussion.....	40
4.6.1	Small Specimen Deductions	40
4.6.2	Anchorage Presumptions and Hypothesis.....	41
5	CONCLUSION	46
5.1	Project Results.....	46
5.1.1	Summarized Conclusions.....	46
5.2	Research Contribution and Continuation	47
5.2.1	Research impact.....	47
5.2.2	Recommendations for Future Research	48
APPENDIX A.....		49
List of formulae		49
REFERENCES.....		52

List of Figures

Figure 1 Anchor failure modes	12
Figure 2 drawing of failure angle θ	13
Figure 3 Steel fibers used in this research.....	16
Figure 4 Wood formwork – Plan view	17
Figure 5 Wood formwork – Elevation at Frame A.....	18
Figure 6 Wood formwork – Elevation at Frame B.....	18
Figure 7 Pouring aggregates into the concrete mixer.....	20
Figure 8 Pouring aggregates into the concrete mixer.....	20
Figure 9 Slump cone procedure.....	20
Figure 10 Collection of aggregates prior to mixing concrete	20
Figure 11 Slump test of 0.0% steel fiber reinforced concrete.....	22
Figure 12 Slump test of 0.5% steel fiber reinforced concrete.....	22
Figure 13 Test set-up, frame, hydraulic ram and load cell.....	24
Figure 14 Test set-up, frame, hydraulic ram and load cell.....	24
Figure 15 Research team in front of one of the beam	25
Figure 16 Research team in front of one of the beam on casting day.....	25
Figure 17 Compression test of concrete for 0% steel fiber by volume before test.	26
Figure 18 Compression test of concrete for 0.5% steel fiber by volume after test.	26
Figure 19 Compression test of concrete for 1% steel fiber by volume after test.	26
Figure 20 Compression test of concrete for 1% steel fiber by volume before test.	26
Figure 21 Split tensile test of concrete cylinder of 0.5% steel fiber by volume.....	27
Figure 22 Modulus of rupture test of concrete beam of 0.0% steel fiber by volume.....	28
Figure 23 Modulus of rupture test of concrete beam of 0.5% steel fiber by volume.....	29
Figure 24 0.0% steel fiber reinforced concrete beam with embedded anchor bolt	30

Figure 25 0.0% steel fiber reinforced concrete beam with embedded anchor bolt	30
Figure 26 0.5% steel fiber reinforced concrete beam with embedded anchor bolt.	30
Figure 27 0.5% steel fiber reinforced concrete beam with embedded anchor bolt.	30
Figure 28: 1% steel fiber reinforced concrete beam with embedded anchor bolt after test #1 anchor	31
Figure 29: 1% steel fiber reinforced concrete beam with embedded anchor bolt after test #2 anchor	31
Figure 30: 1% steel fiber reinforced concrete beam with embedded anchor bolt after test #3 anchor	32
Figure 31 Compression Test Results.....	33
Figure 32 Tensile Test Results	34
Figure 33 Modulus of Rupture of Concrete Test Results.....	35
Figure 34 Ultimate tensile load capacity of concrete	37
Figure 35 Average ultimate tensile load capacity of concrete	37
Figure 36 Concrete Breakout Cone Diameter Comparison	38
Figure 37 Cone of Influence Failure Angle Comparison.....	39
Figure 38 Compressive strength of Concrete	41
Figure 39 Ultimate tensile load capacity of concrete	42

List of Tables

Table 1 Steel fiber physical properties	16
Table 2: Fiber Concrete Design Mixture	21
Table 3 Concrete Compression Test Results.....	33
Table 4 Concrete Split Tensile Test Results	34
Table 5 Modulus of Rupture of Concrete Test Results	35
Table 6 Concrete Breakout Strength in Tensile Test Results for 0.00% SFRC	36
Table 7 Concrete Breakout Strength in Tensile Test Results for 0.50% SFRC	36
Table 8 Concrete Breakout Strength in Tensile Test Results for 1.00% SFRC	36
Table 9 Average Concrete Breakout Cone Diameters and Failure Angle Results	38
Table 10 Compressive strength of Concrete	41
Table 11 Tensile load capacity of concrete	42
Table 12 Value of Z for various fiber volume fraction(%)	44
Table 13 Data from experiment and modified CCD	44

Acknowledgment

I would like to offer my sincere appreciation to Dr. Raad Azzawi for his guidance and support throughout my graduate academic career. He has been a wonderful mentor to me, providing invaluable technical and academic guidance over the course of this research. His knowledge and advice have always provided me with great inspiration and motivation in dealing with academic and personal challenges. I would also like to thank Atheer Al Khafaji, David Moore, Travis Pechacek, Nancy Varughese and Mohammed Khanfar who provided me with invaluable support and assistance throughout the course of this project. Appreciations are also extended to Dr. Shih-Ho Chao and Dr. Seyed Mohsen Shahandashti for their valuable advice and guidance. I would like to thank my parents, who have always provided great encouragement and support helping me overcome some of the greatest challenges.

April 29, 2019

Abstract

The University of Texas at Arlington, 2019

Supervising Professor: Dr Raad Azzawi

This research 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 this study for varying steel fiber dosage of 0.0%, 0.5% and 1.0% by volume fraction of concrete. The physical properties of steel fiber reinforced concrete were calculated through various test at the Civil Engineering laboratory Building. In total, 9-cylinder specimens of 4" diameter and 8" height, and 9 beam specimens, 6"x6"x20" were made and tested. After 28 days of curing, the specimens were tested for their compressive strength and modulus of rupture, as well as 9-cylinder specimens of 6" diameter and 12" height to test for split tensile test. Nine headed stud anchors were installed and tested in the various mixtures. The depth of anchor embedment is kept constant, and the spacing between anchors is specified as per ACI 318-14. No grouping action was found. CCD method (ACI 318-14) is modified in order to predict the concrete breakout capacity of the cast-in-place anchor. The experiment revealed that the increase in dosage of fiber fraction increases the compressive strength of the concrete by 35% and 48% for 0.5% and 1% respectively compared from normal weight concrete without steel fibers. The breakout strength of concrete in tension increased by 77% for 0.5% volume fraction of steel fiber in concrete and increased 107% for 1.0% volume fractions of steel fiber in concrete in comparison with 0.0% Steel fiber reinforced concrete. It is found that the diameter of cone of concrete reduced as the dosage of steel fibers increased and the failure angle increased as the dosage of steel fibers increased.

1 INTRODUCTION

We are surrounded by structures, one of the essential materials is concrete. Concrete's inability to withstand tension makes it a poor material to use homogeneously without reinforcement. Concrete foundations carry the loads and distribute it to the soil underneath. Columns and beams are the main structural elements which carry the loads to the foundation through load paths. Connections between these elements is as important as the design of the elements per se. One such connection is anchorage, between column plates and foundation. Hence, it is vital to understand the behavior of these anchor bolts in tension.

There are mainly different types of anchors, Cast-in-place anchors, Post-installed anchors and adhesive anchors, Cast-in-place anchor is typically placed during the pouring of concrete and allows to be cured, whereas, post-installed concrete anchors are installed after the concrete is placed that has already cured. Anchors typically come with a small washer and a Hex head, to prevent them from pull-outs. Adhesive are the bonds created by the steel and concrete hold the anchors in place. "Cone of influence", smaller the cone radius, smaller is the pull-out strength this relation is only applicable for concrete without any reinforcement. Concrete breakout occurs when the force resisted by the cone of influence is greater than force generated by the bond created between concrete and steel. This way, concrete breakout strength is limited to the strength of the concrete. Therefore, there is a need to increase the strength of the concrete in order to obtain high pull-out strength.

Concrete breakout or the "cone of influence" depends on many factors, they are, spacing between the anchors, embedment, or the edge distance between the anchors, angle of the cone and concrete compressive strength.

Another factor, which can influence the cone of influence is the tensile force. Concrete is weak in tension, however, when the fibers are introduced to concrete, the tensile force of the concrete increases considerably. This addition of fibers, the cone geometry changes in a way that the cone radius decreases with increase in pull out strength. This is due to increase in tensile strength of the concrete.

1.1 Objectives

The main objective of this research is to investigate the concrete breakout strength of cast-in-place anchors in tension using different steel fiber dosage in concrete mixtures. To meet this objective, three concrete designs were created with different steel fiber dosages. Specimens of three design mixtures were tested for their physical properties. Anchors were held in place before pouring the concrete to the framework and then tested.

1.2 Research Contribution

Research on cast-in-place anchor in tension using steel fibers is sparse, therefore a research into this topic is interesting to know how it reduces the amount of materials used during connections. This research reduces the need of heavy concrete mass required to produce the same anchorage that a less concrete mass with steel fibers can produce. This research addresses two main issues; economy and increased safety. It can also address sustainability goals for LEED certification. Increase in strength allows to use lesser grade anchors thus cutting the cost significantly. This research will provide a ground for using different dosage of steel fiber reinforced concrete without having to test any specimens by providing a modified ACI 17.4.5.1a clause which, currently does not take steel fiber interaction with concrete.

1.3 Outline of Thesis

This thesis is divided in six following chapters respectively:

Chapter 1 – Introduction: This chapter highlights the basic concept of concrete behavior in tension and how fibers influence on the strength of concrete.

Chapter 2 – Literature Review: This chapters highlights the concepts of anchors, fiber reinforced concrete and past research on concrete within steel fiber reinforcement concrete.

Chapter 3 – Experimental Program: This chapter presents the design of concrete mixture and testing of specimens.

Chapter 4 – Experimental Results and Discussion: This chapter present test results of the specimens introduced earlier.

