Load Deformation Characteristics of Normal & Fiber Reinforced Concrete Columns

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ABSTRACT

Although a lot of works has been done in the field of steel fiber reinforced concrete beam-column joints, slab-column connections, etc. under lateral cyclic loading which represents earthquake and wind forces, a few studies exist that peruse monotonic lateral loading. It is important to determine deformation characteristics of structural elements under monotonic lateral loads in building; meanwhile they are reinforced with both steel bars and hooked end steel fibers.

This thesis tries to find some answers to prediction of effects of steel fibers in deflection of reinforced concrete columns. Therefore, columns have been designed both with normal and fiber reinforced concrete, then lateral displacement versus load behavior has been observed. A test setup was designed and built based on similar tests conditions. Two hydraulic jacks were used to apply lateral and vertical loads simultaneously. The axial load that was applied was almost 300 kN and the lateral load was increasing monotonically. The loading was performed manually and data was recorded by a digital data logger using measurement devices such as LVDTs, strain gauges, and load cells.

As was expected, the test results showed a considerable increase in displacement of fibrous columns in comparison to non-fibrous one, which demonstrated clearly that presence of hooked-end steel fibers increase the displacement capacity of reinforced concrete columns under axial and lateral loads as was expected from all other structural members containing the steel fibers. Steel fibers also reduce cracks in columns surface, and prevent cracks from getting wide during the loading and until the crushing.

Keywords: Concrete columns, deformation characteristics, lateral loading, steel fibers.

ÖZ

Deprem ve rüzgar yükü altında çelik elyaflı betondan yapılmış kiriş-kolon ve plaka-kolon bağlantı noktalarının davranışını çalışan çok sayıda araştırma olmasına rağmen bu sistemlerin iç dinamik yükler altındaki davranışı pek çalışılmamıştır. Bundan dolayı binalardaki bu sistemlerin yatay depremsel yükler altındaki monotonic yatay deformasyon davranışlarının ölçülmesi çok önemlidir. Deneye tabii tutulan bu sistemler hem normal beton çeliği ile hem de çelik elyaf ile üretilmiştir.

Bu çalışmada çelik elyaf katılan betonarme kolonların yük altındaki davranışlarına etkisi araştırılmıştır. Bundan dolayı üretilen kolonlar hem normal beton çeliği ile hem de çelik elyaf katılarak yapılıp deneye tabii tutulmuştur. Üretilen sistemler düşey yükleme sırasındaki deplasmanı ölçülmüş ve karşılaştırılmıştır. Hazırlanan deney düzeneği ile bir düşey bir de yatay yük verebilecek şekilde iki adet hidrolik yükleyici kullanılmıştır. Düşey yük yaklaşık olarak 300 kN yüklendikten sonar yatay yüklemeye geçilmiştir. Manuel olarak yapılan yükleme sırasında deformasyonlar çeşitli noktalardan elektronik olarak ölçülmüştür.

Tahmin edildiği üzere deney sonuçlarına bakıldığı zaman yüklemeler sırasında çelik elyaf donatılı olan sistemin deformasyonunun normal demir donatılı betonarme sistemden daha az olduğu gözlemlenmiştir. Ayrıca meydana gelen çatlak genişliklerinin de normal demir donatılı betonarme sistemlerde nazaran çelik elyaflı sistemde daha az olduğu görülmüştür.

Anahtar Kelimeler: Yatay yük, çelik elyaf, beton kolon, deplasman karakteri.

Dedicated to

My Lovely Mother & My Dear Father

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Chapter 1

INTRODUCTION

1.1 General

The use of discontinuous discrete fibers in reinforced concrete elements can improve many properties of reinforced concrete elements. Fibers can be mixed with concrete by different percentages of reinforcement by weight. The addition of fibers in concrete may improve the durability and ductility performance of reinforced concrete elements. The fibers could be different shape, type and amounts depending on the performance requirements and economical aspects.

1.2 Statement of Problem

Although a lot of works has been done before in the field of steel fiber reinforced concrete beam-column joints, slab-column connections, etc. under lateral cyclic loading which represents earthquake and wind forces, a few studies exist that peruse monotonic lateral loading. It is important to determine deformation characteristics of elements under monotonic lateral load in building; meanwhile they are reinforced with both steel bars and steel fibers.

1.3 Objective of This Study

Monitoring the deformation characteristics of reinforced concrete elements including fibers needs more study although there are some works in the literature. Therefore some tests will be carried out on cantilevered columns subjected to lateral loading. The columns will be designed both with normal and fiber reinforced concrete. Lateral displacement versus load behavior will be plotted and compared with the theoretical results.

1.4 Achievements

It is expected that this research will provide information of reinforced concrete elements load-deformation properties by inclusion of hooked end steel fibers in concrete elements having different concrete classes (compressive strength). The amount of hooked-end steel fibers will be two different percentages by volume of concrete.

1.5 Conceptual Definitions

The amount of hooked-end steel fibers is the main variable parameter in this study, with two different percentages: 1 percent and 1.5 percent by the volume of concrete, with the same aspect ratio, which is 60.

1.6 Works Done

In addition to literature review about fibers, reinforced concretes, and fiber reinforced concretes, a considerable survey has been done in literature about lateral loading setup and the setup was installed in the inspiration of them. Trial mixes were made to determine the best mix design of concrete with 0, 1, and 1.5 percent of steel fibers. The columns and the footings were designed by CSI SAP2000 software version 15 to carry specific vertical load while lateral load is increasing. From each percentage of fibers including reinforcing steel bars, one specimen containing one column based on one footing was built. Curing procedure was done, and after performing the tests, deformation behavior of specimens was observed and discussed.

1.7 Guide to Thesis

In Chapter 2, background and literature review will be explained.

Chapter 3 describes methodology, experimental work and tests.

Results and discussion are in Chapter 4.

Chapter 5 contains conclusions and recommendations, and references given at the end.

Chapter 2

LITERATURE REVIEW AND BACKGROUND

2.1 Introduction

Regarding the fact that, plain concrete is brittle and weak in some properties, such as tensile strength, from very long time ago, people started to reinforce concrete in various ways, like reinforcing with steel bars, steel fibers, and recently by some polymers such as carbon and glass sheets.

2.2 Reinforced Concrete (RC)

Reinforced concrete is concrete mixed with some strong material to improve the tension strength and some other characteristics. The development of reinforced concrete made a revolution in building design industry. There are some materials to reinforce concrete with, but steel bars are the most common reinforcing material.

Reinforcing material must be carefully designed because if it is not reinforced enough, the concrete can be weak and subjected to failure. On the other hand, loading concrete too heavily with reinforcing material can make it inflexible and brittle due to reduction in ductility.

2.3 Fiber Reinforced Concrete (FRC)

Fiber reinforced concrete (FRC) is concrete with fine or coarse and fine aggregate with hydraulic cement, and discontinuous discrete fibers (ACI 544.1R).

There are many different types of FRC, using different fibers such as natural fibers like coconut leafs, bamboo, glass, polyester, asbestos, and steel fibers (Figure 2-1).

Fibers are described by aspect ratio, which is defined as the length of fiber divided by equivalent fiber diameter.

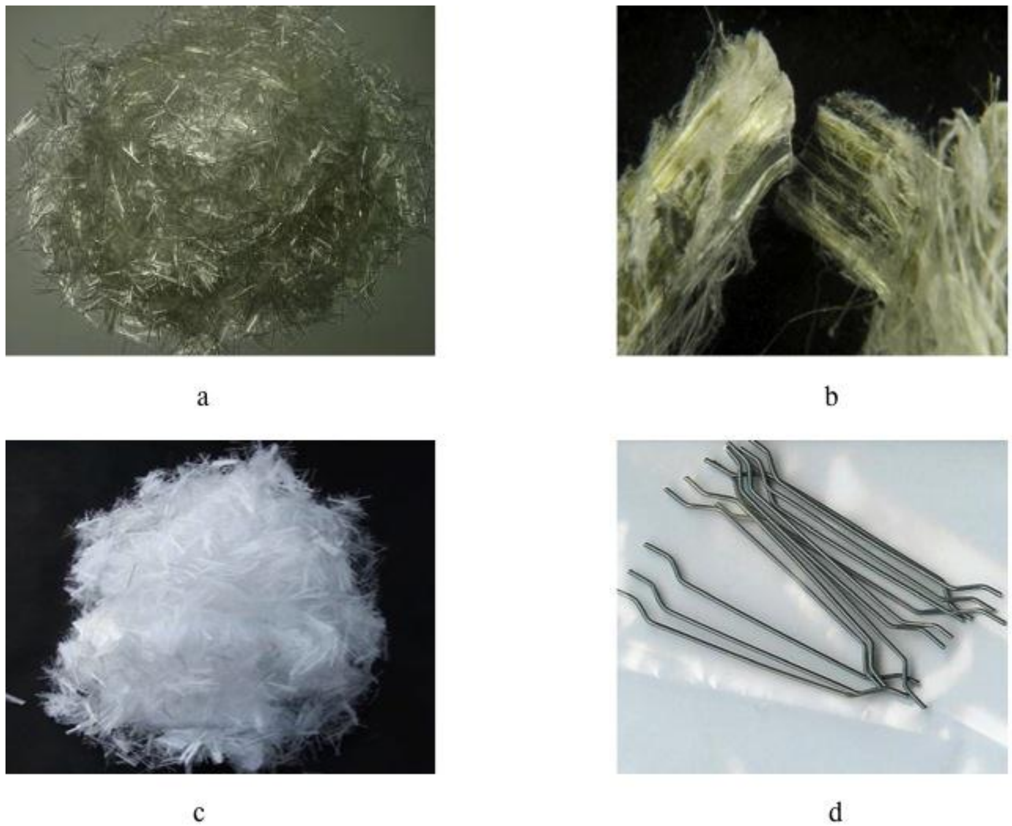


Figure 2-1: a) Glass fibers. b) Asbestos fibers. c) Polyester fibers. d) Steel fibers (Mehta & Monteiro, 1993).

2.3.1 Steel fibers reinforced concrete (SFRC)

Adding discontinuous steel fibers to reinforcing concrete remedy some of the concerns about brittleness and poor resistance to crack growth. After cracking, the fibers between two crack faces arrest the cracking and provide a mechanism that decreases the unstable propagation of the crack (Banthia & Sappakittipakorn, 2007).

To bridge the large number of micro cracks in concrete under load and to prevent large strain localization, it is needed to have a large number of short fibers. The uniform distribution of short fibers can increase the strength and ductility of the composite (Figure 2-2a).

Long fibers are needed to bridge discrete macro cracks at higher loads, however volume fraction, which is defined as the volume of a constituent divided by the volume of all constituents of the mixture prior to mixing, of long fibers is much smaller than short fibers (Figure 2-2b), (Mehta & Monteiro, 1993).

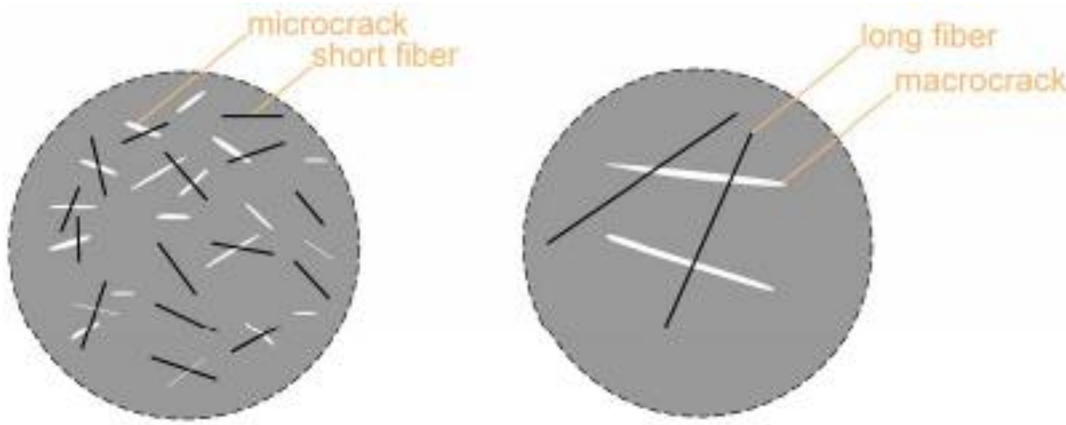


Figure 2-2: a) Effect of short fibers on micro cracking. b) Effect of long fibers on macro cracking (Mehta and Monteiro, 1993).

