NUMERICAL SIMULATION OF ANCHOR GROUP EFFECTS ON CONCRETE BREAKOUT STRENGTH WITHIN STEEL FIBER REINFORCED CONCRETE

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ABSTRACT

This study aims to investigate numerically, the effect of anchor groups on concrete breakout strength using nonlinear finite element analysis. Steel headed studs were cast in place within concrete of different amounts of steel fibers. Different proportions of steel fibers (0%, 0.5%, 1%, 1.5%) were utilized within steel fiber reinforced concrete (SFRC) for the numerical simulation. The physical properties of SFRC were modelled with respect to its composite compressive and tensile strength obtained from the experiments. The analysis was conducted on the concrete breakout strength of anchor bolts within SFRC. A good agreement was achieved between the numerical and the experimental results. The numerical results show that the concrete breakout cone radius decreases, and the concrete breakout strength increases as the percentage of steel fiber in the mix increases. The increase in the breakout strength with respect to plain concrete was around 47%, 84%, and 92% as the steel fiber percentage increased to 0.5%, 1% and 1.5% respectively. The grouping effect of anchors was quantified by conducting a numerical analysis on the concrete breakout strength of single anchor under uniaxial tensile loading. A grouping effect factor was found out, which signifies the percentage of load required to break out a concrete cone when the grouping effect takes place. The numerical analysis found out that the grouping effect factor is 0.8, 0.82, 0.84, 0.84 for SFRC 0%, 0.5%, 1%, 1.5% respectively. A parametric study was carried out, understand the effects of anchor bolt embedded length and its diameter n the concrete breakout strength. The nonlinear finite element analysis shows that increasing the embedded length of the anchor bolt from 2.5” to 3.5” increases the breakout strength by 25%, 26.6%, 26.7% and 26.5% for SFRC 0%, 0.5%, 1%, 1.5% respectively.

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CHAPTER 1

INTRODUCTION

Anchor bolts are designed to connect structural elements to concrete. Therefore, to understand how the anchors function is of utmost importance. It is also highly unlikely that anchors are used in singularity. Most anchors are used in groups to resist the tension and the shear forces applied. If only a tensile force is applied to the anchors, the system of anchor bolts embedded in concrete fail by either the tensile failure of the anchor bolt itself, bond failure between the concrete and the anchor bolts or the failure of concrete in tension. When an anchor is pulled out of concrete, the concrete fails by forming a cone, with the anchor's axis being its axis of revolution. In many cases, the anchor bolts are spaced such that the breakout cone of concrete for one anchor overlaps with the other, hence, the need to study the grouping effects of anchor bolts.

Concrete is a brittle material, due to its low tensile strength. Thus, to improve the brittle properties of concrete, steel fibers can be added to the concrete mixture. Steel fibers not only improve the tensile strength of concrete but have been proven to increase the compressive strength and ductility. Hence, the properties of plain concrete can be improved by the addition of randomly oriented, discrete fibers of steel. Khafaji (2020) investigated the grouping effects of concrete breakout strength within steel fiber reinforced concrete and found that the addition of steel fibers to concrete reduces the cone angle for concrete breakout in concrete, signifying that the tensile strength of concrete is improved [1].

Additionally, steel fibers are cost efficient as compared to the conventional steel rebars. They have also proven to make concrete more durable against shrinkage due to thermal variations by keeping the microcracks in check. The steel fibers can be differentiated on the basis of their type, length, diameter, and surface finish.

The civil engineering industry utilizes different types of anchors with cast-in-place and post installed anchors being the two major distinctions. Cast-in-place anchors are placed in concrete before it cures, with the concrete holding it in as it hardens, whereas the post installed anchors are guided into the concrete after it has cured. There are some anchors in use that utilize adhesives to increase the bond between steel and concrete, but the principal for concrete anchorage remains the same irrespective of the installation method or cohesive properties. Essentially, in both the cases, the anchors form a ‘cone of influence’, which is the cone of concrete surrounding the anchors, that helps it resist the applied forces. As the force acting on the anchor increases, the stresses in the cone of influence also increase until it can no longer withstand the load and the concrete fails.

This study investigates the anchor group effects on concrete breakout strength within steel fiber reinforced concrete (SFRC) using numerical methods. The analysis was performed using the finite element software ABAQUS/Explicit version 6.10. Furthermore, the validation of the model was conducted using the available experimental results for concrete breakout strength within steel fiber reinforced concrete when the anchors are under the action of tensile force [1].

1.1 Objectives

The main objective of this research is to numerically investigate the anchor group effects on concrete breakout strength within steel fiber reinforced concrete using nonlinear finite element analysis. The main parameters under consideration are modulus of elasticity and the compressive and tensile behavior models for plain concrete and SFRC with different fiber volumes, compressive strengths, tensile strengths, constitutive model for damage parameter of steel fiber reinforced concrete, mesh size and the boundary conditions. Another parameter of interest was the interplay between the anchors and the concrete, the stress transfer taking place between the two surfaces in contact. To achieve this, four constitutive models were considered, and simulations were conducted accordingly. The model was verified for various steel fiber dosages using the available experimental results. A study on the effect of increasing embedded length and increasing diameter of the anchor bolts on the concrete breakout strength was conducted.

1.2 Research Contribution

This research provides a numerical method to investigate the effects of anchor groups on concrete breakout strength within SFRC. The model has been validated by the available experimental results. This limits not only to the anchor bolts, but any structure where concrete tensile breakout strength is a factor of concern. The improved mechanical properties of SFRC results in a better anchor grip, hence, a larger load can be applied. This comes in handy specifically for structures such as bridge handrails, where a lower strength grade of steel and less concrete mass could be used to achieve the same strength with the addition of steel fibers, ultimately reducing the cost of construction. The main aim is to generate a, numerical model for different dosages of SFRC, so that further research on these could be conducted without the need of actual experimentation. This would help get the results for a lot of similar experiments without performing any. This saves a lot of time and effort and the results are very accurate as well. In summary, this research addresses the strength issue of utilizing SFRC, using nonlinear finite element analysis.

1.3 Outline of the thesis

Chapter 1 - INTRODUCTION

The basic outline of anchor group effects on steel fiber reinforced concrete, need for this research, benefits, objectives, and the research contributions are discussed.

Chapter 2 - LITERATURE REVIEW

Previous research on the SFRC, anchor group effects and all the concepts of concrete breakout within SFRC are discussed. Along with this, the numerical modeling techniques and the concrete damage plasticity models are also discussed.

Chapter 3 - EXPERIMENT PROGRAM

The results of the previous experimental study conducted, to use as an input and to validate the model in this research, are discussed.

Chapter 4 - FINITE ELEMENT MODELING

Discusses the steps taken to produce the finite element model, from creating parts to providing the mesh elements and running the job, i.e., cradle to grave design of the model.

Chapter 5 - NUMERICAL ANALYSIS

The results of the finite element model and the parametric study are discussed. This chapter also discusses the validation of the model by comparing the results with previous experiments.

Chapter 6 - CONCLUSION

Discusses the research conclusion on how the objectives are met and what the result is.

CHAPTER 2

LITERATURE REVIEW

2.1 Previous research and design practices

2.1.1 Steel fibers

Steel fibers are small discrete fibers made from steel. They have been increasingly utilized in the construction industry because steel fibers prevent the microcracks that appear in concrete and hence improve its load carrying capacity. Steel fiber reinforced concrete (SFRC) is a cementitious matrix of randomly oriented steel fibers and concrete. SFRC has found several different applications such as a supplementary reinforcement for temporary loading, additional reinforcement for cases where primary reinforcement is provided and in complete replacement to the conventional rebars where the load acting only produces compressive stresses [2][16]. Utilizing steel fibers as a partial replacement to the conventional steel rebars is gaining popularity because of the superior behavior of the concrete with fiber reinforcement because of the crack bridging action of fibers [3][17].

In a research conducted by Irem Sanal et. al 2016, [4][19][20], concrete mix with the two different types of steel fibers was tested for flexural strength. The type of fibers utilized were straight fibers and hooked end fibers. The concrete mix design for both the cases was same. The mix proportions were as follows, Cement: Sand: Slag: Water: Plasticizer: Fiber is 497:1114:418:220:18: 94.8 kg/m3. 100mm x 18mm specimens were produced and these were tested using the four-point flexural testing machine. The results showed that the average peak stress value for the straight fibers with same thickness to length ratio as the hooked end fibers under consideration was 13.17Mpa and that for the hooked end fibers was 16.16Mpa. This clearly shows that the steel fibers with hooked ends have a better bonding with the concrete and hence the strength of SFRC with hooked end fibers is higher.

A research conducted by Raad Azzawi and Ali Abolmaali in 2020 [13], studied the effects of steel fiber reinforced hollow columns under eccentric loading. The study was conducted by casting two groups of samples. Sample group 1 had a hollow ratio of 10% and sample group 2 had a hollow ratio of 20%. Each of these groups consisted of four hollow reinforced concrete columns and one solid column with dimensions, 200mm x 200mmx 1600mm. The load eccentricity to the column depth ratio was kept equal to 0.75, and the specimens were tested for different steel fiber ratios 0f 0.5%, 1%, 1.5%. The compressive strength at 28 days was noted to be 30.9 Mpa, 32.75 Mpa, 34.53 Mpa, 35.25 Mpa for 0%, 0.5%, 1%, 1.5% respectively. The study concluded that the addition of steel fibers significantly improved the mechanical response of the specimens, especially the ultimate cracking load. The cracking load for the specimen with 10% hollow ratio and 1.5% steel fibers increased 2.346 times the cracking load for the specimen with 10% hollow ratio and 0% steel fibers and the cracking load for the specimen with 20% hollow ratio and 1.5% steel fibers increased 2.181 times the specimen with 20% hollow ratio and 0% steel fibers, signifying an improved performance with specimens with a higher dosage of steel fibers. It was also observed that the crack propagation after the initial cracking was a lot more gradual in the specimen with steel fibers[13][21]. The ultimate load carrying capacity displayed a similar trend with the load carrying capacity for 10% hollow ratio and 1.5% steel fiber ratio displaying an increase of about 1.094 times the load carrying capacity for 10% hollow ratio, without steel fibers and an increase of about 1.23 times the value for 20% hollow ratio and 1.5% steel fiber ratio as compared with 20% hollow ratio and no steel fibers.

In another research conducted by Raad Azzawi and Nancy Varughese [14], a finite element analysis was performed to determine the flexural behavior of preflex sfrc-encased steel joist composite beams. A nonlinear finite element analysis was performed using ABAQUS. In the first study, three beams with different proportions of SFRC were monotonically loaded by 2kips until their ultimate load is reached. The load required to reach the ultimate stage increased by 20% from beam with no steel fibers to beam with 5% steel fibers and the displacement decreased by 60%. Comparing the beam with 1% steel fiber to the beam with 0% steel fiber, the ultimate load increased by 33% and the displacement decreased by 70% in beam with 1% steel fiber. This shows that increasing the fiber percentage in beams results in a higher ultimate strength of the concrete and the concrete gets stiffer. In another study, the beams were modeled with a 0.45in camber upwards. The results show that the beam with 0.5% steel fiber had a 20% increase in the ultimate load carrying capacity and a 16% decrease in the displacement and the beam with 1% steel fiber by volume, had a 38% increase in the ultimate capacity and a 33% decrease in the mid span displacement. Overall, it was observed that adding steel fibers to the preflex beams provided improved results. Adding just 1% of steel fibers to the preflex beam increased a plain concrete straight beam’s loading capacity by 47% and reduces its midspan displacement by 60%.

Twelve flexural slabs were tested by Raad Azzawi and Sam Kafaji [15], to experimentally investigate the utilization of steel fibers as concrete reinforcement in bridge decks. Three slabs of each concrete mixture, reinforced concrete slab, 0.5% SFRC, 1% SFRC, 1.5% SRFC, were cast and tested using the 400-kip compression machine. Each specimen had dimensions 45” x 20” x 3.5”. The RC slab had minimum reinforcement of #3 bars placed 8”o.c. The experimental results show that the maximum load that the RC slab could carry was 9259lbs. The maximum load carried by 0.5% SFRC slab was 3958lbs, for 1% SFRC slab was 4564lbs and for 1.5% SFRC was 5606lbs.

This lead to the conclusion that, although the load carrying capacity of the slab increased with an increase in the steel fiber percentage, just mere addition of steel fibers is not enough to replace the conventional steel rebars.

To conclude, there are different types of steel fibers available, with varying lengths and aspect ratios, and every kind of fiber has a particular kind of effect on the behavior of SFRC, but in general, all the previous research shows that addition of any type of steel fiber to concrete has a positive effect on the compressive, tensile, and flexural strength of concrete.

2.1.2 Anchor bolts

Anchors play an important role in the construction of power transmission towers, bridges, and buildings. These can be cast-in-place before pouring the concrete or can be drilled into it afterwards. It is of the utmost importance to understand the behavior of steel anchors under tension in SFRC. There is quite some literature available to acknowledge the anchor bolt behavior embedded in SFRC.

The anchor bolts could be distinguished mainly on the basis of their installation process. There are two main installation processes, cast-in-place, and post installed anchors. As the name suggests, cast-in-place anchor bolts are placed in concrete first and then the concrete is poured and hardened. These are considered better for the fiber interaction of concrete because the fibers get to settle around the anchor bolt. But in case of the post installed anchor bolts, the anchor bolts are drilled into the concrete after the concrete has been cured. This has been linked to a reduced strength of fiber reinforced concrete owing to the damage that happens during drilling.

According to ACI 318-19, the anchor bolts embedded in concrete can fail via five failure modes, depending on the embedded length, the strength of concrete, strength of steel and the edge distance. The five failure modes are as discussed, and figure 1 provides a pictorial representation of different failure modes.

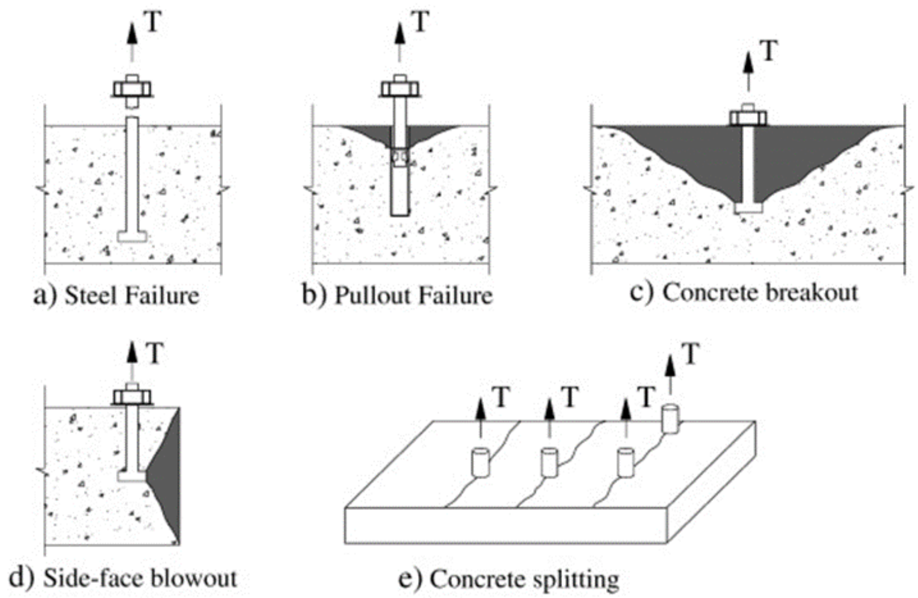


Figure 1: Different failure modes of anchor bolt system according to ACI 318-19

The above mentioned are the anchor bolt system failure modes when a tensile load is applied. The anchor bolt system could fail either by the failure of concrete, the failure of steel or the failure of the bond between the two. The failure in figure 1(a) shows the steel failure, which can occur if the tensile capacity of steel is less than that of concrete and the applied loading. In this type of failure, the anchor bolts fail in tension. The figure 1(b) depicts the pullout failure, which occurs when the bond between the concrete and anchor bolt fails. This can be prevented by adding a nut at the bottom of the bolt. Figure 1(c) represents the concrete breakout strength. This is the most common type of failure whenever a similar system is subjected to tensile loading. In this failure, the concrete is pulled out forming a cone. The concrete is damaged in tension and the area of the cone keeps on increasing as the strength of concrete decreases. The failure mode shown by figure 1(d) represent the side face blowout, which usually occurs when the edge distance of the anchor bolts is not enough. The final mode of failure shown in figure 1(d) depicts the concrete splitting failure. This mode of failure occurs if the concrete block in which the anchor bolts are embedded is not deep enough, i.e., if the thickness of the concrete block is not enough.