Chapter 5 – Summary and Conclusion: The findings of the research are summarized, and the conclusions are presented.

2 LITERATURE REVIEW

2.1 Previous Research and Accepted Design Practices

2.1.1 Anchoring to Concrete

A research by Al-Ta'an et al. 2011, studied the breakout capacity of cast-in-place single short-headed anchor bolts embedded in both normal and high strength steel fibrous reinforced concrete. Concrete strength ranged from 27.4 to 58 MPa, four volume fractions of steel fibers (0.4, 0.8, 1.2 and 1.6%), two aspect ratios (19.63, 36.36), three anchor diameters (8, 10 and 12 mm) and four embedment depths (25, 37.5, 50 and 62.5 mm) were used. Most of the specimens were failed by concrete cone failure and the cone breaks into pieces in some cases (concrete failure), while the other specimens were failed by yielding or fracture of the bolts (steel failure). The tests results showed that the concrete angle cone is increasing with the embedment depth, the fiber reinforcing index and decreasing with the concrete strength. The breakout capacity of the anchors was increased by the addition of steel fibers to concrete and the size of the cones failure in fibrous concrete were smaller than the cones in plain concrete specimens. Based on the experimental results, an expression is proposed to estimate a variable concrete cone angle which is then used to predict the breakout capacity of single headed anchors embedded in normal and high strength fibrous concrete and showed good agreement with the test results. A regression equation based on the observed breakout capacities is also proposed to predict the breakout capacity and both methods showed the same degree of accuracy.

A paper by Mehmet Gesoglu et al. 2005, addresses the load-deflection behavior of adhesive and grouted anchors embedded in both plain and steel fiber-reinforced normal- and high-strength concretes. Both 12 and 16 mm-diameter adhesive anchors were tested at embedment depths ranging from 40 to 160 mm, while grouted anchors of 16 mm diameter were tested at 80, 120, and 160 mm embedment depths. A total of 57 anchors

(39 adhesive and 18 grouted anchors) were tested under monotonic tension loading. Test results showed that pullout capacities of the anchors were not significantly affected by the addition of steel fibers into the concrete. The ultimate deflection and toughness, however, were greatly improved provided that the anchor failed through concrete breakout. Current design methods (ACI 349-85 and concrete capacity design [CCD]) overpredicted the pullout capacity as governed by concrete failure. The overprediction increased with increasing concrete strength, but slightly decreased with the addition of steel fibers for a given concrete strength.

There are two types of anchors used, Cast-in anchors and Post-installed anchors. Post installed anchors as the name suggest is installed after the concrete has been cured. These anchors are proven to reduce the fiber interaction with concrete, because of the drilling of concrete. However, cast-in anchors utilize the full effect of fibers influence within the concrete. These anchors are placed in place before the concrete is poured and cured. Cast-in anchors achieves maximum bond between concrete and the anchors. The main drawback of this anchor is it cannot be moved once the concrete is placed and set. The ACI code allows the design of both the types of bolts and provides guidance in calculating the three different types of anchorage failures, concrete breakout, and pullout failure.

A recent study done by Travis et al. 2018, investigates the effects of Polypropylene fibers on the concrete breakout of post-installed screw anchor bolts. Concrete anchors were installed within concrete specimens of differing amounts of Polypropylene fibers. Four differing mixtures were produced using, 0, 0.5, 1, and 1.5% fibers by volume of the mixture. Their physical properties were calculated through testing at the Civil Engineering Laboratory Building (CELB). In total, 16 cylindrical specimens, 4" in diameter and 8" in height, and 6 beam specimens, 6"x6"x20" were produced and tested. After 28 days of curing, the specimens were tested for their compressive and tensile strengths, as well as

their modulus of rupture. Additionally, twenty screw anchors were installed and tested in the varying mixture types. The results of the tests were then analyzed. It was discovered that as the fiber reinforcement approached 1% and over, the compressive strength of the concrete decreased which was attributed to reduced workability and increasing air voids from poor consolidation. Although the compressive strengths of the 1% and 1.5% were reduced, there was a linear trend between the addition of fiber reinforcement and tensile breakout capacity, however the results also showed a relationship between the compressive strength of the concrete and the tensile breakout capacity. Regression analysis was performed, and the CCD method modified in order to predict the breakout capacity of a post-installed anchor. In conclusion, the addition of fiber reinforcement will lead to an increase in the breakout capacity of an anchor, while the reduction in compressive strength of a specimen will lead to a decrease in the breakout capacity of an anchor. Due to loss in workability the addition of fibers can also lead to poor consolidation which can lead to a reduction in the compressive strength, and thus a reduction in the breakout capacity of the anchor.

Another recent study done by Mohammed Ghori et al. 2018, investigates the short-term effect of Polypropylene fibers on the shear strength and failure performance of longitudinally reinforced concrete beams with and/ or without transverse reinforcement. 8 large scale beams with various volumes of polypropylene fibers were constructed and tested at Civil Engineering Laboratory Building (CELB). This includes flexure reinforced concrete beams (RC), reinforced concrete beam with minimum transverse reinforcement (RCS), 0.5% volume synthetic fiber reinforced concrete beam (SNFRC 0.5%), and 0.75% Synthetic fiber reinforced concrete beams (SNFRC 0.75%). In addition, a total of 19 cylindrical specimens, 4 in. in diameter and 8 in. in height, were tested after 28 days curing. Moreover, a total of 9 beam specimens, 6in by 6 in. by 20 in. were produced and tested at

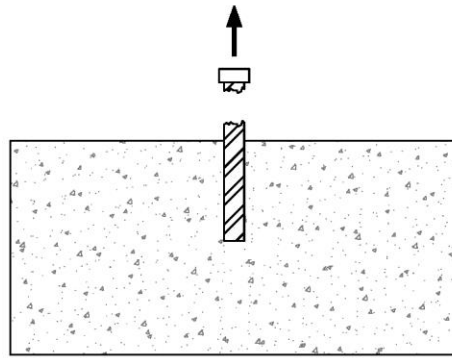
CELB. This study reports on the increased shear strength performance of large-scale beams due to the application of 0.5% and 0.75% Polypropylene fibers into the concrete matrix.

A combined experimental and computational study done by R. Piccinin et al. 2012, shows that the pullout capacity of anchors embedded at small depths in prestressed concrete is associated with the strongest possible (linear elastic fracture mechanics) size effect. A design formula is proposed that reflects the effects of embedment depth and the nondimensional parameters that quantify the level of prestressing and the characteristic length of the matrix.

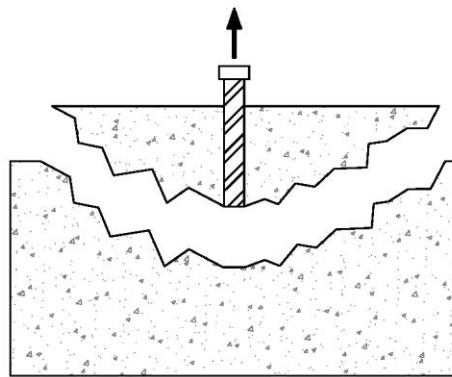
A study done by David A. Grilli et al. 2015, Steel column bases in seismically braced frames and other similar structures must be designed for high uplift or tensile forces. A common detail for this connection involves anchors embedded in the footing with a plate at their lower end, also embedded in the footing. This detail is increasingly prevalent in construction practice, since it is exempt from the strength calculations of ACI 318 Appendix D. However, no experimental data or validated design guidelines are available to support the design of this detail. As a consequence, approaches from other similar situations (such as punching shear of slabs) are adapted for this purpose. To address this practical need, this report presents tension tests on two full-scale specimens featuring this anchorage detail. The main variable examined in the experiments is the embedment depth, such that two depths – 12 inches and 18 inches, are tested. The test specimens exhibit a classic concrete failure cone extending upwards from the edges of the embedded base plate. The experimental data provides evidence that the anchorage detail provides an effective means to carry high tensile loads. The data is evaluated against three strength models, including the ACI-318 Appendix D method, the ACI 318 punching shear equation, and the Concrete Capacity Design (CCD) method. It is determined that the Appendix D method is

significantly conservative (average test-predicted ratio 1.34), because it does not consider the beneficial effects of the embedded plate. On the other hand, the punching shear method is unconservative (average test-predicted ratio 0.62) because it does not explicitly incorporate the size effect in concrete. The CCD method shows most promise, with an average test-predicted ratio of 0.99. Limitations of the study include the small size of the test set, and the absence of reinforcement in the specimens.

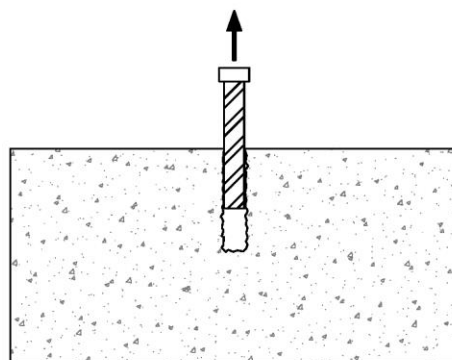
A study done by Rasoul Nilforoush et al. 2017, Cast-in-place anchor bolts embedded in plain and steel fiber-reinforced normal- and high-strength concrete members were subjected to monotonic tensile loads. The influence of the concrete member thickness, concrete strength, and the addition of steel fibers to the concrete mixture, on the anchorage capacity and performance was evaluated. The experimental results were evaluated in terms of anchorage capacity, anchorage ductility and stiffness as well as failure mode and geometry. Furthermore, the validity of Concrete Capacity (CC) method for predicting the tensile breakout capacity of anchor bolts in plain and steel fiber-reinforced normal- and high-strength concrete members was evaluated. The anchorage capacity and ductility increased slightly with increasing member thickness, whereas the anchorage stiffness decreased slightly. In contrast to the anchorage ductility, the anchorage capacity and stiffness increased considerably with increasing concrete compressive strength. The anchorage capacity and ductility also increased significantly with the addition of steel fibers to the concrete mixtures. This enhanced capacity and ductility resulted from the improved flexural tensile strength and post-peak cracking behavior of steel fiber-reinforced concrete. The average ratio of measured strengths to those predicted by the CC method for anchors in plain concrete members was increased from 1.0 to 1.17 with increasing member thickness. In steel fiber-reinforced concrete, this ratio varied from 1.29 to 1.51, depending on the member thickness and the concrete strength.



