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**SHEAR STRENGTH ENHANCEMENT OF PRESTRESSED
HOLLOW-CORE SLABS USING FIBER REINFORCED
CONCRETE**

**M.Sc. THESIS
IN
CIVIL ENGINEERING**

**BY
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**M.Sc. Thesis
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January 2022



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CORE SLABS USING FIBER REINFORCED CONCRETE**

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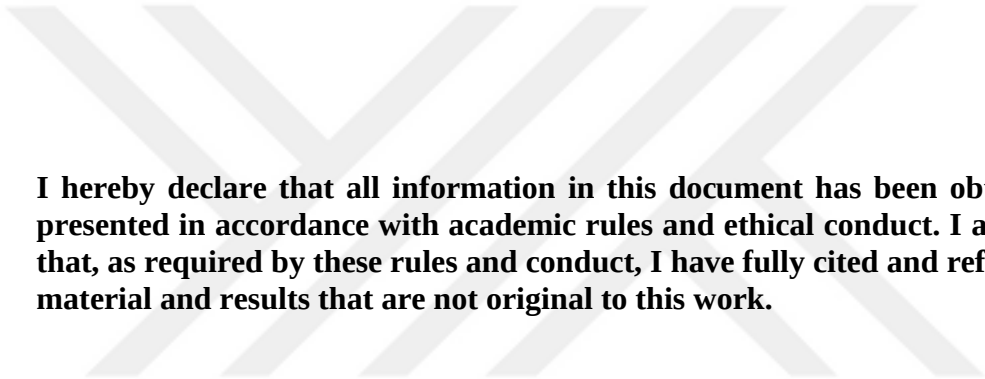
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ABSTRACT

SHEAR STRENGTH ENHANCEMENT OF PRESTRESSED HOLLOW-CORE SLABS USING FIBER REINFORCED CONCRETE

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M.Sc. in Civil Engineering

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Many countries used the precast prestress hollow slabs due to their easy installation and reduced construction time and high-quality control. Shear reinforcements are utilized to improve shear resistance and shift reinforced concrete's failure mode to a more ductile failure mode. Hollow-core slab failure, caused by concrete brittleness, is one of the most hazardous failures in structure construction. Many experimental and analytical research investigations have shown that the addition of fibers in the appropriate amounts improves the shear behavior of Reinforced concrete elements, allowing them to completely or partially replace conventional web reinforcement. The objective of the current research is to study the effect of polypropylene on the shear strength in the prestressed precast hollow slabs. Hollow-core slab (42 cm high, 120 cm wide, and 600 cm long) were investigated under shear loading. Two sample model were investigated on each model varying the shear-span-to-effective depth ratio ($a/d = 2.8$ and $a/d = 3.5$ according to EN1168). The test program was carried out to investigate the effect of Polypropylene fiber mix with concrete by varying content such as 0, 0.5, 0.8, 1.15, and 1.5% to find the optimum polypropylene fiber content. All the groups were tested by using the ANSYS program as a tool for finite element investigation. The results showed improvement of up to 35% in the load capacity with 1.15% of fibers, moreover, the deflection decreased by 20% at the same load level.

Key Words: ANSYS, Hallow Core Slabs, Numerical Analysis, Polypropylene Fibers, Shear Strength.

ÖZET

ÖNGERMELİ DELIKLİ DÖŞEMELERİN KAYMA DAYANIMININ LİF TAKVIYELİ BETON İLE ARTTIRILMASI

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Birçok ülke, kolay kurulumları, azaltılmış inşaat süreleri ve yüksek kalite kontrolleri nedeniyle prekast ön gerilimli içi boş döşemeler kullanılmaktadır. Kayma donatıları, kesme direncini artırmak ve betonarmenin kırılma modunu daha sünek bir kırılma moduna kaydırmak için kullanılır. Beton gevrekliğinden kaynaklanan boşluklu döşemenin çökmesi, yapı yapımındaki en tehlikeli problemlerden biridir. Birçok deneysel ve analitik araştırma, uygun miktarlarda liflerin eklenmesinin, betonarme elemanların kesme davranışını iyileştirdiğini göstermiştir. Mevcut araştırmanın amacı, polipropilenin öngerilmeli prekast içi boş döşemelerde kesme mukavemeti üzerindeki etkisini incelemektir. Boşluklu döşeme (42 cm yükseklik, 120 cm genişlik ve 600 cm uzunluk) kesme yükü altında incelenmiştir. Kesme açıklığı- derinlik oranını iki örnek model incelenmiştir (EN1168'e göre $a/d = 2.8$ ve $a/d = 3.5$). Test programı, optimum polipropilen elyaf içeriğini bulmak için %0, 0,5, 0,8, 1,15 ve 1,5 gibi çeşitli içeriklerle polipropilen elyaf karışımının betonla etkisi araştırılmıştır. Tüm modeller, sonlu elemanlar araştırması için bir araç olan ANSYS programı kullanılarak incelendi. Sonuçlar, liflerin %1,15'i ile yük kapasitesinde %35'e varan iyileşme gösterdi, ayrıca aynı yük seviyesinde deplasman %20 azaldı

Anahtar Kelimeler: ANSYS, Delikli Döşeme, Sayısal Analiz, Polypropylene Lif, Kesme Dayanımı



"Dedicated to my family"

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LIST OF SYMBOLS

ϵ_u	Ultimate strain of concrete
ϵ	Strain at stress f_c
δ	Displacement
ϵ_o	Strain at ultimate compressive stress f_c'
ϵ_y	Yield strain of steel
ϵ_u	Ultimate strain of concrete
N_f	Failure impact number
A	Area
d	Depth of Tensile Reinforcement
EC	Modulus of elasticity for concrete
ES	Modulus of elasticity for steel Plates
a/d	Shear span over effective depth
$\emptyset$	Diameter
V_f	Volume fraction of polypropylene fibers
f_c'	Compressive strength of concrete
ν	Poisson's ratio
I	Moment of inertia
ν_{cw}	The web shear cracking stress
M_n	Nominal flexural strength
V_{cw}	the web shear capacity
M_{cr}	Flexural cracking strength
f_{pu}	Ultimate tensile strength of steel
$\rho_p = A_{ps}/bwd_p$	Ratio of prestressing steel
b_w	Net web-width of the slab
d_p	The depth of slab
ν_s	Poisson's ratio of steel
ν_c	Poisson's ratio of concrete
W_c	The unit weight of hardened concrete
f_t	Uniaxial tensile strength for concrete
f_y	Yield stress of steel
xyz	Global coordinate system

LIST OF ABBREVIATIONS

PPHS	Precast prestress hollow core slab
FE	Finite Element
HCSs	Hollow Core Slab Structure
RCHCS	Reinforced Concrete Hollow Core Slab
N_{cr}	The initial crack impact number
PFRC	Polypropylene fibers reinforcement
ACI	American Concrete Institute
ANSYSE	Analysis System Software

CHAPTER I

INTRODUCTION

1.1 Motivation of Study

In several countries around the world, precast concrete is utilized in flooring systems. Pre-cast Pre-stressed Hollow-core Slab (PPHS) units are commonly used in precast manufacturing and have several functions in construction structure, especially as floor and roof elements. construction with Short time, good quality, and stable self-weight decrease are possible, permitting manufacturers to cover big areas in a short period., allowing manufacturers to cover long spans [1]. It was introduced in 1950 when the technology of pre-stress entered the mass production phase and was categorized as high quality in the production point of view due to high-quality control,

It's generally made of high-strength concrete and reinforced with high-strength pre-stressing strands with diameters ranging from 9 to 16 mm. To reduce self-weight and improve several properties such as voice and thermal isolation, the tendons are sleeved in holes expanded along the axis of the member longitudinal. Hollow slabs are commonly manufactured in thicknesses of 100 to 500 mm and widths of 900 to 1250 mm. The span length can be up to 18m [2]. Recently A lot of studies have indicated that adding fibers to concrete structures improves their performance where concrete is a weak material and also has low tensile resistance. The main advantage of fibers is their capability to transmit stresses through the cracks, Enhance the concrete hardness and resistance, and the capability to absorb under the load's impact. Reinforcement fibers are produced from high tensile fibers like carbon, glass, aramid, etc. in polymeric matrices which are produced in the rods form, In tensile conditions, reinforcement fibers fail only after this fiber breaks or are pulled out of the cement matrix. This occurs when it depends on the bond strength of the matrix. Fiber pulling is more desirable because it makes reinforcement fibers more flexible while absorbing more energy [3,4].

One of the significant challenges in structural design aspects is the shear forces effect. For the compound action, enough shear strength at the interface is required; the horizontal and vertical shear strength of the connection between nearby hollow-core units must be sufficient to transmit forces due to horizontal diaphragm action and load-sharing of concentrated loads. [1]. It is produced by the transfer mechanism of shear forces and happens at end zones. These shear stresses are developed from gravity loads and unbalanced moments and movement during events; such as earthquakes and high winds. The failure of the hollow-core unit can be shown in Figure 1.1. [5-6].



Figure 1.1 Failure of hollow-core in the 1994 Northridge earthquake [5] and experimental test [6]

Over the earlier years, 200- and 265-mm thick units, categorized by cross-sections with circular voids, were changed by greater depth (320, 370, 400, and 500 mm), presenting cross-sections using non-circular voids. Standardized cross-section shapes, generally categorized by related void ratios, initially depending on the thickness of the HCS itself, were increasingly gradually optimized. American Concrete Institute (ACI) [7] and Eurocode 2 [8], bring to light that these units, which are generally not feasible without transverse reinforcement, can fail due to web-shear cracking in the disturbed end regions at loads lower than those prophesied by conventional design methods. Despite prestressed precast, HCS has been extensively adopted, some aspects of the extensively - used design approaches against shear are still a cause of short bearings, and not fully developed prestressing forces affect their response. Also, their common production system (i.e. extrusion) could result in features not suitably in agreement with those of the standard concrete strength monitoring procedures. The prestressed

precast HCS has undergone extensive experimental tests to confirm their compliance with the provisions of conservative Codes and Standards and organize the possible failure modes [1].

1.2 Prestressed Hollow Core Shear Capacity

Prestressed precast HCS has a wide range of uses. Under a uniformly distributed load, this type of HCS is typically used to resist bending moments. Furthermore, the HCS may be exposed to concentrated stress or line load in a variety of situations, resulting in shear failure. Increasing the depth of the HCS and refilling the holes are traditional approaches for strengthening the shear capacity of prestressed precast HCS. According to ACI 318-08 [7], extending the depth of the HCS structure beyond a certain point would have a negative impact on shear capacity. Filling holes would also reduce the benefit of light self-weight and be more expensive. Shear reinforcement cannot be arranged during HCS manufacturing using the produced technique of prestressed precast HCS. Prestressed precast HCS rely only on the tensile strength of concrete to resist shear force in the absence of shear reinforcement. The manufactured method of prestressed precast HCS is not able for arranging shear reinforcement during HCS fabrication. Without shear reinforcement, prestressed precast HCS just depends on the tensile strength of concrete to resist shear force. Therefore, enhancing the shear capacity by addition materials of a prestressed precast HCS is the best procedure to prevent shear failure while retaining its advantages [9]. Shear failure in the HCS as shown in Figure 1.2

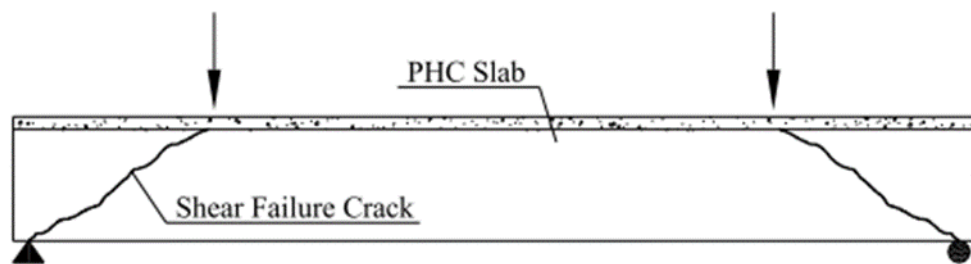


Figure 1.2 Shear failure of the prestressed HCS [9]

Shear reinforcements are used to enhance the shear strength of Reinforced Concrete (RC) members and replace the mode of failure with a more ductile failure. Failure in prestressed precast HCS considered as one of the dangerous failures in building

construction caused by the weakness tensile of concrete. Many methods for improving (increasing) the shear strength of flat HCS against shear failure have been proposed.

Hassan et al [10] noticed when steel fibers are added to concrete mix improve all mechanical properties of all hollow beams through their ability to transfer tensile stress across crack surfaces of concrete so higher load-bearing capacity is achieved. The adding of steel fiber to concrete mix decrease the diagonal crack's expansion rate and increased deformation at failure so the weakness of diagonal shear failure was avoided and changed to a more ductile one. For hollow under steel Fiber Reinforced Concrete (FRC) beams, absorbed energy and ductility index increased than hollow RC beams by value up to 39.64% and 186.25% respectively [3].

Elhashimy et al [11] presented a study program to research the performance of full-scale hollow-core HCSs prestressed with glass fiber-reinforced polymer bars. Under uniformly distributed load, the hollow core slab structure was load-tested. The glass-fiber-reinforced polymer bars were manufactured from locally existing materials with a 10 mm nominal diameter. The mechanical feature of the samples was studied in the laboratory. The average ultimate tensile strength (f_u) and elastic modulus (E) of the members were 1000 MPa and 46 GPa, respectively. Four full-scale hollow-core HCS samples with a specific strength of 80 MPa were made and solely reinforced with a single prestressed glass fiber-reinforced polymer bar. All HCS specimens were one complete hole with a width of 140 mm, a thickness of 150 mm, as well as a total length of 4000 mm. These specimens were simply supported during the tests where the glass fiber-reinforced polymer bar was located at the centerline of the vent near the soffit. The bars were prestressed to various stress levels, that is (10, 20, 30, and 40%) of their ultimate tensile strength (f_u). Under uniformly distributed load, all hollow-core slabs samples were load-tested. The crack patterns, deflection, and strain were studied during load-testing. From the achieved testes results, it was noticed that the optimum prestressing level was 20% of the bar's ultimate tensile strength for both moment load capacity and deformation.

Al-Yassir et al [12] Studied an experimental investigation to study the impact of hybrid reinforcement on the performance or behavior of HCS cast with conventional strength concrete. The experimental results revealed that applying hybrid reinforcement (carbon FRP and steel bars) as internal reinforcement increases ductility compare it to

HCS reinforced absolutely with carbon FRP bars. In contrast, using carbon FRP bars as an internal reinforcement has a slight effect on the shear strength capacity of HCS. On the other hand, carbon FRP reinforcement leads to a decrease in the stiffness of HCS at post cracking stage; therefore, the same load the deflection will increase after cracking.

El-Arab [13] presented specific characteristics of the deep HCS to enhance and improve the web shear strength capability of HCS 400 and 500 mm depths, At the open parking area respectively. To achieve the LRFD Code's standards, this is exposed to significant truck wheel loads. However, large web shear cracks of HCS have been seen in the parking area of various projects Gulf Region projects. furthermore, ACI318-14 [14] allows no shear reinforcement during production in prestressed HCS thicknesses less than 12.5 inches (320 mm). In addition to the strengthening techniques, An experimental test program is included in the study to assess the numerical Finite Element (FE) of deep HCS under maximum design uniform loads. The proposed strengthening procedures achieve a significant increase in web shear capacity. With a great value, The suggested features for HCS 400 result in a 68 percent to 256 percent improvement in web shear capacity over the standard HCS section. Furthermore, the shear capacity of the HCS 500 is increased from 55 percent to 197 percent. Moreover, the current processes have the benefit of being straightforward to implement on-site; they also improve deep HCS shear performance. In contrast to other traditional strengthening approaches, casting with structural topping may be done in a precast plant before site handover, saving time and costs.

1.3 Fiber Reinforced Concrete

FRC is concrete combined with fibrous material. The effect of these materials is to increase the structural integrity. The FRC as a composite material contains short discrete fibers which is randomly oriented and uniformly distributed in both infrastructure and building construction, In both infrastructure and building construction, FRC can replace steel rebars for structural reinforcement of concrete components. This method avoids the brittle fracture behavior of concrete, as well as other benefits such as the prevention of cracking due to initial shrinkage and internal shrinking of concrete at an early age.

In the situation of shear stresses, the usage of FRC can replace conventional rebars, resulting in savings in process time, labor force, and weights, and also lower overall manufacturing costs [15]. Also, adding fiber is used to prevent the formation of micro openings caused by micro cracks. These additives provide lower stress at the end of the cracks based on fiber transportation of tensile forces, which means minimizing crack growth and enhancing the concrete material to endure loads even after visible crack occurred. Fibers are added for the long-term durability of concrete [16, 17]. The concrete failure mechanism is determined by a number of factors, including concrete size, loading speed, which causes rebar to slide out of the concrete, and steel breakage when the steel reaches its maximum strength. Adding fibers can enhance the concrete strength and provide an increment to the strength of the concrete [18]. FRC contains concrete mixed with distributed fibers. Combining fibers with concrete generates an increased strength and enhances crack patterns. The FRC fault behavior observes several small cracks instead of one or two larger cracks in traditional concrete. The fibers can be produced from many different materials.

Fibers are used to improve the concrete properties and cementations composites. There are many synthetic fibers which are used to incorporate the cement matrices involves polyvinyl acetate (PVA), polypropylene (PP), polyethylene (PE), acrylics (PAN), polyester (PES), polyamides (PA), carbon, and aramid. Some examples of different commercially available fibers can be shown in Figure 1.3. Some types of fiber are used to enhance the toughness and reduce crack widths, but other fiber types reduce shrinkage cracking [20,21].

Both geometrical and mechanical properties of fiber vary based on their effects and provide unique properties of concrete. Many factors affect the FRC reliability such as orientation, fiber type, and percentage of fibers. The mix workability is decreased if the quantity and size of particles increased greater than 5 mm. The aspect ratio (l/d) is another important factor. It has a major effect on the workability of the fibers. The fiber's workability decreases with an increasing aspect ratio [22].



Figure 1.3 Types of fiber are used to enhance the toughness and reduce crack widths [21].

1.4 Problem Statements

The HCS is always designed as a simply supported panel. The production technique of HCS does not allow -the possible establishment of shear and torsion reinforcement. Therefore, it may fail without warning due to shear and/or torsion stresses. There are a huge number of researches addressing this subject, many mechanical models had been proposed, and any code equations were introduced, but still many problems to be resolved, such as, how to increase the concrete strength and ductility at the same time. Many methods had been suggested to increase the ductility and resist the shear action of partially loaded HCSs. Using shear reinforcements and steel studs are widely used nowadays, but using FRC shows good improvement [16,18].

1.5 Objectives and Scopes.

Polypropylene fiber has been tested to check how it affects the residual strength of HCS. To achieve this objective, polypropylene FRC flat plate is exposed to different reinforcements are studied through the:

- Comparison between the residual shear behavior of PFRC HCS due to different fiber conditions and punching shear behavior of PFRC HCS at normal conditions.
- Investigation of the impact of polypropylene fiber volume fraction on shear capacity.

1.6 Thesis Organization

This thesis has six chapters. Chapter 1 includes an introduction to the HCS behavior under shear strength and the impact of fiber on the performance.

Chapter 2 presents a literature review about HCS.

In Chapter 3, the work methodology, and the modeling of HCS specimens, are presented.

Chapter 4 presents the verification of FE models

Chapter 5 presents the parametric study.

Chapter 6 present the conclusion and suggestions for further work.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Concrete material is one of the most important construction materials due to its functionality and stability in structure construction. HCS concrete represents a structural element of a modern building. The wide diversity of materials used in the behavior of HCSs. For that, studying the factors and characteristics that can improve the performance of HCS considered a major issue in the engineering industry where it gradually becomes a new horizon in composite material in a construction project [2]. Many independent methods have been used to achieve this target such as adding different materials such as steel fiber [24], polypropylene fiber [25], and hybrid fibers [26]. One of the interesting methods is the polypropylene FRC. It is described as a mixed concrete with fibrous materials. When polypropylene is added to concrete, it improves structural properties such as flexural strength and tensile. The mechanical properties achieved by using polypropylene FRC depend on several factors, such as percentage, volume, and distribution of fibers [27,28]. Plastic shrinkage concrete is a constant source of concern in the concrete industry. Concrete cracking can be worsened by drying shrinkage, which exposes the concrete to aggressive chemicals that can cause deterioration such as steel oxidization. Cracking will be minimized as a result of managing the drying shrinkage in concrete, which will increase the structure's durability for long service life. Experimental data focused on the performance of polypropylene fibers on the plastic shrinkage cracking stage. It improves the concrete brittleness and weak endurance to shear and tensile forces. Plain concrete does not easily resist vibrations, wind, earthquakes, and other forces. Adding fibers enhance the concrete quality against the failures [29]. The theoretical models developed the researchers apply an applicable structural solution to modify the resistance of the concrete force by using polypropylene FRC as in Figure 2.1.

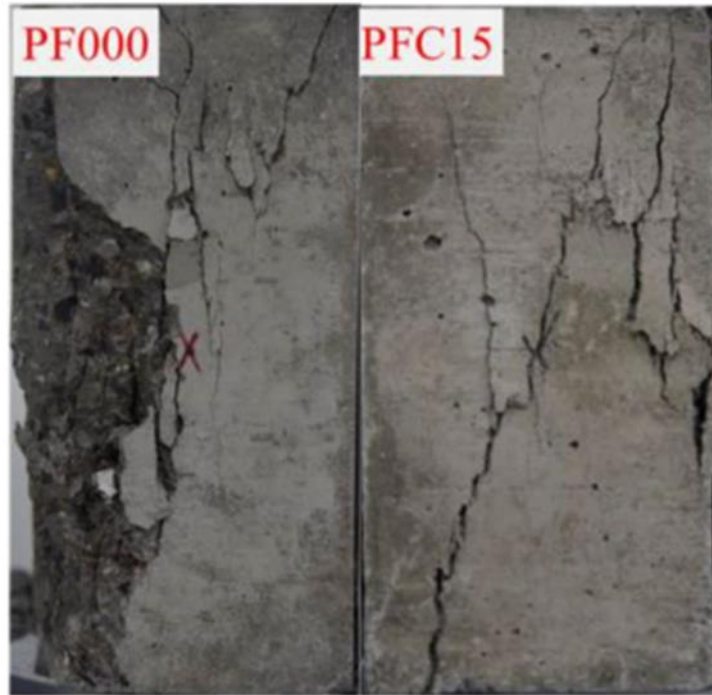


Figure 2.1 Comparison between the strength of concrete with polypropylene FRC and without polypropylene FRC [30].

The present chapter will overview the previous related works of polypropylene FRC concrete reinforcement and present the effective factors and properties of concrete to employ this information in simulation tests to investigate the response of different reinforcement effects based on fibers structure.

2.2 Types of Fibers for Reinforced Concrete

FRC places on further than 50 years of experience and improvement with fibers randomly placed in the concrete matrix. Other fiber kinds have been found in recent years to be sufficient for structural concrete components and to function similarly [15]. One of them is steel FRC. It is expressed as a composite material that has fibers as the additional ingredients. The steel fiber reinforcement effects as rigid inclusions in the matrix of the concrete. Adding steel fibers to the concrete can enhance the strength of traditionally RC structural units to cracking, deflection, and other serviceability conditions due to the inherent properties of steel fiber material. the steel fiber reinforcement can be used in various forms in the body of concrete. One of the forms is a one-dimensional random distribution which added to the steel fiber shear resistance a significant advantage to control cracks. Steel FRC mechanism behaves

differently during loads increasing. When concrete starts to crack, steel fiber will carry out the load, then the mechanism depends on the steel fibers' shape and properties only. Sometimes the steel is obtained from chopping wires milled from ingots or cutting steel sheets, or it is produced from hot melt extract [31]. There are two main categories of steel fibers, smooth and deformed [32]. It comes in various shapes like circular, rectangular, hook-shaped, etc., as shown in Figure 2.2.

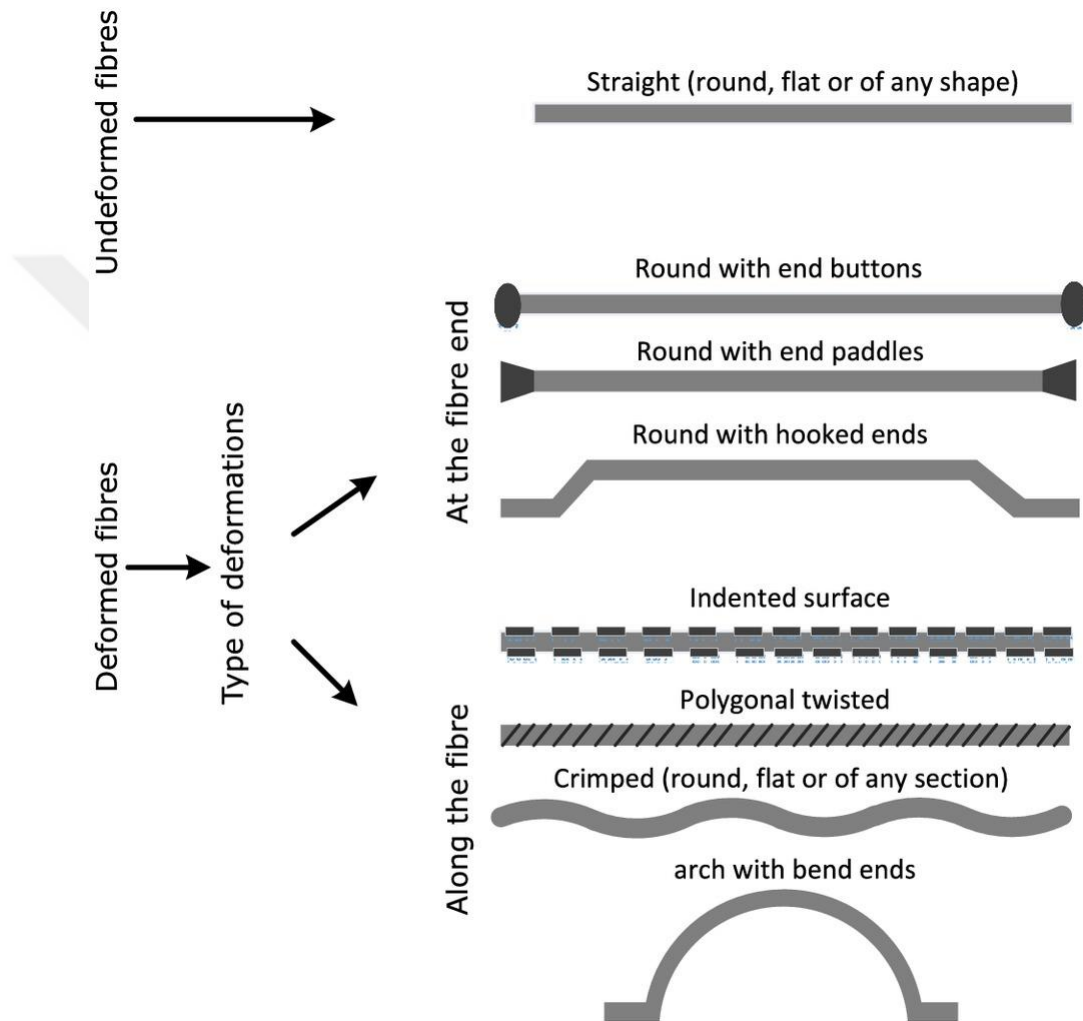


Figure 2.2 Types Steel fiber types [33]

The deformed steel fibers are more efficient due to the surface area effect which increases the cement-matrix bond this results in an improvement in pull-out resistance [33]. Fibers may split out or fracture, which depends on the length of steel fiber and concrete strength. The steel fibers forms can be found in different sizes, shapes, and properties which involve stainless steel fibers, high tensile steel fibers, and normal steel. The characteristics of steel depend on manufacturing process types. It may

produce by cold or hot working methods which are affecting the steel specifications. The straight fibers which are not deformed can be bonded in the concrete component by friction and chemical adhesion. Steel fiber lengths are in a reach from 10 to 65 mm with diameters ranges between 0.5 and 1.2 mm [33]

Glass fiber has been used in construction elements for over 30 years such as pipes for sewage and water lines. Glass FRC is composed of cement, water, sand, and an admixture matrix into which short-length glass fibers are placed. The effect of the fibers leads to an increase in the impact strength and tension of the material. Fiberglass is material manufactured from fine fibrous glass materials. Fiberglass is considered an extremely strong, and lightweight material. Also, it's very favorable when compared to metals, due to being simply created using molding processes. Glass fiber is the most familiar and oldest performing fiber [34].

