Experimental investigation of concrete breakout strength of anchors in shear within fiber reinforced concrete.

Presented to the Faculty of the Graduate School of

The University of Texas at Arlington in Fulfillment

of the Requirements for the Degree of

M.Sc. Civil Engineering — Structures

May 2019

By

Mohammad A. Khanfar

Supervisor: Dr. Raad Azzawi

THE UNIVERSITY OF TEXAS AT ARLINGTON

Acknowledgment

First and foremost, I acknowledge my gratitude to my God for giving me the strength to complete this research and my Master of Science in Structural Engineering program, then to my Mom, Dad and my brothers. My deepest appreciation goes to my advisor Dr. Raad Azzawi for his generous guidance, consistence support and advices through all stages of this research work. I am thankful to Dr. Nur Yazdani, Dr. Suyan Ham for readily accepting to serve on my dissertation committee as well as for their support during my study. Many thanks to my research assistance team, Karthik Vidyaranya, Atheer Al Khafaji, Ghasan Sulaiman, Ahmad Alateeq, Travis Michael. I will always be thankful to the Civil Engineering Department at UT Arlington for supporting me throughout my research work.

Abstract

The University of Texas at Arlington, 2019

By Mohammad Akram Khanfar, Supervising Professor: Dr. Raad Azzawi

This study investigates the effects of Polypropylene fibers on the concrete breakout strength of cast in place anchors in shear under different loading rates. The steel headed anchors were cast within concrete specimens of different 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. 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. 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 reduce workability and increasing air voids from poor consolidation. In contrast, using Polypropylene fibers leads to increase the concrete tensile strength and the concrete shear breakout capacity for the anchor. Also, it's found that the cone of influence increase as the anchor embedded length or edge distance increase. Cone of influence control the anchor shear mode failure, once the cone of influence is high that leads to steel failure proceeded by concrete spall, for that mode of failure increasing fiber dosage 1.0% leads to decrease load failure 55% and decrease displacement 50%. Loading rate will play a major roll to determine the failure load, once the loading rate is higher that will provide a higher impact load, where increasing loading rate 150% leads to decrease load failure 25% and increase displacement 15%.

Table of Contents

List of Illustrations

List of Tables

List of Equations

1 INTRODUCTION

Concrete is important and multi-use. Concrete foundations carry the loads of a structure and distribute them to the soil beneath. Concrete pavements carry the loads of vehicles and pedestrians and distribute their loads to the soil below. Additionally, concrete columns and beams can be used to construct entire buildings, residential, parking garage, bridges and many more different type of concrete structural members involve to construct the buildings. Whether a steel column, an architectural panel, or a traffic barrier, attaching different elements to concrete is typical in the design of different concrete systems. Anchorage is vital. Therefore, it is important to understand how these anchors function, and what can be done to make these anchors more efficient once they are attached to our structural members.

All concrete anchors are not alike. Some anchors are CIP anchors, meaning that the anchor is placed within the concrete pour, locking it in place as the concrete cures. Other anchors are post-installed, meaning that the anchor is installed into concrete that has already cured. Many anchors have a small washer and nut that is tack welded to the end of the anchor rod that will work as a key to prevent the anchor from simply being pulled up. Others are adhesive, where the bond created between steel and concrete holds the anchor in place. The principle of all these anchors is essentially the same. The anchor has a volume of concrete, otherwise known as a “cone of influence”, that holds the anchor in place. This influenced concrete resists forces, such as tension and shear that threaten to tear the anchor away from the concrete. Concrete breakout occurs when the force resisted by the cone of influence is too high and the anchor breaks out of the concrete. Sometimes the anchor itself, or even the adhesive bond can fail before concrete breakout occurs. Often times, an anchor design may be controlled by the concrete breakout strength of an anchor. If so, how can the concrete breakout strength of an anchor be increased?

Concrete breakout is controlled by many different factors, such as the spacing, the embedment, or the edge distance of the anchors. These factors are directly related to the cone of influence. As the anchors become spaced further apart, when the embedment becomes deeper, or as the edge distance becomes further, the cone increases. As the cone of influence increases, so does the breakout strength. Another seemingly obvious factor includes the compressive strength of the concrete. As the compressive strength of the concrete increases, so does the concrete breakout strength. Sometimes these factors may play a pivotal role in a structure's design. Can another factor be added that may help increase the concrete breakout strength of an anchor?

The tensile strength of concrete in design is considered negligible. However, when fibers are introduced to the mixture, these fibers drastically increase the tensile strength of the concrete. Is it possible that increasing the tensile strength of the concrete would lead to an increase in concrete breakout strength of an anchor? Could this new mixture change the angle of the cone of influence thereby increasing or decreasing the influential volume of concrete? Would changing the mixture design be a cost-effective way to increase anchorage efficiency?

A sizable amount of past research has be dedicated to fiber-reinforced concrete (FRC) due to its potential to enhance existing concrete design methods and practices. In particular, propylene fibers are corrosion resistant making them more beneficial than other steel fiber products. Additionally, FRC is known to both provide ease in construction and, more importantly, allow the shrinkage of cracks developed throughout the design life of a concrete member. If FRC can stay uncracked throughout its design life and increase the mixture's tensile strength, then the benefits of using fibrous concrete for anchorage could be unrivaled.

1.1 Objectives

The main objective of this study is to investigate the concrete breakout strength for steel headed anchors in shear within concrete mixtures of varying polypropylene fiber dosages. Also, the effect of the loading rates on the concrete breakout strength of anchors in shear. To meet these objectives, four concrete mixture designs were created using varying amounts of fibers. Specimens of all four design mixtures were tested for their physical properties. Steel headed anchors were then attached within the specimens of differing mixtures (different percentage of Polypropylene fibers) and then tested.

1.2 Research Contribution

The benefits of this research include the possible reduced costs and increased concrete breakout strength of anchor in shear by the simple addition of fibers in lieu of special concrete reinforcement, designs changes or specialty anchors. For applications such as anchorage to fiber reinforced pavement for guardrails, this research will allow designers to consider the additional strength provided by the fiber reinforcement. The additional strength provided by the fibers will allow cheaper anchors to be used while still maintaining the necessary strength requirements.

1.3 Outline for Dissertation

This thesis is organized into the five following chapters respectively:

Chapter 1 – Introduction: This chapter explains the nature of concrete in shear and why fibers have been introduced to the concrete mixture.

Chapter 2 – Literature Review: This chapter presents the background of anchors, fiber reinforcement concrete and previous studies on concrete within steel fiber reinforced concrete so its easier to compare with propylene fibers.

Chapter 3 – Experimental Program: This chapter presents the concrete mixture design, and the fabrication, curing, and testing set-up of all specimens

Chapter 4 – Experimental Results and Discussion: This chapter presents compressive and tensile strength of cylinder specimens, the modulus of rupture of the beam specimens, and the ultimate tensile strengths of the screw anchors installed and how increasing fibers will effect on the shear concrete strength.

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

2 LITERATURE REVIEW

2.1 Previous Research and Accepted Design Practices

2.1.1 Concrete Anchors

Many research where on anchors attached to concrete, however there are only two main branches of concrete anchors: cast-in-place and post-installed. Like the name implies, cast-in-place anchors, such as hex head bolts or J bolts, are set in place as the concrete is poured. Once the concrete cures, the anchors are already in place and can be used. Cast-in-place anchors are common in applications such as steel frame design and can be used in groups of anchors connected via steel base plate. Post-installed anchors are installed after the concrete has cured. These anchors are installed via drilling into the concrete and then applying adhesive to the anchor bolt, torqueing into place, etc, depending on the type of post-installed anchor bolt used. Post-installed anchors are much more versatile than cast-in-place bolts since they can be installed after the concrete has cured. The ACI-318-14 code allows the designs of both types of bolts and provides guidance in calculating the three different types of anchorage failures: steel failure, concrete breakout, and pullout failure. For our specimens we have long embedment and edge distance of the anchors is high, so the fail will be steel failure but still we have clear effect of concrete strength on the failure, based on ACI-318-14, usually with pure shear load on anchor we have three types of failure, steel failure proceeded by concrete spall, concrete pryout for anchors far from the edge and concrete breakout.

(Saiosh, 2019) There are three basic forces in anchors,

Axial tension force: Those actions that produce axial tension stresses in anchors and act in a direction that coincides with the axis of the anchor.

Shear force: Those actions that produces shearing stresses in anchors and that act at right angles to the axis of the anchor, close to the face of the concrete.

Bending force: Those actions that produces bending stresses in anchors due forces that act at right angles to the axis of the anchor but not close to the surface thus causing lever-arm moments.