A research by Rasoul Nilforoush et al. 2017 [5] explains the experiment behavior of single cast-in-place anchor bolt in plain and steel fiber reinforced normal and high strength concrete. The test apparatus is similar to the one used in our study. It includes a cross steel beam, a load cell, a loading rod, and a hydraulic jack. The embedded length of all the specimens was kept the same. The results of the experiment show the type of failure and the failure load. It shows that as the strength of concrete increases, the failure load increases. The addition of steel fibers shows a positive effect on the breakout strength as well. For the plain concrete, the breakout strength is around 320kN and for SFRC the breakout strength is shown to be 411kN.

2.1.3 Numerical analysis

For the numerical analysis of steel fiber reinforced concrete using nonlinear finite element analysis, we need to figure out a way to model the SFRC because it is not a feasible to model single steel fiber and randomly embed it into the concrete block.

A research conducted by Wahalathantri et al. 2011 [6], suggests a way to model the post cracking behavior of concrete in both tension and compression. Wahalathantri et al. 2011, states that the stress at any strain in concrete in compression could be defined using the following equation

$$\sigma_c = (\beta\, (\epsilon_c / \epsilon_o) / (\beta - 1 + (\epsilon_c / \epsilon_o)^\beta))\, \sigma_{cu} \qquad \text{---- Eq 2.1}$$

where,

$\beta = 1/ 1- (\sigma_{cu} / \epsilon_o * E_o)$ ---- Eq 2.2

and

$Eo = 1.2431*10^2 \sigma cu + 3.28312*10^3$ (ksi) ---- Eq 2.3

$\epsilon o = 8.9*10^{-5} \sigma cu + 2.114*10^{-3}$ (ksi) ---- Eq 2.4

$\epsilon_{in} = \epsilon_c - \sigma_c E_o$ ---- Eq 2.5

$d = 1 – \sigma/\sigma_{peak}$ ---- Eq 2.6

In the above equations

σ_c = Stress at any point on the stress strain curve

σ_{cu} = ultimate compressive strength of concrete

ϵ_c = Total strain

ϵ_o = Strain at ultimate compressive stress

d = damage parameter

E_o = Young’s modulus

The stress strain behavior in tension could be defines as the following table

Concrete tension behavior		
Yield stress	Cracking strain	Damage parameter
σ_{to}	ϵ_{cr}	0
$0.77\sigma_{to}$	$1.25\epsilon_{cr}$	0.23
$0.45\sigma_{to}$	$4\epsilon_{cr}$	0.55
$0.1\sigma_{to}$	$8.7\epsilon_{cr}$	0.9

Table 1: Concrete tension behavior

Where,

σ_{to} = Tensile capacity of concrete

ϵ_{cr} = Strain at tensile capacity of concrete

Another research by Luiz Álvaro de Oliveira Júnior et al. 2010 [7][18], provides a numerical model for the stress strain behavior of SFRC in compression. The model is based on equations from the previous study. The study proposes to use β as the following equation

$\beta = (0.0536 - 0.5754V_f)f_c$ ---- Eq 2.7

where,

V_f = Volume fraction of steel fibers

f_c = Ultimate compressive stress

A study performed by Xi jun Shi et al. 2020 [8], provides a numerical formula to understand the tensile behavior of SFRC. Straight steel fibers under uniaxial tension were examined. The results showed that the fibers remarkably enhanced the concrete post-cracking behaviors in terms of achieving higher ductility, residual strength, and toughness under compression and tension [8]. The equation that could be used to model the behavior are,

The ultimate tensile stress = f_{ct}

Reinforcing Index, RI = $\zeta * l * V_f / d$ ---- Eq 2.8

Where,

ζ = Shape factor

l = fiber length

d = fiber diameter

V_f = volume fraction of fiber

RI = Reinforcing Index

The stress behavior is as follows

Tensile behavior of SFRC	
Stress	Strain
f_{ct}	ϵ_{ct}
$\alpha_t f_{ct}$	$\gamma_t \epsilon_{ct}$
$\beta_t f_{ct}$	0.0005

Table 2: Tensile behavior of SFRC

Where,

$\alpha_t = 0.3301RI + 0.18$ ---- Eq 2.9

$\beta_t = 0.2134RI + 0.0665$ ---- Eq 2.10

$\gamma_t = 0.025RI + 1.194$ ---- Eq 2.11

CHAPTER 3

EXPERIMENT

3.1 General

This chapter reviews the experimental study conducted at UTA in 2020. The results of this study were utilized in the numerical program [1]. The compressive strength, tensile , and flexural strength of the concrete under consideration was obtained. ASTM C39 concrete compression test on 12 cylinders (3 cylinders each for 0.0%, 0.5%, 1%, 1.5% volume fraction of SFRC) of size 4”x8” was conducted to determine the compressive strength of concrete. ASTM C496 cylinder split tensile test was performed on 12 cylinders of size 6”x12” each. The flexural strength was found using ASTM C78 flexural beam test on four beams with dimensions 6”x6”x20” each [1].

The anchor groups pull out test was conducted on two anchors placed at 5” from each other (to inculcate the grouping effect in accordance with ACI 318-19). The anchors were embedded into a SFRC concrete beam with the edge distance of 6.5” and 9”. The 8” long anchor rod was submerged into the beam up to a depth of 2.5” from the top. A single beam with dimensions 54”x18”x10” was cast and, preinstalled anchor bolts with nut at the bottom were used for the test. The length of the beam allowed a larger distance between the adjacent anchors so that their cone of influence does not interfere with one another.

3.2 Materials and properties

3.2.1 Steel Fibers

Dramix unhooked straight steel fibers with an aspect ratio of 13/0.21 were utilized for the purpose of this study. Table 1 provides the properties of the steel fibers used. For most practical purposes, steel fibers are incorporated into concrete to improve it compressive strength, tensile strength, flexural strength, durability, residual strength, cohesion, to control shrinkage cracks, settlement cracks, and other micro cracking. Figure 2 shows the type of fibers used for this study. Manufacturer's specifications were followed while adding the fibers to concrete.

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

Table 3: Properties of steel fibers

Figure 2: Actual steel fibers utilized in the experimental work

The compressive strength, tensile strength and flexural strength values were adopted form the previous research [1].

3.2.2 Concrete

Concrete is composite material. It is made by mixing cement, sand, gravel, and water. The plain concrete produced for the purpose of the test was aimed to achieve a compressive strength of 4000psi. The cylinder specimens for each batch were tested after 28 days of curing. Testing was done to determine the compressive strength, the split tensile strength, and the flexural strength of concrete. The mix proportions of the concrete are provided in the table 4, given below.

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

Table 4: Mix proportions of concrete

3.3 Test results

The following tables, table 5, table 6, table 7, and table 8 summarizes the test results obtained from the experiment. These test results were further utilized to obtain the concrete damage plasticity values of SFRC, which are an integral part of the modeling.

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

Table 5: Compressive strength test data

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

Table 6: Split tensile test data

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

Table 7: Flexural strength test data

C.V% = coefficient of variation

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

Table 8: Summary of test results

3.4 Test result for breakout strength

The breakout strength of the concrete was tested in accordance with ASTM E488 (Standard Test Methods for Strength of Anchors in Concrete Elements) [1]. Table 9 shows the results that were obtained from this test.

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

Table 9: Concrete breakout strength

CHAPTER-4

FINITE ELEMENT MODELLING

Finite element modelling can be used to achieve a wide variety of tasks. It helps us model different types of materials, analyze complex geometries and study the local effects of loads on different structures. The finite element software used in this research is ABAQUS. The model in this research consists of a SFRC block and anchor bolts as seen in figure.

The objective of this study is to replicate the results achieved by the experiments described in chapter 3 with the help of a numerical model. This numerical model, after making sure that the results are in agreement with the experimental values obtained, is further used to conduct similar studies by changing different parameters. This results in saving a lot of time and monetary resources. In this study, the anchor bolts embedded in the SFRC block are loaded in uniaxial tension. This chapter discusses the finite element model, the damage properties and parameters and the numerical results obtained.

The constitutive model used in the following FEA is in good conjunction with the experimental results, in consequence, we can say that the constitutive model utilized for this study is appropriate. Hence, the parameters are varied for the parametric study to obtain results for similar problems.

4.1 Modeling in ABAQUS

4.1.1 Creating Parts

The initialization of any modeling in ABAQUS requires creating parts. This is done using the create part tool under the part module. This tool enables the user to create different components of the model with different types and base features. ABAQUS user interface defines a grid for the user to mark the coordinates in order to specify the dimensions for the said part the user is trying to model. The geometry of the part could be changed anytime if the user wishes to do so. Figure 3 shows the dialogue box that appears for the creating part window.

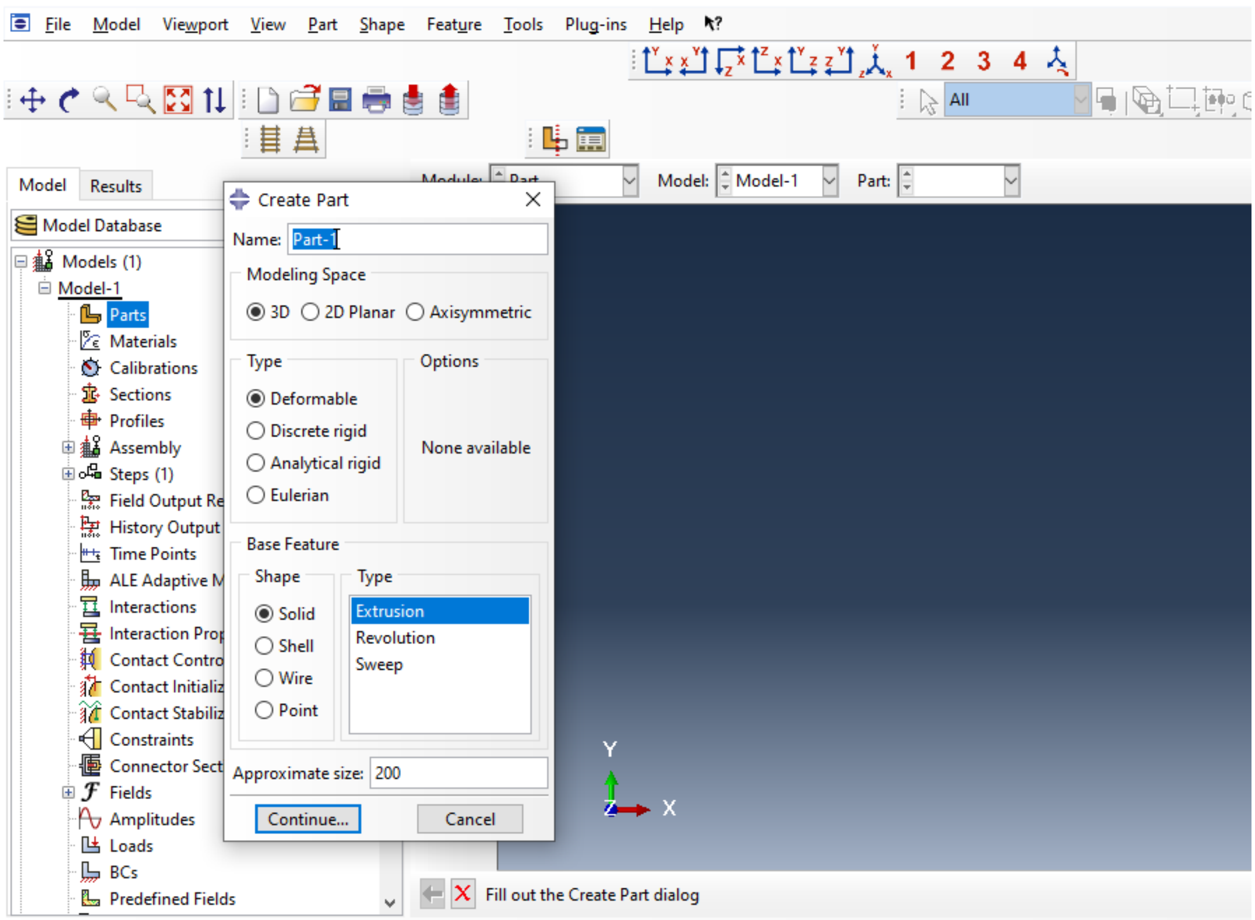


Figure 3: Creating parts dialogue box

For the purpose of this study, steel anchors and SFRC block was modeled using the create parts instance. They were initially modeled as separate entities and then combined using the assembly tool. The SFRC concrete block was modeled as a 3D deformable solid using the extrusion type. Figure 4 illustrates the solid SFRC block in ABAQUS. The block was a cuboid with length and width equal to 18” and depth equal to 10”. In the experiment, the length of the beam was 54”. But since the beam had three sets of two anchor bolts embedded in it, for uniformity of concrete strength, this beam was not modeled in this study. Instead, a single set of two anchor bolts was chosen and a concrete block of 1/3 length of the beam, i.e., 18" was modeled. The anchor bolts used in the experiment had a nut provided at the embedded end to improve the cohesion between anchor bolt and SFRC block. This was used to reduce the possibility of steel pullout failure or the steel concrete slip failure. Hence the anchor bolts were modeled as 3D deformable solid using the revolution type. The anchor bolts had a diameter of 0.5", a length of 8" and an embedded length of 2.5". The diameter of the nut, which was modeled as a uniform body with the bolt, was assumed to be three times that of the bolt diameter that is 1.5". The angle of revolution was taken as 360^{o}. Figure 6 illustrates the anchor bolts used in this study. Table 10 summarizes the dimensions of the concrete block and the anchor bolts.