Shakor and Pimplikar [35] tests concrete without glass fiber and with glass fiber to find out the differences in flexural strength and compressive strength. The study's many uses of glass FRC, experimental test findings, techno-economic comparison with other types, and financial calculations all point to glass FRC's enormous potential as an alternative construction material.

Chaitanya et al [36] proposed that glass fiber increases the properties of concretes such as compressive, tensile, and split tensile strength. This research examined the concrete with glass fiber of 0.5, 1, 2, and 3% of cement by adding as an admixture. Arunakanthi and Kumar [37] compare glass fiber and steel fiber. They studied the strength of the FRC which was added at percentages of 0.5, 1, 2, and 3%. They found that the flexural strength, compressive, and split tensile strength is increasing linearly by adding steel fiber, on the other hand adding glass fiber up to 1% the strength is increasing but it starts to decrease at 2%. They found that the workability of glass FRC decreases with an increase of fiber and the compression factor is less than the conventional mix. Also, Flexural strength, compressive strength, and split tensile strength increased because of the addition of glass fiber.

Natural fibers are used to improve the durability and strength of brittle materials [38]. Natural fibers that are suitable for reinforcing concrete are classified as shown in Figure 2.3. Fibers derived from palm trees observed stronger results than coconut

fibers. The addition of coconut and jute fibers increases only slightly the tensile strength of the concrete composites and decreases the compressive strength [39].

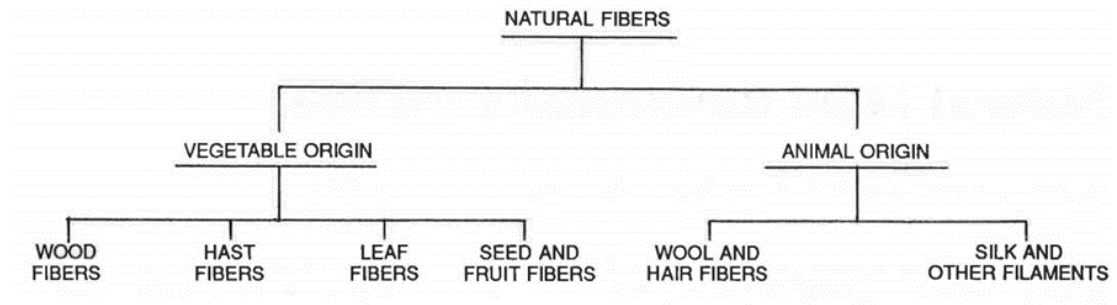


Figure 2.3 Natural fibers classification [40]

Padmaraj et al [41], added areca husk coir fiber extracted from coconut husk to high-strength concrete. The test results show that a reduction in flexural strength in most cases except for 2% coir FRC. Pickering et al [42] review the recent development in natural fibers and investigate the factors that affect the performance of mechanical characteristics and durability of natural fiber composites.

Synthetic fibers have been used to improve the concrete structure performance by enhancing the modulus of elasticity, flexural strength, and other mechanical properties of concrete. Synthetic fibers engineered to utilize in the aramid, polyethylene (PE), polypropylene (PP), acrylics (PAN), polyamides (PA), poly-vinyl alcohol (PVA), polyester (PES), and carbon reinforcements. These fibers are manufactured polymer-based such as nylon, or polyethylene, polypropylene [43]. Camille et al [44] proposed mechanical Properties of synthetic FRC under static loading for railway transoms application. They found that Synthetic fiber enhanced the workability, durability, and flexibility of the concrete sleeper.

2.3 Polypropylene Fiber Reinforced Concrete

The capability of a durable structure to withstand the chemical assault, weathering action, abrasion, and other degradation processes while requiring little maintenance is as significant as the structure's ability to withstand stresses applied to it. Even though concrete has several benefits in terms of mechanical and economic elements of brittle properties nevertheless, the material's structure remains a greater hindrance in the earthquake and other applications where flexibility is necessary. Recent advancements

in polypropylene FRC have provided a technological framework for addressing these deficiencies. The impact of polypropylene fibers on several properties of concrete in a fresh and hardened state, including compressive strength, tensile strength, flexural strength, workability, bond strength, fracture properties, creep strain, impact, and chloride penetration, is presented in this study. [45].

2.4 Polypropylene Fibers Properties

Polypropylene is made from monomeric C_3H_6 , a pure hydrocarbon, as its starting material. Polypropylene fibers have very useful properties due to their mode of polymerization, high molecular weight, and the way they are processed into fibers, as explained following [46, 47]:

- The polymer molecule has a sterically regular atomic arrangement and high crystallinity. Isotactic polypropylene is named after its regular structure.
- The fibers' chemical inertness makes them resistant to a wide range of chemicals. Any chemical that isn't harmful to the concrete's constituents will also be harmless to the fiber. Concrete will always deteriorate first when exposed to more aggressive chemicals.
- Because the hydrophobic surface is not wet by the cement paste, divided fibers do not ball up during mixing like other fibers.
- Polypropylene fibers have no water requirements.
- The film is weak in the lateral direction due to the orientation, which facilitates fibrillation. As a result, the cement matrix can penetrate the mesh structure between the individual fibrils and form a mechanical link with the fiber.

The fibers are made using either a circular cross-section pulling wire procedure or rectangular cross-section extrusion of a plastic film. There are basically two types of polypropylene fiber. These are

- Monofilament polypropylene fibers (see Figure 2.4)
- fibrillated polypropylene fibers (see Figure 2.5)

Table 2.1 lists the properties of these different types of polypropylene fibers. The fibrillated polypropylene fibers are made by stretching a plastic film that is then cut into strips and slits. The fiber bundles are cut into specified lengths and fibrillated. inclusion of buttons at the fiber's ends enhances the pullout load in monofilament

fibers. Twisting fibers might also accomplish maximal load and stress transmission.
fibers. Twisting fibers might also accomplish maximal load and stress transmission.

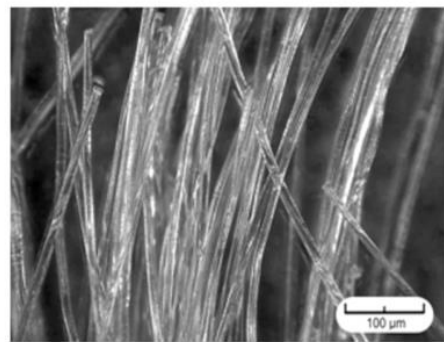
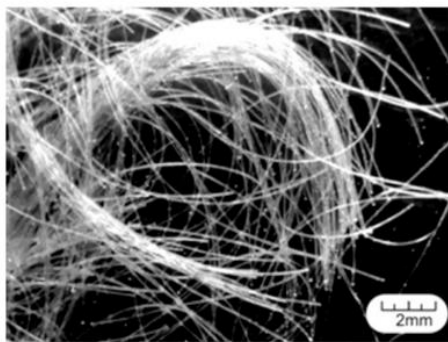
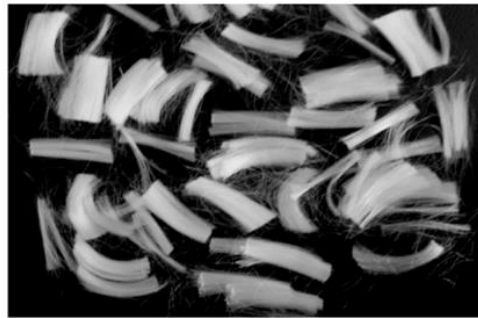


Figure 2.4 Monofilament polypropylene fibers [48]

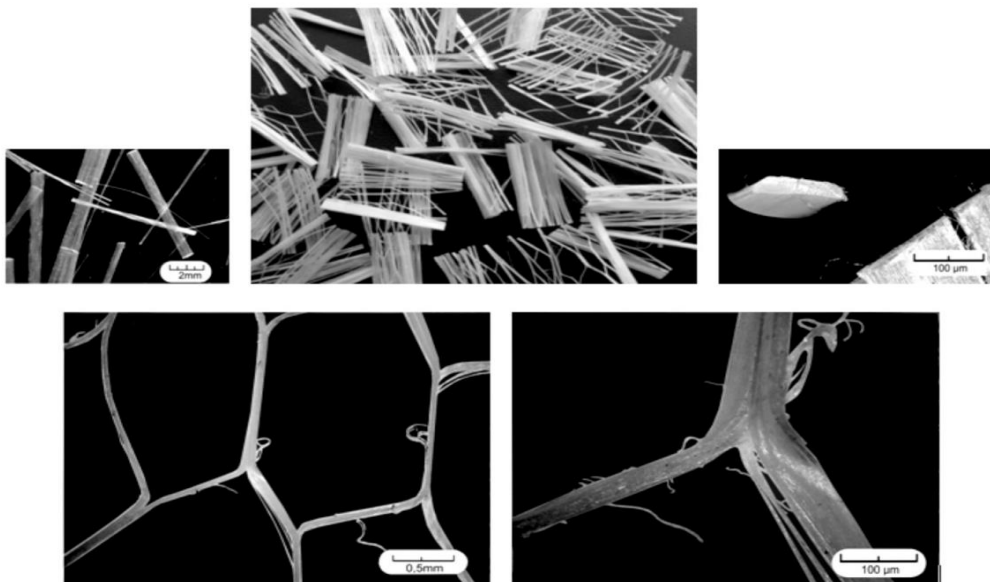


Figure 2.5 Fibrillated polypropylene fibers [48]

Table 2.1 Properties of various types of polypropylene fibers

Fiber type	Length (mm)	Diameter (mm)	Tensile strength (MPa)	Modulus of elasticity (GPa)	Specific surface (m²/kg)	Density (kg/cm³)
Monofilament	30-50	0.30-0.35	547-658	3.50-7.50	91	0.9
Microfilament	12-20	0.05-0.20	330-414	3.70-5.50	225	0.91
Fibrillated	19-40	0.20-0.30	500-750	5.0-10.0	58	0.95

2.4.1 Role of fibers

Because the elements of concrete structures change, cracks in the concrete play an important role. Cracks not only decrease the concrete's quality and render it unusable, but they also render structures useless. If indeed the crack does not extend beyond the critical width, it poses no threat to the structure's structural integrity or serviceability. It is critical to reducing crack width, which can be accomplished by incorporating polypropylene fibers into concrete. As a result, extra fibers in the concrete matrix act as a bridge between the cracks, preventing them from widening further. Increased forces in demand to pull out or fracture the fibers in order to achieve more deflection in the beam. Beyond cracking, this process improves a structural member's load-carrying capacity. In the concrete load-deflection curve, the enhancement creates a long post-peak descending portion. Steel bars used to reinforce concrete have the same beneficial influence as long continual fibers [49].

2.4.2 Plastic shrinkage

When surface water evaporates before bleed water reaches the surface, plastic shrinkage happens. Because of their polypropylene's flexibility and ability to conform to form, it reduces the plastic shrinkage crack area. It was discovered that adding 0.1 percent of the fiber volume actually reduced the extent of cracking by a factor of 5-10. The range of crack reduction is inversely proportional to the concrete's fiber content. [50].

2.4.3 Plastic settlement

Settlement cracking is attributed to the high level of water bleeding and settlement combined with settlement restraint (e.g., reinforcing bars). When adding the

polypropylene fibers are consistently dispersed. Because the fibers are flexible, they cause little restriction in the aggregate's settling. [51].

2.4.4 Damage of freeze-thaw

The presence of polypropylene fibers in concrete decreases the movement of water across the concrete matrix by stopping water from entering through the usual channels, such as capillaries and pore structures. When polypropylene fiber is added to concrete, the benefits include improved cement hydration, reduced aggregate separation, and reduced water flow through concrete, which causes deterioration due to freeze/thaw action, as well as reduced rebar corrosion, all of which contribute to a more durable environment. [52].

2.4.5 Fire damage

In a fire, heat penetrates the concrete, allowing the outer layer to desorb moisture. Moisture vapors return to the cold interior, where they are reabsorbed into voids. Water and vapor collect in the interior, rapidly raising the vapor pressure and causing concrete cracks and spalling. The presence of polypropylene with concrete, at 160 °C the fibers will be making voids in the concrete allowing moisture vapors to exit [53].

2.5 Polypropylene Fiber Properties

When compared to traditional concrete mixes, polypropylene concrete mixes have a higher mortar volume. The fiber's aspect ratio is limited to 100 to 200 because fibers that are too long incline to "ball" in the concrete mix and cause workability troubles. In most cases, fibers in concrete are dispersed at random; While concrete should be placed in the direction of applied stress and should produce from higher flexural and tensile strengths. Significant compaction is required to ensure that the fresh concrete flows well enough and regularly with the polypropylene fibers dispersed in the mix. In concrete, the fibers should not reach the bottom or float to the top. Superplasticizers optimize the strength, water content, volumetric stability, cement ratios, and the wet mix's handling characteristics. The properties of polypropylene FRC with different fiber volume fractions are exposed in Table 2.2 [54,55].

Usually, there are two ways to use Polypropylene fibers to enhance the concrete. In one application Polypropylene is used as a primary reinforcement material in thin sheet

components. It has a high volume content, exceeding 5%, to provide both strength and toughness. In other applications, the polypropylene volume content is low, less than 0.3 percent by volume, and it is intended to act primarily as secondary reinforcement for crack control rather than structural load-bearing applications. Because the function and impact of adding polypropylene fibers in fresh and hardened concrete differ, these two topics are discussed separately.

The compressive strength of concrete can be considered as an important property that distinguishes it from other properties like flexural, tension, etc. the compressive strength of concrete may be increased or decreased by effect adding polypropylene fiber to concrete. The experimental error can conceal the low volume of polypropylene fiber effect on concrete compressive strength. [45].

2.5.1 Flexural tensile resistance

The increase in the volume fraction of fiber leads to an increase in flexural tensile strength. It is also noticed that there was an increase in strength with the increase in an aspect ratio of fiber [56].

Strength of bond: It must be a high bond between the fiber and the matrix that is in concrete data specification. multiple cracking can obtain When the concrete's critical fiber volume for strength has been achieved. this is a required state Because it is replaced in weak materials with a single fracture surface to fracture that can grasp transient slight overload and shocks with visible damage. For this reason, concrete reinforcement purposes to create a large number of multiple cracks with as close a placing as possible, , It is almost imperceptible to the naked eye, so that aggressive substances have difficulty penetrating into the matrix. close crack space produced from high bond strength but It's also important that the fibers have enough ductility to absorb impacts.

Table 2.2 Polypropylene Mechanical Properties [52]

No	Concrete mix					Fibers			Vf %	f _{cu} (MPa)	f _t (MPa)	f _s (MPa)	Slump (mm)	
	w/c	Cement (kg/m ³)	CA (kg/m ³)	FA (kg/m ³)	Admixture	Specimen shape	Type	l/d						
1.	0.49	390 (OPC)	1000 (10mm)	640	Super plasticizer (Fosroc 430)	Cylinder, Cubes & Prism	Fibrillated (20mm long & 0.29mm dia)	69	0	17.2	1.08	4.5	100 – 120	
									0.10	14.1	1.72	2.5		
									0.30	12.6	1.34	3.0		
2.	0.45	360 (OPC)	1100 (20mm)	647	-	Prism	Micro filament (19mm long & 0.048mm dia)	396	0	0.045	-	2.24	4.01	-
									0.082	-	2.33	3.76	-	
									0.128	-	2.40	4.01	-	
											2.43	4.22		
3.	0.45	360 (OPC)	1100 (20mm)	647	-	Prism	Mono filament (30mm long & 0.55 mm dia)	55	1.0	-	2.50	5.36	-	
									1.2	1.4	-	2.68	5.47	-
												2.70	5.51	-
4.	0.48	418 (OPC)	724 (25mm)	998	-	Cylinder	Mono filament	56	0	1.0	35.03	2.23	-	102
									1.5		35.42	3.21		38
											30.74	3.21		7
5.	0.40	372 OPC + 28 SF	1140 (20mm)	750	Super-plasticizer	Prism	Mono filament	200	0	0.5	56.10	4.10	5.21	100
											56.10	4.40	5.61	80
6.	0.50	383 (PPC)	1162 (20mm)	572	-	Cylinder, Cubes & Prism	Graded Fibrillated (12mm ~ 24mm)	NR	0	0.1	35.23	3.54	5.23	-
									0.2	0.3	39.50	4.42	5.47	-
											41.00	4.88	5.65	-
											48.00	4.95	6.35	
7.	0.44	430 (PPC)	1154 (20mm)	540	-	Cylinder, Cubes & Prism	Graded Fibrillated 12mm ~ 24mm)	NR	0	0.1	41.22	3.72	5.35	-
									0.2	0.3	49.78	4.53	5.99	-
											50.22	4.67	6.12	-
											52.00	4.75	6.29	
8.	0.39	498 (PPC)	1136 (20mm)	503	NIL	Cylinder, Cubes & Prism	Graded Fibrillated 12mm ~ 24mm)	NR	0	0.1	46.15	3.89	5.56	-
									0.2	0.3	50.67	4.88	5.70	-
											55.33	5.09	6.40	-
											57.11	5.52	6.84	
9.	0.30	567 (OPC)	630	1050	Superplasticizer(Paric FP300U)	Cylinder	Fibrillated (6 mm long & 0.06 mm dia)	100	0	0.25	81.60	4.40	-	400-
									0.50		60.80	4.10	-	600
											60.00	4.30		
10.	0.30	567 (OPC)	630	1050	Superplasticizer (Paric FP300U)	Cylinder	Fibrillated(30mm long& 0.06mm di)	500	0.25		71.90	5.40	-	400-
									0.50		59.40	4.70		600

Using wedge action at the slightly open fiber ends, as well as mechanical bonding using fibrillation, sliced and twisted fibrillated polypropylene fibers with open structures have partially treated the lack of interfacial adhesion. The pull-out loads of twisted fibrillated fibers can range from 300 to 500 N for usually utilized staples, but correct link strength calculation is difficult due to a lack of data on the fiber's surface area in contact with the cement. It noted when performing a laboratory experiment on concrete reinforced with fibers, the fibers usually break instead of pulling out. [57].

2.5.2 Fracture properties

Fibers significantly enhance the failure behavior of high-strength concretes. It may be possible to prevent the normal shear bond breakage caused by strain localization. Rather than this, a significant amount of longitudinal cracking, which was often parallel or almost parallel to the external compressive stresses, was generated throughout the concrete specimens.

Concrete creep and shrinkage properties: Fibers lower creep strain, which is described as the time-dependent deformation of concrete under constant pressure. Nevertheless, compressive creep values may be only 10% to 20% of those for ordinary concrete. Fibers also help to prevent concrete shrinkage, which is caused by the loss of water during the drying process. The creep, shrinkage, and total time-dependent deformation of diverse polypropylene FRC combinations in comparison to a non-fibrous concrete blend. Figure 2.6, shows a hybrid fiber-reinforced mix is compared to that one reinforced with high-performance polypropylene fibers (HPPFR) at various doses in a panel load-deflection shotcrete experiment. Steel fibers at 30kg/m³ and polypropylene fibers at 5kg/m³ were utilized in the hybrid fiber mix, whereas polypropylene fibers at 10kg/m³ and 7kg/m³ were used [43].

Reduced shrinking owing to the existence of fibers is predicted From a variety of viewpoints. . Initially, the fibers do not present any shrink, which decreases the total shrinking of the combination. furthermore, the fibers function to maintain the water content of the concrete mix within a certain range, which aids in postponing shrinkage. Moreover, the fibers have a role in limiting the amount of water in the concrete mix, which helps to postpone shrinkage. As a consequence, fibers in concrete mixtures are often beneficial in decreasing shrinkage deformation.

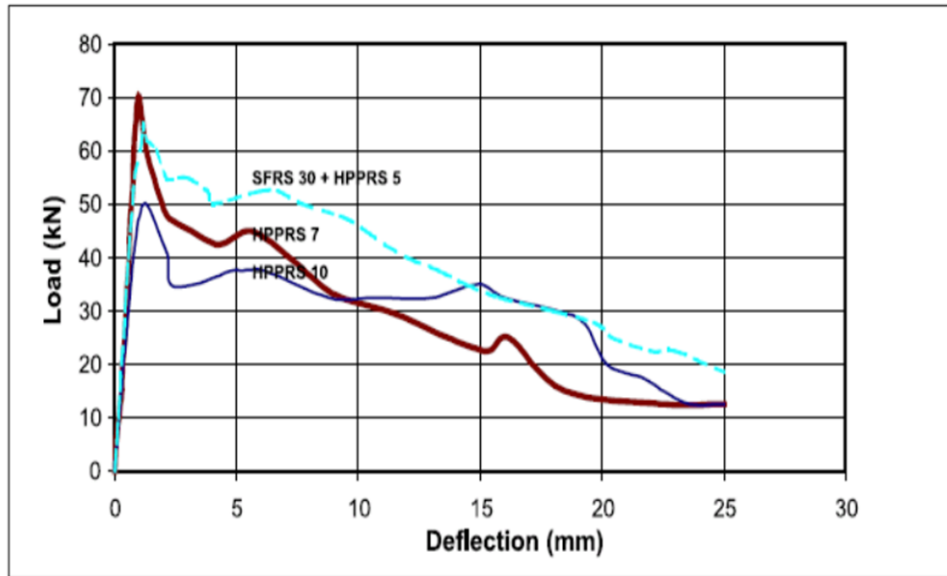


Figure 2.6 Comparison of hybrid fiber reinforcement to HPPFR [44]

2.5.3 Flexural impact properties

The first crack impact number (N_{cr}) is described as the number of blows necessary to form the first apparent crack on the beam's bottom surface. The number at which one primary macro-crack forms from the bottom to the top of the beam is known as the failure impact number N_f . The impact ductility index is described as the proportion of the number of failures impacts to the number of beginning crack impacts, and it may be utilized to determine the flexural impact ductility.

$$J = N_f / N_{cr} \quad (2.1)$$

where J represents the index of impact ductility, which is equal to one for plain concrete. Table 2.3 displays the impact resistance of concretes containing different volume fractions of monofilament polypropylene fibers. The results reveal that concrete's impact resistance has significantly improved. can be attained with a rather small proportion of polypropylene fibers in the volume fraction [58].

Table 2.3 Impact properties of FRC [59]

Type of mix	Vf %	Average Impact number	Average failure Impact number	Impact ductility index
Control	0	25.8	26.8	1.04
Microfilament	0.05	34.7	46.5	1.34
	0.095	28.6	30.4	1.06
	0.14	38.1	40.1	1.05
Monofilament	1	68.9	224.2	3.26
	1.2	70.7	712.7	10.08
	1.4	62.8	831	13.23

2.5.4 Chloride penetration

Apart from the enhanced mechanical characteristics as a result of the presence of fibers, Antoni examined the effect of chloride penetration and concluded that it is negligible for shorter fibers because of their random orientation in comparison to lengthy fibers. Additionally, the presence of fiber as an interfacial transition area considerably reduces chloride migration into concrete in the direction perpendicular to the chloride penetration, while fiber provides an easier channel for the chloride to migrate in the direction of the fiber [54].

2.6 Obstacles in Use of Polypropylene FRC

Despite polypropylene fibers are achieving widespread use in a variety of sectors, In certain properties, there is still a need for improvement. A significant fire will leave the concrete with increased porosity equivalent to the quantity of fibers included in the concrete by a volumetric proportion, which is typically of the order of 0.3 to 1.5 percent. Monofilament fibers have a low pull-out strength due to the inadequate bond among fiber and matrix. Additionally, sunshine and oxygen attack the polypropylene fibers. The polypropylene fibers are also attacked by sunlight and oxygen but the polypropylene FRC that surrounds the concrete shields the fibers so effectively that this flaw isn't noticeable. Furthermore, the function of the fiber as the microcracking initiator is sometimes related to its low modulus of elasticity in comparison to the cement matrix. As a result, the mechanical link between the particles and the cement matrix is similarly weak. By increasing the number of micro-defects in the cement matrix, the fibers increase the volume of the pores in concrete [59].

2.7 Typical Crack Pattern

The combined effects of mechanical stress and environmental variables cause concrete cracking. The stress mechanisms that might result in concrete cracking can really be classified as those that happen in the state of plastic and those that occur in the state of hardened, after which it may be distinguished by if they are caused through internal or external factors. For instance, thermal expansion, Overloading, chemical reactions thermal expansion, and constraint. The fractures generally can vary from minute interior microcracks to extremely massive cracks produced by natural factors [60]. Every neglect throughout the construction process can cause distress in concrete

HCS pavement. Cracks could appear to form these distress in concrete HCSs resulting from a number of variables such as water inclusion, seasonal temperature changes that cause expansion and contraction, and exposure to the sun. Two separate points must be specified in order to construct the theoretical capacity curve: Initially, the activated flange's width is at its first yield panels, and then it's at its complete plasticity of super-assembly [12].