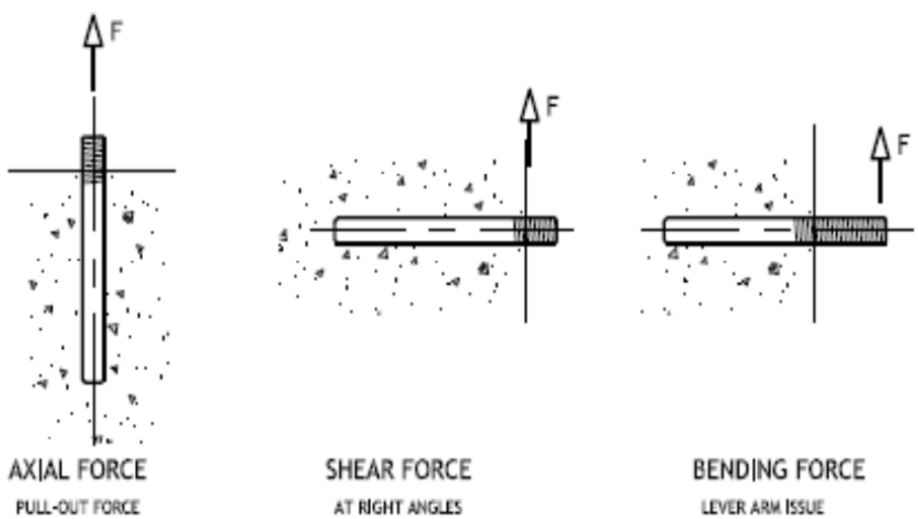


Figure 1: Basic forces in anchors

(Travis, 2017) When a column or some instance a beam is subjected for tensile loadings, the said amount of force shall be resisted by anchors, in addition, anchors shall satisfy the required edge distances, spacing, and thicknesses to prevent splitting failure. By definition, an anchor is a steel element either cast into concrete or post-installed into a hardened concrete member and used to transmit applied loads to concrete. In connection with this, the strength or the capacity of anchors shall be checked and design.

Before we proceed further, it is important to understand the different possible extent of failure if the member is subjected to a huge amount of tensile force. The images below are excerpts from ACI 318M-14 shows the possible failure modes of an anchor in tensile and shear loadings.

To prevent the above failures from happening, anchors should be designed accordingly. In this article, we will dissect the code requirements set forth in Chapter 27 of ACI 318M-14 or Appendix D of ACI 318M-08: Anchoring to Concrete. This is a two-part article for the design considerations on anchoring to concrete. To sum it up, the following are the general requirements for the strength of anchors.

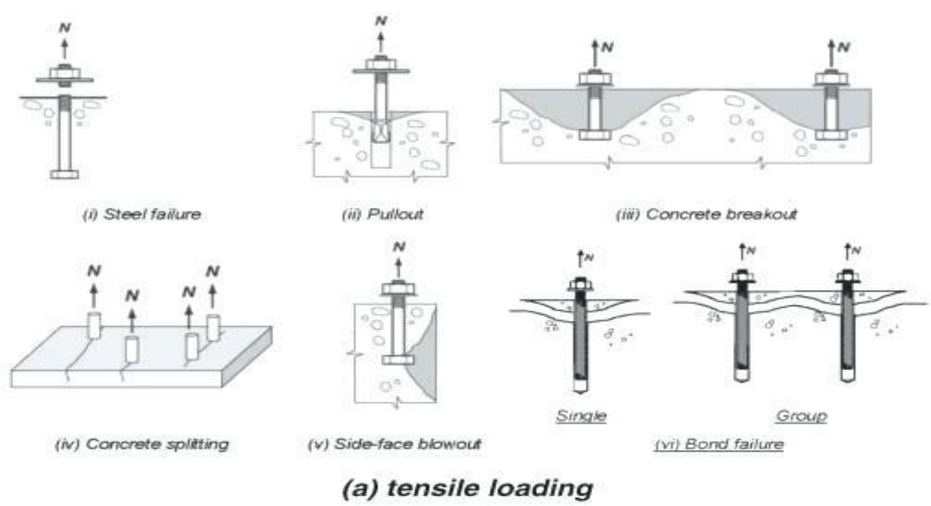


Figure 2: Anchor failure modes (tensile loading)

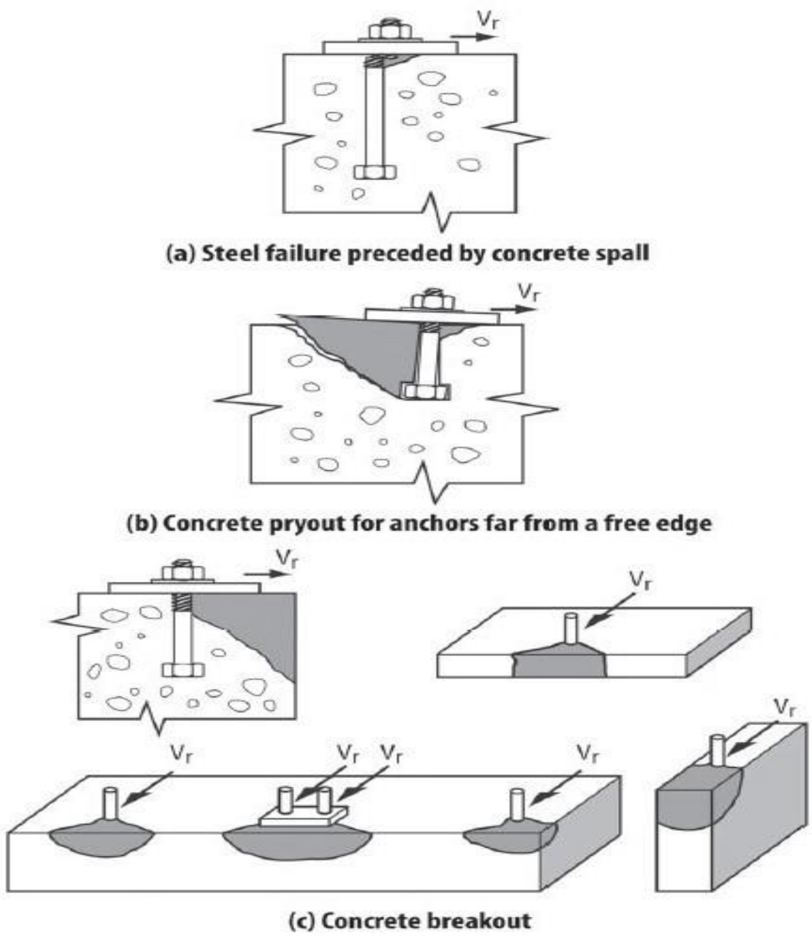


Figure 3: Anchor failure modes (shear loading)

Shear Loadings

- Steel strength of anchor in shear
- Concrete breakout strength of anchor in shear
- Concrete pry out strength of anchor in shear

Tension Loadings

- Steel strength of anchor in tension
- Concrete breakout strength of anchor in tension
- Pull out strength in tension
- Concrete side face blowout strength of headed anchor in tension
- Bond Strength of adhesive anchor in tension

Anchors failure under shear load ACI 318M-14,

1- Steel failure,

Steel failure is the fracture of the shank of the anchor. As the shear load increases on the anchor and anchor may begin to yield, and the cross sectional area will begin to pinch together and decrease. If the shear load continues to increase and surpass the ultimate shear strength of the anchor, the anchor will fracture. The ACI code currently prescribes equation utilizing the ultimate strength of the steel, as oppose to the yielding strength. Equation 1 is the accepted equation for nominal strength of an anchor bolt for shear Vsa shall not exceed (a) through (c):

(a) For cast-in headed stud anchor,

$$V_{sa} = A_{se,v} * f_{uta} \quad \text{.......................................(1)}$$

Steel strength in anchor design equation (ACI 17.5.1.2a)

(b) For cast-in headed bolt and hooked bolt anchors and for post-installed anchors where sleeves do not extend through the shear plane,

$$V_{sa} = 0.6 * A_{se,v} * f_{uta} \quad \text{.......................................(2)}$$

Steel strength in anchor design equation (ACI 17.5.1.2b) where ***Ase,V*** is the effective cross-sectional area of an anchor in shear, in.2, and ***futa*** shall not be taken greater than the smaller of **1.9*fya*** and 125,000 psi.

(c) For post-installed anchors where sleeves extend through the shear plane, ***Vsa*** shall be based on the results of tests performed and evaluated according to ACI 355.2. Alternatively, Eq. (17.5.1.2b) shall be permitted to be used.

2- Pryout failure,

The pryout mechanism for cast-in anchors usually occurs with very short, stocky studs welded to a steel plate or beam flange. The studs are typically so short and stiff that under a direct shear load, they bend primarily in single curvature. The ensuing deformation results in the “heel” of the stud head “kicking back,” which breaks out a crater of concrete behind the stud. Internal bearing pressures develop in the concrete near the concrete surface at the stud weld and at the stud head due to rotational restraint. This failure mechanism occurs away from all edge effects, when the anchorage is located “in-thefield” of the member. The behavior is somewhat analogous to a laterally loaded pile in earth. A longer and less stiff stud behaves differently. The longer and deeper embedded stud bends in double curvature and the deeply embedded head portion of the stud remains essentially stationary or fixed in the concrete. At the junction of the headed stud and plate or flange, the projected stud diameter in front of the stud bears directly on the concrete near the surface and induces a zone of concrete crushing. If the connection is close to an edge, the concrete anchorage assembly will likely break out a concrete section due to the edge effects. If the connection is located sufficiently away from the edge to preclude an edge breakout, the stud or studs will likely fail in a steel shear failure mode, the shear capacity of the stud group clear of the edge effects can be defined by:

$$Vs = n * As * fut \qquad \text{……………………………………..(3)}$$

Shear capacity of the stud group clear of the edge equation

V_s = nominal shear strength of a single headed stud or group of headed studs governed by steel strength (lb) n = number of studs or anchors in a group A_s = effective cross-sectional area of a stud anchor (sq in.) f_{ut} = design minimum tensile strength of headed stud steel in tension (psi) Currently, this equation is the same as Eq. D-17 of ACI 318-05 Appendix D,1 without the capacity reduction factor, φ.