SFRC Block		
Length (in.)	Height (in.)	Depth (in.)
18	10	18
Anchor bolt		
Diameter (in.)	Total Length (in.)	Embedded Length (in.)
0.5	8	2.5

Table 10: Dimensions of the concrete block and anchor bolt

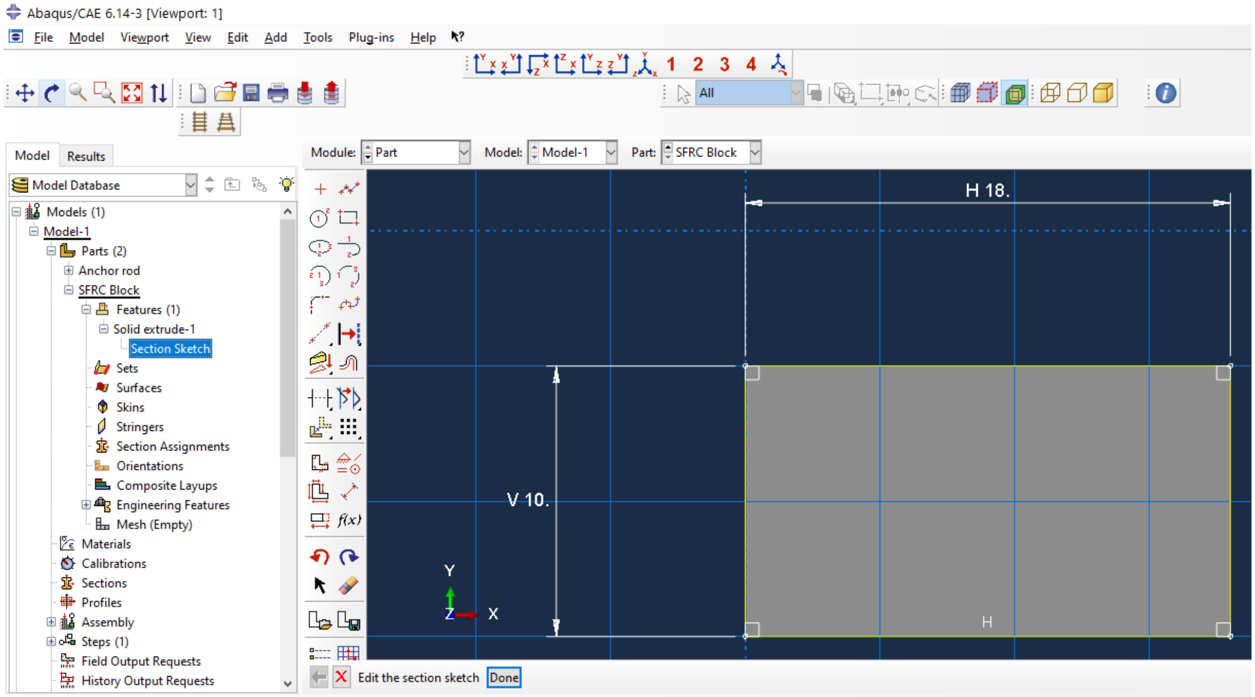


Figure 4: Creating parts, SFRC block

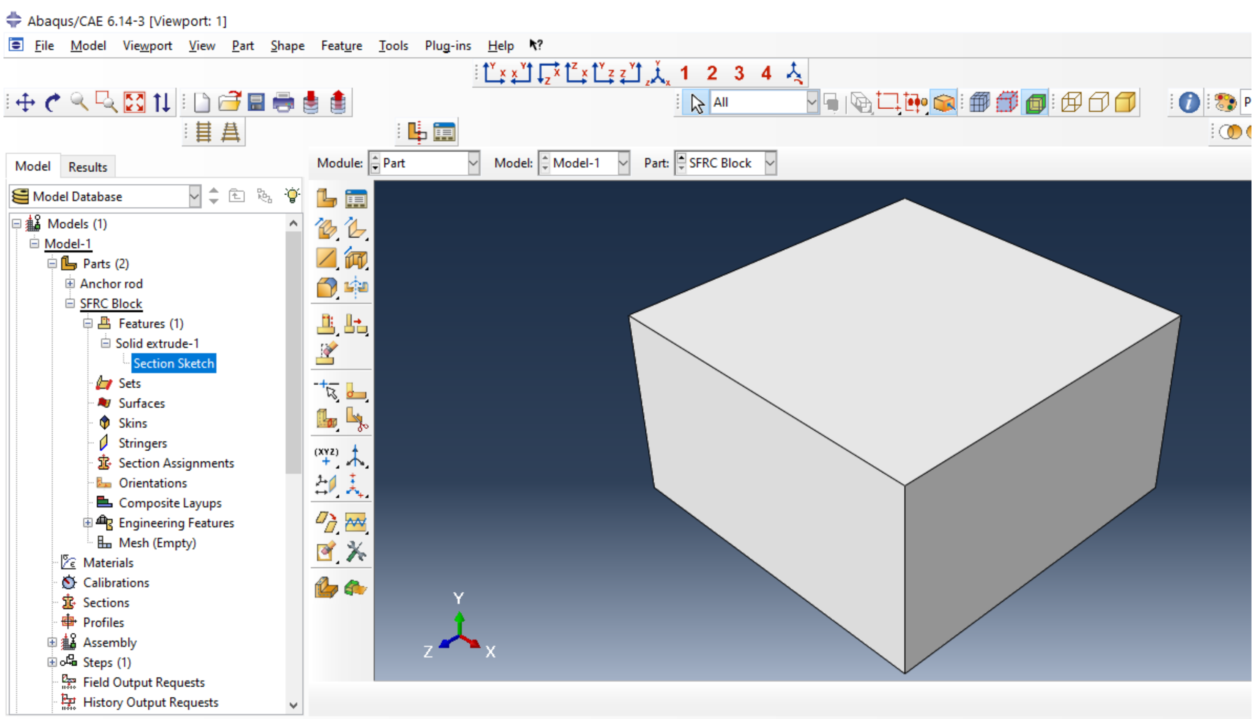


Figure 5: Solid SFRC block

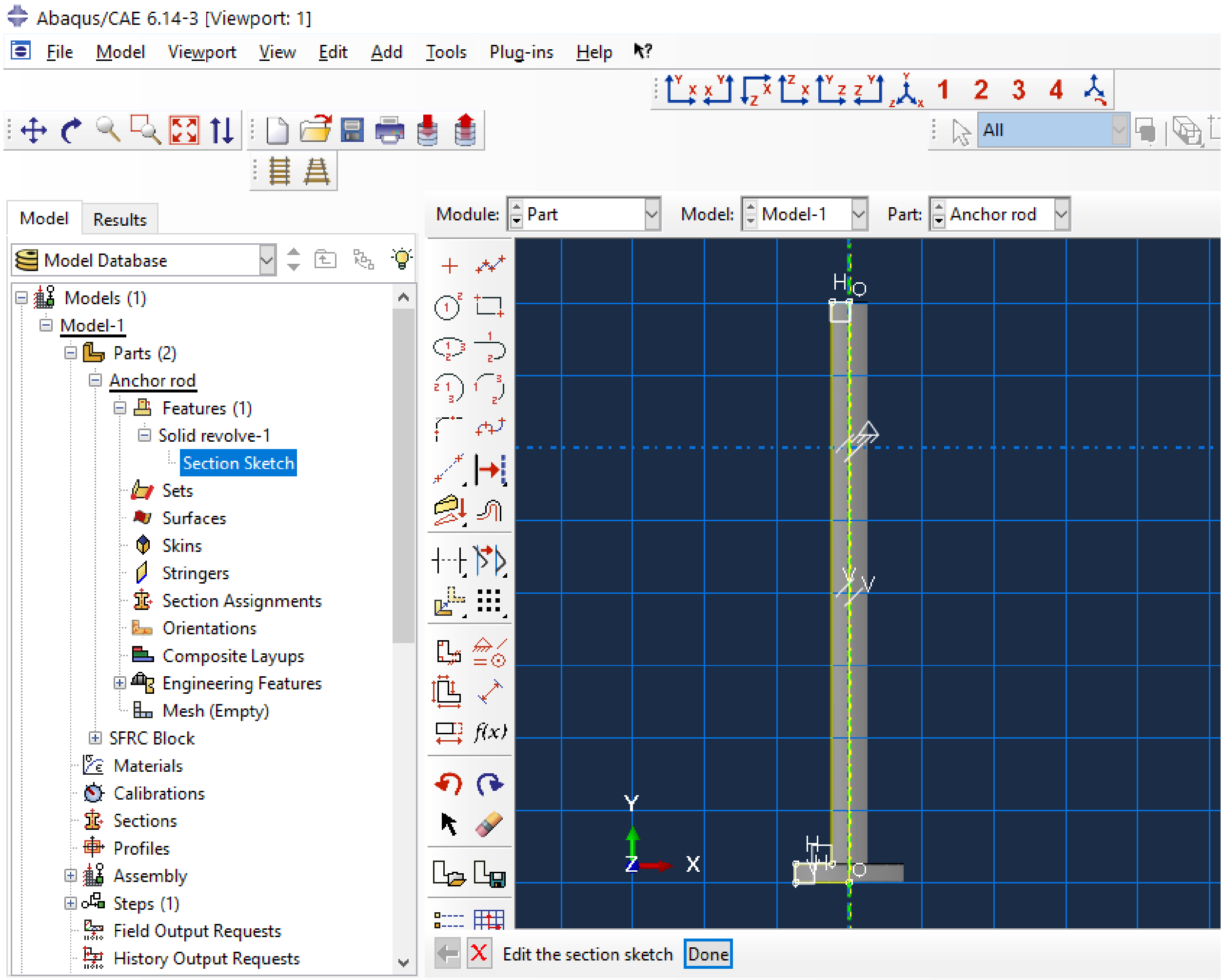


Figure 6: Creating parts, anchor bolt

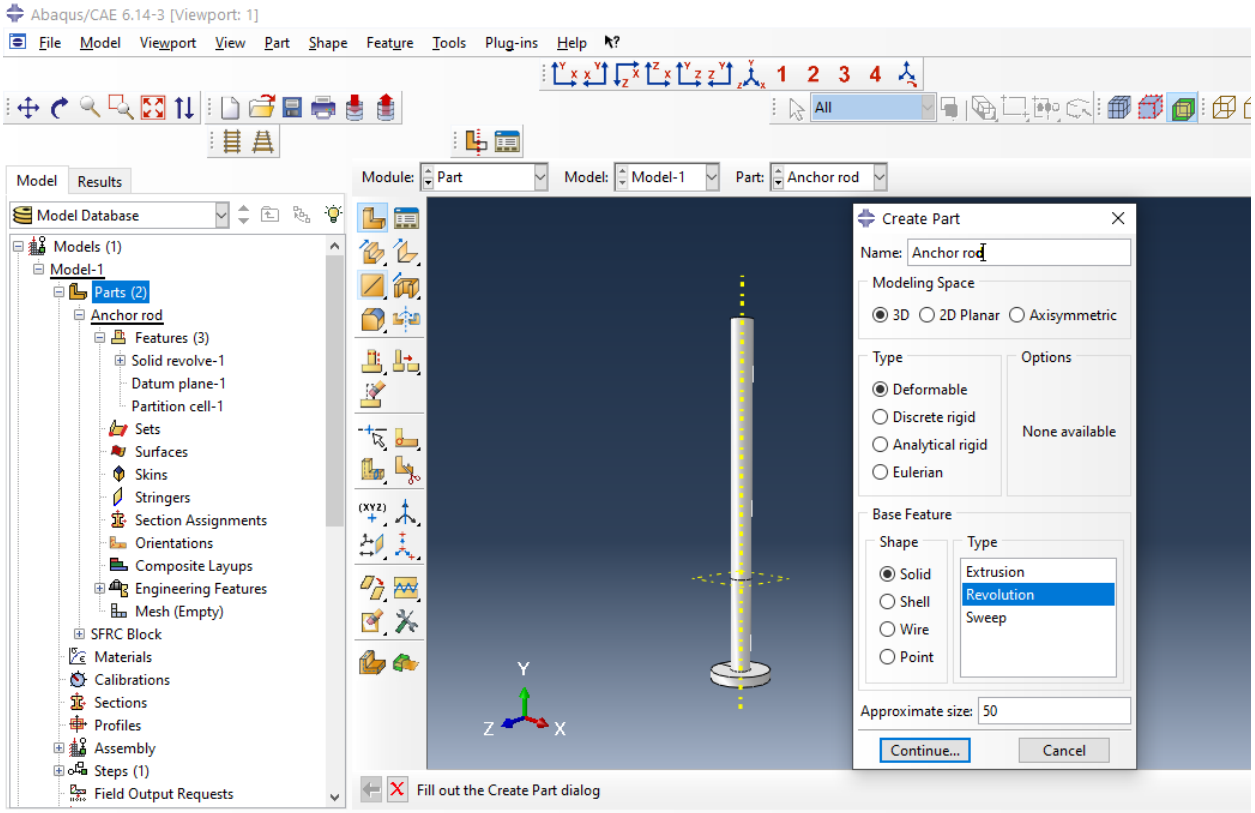


Figure 7: Solid anchor rod

4.2 Material Properties

For a material to behave in a particular way, ABAQUS needs the user to define its properties. The physical properties of different parts created needs to be defined under the property module in the material manager option. The material manager tool helps to define the general, mechanical, thermal, electrical, and other properties of the created part. In summation, the material properties are defined under the property module where the section sets are created and assigned. These section sets define the material behavior under any given loading while performing the finite element analysis(FEA).

The properties for steel fiber reinforced concrete and the steel anchor bolts were defined in using the material manager tool. Different properties mainly, the compressive strength, tensile strength, Young's modulus, poisson's ratio and yield strength. The values used can be seen in the subsequent images and tables.

SFRC Parameters				
Fiber volume fraction	0.0%	0.5%	1.0%	1.5%
Compressive strength (psi)	4224	4625	5300	4962
Tensile strength (psi)	331	399	439	448
Flexural strength (psi)	512	531	562	596

Table 11: SFRC Parameters [1]

Steel Anchor Bolt (F1554 G105)	
Yield stress (psi)	105000
Elastic Modulus (psi)	29000000
Poisson's ratio	0.3

Table 12: Steel anchor bolt parameters

4.2.1 Concrete Damage Plasticity (CDP)

The concrete damage plasticity model is based on the assumption of an isotropic damage in combination with tensile and compressive isotropic failure, to represent the behavior of concrete under arbitrary loading. The CDP model used in this study is based on previous research performed, namely the stress strain curve for steel fiber reinforced concrete by Luiz Alvaro de Oliveira Junior et al and bulking effects on the performance of solar cells under different loading conditions by Ahmed Alateeq [9] [10].

The above stated constitutive models are utilized for representing the stress strain curve of concrete and SFRC under uniaxial compression and tension. For plain concrete under uniaxial compression, i.e. steel fiber percentage volume 0.0%, the following equation was used to find out the stresses [10],

$$\sigma_c = \left(\frac{\beta\left(\frac{\epsilon_c}{\epsilon_o}\right)}{\beta - 1 + \left(\frac{\epsilon_c}{\epsilon_o}\right)^{\beta}}\right)\sigma_{cu}$$

---- Eq 4.1

Where,

ϵ_c = total strain

$\epsilon_0 = 8.9*10^{-5}\ \sigma_{cu} + 2.114*10^{-3}$

And β is a parameter that depends on the shape of the stress strain curve. It can be calculated using the following equation.

$$\beta = \frac{1}{1-(\frac{\sigma_{cu}}{\epsilon_0 * E_0})}$$

---- Eq 4.2

The strain value that is to be input in the concrete damage plasticity table in ABAQUS is the inelastic strain ϵ^{in} . This value can be calculated by subtracting the elastic strain values from the total strain.

$$\epsilon^{in} = \epsilon_c - \frac{\sigma c}{E_0}$$

---- Eq 4.3

The values input in the CDP compressive behavior for plain concrete (0.0% SFRC) is provided in the following table.