In Figure 2.7, the diagonal cracks were observed within the shear span region. The major diagonal crack propagated with advanced stages of loading until shear failure occurs



Figure 2.7 Mode of failure and cracks pattern of HCS [12]

2.8 Flexural and Shear Load Capacity of Hollow-Core Slabs

The basis for computing the flexure-shear and web-shear strengths in accordance with the ACI 318-05 code. [8] is provided, as well as a shear computation and flexural review for pre-stressed polypropylene HCSs as per ACI 318-05. In a precast HCS exposed to four points loads, web-shear, flexural, flexure-shear, and occurred bond-slip fractures. In the design of HCS, cross-section effective with entire solid lumped components collectively as shown in Figure 2.8 [61]

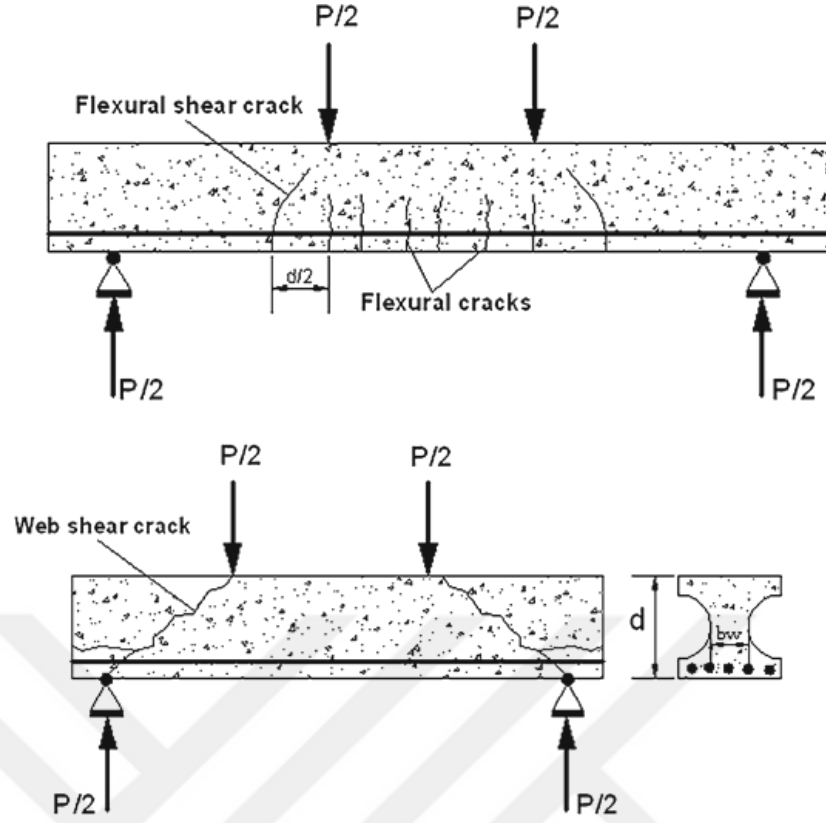


Figure 2.8 Flexural, flexure-shear, and cracks of web-shear in pre-stressed polypropylene HCS [61]

Computed The flexural for concrete prestressed slabs is utilizing the below equation ACI 318-05 [7]:

$$Mn = Apsfps(dp - \frac{\alpha}{2}) \quad 2.1$$

where,

$$\alpha = \frac{Aps.fps}{0.85fc'.bw} \quad 2.2$$

$$fbs = fpu(1 - \frac{\gamma p}{\beta} \cdot \rho p \cdot \frac{fpu}{fc'}) \quad 2.3$$

$$Mu = \phi Mn \quad 2.4$$

$$Mn \geq 1.2Mcr \quad 2.5$$

The flexural cracking strength is given by:

$$Mcr = \frac{1}{yb} \left(\frac{p}{A} + \frac{Pe}{sb} \cdot 0.67\sqrt{fc'} \right) \quad 2.6$$

where Aps is represented to the area of steel prestressing, ϕ refer to factor strength reduction, fps stress in prestressed reinforcement at nominal strength, dp effective depth of the slab, bw net web-width of the slab, β refer to the factor based on strength concrete, specified compressive strength of concrete, $\rho p = Aps/bwdp =$ prestressing

steel ratio, f_{pu} ultimate tensile strength of steel, I is a moment of inertia about the centroid of the section, e represent the distance from the of the gross section centroidal axis to tensile face, S_b moduli for the bottom fiber section, M_n nominal flexural strength and M_{cr} flexural cracking strength.

2.9 Shear Load Capacity of Hollow-Core Slabs

Hawkins and Ghosh [62], Pajari [63], and Pisanty [64] discovered in diverse programs that equations are inadequate in predicting HCS shear load capacity. Without web reinforcement, it is difficult to forecast the shear strength capacity of RC components, and experimental results are inconsistent.

Calculating the shear strength computation of prestressed HCSs also falls into this kind, with a compounding complication factor owing to the variety of voids present in the cross-section and the stresses generated at the holes due to the process manufacturing. These pressures may cause the shear strength of the webs in HCSs to decrease. Simplifications are required when calculating the shear capacity of prestressed polypropylene HCSs with various kinds of voids. In different design programs, the shear capacity equations assume an equal rectangular part or treat finite wide slabs as an I-section with solid portions lumped collectively. The slab's shear strength is calculated using the minimum width of the web in the cross-section via voids circular.

Shear failure in HCSs may be generated by the production of flexural shear fractures or web shear cracks, based on the shear span to ratio depth (a/d) in the arrangement load. The third mechanism of shear failure, which is caused by prestressing steel bond-slip, causes web shear failure in the HCS, which can be catastrophic. The anomaly in the forecast of the flexural and web-shear capacities of HCSs identified in various studies necessitates a knowledge of the ACI 318 code equations used to compute flexural and web-shear strengths

2.10 ACI Equations for Web-Shear Computations

In high shear zones, when the main tensile stress in the web reaches the concrete's tensile strength, web shear cracks develop. At the neutral axis, these inclined fissures begin in the web of the pre-stressed polypropylene HCSs. where the thickness of the web is thin, and then spread in diagonal directions when the load is raised. The web is

stressed in a mixed condition at this high shear zone, with compressive stress induced by prestressing force and shear stress. Vertical tension can be ignored. When the main tensile stress in a small element in this area exceeds the tensile strength of the concrete, web shear cracking develops (f_t). Tensile tension may be expressed using Mohr's circle as [8]:

$$f_t = \sqrt{v^2 + \left(\frac{f_{bc}}{2}\right)^2} - \left(\frac{f_{bc}}{2}\right) \quad 2.7$$

From Eq 2.7, the web shear cracking stress can be written as:

$$V_{cw} = f_t \sqrt{1 + \frac{f_{bc}}{f_t}} \quad 2.8$$

The web shear capacity (V_{cw}) of HCS with prestressing steel is then shown as:

$$V_{cw} = \left(f_t \sqrt{1 + \frac{f_{bc}}{f_t}}\right) b w d p + V_p \quad 2.9$$

Using a conservative value of $f_t = \sqrt{1 + \frac{f_{bc}}{f_t}}$

and simplifying the term under square root which gives a close result, the web shear capacity for HCS with horizontal prestressing steel ($V_p = 0$) can be written as:

$$V_{cw} = (0.3\sqrt{f_c'} + 0.3f_{pc}) b w d p \quad 2.10$$

where f_{pc} is the effective prestress at the centroid of the slab.

CHAPTER III

METHODOLOGY

3.1 Introduction

This chapter presents all the procedures utilized throughout the project in order to investigate the behavior of polypropylene FRC panels. The present work used a model of polypropylene FRC hollow slab to investigate the shear strength of one-way slab of FRC and the degradation of concrete mechanical properties. The different numerical methods and a number of computerized algorithms are applied in order to solve and analyses problems that involve the structural and materials. The analysis incorporates many critical parameters, particularly the slab thickness and the reinforcing system, to investigate their impact on the flat slab behavior. A parametric analysis was conducted to investigate the variables that may have the most impact on the model's mechanical behaviors, like changing the loading types. This work purpose to produce a numerical model capable of forecasting the one-way slab of polypropylene FRC characteristics in the simulated model in order to investigate the shear strength behavior. The calculations required simulating the interaction of structures with different effective parameters, and initial conditions are done by the ANSYS software program. The methodology procedure in this work will test the model by discretizing the partial differential equations into such a limited set of control volumes, which also are denoted by the terms meshes and cells. After that, the solver will prepare the general conservation equations. The partial differential equations are solved numerically to render the solution field based on structural analysis. The procedures utilized throughout this project as shown in Figure 3.1 which represent the first stage of this work.

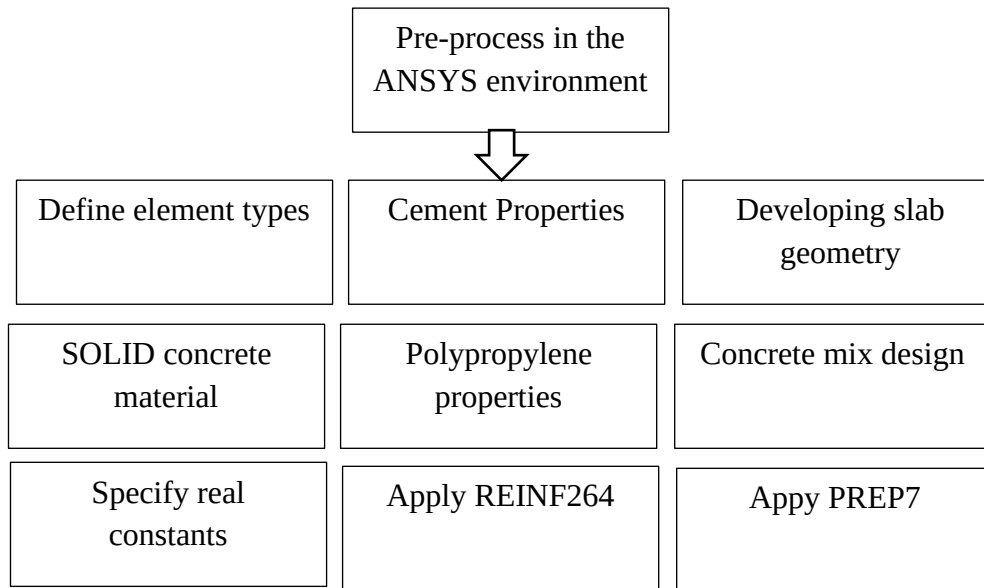


Figure 3.1 First stage of the project

The second stage is by modeling the representation of the hollow core structure and operation of an interesting system. A model is a representation of a system that is comparable to but easier than the system it represents. A model's objective is to enable the analyst to forecast the impact of system modifications. Also, a model ought to be a close representation of the actual system and include the majority of its salient characteristics. On the other hand, it should not be so difficult that it becomes unusable to comprehend and experiment with. The general modeling solution processes are shown in Figure 3.2. The sequence could be classified into a few major steps:

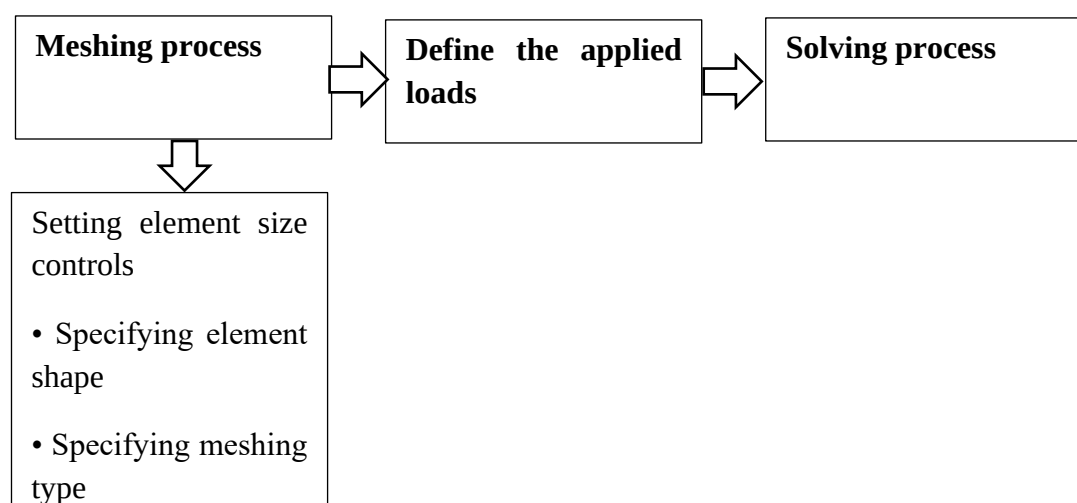


Figure 3.2 Modelling solution sequence

An excellent model is a judicious trade-off between simplicity and realism. The commercial software which is used to solve structural problems can be expressed by ANSYS. ANSYS structural analysis software enables the simulation of all structural aspects of a product, incorporating linear static analysis, which provides basic deformation or stress. Vibration characteristics are determined by modal analysis, through advanced transient nonlinear phenomena including complex behaviors and dynamic effects in accordance with the current procedure, the present work will be implemented as in the next sections.

3.2 Steps for Pre-Processing in the ANSYS

The process of parameters identification of the chosen material model from ANSYS database was carried out in the ANSYS environment via numerical calculation of the database of the model. Initial data of materials parameters represent the basis for the optimization or the evaluation process. The requirements for initial studies depend on the constraints and goals of the study. The first role in the initial study is all studies referenced in defining constraints and goals must belong to the same configuration. The phases are considered below:

3.2.1 Specify geometric data specification

The first stage to investigate the slab model involves specifying the concrete and other components' characteristics. It's an important part of the simulation procedure to gain accurate results of the model behavior. The following steps present the ANSYS procedure:

3.2.1.1 Define element types

In this step, the window message will present a set of options, For 3D modeling of solids both with and without reinforcement bars, the option SOLID65 is utilized. Another circumstance for which the element is also usable would be geological substances (like rock), and reinforced composites (like fiberglass). In tension, the solid might crack, and in compression, it can crush. Eight nodes describe the element, each node with three degrees of freedom: there are translations in the nodal directions x , y , and z as shown Figure 3.3. Up to three distinct rebar specifications might be described. The element of concrete resembles a three-dimensional solid structure, but it has additional particular cracking and crushing abilities. The much more vital point

about this element is how it deals with nonlinear material characteristics. Concrete has the ability to fracture (in three orthogonal directions), flex plastically, creep and crush. The rebar is capable.

The bar is tensile and compression resistant, Plastic deformation and creep are also possible.

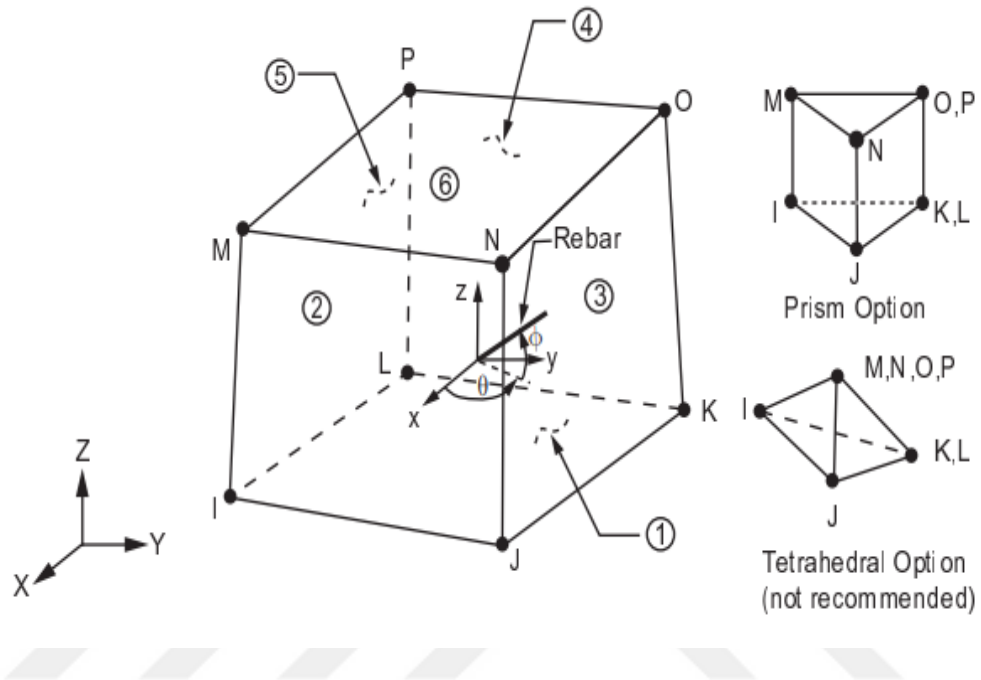


Figure 3.3 SOLID65 element representation in ANSYS

The added concrete material information such as shear transfer factors, tension stresses, and compressive stresses are entered in the data table, as shown in Table 1. The ANSYS configuration of practical model implementation is shown in Figure 3.4.

Table 3.1 Solid concrete material options

Constant	Meaning
1	Shear transfer coefficients for an open crack.
2	Shear transfer coefficients for a closed crack.
3	Uniaxial tensile cracking stress.
4	Uniaxial crushing stress (positive).
5	Biaxial crushing stress (positive).
6	Ambient hydrostatic stress state for use with constants 7 and 8.
7	Biaxial crushing stress (positive) under the ambient hydrostatic stress state (constant 6).
8	Uniaxial crushing stress (positive) under the ambient hydrostatic stress state (constant 6).
9	Stiffness multiplier for cracked tensile condition, used if KEYOPT(7) = 1 (defaults to 0.6).

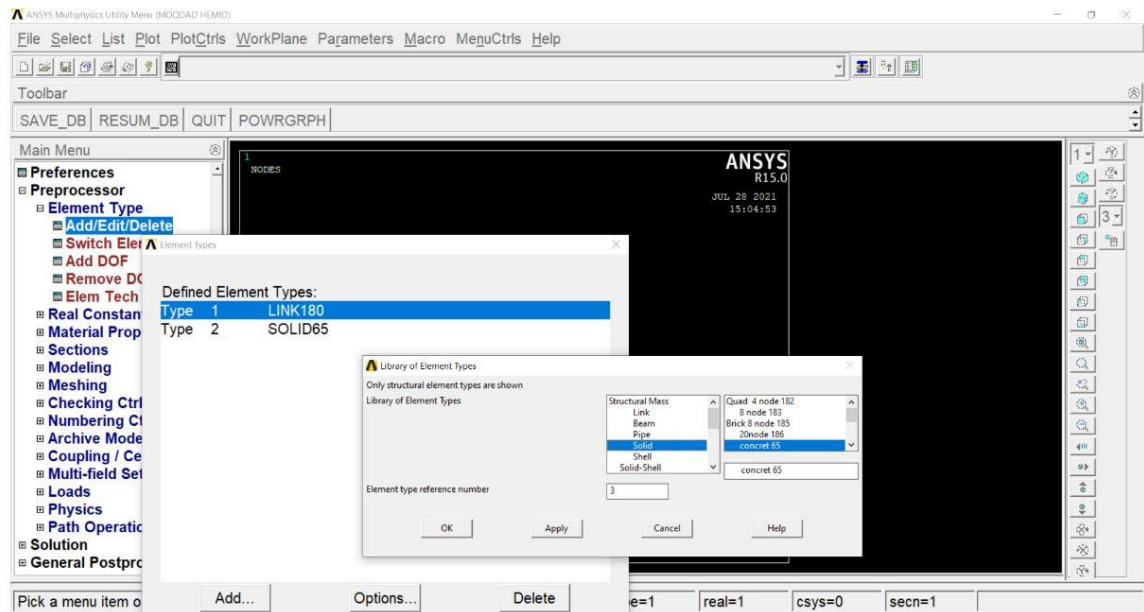


Figure 3.4 Configuration of elements type definition

3.2.1.2 Specify the real constants

The information needed for the calculation of the component matrices and load vectors is entered as real constants (see Figure 3.5). (eight characters maximum) A name is used to identify an element form. The Element Library is arranged in order to identify numbers and by typing its name into the element type order, can select from the library for use in the analysis (ET).

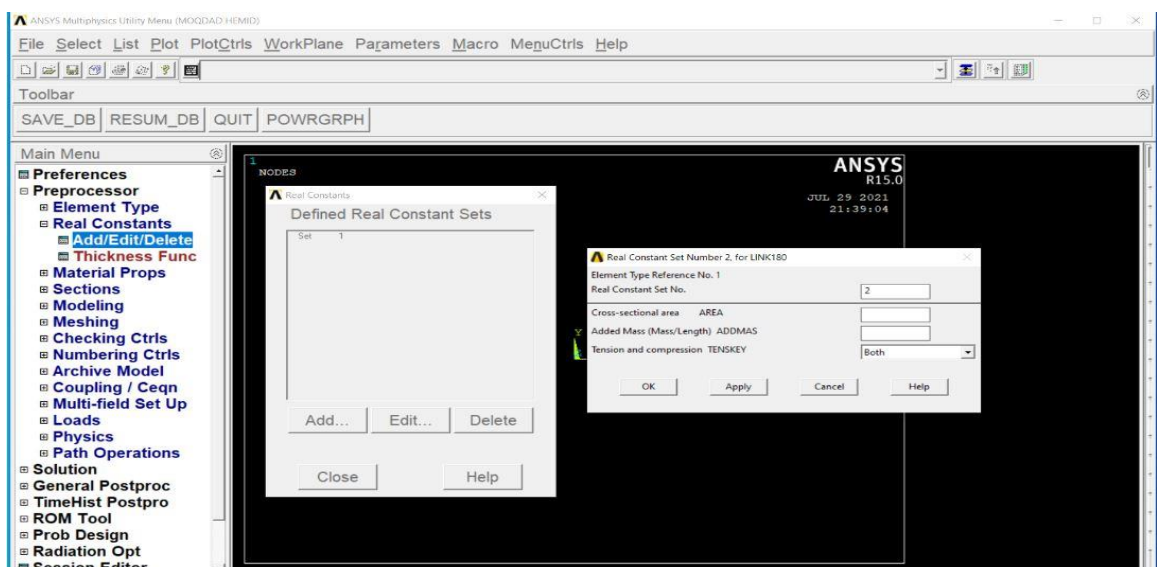


Figure 3.5 Real constant specification

For structural reinforcing analysis, to supply additional reinforcement to the tendon 3D link, beam, shell, and solid elements (referred to as the base elements), use REINF264. The element can usage to model reinforcing fibers of any direction. Each fiber is performed as a single spar with only uniaxial toughness or accessibility. Multiple reinforcing fibers can be particular in a single REINF264 element. The REINF264 element has similar nodal locations, freedom degree, and connectivity as the base element.

3.2.1.3 Used material properties

The most important requirements in the modern technological age are building materials and construction materials. For various construction projects, a variety of building materials are used.

The concrete: Table 3.2 shows the typical properties of normal strength Portland cement concrete..

Table 3.2 Material properties of concrete

Parameter	Value
Density – ρ	2400 - 2 kg/m ³ (140 - 150 lb/ft ³)
Compressive strength	40 – 45.1 MPa (6000 - 6300 psi)
Flexural strength	5 - 6 MPa (700- 8500 psi)
Tensile strength – σ	4-4.5 MPa (700 - 7500psi)
Modulus of elasticity – E	31- 32 GPa (6 - 7 x 10 ⁶ psi)
Permeability	1 x 10 ⁻¹⁰ cm/sec
Coefficient of thermal expansion – β	10 ⁻⁵ oC ⁻¹ (5.5 x 10 ⁻⁶ oF ⁻¹)
Drying shrinkage	8 - 9 x 10 ⁻⁴
Drying shrinkage of RC	3 - 3.25x 10 ⁻⁴
Poisson's ratio	0.20 - 0.21
Shear strength – τ	17- 20 Mpa
Specific heat – c	0.75J/kg K (0.18 Btu/lbm oF)

Polypropylene: the typical properties of normal strength fiber materials as taken in Table 3.3

Table 3.3 Fiber polypropylene of properties

Parameter	Polypropylene
Density ρ (kg/m ³)	910
Tensile Strength (MPa)	400
Elastic Modulus E (GPa)	3.64
Nominal aspect ratio (length/diameter)	53
Length (mm)	40

Tendons: The longitudinal reinforcement's yielding stress f_{ym} and ultimate stress f_{um} are specified in Table 3.4.

Table 3.4 Tendon Properties

Parameters	Bar samples		
	6/10"seven-wire strands	3/8seven-wire strands	6Three-wire tendons (D of wire 3mm)
Yield strength MPa	1819 MPa	1734	1854
Ultimate tensile strength, MPa	1986	1933	2021
Elongation, %	1.05%		
Reduction in area, %	1.05%		
Initial Prestress MPa	1200		

According to earlier researches and studies, fibers are more active with a mixture with total mix percentage as shown in Table 3.5.

Table 3.5 Concrete mix design for RC and polypropylene FRC.

Mix code	River sand (kg/m ³)	Crushed sand (kg/m ³)	Crushed gravel 2/7mm (kg/m ³)	Crushed gravel 8/15 mm (kg/m ³)	Cement I 52.5R (kg/m ³)	Cement II/A-LL 42.5R (kg/m ³)	Water /cement ratio	PP fiber (kg)
RC	330	410	551	650	120	240	0.43	0
FRC	330	410	551	650	120	240	0.43	10.5

3.2.1.4 Specify material models

The material model was set using a pre-programmed batch process. It was capable of completing the entire calculation this way. The simplicity with which an external script could be called to evaluate the similarity between the reference data and the calculated results was a benefit of this procedure. There are many different types of material elements to select (such as anisotropic hyper elasticity, cast iron plasticity, enhanced Drucker-Prager plasticity, Hill plasticity, hyper elasticity, shape memory alloy, plasticity, rate-dependent plasticity, viscoelasticity, and others). As a result, the programmed batch completed the assembly of the computational model's geometry, the definition of the material model, the start of nonlinear calculations, and the execution of the external script that enabled the calculation of the objective function value. see Figure 3.6).

Steel bars of steel reinforcement modeling approach was introduced for the linear isotropic model with 2×10^5 MPa and poisson ratio of 0.3 and nonlinear inelastic with yield stress preliminary values were 1819 MPa for 6/10" seven-wire tendons; 1734 MPa for 3/8" seven-wire tendons; 1854 MPa for three-wire tendons.

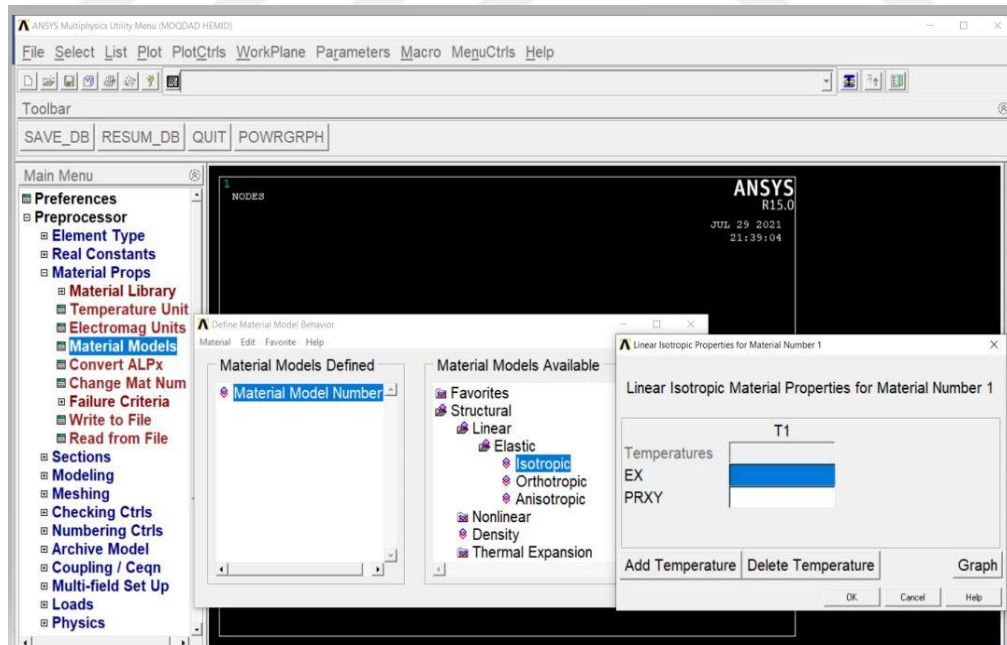


Figure 3.6 Material constitutive options

Nonlinearity was incorporated by linear interpolation of the material parameters concerning stress in the models, which have an integral form based on classical linear viscoelastic cases. The generated viscoelastic model follows the traditional rheological

linear viscoelastic modeling approach. Figures 3.6 and 3.7 show the modeling processes.