2.3.1.1 Classification of discontinuous fibers

Typical profiles of steel fibers that commonly used in SFRC are shown in Figure 2-3.

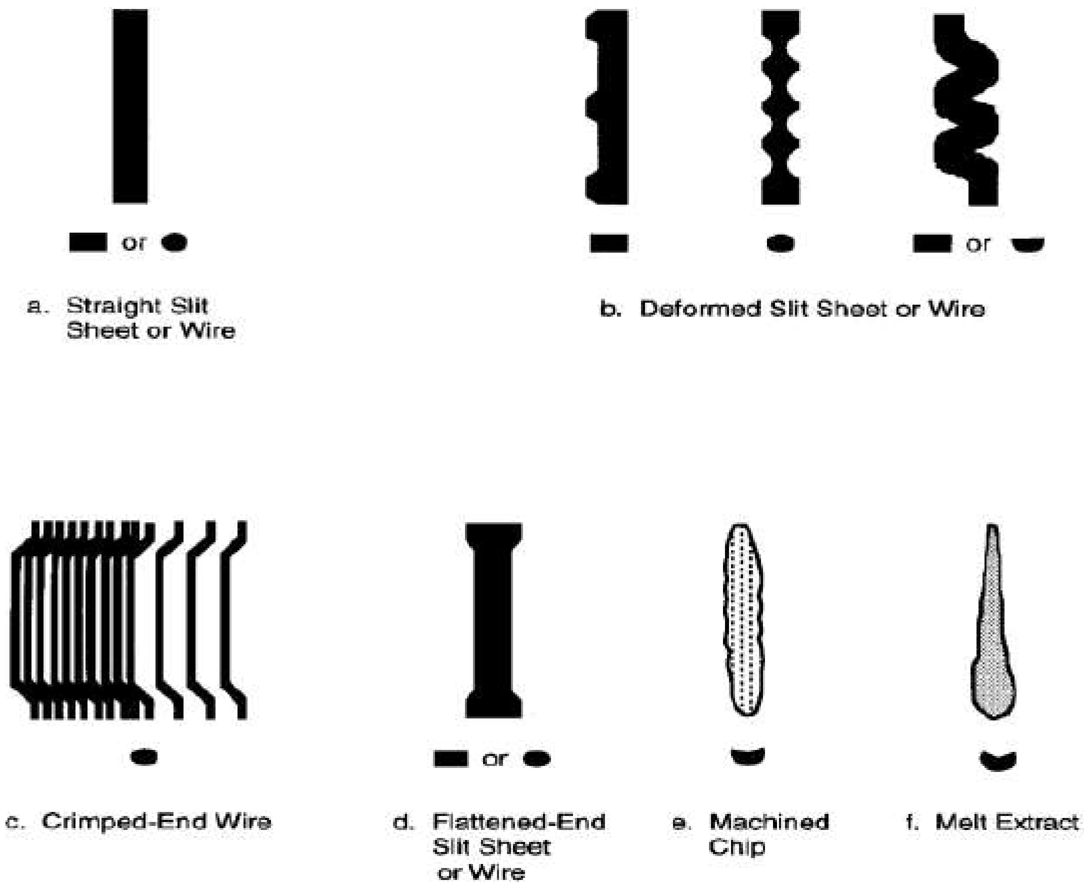


Figure 2-3: Typical profiles of steel fibers that commonly used in SFRC (ACI 544.1R).

Most of steel fibers that are common have round cross-section, with a range of diameter from 0.4 to 0.8 mm, and their aspect ratio is generally less than 100, usually between 40 and 80 (Namman, 2003).

2.3.1.2 Application of steel fiber in reinforced concrete

The fiber volume fraction (V_f) in typical fiber reinforced concretes application is briefly shown in Table 2-1.

Table 2-1: Range of volume fraction of fibers for typical SFRC (Namman, 2003).

Material	**Range of V_f**	**Remark**
Fiber reinforced concrete	$V_f \leq 2\%$	Fibers are premixed with the concrete matrix. Finer aggregates may be needed.
High performance fiber reinforced concrete	$V_f \geq (V_f)_{critical}$ $V_f \geq 1\%$	Strain hardening and multiple cracking characteristics in tension. With proper design, critical V_f can be less than 2%.
Shotcrete (steel fibers)	$V_f \leq 3\%$	Applications in tunnel lining and repair.
Spray Technique (glass fibers)	$4\% \leq V_f \leq 7\%$	Application is cladding and panels
SIMCON (steel fibers)	$4\% \leq V_f \leq 6\%$	Slurry Infiltrated Mat Concrete. A prefabricated fiber mat is needed
SIMCON (PVA fibers)	$V_f \approx 1\%$	Recently available
SIFCON (steel fibers)	$4\% \leq V_f \leq 15\%$	Slurry Infiltrated Fiber Concrete. Fibers are preplaced in a mold and infiltrated by a fine cementitious slurry matrix

2.3.1.3 Mechanical and physical properties of SFRC

2.3.1.3.1 Compressive strength, modulus of elasticity, and Poisson's ratio

Using steel fibers in concrete increases the compressive strength, modulus of elasticity, and Poisson's ratio, which is ratio of the lateral strain to the vertical strain, less than 10 percent, that is quite small amount, however it increases the tensile strength of concrete considerably (ACI 544.1R).

2.3.1.3.2 Modulus of rupture and strain corresponding

Steel fibers increase the modulus of rupture of the concrete about 40 percent that justifies adding fiber in concrete primarily. The post cracking response is significantly enhanced.

The strain corresponding increases to the peak compressive strength is about 30 percent by presence of fibers in concrete. Enhanced peak strain capacity is another important benefit derived for using the fibers (Thomas & Ramaswamy, 2007).

2.3.1.3.3 Flexural fatigue strength

Based on experimental studies, there is considerable increase in flexural fatigue strength while the percentage of steel fiber is increasing (ACI 544.1R) (Kormeling & Reinhardt, etc.1980).

2.3.1.3.4 Flexural strength

Previous data shows that SFRC has 50 to 70 percent more flexural strength in comparison with unreinforced concrete in the normal third-point bending test (ACI 544.1R) (Johnston, 1974).

2.3.1.3.5 Thermal conductivity

There is small increase in thermal conductivity of steel fiber reinforced concrete with using 0.5 to 1.5 percent fibers by volume of concrete (ACI 544.1R) (Cook & Uher 1974).

2.3.1.3.6 Creep and free shrinkage behavior

Presence of less than 1 percent of fiber has not major effect on the creep and free shrinkage behavior of concrete (ACI 544.1R) (Grzybowski & Shah, 1990).

2.3.1.3.7 Abrasion resistance

Generally, abrasion resistance that relates to slab wear and pavement under wheeled traffic is unaffected by using steel fibers in concrete (ASTM C779-procedure C) (Nanni, 1988).

2.3.1.3.8 Friction and skid resistance

The friction and skid resistance of a surface made by SFRC is about 15 percent higher than plain concrete surface in frozen, wet, and dry surface conditions (ACI 544.1R).

2.3.1.3.9 Shear strength

It was found that, steel fiber increases the shear capacity of concrete expressively. (Presence of 1 percent by volume of hooked-end steel fibers increases the shear strength of steel fiber reinforced concrete about 144 to 210 percent in comparison to plain concrete) (Khaloo & Kim, 1997, Jindal, 1984).

2.3.1.3.10 Durability

Due to the effect on alkali-acid reaction, freezing and thawing characteristics, reinforcement corrosion, resistance to chloride of sulphate attack, and leaching characteristics, porosity and permeability are the main factors that affect on durability of concrete (Ramakrishnan, 1985).

SFRC mixes have high permeability and porosity, hence apart from corrosion of steel fibers, SFRC has the same durability of plain concrete (Hoff, 1987).

According to previous studies, un-cracked steel fiber reinforced concrete specimens, in a long time period in marine environment, had no corrosion of fibers, unless limited to their surfaces, but in cracked specimens corrosion has occurred through the crack depth, and it caused reduction on flexural strength (Schupack, 1985).

Exposure tests have shown that, generally for freezing and thawing resistance, SFRC must be air-entrained (ACI 544.1R) (Balaguru & Ramakrishnan, 1986).

2.3.1.3.11 Shrinkage cracking

The tendency for cracking is common, because of the fact that concrete is almost always restrained. In this situation steel fibers play three roles: (1) allow tensile stresses to transfer across cracks, (2) allow multiple cracking to happen, (3) stress transfer can occur for a long time, permitting healing/sealing of cracks (Hoff, 1987) (Swamy & Stavrides, 1979).

2.4 Lateral Loads

Lateral loads are loads whose main component is horizontal force acting on the structure. Typical lateral loads would be a wind load against a facade, an earthquake, the earth pressure against a beachfront retaining wall or the earth pressure against a basement wall.

2.5 Literature Review

To consider the structural safety, both strength and ductility are in the same importance. The design methods are developed from many tests within the quantifying the deformation capacity of elements under flexure, for monotonic and also cyclic loads.

Generally speaking, the aim of the studies that focus on monotonic loads is to investigate the capacity of the force redistribution for vertical and horizontal combinations of loads. Although there are several studies in literature about cyclic loads, monotonic load studies are much fewer. To bridge this lack, some studies have been done to investigate deformation capacity of reinforced column under axial and lateral forces (Barrera, Bonet, Romero & Miguel, 2011).

In another study, behavior of high-strength FRC column-slab connection under gravity and lateral loads was perused and it was found that the ultimate deflection of high-strength concrete column-slab connection was larger than normal strength concrete by 14 to 185 percent, and also the displacement for high strength concrete specimens were larger than normal strength concrete by 11 to 64 percent (Samdi & Bani Yasin, 2007).

There are several works with high performance steel fiber reinforced concrete (HPFRC) in literature. In 2005, “Shannag, Abu-Dyya, etc.” made several specimens containing different amount of brass-coated (BCSF) or hooked-end steel fibers (HSFC) and studied the lateral load response of reinforced concrete beam-column joints, but again cyclic load were applied, moreover the high percentages of fiber were used (2 to 4 percent), that it is not workable. Hence, there is a gap for a load-deformation study of fiber reinforced concrete columns under axial and monotonic loads. This thesis tries to bridge this gap.

Chapter 3

EXPERIMENTAL WORKS

3.1 Introduction

A total of three specimens that were designed by CSI SAP2000 software version 15 to carry simultaneously 300 kN of axial load and increasing monotonic lateral load, each including a column based on a footing, reinforced by steel bars, and containing steel fibers of 0, 1, and 1.5 percent by volume of concrete were made.

Portland cement, crushed lime stone aggregate (fine and coarse), super plasticizer and steel fibers with aspect ratio 60 were used in laboratory to make steel fiber reinforced concrete mixes. To evaluate the workability of fresh mixes, slump test was done for plain concrete and for fibrous concrete, VeBe time test was performed, and other tests such as compressive strength on cubic specimens was done after 28 days curing, and also after tests one core from each specimen were taken.

According to the sizes of designed specimens, one wooden formwork for each column and each footing were made, and the same formworks were used for next specimens too.

3.2 Mixes and Material Details

3.2.1 Information of the cement

In this study, CEM II/B-M (S-L) 32.5 R type cement according to EN 197-1was used. The details and compositions of this cement are shown in Table 3-1.