Stress (psi)	Inelastic strain
751.727	0.0
3426.262	0.0
4224	0.0
3977.213	0.002655
3004.26	0.006011
2631.978	0.0077088
2356.251	0.0092812

Table 13: CDP values for SFRC0.0%

For steel fiber reinforced concrete, the value of β can be found out using the following equation

$$\beta = \left(0.0536 - 0.5754 V_f\right) f_c$$

---- Eq 4.4

Where,

V_f = volume fraction of steel fibers

f_c = Compressive strength of concrete, psi

And the strain values could be found out using the equation

$$\varepsilon_{c,0} = \left(0.00048 + 0.01886\ V_f\right) \ln f_c$$

---- Eq 4.5

The consideration of the tensile behavior is much more simplified. The following image shows the response of concrete to uniaxial loading in tension.

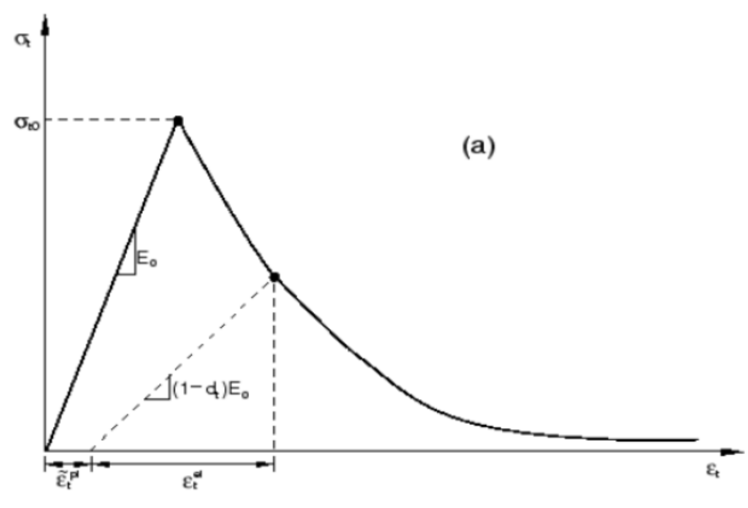


Figure 8: Response to concrete under uniaxial loading in tension [10]

The above model is simplified by dividing the failure into three primary ranges, namely, the elastic range, the primary cracking range, and the secondary cracking range. The elastic region extends until the ultimate tensile stress is reached with the corresponding initial cracking strain. After that, there is a considerable drop in the stresses till the value reaches 0.77 time the ultimate stress. The value of strain corresponding to this is 1.25 times the initial cracking strain. The primary cracking stage begins after the stress reaches 0.77 times the ultimate stress and extends till the value becomes 0.45 times the ultimate stress with the corresponding strain value being equal to 4 times the initial cracking strain. This point acts as the starting point for the secondary cracking stage, extending from 0.45 times the ultimate stress to 0.1 times the ultimate stress, with the corresponding stain value being equal to 8.7 time the initial cracking strain [10]. This model is summarized and shown in a graphical form in the subsequent figure 9.

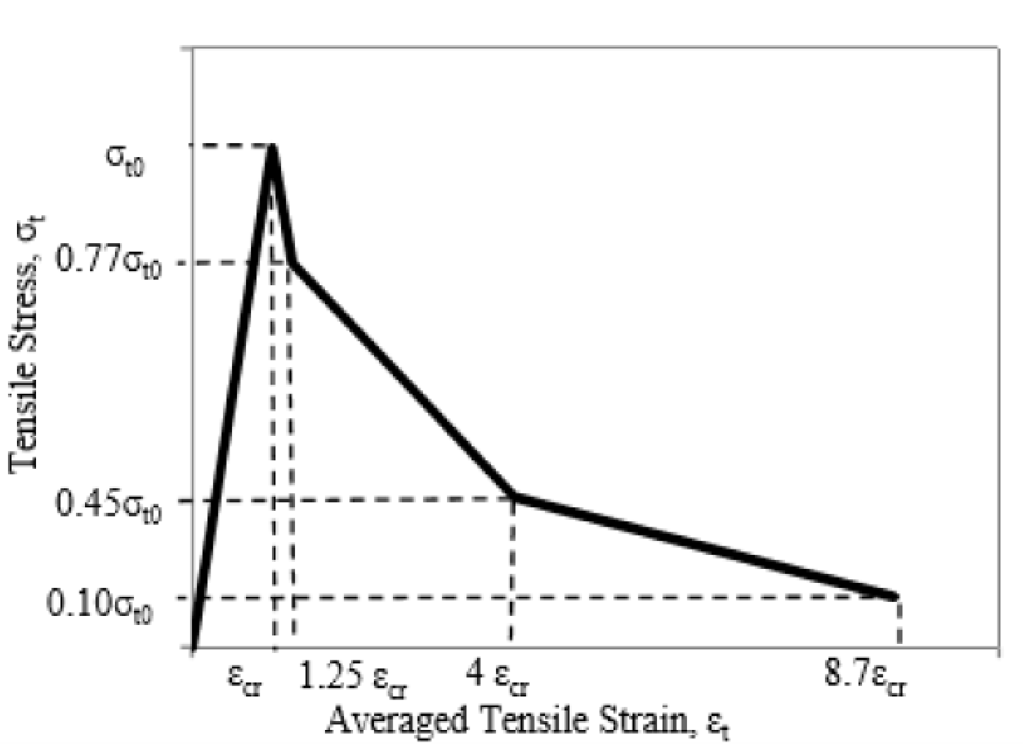


Figure 9: Tensile stress vs averaged tensile strain

The modulus of elasticity of SFRC was found out using the equation

$E_c = 0.242\ E_{cp} + 1.25\ V_f\ S_p$ ----Eq 4.6

Where,

E_c = Modulus of elasticity of composite SFRC

E_{cp} = Modulus of elasticity of plain concrete

V_f = Volume fraction of steel fibers, %

S_p = Aspect ratio of the fiber

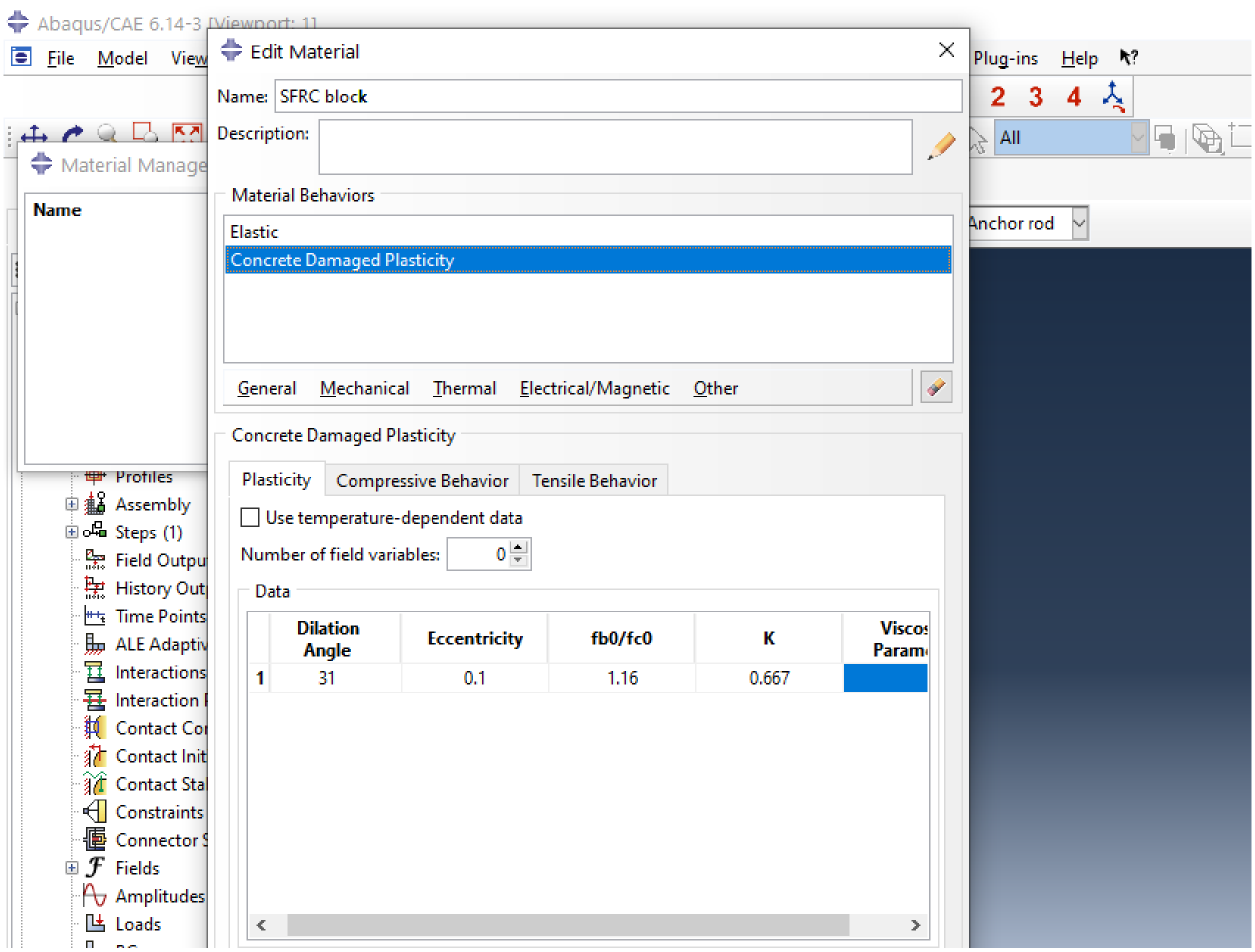


Figure 10: Abaqus concrete damage plasticity

4.3 Assembly

The parts that have been modeled and assigned a material need to be assembled in a similar manner as the original test setup. This is done under the assembly module. The anchor bolts and the concrete block are brought together using the instances tool. The reinforcement is duplicated using the array tool and appropriate spacing is provided. Then these are embedded in the concrete block 2.5” deep. But bringing the two parts together in close vicinity with each other is not enough for them to interact in ABAQUS. There is a need to define the physical interaction between the surfaces in contact.

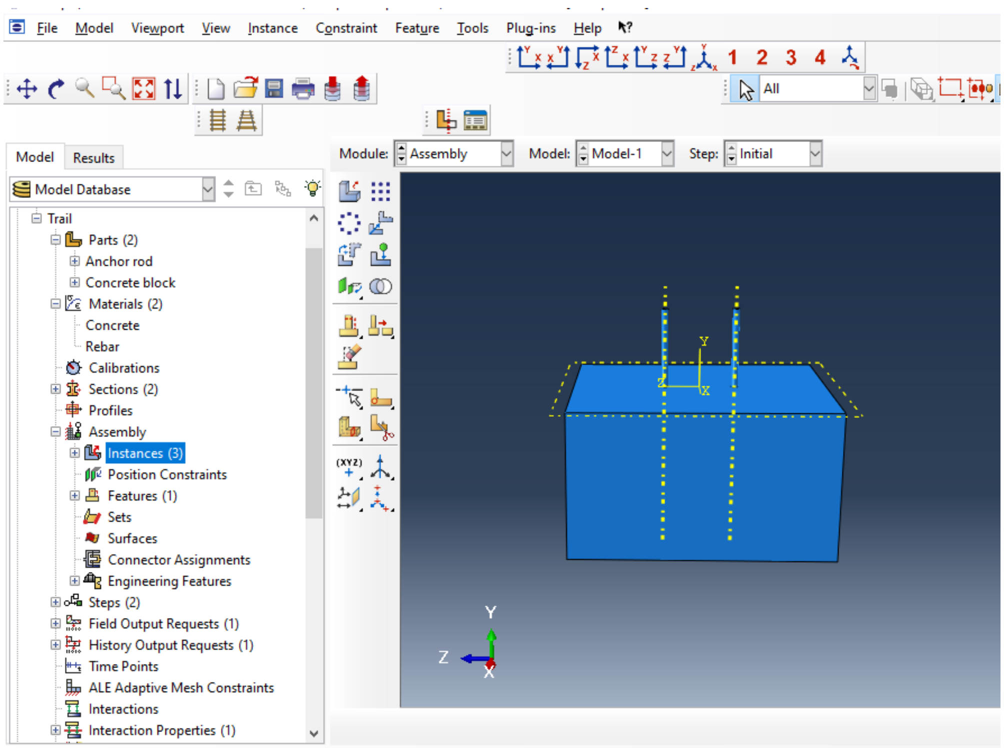


Figure 11: ABAQUS model for parts assembly

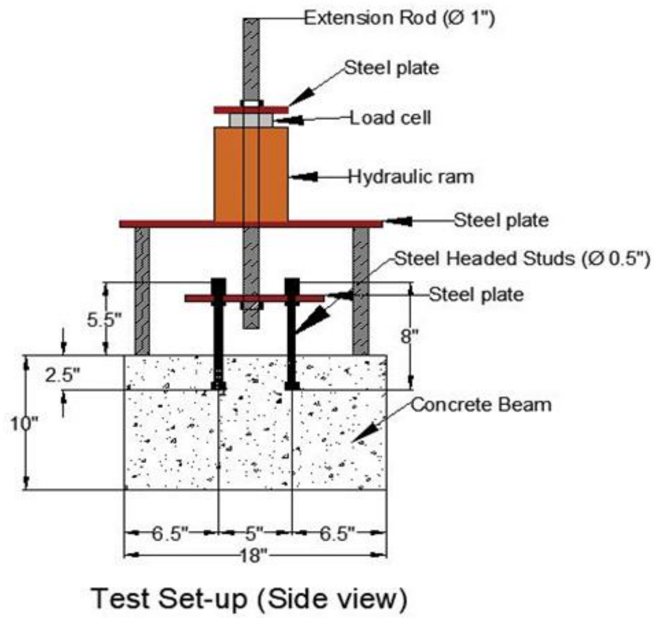


Figure 12: Pictorial representation of the test setup [1]

4.4 Step

Under the step module, there are a lot of options to either define the step, increments and the field outputs. The step manager helps in creating steps that help in solving the numerical analysis. This tool aids in defining the total number of increments that are allowed within each step, the maximum number of steps that can occur, the minimum and maximum values of each increment etc. For this study, the step function created had the default name of step-1 and the number of increments were deliberately kept high so as to reduce a factor which could result in the termination of the analysis. The initial increment size was kept being 0.1 and the maximum increment was kept equal to 1.

The field output request had to be put in for the tension damage output and the nodal force value. This was done using the field output options.