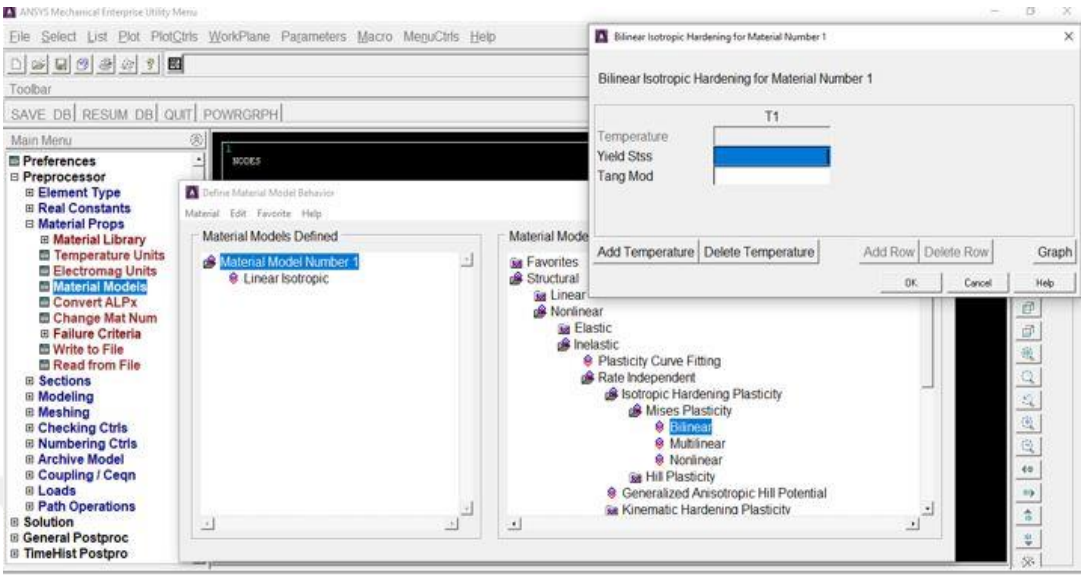


Figure 3.7 Initialize material parameters

For concrete material, a modeling approach was introduced for the elastic isotropic model with elastic isotropic preliminary values of 31560 MPa and poison ratio of 0.2 and multi-linear strain preliminary values from 0.0001 to 0.003 and stress values from 3.1560 to 45.1 as shown in Figure 3.8. Then the density of concrete will be transferred throw the model with the preliminary values of 2500 kg/m³ as shown in Figure 3.9.

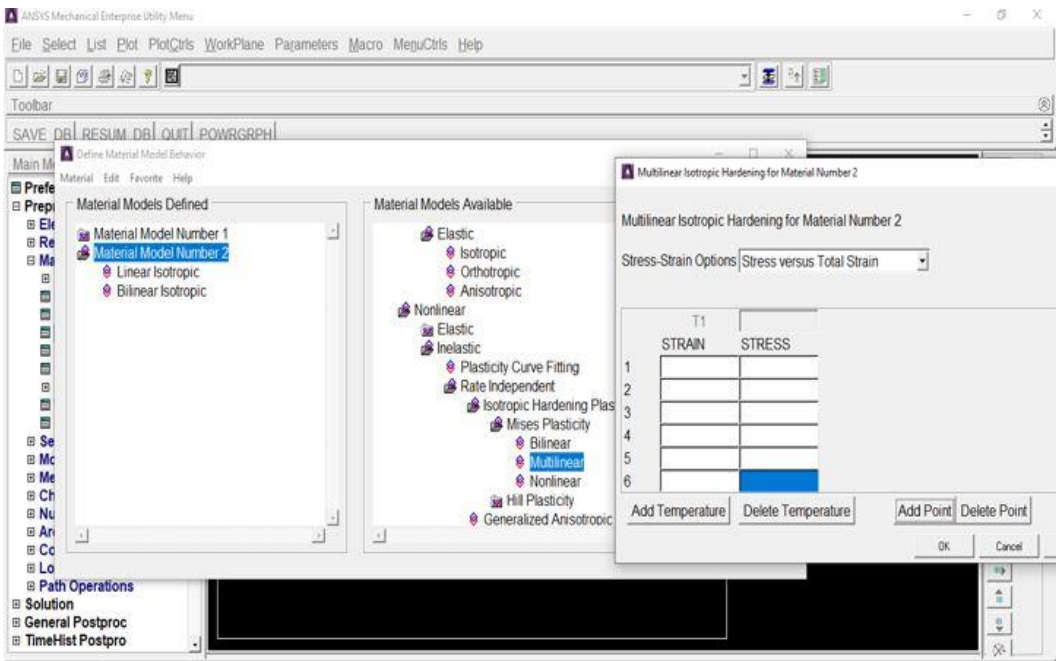


Figure 3.8 Strain stress initialization

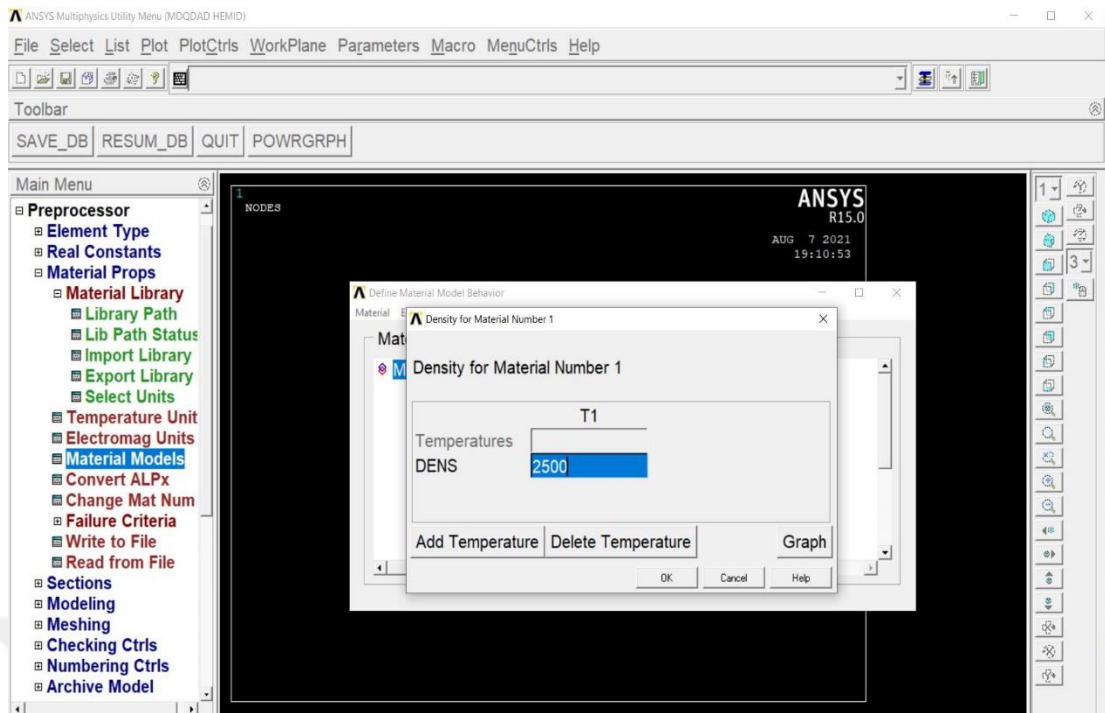


Figure 3.9 Density initialization

The other concrete features will be fixed in the integration with non-metal plasticity and the preliminary values presented in Table 3.6 and ANSYS plasticity interface is shown in Figure 3.10

Table 3.6 Non-metal plasticity initialization

Parameter	RC	FRC
Open shear transfer coefficient	0.2	0.2
Close shear transfer coefficient	0.8	0.8
Uniaxial cracking stress MPa	4.5	4
Uniaxial crushing stress MPa	45.1	40

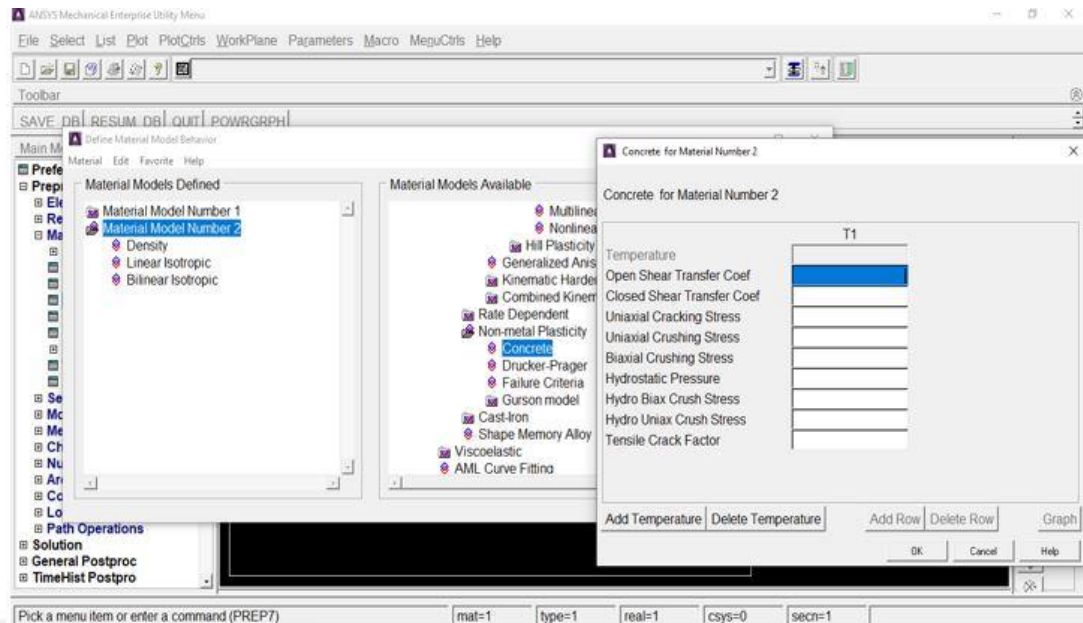


Figure 3.10 Non-metal plasticity interface

Based on the inserted data, the geometrical shape must be developed using the dimensions mentioned in previous studies.

3.2.1.5 Developing slab geometry

The procedure for specifying the geometric configuration of the model's elements and nodes will be presented in a model generation. ANSYS has two essential features to build geometry; they are; Nodes, which can be defined as a coordinate location in a field describing the Degrees of Freedom (DOF). The DOF of the structure for the point indicates the plausible movement of this node or point as a natural result of the structure's loading. The degree of freedom (DOF) of structure also indicates how forces and moments are transferred from one element to the next. The second feature is the elements which can be defined as the primitive building block of FE analysis. It is a calculated relationship that describes how a node's degree of freedom relates to the degree of freedom of the next node. There are many essential types of elements. Lines (trusses or beams), areas (2D or 3D plates), and solids (bricks or tetrahedral) are examples of these elements. Different element types are chosen based on the analysis class that is going to be completed. ANSYS program involves the following approaches to model generation:

- a. Start with planning the slab dimensions and reinforcement type and steel bars position.

- b. Launch the preprocessor (PREP7) to begin a model-building session using solid modeling procedures.
- c. Generate a solid model from the modeling code, then create the slab block by dimensions as shown in Figure 3.11.

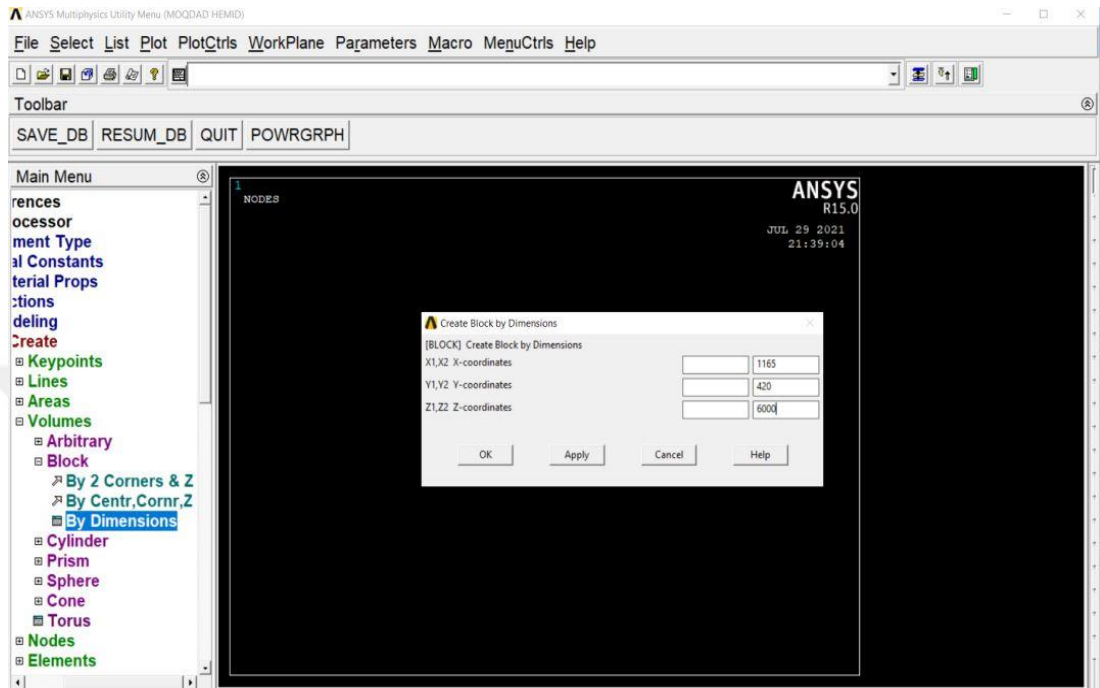


Figure 3.11 Drawing geometry shape

By using the basic tools of drawing which plane is utilized to draw the model, On the detail drawing, the proper views are can simply be generated. A list of import preferences is presented for each geometry cell. When enabling property viewing in the project schematic, these preferences should show in the properties pane. When a geometry cell is created, the preferences associated with the geometry section should be used to determine its initial settings. When importing the geometry into an editor, the import preferences scheduled for that cell in the property view will be utilized.

Display in working plane operators the offsets to create reinforced steel bars. The result of the drawing step is the geometric shape of the slab plane as exposed in Figures 3.12 and 3.13.

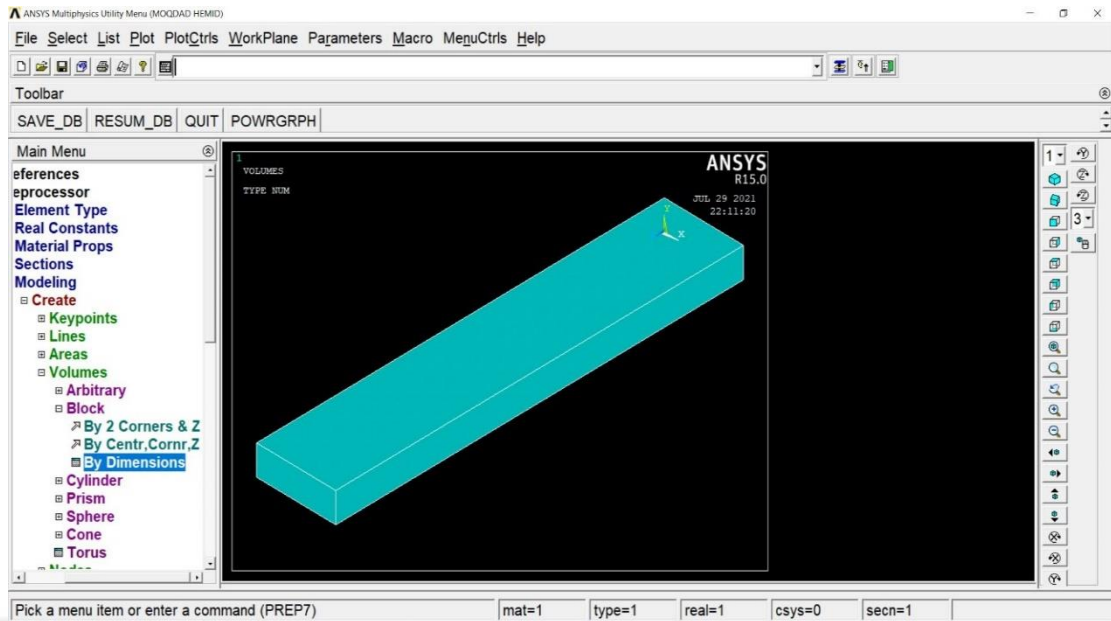


Figure 3.12 Slab plane drawing result

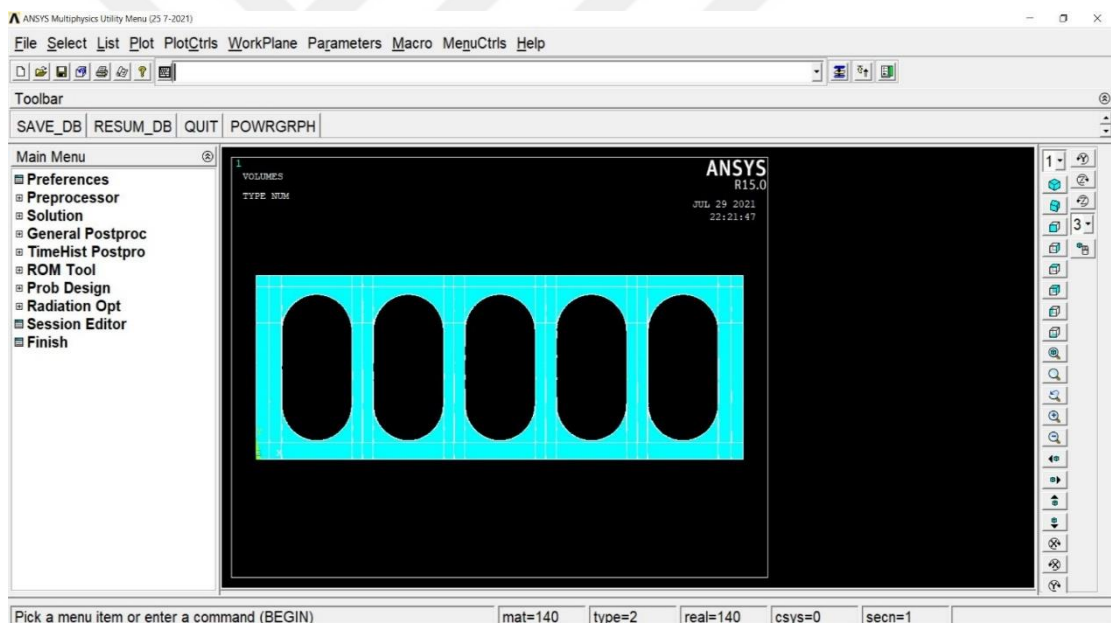


Figure 3.13 Slab plane reinforcement result

After that, the process of meshing the geometry will apply to create the nodes and elements inside the slab plane to discrete the geometry and find the force effects.

3.2.1.6 Meshing process

The next step is to mesh the geometry. It needs to utilize the ANSYS Meshing function to make a computational mesh for the analysis of structure during the slab volume. Setting element attributes and Mesh controls are required steps in the procedure for

creating a mesh of nodes and elements. A large number of mesh controls are displayed in ANSYS. The ANSYS Mesh Tool (Main Menu> Preprocessor> Meshing> Mesh Tool) provides appropriate access to many of the most commonly used mesh controls as well as meshing operations. The Mesh Tool is a user-interactive "toolbox" that will remain open until close or exit PREP7. Even though each of the jobs existing via the Mesh Instrument is too existing by the conventional ANSYS utilizing the Mesh Instrument as a shortcut for commands and menus is a handy shortcut. The Mesh Tool has numerous purposes, including:

- Governing Smart Sizing levels
- Set element size orders
- Defining a form of an element
- Choosing a meshing form (free or mapped)
- Entity meshing of Solid model
- Meshes for clearing
- Refinement of Meshes

The 3D mesh elements can be of two types namely Triangular and Quadrilateral. The use of a triangular element creates an unstructured mesh whereas; the use of a quadrilateral element creates a structured mesh. To make a mesh, each count of elements or the size of the element can be identified. usually, to controller the size of mesh-element ends for the geometric ends and for aspects or sizes that are meshed utilized the size functions. Meshing results propose a discretization of the case study. It is the most important part of an analysis and can determine the efficiency and effectiveness of analysis because it gives the FE analysis. Therefore, a lot of time is given to the meshing of complex models. In our case study, the mesh result can be shown in Figure 3.14.

It observed that the boundary layer contains multi types of discretization which enable us to analyze the boundary layer in more specific detail to get higher accuracy results. the plane of difficulty occurrence in meshing the geometry is measured by complexity is a measure of. Many sides are identified to create mesh generation hard involving topology regulation, near-tangencies, etc. Meshing complication includes the translation of these complexities into a metrical that specified them.

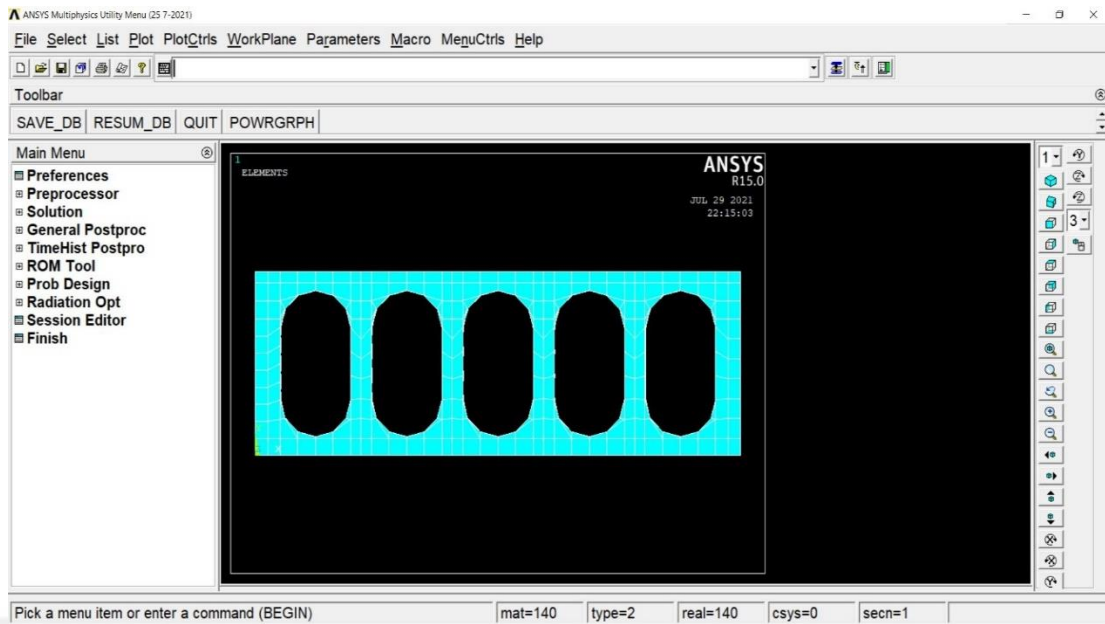


Figure 3.14 Mesh file configuration

For example, There's a lot of geometry out there with amazingly complex curves and surfaces that can be meshed easily .similarly, a model might be constructed quickly using linear curves and flat surfaces but may be difficult to mesh. The measure may be utilized to identify invalid and potentially poor-quality parts, which could result in a bigger solution. In this model, it was meshed into relatively large elements due to the large dimensions of the panel, 50 * 50 *50 cm dimension the elements, to produce 33,909 elements and the number of nodes 41140

3.2.1.7 Define applied loads

The applied loads can be defined directly on the solid model before or after FE meshing. Each element with structural degrees of freedom and mass (that is, elements with mass as an input real constant or a density (DENS) material attribute) are subject to inertial loads (gravity, spinning, etc.). two types there are of load applying methods; nodal loads can be utilized at nodes but aren't directly associated with the elements. The D and F commands are used to input nodal loads, which are connected to the degrees of freedom at the node (such as nodal displacement constraints and nodal force loads). For an element, the element loading format takes precedence over the nodal loading format. KEYOPTs (key options) are used by some beam and shell elements to impact element behavior, formulation, and output. The KEYOPT is the most significant input element and should be chosen carefully. The KEYOPTs can be used

to regulate stress states, degrees of freedom, element technologies, formulation choices, element coordinate systems, printing, results file (.rst) output, loads, and temperatures, among other things, depending on the element type. Each KEYOPT has a simple definition as well as a full description of each element type. Due to KEYOPTs being able to be combined, a large deal of elasticity is existing for improving the element form to completely match a definite problem. Figure 3.15 observes the application of this operation on the slab plane.