3- Concrete breakout

Concrete breakout strength of anchor in shear,

The nominal concrete breakout strength in shear, ***Vcb*** of a single anchor or ***Vcbg*** of a group of anchors, shall not exceed:

(a) For shear force perpendicular to the edge on a single Anchor

$$V_{cb} = A_{vc}/A_{vco} * \psi_{ed,v} * \psi_{c,v} * \psi_{h,v} * V_b \text{ ....(4)}$$

Nominal concrete breakout strength in shear equation (ACI 17.5.2.1a)

(b) For shear force perpendicular to the edge on a group of anchors

$$V_{cbg} = A_{vc}/A_{vco} * \psi_{ec,v} * \psi_{ed,v} * \psi_{c,v} * \psi_{h,v} * V_b \text{ ....(5)}$$

Nominal concrete breakout strength in shear equation (ACI 17.5.2.1b)

(c) For shear force parallel to an edge, ***V_{cb}*** or ***V_{cbg}*** shall be permitted to be twice the value of the shear force determined from Eq. (17.5.2.1a) or (17.5.2.1b), respectively, with the shear force assumed to act perpendicular to the edge and with ***$\psi_{ed,V}$*** taken equal to 1.0.

(d) For anchors located at a corner, the limiting nominal concrete breakout strength shall be determined for each edge, and the minimum value shall be used.

Anchor bolts loaded in shear, and located without a nearby free edge in the direction of load, can fail by local crushing of the masonry under bearing stresses from the anchor bolt; by pryout of the head of the anchor in a direction opposite to the direction of applied load, or by yield and fracture of the anchor bolt steel. Anchor bolts loaded in shear, and located near a free edge in the direction of load, can also fail by breakout of a roughly semi-conical volume of masonry in the direction of the applied shear.

2.1.2 Fiber Reinforced Concrete

(Travis, 2017) Fiber Reinforced Concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers. Fiber reinforced concrete are of different types and properties with many advantages. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibers.

Fiber is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat. The fiber is often described by a convenient parameter called “aspect ratio”. The aspect ratio of the fiber is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to 150.

Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers. Within these different fibers that character of fiber reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation and densities.

Fiber-reinforcement is mainly used in shotcrete, but can also be used in normal concrete. Fiber-reinforced normal concrete are mostly used for on-ground floors and pavements, but can be considered for a wide range of construction parts (beams, pliers, foundations etc) either alone or with hand-tied rebars

Concrete reinforced with fibers (which are usually steel, glass or “plastic” fibers) is less expensive than hand-tied rebar, while still increasing the tensile strength many times. Shape, dimension and length of fiber is important. A thin and short fiber, for example short hair-shaped glass fiber, will only be effective the first hours after pouring the concrete (reduces cracking while the concrete is stiffening) but will not increase the concrete tensile strength

Effect of Fibers in Concrete,

Fibers are usually used in concrete to control plastic shrinkage cracking and drying shrinkage cracking. They also lower the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact, abrasion and shatter resistance in concrete. Generally fibers do not increase the flexural strength of concrete, so it cannot replace moment resisting or structural steel reinforcement. Some fibers reduce the strength of concrete.

The amount of fibers added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) termed volume fraction (V_f). V_f typically ranges from 0.1 to 3%. Aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio.

If the modulus of elasticity of the fiber is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increase in the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. However, fibers which are too long tend to “ball” in the mix and create workability problems.

Some recent research indicated that using fibers in concrete has limited effect on the impact resistance of concrete materials. This finding is very important since traditionally people think the ductility increases when concrete reinforced with fibers. The results also pointed out that the micro fibers is better in impact resistance compared with the longer fibers.

Necessity of Fiber Reinforced Concrete,

- It increases the tensile strength of the concrete.
- It reduce the air voids and water voids the inherent porosity of gel.
- It increases the durability of the concrete.

- Fibers such as graphite and glass have excellent resistance to creep, while the same is not true for most resins. Therefore, the orientation and volume of fibres have a significant influence on the creep performance of rebars/tendons**.**
- Reinforced concrete itself is a composite material, where the reinforcement acts as the strengthening fibre and the concrete as the matrix. It is therefore imperative that the behavior under thermal stresses for the two materials be similar so that the differential deformations of concrete and the reinforcement are minimized.
- It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its static and dynamic properties.

Many studies have been conducted on the change in material properties in concrete with the addition of fiber reinforcement. Studies have shown that with the introduction of fiber reinforcement, the tensile and flexural strength subsequently increases (Ramli, 2011). The fibers embedded within the concrete further bind the aggregate together. The tensile strength of typical concrete is rather low. Regular concrete is bound together by chemical bonds created between cement and aggregate through hydration. The chemical bonds binding regular concrete together do not have a strong tensile strength and as regular concrete is pulled apart, the concrete cracks and fails easily. As fibers are introduced to the concrete mixture, the fibers further confine the concrete and bind it together. As a shear and tensile force acts upon fiber reinforced concrete, both the chemical bonds and the fiber bind the concrete together, resulting in a higher tensile strength (f't). Likewise, as the tensile strength of the concrete increases, so does the flexural strength. Since the fiber reinforced concrete can withstand higher tensile stresses, increasing flexure resulting in higher shear and tensile stresses can also be resisted.

Furthermore, compressive strengths of fiber reinforced concrete have also been documented as slightly increasing, or no effects with the addition of fiber reinforcement (Ramli, 2011). This is due to the confining effects of the fiber on the concrete's aggregate. However, as the dosage of fiber increases, the workability of the concrete typically decreases. Once enough fiber has been added to a concrete mixture the workability of the concrete may be too low to properly place, compact and consolidate. If the workability is too low and the concrete is not properly consolidated, small air voids may be present within the cured concrete. These air voids can lead to a reduction in compressive strength of the concrete.

There are several varieties of fiber reinforcement including steel and polypropylene fibers. Steel fibers are commonly used in the design of fiber reinforced pavement in order to reduce the cracking of the concrete due to exposure and service loading. Steel fibers, however, are susceptible to rust. Polypropylene fibers are a synthetic fiber with similar effects to the mechanical properties of concrete but cannot rust. Both steel and polypropylene fibers can be used to replace small reinforcing bars such as #3 or #4 rebar (MasterFiber MAC Matrix).

2.1.3 Fiber Reinforced Concrete Anchorage

There have been past studies focusing on the anchorage to fiber reinforced concrete. One study performed in Iraq focus on the use of cast-in-place anchor bolts embedded within steel fiber reinforced concrete (Al-Taan, 2011). The anchor bolts were embedded at varying depths in concrete with varying amounts of fiber reinforcement. It was discovered that the failure angle was influenced by the embedment depth, the amount of fiber reinforcement and the compressive strength of the concrete. As the embedment depth and fiber reinforcement increase, the angle of failure increased. As the concrete compressive strength decrease, the angle of failure decreased. Their results also showed an overall increase in the tensile strength of an anchor with increasing amounts of fiber reinforcement.

Many post-installed anchor manufacturers, such as DEWALT, Powers, Simpson, etc, test their own anchors and publish their findings. Currently DEWALT Screw-Bolt+ anchors have published data for installation into normal and lightweight concrete, masonry, brick and concrete on metal deck. There does not appear to be any published data for DEWALT Screw-Bolt+ anchors installed in fiber reinforced concrete.

3 EXPERIMENT PROGRAM

3.1 Fabrication of Test Specimens

3.1.1 Design of Test Specimen Formwork

Four different types of specimens were designed according to the test to be performed: compression, split, flexure and anchor shear tests. The compression tests performed utilized small 4”x8” cylinders. The split tests were also performed using 4”x8” cylinders. The flexure tests required 6”x6”x20” beams. The anchor shear tests required beams that would be large enough to ensure the anchors would have sufficient spacing because the test was for single anchors not in a group, and deep enough to ensure sufficient bearing area that will resist the shear. For these reasons, a large 54”x24”x18” beam was chosen as the anchor specimens’ size. The large beam would allow multiple anchors to be sufficiently spaced with minimal possibility of breaking through another nearby anchor’s influence area.