Table 3-1: The compositions of CEM II/B-M (S-L) 32.5 R

Compositions	66% Portland cement brick 17% Granulated blast furnace slag 11% Limestone low toc 6% natural anhydrite
Principal properties	The cement quality CEM II/B-M (S-L) 32.5 R is ground to moderate fineness, which allows using it in the manufacture of normal quality concrete.
Fields of application	The cement quality CEM II/B-M (S-L) 32.5 R is recommended in the manufacture of lean concrete and ordinary concrete used on site.
Initial setting time (minutes)	225
Final setting time (minutes)	345
Specific weight (gr/cm^3)	3.23

3.2.2 Information on aggregates

All of the aggregates used in this study were local crushed limestone with maximum size of 20 mm. The fine and coarse aggregate grading was satisfying the ASTM standard (ASTM C 33, 2008). Table 3-2 shows the aggregate properties. Details of the sieve analysis for coarse and fine aggregates are given in Table 3-3 and Table 3-4, respectively. The grading curve of coarse aggregates is in Figure 3-1, and the grading curve of fine aggregates is in Figure 3-2 according to the standard (ASTM C 33, 2008).

Table 3-2: The properties of fine and coarse aggregates

Properties	**Standards**	**Fine aggregate**	**Coarse aggregate**
Relative density	(ASTM C 127, 2007) (ASTM C 128, 2007)	2.65	2.7
Water absorption (% of dry mass)		2.59	0.6
Dust content (%)	(ASTM C 117, 2004)	16.9	4.7

Table 3-3: Sieve analysis data for coarse aggregate

Sieve size (mm)	**Percentage passing of coarse aggregate (by weight)**
25	100
19	91
9.5	51
4.75	11
2.36	2
1.18	0

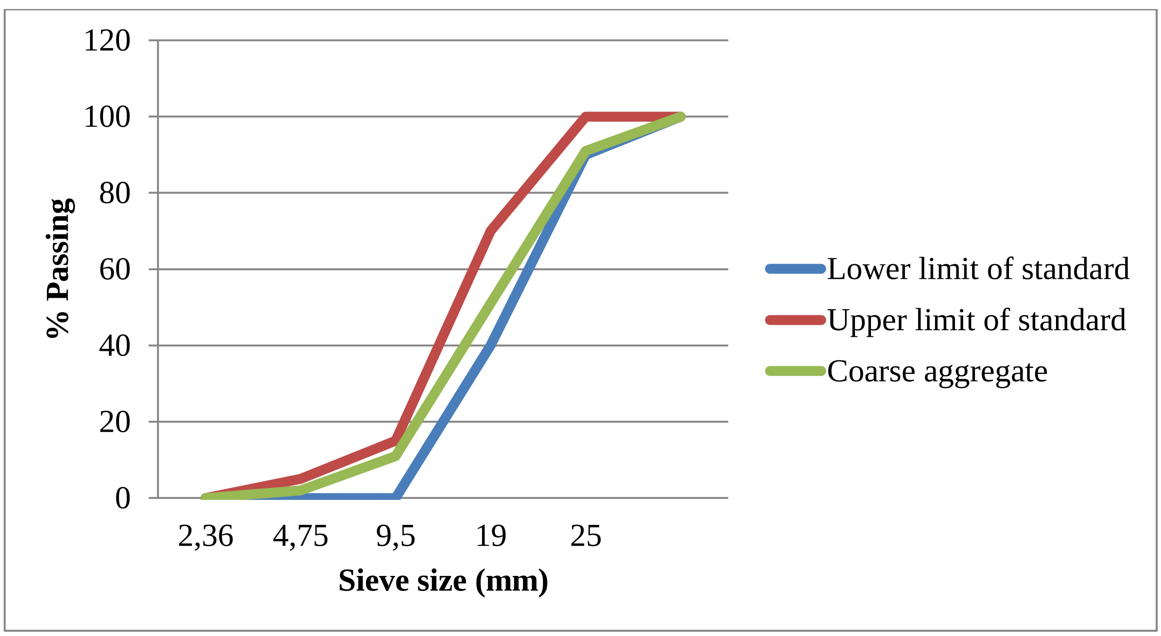


Figure 3-1: Particle size distribution of coarse aggregates

Table 3-4: Sieve analysis data for fine aggregate

Sieve size (mm)	Percentage passing of fine aggregate (by weight)
4.75	100
2.36	89
1.18	66
0.6	40
0.3	22
0.15	8

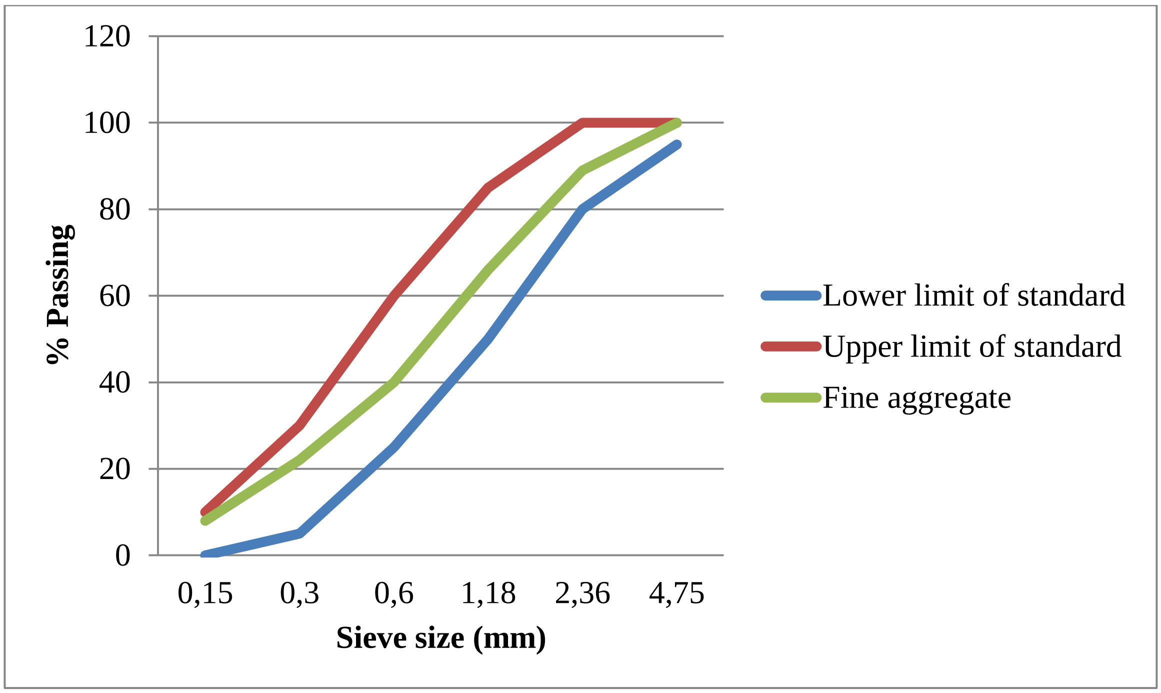


Figure 3-2: Particle size distribution of fine aggregates

3.2.3 Mixing water

The mixing water that was used for mixing the concrete was at drinking quality.

3.2.4 High range water reducer (superplasticizer)

To enhance the workability of concrete mixes a high range water-reducing admixture (Glenium 27 as super plasticizer) was used. The properties of Glenium 27 are given in Table 3-5.

Table 3-5: Properties of Glenium 27 (Keikhaei, 2012).

Product Information	
Color/appearance	Brown liquid
Storage condition/shelf life	Store in reasonable temperature above +5°C in closed packs. Recommended to store in unopened containers up to 12 months under manufacturer's instructions.
Packing	Available in 200-liter drums, 1000-liter gallons and bulk.
Product technical information	
Chemical base	Based on a unique carboxylic ether polymer with long lateral chains.
Application information	
Dosage	0.4-1.6 liters per 100kg of cement is recommended. The dosage rate also depends on mix design and other requirements.
Application notes	Should be added to the concrete mix after 50-70% of water is added. It should be added carefully for a complete dispersion during the mix. Should not be added to the dry aggregates.
Features and Benefits	Having concrete with good workability and no segregation with the lowest w/c ratio. Excellent slump retention without retardation. Reduce the curing cycle. Reducing the vibration time even in case of congested steel reinforcement. Developing the surface and quality of finished concrete. Gelenium 27 has more benefits than old Superplastisizer, adding it to the mix will improve concrete durability and physical properties. Decreases the risk of shrinkage

3.2.5 Steel fibers information

The hooked-end steel fibers with the same aspect ratio equal to 60 were used in this investigation.

3.2.6 Steel bars information

Table 3-6 shows the information of three steel bars due to the tension test.

Table 3-6: Mechanical properties of steel bars

Specimen number	**Yielding Strength MPa**	**Ultimate Strength MPa**	**Strain %**
1	420.70	581.90	22.77
2	450.18	605.49	20.56
3	456.08	605.49	21.67
Average	442.32	597.63	21.67

3.3 Mix Design Details for Concrete

The concrete mixes in this study were designed according to the standard (BRE 331, 1988). All of the three mixes were the same and only the percentages of steel fibers by volume of the concrete were different. In Table 3-7, the details of mix design are shown, and Table 3-8 shows the amount of steel fibers for each of two SFRC mixes.

Table 3-7: Mix design details

	Cement	Water	Fine Aggregate	Coarse Aggregate			Super plasticizer
				10mm	14mm	20mm	
Per m^3 of concrete	450 kg	225 kg	776 kg	380 kg	362 kg	207 kg	22.5 kg

Table 3-8: Amount of steel fibers in SFRC mixes

Fiber (%)	Per m^3 of concrete (kg)
1.0	78.50
1.5	117.25

3.3.1 Control mix compressive strength

From each percentage of steel fibers, three 150 mm size cubic specimens were made.. At the end of the tests, one core was taken from each specimen. Diameter of core cylinders was 10 cm and length of cylinder was 25 cm. Figure 3-3 shows the core taking of specimens after main test.

a b

Figure 3-3: a) Taking cores from specimen. b) The cylinder core

3.4 Details of Specimens

The column cross-section was 25 cm × 25 cm and the height of the column was 1 meter, meanwhile the footing's cross-section was 50 cm × 50 cm and footing's length was 150 cm, and the columns and the footings were reinforced by steel bars. Reinforced cross sections are shown in Figure 3-4 and Figure 3-5.