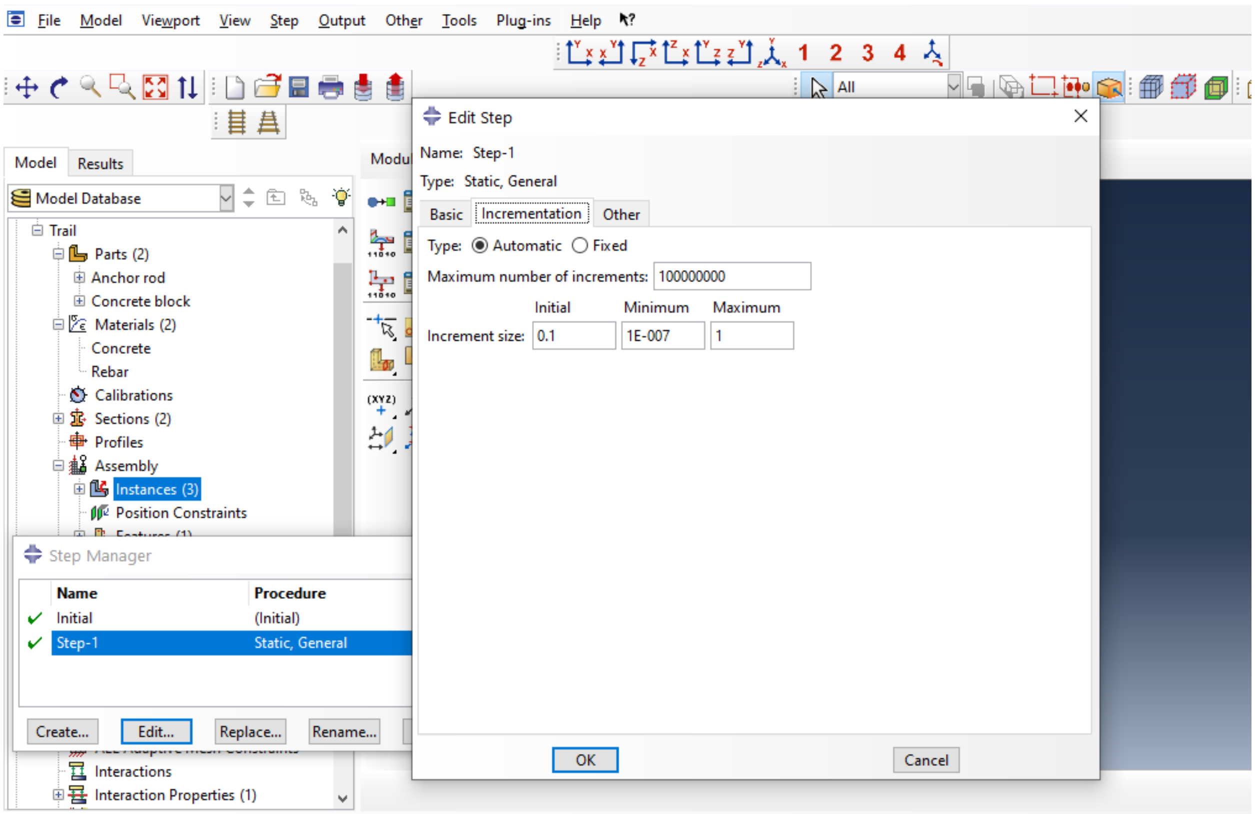


Figure 13: Step dialogue box

4.5 Interaction and constraint

As stated earlier, bringing two objects in each other's vicinity is not enough for ABAQUS to consider them as connected. ABAQUS needs the user to define the exact way the two objects will behave when they are in contact with each other. The interaction module helps achieve that. The interaction manager tool helps the user to define different types of contacts, such as the surface-to-surface contact or the node to node contact etc. The constraint tool helps in defining the constraints for different nodes. In this study, the portion of the anchor rods that is immersed in the concrete block is constrained using the embedded constraint.

The embedded constraint restricts the translational degrees of freedom of the node and the node is henceforth known as the embedded node. The embedded node requires a host region. In this research, the concrete block was chosen to be the host region. ABAQUS defines the host region in such a way, that the translational degrees of freedom of the embedded region are now constrained by the translational degrees of freedom of the host region. The following figure shows the embedded and the host regions as defined in this model.

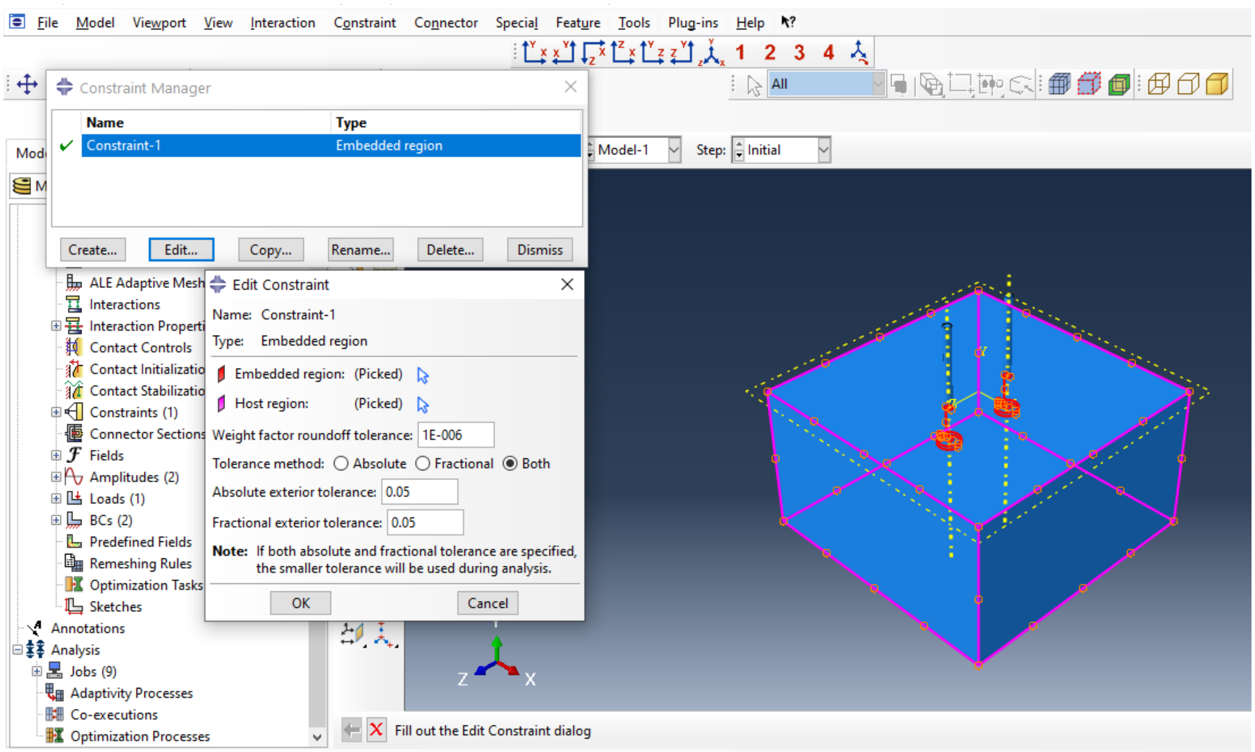


Figure 14: Interaction

4.6 Loads and boundary condition

Loads are defined using the loads manager tool under the load module. Using the create load tool in the load manager, we can define the type of load, its intensity, direction, and magnitude of the load. For this study, the load tool was not used. Instead, a displacement control approach was utilized. The top of the anchor bolts was displaced by 0.5” each and the load required to produce that displacement was found out. The displacement is provided as a uniform boundary condition at the top surface of the rebars. This is to observe the behavior of concrete when the anchor rods are applied upon by a tensile force as done in the experiment.

The displacement provided during the analysis is provided in increments. The increment size is decided by the software on its own so as to create a convergence in the results. The figure 15 defines the boundary condition of the anchor bolts and figure16 provides the dialogue box which shows that the displacement takes place in the positive y-direction.

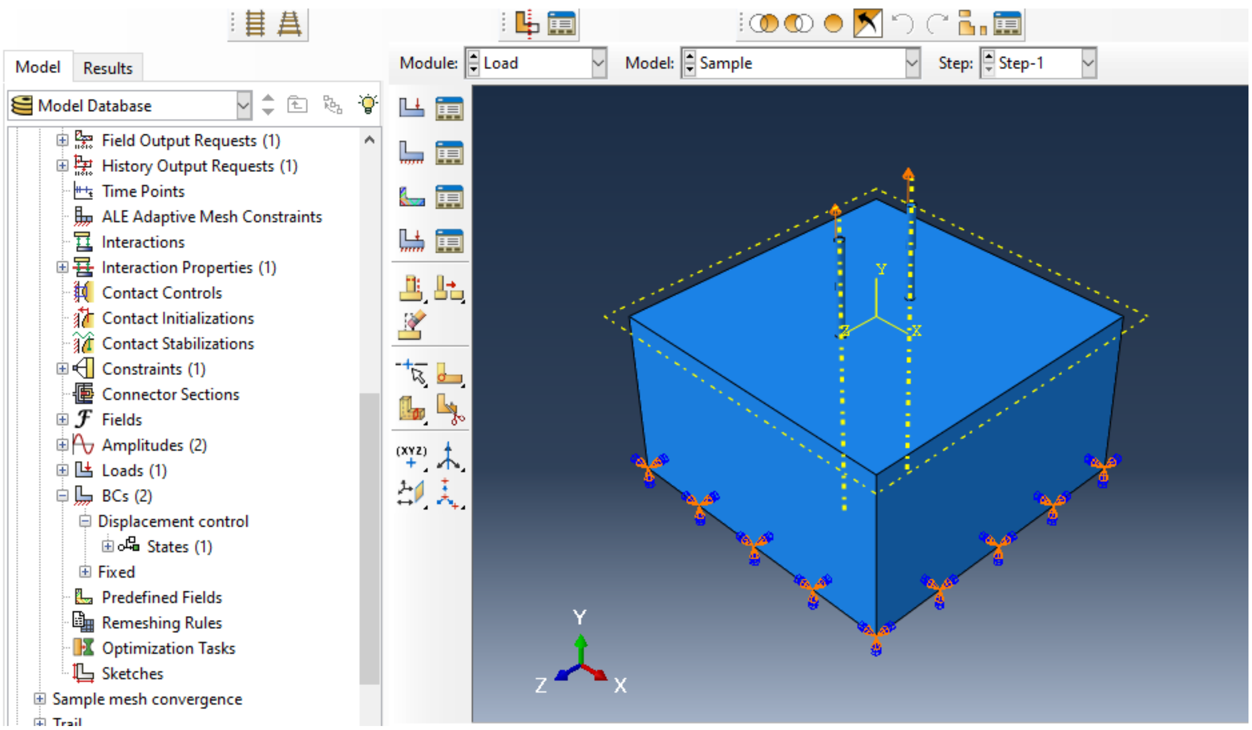


Figure 15: Displacement control

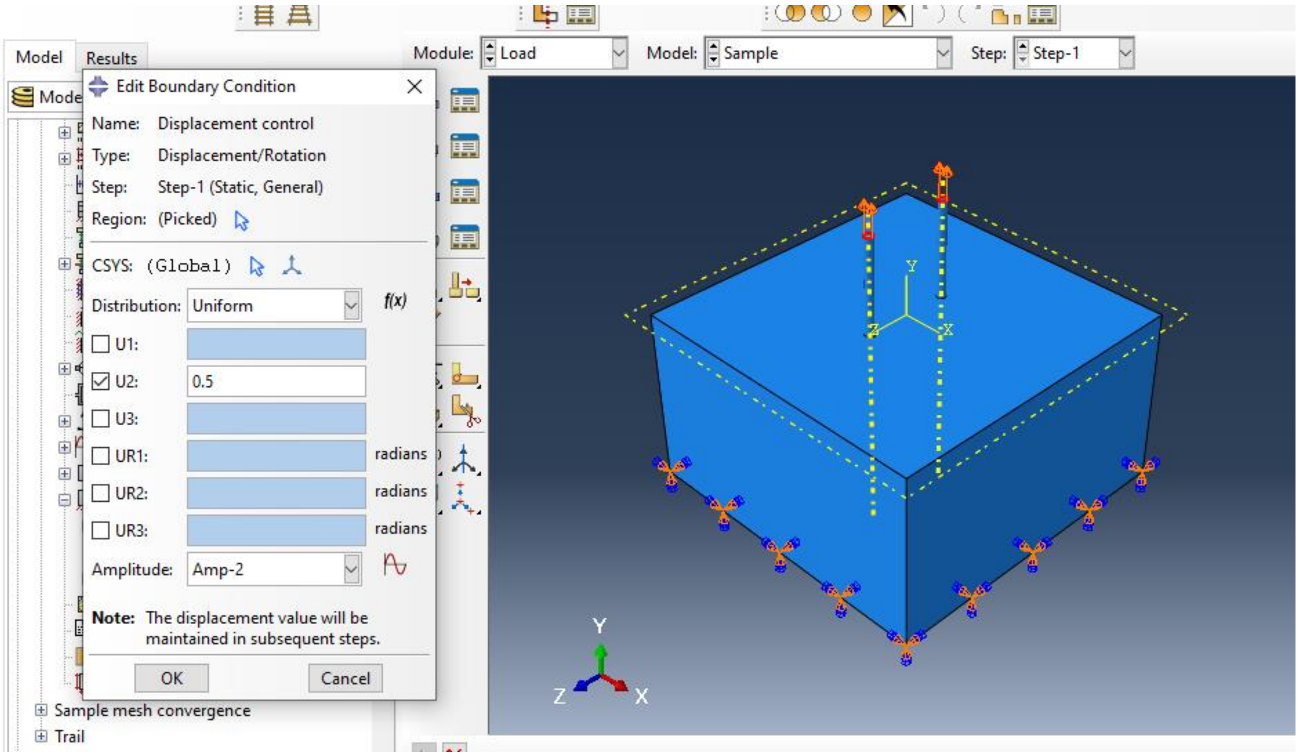


Figure 16: Displacement control dialogue box

The boundary condition is defined to simulate the conditions of the experiment. But, since the self-weight of the concrete beam is not considered, because the original length of the beam used in the experiment was larger owing to the three samples that were tested using the same beam and the beam modeled was only one third of the original size, the effects were replicated by considering the concrete block to be fixed at the bottom surface.

The above stated is achieved using the boundary condition manager tool. This tool helps the user define the degrees of freedom for any surface or node. For this research, the bottom surface of the concrete block was fully fixed, i.e., there were no degrees of freedom, either translational, or rotational. This is shown in the figure below.