3.1.2 Construction of Formwork

The smaller specimens utilized 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”x24”x18” specimens were formed using constructed wood forms. The design of the wood forms is shown in figures 4, 5 and 6:

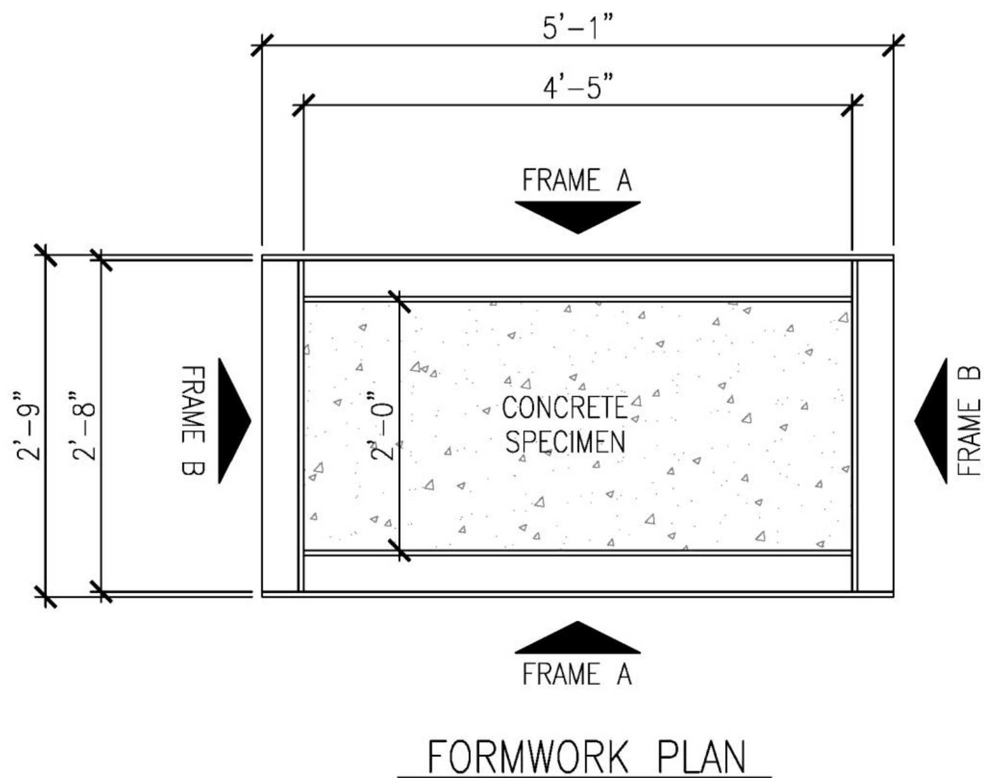
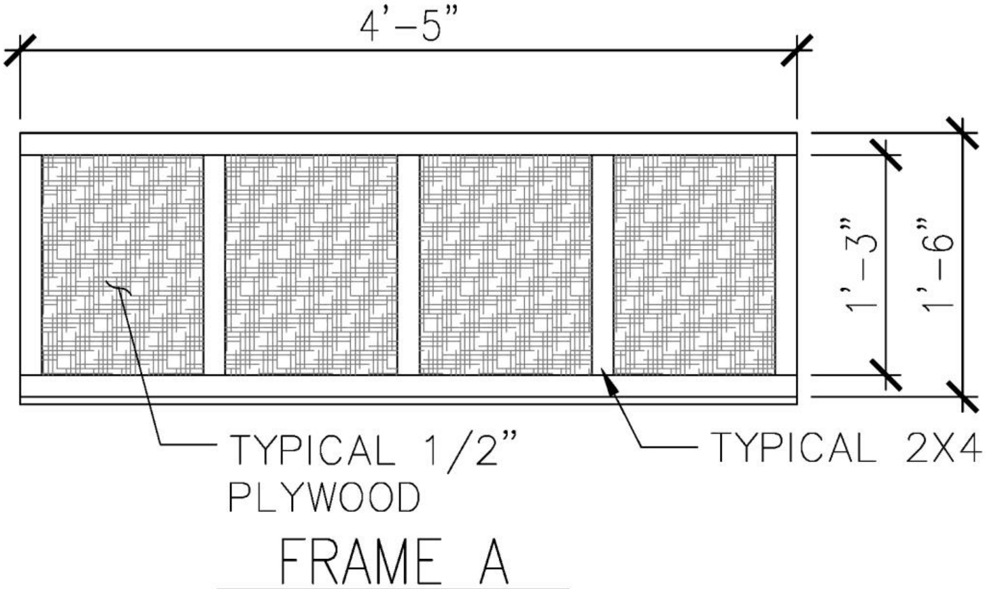


Figure 4: Wood Formwork - Plan View



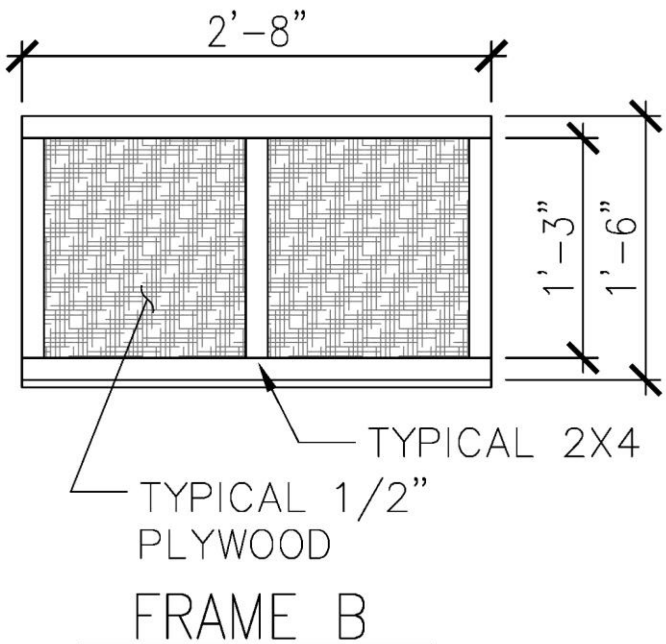


Figure 5: Wood Formwork - Elevation Views

Figure 6: Wood Frames for Anchor Specimens

Using the formwork plans, typical 2x4's were nailed together to create the frame of the formwork. 7/16" plywood was nailed to the sides of all of the frame. Additional 7/16" plywood was nailed to the exterior of the "A" frames in order to connect the frame together, and ensure the pressures from the poured concrete could be resisted by the created diaphragm. An additional piece of 7/16" plywood was nailled to the bottom of the frames and along with several 2x4's in order to lift the framework as necessary. The figures below show the construction of the formworks:

3.1.3 Concrete Pouring

Prior to the pouring of concrete, all of the cylinder, small beam and large wooden forms were prepped by spraying the insides with WD-40. The WD-40 acts as a concrete releasing agent and stops the concrete from sticking to the forms as it cures. After the forms were sprayed, the rebar, for the large beams, was put in place using typical 3" chairs and tying the rebar down using typical rebar ties.

The concrete mixtures used are shown in Tables 1-4:

Table 1: 0% Fiber Concrete Design Mixture

0% Fiber Concrete Design Mixture				
Component	ASTM	Density (lbs/cf)	Weight (lbs)	Volume (cf)
Type I/II Cement	C150	196.6	541	2.75
#67 Size Coarse Aggregate	C33	167.3	1885	11.27
Concrete Sand	C33	163.6	1458	8.91
Water		62.4	254	4.06
Polypropylene Fiber		59.06	0	0.00
Concrete		153.3	4138	27

Table 2: 0.5% Fiber Concrete Design Mixture

0.5% Fiber Concrete Design Mixture				
Component	ASTM	Density (lbs/cf)	Weight (lbs)	Volume (cf)
Type I/II Cement	C150	196.6	534.0	2.72
#67 Size Coarse Aggregate	C33	167.3	1880	11.24
Concrete Sand	C33	163.6	1452	8.88
Water		62.40	251.2	4.03
Polypropylene Fiber		59.06	7.973	0.14
Concrete		152.8	4125	27

Table 3: 1.0% Fiber Concrete Design Mixture

1.0% Fiber Concrete Design Mixture				
Component	ASTM	Density (lbs/cf)	Weight (lbs)	Volume (cf)
Type I/II Cement	C150	196.6	527.4	2.68
#67 Size Coarse Aggregate	C33	167.3	1874	11.20
Concrete Sand	C33	163.6	1447	8.84
Water		62.40	249.1	3.99
Polypropylene Fiber		59.06	15.95	0.27
Concrete		152.4	4113	27

Table 4: 1.5% Fiber Concrete Design Mixture

1.5% Fiber Concrete Design Mixture				
Component	ASTM	Density (lbs/cf)	Weight (lbs)	Volume (cf)
Type I/II Cement	C150	196.6	520.7	2.65
#67 Size Coarse Aggregate	C33	167.3	1869	11.17
Concrete Sand	C33	163.6	1441	8.81
Water		62.4	247.0	3.96
Polypropylene Fiber		59.06	23.92	0.41
Concrete		152.0	4101	27

MasterFiber MAC Matrix was used in the various mixtures. MasterFiber MAC Matrix is a macro-synthetic fiber with a specific gravity of 0.91 and with a recommended dosage range between 3 and 12 lbs per cubic yard. Fibers were added to the mixture in accordance to the manufacturer's specifications. The concrete pour began with the 0% fiber specimens and ended with the 1.5% specimens. Fibers were added in stages. 0 lbs of fibers was added to the 0% mixtures, approximately 8 lbs to the 0.5% mixtures, 15 lbs to the 1.0% mixture, and 24 lbs to the 1.5% mixture. Once the concrete was poured into the frames, an internal vibrating device was used. The vibrating of the concrete was to properly consolidate the concrete and reach its full potential strength.

Figure 7: Concrete beam being vibrated and consolidated

Slump tests were performed in accordance to ASTM C143. These tests used a 8" base, 4" top 12" tall slump cone. Concretes from all four mix designs were poured into the cone, filling the cone in three lifts. After each lift the cone was rodded 25 times. Once the cone was filled and flush at the top, the cone was carefully lifted. The concrete crumbled downward or "slumped" and the slump was measured from the top of the cone using a tape measure. It was discovered that the slump would decrease as more fibers were added to the mixture. The workability of the mixtures was also seen to decrease as more fibers were introduced to the mixture. The slump test performed can be seen in Figure 6 and 7:

Figure 8: Filled slump cone

Figure 9: Slump test

After the pours were complete, the large beams were left in place, covered with wetted towels and tarps to reduce dehydration of the beams and properly cure the specimens. The smaller specimens were taken and cured within the curing room at the CELB. Their forms would later be removed and the smaller specimens would once again be placed inside the curing room. The specimens were all left to cure for 28 days. He larger specimens would keep their forms on until after 28 days of curing to reduce the risk of moisture loss from exposure. After 28 days the large specimens were lifted by crane and their formwork simply slipped off and removed. The large specimens would then be turned onto their sides so the post-installed anchors could later be installed and tested.