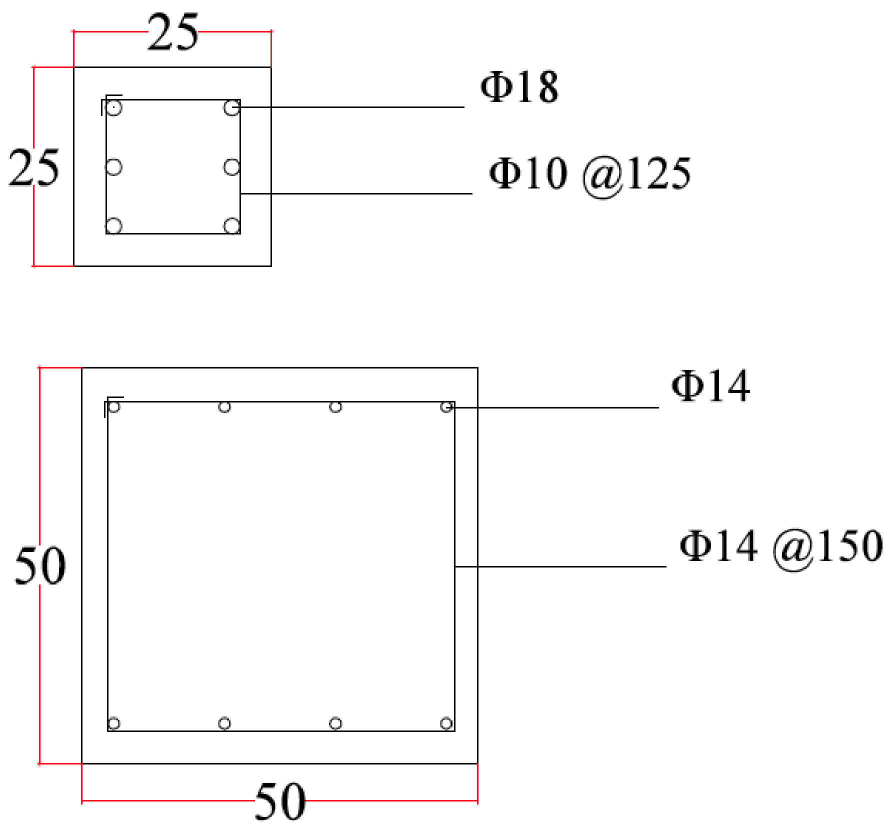


Figure 3-4: Reinforced concrete column and footing cross sections

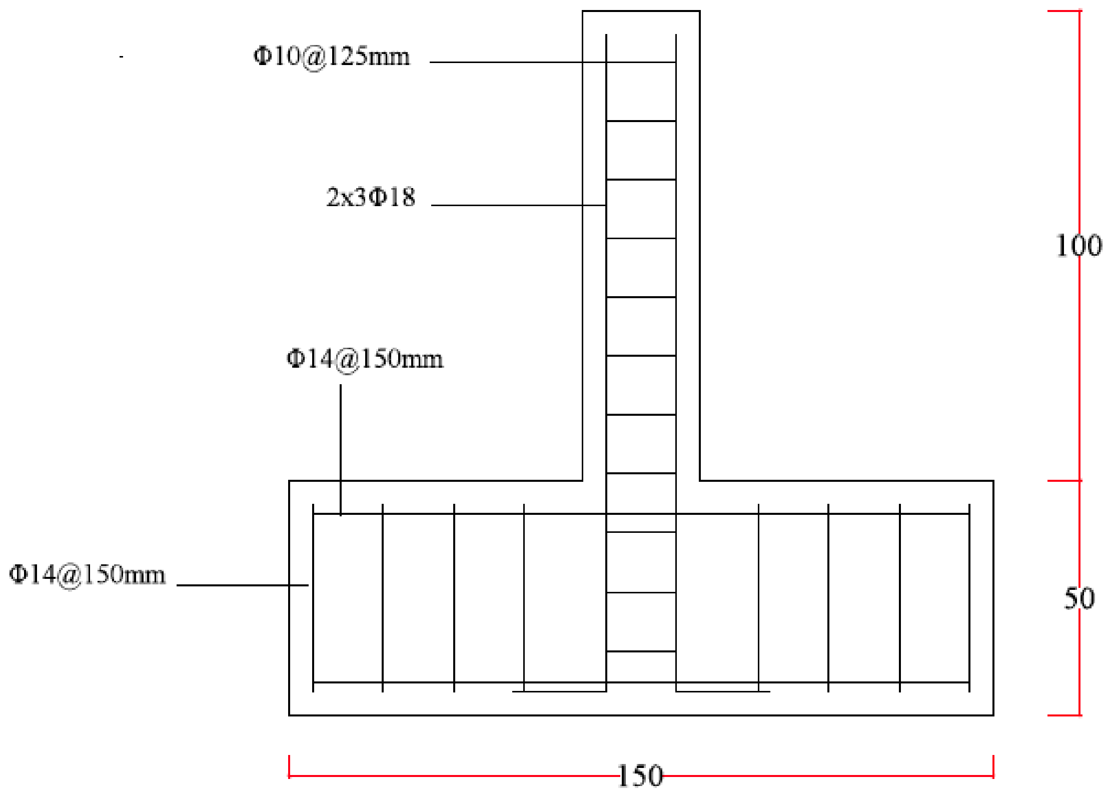


Figure 3-5: Details of specimens and reinforcements

3.5 Reinforcement process

Initially, each specimen had to be reinforced. As it was mentioned before, Φ18 and Φ14 steel bars were used to reinforce columns and footings, respectively. First, steel bars had to be cut. After that steel bars were bent according to design and drawing of specimens, and finally bent steel bars were joined together by using thin steel wires.

Figures 3-6 to 3-10 show the reinforcement process.

Figure 3-6: Cutting the steel bars

Figure 3-7: Bending the stirrups

Figure 3-8: Bent bars and stirrups

a

b

Figure 3-9: a) Fixing the main bars. b) Fixing the stirrups

Figure 3-10: Adjusting the bottom concrete cover

3.6 Formwork process

To create the concrete formworks, timber was used, as it is common in North Cyprus. The same formworks were used to make concrete footings and columns. To support the formworks and prevent the deformation during the concrete pouring, some timbers around the main formwork were used to hold them. Moreover, two plastic pipes and one timber box were used to make bolt places into the footing. Figures 3-11 to 3-17 show the formwork process.

a

b

Figure 3-11: a) Fixing the footing sides. b) Fixing the footing bottom

Figure 3-12: Using corner staples to fix the formworks part

Figure 3-13: Placing the steel bars in the formwork

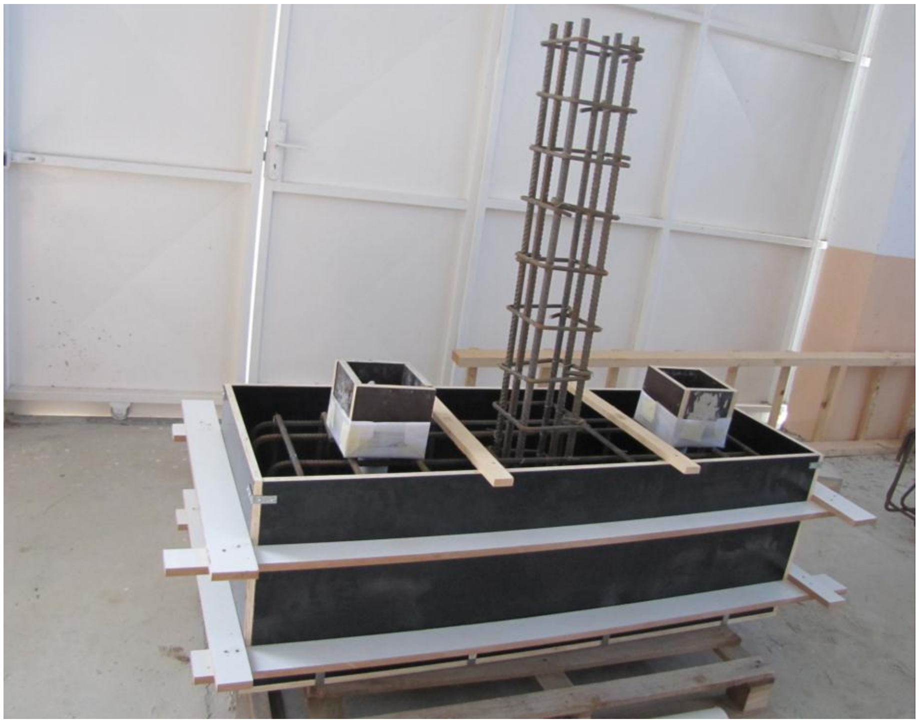


Figure 3-14: Timber supports around the main formwork

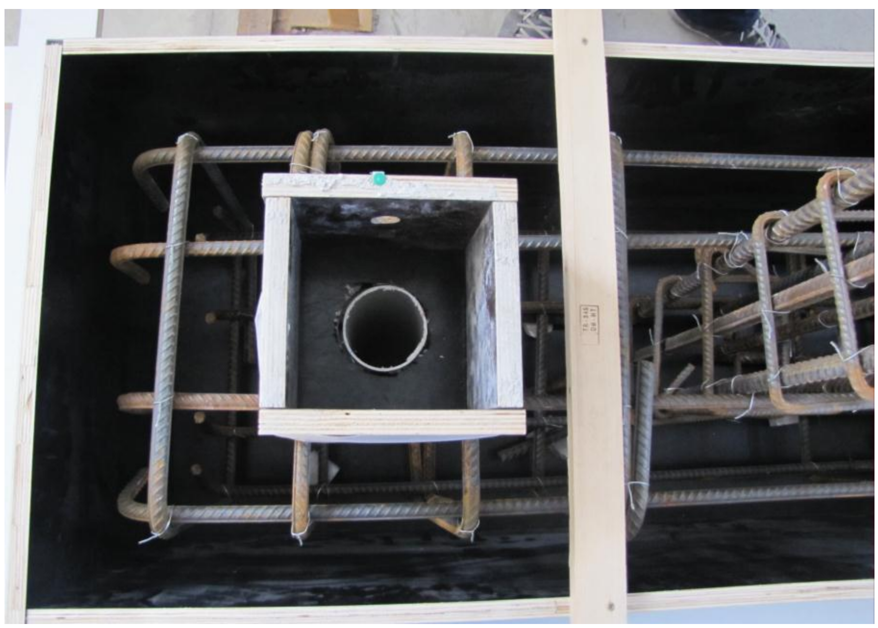


Figure 3-15: Timber box and pipe

a

b

Figure 3-16: a) Fixing the column formwork. b) Supporting column formwork

Figure 3-17: Adjusting the concrete cover for column

3.7 Mixing Process

3.7.1 Preparing the aggregates

Due to the fact that, the existing mixer in laboratory had limited capacity, four batches concrete for each footing were needed. As making the concrete has to be nonstop, aggregates for each batch were first prepared.

3.7.2 Preparing the mixture

For each batch, coarse and fine aggregates, cement, water, steel fibers and super plasticizer were put in the mixer respectively. Steel fibers were added to the mix after that water and superplasticizer were added. Figures 3-18 to 3-20 show this procedure.

a b

Figure 3-18: a) Adding Aggregates. b) Adding cement.

a

b

Figure 3-19: a) Adding water. b) Adding fibers.

a

b

Figure 3-20: a) Adding superplasticizer. b) Final mixture.

3.8 Concrete Pouring Process

3.8.1 Footing

Right after mixing pouring started. A wheelbarrow was used to transfer the concrete from the mixer to the formworks. Almost eight full wheelbarrows were taken to pouring the concrete into the footing formwork.

Vibration was done by electric vibrator during the pouring. Figures 3-21 to 3-24 show the concrete pouring process for footing.

Figure 3-21: Using wheelbarrow to transfer the concrete

a

b

Figure 3-22: a) Transfering the concrete to formwork. b) Pouring the concrete

Figure 3-23: Vibrating the concrete with poker vibrator

Figure 3-24: Finished footing surface

3.8.1 Column

The column concreting process was similar. However, since concrete amount was less than footing, one batch was enough to fill the formwork. Because of the high height of pouring, the procedure was done carefully to avoid the segregation. Figure 3-25 shows the concrete pouring for column.

a

b

Figure 3-25:a) Pouring the concrete. b) Column inside view

A long steel bar was used to vibrate the lower half of the column and an electric vibrator was used for the rest of the column. Figure 3-26 shows the vibration stages.

a

b

Figure 3-26:a) Vibrating by steel bar. b) Vibrating by electric vibrator

3.9 Curing Process

After concrete was poured, the surfaces of footing and column were covered by thick nylons. After 24 hours, when formworks were removed specimens got wet every two days until 28 days of curing was finished. Figure 3-27 shows a specimen after removing the formworks. Curing process is shown in Figures 3-28 and 3-29.

Figure 3-27: After removal of the formworks

Figure 3-28: Covering the concrete surface

Figure 3-29: Curing the specimens

3.10 Test Setup

Two hydraulic jacks were used to load the column in axial and lateral directions. The 500 kN axial hydraulic jack was fixed to a large frame. The frame was fixed to the ground, and the 1000 kN lateral hydraulic jack was fixed to a steel plate. The steel plate was fixed to a concrete wall.

Since after loading, the column movement in lateral direction was expected, each of hydraulic jacks had a pin connection in the surface of specimen that they were loading to. It gave them the ability to keep the loading perpendicular to the column surface.

To measure the applied load by each hydraulic jack, the load cells were used between the pins and the plates, which were grabbing the column surface. Figure 3-30 shows the details of steel base plate, Figure 3-31 shows pin connections details, and Figure 3-32 shows the whole setup.