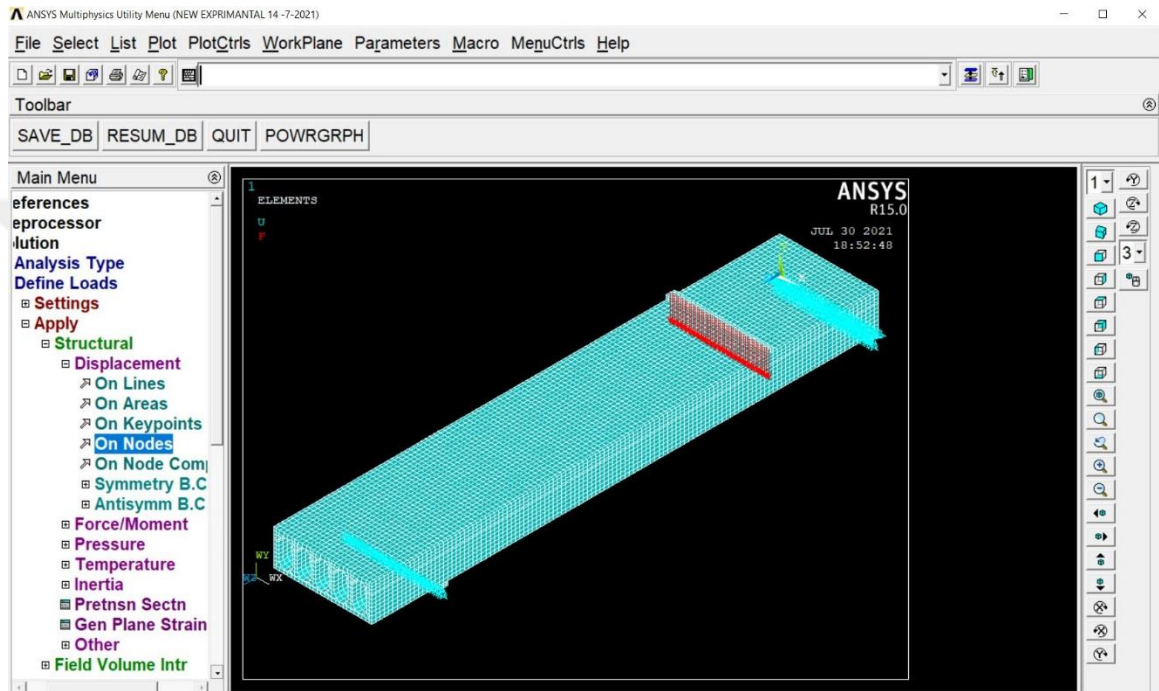


Figure 3.15 Applied load on slab elements

3.2.1.8 Solving process

When the solution calculations are applied, the loads from the solid model are immediately transferred to the finite element model. SOLVE order includes (Main Menu> Solution> Solve> Current LS)) as exposed in Figure 3.16.

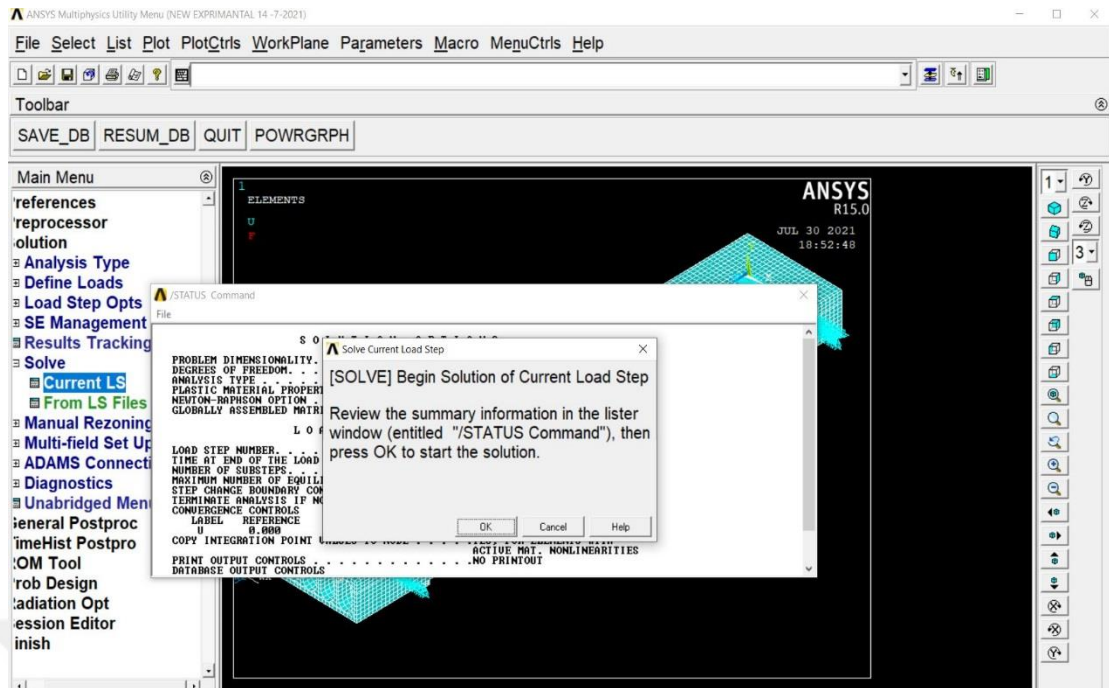


Figure 3.16 ANSYS solve command

The model creation, which includes meshing, is finished after preprocessing. The solution phase is offered by ANSYS. During the solution process, ANSYS allows you to pick specific choices. They can be set up using Analysis Options or Solution Controls. Users are able to use APDL orders to plot stresses from the ANSYS APDL simulation to check the plotted stress account in the receiving model. It can be capable of restricting each degree of freedom in the receiving model, deleting any other loads, and solving. When these material properties are linear, the charted stress values should be existing to list and draw as results over the model.

CHAPTER IV

VERIFICATION OF FINITE ELEMENT MODELS

4.1 Introduction

Chapter four includes an analysis of one-way RC HCSs using the FE method .The investigations are carried out using ANSYS software and FE modeling to investigate the flexural behavior and Sustainability Analysis under static load. Two examples that are experimentally tested by Mahdi and Ismael [65] were modeled and analyzed. The FE model's predicted response is hollow-core RC one-way slabs as compared to the corresponding experimental response. Verification examples are used to ensure that these models are valid and accurate.

4.2 Hollow Slab and Solid Slab under Flexural Load

4.2.1 Model 1: Normal concrete solid and one-way HCSs

Mahdi and Ismael [65] tested four specimens to study flexural behavior and sustainable term analysis of RC HCSs is modeled in this research.

4.2.1.1 Description of experimental specimen

Four one-way RC slabs with dimensions of, length =1700 mm, width 435 =mm width, and depth =125 mm, when cast then tested by Mahdi and Ismael [65]. As a starting point, use the first solid slab, The others were HCSs with different numbers of longitudinal voids (two, three, and four) with 75mm diameters and the descriptions 2D75, 3D75, and 4D75, respectively. The effective span of the tested beam was 1500mm. The cylinder compressive strength (f'_c) of the specimen was 28.6 MPa. steel reinforcement As main and secondary, steel bars with diameters of 6 and 4mm and yield stresses of 497MPa and 430MPa respectively. The modulus of elasticity was 197,194 GPa. Figures 4.1 and 4.2 show details of solid and HCSs,

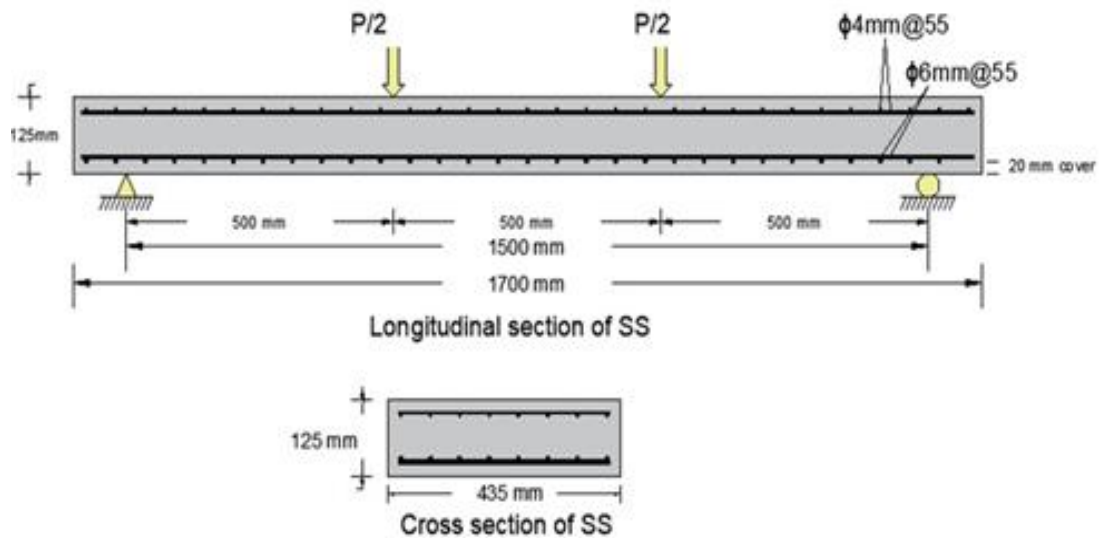


Figure 4.1 Details of the solid slab [65]

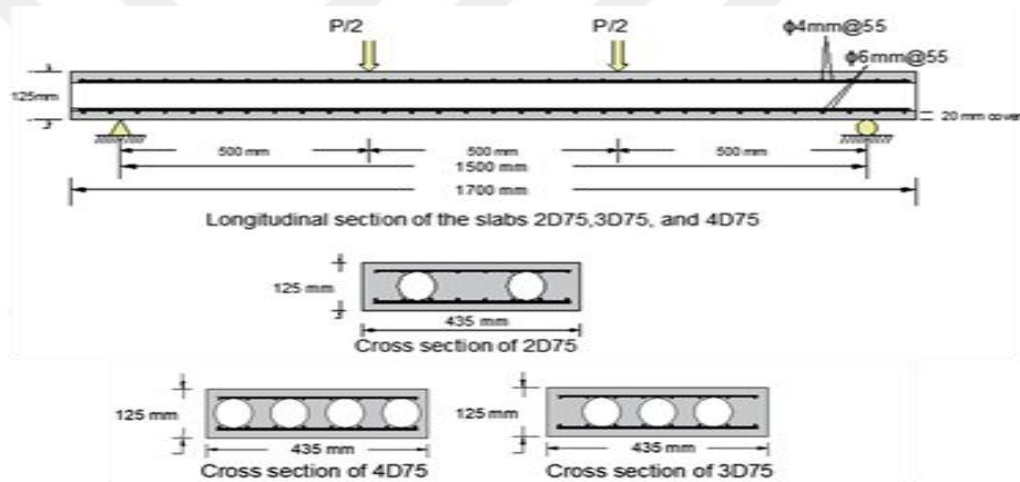


Figure 4.2 Details of the HCS with the different number of longitudinal voids [65].

4.2.1.2 Finite element modeling and material properties

The one-way slab was modeled as simply supported under two loads. The model was generated with the three-dimensional finite solid element one-way slab was modeled using SOLID65 brick elements for concrete while the steel reinforcement was modeled using LINK180. SOLID185 elements were used to simulate steel plates which were chosen for supports and load placement at the top and bottom. Table 4.1 shows material properties and additional material parameters.

Table 4.1 Material properties for normal strength RC solid and HCSs [65].

Concrete ($f'c=28.6\text{MPa}$)
Modulus of elasticity $E_c = 25135 \text{ MPa}$
Poisson's Ratio $\nu = 0.2$
Uniaxial Cracking Stress = 3 MPa
Uniaxial Crushing Stress = 28.6MPa
Open Shear Transfer Coef. $\beta_t = 0.4$
Close Shear Transfer Coef. $\beta_c = 0.9$
Steel reinforcement
Modulus of elasticity $E_c = 200000 \text{ MPa}$
Poisson's Ratio $\nu = 0.3$
Yield Stress with diameters of 6 $f_y = 497 \text{ MPa}$
Yield Stress with diameters of 4mm $f_y = 430\text{MPa}$
Load Plates
Modulus of elasticity $E_c = 2\text{E}10\text{MPa}$
Poisson's Ratio $\nu = 0.3$
Yield Stress $f_y = 400 \text{ MPa}$

4.2.2 Model 2: High strength, self-compacting concrete solid and HCSs

Mahdi and Ismael [65] tested two groups of specimens to study the effect of longitudinal voids diameter and longitudinal voids numbers on the structural behavior of high strength HCS.

4.2.2.1 Description of experimental specimen

Six reinforced high strength self-compacted concrete one-way slabs have been tested Mahdi and Ismael [65]. The dimensions are 1700 mm long, 435mm wide, and 125 mm thick. These slabs were divided into two groups. The first group consists of one solid slab that acts as a control and three HCSs with three longitudinal gaps of varying diameters. (50, 63, and 75 millimeters), The second group consists of three HCSs with varied numbers of 75mm diameter longitudinal voids (two, three, and four), as well as the identical solid slab as group one. The cylinder compressive strength ($f'c$) of the specimen was 60.8 MPa. As main and secondary steel reinforcement, deformed steel bars with diameters of 6 and 4mm and yield stresses of 497MPa and 430MPa

respectively. Modulus of elasticity was 197,19 GPa. Figures 4.3 - 4.5 show details of solid and HCSs.

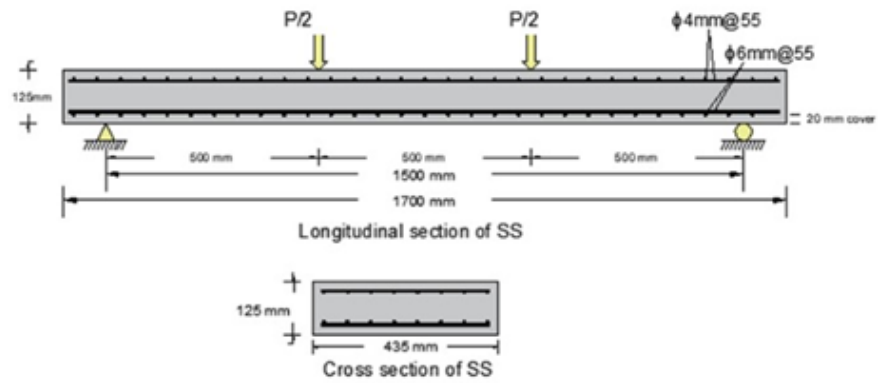


Figure 4.3 Details of the solid slab [65]

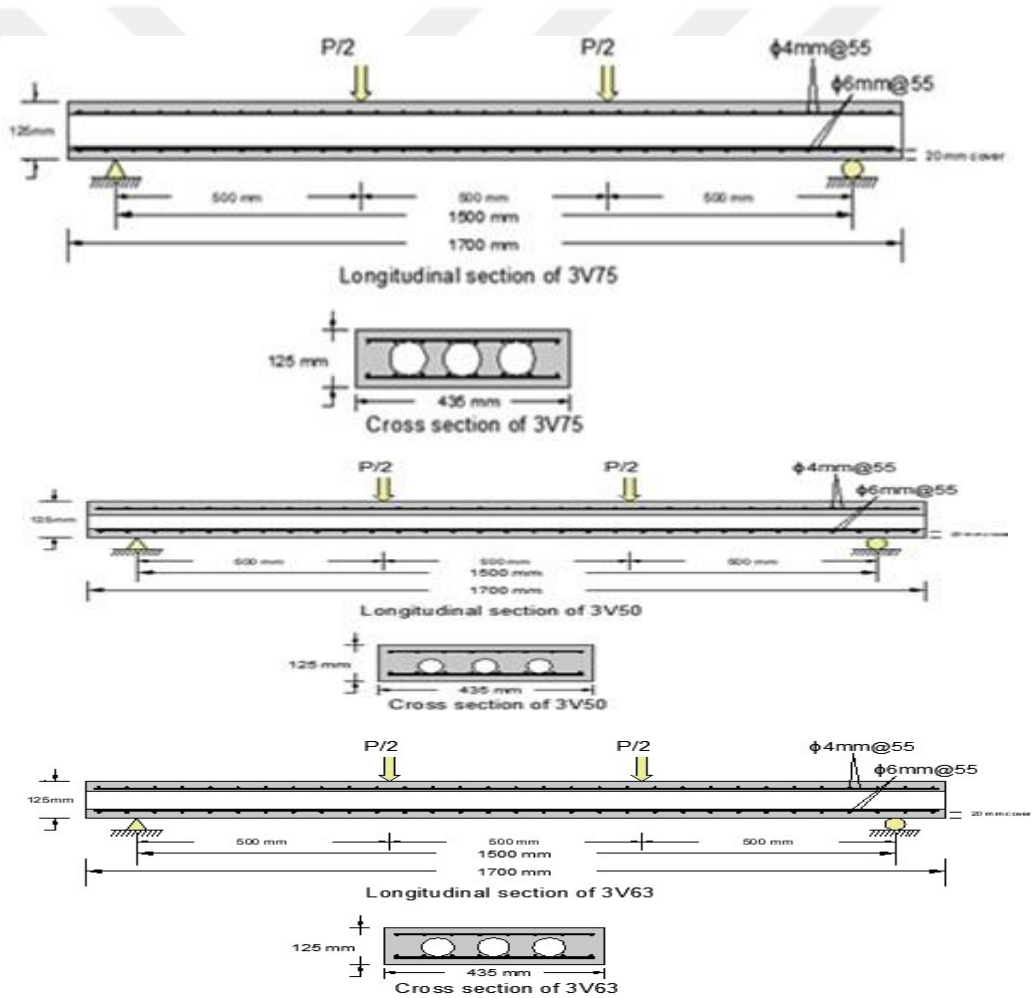


Figure 4.4 Details of the HCS slabs with variable hole diameter [65]

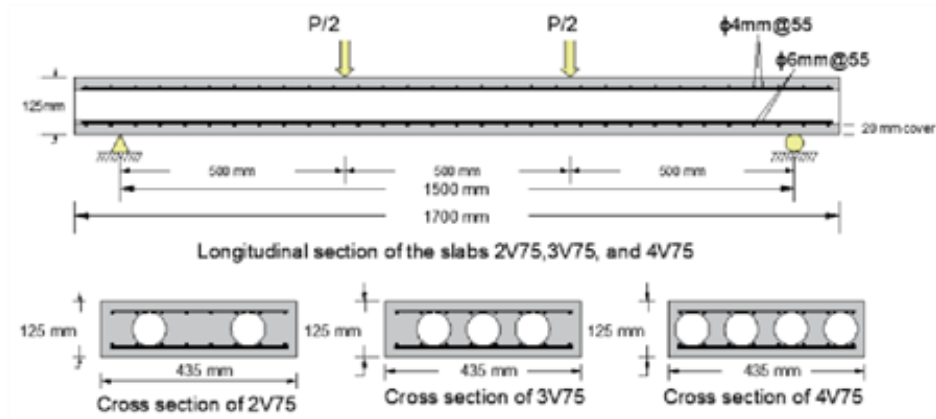


Figure 4.5 Details of the HCS slabs with 2, 3, and 4 holes [65].

4.2.2.2 Material properties and finite element modeling

One way was tested as a simply supported slab under two loads and the model was generated with the three-dimensional finite solid element one-way slab was modeled using Solid65 brick elements, while the steel reinforcement was modeled using LINK180. SOLID185 components were used to simulate steel plates. the normal properties of typical strength Portland cement concrete and the typical properties of normal strength steel bar materials exposed in Table 4.2.

4.2.3 Loading and boundary conditions

Dimensions of the steel plates with dimensions of 50 mm width, 435 mm length, and 30 mm thickness were used for supports and load placement at the top and bottom. The size of the plate mesh was set to correspond with the concrete mesh element to minimize stress concentration and ensure the most uniform distribution of stresses. SOLID185 components were used to simulate steel plates with three degrees of freedom for each node (the displacements in X, Y, and Z directions). As shown in Figures 4.6 and 4.7, the applied loads were modeled as a line load distributed on top nodes (13 nodes per plate) along the centerline of the plates. Figure 4.8 shows the shape of HCS 4D75.

The centerline of the steel plate of supports was constrained as a simple support to enable rotation of the support under the concrete nodes to apply the true boundary requirements. As shown in Figure 4.7, the right steel plate was assumed to have $U_Y=0$, whereas the left steel plate was constrained to have $U_Y=0$ and $U_Z=0$.

Table 4.2 Material properties for high strength RC solid and HCSs

Concrete($f'c=60.8$ MPa)
Modulus of elasticity $E_s = 36647\text{MPa}^*$
Poisson's Ratio $\nu = 0.2$
Uniaxial Cracking Stress = 6MPa
Uniaxial Crushing Stress = 60.8MPa
Open Shear Transfer Coef. $\beta_t = 0.4$
Close Shear Transfer Coef. $\beta_c = 0.8$
Steel reinforcement
Steel reinforcement
Modulus of elasticity steel diameters 6mm $E_s = 197000$ MPa
Modulus of elasticity steel diameters 4mm $E_s = 194000$ MPa
Poisson's Ratio $\nu = 0.3$
Yield Stress steel diameters 6mm $f_y = 497$ MPa
Yield Stress steel diameters 4mm $f_y = 430$ MPa
Loading plates
Modulus of elasticity $E_s = 2e10$ MPa
Poisson's Ratio $\nu = 0.3$
Yield Stress $f_y = 400$ MPa

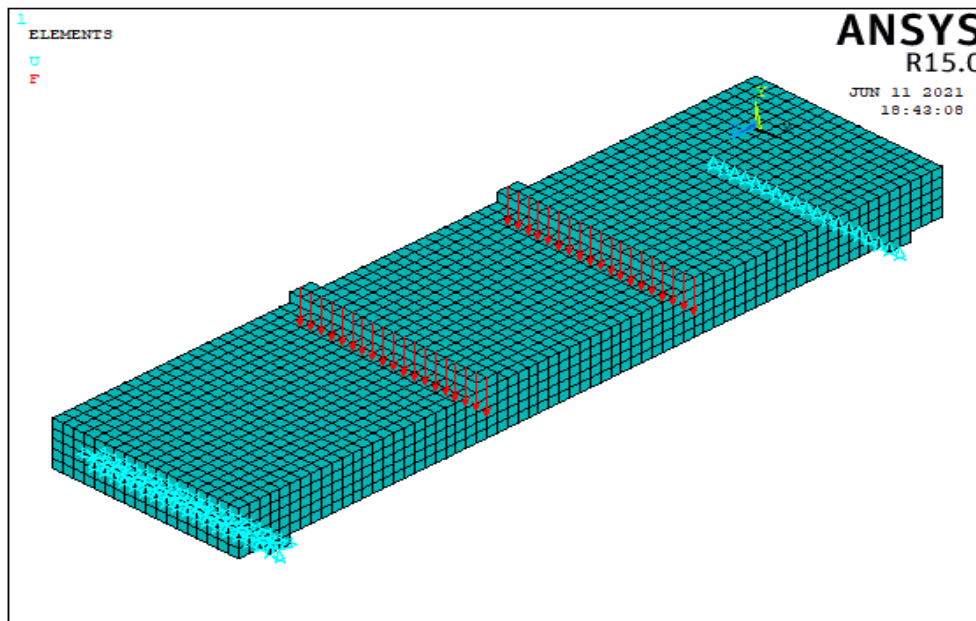


Figure 4.6 Applied loads for solid slab

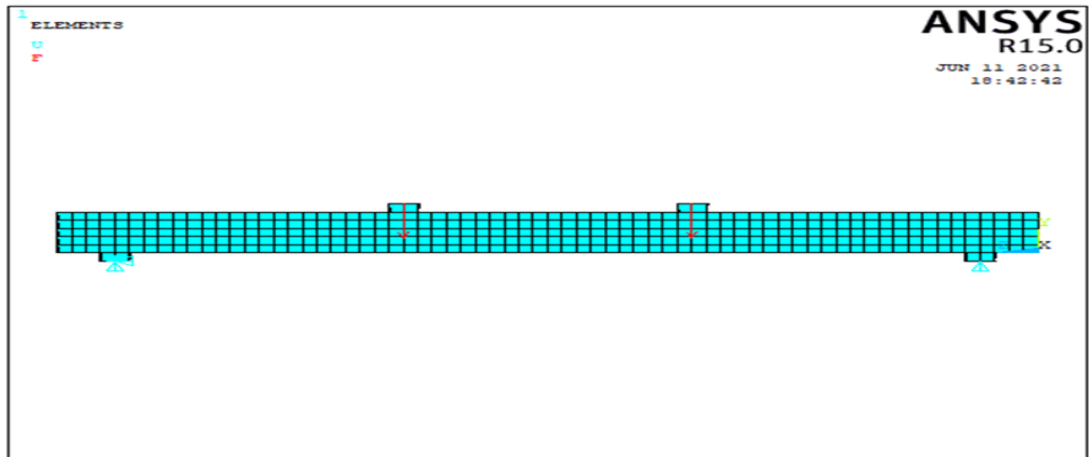


Figure 4.7 Boundary conditions

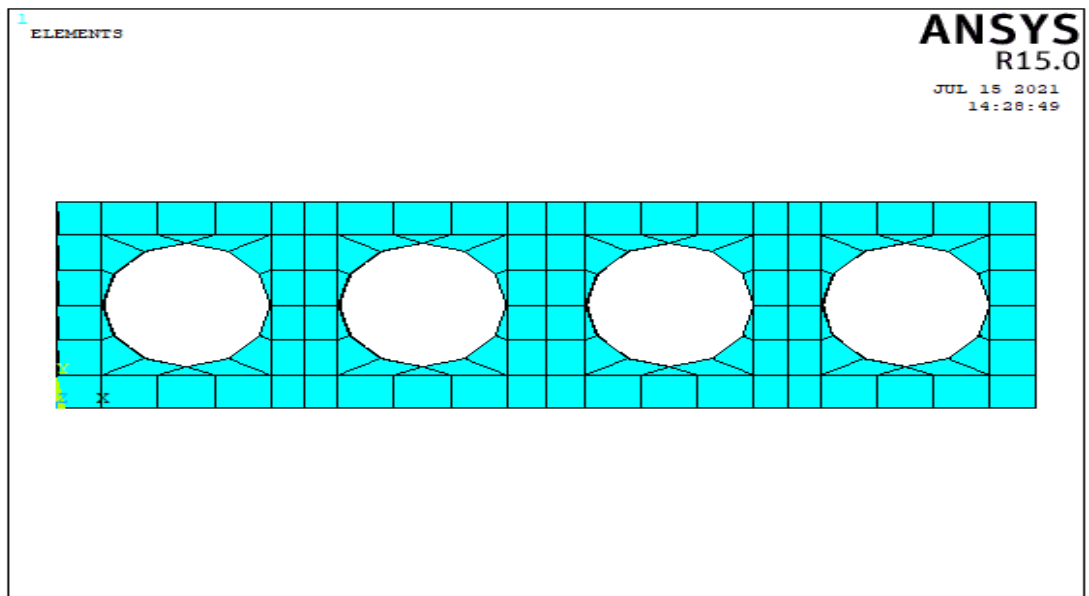


Figure 4.8 Cross-sectional view of 2D FE model of HCS 4D75

4.2.4 Results of ANSYS analysis

4.2.4.1 Model 1: Normal concrete solid and one -way HCSs

In this model, both solid slab and HCS were tested at f_c' 28.6 MPa by FE analysis. Three types of HCS were considered. All types have the same core diameter but the number of cores differs as follows 2D75, 3D75, 4D75.