Figure 10: Large concrete beams after pour

Figure 11: Small specimens placed inside curing room

3.2 Test Set-Up and Procedure

3.2.1 Compression, Tensile & Flexure Testing

After 28 days the smaller specimens were ready to begin testing. The tests performed were the compression, tensile and flexure tests. These tests all utilized the 60 kip compression machine found at the CELB. The 60 kip compression machine operated through the use of the loading table and the supported head. The head was rigidly supported and held the specimen in place. Different heads could be screwed onto the head allowing the different tests to take place. The specimen was placed onto the load table where the load would be applied. The table would be hydraulically lift with the specimen which would eventually make contact with the head and apply load.

The compression tests were performed in accordance with ASTM C39 using 4”x8” cylinders. The specimen was placed in the middle of the load table so the head would apply load to the top of the cylinder. The head had a simple, flat, round surface to applied load to the specimen. The specimen was loaded at an approximate rate of 400 lbs/sec and the ultimate load was recorded. The compressive strength of the concrete was measured using Equation 1, where fc is the compressive strength in psi, P is the applied ultimate load, and r is the radius of the cylinder:

$$fc = \frac{P}{\pi r^2} \quad \text{...(6)}$$

Compressive strength of cylinder Equation

The compression test setup can be seen in Figure 10:

Figure 12: Compression Test Setup

The tensile tests were performed in accordance with ASTM C496 using 4"x8" cylinders. The specimen was placed in the middle of the load table so the head would apply load across the length of the cylinder. The head had a long, pointed surface to applied load to the specimen. The specimen was loaded at an approximate rate of 100 lbs/sec and the ultimate load was recorded. The tensile strength of the concrete was measured using

Equation 7, where ft is the tensile strength in psi, P is the applied ultimate load, L is the length of the cylinder, and D is the diameter of the cylinder:

$$ft = \frac{2P}{\pi LD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .(7)$$

Tensile strength of cylinder equation

The tensile test setup and results can be seen in Figure 11:

Figure 13: Split test setup

The flexure tests were performed in accordance with ASTM C78 using 6”x6”x20” beams. The specimen was placed in the middle of the load table and supported on both side 1” away from the each of the beam. The head had two long, pointed surfaces spaced

6” away from each other to applied load to the specimen. The specimen was placed on the load table so that the head would contacted the beam 6” away from its supports. The specimen was loaded at an approximate rate of 50 lbs/sec and the ultimate load was recorded. The flexure strength of the concrete was measured using Equation 8, where fr is the modulus of rupture in psi, P is the applied ultimate load, L is the span of the beam, B is the width of the beam and D is the depth of the beam:

$$fr = \frac{PL}{BD^2} \quad \text{……………………………………………….(8)}$$

Modulus of rupture of cylinder equation

The modulus of rupture of the plain concrete (0% fiber) was estimated Equation 9:

$$fr = 7.5\sqrt{fc} \quad \text{………..…………………………………….(9)}$$

Modulus of rupture of normal concrete as prescribed by ACI equation

The tensile test setup and results can be seen in Figure 14:

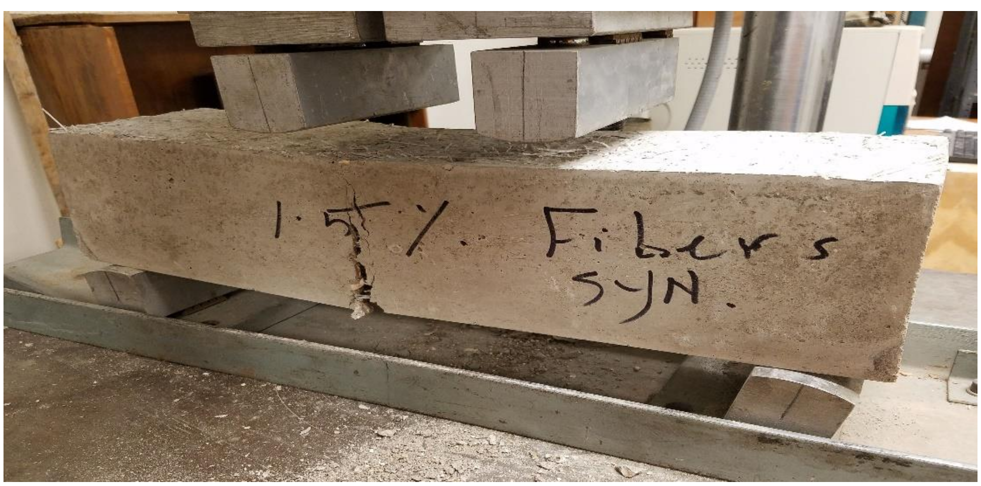


Figure 14: Flexure test setup

3.2.2 shear Testing for anchors

The anchors shear test were for the large 54”x24”x18” specimens, the large specimens were tested using hydraulic compression machine, the specimens were rotated 90 degree before entering the machine then they were supported and set at two "I" cross sectional steel members at each end of the specimens.

Figure15: Two "I" cross sectional steel members to support the specimen

Once the machine start coming up to apply load the only member it will apply load on it is the plate that have a hole to be able to get the anchor thru the hole till the end so the plate can be at the face of the spinescence to get a pure shear and the plate length is 18" where it's more than the edge distance of the anchor bolt so the load will apply on the plate that will deliver the load to the anchor bolt at face of the specimen, the anchor bolt were tested individually (single anchor not group).

Figure16: Specimen stand on the two steel supporters

The load cell is between the base of the compression machine and the steel plate and directly above the load cell there is a thin steel plate to distribute the load and have a uniform load on the load cell.

Figure17: Load cell placement

Linear Variable Differential Transformers (LVDT) used for measuring displacement of the anchors, LVDT attached with the 18" steel plate and adjusted to be vertical and once the anchor start deflect the LVDT start measuring displacement were the sensor is touched to the top of the compression machine that also support to fix the specimens.

Figure18: Linear Variable Differential Transformers (LVDT) placement

The figure down below will show the full setup for testing anchor bolts under shear load including the load cell and the Linear Variable Differential Transformers (LVDT).

Figure 19: Linear Variable Differential Transformers (LVDT) and Load Cell Setup

The load ratio applied is 300 lb/mint, for each specimens two anchors were tested at 300 lb/mint and use the average to compare the results except No-Fiber specimen's only one anchor bolt was tested. For 0.5% and 1.0% fiber spinescences the third anchor bolt was tested at 750 lb/mint so we can see the effect of increasing the load ratio and compare with 300 lb/mint for each specimens by itself, it's most likely making more impact load.

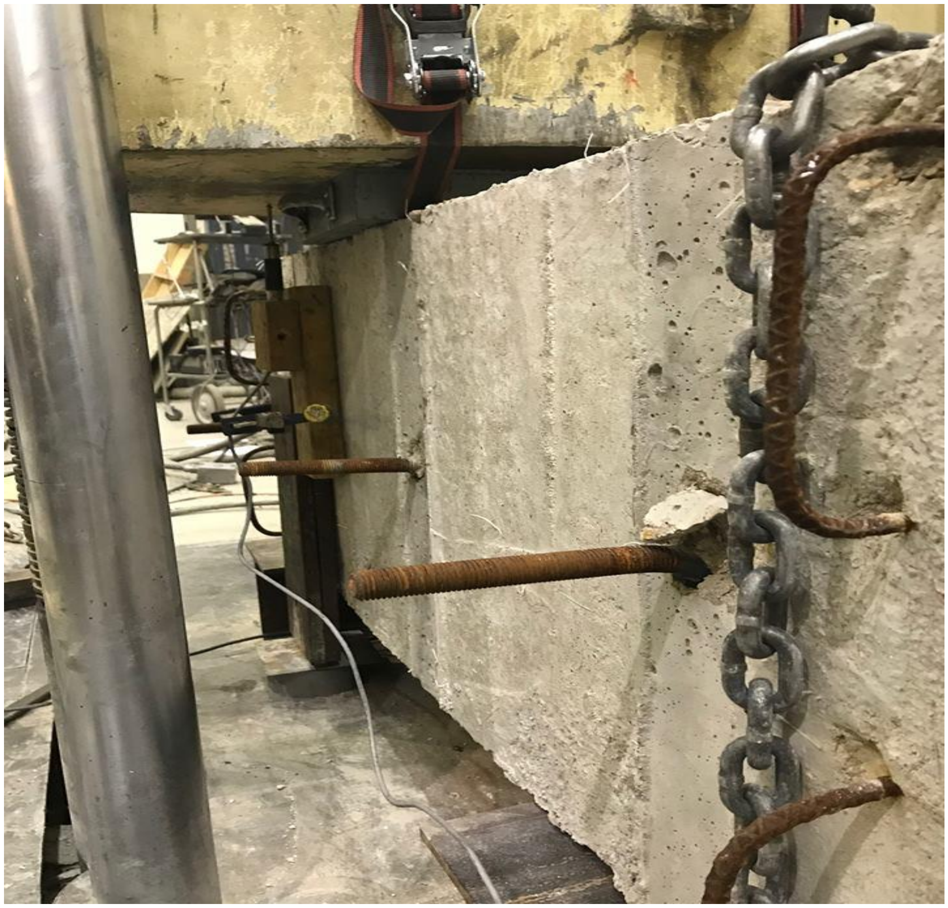


Figure 20: Applying different loading rate for the same specimen (0.50% Polypropylene Fiber)

Since the specimens have sufficient embedment and edge distance of the anchors is high the failure will be steel failure preceded by concrete spall and the displacement will play the major role to indicate the difference of the specimen strength resisting shear, also the fragmentation of concrete surrounding the anchor bolt will show the difference of concrete shear strength resistance.