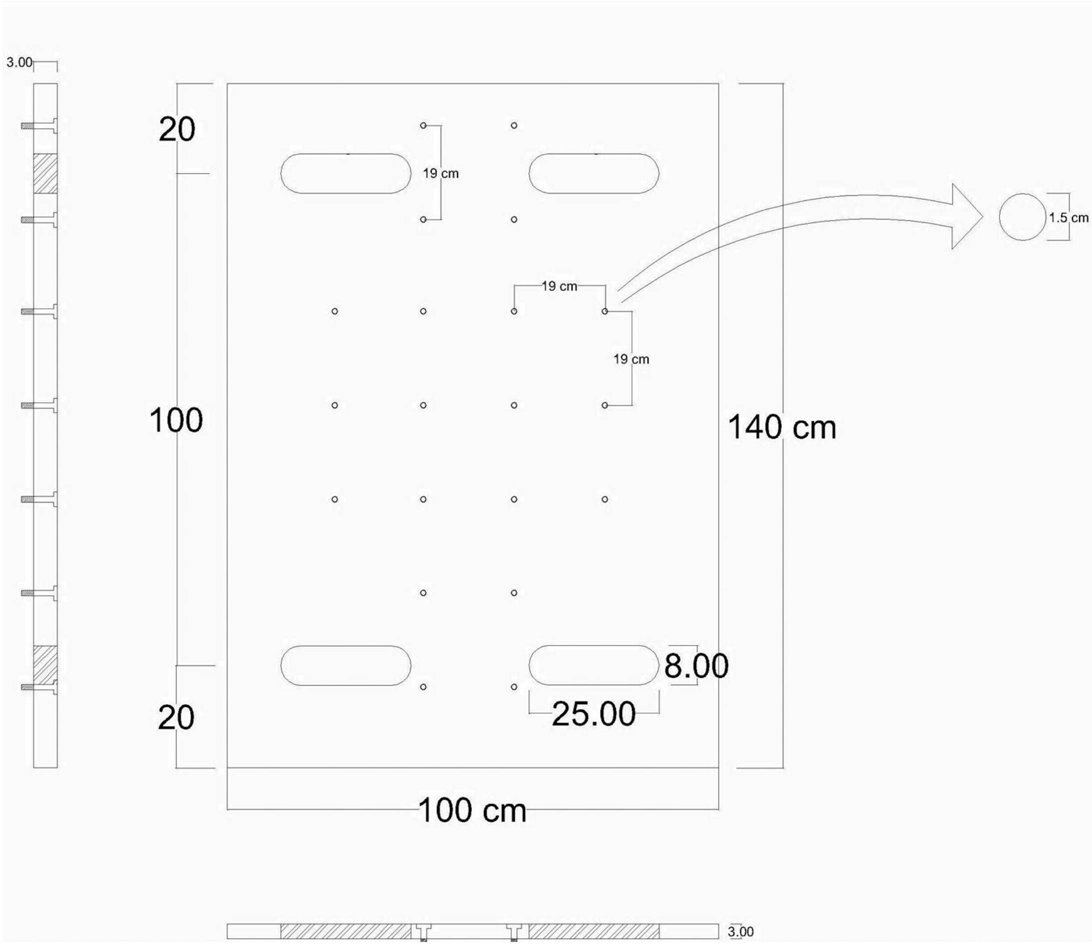


Figure 3-30: Steel base plate details

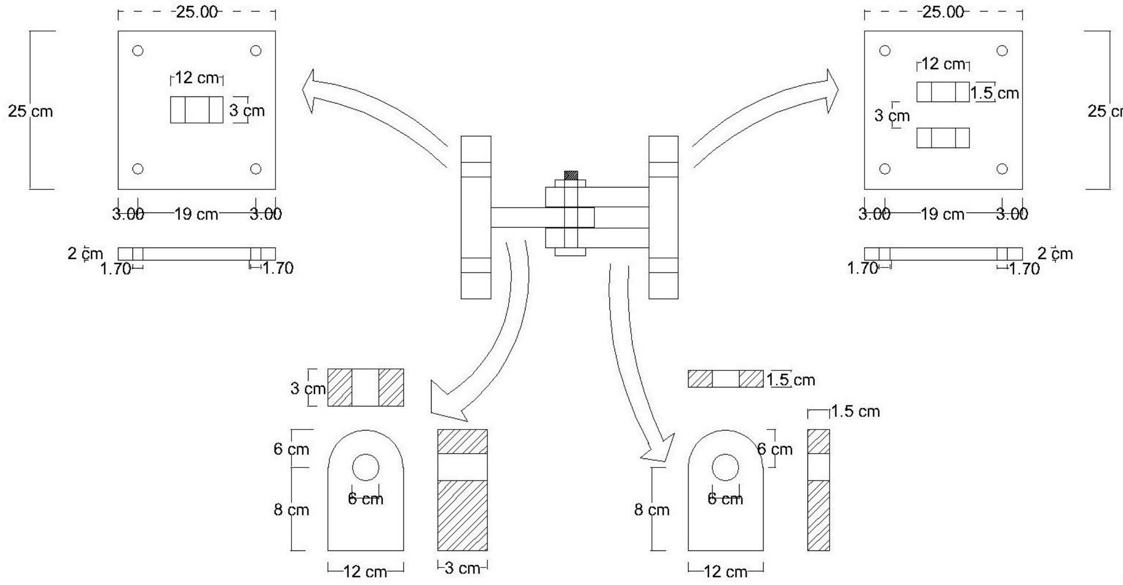


Figure 3-31: Pin connections details

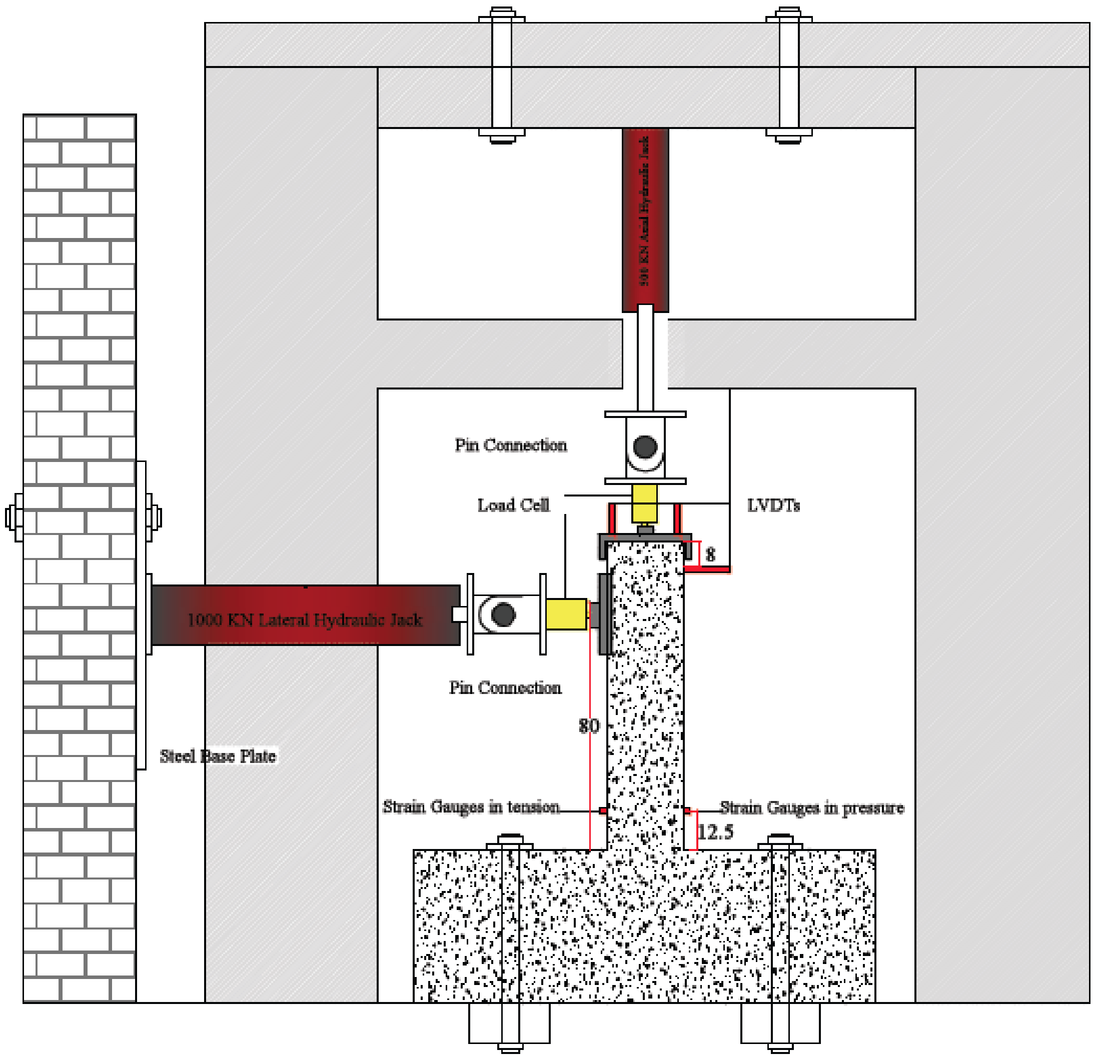


Figure 3-32: Setup details and measurement devices location

3.10.1 Preparing the test setup

To prepare the test setup, some steel parts were needed. The EMU Mechanical Engineering Department Workshop was the place where these parts were prepared.

Figures 3-33 to 3-35 show the procedure of preparing the test setup in the Mechanical Engineering workshop.

a b

Figure 3-33: a) Making holes in the main steel base plate .b) Making holes in other steel plates

a b

Figure 3-34: a) Hole making for pin connections .b) Adjusting pin connection pieces

a b

Figure 3-35: a) Fixing initial base plate for lateral hydraulic jack. b) Connecting head plate for lateral load cell

3.10.2 Installing the test setup

As soon as the setup became ready, the procedure of installing started in the Civil Engineering Department laboratory. Figures 3-36 and 3-37 show the installation steps.

a b

Figure 3-36: a) Moving the base plate. b) Fixed base plate

a b

Figure 3-37: a) Moving lateral hydraulic jack by a loading machine. b) Adjusting a specimen to the ground bolts by crane

3.10.3 Measurement devices

TDS-303 data logger was used to record the deformation data needed. There were four strain gauges in half-bridge situation on each specimen and two of them were for tension side of column and others were for compression side.

The location of measurement devices is shown in Figure 3-38.

3.11 Tests Process

For the first specimen that was the reinforced concrete without steel fibers, after fixing the specimen to the ground by tightening two bolts in footing, the test was started. Initially the axial load was applied and after reaching to the maximum axial load, lateral loading was gradually applied and test was completed.

For the second specimen, which was reinforced concrete with 1 percent of hooked end steel fibers, test was done like the first test. Although, due to the large displacement of second specimen that caused some problems in the axial hydraulic jack connection, for the third specimen, axial load was removed, and test was performed only by applying lateral load. Figures 3-39 to 3-41 show the test process.