For solid slab, the results of FE analysis show a good approval compared with the experimental results. Where, the maximum deflection of the FE analysis for the solid slab is 28.34 mm at load 49.89 kN, while the maximum deflection value of the

experimental was 26.75 mm at load 52.64 kN as shown in Figure 4.9. Deformed shape solid slab for Model 1 is given in Figure 4.10

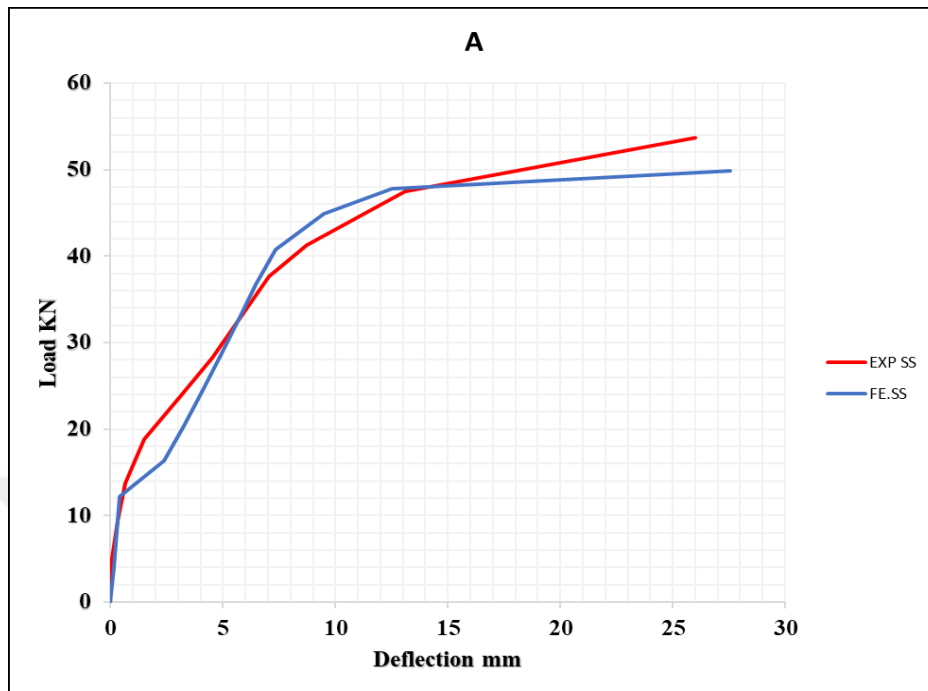


Figure 4.9 Load-deflection relationship of experimental and numerical result for solid slab for Model 1 ($f'_c=28.6\text{MPa}$)

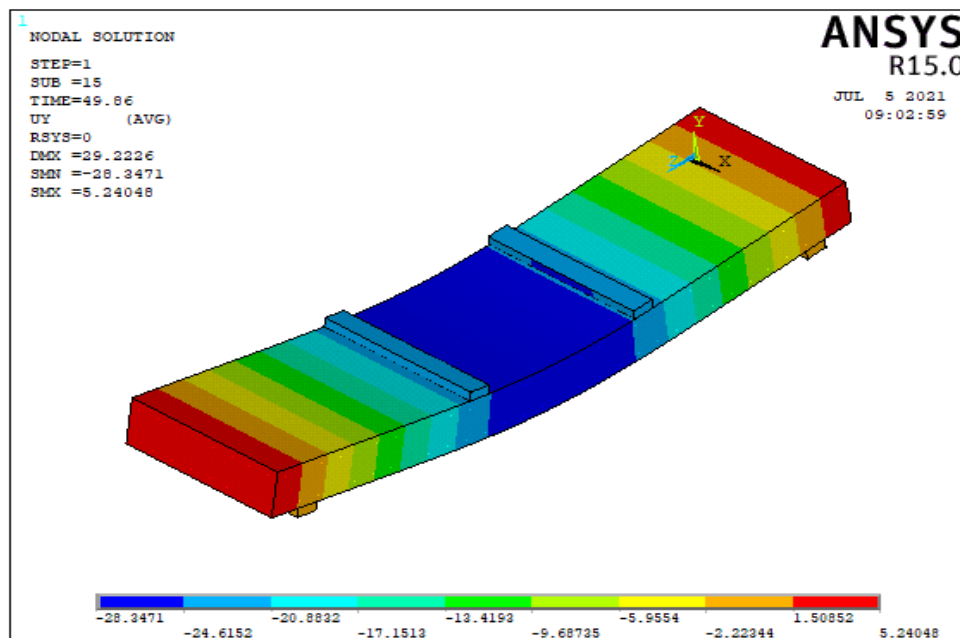


Figure 4.10 Deformed shape solid slab for Model 1 at f'_c 28.6 MPa

For all shapes of HCS test (2D75, 3D75, 4D75), the results of FE analysis show a good approval comper with the experimental results. Figure 4.11 to 4.13 shows the agreement of FE analysis results with experimental results. For example, the maximum deflection value of 2D75 in the FE analysis is 28 mm at load 50 kN while the maximum deflection value in experimental results was 32mm at load 48 kN for the same shape. Table 1 presents the comparison of experimental and FE analysis results of the solid and HCSs for Model 1

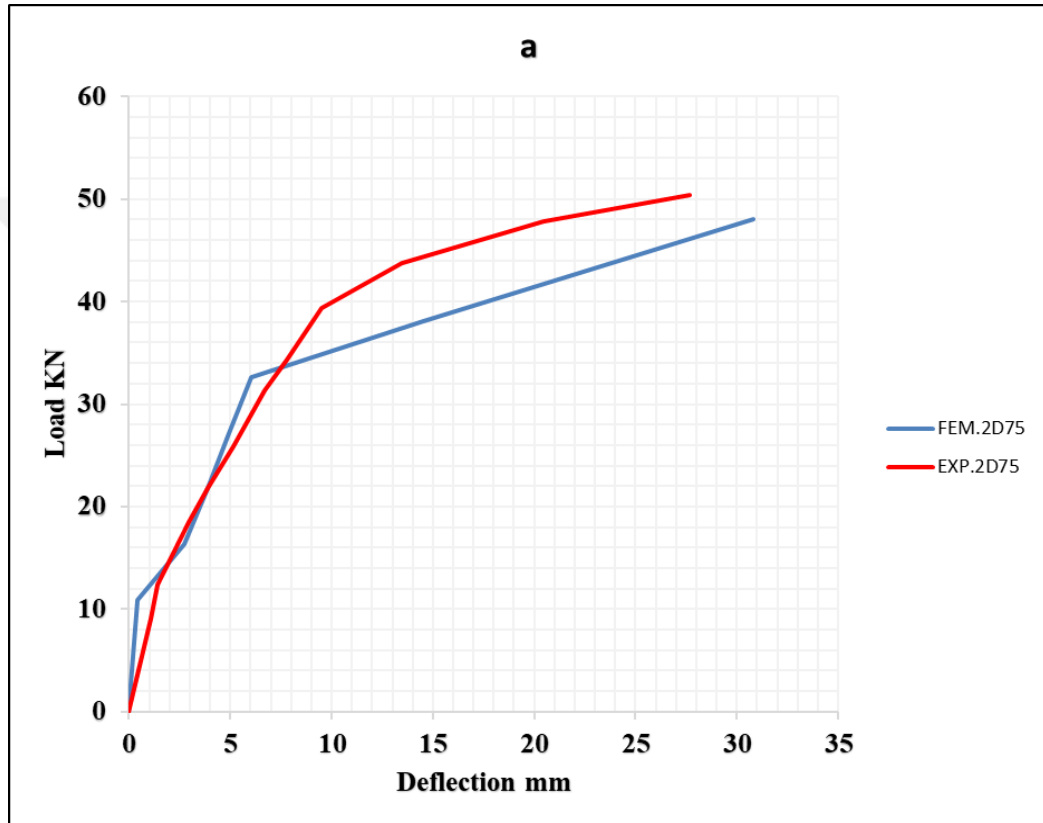


Figure 4.11 Load-deflection relationship of experimental and numerical result HCS for Model 1 ($f'c=28.6$ MPa) for 2D75

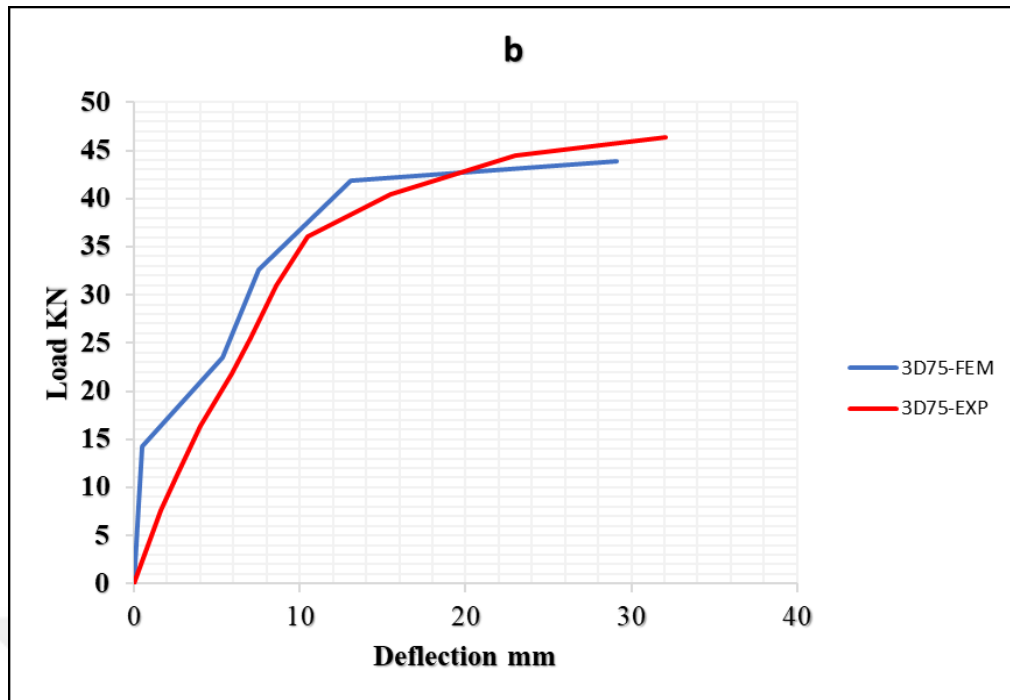


Figure 4.12 Load-deflection relationship of experimental and numerical result HCS for Model 1 ($f'c=28.6$ MPa) for 3D75

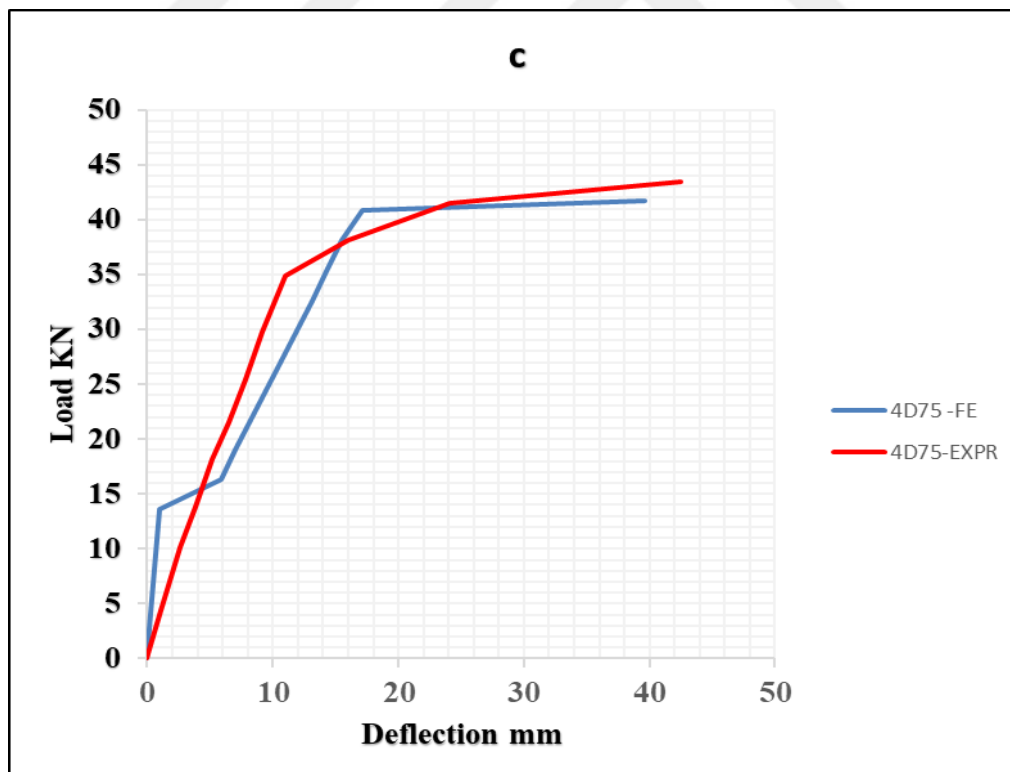


Figure 4.13 Load-deflection relationship of numerical experimental and result in HCS for Model 1 ($f'c=28.6$ MPa) for 4D75

Table 4.3 Comparison of experimental and FE analysis results of the solid and HCSs for Model 1.

Slab designation	Cracking load (kN) Pcr EXP [65]	Cracking load (kN) Pcr FEM	Ultimate deflection Δu (mm). EXP [65]	Ultimate deflection Δu (mm). FEM	Ultimate load Pu (kN). EXP[65]	Ultimate load Pu (kN). FEM
SS.	13.2	12.5	26.75	28.34	52.46	49.86
2D75	12.4	14.2	27.54	28.34	50.3	48.6
3D75	11.7	13.5	34.75	36.09	45.97	43.56
4D75	11.5	12.85	35.12	37.05	43.5	40.08

4.2.4.2 Model 2: High strength, self-compacting concrete solid and HCSs

In this model both of high strength (f_c' 60 MPa) solid slab and HCS were modeled analyzed by FE method. Five types of HCS were considered. All shapes have different core diameter and different number as follow: 3D50, 3D63, 2D75, 3D75, 4D75.

The results of FE analysis show a good agreement with the experimental results for all types of HCS (3D50, 3D63, 2D75, 3D75, 4D75). Figures 4.14 - 4.19 show the agreement of FE analysis results with experimental results.

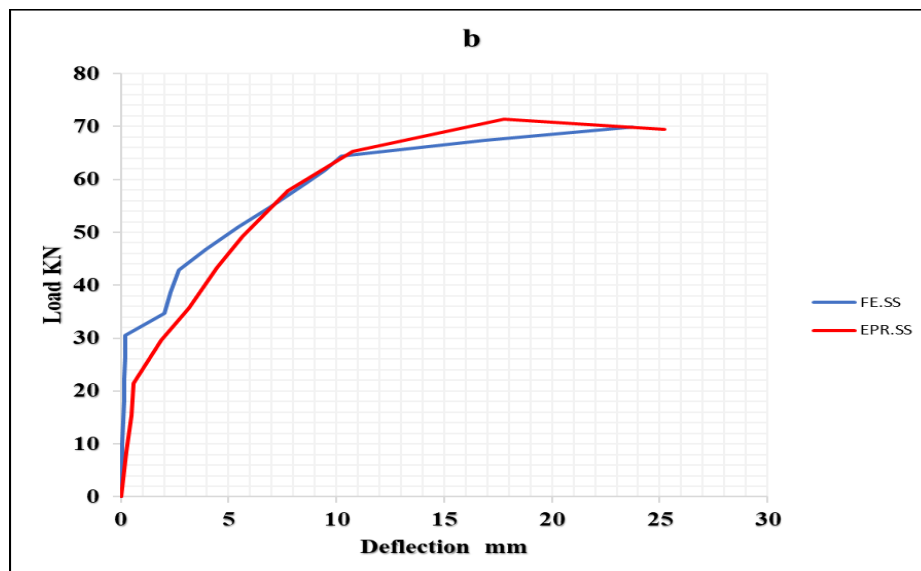


Figure 4.14 Load-deflection relationship of experimental and numerical result for solid slab for Model 1(f_c' =60.8MPa)

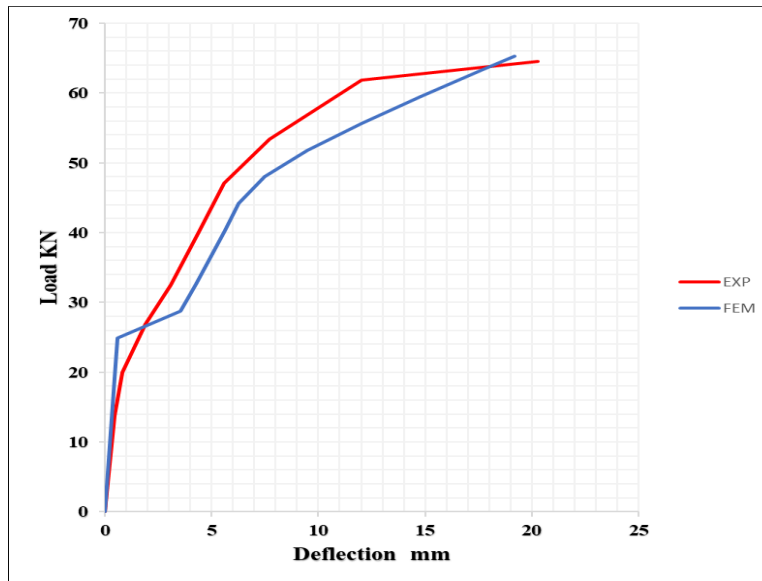


Figure 4.15 Load-deflection relationship of experimental and numerical result HCS 3D50 for Model 2 ($f'_c=60.8$ MPa)

For example, the maximum deflection value of 3D63 in the FE analysis is 26 mm at load 63 kN while the maximum deflection value in experimental results was 29 mm at the same load value. Figures 4.20 and 4.21 show a 3D 45 side view of the contour plot of the deflection of a 1700mm long, 430mm wide, and 125mm thick solid and HCS, respectively, to simulate the flexural failure and scanning profile of the model. This simulation can display the applied force and deflection at any stage throughout the loading process.

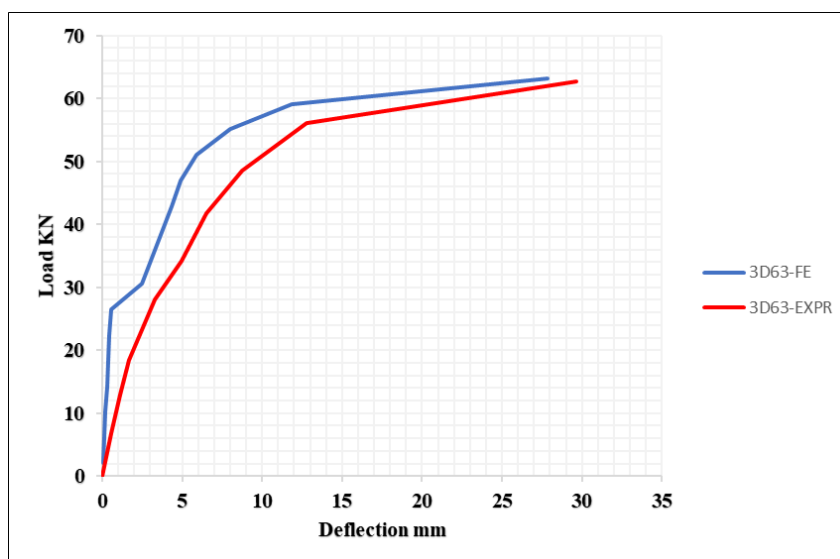


Figure 4.16 Load-deflection relationship of experimental and numerical result HCS 3D63 for Model 2 ($f'_c=60.8$ MPa)

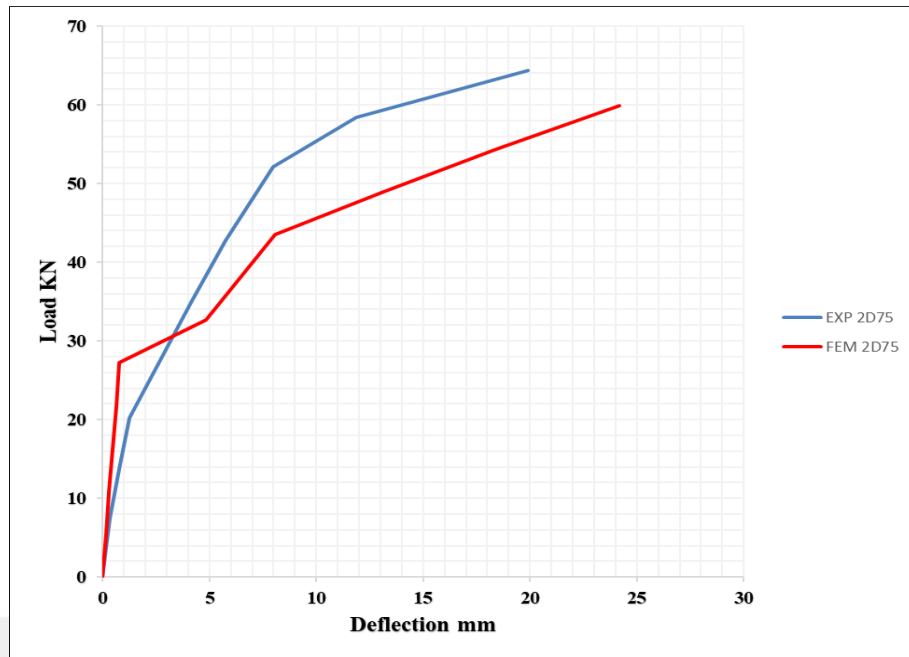


Figure 4.17 Load-deflection relationship of experimental and numerical result HCS for Model 2 ($f'_c=60.8$ MPa) for 2D75

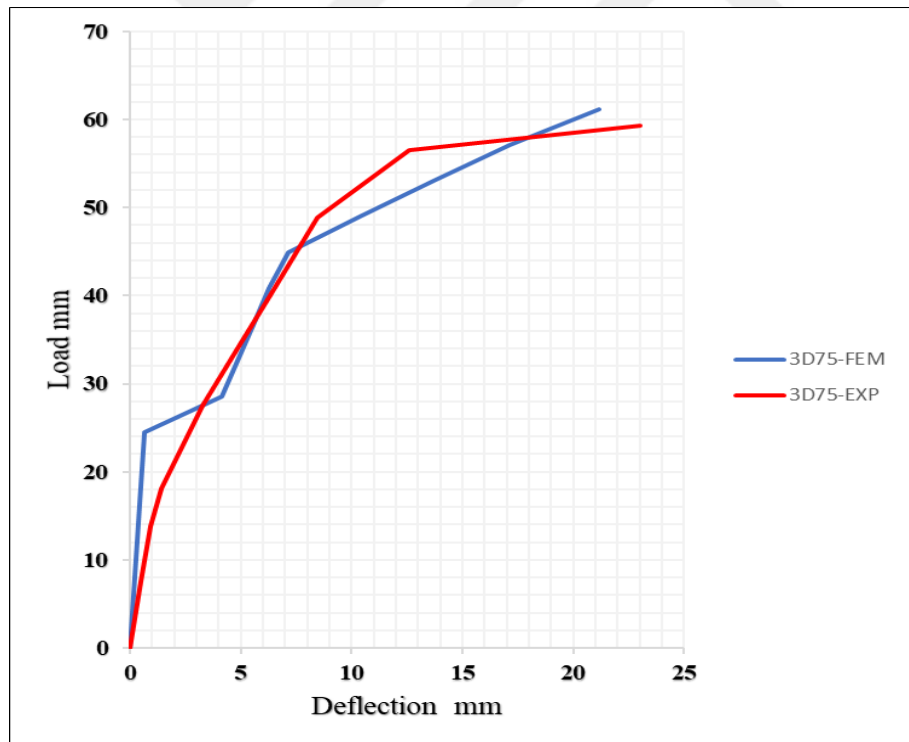


Figure 4.18 Load-deflection relationship of experimental and numerical result HCS for Model 2 ($f'_c=60.8$ MPa) for 3D75

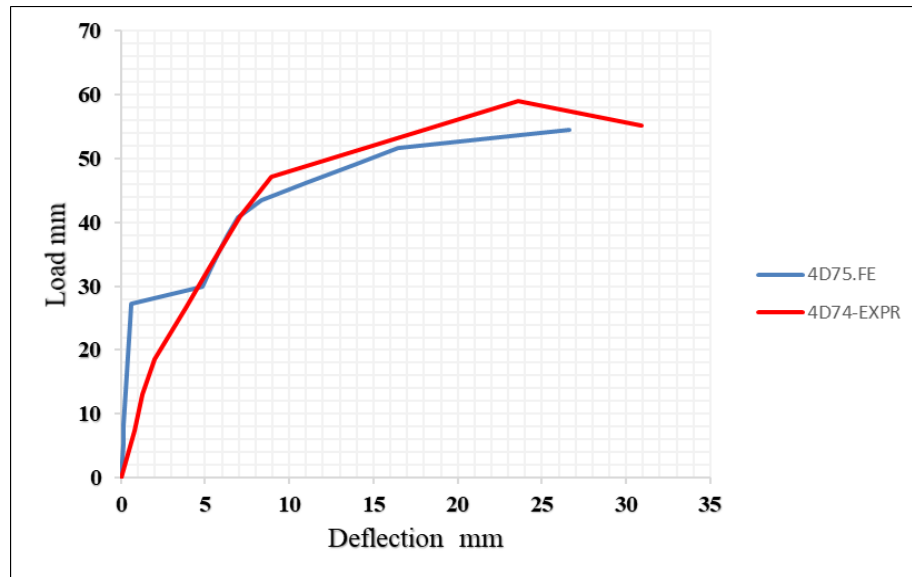


Figure 4.19 Load-deflection relationship of experimental and numerical result HCS 4D75for Model 2 ($f'_c=60.8$ MPa)