STEEL FAILURE



CONCRETE BREAKOUT



PULLOUT

Figure 1 Anchor failure modes

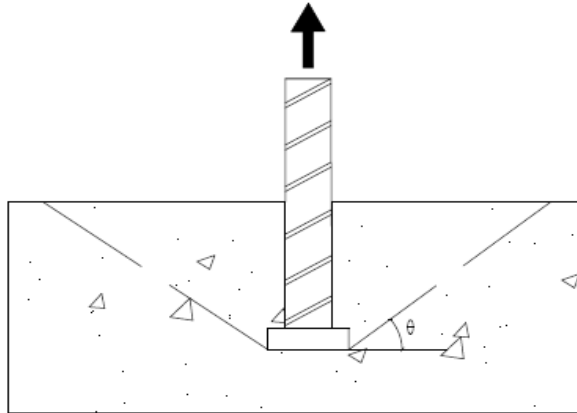


Figure 2 drawing of failure angle θ

Steel failure occurs due to necking near the shank of the anchor. As the tensile forces increase on the anchors and as it approaches yield strength, the cross-sectional area decreases due to necking. When the tensile force increases beyond this point, the anchor will fail at its ultimate strength. The ACI code currently prescribes an equation utilizing the ultimate strength of the steel. ACI 17.4.1.2 clause provides this equation, N_s is the ultimate strength of the steel, A_s is the effective area of the steel in tension, and f_{ult} is the ultimate strength of the material:

$$N_s = A_s * f_{ult}$$

There is another common failure which causes due to bonding, friction failure can occur when the frictional component is surpassed, and the anchor simply slips out of the concrete. This can occur due to various reasons, development length, number of threads embedded in concrete, when the yield strength is much higher than the pullout strength and the frictional force is surpassed by this pullout strength, a friction failure may occur. The ACI code does not take fiber influence on the concrete into the equation for calculating pull out strength of the concrete. This niche requires attention to develop an easy way to utilize the effects of the fiber reinforced concrete, without waiting to test the specimens

during the construction, which can save time.

Breakout failure occurs when the tensile load on the anchor increases more than the tensile strength of the concrete specimen and the anchor breaks out and shears out in a cone. The ACI estimates the typical break out angle is to be approximately 35°, it also depends on the depth of the embedment of anchors. As the embedment increase, the angle of influence increases. As the embedment decreases, the angle of failure can range from 21° to 28° (Yang), in this research it is found that the angle of influence was around 25°. There are many ways to calculate the breakout capacity. ACI 318 prescribes the use of the concrete capacity design (CCD) method. The CCD also assumes a 35° failure angle and a rectangular breakout, as opposed to earlier methods that used an assumed 45° failure angle and a conical breakout. The breakout capacity is predicted by ACI 17.4.2.2a, where N_b is the ultimate breakout capacity, k_c is a constant based on the anchor type, f'_c is the compression strength of the concrete, λ_a is a constant based on the concrete type, and h_{ef} is the effective embedment depth of the anchor.

$$N_b = k_c * \lambda_a * \sqrt{f'_c} * h_{ef}^{1.5}$$

There is another method where the ACI code assumes 45° failure angle and a conical breakout. Equation 4 predicts the breakout strength using this failure angle, where P is the ultimate breakout capacity, L is the embedment length, d is the diameter of the anchor head, and f'_c is the compressive strength of the concrete:

$$P = \pi * L * (L + d) * 4 * \sqrt{f'_c}$$

It is found that ACI 349 method is more conservative for short embedded anchors. There are various methods to calculate breakout capacity which uses tensile strength, changing failure angles, etc. this study utilizes the CCD method.

2.1.2 Fiber Reinforced Concrete

Studies have shown that introduction of fibers into concrete have shown significant increase in tensile and flexural strength. These fibers embedded within the concrete further bind the aggregate together. Concrete is weak in tension. Regular concrete is bound together by chemical bonds between cement and aggregate through hydration. These chemical bonds are weak in tension, due to this concrete crack and fails when subjected to tensile force. When fibers are introduced to the concrete mixture, they bind further with the ingredients and confines the concrete further. This composite binding action increases the tensile strength of the concrete when subjected to tensile force. Therefore, flexural strength of the concrete increase. Due to this increase in resisting tensile stresses from fibers, increasing flexure resulting in higher tensile stresses can also be resisted.

Compressive strengths of fiber reinforced concrete gave also been documented as slightly increasing, or no effects with addition of fiber reinforcement (Ramil). This is caused by the confining effects of the concrete's aggregates. It is found that the increase in fiber dosage results in reduced workability of concrete which results in decrease in compressive strength of concrete due to air voids. Due to this reduction in workability of concrete, it is particularly difficult to place, compact and consolidate concrete.

There are several varieties of fiber reinforcement including steel and polypropylene fibers. Polypropylene fibers are found to reduce compressive strength of concrete due to introduction of large air voids. Whereas, steel fibers are found to increase compressive strength. Steel fibers are commonly used in pavement design in order to reduce the cracking of the concrete due to exposure and service loading. However, steel fibers are susceptible to rust. These fibers can replace small fibers of #3 or #4 rebar.



Figure 3 Steel fibers used in this research

Table 1 Steel fiber physical properties

Length (in)	Diameter(in)	Tensile strength(ksi)
1.3	0.02	174

3 EXPERIMENT PROGRAMS

3.1 Fabrication of Test Specimens

3.1.1 Design of Test Specimen Formwork

Three different types of specimens were designed according to the test to be performed: Compression, split tensile, flexure and anchor pullout tests. The compression test was performed on cylinders of size 4" in diameter and 8" in height. The split tensile test was performed on 4" diameter and 8" in height. The flexure tests were tested on beams of size 6"x6"x20". For anchor pullout the beams sizes were selected such that its edge distance and spacing between each of the anchor were more than specifications of ACI 318-14. Therefore, a size of 54"x16"x10" beam was selected as the anchors specimen size. This large size ensures housing 3 anchors in one beam and allows to place the hydraulic arm on the beam and evenly distribute compressive force back into the beam outside of the anchor's influence area.