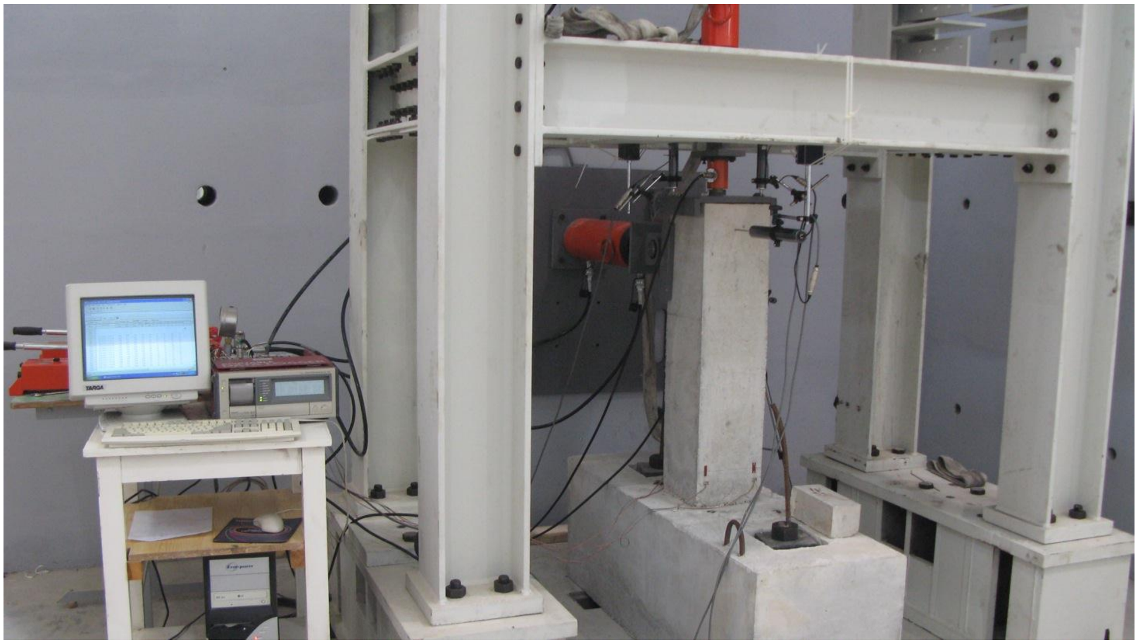


Figure 3-38: The test setup with data logger

Figure 3-39: Tension side view of column under lateral and axial loading

Figure 3-40: Applying loads manually and recording data with data logger

Figure 3-41: Hydraulic jacks with manual function

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Workability Tests

The slump and VeBe test were done on fresh mixes to evaluate workability of concrete with and without fibers. Slump for plain concrete was 12 cm. Table 4-1 shows the results of VeBe tests on fibrous concrete mixes.

Table 4-1: Results of VeBe test on fibrous concrete mixes.

Concrete mix	**VeBe time (sec)**
1.0% SFRC	12
1.5% SFRC	14

4.2 Compression Test

4.2.1 Cubic samples

Cubic samples had been tested after 28 days curing in water. Table 4-2 shows the results of compressive strength test on 28 days aged cubic samples.

Table 4-2: 28 days compressive strength test result

Specimen	**Average compressive strength (MPa)**
Plain concrete	40.7
1.0% SFRC	44.5
1.5% SFRC	43.3

4.2.2 Core samples

To find out the exact compressive strength of specimens on the test days, one core sample was taken from each column. Table 4-3 shows the result of compressive strength test on core samples.

Table 4-3: Results of compressive strength test on core samples (converted to cube strength)

Specimen	**Compressive strength (MPa)**
Plain concrete	50.1
1.0% SFRC	45.4
1.5% SFRC	44.1

Results of compressive strength tests on core samples are converted from cylinder to cubic samples. Results show that due to vibration difficulties of FRC in columns, the fibrous specimens had more voids. Besides, however the test days was almost 4 months after casting, there was a low increases in compressive strength of the core samples in comparison with the cubic samples. It could be because of different curing conditions as well. Figure 4-1 shows the compressive strength comparison for core samples.

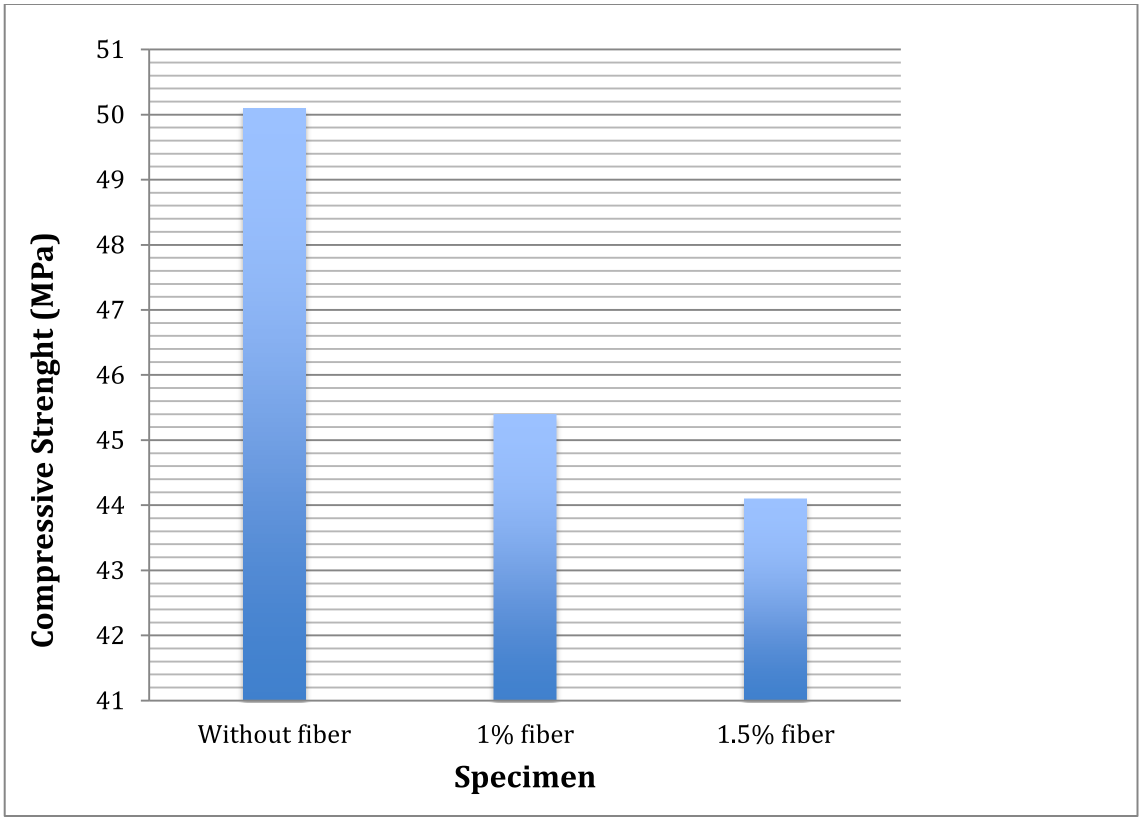


Figure 4-1: Comparison of compressive strength for core samples

4.3 Columns Tests Under Axial and Lateral Load

4.3.1 Slip

In both without fiber, and with 1% fiber columns, after applying the lateral load, a gradual horizontal displacement was observed, but the column had a slip at the joint of column and footing. It can be seen in Figures 4-2 and 4-3.

Slip in column-footing joint can be because of creation of a cold joint that it would be because of low bonding between steel bars and concrete.

However pouring the concrete of column and footing separately is common in real buildings, it can make cold joint in footing-column section as well.

Figure 4-2: Slip in footing-column joint of column without fibers

a b

Figure 4-3: Slip in footing-column joint of 1% fibrous column

4.3.2 Shear cracks

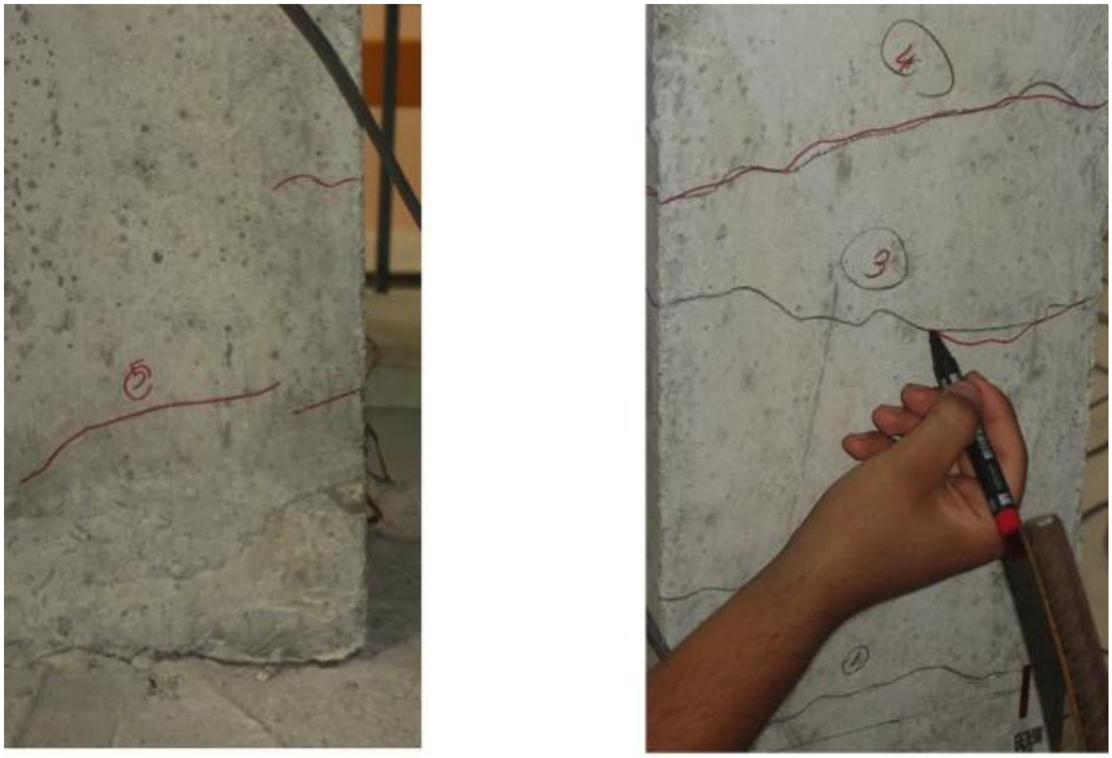
Figures 4-4 and 4-5 show the shear cracks in both specimens.

a b

Figure 4-4: shear cracks in column without fibers

Shear cracks can be seen in Figure 4-4. Cracks started with 45° angle, then in some places became parallel to the steel bars directions. It could be because of loss of bonding between bars and concrete due to the cracks.

Shear cracks in Figure 4-5 show that in fibrous specimen, cracks started with angle less than 45°, and in some places they became parallel to stirrups directions. This cracks can be known as flexural-shear cracks as well.



a b

Figure 4-5: Shear cracks in 1% fibrous column

4.3.3 Failure

In both columns, failure was observed in compression side of columns and it was exactly in expected section, which was the first h/2 =12.5 cm from bottom of the columns (h is height of column cross section).

In specimen without fiber, crushing occurred with 106.6 kN lateral loading, and in specimen with 1% steel fibers crushing happened with 114.5 kN. Figure 4-6 shows the comparison of maximum lateral load before crushing between two specimens.

Figures 4-7 and 4-8 show the ultimate cracks. Figure 4-9 shows the start of crushing in the column without fibers, and Figures 4-10 and 4-11 show the crushing mode of both columns.