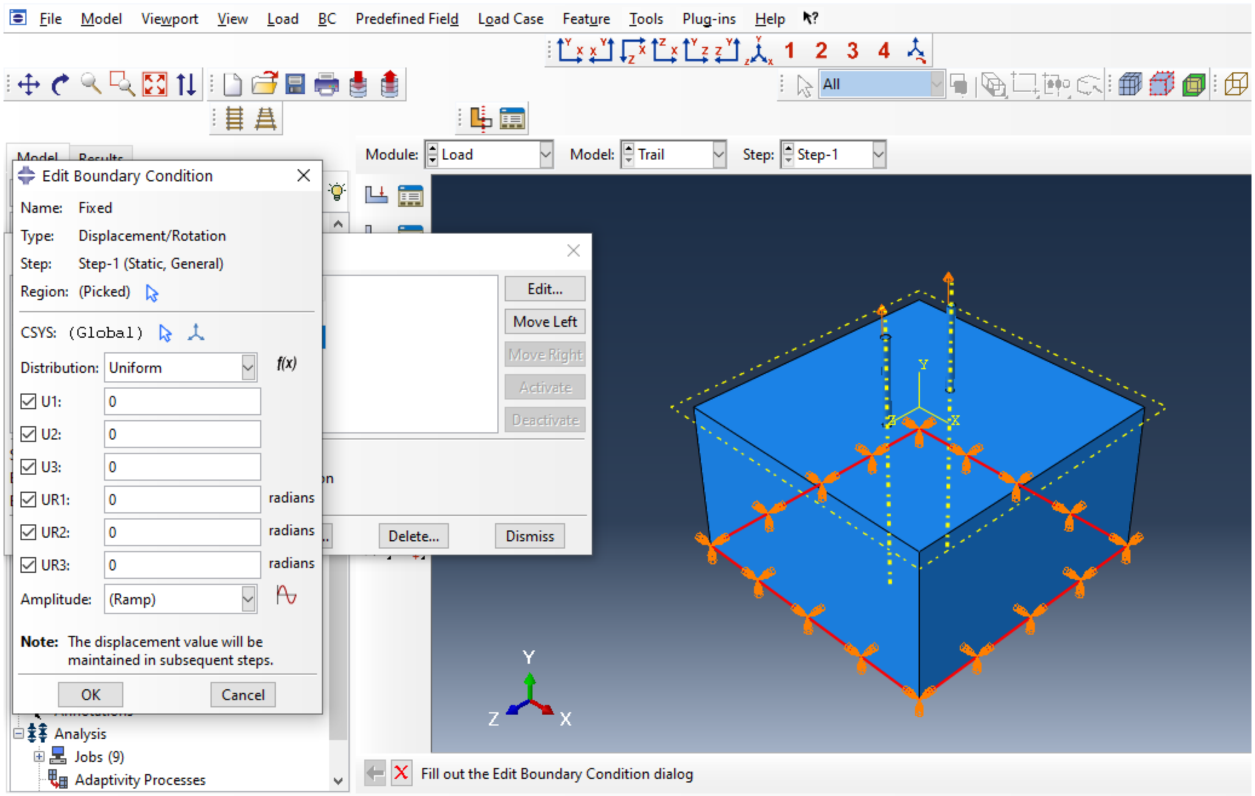


Figure 17: Boundary condition dialogue box

4.7 Mesh

The SFRC block is modeled with 8-node hexahedral(hex) element and the anchor rod is modeled as a combination of the hexahedral element and tetrahedral element. This done because of the relatively complex geometry of the anchor rod owing to the bolt at the bottom. The portion of the anchor rod embedded in the SFRC block is modeled using the tetrahedral element and the portion outside the SFRC block is modeled using the hexahedral element. Figure 18 and figure 19 depict SFRC block and anchor bolt and their meshes, respectively.

A more refined mesh provides a better result as a greater number of elements are created, which helps getting a greater number of values closer to each other. But refining the meshes could sometimes lead to a higher processing time, which needs to be taken into consideration as well, so basically, we need to find an optimum size of the mesh which provides us with acceptable results.

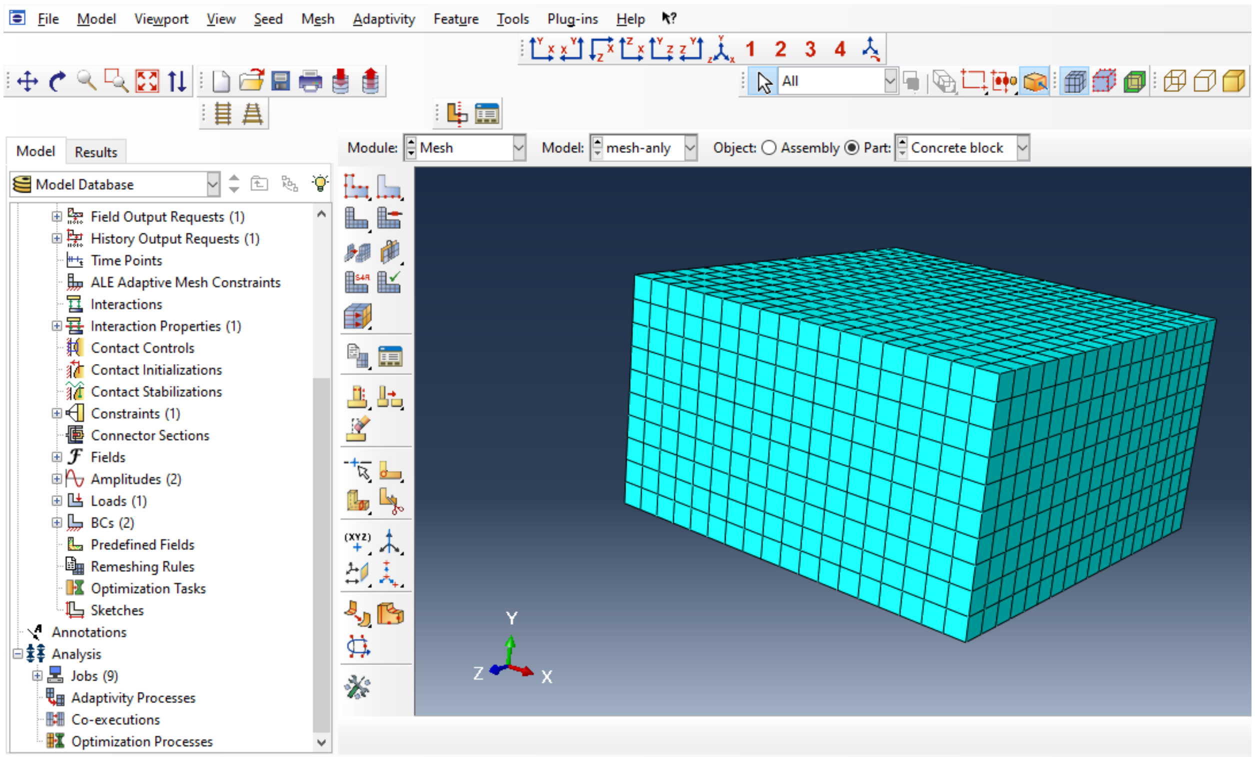


Figure 18: SFRC Mesh

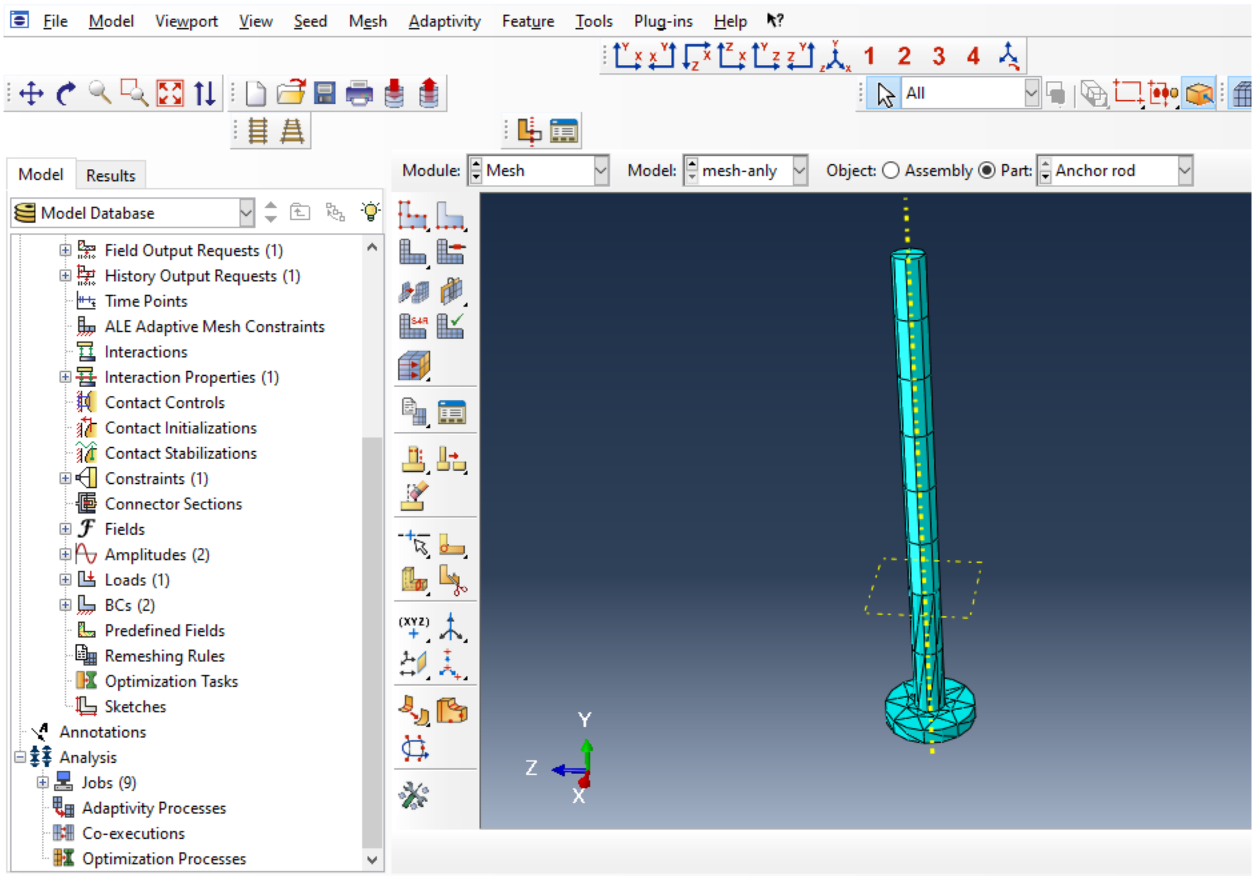


Figure 19: Anchor bolt mesh

4.8 Results Visualization

After running the analysis successfully, ABAQUS allows the user to visualize the results in a pictorial representation as shown in the following figure. The results show the area where the tension damage has occurred. Different colors are used to represent the intensity of damage at different locations.

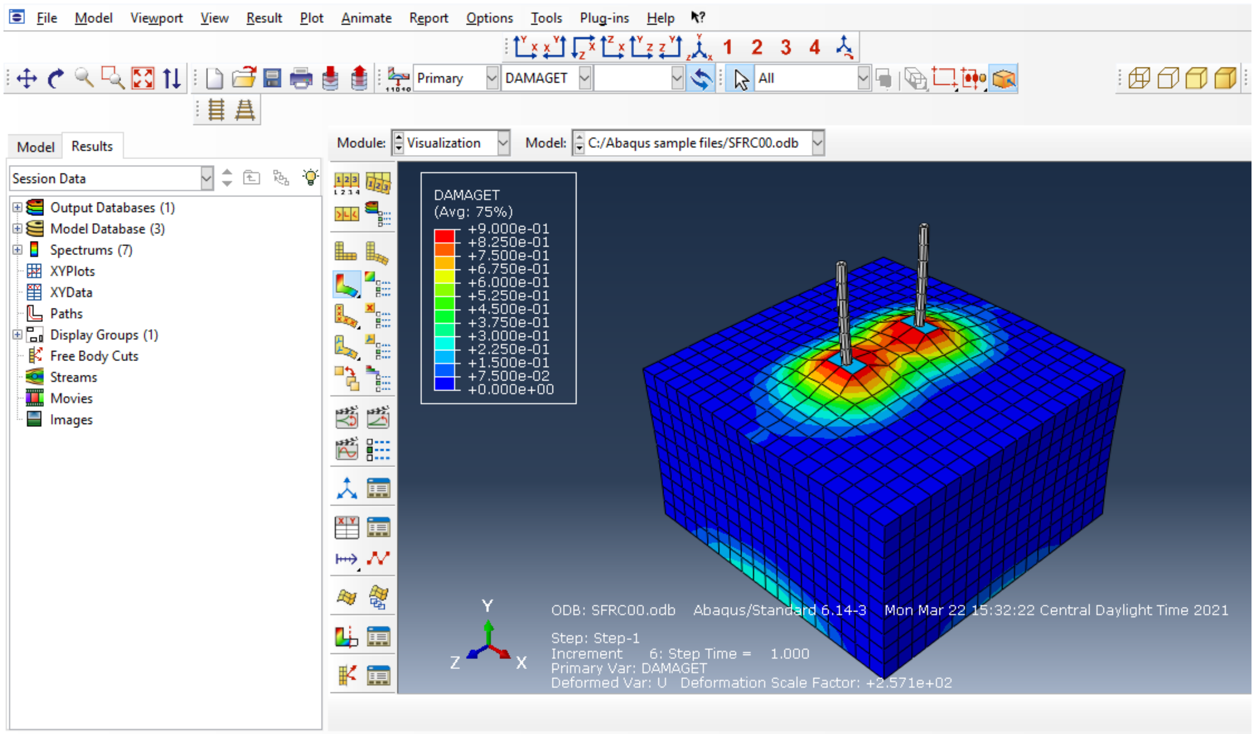


Figure 20: Visualization

CHAPTER-5

NUMERICAL ANALYSIS

5.1 General

Concrete is a material with high compressive strength and low tensile strength. The addition of steel fibers is done keeping in mind the positive effects it has on improving the tensile strength of concrete, but it helps increase the compressive strength as well. The results from the experiment depend on a lot of factors, some of which are, the steel fiber dosage, the diameter of the anchor bolt, the embedded length etc. It would be expensive and time consuming to perform the experiments, by changing these parameters one at a time. This is where the need for numerical analysis lies.

In this research, the numerical analysis is performed on the cast in place anchor bolts to test the grouping effects of anchor bolts in tension. Concrete breakout strength is found out with anchor bolts under tensile loading. Various simulations are performed using different boundary conditions, mesh size, anchor bolt diameter, and the embedded length, the results of which are discussed in this chapter.

5.2 Mesh Convergence

Mesh convergence study is important to know the number of elements that are needed in order to get acceptable results in optimum time. A finer mesh provides a better result in the affected area because of a large number of elements coming together, but the analysis can take up a considerably large amount of time. Sometimes, the convergence can occur on a larger mesh size and a finer mesh could provide a value different from the desired results.

Figure 21 shows the results for same simulation with different mesh sizes. The mesh size 0.5”x0.5” produces a large number of elements, which causes the software to take longer time for the analysis and the results are not a close match. The mesh size 2”x2” and 3”x3” are comparatively larger and the analysis time is considerably reduced but the results are not acceptable. The simulations done for the 1”x1” mesh size produce results that are close to the available experimental results and shows convergence.