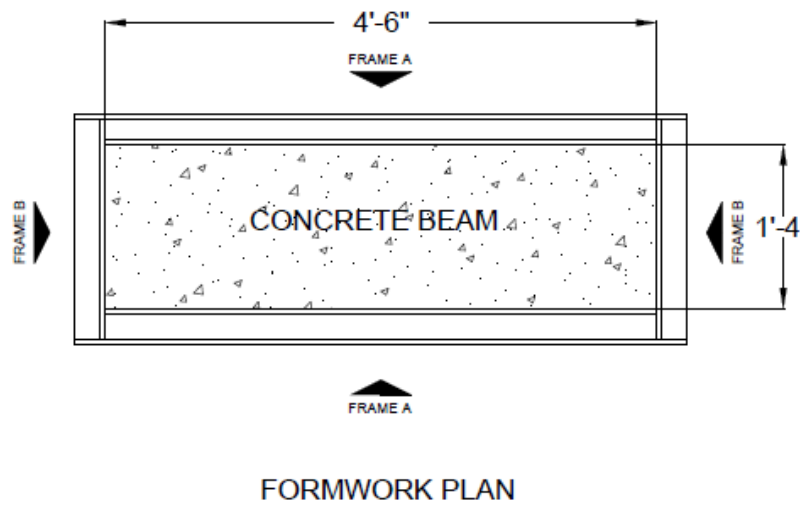


Figure 4 Wood formwork – Plan view

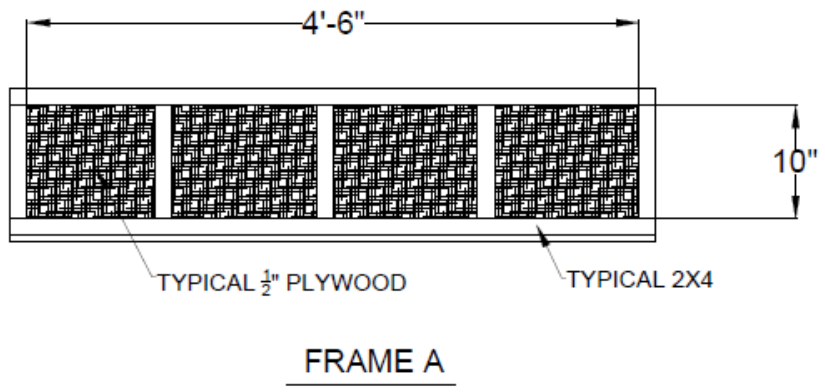


Figure 5 Wood formwork – Elevation at Frame A

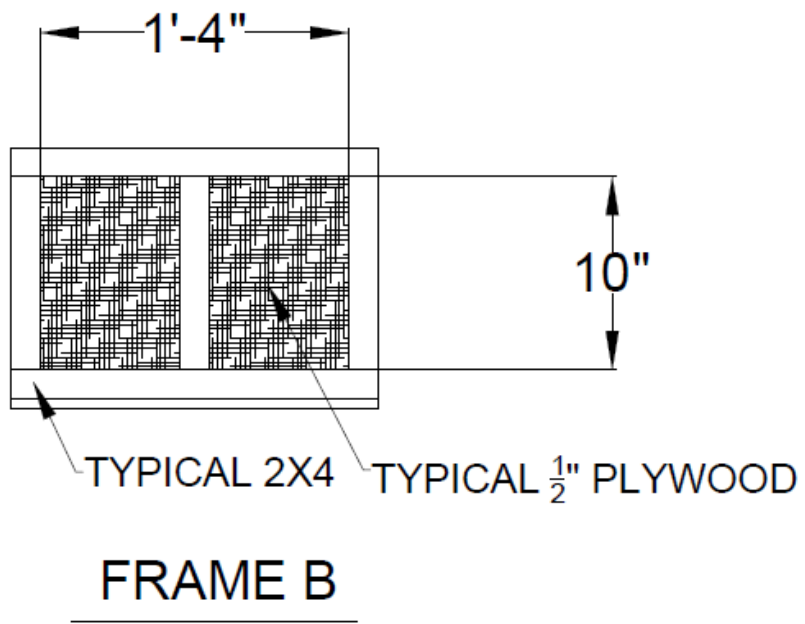


Figure 6 Wood formwork – Elevation at Frame B

3.1.2 Construction of Formwork

The cylinders and smaller beams were produced by the preexisting forms found at the UTA Civil Engineering Lab. The cylinder specimens were all formed using typical 4"x8" plastic forms. The smaller beam specimens were all formed using assembled 6"x6"x20" steel forms. The large 54"x16"x10" specimens were formed using constructed wood forms. The design of wood forms is shown in figures 2, 3, and 4.

Using the formwork plan, typical 2x4's was nailed together to create the frame of the formwork. 7/16" plywood was nailed to the sides of all the frame. Additional 7/16" plywood was nailed to the exterior of the "A" frame in order to connect the frame together and ensure the pressures from the concrete could be resisted by the created diaphragm. The figures show the construction of the formworks.

3.1.3 Concrete Pouring

The formworks or smaller specimens and the main frame were prepped by spraying the insides with WD-40. The WD-40 acts a concrete releasing agent and prevents the concrete from sticking to the forms.

The concrete was mixed by mixers available at the CELB lab, three batches were made to pour concrete for one beam and all other specimens. A slump test performed before pouring the concrete into the forms. These are the specification of concrete mixes made:



Figure 7 Pouring aggregates into the concrete mixer.



Figure 9 Slump cone procedure



Figure 8 Pouring aggregates into the concrete mixer.



Figure 10 Collection of aggregates prior to mixing concrete

Table 2: Fiber Concrete Design Mixture

Steel Fiber Reinforced Concrete Design Mixture			
Component	Density(lbs./cf)	Weight(lbs.)	Volume (cf)
Type I/II Cement	196	680	3.5
Coarse Aggregate	161	1246	7.9
Fine Aggregates	176	1741	10
Water	62.4	335	4.9
Air	-	-	0.7
Concrete mix total	-	4001	27

This is a standard concrete mix design with a design strength of 4000 psi for a total volume of 27cf. Therefore, it is recommended to use this standard mix design for achieving this design strength and addition of steel fiber is according to the percentage of steel fiber required multiplied by the total volume in lbs. of steel fibers.

Slump test was performed in accordance with ASTM C143. The standard 8" base, 4" top and 12" tall slump cone. Concrete of all three mixtures were poured into the slump cone in three layers compacting each layer by giving 25 blows using a steel rod. Once the cone was filled and flush at the top, the cone was carefully lifted. The concrete slumped and the slump was measured from the top of the cone using a tape measure. It was discovered that the slump was decreasing as the percentage of fibers increased, due to decrease of the workability of the concrete.



Figure 11 Slump test of 0.0% steel fiber reinforced concrete



Figure 12 Slump test of 0.5% steel fiber reinforced concrete

After the pour was done, after 3 days the formwork was removed, and the curing of specimens took place in curing room found in CELB lab at UTA for 28 days. The anchor beams however were kept in the formwork throughout the curing period and testing due to the small width of 16" of the beams and the hydraulic jack setup required a base of 18", therefore formworks was never removed. It was carefully cured for 28 days by providing wet towels and tarps to reduce dehydration.

3.2 Test Set-up and procedure

3.2.1 Compression, Tensile and Flexure Testing

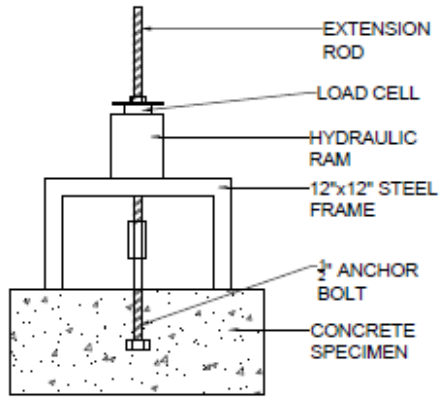
After 28 days of curing the specimens were ready for testing. Compression, tensile and flexure tests were performed. These tests all utilize the 60-kip compression machine found at the CELB. The 60-kip compression machine is operated using the loading table and the supported head. The head was rigidly supported and held the specimen in place. Different heads were used for different tests. The specimens were placed on the loading table and adjusted to align the center of gravity of specimen with the center of loading head. The specimen was eventually met the bottom of the loading head and the test was commenced.

The compression tests were performed in accordance with ASTM C39 using 4"x8" cylinders. The standard procedure of compression test was performed. The head had a simple round flat top to apply load onto it. The specimens were loaded at an approximate of 500 lbs./sec and the ultimate load was recorded. The compressive strength f'_c was calculated using the following equation, where f_c is the compressive strength in psi, P is the applied ultimate load, and r is the radius of the cylinder:

$$f'_c = \frac{P}{\pi r^2}$$

The test set up involves four main parts:

1. Steel frame: it supports the hydraulic ram and load cell
2. Hydraulic ram: connected to hydraulic machine to pull the anchors
3. Load cell: records tensile force applied by the hydraulic ram
4. Extension rod: connected anchors and all other elements of the setup.



EXPERIMENTAL SET-UP

Figure 13 Test set-up, frame, hydraulic ram and load cell



Figure 14 Test set-up, frame, hydraulic ram and load cell



Figure 15 Research team in front of one of the beam



Figure 16 Research team in front of one of the beam on casting day



Figure 17 Compression test of concrete for 0% steel fiber by volume before test.

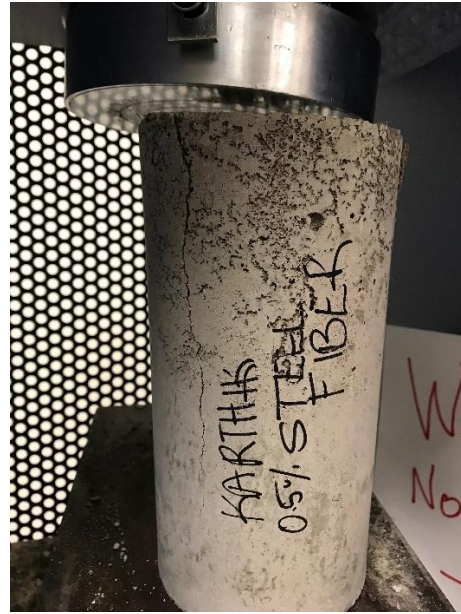


Figure 18 Compression test of concrete for 0.5% steel fiber by volume after test.

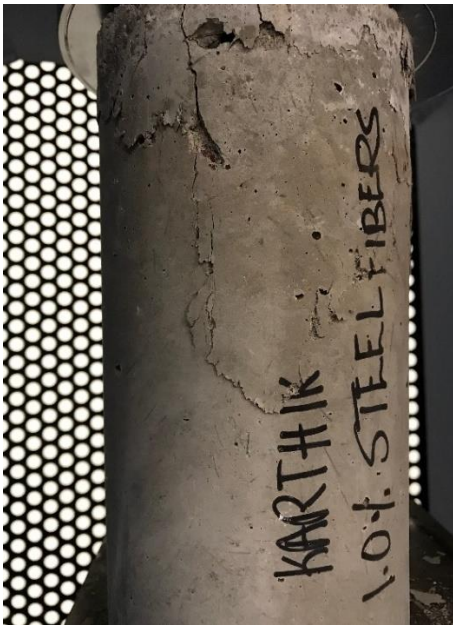


Figure 19 Compression test of concrete for 1% steel fiber by volume after test.



Figure 20 Compression test of concrete for 1% steel fiber by volume before test.