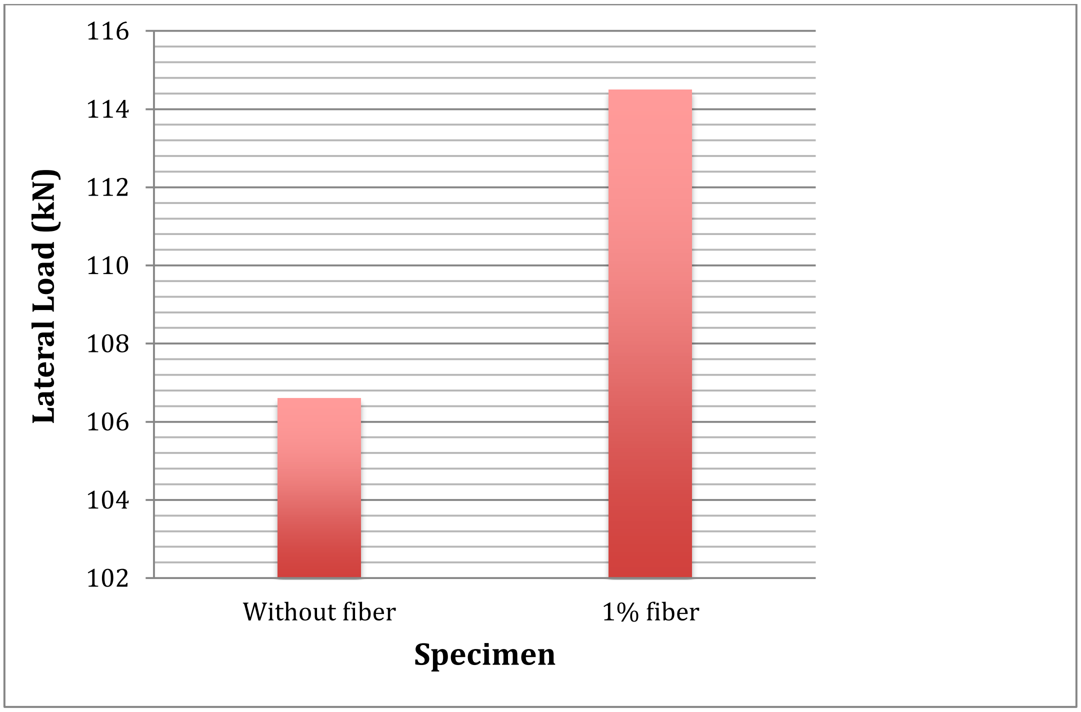


Figure 4-6: Maximum lateral load comparison of two specimens

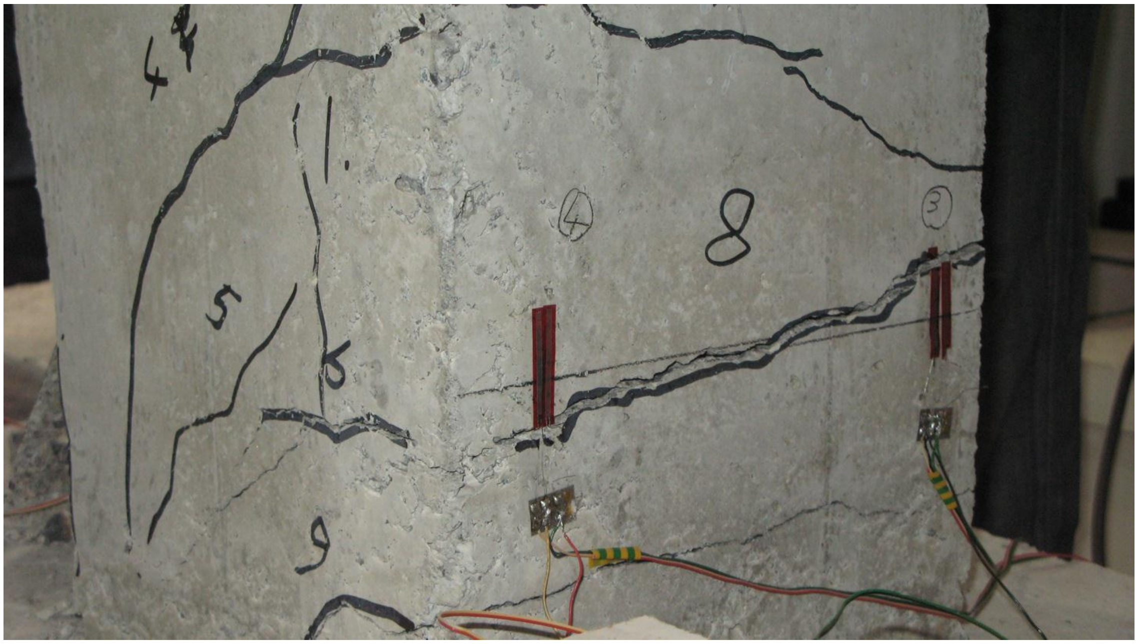


Figure 4-7: Ultimate cracks in tension side of the column without fibers

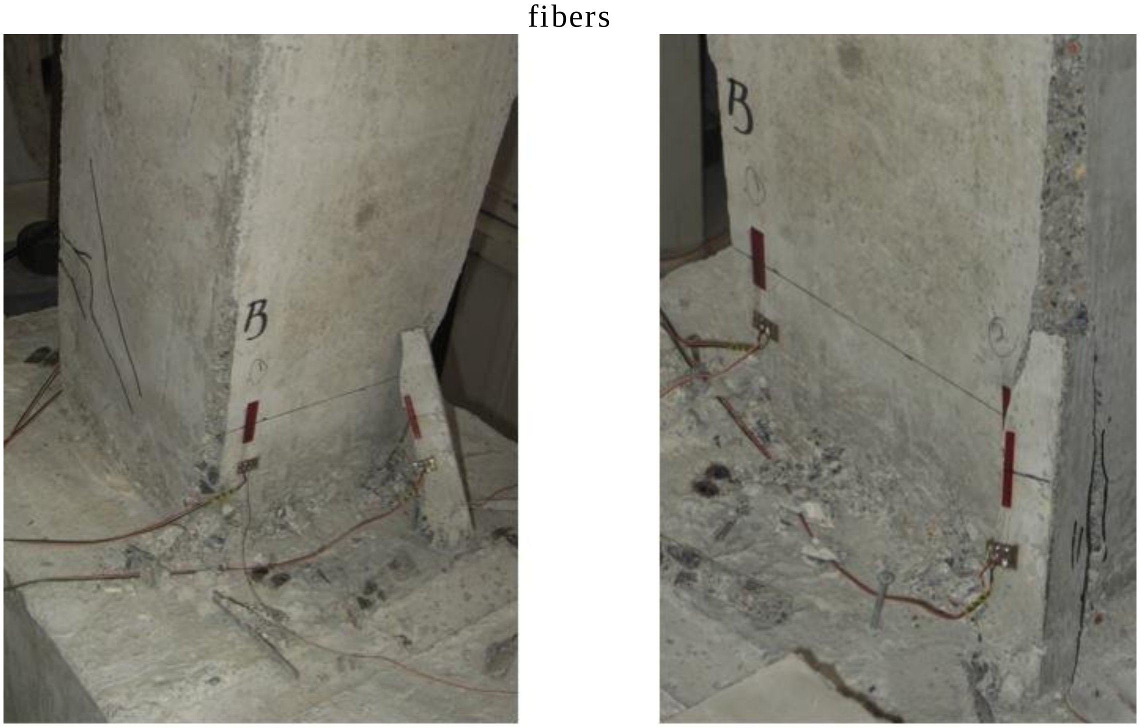
From Figure 4-7 it is clear that crack number 8, is a flexural crack due to the tension, while cracks number 4 and 5 are flexural-shear and shear cracks respectively.

Figure 4-8: Ultimate cracks in tension side of second column (1.5% fiber)

As it can be seen in Figure 4-7 and Figure 4-8, cracks in specimen without fibers are wider, because one of the main advantages of using fiber is preventing cracks from getting wider.

a b

Figure 4-9: Start of crushing in compression side of the column without fibers



a b

Figure 4-10: Crushing in compression side of the column without fibers

In Figures 4-9 and 4-10 it is obvious that two vertical cracks that were parallel to the steel bars direction started at the corner of column, and they gradually got wider during the test. That could be because of loss of bonding between reinforcing steel bars and concrete because of cracks.

Figure 4-11: Crushing in compression side of the column with 1% fibers

From these pictures it can be clearly seen that crushing in the column with 1% fibers was near the footing, while in the first column (without fibers) crushing happened at a large distance form footing.

4.3.4 Maximum displacement

Because of an unknown error in LVDT devices, it was impossible to get a clear graph of load-displacement behavior of columns. Although, in both columns, gradual deformation versus gradual loading was seen clearly.

In specimen without fiber, maximum displacement before crushing was 17 mm, and in specimen with 1% steel fibers maximum displacement before crushing was 19.9 mm.

As was expected from theoretical point of view, the maximum displacement in fibrous column was higher than that of plain concrete. Figure 4-12 shows the comparison between maximum displacements in columns.

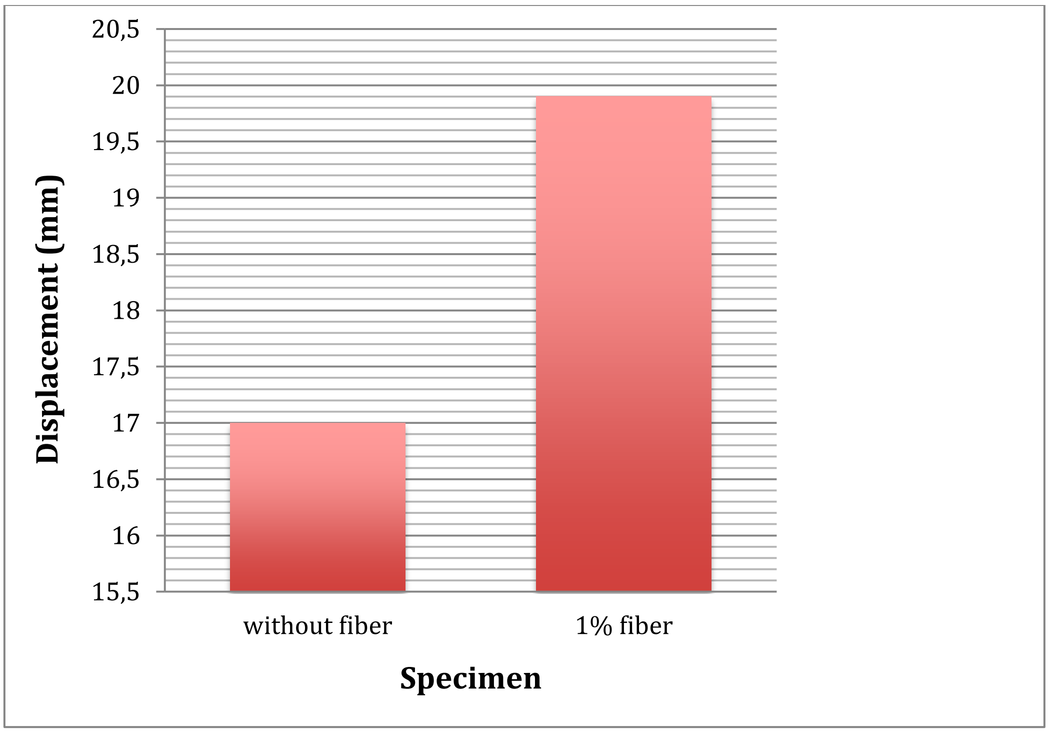


Figure 4-12: Maximum displacement comparison of two specimens

4.4 Column Test Under Only Lateral Load

4.4.1 Slip and crack

The column with 1.5% steel fibers was tested only under lateral loading. The procedure of test was like previous tests. Figure 4-13 shows the third test setup.

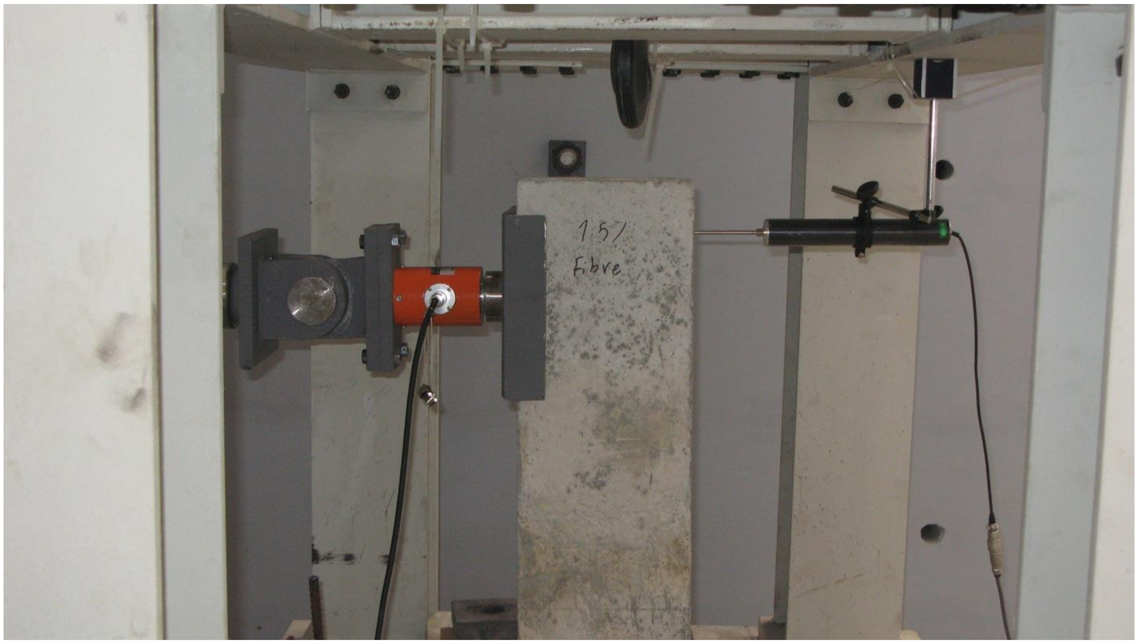


Figure 4-13: The third test setup

A gradual displacement versus gradual loading was observed in the third column as well; also slip occurred due to the same problem at column-footing joint. Figure 4-14 shows the slip in specimen with 1.5% fibers.