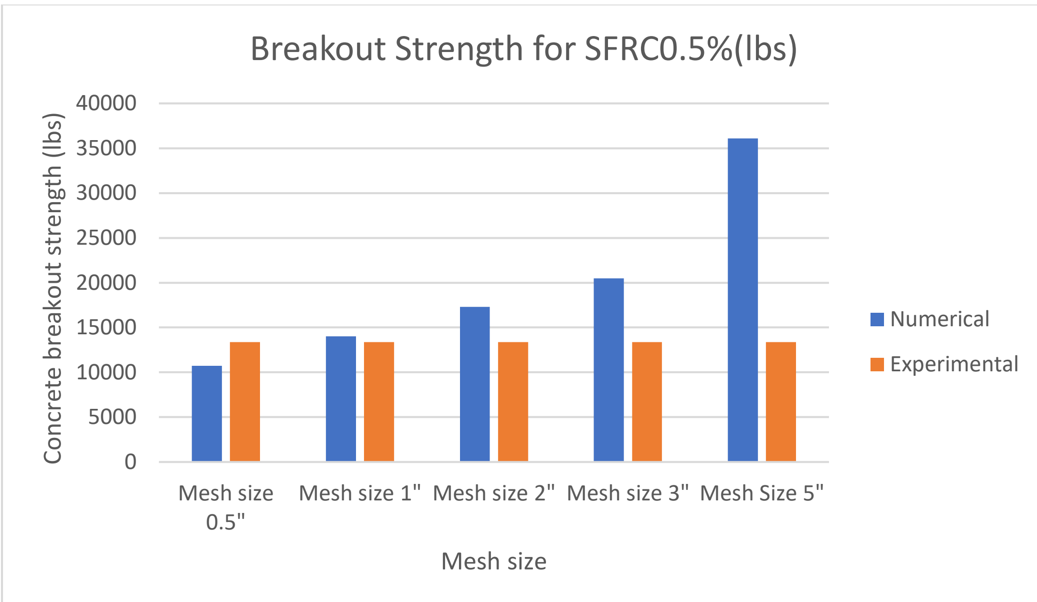
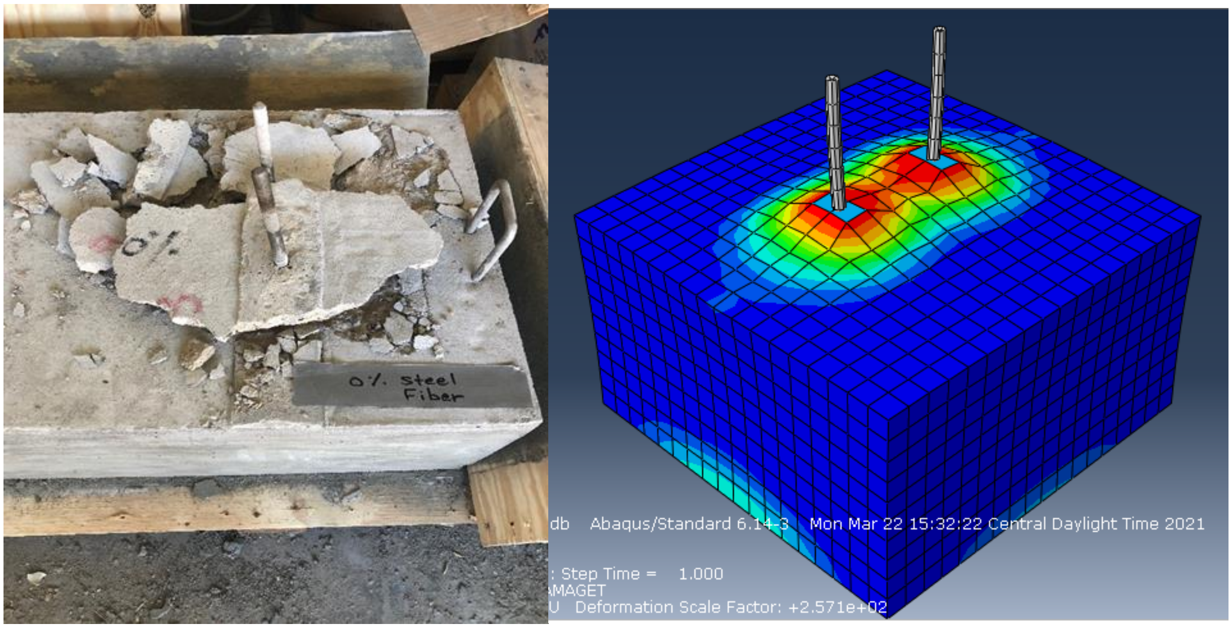


Figure 21: Mesh convergence

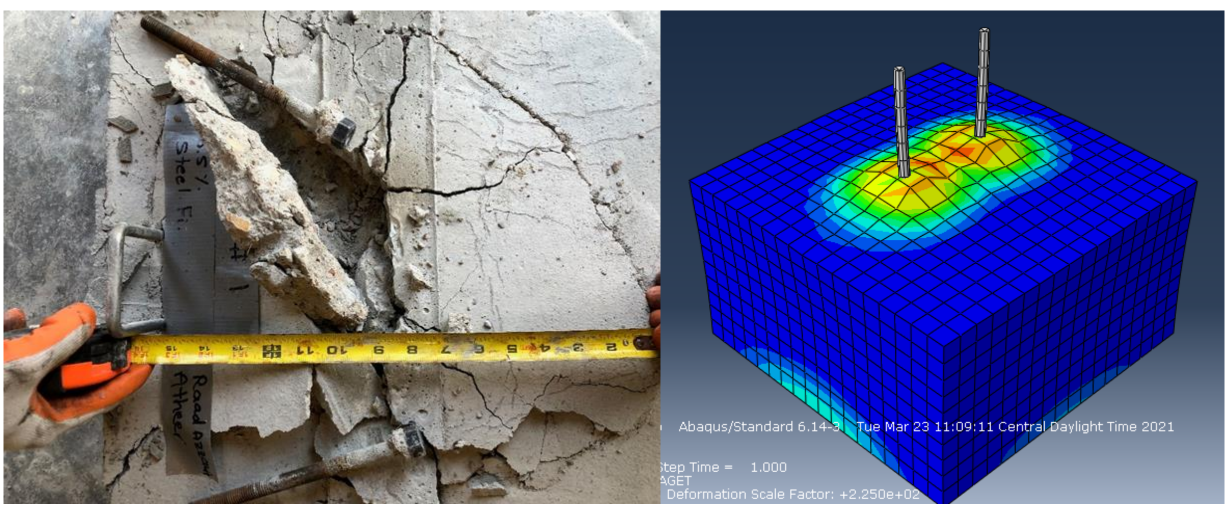
5.3 Model Analysis

In this research, the cast in place anchor bolts were modeled and the concrete breakout strength was found out using the finite element analysis. The FEA was performed using the same loading conditions and same steps as the experimental setup [1]. The properties of the SFRC with varying percentages of steel fibers was found out experimentally and utilized in this model to get the results. Figure 22 shows a comparison between the experimental and the numerical results of the concrete block after failure for plain concrete and the other percentages of steel fiber follow in the subsequent figures.



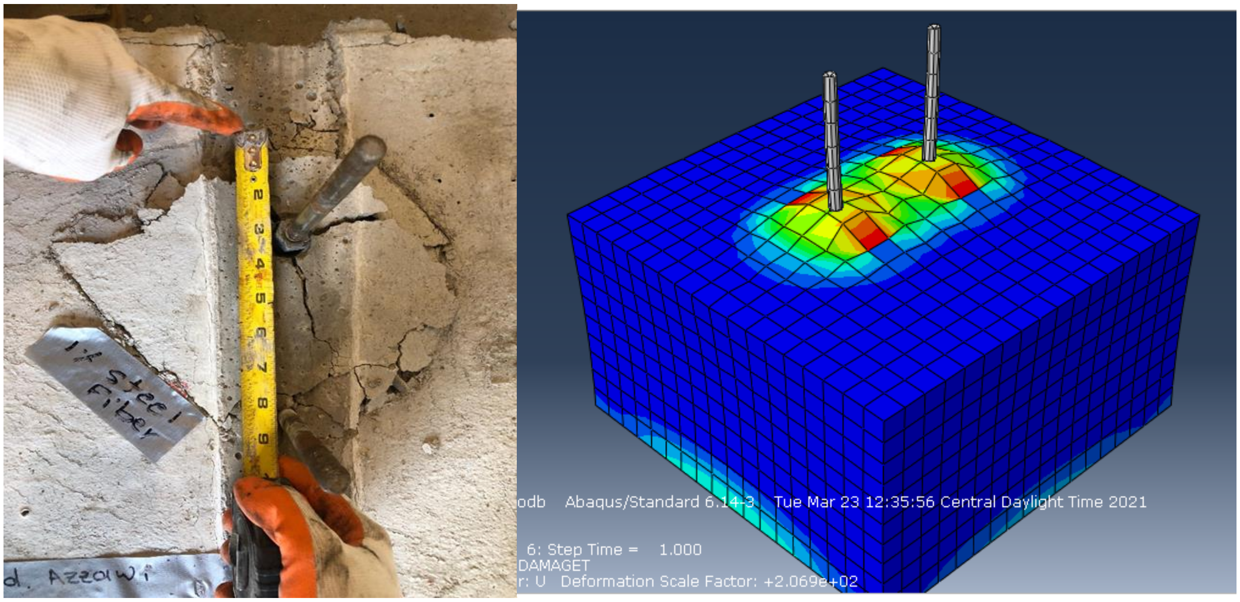
(a) (b)

Figure 22:(a) Experimental test for 0% steel fibers. (b) Numerical analysis for 0% steel fibers in ABAQUS



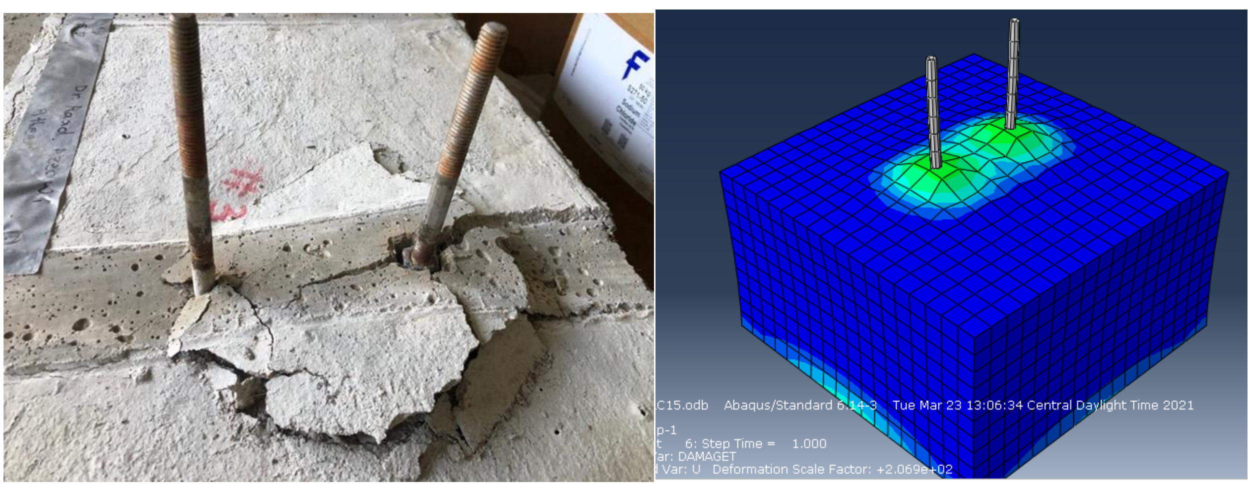
(a) (b)

Figure 23:(a) Experimental test for 0.5% steel fibers (b) Numerical analysis for 0.5% steel fibers in ABAQUS



(a) (b)

Figure 24: (a) Experimental test for 1% steel fibers (b) Numerical analysis for 1% steel fibers in ABAQUS



(a) (b)

Figure 25: (a) Experimental test for 1.5% steel fibers (b) Numerical analysis for 1.5% steel fibers in ABAQUS

It is quite evident from the figures that as the steel fiber percentage in the concrete increases, the stress in the region surrounding the anchor bolt decreases. Also, the breakout cone formed by concrete around the embedded region gets more localised and the diameter decreases. This could be attributed to the confinement of steel fibers around that region, which lead to a higher resistance developed.

The model was not genereated in a form to provide steel fibers at a random orientation within the concrete block. Instead, the concrete was provided with properties that resembeled that of the steel fiber reinforced concrete with different fiber percentage. Hence the modulus of elasticity plays a huge role in this. The modulus of elasticity was calculated using the equation [11],

$$E_c = 0.242E_{cp} + 1.25V_fS_p \quad \text{---- 5.1}$$

Where,

Ec = modulus of elasticity of steel fiber reinforced concrete

Ecp = modulus of elasticity of plain concrete

Vf = volume fraction of steel fibers

Sp = aspect ratio of steel fibers

5.4 Anchor group vs Single anchor in tension

This section discusses the effect of anchor grouping effect on the tensile breakout strength of concrete when the anchor bolts are subjected to tensile loading. A previous research conducted by Karthik Vidyaranya [12], provided the experimental results of the concrete breakout strength of concrete when a single anchor bolt is subjected to uniaxial tensile force. The test conditions and material properties were similar to the ones used by Atheer Alaa Al Khafaji [1]. The numerical model generated for this research was sufficient to replicate the results for single anchor under tensile loading. The concrete breakout strength for the numerical model for the SFRC 0%, 0.5%, 1%, 1.5% are at a difference of 2.8%, 6.4%, 9%, 10.4% respectively. The exact values are provided in the table below.

The concrete breakout strength values for a single anchor under uniaxial tensile loading are higher than that of the breakout strength of concrete for anchor grouping effect owing to the fact that there is no grouping action taking place, i.e., the concrete breakout cone of two adjacent anchors does not interact with each other. Both the experimental and the numerical results justify this claim. The table given below provides us with the numerical and the experimental values for the breakout strength of concrete using a single anchor and an anchor group, under a uniaxial tensile loading.

Concrete mix	Average concrete breakout strength (lbs) of anchor groups with grouping effect (experimental)	Average concrete breakout strength (lbs) of anchor groups with grouping effect (numerical)	Average concrete breakout strength (lbs) of 2 single anchors without grouping effect (experimental)	Average concrete breakout strength (lbs) of 2 single anchors without grouping effect (numerical)	Grouping effect factor (experimental)	Grouping effect factor (numerical)
0.0%	9334	9507	11588	11921	0.81	0.80
0.5%	13379	14004	16085	17112	0.83	0.82
1.0%	16187	17539	19208	20936	0.84	0.84
1.5%	16901	18267	19654	21712	0.86	0.84

Table 14: Average concrete breakout strength of anchor group vs 2 single anchors

5.5 Results

Figure 26 and figure 27 show the graph for experimental and numerical results for different percentages of steel fiber reinforced concrete.