Figure 21: Steel failure proceeded by concrete spall for (0.50% Polypropylene Fiber) specimen

Figure 22: Anchor bolt after steel failure

Figure 23: Shear test setup for anchors

Figure 24: Shear test setup for anchors

4 EXPERIMENT RESULTS

4.1 Concrete Compression Test Results

4.1.1 Compression Test Results Data

Table 5: Compression Test Results

Concrete Compressive Strength (psi)				
Fiber Volume Fraction (%)	0.0%	0.5%	1.0%	1.5%
Specimen #				
1	2398	3245	2171	2026
2	3649	2729	2707	2658
Average	**3024**	**2987**	**2439**	**2342**

4.1.2 Compression Test Results Graph

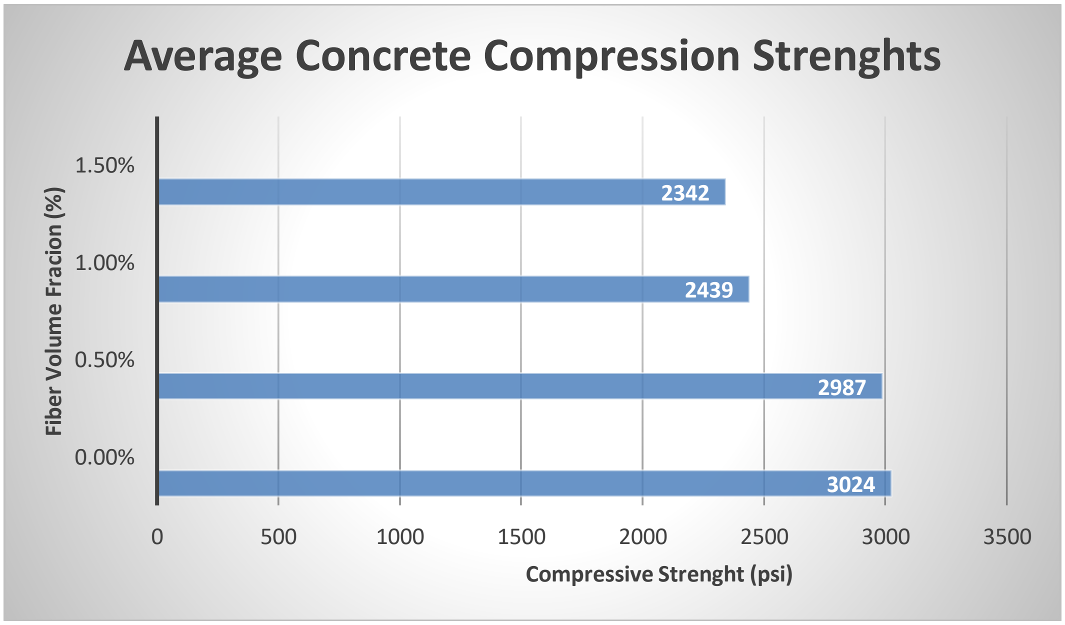


Figure 25: Concrete Compression Test Results

4.2 Split Test Results

4.2.1 Split Test Results Data

Table 6: Split Test Results

Concrete Tensile Strength (psi)				
Fiber Volume Fraction (%)	0.0%	0.5%	1.0%	1.5%
Specimen #				
1	201.2	142.1	290.1	252.4
2	69.4	185.5	100.0	175.6
Average	**135.3**	**163.8**	**195.1**	**214.0**

4.2.2 Split Test Results Graph

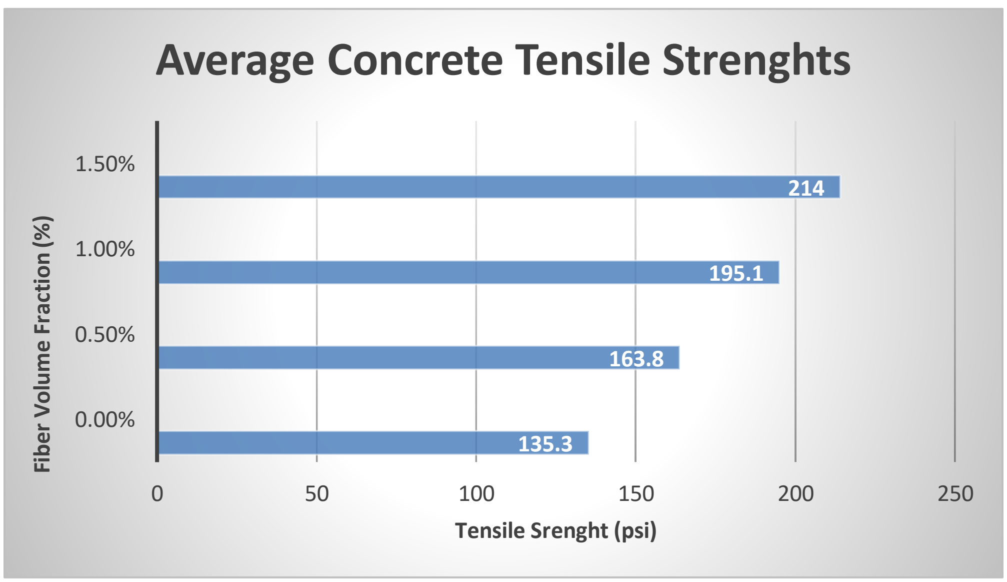


Figure 26: Tensile Test Results

4.3 Flexure Test Results

4.3.1 Flexure Test Results Data

Table 7: Flexure Test Results

Modulus of Rupture (psi)				
Fiber Volume Fraction (%)	0.0%	0.5%	1.0%	1.5%
Specimen #				
1		448.8	577.8	756.5
2		506.6	495.4	549.8
Average	**412.4**	**477.7**	**536.6**	**653.2**

4.3.2 Flexure Test Results Graph

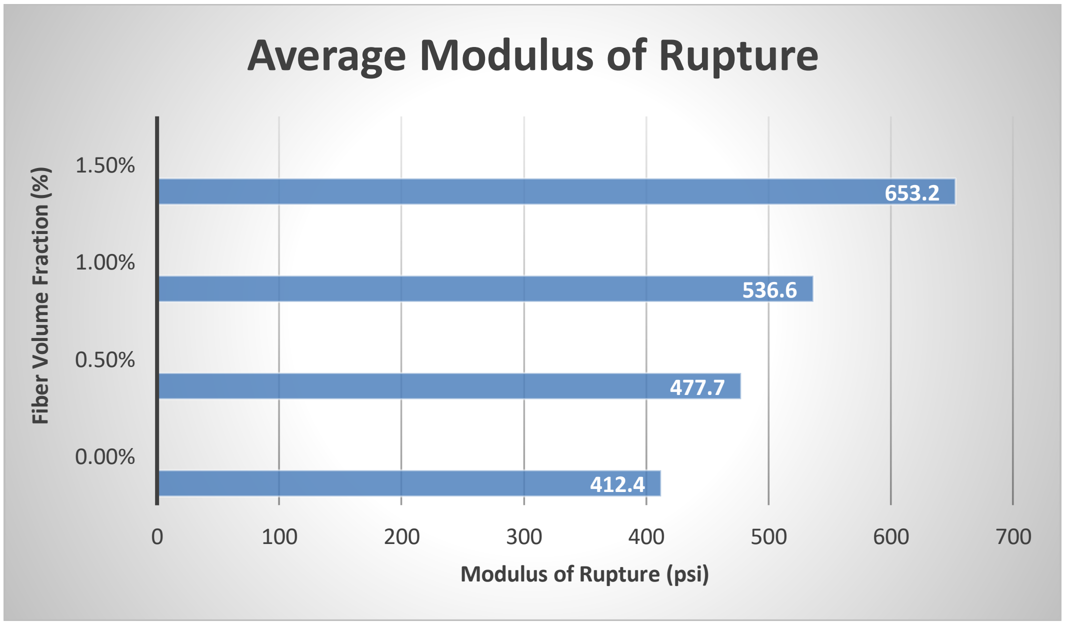


Figure 27: Flexure Test Results Comparison

4.4 Anchor Shear Test Results

4.4.1 Anchor Failure Load Data and Displacement at the Same Loading rate for Different Specimens.

Table 8: Anchor shear strength test results at (300 lb /min) loading rate

Fiber Volume Fraction (%)	Specimen #	Failure Load (lbs)	Displacement (in)
0.0%	**1**	**23939**	**1.155**
0.5%	1	23973	1.021
	2	22770	.968
	Avg.	**23372**	**0.995**
1.0%	1	10233	0.512
	2	11155	0.629
	Avg.	**10694**	**0.571**
1.5%	1	6709	0.172
	2	6302	0.286
	Avg.	**6506**	**0.229**