The tensile tests were performed in accordance with ASTM C496 using 4"x8" cylinders. The specimen was tested according to the standard procedure. The load will be applied across the cylinders. The specimens were loaded at a rate of 100lbs/sec and the ultimate load was recorded. The strength of the concrete was obtained using the equation 6, where f_t is the tensile stress in psi, P is the applied ultimate load, L is the length of the cylinder, and D is the diameter of the cylinder:

$$f_t = \frac{2P}{\pi LD}$$



Figure 21 Split tensile test of concrete cylinder of 0.5% steel fiber by volume

The flexure test is performed according to ASTM C78 using 6"x6"x20" beams. The specimens were tested according to the standard procedure, using 2-point loads and the

beam is simply supported. The beam was placed at 6" away from its supports. The specimen was approximately loaded the rate of 100 lbs./sec and the ultimate load was recorded. The flexure strength of the concrete was measured using equation 7, where f_r is the modulus of rupture in psi, P is the ultimate load, L is the span of the beam, B is the width of the beam and D is the depth of the beam:

$$f_r = \frac{PL}{BD^2}$$



Figure 22 Modulus of rupture test of concrete beam of 0.0% steel fiber by volume



Figure 23 Modulus of rupture test of concrete beam of 0.5% steel fiber by volume

The modulus of the plain concrete (0% fiber) is calculated by equation 7:

$$f_r = 7.5 \sqrt{f_c}$$

3.2.2 Anchor Testing

The testing of Portland bolt F1554 G105 anchor rods were performed. The anchors were 8" in length and 3" threaded, they were embedded about 2.5" into the concrete. 3 anchors were placed at 18" to each other, and the edge distance of 9". These anchors were placed using 2x4's which was nailed to the sides of the frame and a hole was drilled at the mid-section of the wood given us 7.75" towards the edge. Later the anchor rods were placed using nuts and we also placed a nut on the other side of the anchor bolt which would be embedded in the concrete just to mimic an anchor bolt with head.



Figure 24 0.0% steel fiber reinforced concrete beam with embedded anchor bolt



Figure 25 0.0% steel fiber reinforced concrete beam with embedded anchor bolt



Figure 26 0.5% steel fiber reinforced concrete beam with embedded anchor bolt.



Figure 27 0.5% steel fiber reinforced concrete beam with embedded anchor bolt.



Figure 28: 1% steel fiber reinforced concrete beam with embedded anchor bolt after test
#1 anchor



Figure 29: 1% steel fiber reinforced concrete beam with embedded anchor bolt after test
#2 anchor



Figure 30: 1% steel fiber reinforced concrete beam with embedded anchor bolt after test
#3 anchor

The anchors were tested in accordance with ASTM E488. The anchors were all tested individually by placing a setup which comprises of a frame, a hydraulic jack, a load cell, a small plate and an extension rod. This setup was used on all the anchor bolts. The 11"x11" steel frame box and the hydraulic jack rested on the beam and this setup exerted compressive stress on the beam whereas the hydraulic jack, extension rod and the plate exerts tensile force on the anchors. This force was recorded by the load cell. The tensile force on the bolt would then be increased until the concrete failed, and the anchor bolt broke out.

After the anchor had been successfully tested, and pulled out, the ultimate tensile load was recorded and the breakout/cracked area around the anchor was recorded. The failure angle was then recorded using equation 9, where θ is the failure angle, D is the breakout diameter and Y is the embedment depth:

$$\theta = \arctan\left(\frac{Y}{D/2}\right)$$

4 EXPERIMENT RESULTS

4.1 Compression Test Results

4.1.1 Concrete Compression Test Results Data

Table 3 Concrete Compression Test Results

Compressive Strength of Concrete (psi)			
Fiber Volume fraction	0.00%	0.50%	1.00%
Specimen #1 (psi)	2811	3930	4333
Specimen #2 (psi)	2950	3860	4200
Specimen #3 (psi)	2944	3789	4246
Average (psi)	2901	3859	4259

4.1.2 Concrete Compression Test Results

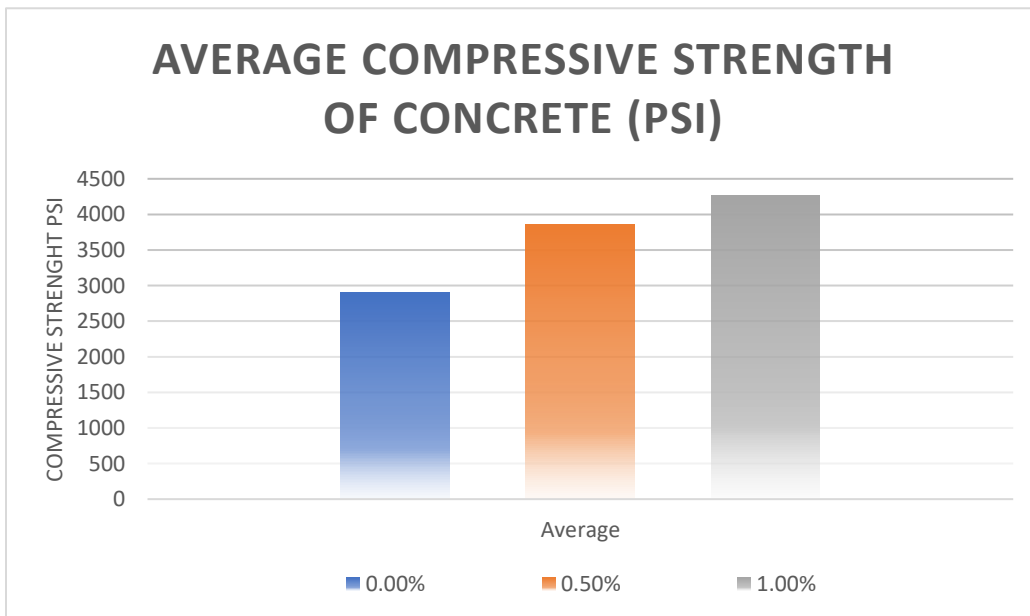


Figure 31 Compression Test Results

4.2 Split Tensile Test Results

4.2.1 Concrete Split Tensile Test Data

Table 4 Concrete Split Tensile Test Results

Concrete Spilt Tensile Strength (psi)			
Fiber Volume fraction	0.00%	0.50%	1.00%
Specimen #1 (psi)	268	378	531
Specimen #2 (psi)	257	354	585
Specimen #3 (psi)	214	323	558
Average (psi)	246	352	558

4.2.2 Split Tensile Test Results

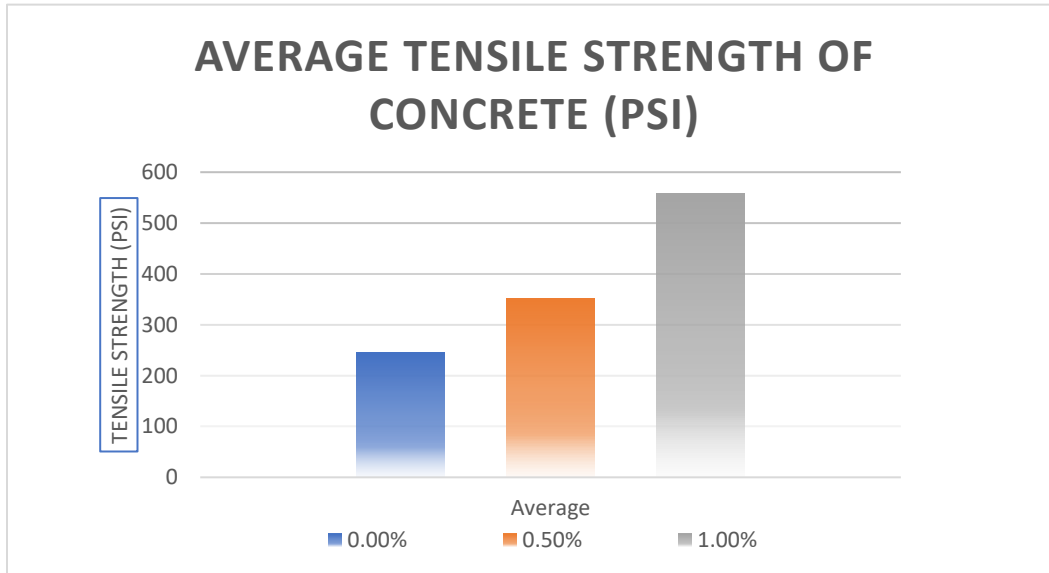


Figure 32 Tensile Test Results

4.3 Modulus of Rupture Test Results

4.3.1 Modulus of Rupture of Concrete Test Results Data

Table 5 Modulus of Rupture of Concrete Test Results

Modulus of Rupture of Concrete (psi)			
Fiber Volume fraction	0.00%	0.50%	1.00%
Specimen #1 (psi)	568	652	811
Specimen #2 (psi)	656	733	861
Specimen #3 (psi)	606	718	842
Average (psi)	610	701	838

4.3.2 Modulus of Rupture of Concrete Test Results

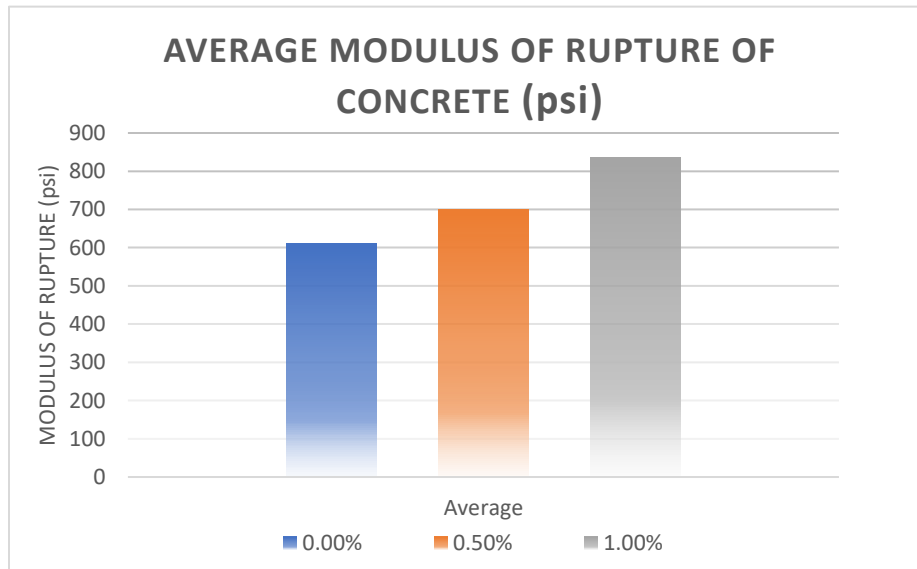


Figure 33 Modulus of Rupture of Concrete Test Results

4.4 Concrete Breakout Test Results

4.4.1 Concrete Breakout Strength in Tensile Data

Table 6 Concrete Breakout Strength in Tensile Test Results for 0.00% SFRC

Anchor #	#1	#2	#3	Average
Concrete Breakout Strength (lbs.)	5805	5794	5783	5794

Table 7 Concrete Breakout Strength in Tensile Test Results for 0.50% SFRC

Anchor #	#1	#2	#3	Average
Concrete Breakout Strength (lbs.)	9813	9857	11105	10258