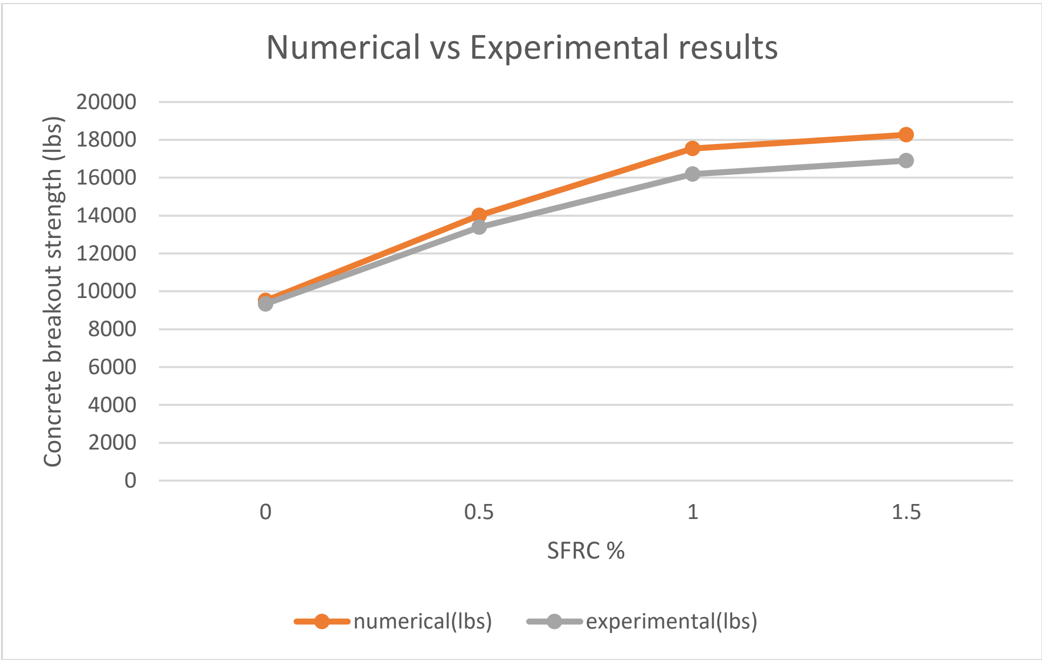


Figure 26: Experimental vs Numerical results

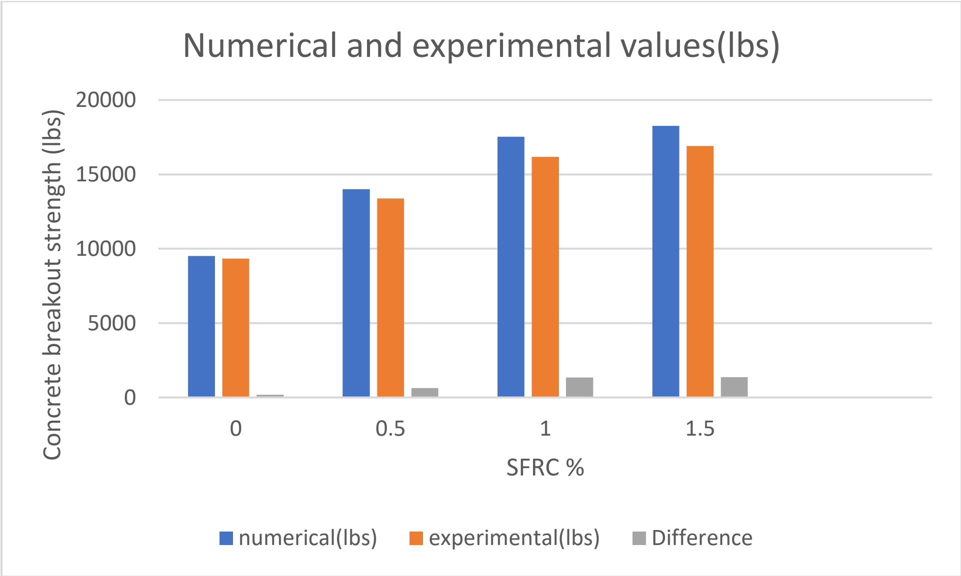


Figure 27: Numerical and experimental results with difference between the two

Breakout strength of concrete (lbs) (numerical vs experimental)		
SFRC%	Numerical	Experimental
0	9507	9334
0.5	14004	13379
1	17539	16187
1.5	18267	16901

Table 15: Breakout strength of concrete (lbs) (numerical vs experimental)

It is evident from the figure 26 and figure 27 and table 15 that the numerical results are a close match to the experimental values. The greatest difference in the numerical and the experimental values provides a difference of around 8% which is well within the limits. This validates the numerical results. The reason for the numerical values being higher than the experimental values can be attributed to the inconsistencies of the experimental procedures, which is normal.

5.6 Parametric study

5.6.1 Embedded length effect

Since the results of the FEA were a close match to the experimental values, we can use this model to change one parameter at a time to get results for similar experiments. A parametric study was performed by changing the embedded length and the diameter of the anchor bolts. The results of the parametric study are presented in the subsequent figures.

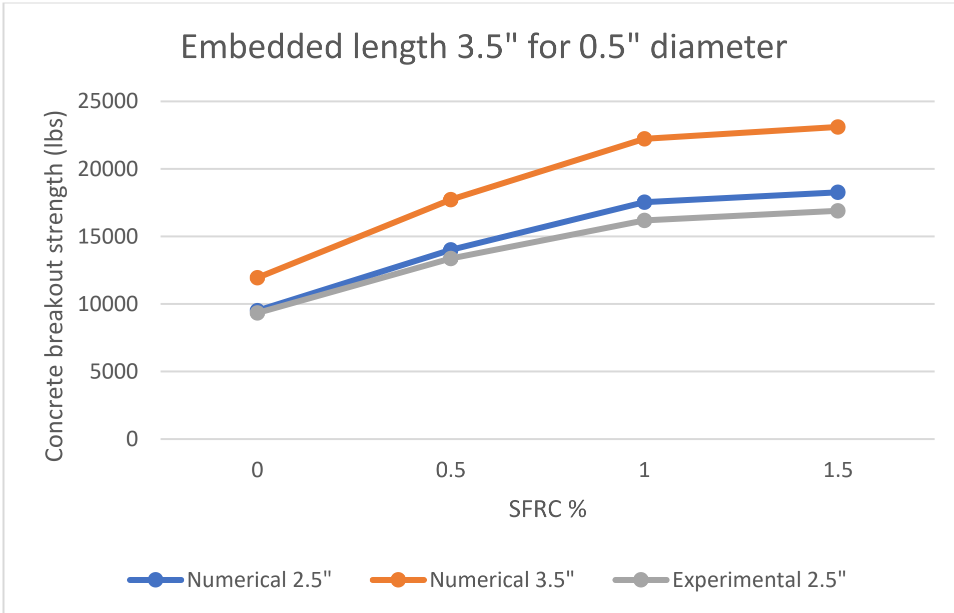


Figure 28: The breakout strength (lbs) of 0.5" dia anchor bolts with 3.5" embedded length

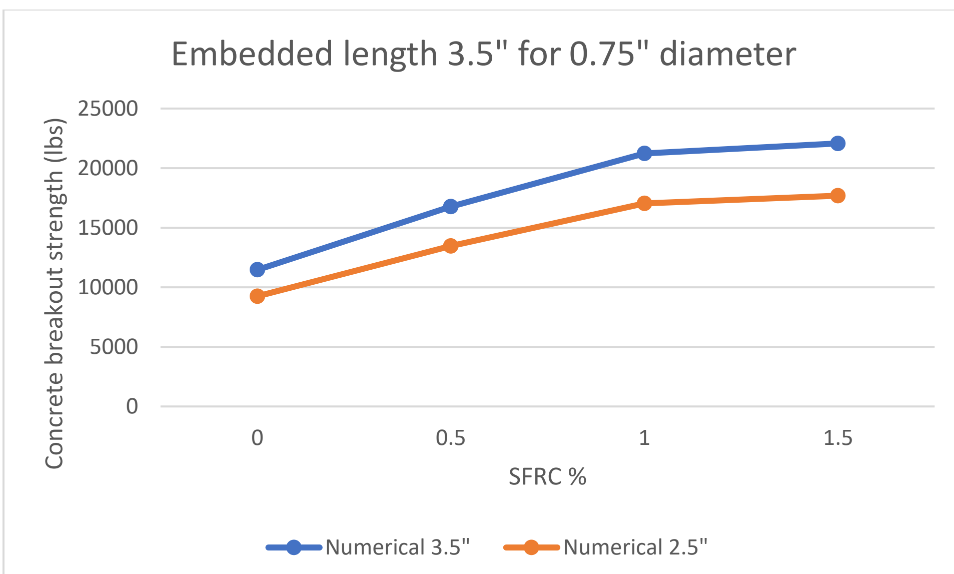


Figure 29: The breakout strength (lbs) of 0.75" dia anchor bolts with 3.5" embedded length

The embedded length was increased from 2.5” to 3.5” and a numerical analysis was performed. As expected, the breakout strength of the concrete increases. The increase in the breakout strength is about 26% for the increase in the embedded length. This could be attributed to the fact that more cohesion is achieved between anchor bolts and concrete and the concrete cone has a larger depth, hence making it difficult to pull the anchor bolt out as compared to a smaller length.

5.6.2 Anchor bolt diameter effect

The diameter of the anchor bolts was increased from 0.5” to 0.75” for the purpose of the parametric study, the results of which are presented in the graphs below.

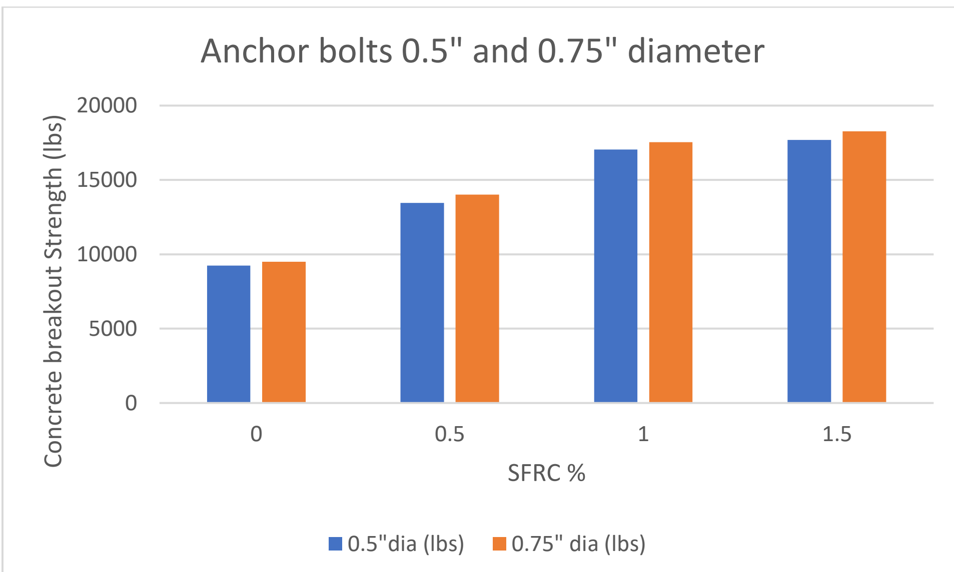


Figure 30: Breakout strength of different diameter anchor bolts

It can be seen that, although the breakout strength for the larger diameter is higher, the difference between is two values is not that large. The difference in the values is about 4% which is very low, implying that the bolt diameter does not considerably affect the breakout strength of the anchor bolts in tension.

5.7 Discussion of results

5.7.1 Finite element model

The addition of steel fibers improve the properties of concrete when acted upon in tension. The global stiffness of the concrete is increased which reduces the risk of splitting at the location of the anchor bolt. Also, it increases the confinement of concrete, which in turn increases the tensile capacity of concrete. The results in ABAQUS show a similar trend where the angle of the concrete breakout cone is reduced as the dosage of steel fibers is increased. The concrete breakout strength for 0% SFRC is 9507lbs which is around 2% more than the experimental value, but as the fiber dosage is increased, the difference keeps on increasing. For 0.5%,1%,1.5% SFRC the difference in values is around 5%, 8%, and 8% respectively. This could be attributed to the poor workability and non uniform distribution of steel fiber for higher fiber dosages. But, overall, the numerical results are a good overlap with the experimental values.

5.7.2 Parametric study

The results of the parametric study clearly show that as the embedded length of the anchor bolts in concrete is increased, the force required to breakout the concrete increases as well. The perecntage increase in the breakout strength for 0%, 0.5%, 1%, 1.5% SFRC with 1” increase in the embedded length was recorded to be around 25.5%, 26.5%, 26.6%, 26.5% respectively. This could be attributed to the increased depth of the concrete breakout cone. As the depth of the breakout cone increases, the force required to break the concrete increases as well.

It was also noticed that the diameter of the anchor bolt did not have a significant effect on the breakout strength of the concrete because although increasing the diameter of the anchor bolts increased the surface area of contact between the two materials, it did not affect the concrete cone in any way. The concrete breakout force for 0.75" diameter for 0%, 0.5%, 1% and 1.5% was only about 2.7%, 4%, 3.9%, and 3.1% greater than the concrete breakout strength for 0.5" diameter. This shows that the diameter of the anchor bolt does not have a considerable effect on the concrete breakout strength. These results are validated by the the equation provided in appendix D, ACI 318-08. The equation is as follows,

$$\phi N_{cbg} = \phi \psi_3 24 \sqrt{f_c'}\, h_{ef}^{1.5} \frac{A_N}{A_{No}} \text{ for } h_{ef} < 11 \text{ in.}$$ ---- Eq 5.2

$$\phi N_{cbg} = \phi \psi_3 16 \sqrt{f_c'}\, h_{ef}^{5/3} \frac{A_N}{A_{No}} \text{ for } 25 \text{ in.} \geq h_{ef} \geq 11 \text{ in.}$$ ---- Eq 5.3

Where,

$\Phi = 0.7$

$\Psi_3 = 1.25$ considering the concrete to be uncracked at service loads, otherwise = 1.0

h_{ef} = depth of embedment, in.

A_N = concrete breakout cone area for group, in^2

A_{NO} = concrete breakout cone area for single anchor, in^2

The above equations state how the breakout force for the cocnrete cone is not dependent on the diameter of the anchor bolt. The concrete cone breakout area for a single anchor could be found out using the embedded length as the depth of the embedment and the slope of the cone is assumed to be 1.5:1 according to ACI.

CHAPTER – 6

CONCLUSION

6.1 Conclusion

This research has led to the following conclusions

1. Nonlinear finite element analysis shows a good agreement with the experimental results for the concrete breakout strength.
2. The use of concrete damage plasticity model with both compressive strength and tensile strength of concrete together seems to be the most appropriate for simulation.
3. The SFRC post cracking behaviour can be successfully modeled and simulations were performed using nonlinear finite element analysis.
4. As the steel fiber dosage in the concrete is increased from 0% to 0.5%, 1%, 1.5%, the concrete becomes stiffer and can take more load in tension and compression. The concrete cone breakout strength increases from 9506lbs to 14005lbs, 17539lbs, and 18267lbs for SFRC 0%, 0.5%, 1%, 1.5% respectively.
5. The grouping effect of anchor bolts reduce the load carrying capacity of the system as compared with two single anchor bolts of same strength and diameter. The grouping effect factor for SFRC 0%, 0.5%, 1% and 1.5% are 0.8, 0.82, 0.84, 0.84 respectively.
6. The parametric study shows that the concrete breakout strength increases with an increase in the embedded length of the anchor bolt. A percentage increase of 25%, 26.6%, 26.7% and 26.5% in the concrete breakout strength was calculated for SFRC 0%, 0.5%, 1%, 1.5% respectively, when the embedded length of the anchor bolt was increased from 2.5” to 3.5”.
7. Although increasing the diameter of the anchor bolt increased the concrete breakout strength of concrete, it did not have a sizeable effect. The value of the breakout strength

increased about 2.7%, 4%, 3.9%, and 3.1% for SFRC 0%, 0.5%, 1%, 1.5% respectively, when the diameter of the anchor bolts was increased from 0.5” to 0.75”.

6.2 Recommendation for future work

1. Perform numerical analysis to study the behavior of anchor group effects under lateral forces, i.e, the shear analysis.
2. Perform experimental and numerical analysis on the behavior of anchor groups under cyclic or dynamic loading.
3. Study the behavior of single anchor and anchor groups under impact loading.
4. A study could be performed to find out the anchor group behavior within different materials of fibers in concrete.

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