4.4.2 Load displacement curve at same loading rate for different specimens.

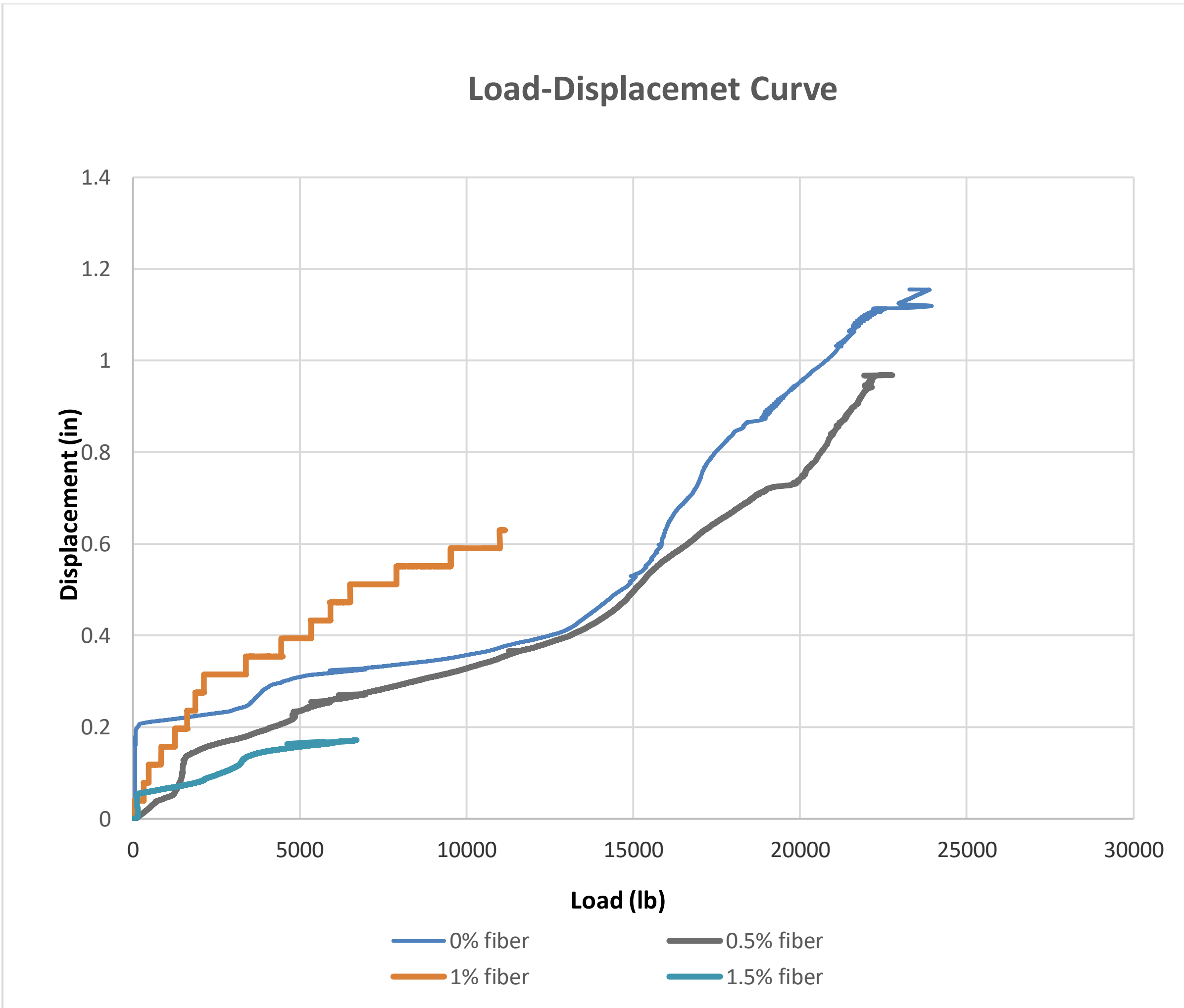


Figure 28: Failure load and displacement for each specimen using same loading rate

(300 lb /min)

4.4.3 Anchor Failure Load Data and Displacement at Different Loading Rate for the Same Specimen.

Table 9: Anchor shear strength test results at (300 & 750) lb. /min for the same specimen.

Fiber Volume Fraction (%)	**Loading Rate (lb. /mint)**	**Failure Load (lbs)**	**Displacement (in)**
0.5%	300	**23372**	**0.995**
	750	**18874**	**1.110**
1.0%	300	**10694**	**0.571**
	750	**7522**	**0.669**

4.4.4 Load Displacement Curves at Different Loading Rate for the Same Specimen.

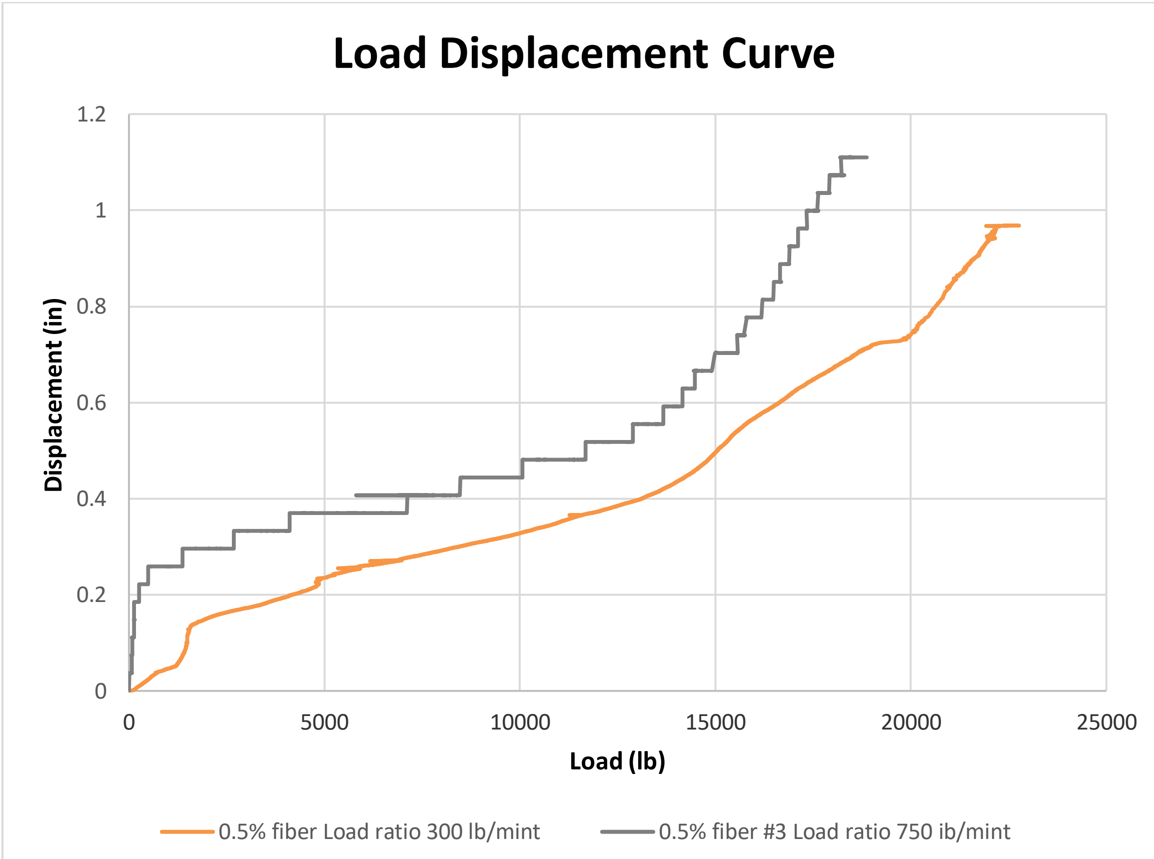


Figure 29: Failure load and displacement for same specimen (0.50% fiber) at Different loading rate (300 & 750) lb. /min