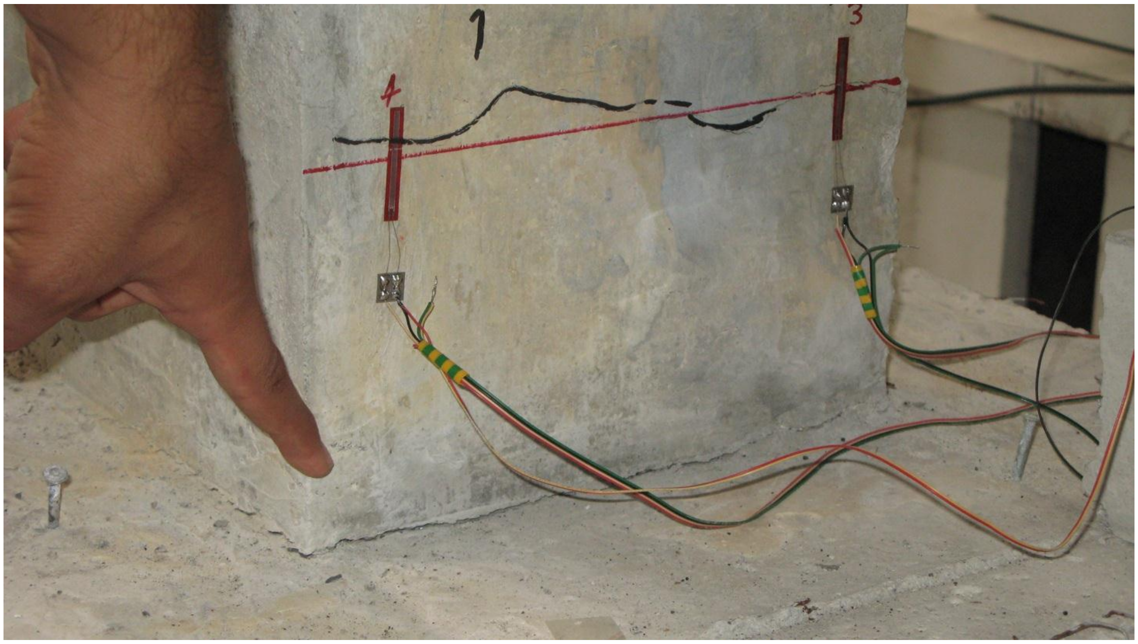


Figure 4-14: Slip in the column with 1.5% fibers

Presence of 1.5% of steel fibers caused an obvious decrease in cracking in the column. The first crack occurred exactly in 12.5 cm from bottom of the column, and it had a little expansion during the test. Figure 4-15 shows the main crack location.

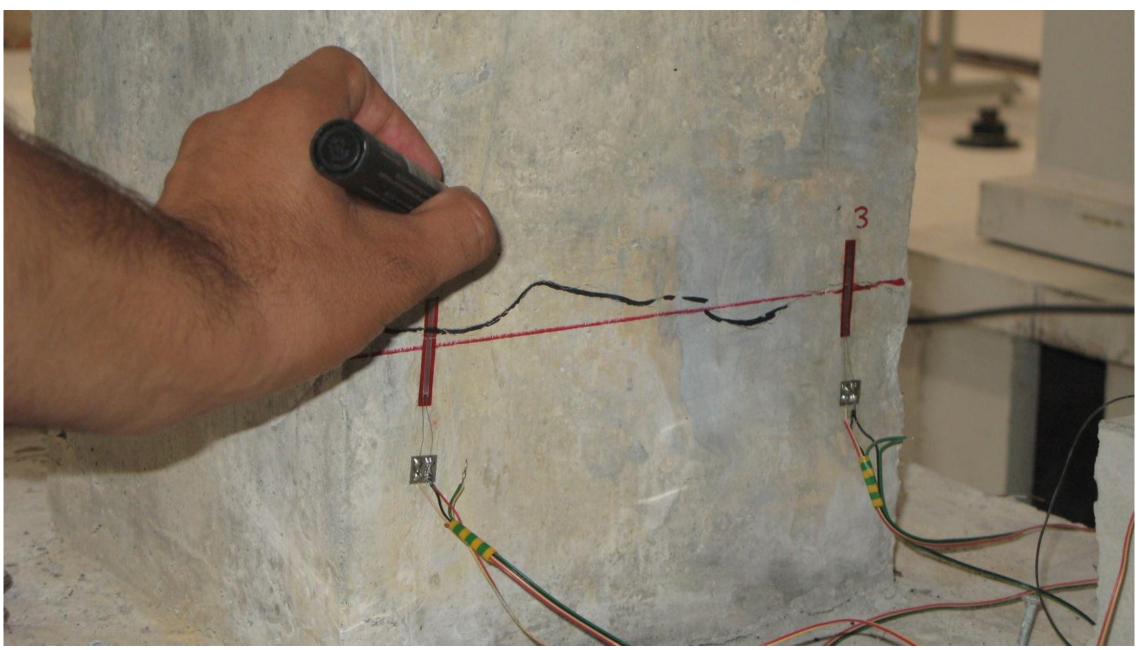


Figure 4-15: The first and main crack in the column with 1.5% fibers

4.4.2 Failure of the column with 1.5% fibers

Crushing of the third specimen happened under 84 kN lateral load, the crushing place was near to the footing-column connection. In Figure 4-16 and 4-17 crushing of concrete is shown.

Figure 4-16: Start of crushing in compression side of column

Figure 4-17: Crushing of the column with 1.5% fibers

4.4.3 Maximum displacement

Maximum displacement before crushing in specimen with 1.5% of steel fibers was 82.25 mm. Figure 4-18 shows the load-displacement graph of the column with 1.5% fibers.

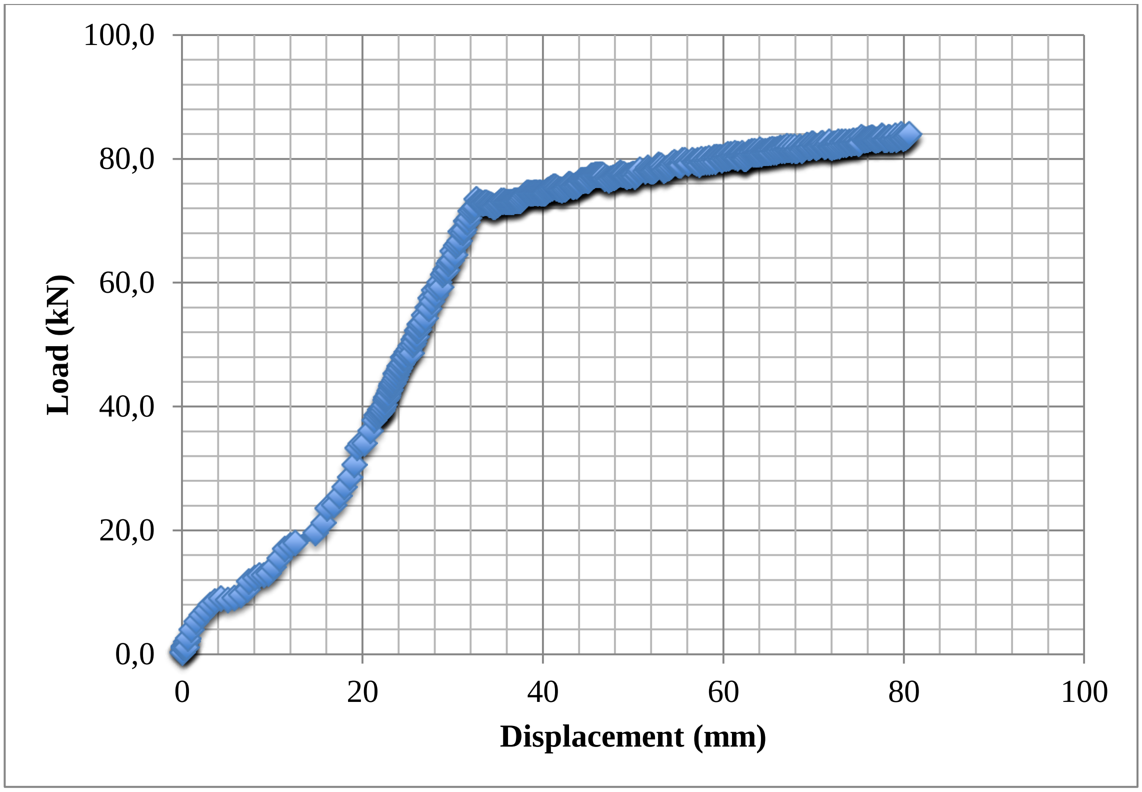


Figure 4-18: Load-Displacement diagram of 1.5% fibrous column under lateral loading

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5-1 Conclusions

In this study three concrete columns with 0, 1, and 1.5 percent of steel fibers were made and column without fibers and column with 1% fibers were tested under 300 kN axial load and increasing monotonic lateral load was applied. The column with 1.5% fibers was tested only with lateral load. Results of the tests on the column without fibers and the column with 1% fibers showed a considerable improvement in deflection capacity and also ductility of column with 1% fibers. Result of the test on the column with 1.5% fibers in absence of axial load showed a high lateral displacement in 1.5% fibrous column.

Also the following conclusions have been achieved:

This study shows that presences of steel fibers increase the displacement capacity of concrete columns under axial and lateral loads as expected from all other structural members containing steel fibers.

Steel fibers reduce cracks on columns surface, especially shear cracks, and prevent cracks from getting wider during the loading until crushing of concrete in compression.

Use of steel fibers in concrete, is an easy, cheap, and useful way to improve ductility and deformation capacity of concrete columns.

Although, presence of steel fibers increases concrete compressive strength, it decreases the concrete workability. Vibrating should be done in perfect way; otherwise the compressive strength would be affected and decreased.

5-2 Recommendations for Further Studies

The followings are some recommendations for further studies:

- In this study for each percentage of steel fibers, one specimen was made, it is recommended to make three specimens from each percentage of steel fibers, to achieve reliable results and reduction of errors in data.
- It is needed to provide suitable instruments for such large-scale tests. For example a big capacity mixer would help to perform high volume concrete pouring in similar studies.
- It is better to pour concrete of column and footing at the same time to avoid creation of cold joint in footing-column connection. To overcome the problem of height of column while pouring concrete, rotated formworks can be used.
- Making holes in footing and fixing the specimens with internal bolts, as was used in this study, not only makes footing weak, but also was not useful enough. It is easier to fix specimens by some external holders that they can be fixed separately.

- Regarding the fact that a large lateral displacement was expected in fibrous specimens, it is better to have a roller function on the axial hydraulic jack connection so the vertical loading can remain axial during the test.
- Using more measuring devices such as LVDTs and strain gauges in several locations of specimen is recommended.

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