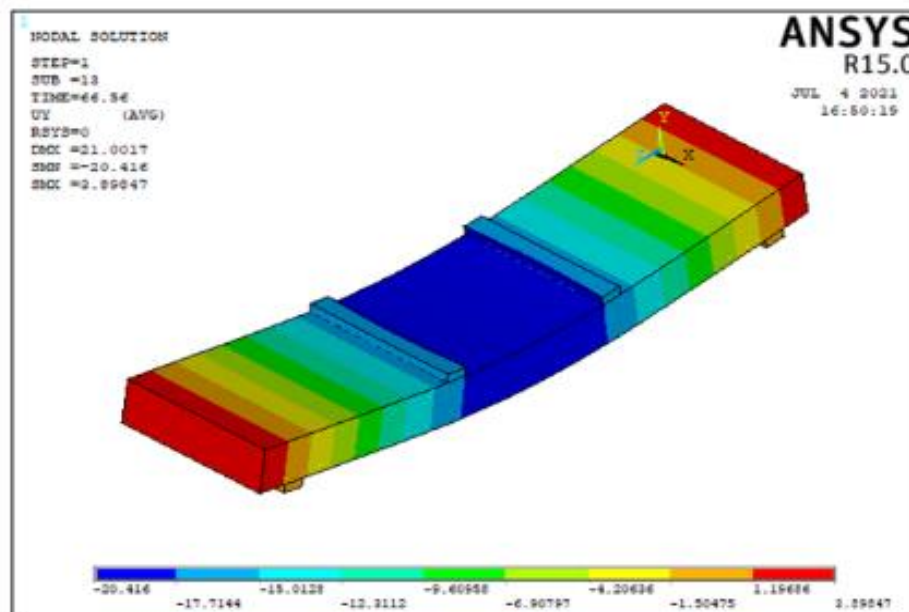


Figure 4.20 Deformed shape of solid slab for Model 2

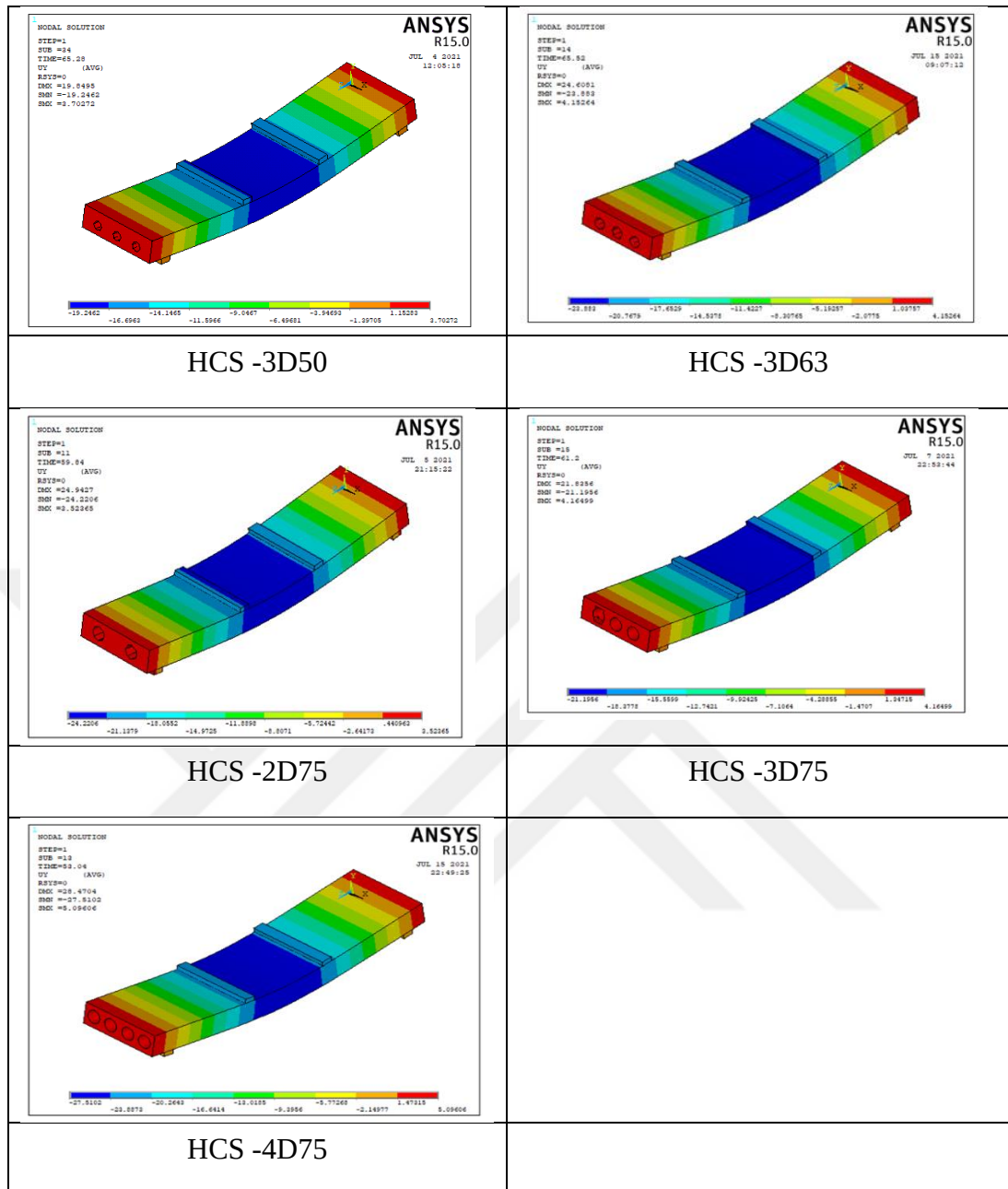


Figure 4.21 Deformed shapes of HCS for Model 2

4.2.5 Crack patterns

When the concrete element stress exceeds the tensile strength of concrete, cracks evolve into concrete elements. At the early stages, several cracks were initiated in the tension zone of the loading of test specimens. With increasing loading, the cracks extended upwards and became wider up to the failure point of the slab by cutting up the reinforcement. The cracking pattern for solid and hollow slabs are given in Figures 4.22 to 4.26

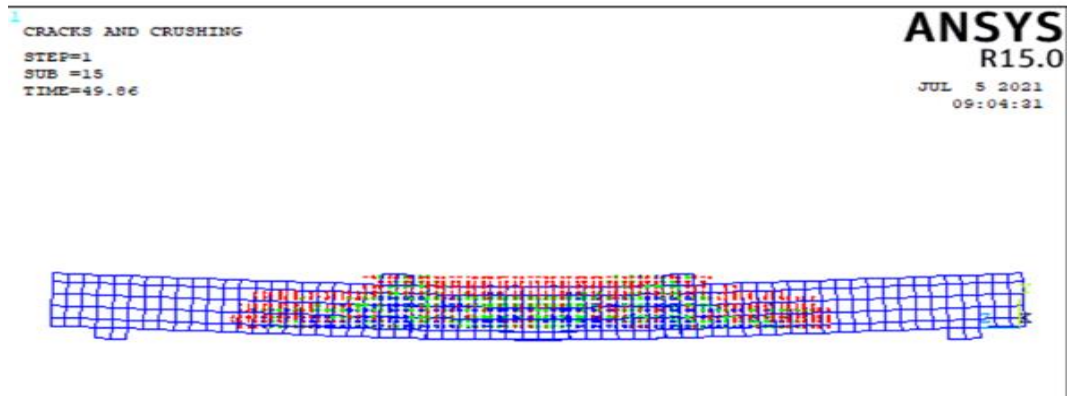


Figure 4.22 Crack pattern solid slab Model 1 ($f_c=28.6$ MPa)

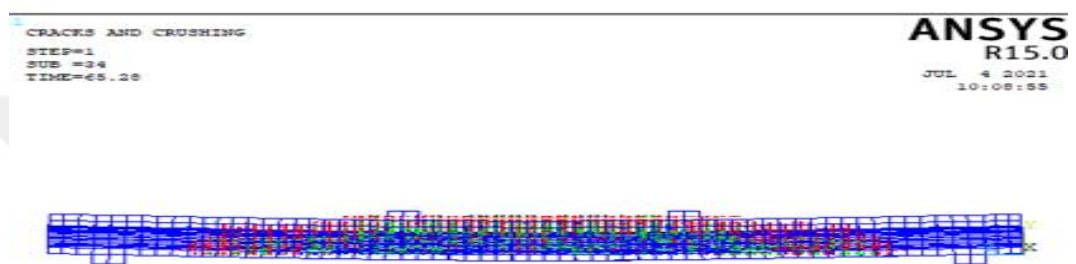


Figure 4.23 Crack pattern hollow slab Model 2($f_c=60.8$ MPa) 3D50

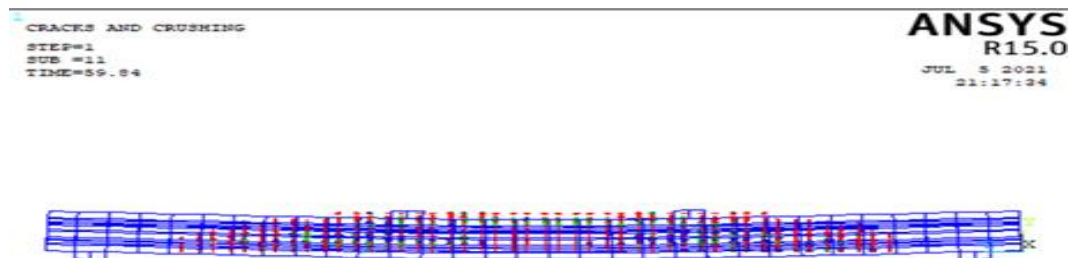


Figure 4.24 Crack pattern hollow slab Model 2($f_c=60.8$ MPa) 2D75

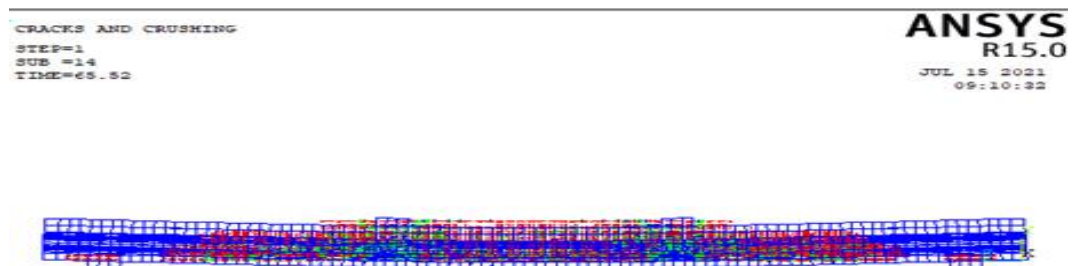


Figure 4.25 Crack pattern hollow slab Model 2($f_c=60.8$ MPa) 3D63

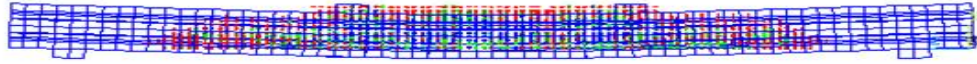


Figure 4.26 Crack pattern hollow slab Model 2 ($f_c=60.8$ MPa) 4D75

The FE analysis results for ultimate load, cracking pattern, load-deflection of the solid and hollow slab are given in Tables 4.3 and 4.4. The simulation results show a good agreement with the experimental observation for load-deflection relationships.

Table 4.4 The result value of the solid and hollow-core slabs for EXP. and FEM Model 2

Slab designation	Cracking load (kN) EXPR.	Cracking Pcr (kN) FEM	Ultimate deflection Δu (mm) EXP	Ultimate deflection Δu (mm) FEM	Ultimate load Pu (kN) EXP	Ultimate load Pu (kN) FEM
SS	21.5	26.32	17.12	20.41	71.32	66.56
3D50	20.5	24.87	20.3	19.24	64.23	65.28
3D63	19.7	23.34	20.8	22.88	62.67	65.52
3D75	18.6	22.58	23.34	21.19	60.67	61.2

Table 4.5 The result value of the solid and hollow-core slabs for EXP. And FEM Model 2

Slab designation	Cracking load (kN) EXPR.	Cracking Pcr (kN) FEM	Ultimate deflection Δu (mm) EXP	Ultimate deflection Δu (mm) FEM	Ultimate load Pu (kN) EXP	Ultimate load Pu (kN) FEM
SS	21.5	26.32	17.5	20.41	71.32	66.56
2D75	19.6	27.56	20.5	24.22	63.8	59.84
3D75	18.6	22.58	23.34	21.19	60.67	61.2
4D75	17.8	23.7	24.6	27.51	58.91	52.02

4.3 Precast polypropylene FRC solid and HCS

In this study, the experimental work using a model of precast HCS with use and without polypropylene fibers was carried out to study the behavior and characteristics using ANSYS software by Conforti et al [66]. The support mimics of the actual hollow slab were applied to a three-point loading test orthogonally using various types of stressed bars in each direction with prestressed 1200 MPa under shear load were performed Two tests on HCS the shear-span-to-effective depth ratio ($a/d = 2.8$ according to EN1168 and $a/d = 3.5$). Specimen dimensions were 42 cm high, 120 cm wide, and 600 cm long as shown in Figure 4.27. Reinforcements were placed orthogonally at the tension face and compression phase as a reinforcement layer with a clear upper cover of 43 mm and lower cover of 38 mm.

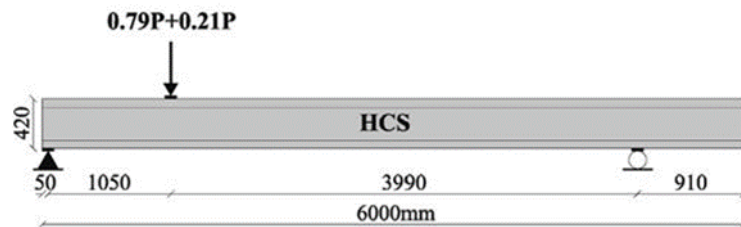
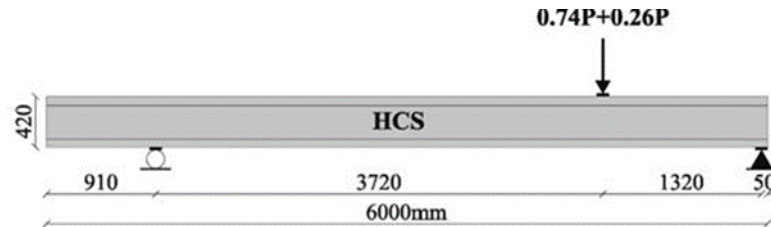
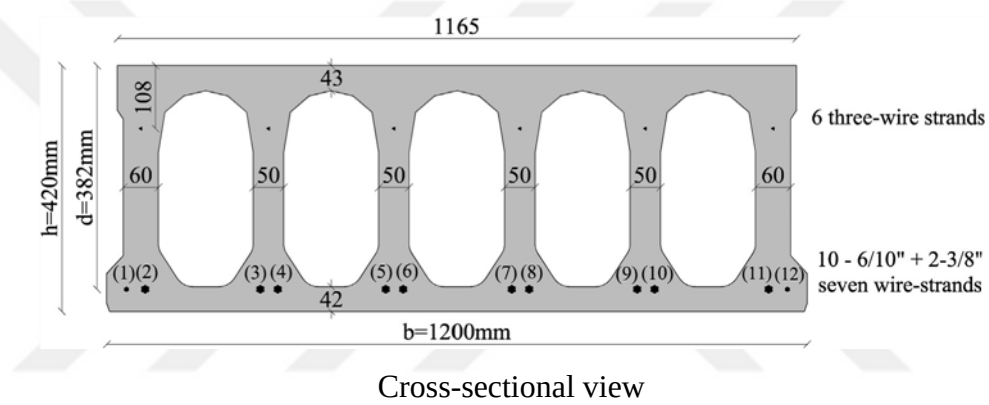


Figure 4.27 Precast polypropylene FRC HCS

4.3.1 Finite element modeling and material properties

In this day and age technology, materials or hollow construction materials are essential. There are many different types of building materials that are employed in various construction projects. In this work the HCS was tested under shear load at the end zone; the model was generated with the three-dimensional FE. HCS was modeled using Solid65 brick elements with 33909 elements for concrete while the prestressing strands were modeled using LINK180. Solid185 elements of the steel plate have linear elastic properties. The model has been drawn using the ANSYS software program. Figure 4.28 illustrates the generated FE model for the HCS. Table 4.5 shows material properties and additional material parameters.

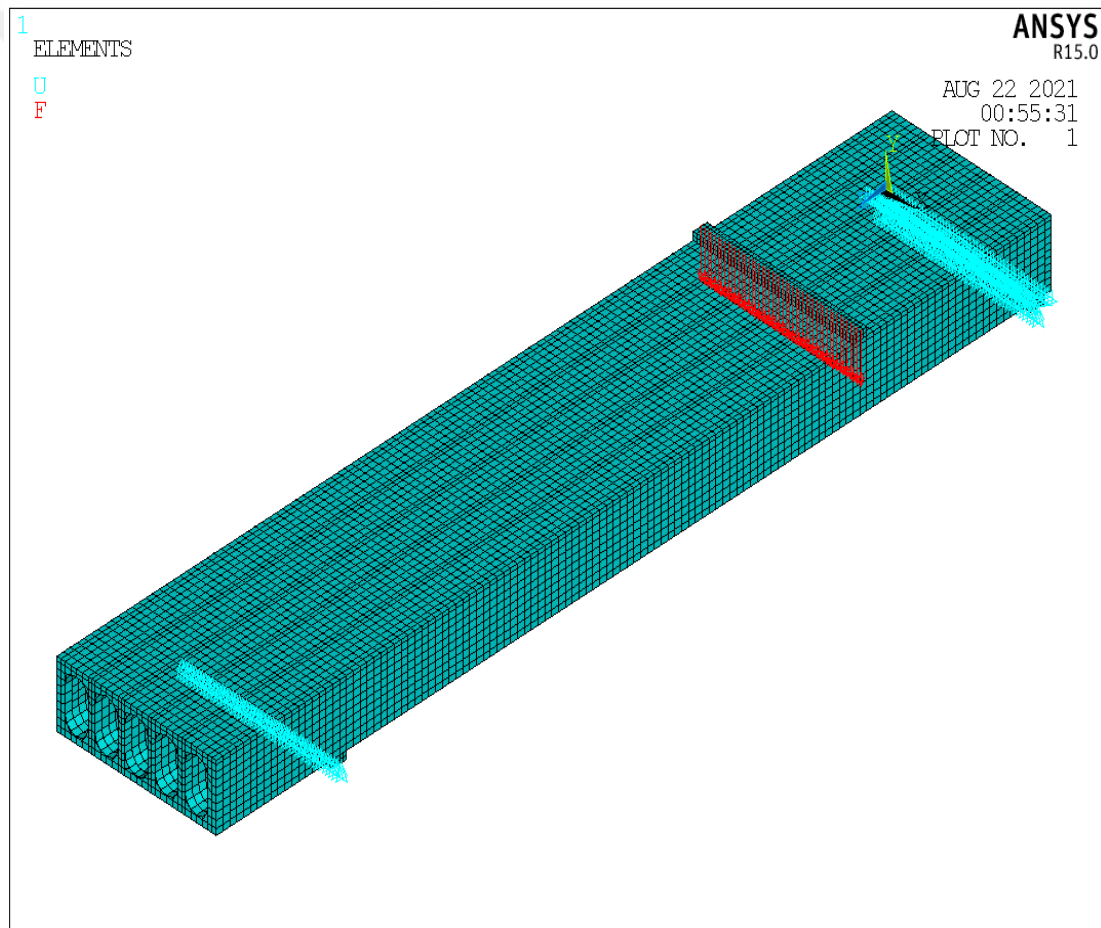


Figure 4.28 Geometry mesh process and applied loads

Table 4.6 Material properties of precast polypropylene FRC HCS

Concrete $f_c = 45.1$ MPa
Compressive strength = 45.1 MPa
Modulus of elasticity $E_c = 31607$ MPa*
Poisson's Ratio $\nu = 0.2$
Uniaxial Cracking Stress = 4.5 MPa
Open Shear Transfer Coef. $\beta_t = 0.4$
Close Shear Transfer Coef. $\beta_c = 0.8$
Concrete $f_c = 40.6$ MPa
Compressive strength = 40.6 MPa
Modulus of elasticity $E_c = 29725$ MPa*
Poisson's Ratio $\nu = 0.2$
Uniaxial Cracking Stress = 4 MPa
Open Shear Transfer Coef. $\beta_t = 0.4$
Close Shear Transfer Coef. $\beta_c = 0.8$
Steel reinforcement
Modulus of elasticity $E_s = 200000$ MPa
Poisson's Ratio $\nu = 0.3$
Yield Stress with diameters of 16 mm $f_y = 1819$ MPa
Yield Stress with diameters of 9 mm $f_y = 1734$ MPa
Yield Stress with diameters of 3 mm $f_y = 1854$ MPa
Loading Plates
Modulus of elasticity $E_s = 2 \times 10^{10}$ MPa
Poisson's Ratio $\nu = 0.3$
Yield Stress $f_y = 400$ MPa
Polypropylene fibers
Modulus of elasticity $E_s = 3.5$ GPa
Poisson's Ratio $\nu = 0.3$
Yield Stress $f_y = 400$ MPa

4.3.2 Loading and boundary conditions

Two steel plates with the model's dimensions of 50 mm width, 1200 mm length, and 50 mm thickness were used for supports and load placement at the top and bottom.

The size of the plate mesh was set to correspond with the concrete mesh element to minimize stress concentration and ensure the most uniform distribution of stresses. SOLID185 components were used to simulate steel plates with three degrees of freedom for all nodes (the displacements in X, Y, and Z directions) as shown in Figure 4.27. The applied loads were modeled as a line load distributed on top nodes (13 nodes per plate) along the centerline of the plates.

The centerline of the steel plate of supports was constrained as a simple support to enable rotation of the support under the concrete nodes to apply the true boundary requirements verify that the structural simulation model is developed under the proper circumstances and that it is solved in a realistic manner, The validation approach compares the results based on a certain model that has been chosen. The researcher uses the results of laboratory experiments which is developed by (Conforti et al, in 2020) as a validation model and the experimental results have been performed by applying the multi loads on the center of the hollow slab in order to measure the deflection in the slab. The numerical results of HCS are compared with (Conforti et al, 2020).

4.3.3 Verification and validation

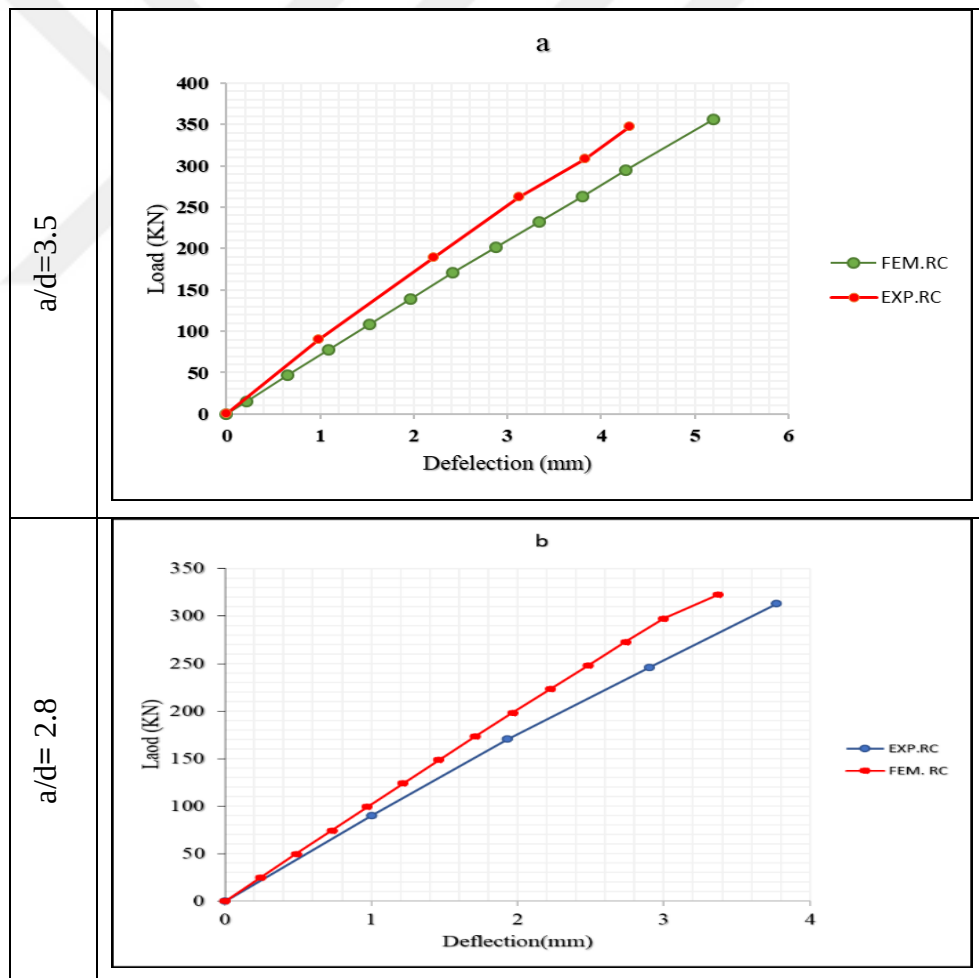
This section discusses the study's validation and verification of the HCS model based on the test parameters from the previous study, the HCS is simulated. The experimental results are utilized to validate the models in this study, It's also used to select a good turbulence model with the necessary model configuration and mesh approach that can be created and employed on the boundary condition we're interested in. By carrying out all those studies, the results observe the way to generate a correct model and also understand the concrete behavior based on the selected hollow-core model.

The predicted ultimate shear strength under load from the numerical models accomplished by using ANSYS software is compared to the experimental data received from the tests as shown in Table 4.6. The numerical models' values for specimens are very well approved by the lab. test results.

The typical load versus deflection behavior of the FRC hollow slab is presented in this section. The vertical deflection is measured at the lower face of HCS. The results of the FE model and the experimental were in good agreement as shown in the load-deflection curve (see Figures 4.29 and 4.30).

Table 4.7 Verification of numerical results at fibers contain ($V_f=0$, $V_f=1.15$)

$a/d=3.5$							
No	Fiber fraction	volume	Pmax (kN) EXP [66]	$\delta(\max)$ (mm) EXP [66]	Pmax. (kN) FEM	$\delta(\max)$ (mm) FEM	Error in P_{Max}
1	($V_f=0$)		346.64	4.31	356	5.23	3%
2	($V_f=1.15\%$)		465.8	5.18	471.2	5.34	1%
$a/d=2.8$							
1	($V_f=0$)		316	3.4	322	3.37	2%
2	($V_f=1.15\%$)		381.6	4.68	396	4.67	2%

**Figure 4.29** Load-deflection of experimental and numerical results for ($V_f=0$)

The relationship between experimental work results and the numerical FE analysis is presented in Figure 4.29 and Figure 4.30, it can be observed that all load-deflection curves have similar behavior. In comparison with the experimental results, the numerical models approximately display small deflection at the ultimate stage.