Table 8 Concrete Breakout Strength in Tensile Test Results for 1.00% SFRC

Anchor #	#1	#2	#3	Average
Concrete Breakout Strength (lbs.)	9379	12683	13953	12005

4.4.2 Ultimate Tensile Load of Concrete Graphs

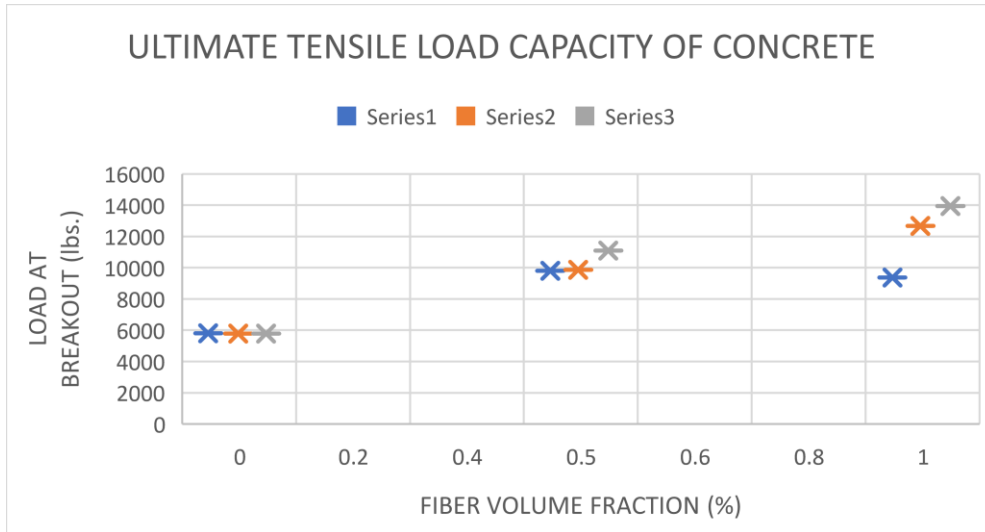


Figure 34 Ultimate tensile load capacity of concrete

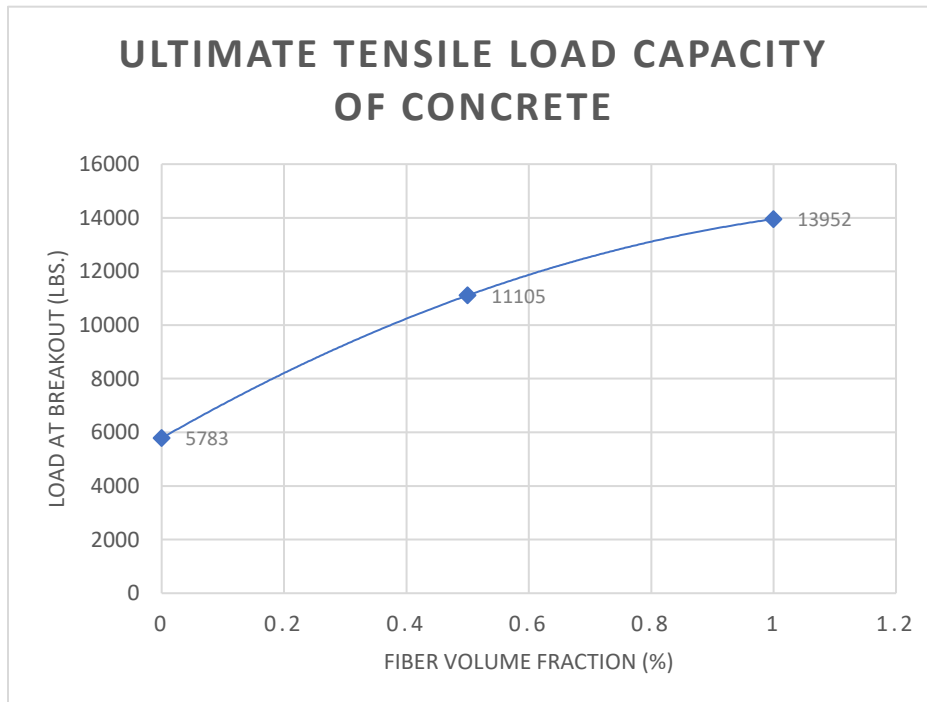


Figure 35 Average ultimate tensile load capacity of concrete

4.4.3 Concrete Breakout Cone Diameter and Failure Angle Data

Table 9 Average Concrete Breakout Cone Diameters and Failure Angle Results

Fiber Volume Fraction (%)	Average Cone Diameter (in)	Average Failure Angle (°)
0.00%	9.6	26.51
0.50%	7.0	35.54
1.00%	6.0	39.86

4.4.4 Concrete Breakout Diameter and Failure angle Graphs

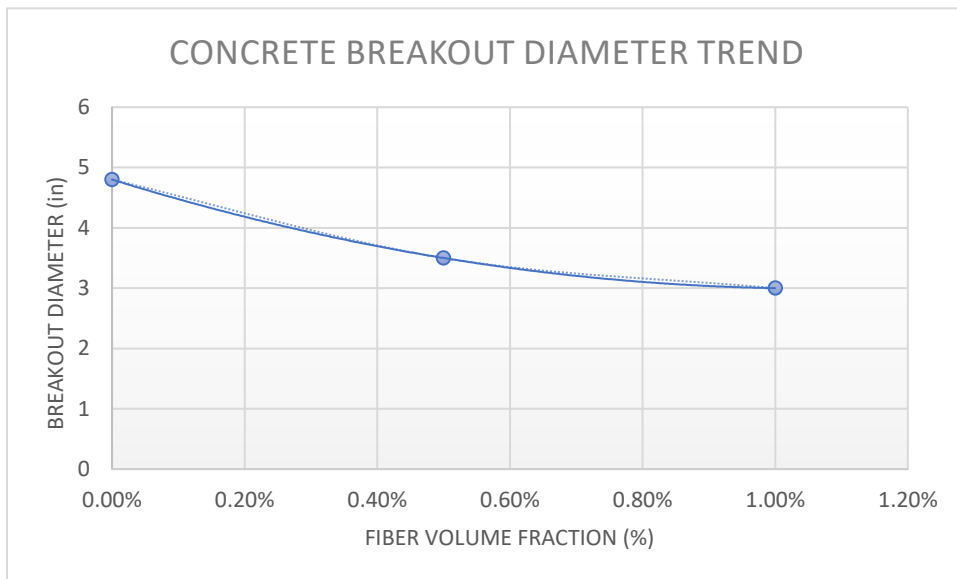


Figure 36 Concrete Breakout Cone Diameter Comparison

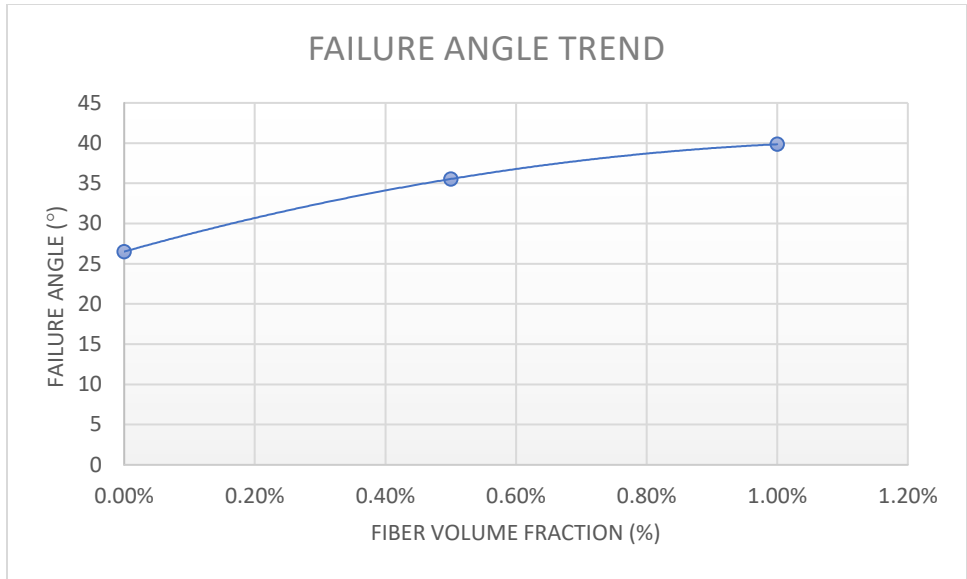


Figure 37 Cone of Influence Failure Angle Comparison

4.5 Project Summary

4.5.1 Experiment and Results

In total eighteen concrete specimens were constructed during the research. Three wooden frames were constructed before pouring concrete into the frame for casting the concrete beam specimens. Nine cylinders were cast using plastic forms. Six 6"x6"x20" beams were cast using plastic frames available at CELB. Three 54"x16"x10" beams were cast using the constructed wooden frames. Three concrete mixtures were used which differed in percent volume of fibers, i.e. 0.0%, 0.5% and 1.0% of fibers. The specimens were cured for 28 days after casting them. The smaller specimens were cured in the curing room and were tested, and the results were recorded. Six cylinders were tested in compression per ASTM C39. The compression results as expected showed exponential increase across all the mixes. Split tensile tests were conducted on six cylinders per ASTM C496. Split tensile tests results showed exponential increase across all the mixes made. Flexure tests were conducted on six beams of 6"x6"x20" beams per ASTM C78. The modulus of rupture

increased as the volume of fiber increased in the concrete. The anchors were all tested in accordance with ASTM E488. The largest load was recorded on 1.0% mixture. It was noticed that the cone of influence was much larger than expected in 0.00% beam, due to excessive cracking.