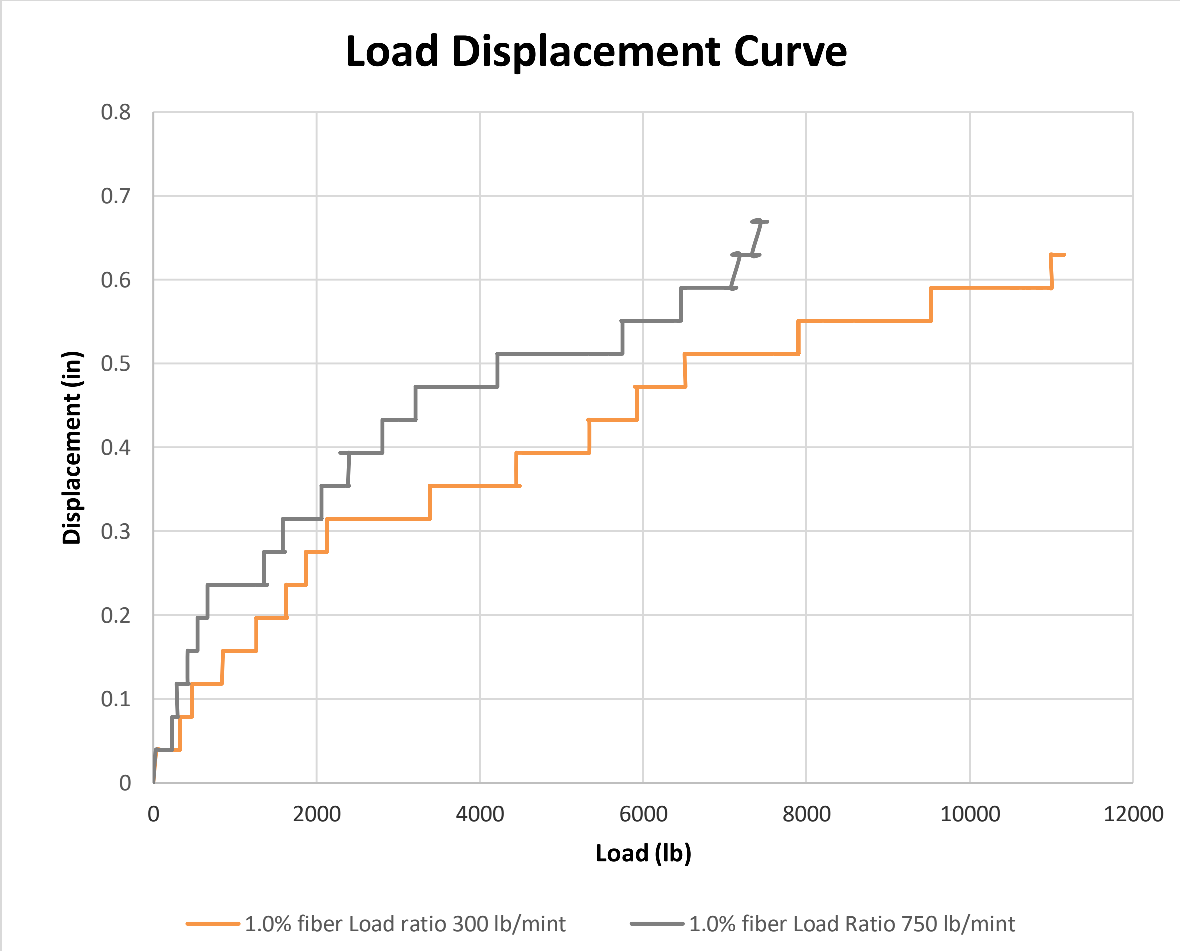


Figure 30: Failure load and displacement for same specimen (1.0% fiber) at Different loading rate (300 & 750) lb. /min

4.5 Project Summary

4.5.1 Experiment and Results

A total of twenty-six concrete specimens were constructed during the experiment. Four large wooden frames were constructed prior to pouring in order to cast the large concrete beam specimens. Sixteen concrete cylinders were cast using plastic cylindrical forms. Six 6”x6”x20” beams were cast using metal frames. Four 54”x24”x18” beams were cast using the constructed wooden frames. Four separate concrete mixtures were used which differed by varying amounts of MasterFiber MAC Matrix, a macro synthetic fiber. The differing mixtures had 0%, 0.5%, 1.0% and 1.5% of fibers by volume. Once the concrete had been cast into all of the forms, the specimens were cured for 28 days. After the specimens had been cured, the smaller specimens were tested and the results recorded. Eight cylinders were tested in compression per ASTM C39. The compression test showed similar results in strength between the 0% and 0.5% fiber mix designs and a significant drop in strength in the 1.0% and 1.5% mix designs. Split tests were conducted on eight cylinders per ASTM C496. The split tests results demonstrated tensile strength growth as the amount of fibers increased. Flexure tests were conducted on the six 6”x6”x20” beams per ASTM C78. The results of the flexure tests displayed an increase in the modulus of rupture as the amount of fibers increased. The anchors were all tested at pure shear loading. Increasing fiber dosages lead to higher loaded required to crush the concrete surrounding the anchor and create less anchor displacement. Also, increasing loading rate reduce the anchor shear failure load and increase anchor displacement.

4.6 Results Discussion

4.6.1 Small Specimen Deductions

Concrete is naturally very brittle and has very little tensile strength. The addition of fibers changes the structural properties of concrete. In the non-fiber reinforced concrete, the tensile strength came from the chemical bond between the aggregate and the cement. With the addition of fibers, the tensile stress applied to the concrete specimens was also resisted by the fiber embedded within the concrete. Thus, as the amount of fibers increase from one mixture to the next both the tensile and modulus of rupture increased. Also discovered was the linear trend between the measured tensile strength and moduli of rupture. As seen in the Split Test Graph, the tensile strength of the concrete increased by approximately 21.1% for every 0.5% of fiber by volume added to the concrete mixture. As seen in the Flexure Test Graph, the modulus of rupture increased by approximately 15.8% for every 0.5% of fiber by volume added to the concrete mixture. As more and more fiber is added to the mixture the flexural and tensile strengths of the concrete are increased linearly, which was as expect.

It's believed that the increasing fibers led to a reduction in workability which then lead to reduction in compressive strength. As seen below, small air pockets, also known as bug holes, are visible near the surface of the concrete, indicating the probability of air voids being within the concrete specimen due to poor consolidation:

Figure 31: Bug holes seen on the surface of the 1.5% mixture specimen

As the fiber content of the mix designs increased and the workability of the concretes decreased, it appears that the fiber rich concretes contained more air voids. The increasing air voids reduced the compressive strength of the concrete, whereas it was expected to remain about the same or slightly increase. While the fibers did not directly increase the compressive strength of the concrete, the fibers may have had an indirect effect due to the reduced workability. Reducing the amount of fibers or the maximum size of the aggregate may to avoid issues with consolidation in future experiments.

4.6.2 Anchorage Presumptions and Hypothesis

For high anchor embedded length or high edge distance that means we have high "Cone of influence" that holds the anchor in place. This influenced concrete resists forces, such as tension and shear that threaten to tear the anchor away from the concrete. specially if the anchors are not work in a group (single anchors) that will lead to different type of failure like concrete pryout for anchors far from free edge or steel failure preceded by concrete spall, Now as we discus recently that increasing Polypropylene fibers will increase the concrete shear resistance But in the case of Steel failure proceeded by concrete spall that increment will provide more rigid able concrete that leads to less displacement of anchor and less bending, so the load will stay almost pure shear. And the anchor shear resistance will be almost the smallest cross section of the anchor which it's the cross section of the anchor due to no bending In contrast, the lower of Polypropylene fiber percentage will provide more displacement an bending so the load will be shear and tension and the bending will provide higher anchor shear resistance cross sectional area, so it will required a higher load fail the anchor. Actually, displacement and bending are very slight but have major effect on the Steel load failure. Figures below shows the difference in anchor displacement and the concrete crush that surround the anchor.

Figure 32: Steel failure preceded by concrete spall for 0% synthetic fiber

For specimens that have low fiber dosage, the anchor have a high displacement with bending due to crushed concrete around the anchor.

Figure 33: Steel failure preceded by concrete spall for 0.5% synthetic fiber

Figure 34: Steel failure preceded by concrete spall for 0.5% synthetic fiber

Figure 35: Steel failure preceded by concrete spall for 1.0% synthetic fiber

Figure 36: Steel failure preceded by concrete spall for 1.0% synthetic fiber

Figure 37: Steel failure preceded by concrete spall for 1.5% synthetic fiber

Figure 38: Steel failure preceded by concrete spall for 1.5% synthetic fiber

Moving body has kinetic energy due to motion. This energy is transferred to the member or structure when body comes at rest. This energy dissipation is experienced as impact load, so loading rate will play a major roll to determine the failure load, Since the loading rate is higher that will provide a higher impact load which it leads to lower load failure and higher displacement.

5 CONCLUSION

5.1 Project Results

5.1.1 Summarized Conclusions

- For steel anchor failure prodded by concrete spall, increasing fiber dosage 1.0% leads to decrease load failure 55% and decrease displacement 50%.
- Increasing Loading rate 150% lead to decrease load failure 25% and increase displacement 15%.
- Crushing concrete area that's surround the anchor will always have an inverse relationship with synthetic fiber dosage whatever is the failure mode.
- Anchor shear failure mode depend on the cone of influence, In addition to the fiber dosage provided.
- For shear concrete breakout failure, adding higher fiber dosage will provide higher concrete shear resistance. In contrast, shear steel failure mode proceeded by concrete spall, adding higher fiber dosage will required lower steel load failure and create lower anchor displacement.

- The addition of fiber reinforcement increased the tensile capacity of the anchors by approximately 29.2% for every 1% of polypropylene fiber added.

5.2 Research Contribution & Continuation

5.2.1 Research Impact

There does not appear to be many published researches for cast-in-place anchors attached with different percentage of synthetic fibers tested at pure shear. These findings can be used for future research into the subject. Additional research and publication of the results will allow designers the ability to design with cast-in-place anchor bolts with the increased strength that the addition of fibers will allow. While post-installed anchors may provide lower strength than the cast-in-place typical anchor.

5.2.2 *Recommendations for Future Research*

- Investigation the behavior of cast-in-place anchors, including hex head & J-bolts, embedded within fiber reinforced concrete.
- Investigate new methods for the consolidation of concrete with high amounts of fiber reinforcement.
- Investigate the effects of Impact loads on anchors installed or embedded within fiber reinforced concrete.
- Test groups of anchors installed or embedded within fiber reinforced concrete.
- Study the behavior of anchors of different diameters and/or embedment lengths for anchors embedded within fiber reinforced concrete.
- Test the effects of using various types of post installed anchors installed within fiber reinforced concrete.
- Finite element modeling for cast in place anchors under pure shear.

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-Taan, 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, FEIIC, MSET and UPM, pp: 244-257

Al-Taan, 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-Taan, 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 Evalulation 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.

South African Qualifications Authority (SAQA), 2019

The constrecter civil engineer home

The Strctural Home