4.6 Results Discussion

4.6.1 Small Specimen Deductions

Concrete in nature is brittle and is weak in tension. The addition of fibers changes the tensile strength of concrete without any introduction of rebars. In non-fiber reinforced concrete, tensile strength derives from chemical bond between aggregates and cement. Addition of fiber introduces tensile strength to concrete due to the bond between fibers and concrete. Therefore, increase in fiber fraction increased the compressive strength, tensile strength and modulus of rupture. There was a linear trend in all three tests mentioned above. The modulus of rupture increased by average 16.94% for every 0.5% of fiber by volume added to the concrete mixture,

The compressive stress of concrete was designed for 4000 psi, and addition of fibers were expected to increase compressive stress passively. As expected, the more addition of fibers exponentially increases the compressive stress.

It can be noted that the tensile strength of concrete increased by 112.6% from 0.0% to 1.0% fiber volume fraction in concrete.

4.6.2 Anchorage Presumptions and Hypothesis

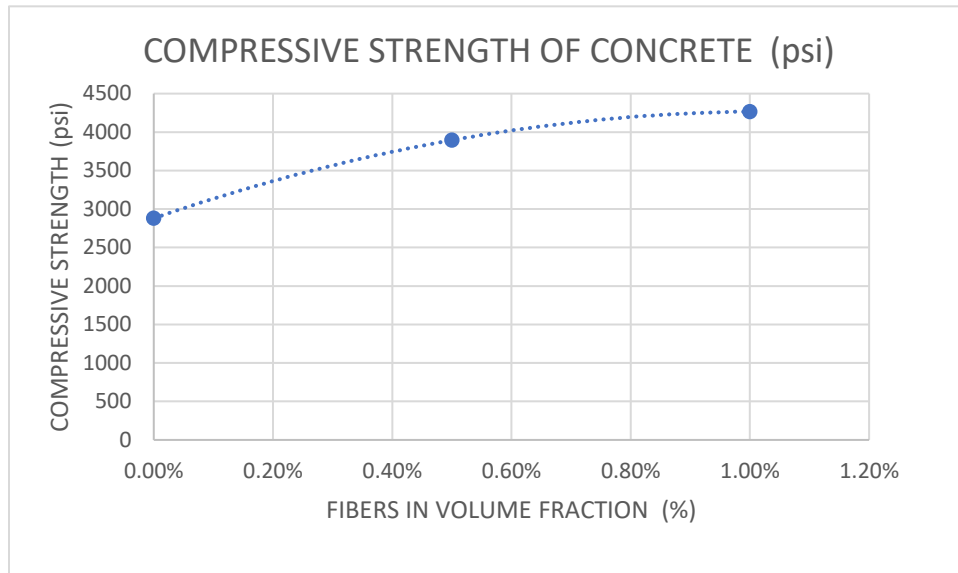


Figure 38 Compressive strength of Concrete

Table 10 Compressive strength of Concrete

Fiber Volume fraction(%)	Compressive Strength (psi)
0.00%	2901
0.50%	3859
1.00%	4259

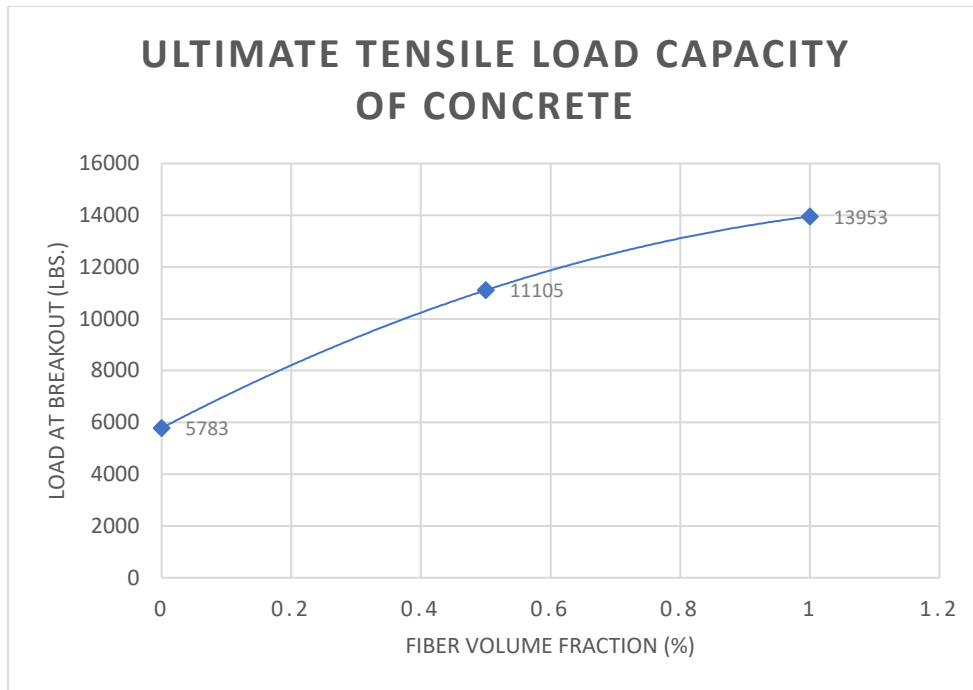


Figure 39 Ultimate tensile load capacity of concrete

Table 11 Tensile load capacity of concrete

Percent (%)	Average Tensile load capacity (lbs.)
0	5795
0.5	10258.33
1	12004.66

The nominal concrete breakout strength in tension for single anchor should not exceed N_{cb} :

$$N_{cb} = \frac{A_{Nc}}{A_{Nco}} * \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b$$

N_{cb} = The nominal concrete breakout strength in tension

N_b = Ultimate breakout capacity

$\Psi_{ed,N}$ = The modification factor for edge effects for single anchors in tension

$\Psi_{c,N}$ = Modification factor for no cracking at service loads

$\Psi_{cp,N}$ = Modification factor for post-installed anchors

By modifying the CCD method prescribed by the ACI code, for Steel fibers , the ultimate tensile strength of the anchor can be computed. Where, N_b is the ultimate tensile strength of the concrete, k_c is equal to 24 for cast-in anchors and 17 for group anchors, λ_a is 1 for normal-weight concrete , 0.75 for all-lightweight concrete, and 0.85 for sand-lightweight

Concrete, f'_c is the compressive strength of the concrete, h_{ef} is the effective embedment depth of 2.5" used in this research:

$$N_b = k_c * \lambda_a * \sqrt{f'_c} * h_{ef}^{1.5} * (1 + Z\sqrt{f'_c})$$

Where the value of Z can be obtained by the following table,

Table 12 Value of Z for various fiber volume fraction(%)

Fiber volume fraction (%)	Z
0.00%	0
0.50%	0.005
1.00%	0.0075

Using these correction factors the following calculation have been made.

Table 13 Data from experiment and modified CCD

Fiber volume fraction (%)	0.00%	0.50%	1.00%
Experiment (lbs.)	5794	10258	12005
Nominal concrete breakout strength in tension (N _{cb})	6364	9654	11527

The selection of Z values is directly related to percentage change (either percentage increase or percentage decrease) of compressive strength of concrete from 0.0% SFRC to 0.5% SFRC and 0.5% SFRC to 1.0% SFRC. It is found that percentage increase in compressive strength of concrete from 0.0% SFRC to 0.5% SFRC is about 35% ($((3895-2881)/2881)*100$) and percentage increase of compressive strength of concrete from 0.5% SFRC to 1.0% SFRC is about 10% ($((4625-3895)/3895)*100$), it is evident that the compressive strength of concrete is gradually decreasing from 35% for 0.5% SFRC (from 0.0% SFRC) to 10% for 1.0% SFRC (from 0.5% SFRC). This difference of 25% is due to reduced workability of concrete and possible existence of bug holes and air voids.

It is necessary to take this gradual decrease into account, for 0.5% SFRC the Z value is 0.005 (0.5%) whereas for 1.0% SFRC the Z value is reduced by 25% (instead of using 0.01 or 1%, the value is reduced to 0.0075 or 0.75%) .

The initial presumption was that the concrete with the most fiber would yield the largest ultimate tensile load. However, the compressive stress and ultimate load capacity increased up to 1.0% fiber volume fraction. The largest average ultimate tensile load was recorded in the 0.5% fiber mixture.

In addition, the diameter of breakouts and angle of failure were calculated. Diameter of the cone decreased, and the angle of failure increased as the fiber volume increased in the concrete mix. None of the anchors failed due to yielding, all the anchors failed due to concrete breakout. This modified CCD equation predicts the ultimate tensile load of anchor within the experimental value obtain thus giving reliable results. The table provided can be linearly interpolated to obtain value for Z for different fiber volume fraction (%).

5 CONCLUSION

5.1 Project Results

5.1.1 Summarized Conclusions

1. The concrete breakout strength of anchor in tension increased by 77% for 0.5% steel fiber dosage and increased 107% for 1.0% of steel fiber dosage in comparison with 0.0% Steel fiber concrete.
2. The failure angle increased as the dosage of fiber increased in the concrete by 34% for 0.5% steel fiber dosage, and 50% for 1.0% steel fiber dosage with respect to 0% steel fiber concrete.
3. The diameter of the cone of influence decreased as the dosage of the fiber fraction increased in the concrete by 27% for 0.5% steel fiber dosage, and 37.5% for 1.0% steel fiber dosage respect to 0% steel fiber concrete.
4. The breakout strength of concrete in tension is directly proportional to concrete tensile strength.
5. Increasing fiber dosage leads to increase in concrete ductility.
6. The split tensile strength and modulus of rupture strength of the concrete increased as the dosage of steel fiber increased.
7. The failure angle approaches 40° as the dosage of fiber increases to 1.0%.
8. The compressive stress increased for both 0.5% and 1.0% of steel fibers dosages in concrete.

5.2 Research Contribution and Continuation

5.2.1 Research impact

This research throws new light on the concrete breakout strength of hex headed anchors in tension. Although, it is less economical to use SFRC, it is particularly helpful in bridges and pavement. With the information on diameter of cone of influence we can provide steel fibers within that diameter where anchors are to be used and increase concrete breakout strength of concrete with controlled economy. Size of the foundation can drastically decrease due to improved compressive strength, thus reducing the cost of construction. Use of fibers in pavement reduces the cracking, shrinkage and thermal expansion. Use of fibers in pavement eliminate the need to depend upon concrete pavements due to increased compressive strength of pavements.

This research can be extended to sign post foundation, traffic signal foundation and guardrails on bridges and highways.

Additional research on the effects of embedment and rate of loading on the bolts while testing will provide new relationships between ultimate tensile strength and compressive stress.

5.2.2 Recommendations for Future Research

1. Investigation of loading rate on cast-in and post installed anchor bolts.
2. Investigation of depth of embedment of cast-in and post installed anchor bolts.
3. Test the effects of various types of fibers.
4. Test on shear loading on anchors.
5. Investigation of varying dosage of steel fibers in a single beam, by increasing steel fiber dosage in the area of ANCO, thus making a composite beam.
6. Test group action of anchor bolts in tension.
7. Study of anchor bolts action on concrete of varying diameter.
8. Test of anchor behaviors when subjected to impact loading.
9. Anchor behaviors when subjected to stepped loading.
10. Investigation of fatigue loading on the anchor bolts.

APPENDIX A

List of formulae

$$1. N_{cb} = \frac{A_{Nc}}{A_{Nco}} * \Psi_{ed,N} \Psi_{c,N} \Psi_{cp,N} N_b$$

N_{cb} = The nominal concrete breakout strength in tension

N_b = Ultimate breakout capacity

$\Psi_{ed,N}$ = The modification factor for edge effects for single anchors in tension

$\Psi_{c,N}$ = Modification factor for no cracking at service loads

$\Psi_{cp,N}$ = Modification factor for post-installed anchors

$$2. N_s = A_s * f_{ult}$$

N_s = Ultimate strength of the steel

A_s = Effective area of the steel in tension

f_{ult} = Ultimate strength of the material

$$3. N_b = k_c * \lambda_a * \sqrt{f'_c} * h e f^{1.5}$$

N_b = Ultimate breakout capacity

k_c = Constant based on the anchor type

f'_c = Compression strength of the concrete

λ_a = Constant based on the concrete type

h_{ef} = Effective embedment depth of the anchor

4. $P = \pi * L * (L + d) * 4 * \sqrt{f'c}$

P = Ultimate breakout capacity

L = Embedment length

d = Diameter of the anchor head

$f'c$ = Compressive strength of the concrete

5. $f'c = \frac{P}{\pi r^2}$

$f'c$ = Compressive strength of the concrete

P = Applied ultimate load

L = Length of the cylinder

D = Diameter of the cylinder

6. $f_r = \frac{PL}{BD^2}$

f_r = Modulus of rupture in psi

P = Ultimate load

L = Span of the beam

B = Width of the beam

D = Depth of the beam

7. $f_r = 7.5 \sqrt{f'_c}$

f_r = Modulus of rupture in psi

f'_c = Compressive strength of the concrete

8. $\theta = \arctan\left(\frac{Y}{D/2}\right)$

θ = failure angle

D = breakout diameter

9. $N_b = k_c * \lambda_a * \sqrt{f'_c} * h_{ef}^{1.5} * (1 + Z\sqrt{f'_c})$

N_b = Ultimate breakout capacity

k_c = Constant based on the anchor type

f'_c = Compression strength of the concrete

λ_a = Constant based on the concrete type

h_{ef} = Effective embedment depth of the anchor

REFERENCES

2015 International Building Code. Country Club Hills, Ill: ICC, 2014.

ACI Committee 318. Building Code Requirements for Structural Concrete : (ACI 318-14) ; and Commentary (ACI 318R-14). Farmington Hills, MI :American Concrete Institute, 2014.

ACI Committee 349, "Code Requirements for Nuclear Safety-Related Structures", ACI 349-81.

ASTM C39 Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C78 Test Method for Flexural Strength of Concrete

ASTM C496 Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

ASTM E488 Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements

Al-Ta'an, S.A. and A.A. Mohammed, 2010a. Tensile strength and behavior of single short headed anchors in steel fibrous concrete. Proceedings of the 4th World Congress on Engineering, August 2-5, 2010, Sarawak, Malaysia, FEIC, MSET and UPM, pp: 244-257

Al-Ta'an, S.A. and A.A. Mohammed, 2010b. Tensile strength of short headed anchors embedded in steel fibrous concrete. *Al-Radidain Eng. J.*, 18: 35-49.

Al-Ta'an, S.A. and A.A..H. Al-Jaffal, 2011. Tensile capacity of short headed anchor bolts embedded in high strength fibrous concrete. *Int. J. Applied Eng. Res.*, 6: 235-247.

Cannon, R.W., E.G. Burdette and R.R. Funk, 1975. Anchorage to concrete. Tennessee Valley Authority, Knoxville.

Cannon, R. W., discussion of "Concrete Capacity Design (CCD) Approach for Fastening to Concrete," by F. W. Eligehausen, and J. E. Breen, *ACI Structural Journal*, V. 92, No. 6, 1995, pp. 787-791.

Chen, W. F., *Plasticity in Reinforced Concrete*, McGraw-Hill, New York, 1982.

Eligehausen, R., "Anchorage to Concrete by Metalix Expansion Anchors," University of Stuttgart, Germany.

Farrow, C.B., 1. Frigui and R.E. Klingner, 1996. Tensile capacity design of single anchors in concrete: Evaluation of existing formulas on an LRFD basis. *ACI Struct. J.*, 93: 128-137.

Fuchs, W., R. Eligehausen and J.E. Breen, 1995. Concrete capacity design (CCD) approach for fastening to concrete. *ACI Structural. J.*, 92: 73-94.

Gesoglu, M., T. Ozturan, O. Melda and G. Erhan, 2005. Tensile behaviour of post-installed anchors in plain and steel fibre-reinforced normal and high strength concretes. *ACI Structural J.*, 102: 224-231.

ICC-ES Evaluation Report; ESR-3889 DEWALT: SCREW-BOLT+

Nielsen, M. P., *Limit Analysis and Crete Plasticity*, Prentice-Hall, Englewood Cliffs, NJ, 1984.

Primavera, E. J.; Pinelli, J. P.; and Kalajian, E. H., "Tensile Behavior of Cast-in-Place and Undercut Anchors in High Strength Concrete," *ACI Structural Journal*, V. 94, No. 5, Sept.-Oct. 1997, pp. 583-594.

Ramli, R. and E.T. Dawood, 2011a. Effect of steel fibres on the engineering performance of concrete. *Asian J. Applied Sci.*, 4: 97-100.

Ramli, R. and E.T. Dawood, 2011b. Study of hybridization of different fibres on the mechanical properties of concrete. *Asian J. Applied Sci.*, 4: 489-492

Saad Ali AlTaan, AbdulKader Ali Mohammed and Alaa AbdulRahman Al-Jaffal, 2012. Breakout Capacity of Headed Anchors in Steel Fibre Normal and High Strength Concrete. *Asian Journal of Applied Sciences*, 5: 485-496.

Swamy, R.N., P.S. Mangat and S.V.K. Rao, 1974. The mechanics of fibre reinforcement of cement matrices. *Fibre Reinforced Concrete*, SP-44, American Concrete Institute, Detroit, USA., pp: 1-28.

Yang, K. H. and Ashour, A. F., "Mechanism Analysis for Concrete Breakout Capacity of Single Anchors in Tension," *ACI Structural Journal*, Vol. 105, No. 5, 2008, pp. 609-616

Raad Azzawi, Travis Pechacek and Karthik Kondajji Vidyaranya, 2018. "CONCRETE BREAKOUT STRENGTH OF POST-INSTALLED ANCHORS WITHIN FIBER REINFORCED CONCRETE".