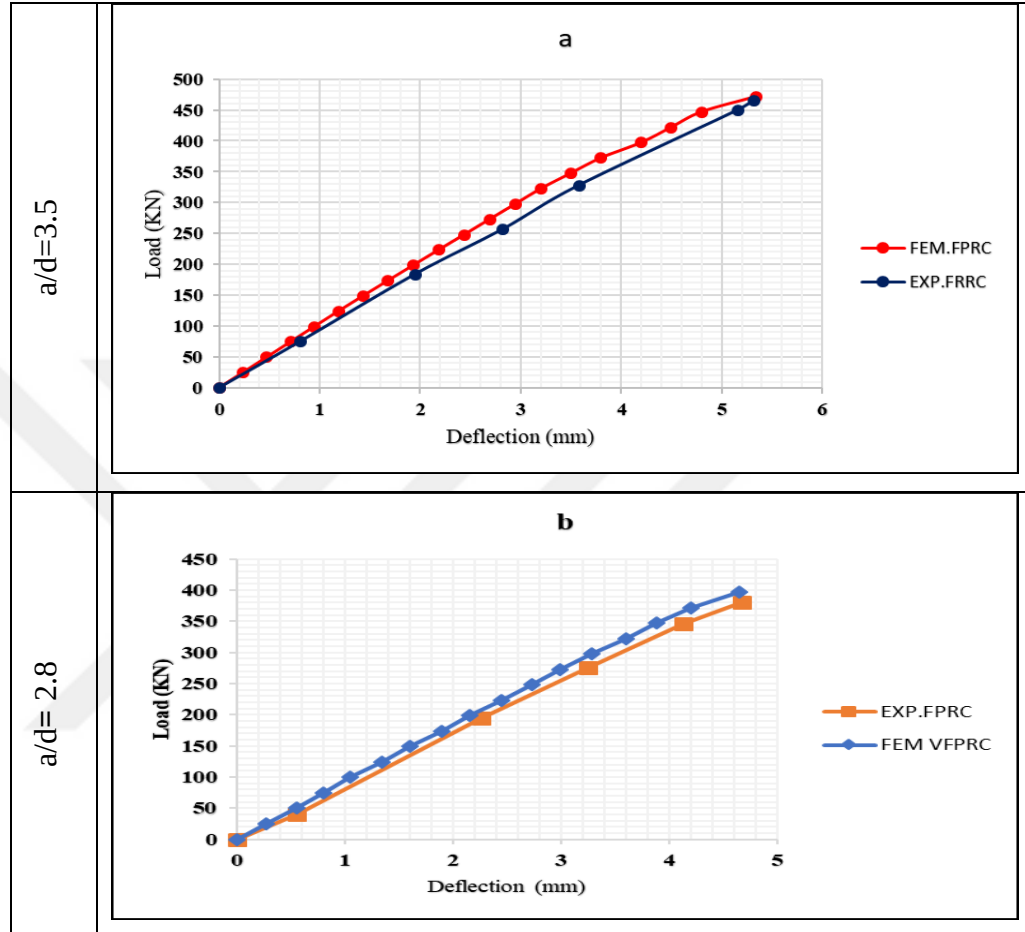


Figure 4.30 Load-deflection of experimental and numerical results for ($V_f=1.15$)

Both Figures 4.29 and 4.30 show that the load-deflection curves from the numerical investigation models agree well with lab test data from experimental for the hollow slab model with variable shear-span-to-effective depth ratio ($a/d = 2.8$ and $a/d = 3.5$). Contour plots are shown in Figures 4.31 and 4.32. The deformed model's minimum and maximum deflection values, the zone colored in red shows the greatest value in concavity, The area colored in blue represent the highest value in the convexity; between the two preceding zones, there is a gradient of zones shaded in different colors that depict the deformation that occurs throughout loading stages or ultimate loading for the HCS model.. for the deformation model in the HCS, there is a clear difference between the specimens. The specimens with fibers reinforcement concrete have

greater deformation than the normal reinforcement concrete hollow slab, this is seen from the high rate of load compared to the deflection ($\Delta P/\Delta \delta$).

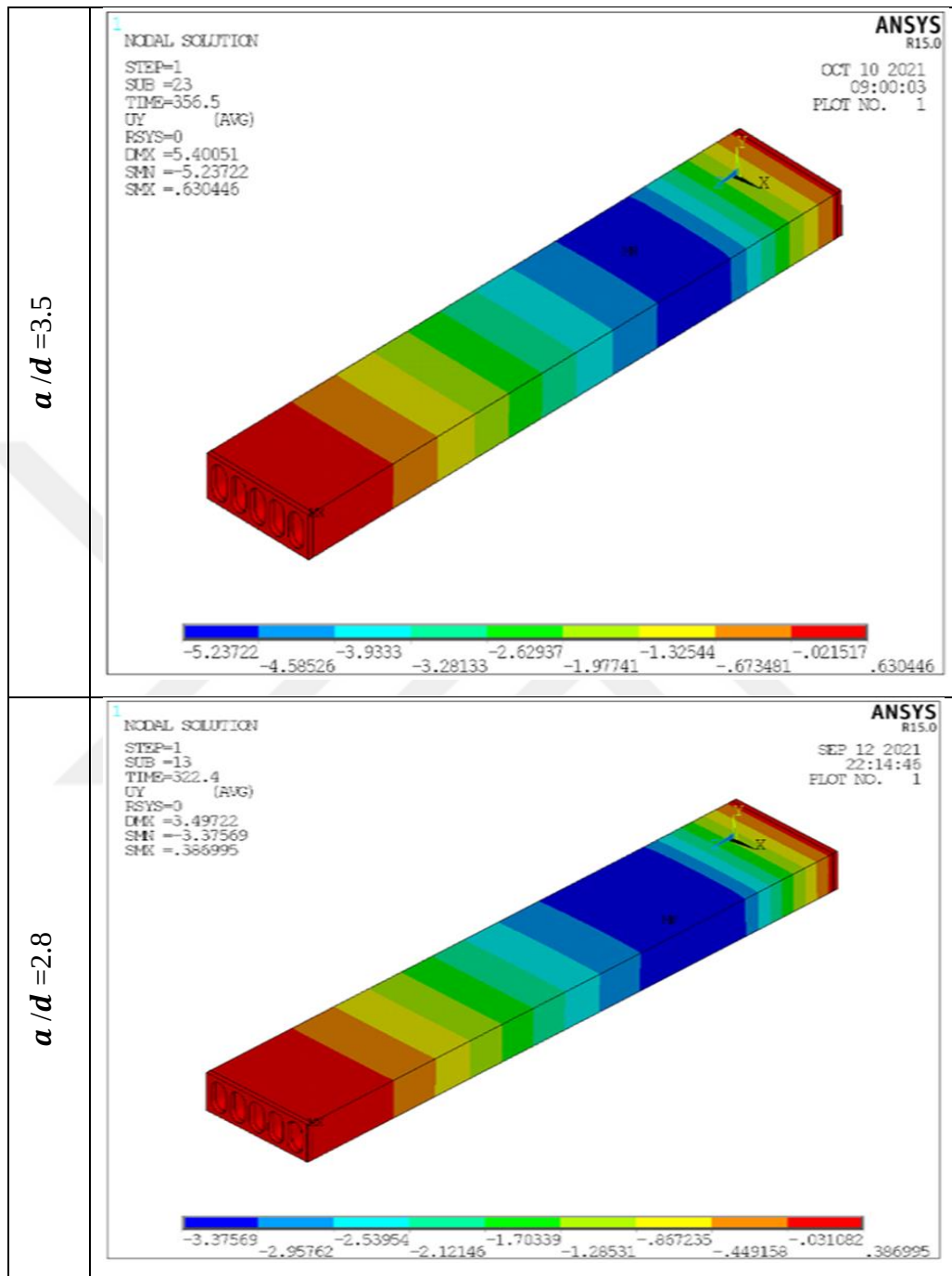


Figure 4.31 Contour plots for verification results of HCS tests ($Vf=0$)

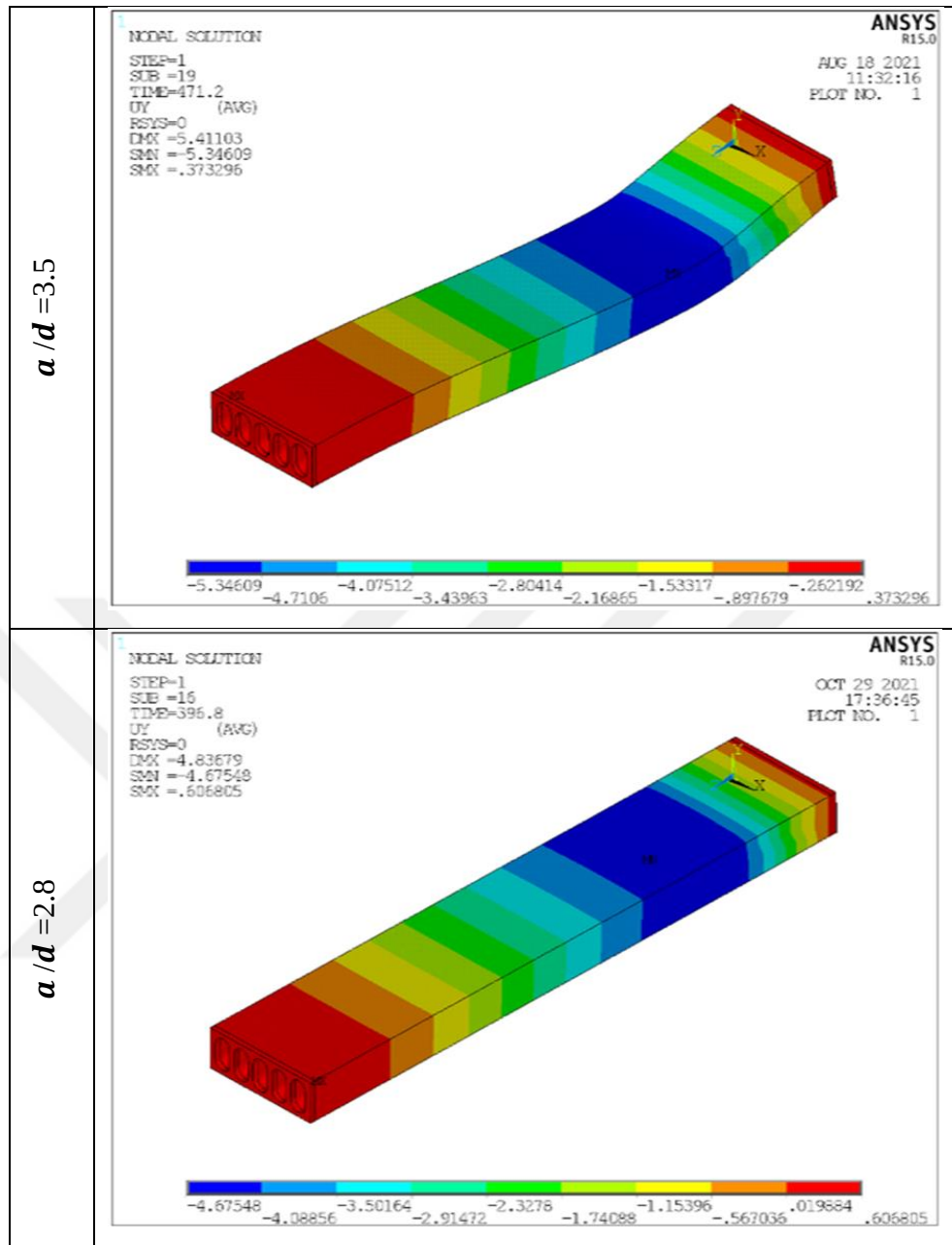


Figure 4.32 Contour plots for verification results of HCS tests ($V_f=1.15\%$)

4.3.4 Results and discussion

The predicted ultimate shear strength under load from the numerical models accomplished by using ANSYS software is in general compared with the experimental results obtained from the laboratory test as shown in Table 4.6. The numerical models' values for specimens are very well approved with the lab test results. The numerical only had a maximum difference of (3%) in ultimate load at one model as shown in Table 4.6.

The difference between experimental work and the numerical 3D FE Model analysis is illustrated in Figures 4.31 and 4.32. and all load-deflection curves for the tested slabs have similar behavior. In comparison with the experimental values, all the FE numerical models approximately display small deflection at the ultimate stage.

Both Figures 4.29 and 4.30 display that the load-deflection curves from FE investigation 3D FE model agree well with lab test data from experimental for the hollow slab model varying the shear-span-to-effective depth ratio ($a/d = 2.8$ and $a/d = 3.5$). The load-deflection curves are good matching for both experimental. when (volume fraction $V_f=0$), the final load of the FE is (356 kN when $a/d= 3.5$) and (322 kN when $a/d=2.8$), which is more than the final load of 346.6 kN and 316 kN respectively from the experimental.

when $V_f=1.15\%$ the final load of the FE analysis 3D FE Model is (471.2 kN when $a/d= 3.5$) and (380 kN when $a/d=2.8$), which is more than the final load of 465 kN and 372 kN respectively from the experimental.

The contour plots for verification results of HCS tests are shown in Figures 4.31 and 4.32. It shows the deformed model's minimum and maximum deflection values. The area colored in red shows the greatest value in concavity. On the other hand, the area colored in blue represents the highest value in convexity. Between the two preceding zones, there is a gradient of zones shaded in different colors that depict the deformation that occurs throughout loading stages or ultimate loading for the HCS model. For the deformation model in the HCS, there is a clear difference between the specimens. The specimens with fibers reinforcement concrete have greater deformation than the normal reinforcement concrete hollow slab; this is seen from the high rate of load compared to the deflection ($\Delta P/\Delta \delta$).

4.3.5 Proposal fiber volume fraction (V_f)

Three different fiber's volume fractions 0.5%, 0.8%, and 1.5% have been employed to evaluate the influence of fiber volume fractions on the behavior of FRC HCS. It is noteworthy that the geometrical properties of developed FE models are similar to those used in the experimental study by Comfortis et al [66]. Table 4.7 provides the deflection at the maximum load of the studied HCS. It is obvious from Figure 4.33 and Table 4.7 that there is a clear correlation between the volume fraction of the fibers and

the maximum load capacity of these HCS. As expected, the maximum load capacity of each HCS tends to increase with using a higher volume fraction. The increase can be attributed to two reasons, first reason is that fiber reinforced concrete improves the shear strength of HCS end regions primarily by enhancing the connection between tendons and concrete, leading to less tendon slippage. This improves the efficiency of prestressing activities on shear strength under higher loads, permitting fiber reinforcement concrete models to achieve greater shear strength than reinforcement concrete HCS (Antonio Comfortis et al .in 2020). The second cause can be linked to the fibers' bridging activity across the fissures, which initially limited the growth of microcracks. After the tensile crack, the stress is passed to the bridging fibers, This prevents fracture development for a period of time and thus also improves tensile strength, could be concluded that using short fiber materials as internal reinforcement led to enhancing the ultimate shear strength of structural concrete members with high rigidity behavior (Jiang et al.in 2014).

Table 4.8 Numerical results of different proposal V_f

a/d=3.5			
N0	V_f of PPHS model	Pmax (kN)	$\delta(\text{max}).(\text{mm})$
1	$V_f=0.5\%$	421	3.85
2	$V_f=0.8\%$	446	4.16
3	$V_f=1.15\%$	471	5.34
4	$V_f=1.5\%$	493	6.20
a/d=2.8			
1	$V_f=0.5\%$	347.2	3.2
2	$V_f=0.8\%$	372	4.15
3	$V_f=1.15\%$	396.8	4.7
4	$V_f=1.5\%$	396.8	5.01

The ultimate shear strength is listed with its corresponding displacement in Table 4.7 for two cases, it shows that adding fibers significantly enhances the resistance of the hollow slab. In case (a/d=3.5) the addition of 0.5%, 0.8% , 1.15% and 1.5%, of polypropylene fibers to the concrete, improved the ultimate shear strength by about 21%, 25%, 36% , and 38% respectively compared to the plain concrete. But In case

($a/d=2.8$) the addition of 0.5%, 0.8%, 1.15% and 1.5%, of polypropylene fibers to the concrete, improved the ultimate shear strength by about 10%, 17%, 25%, and 25% respectively compared to the plain concrete. Based on these findings a raise in concrete tensile strength is best when the fiber V_f is between 1.15 and 1.5 percent.

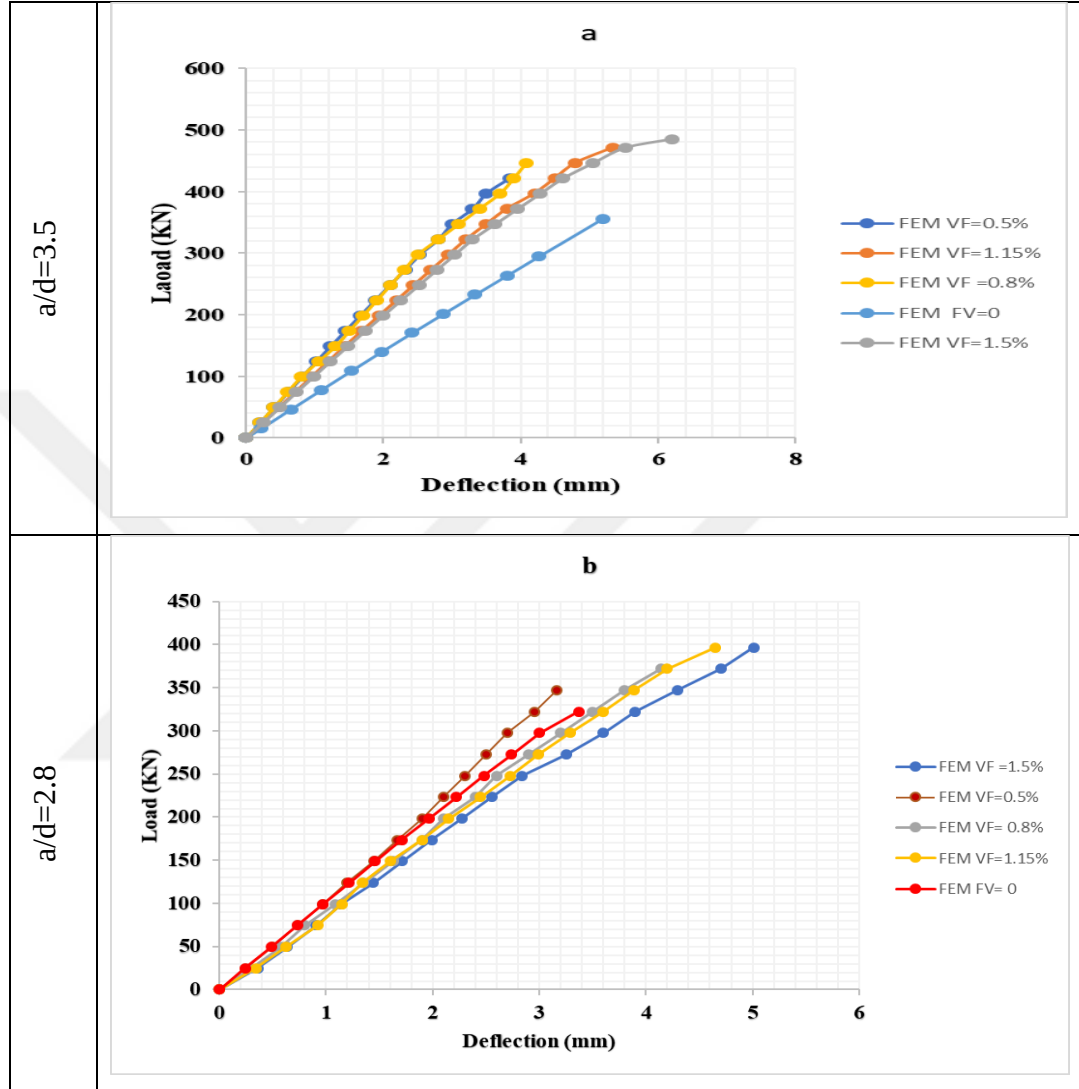


Figure 4.33 Numerical results for various fiber volume fraction: load-deflection

This study shows that fiber insertion with concrete improved the shear strength of FRC HCS as compared to plain concrete, which is consistent with the findings of previous studies. Furthermore, the rigidity behavior of the HCS specimens reinforced with higher fiber volume fraction was increased as indicated in Figure 4.33, to 4.37 and Table 4.7. It could be concluded that using polypropylene fibers as internal reinforcement led to enhancing the shear strength of structural concrete members with high rigidity behavior.

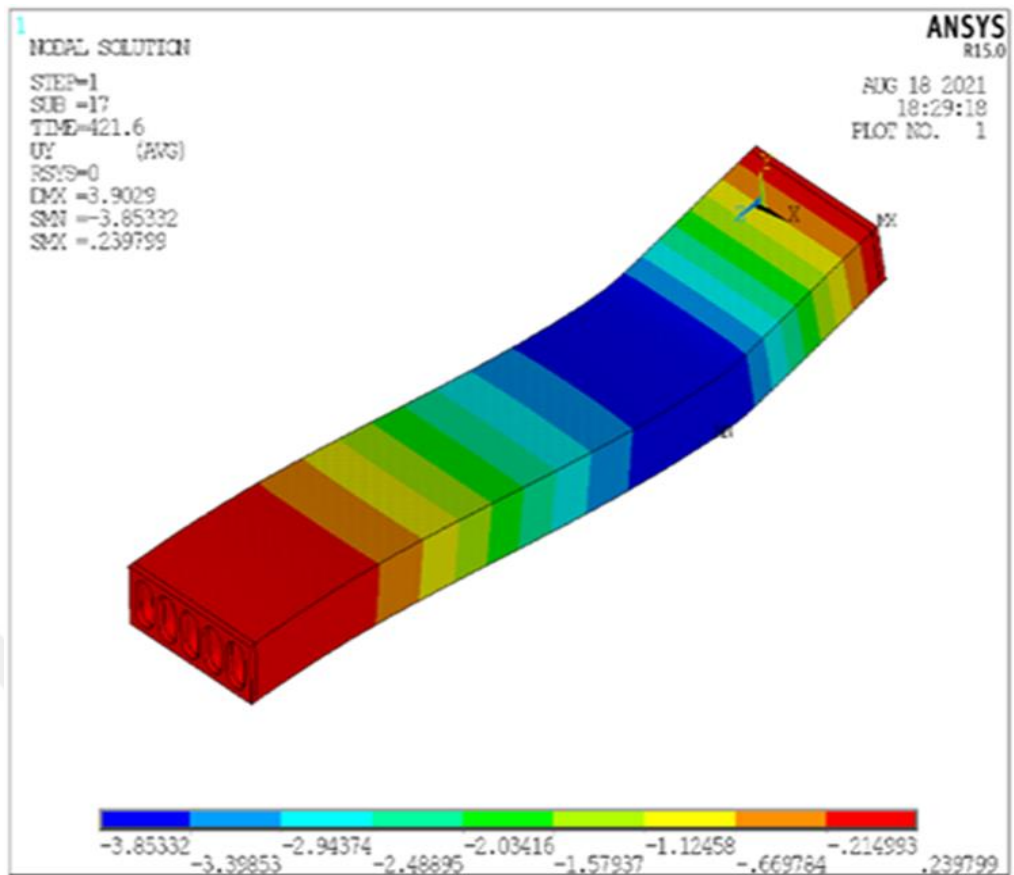


Figure 4.34 Contour plots for verification results of HCS tests ($d = 3.5V$ $f=0.5\%$)

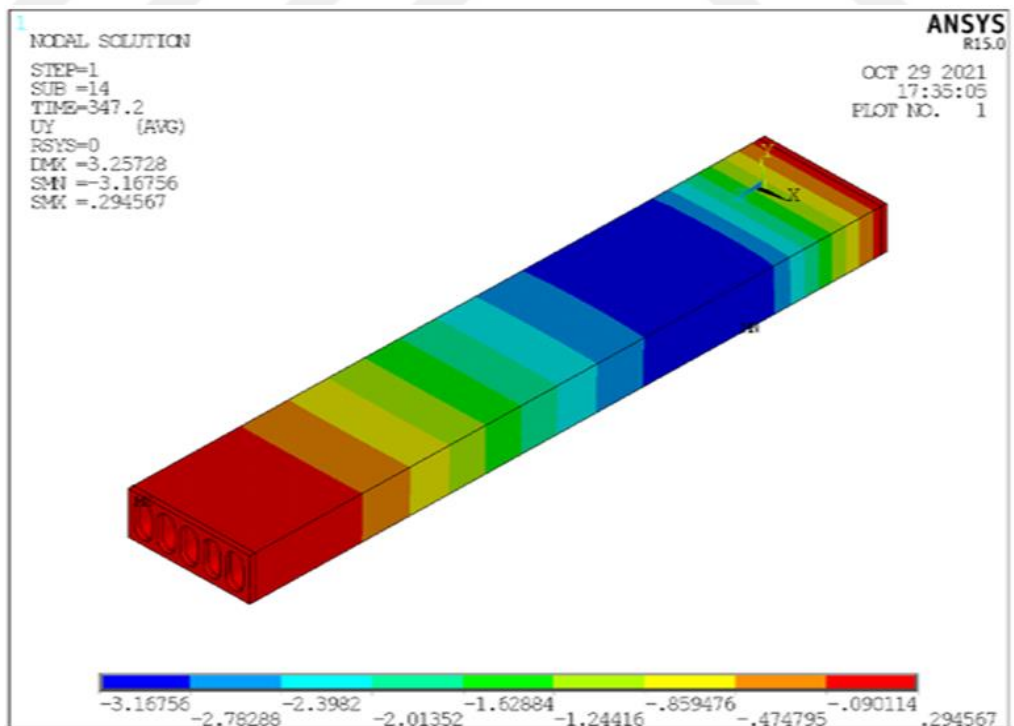


Figure 4.35 Contour plots for verification results of HCS tests ($a/d = 2.8V$ $f=0.5\%$)

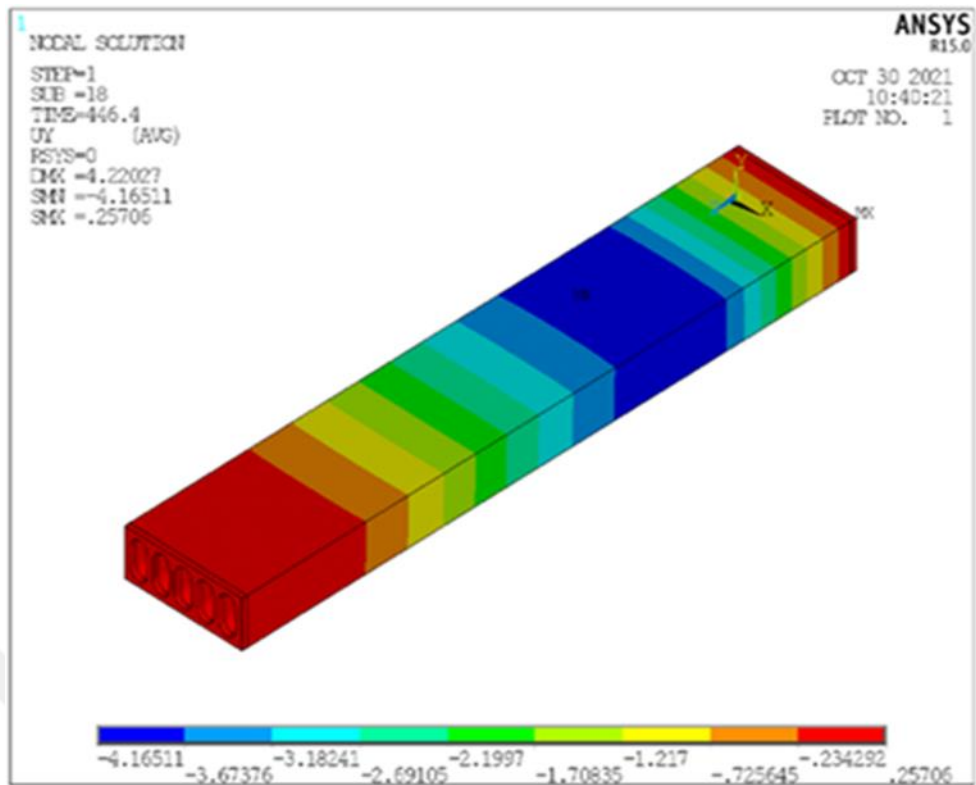


Figure 4.36 Contour plots for verification results of HCS tests ($a/d = 3.5Vf = 0.8\%$)

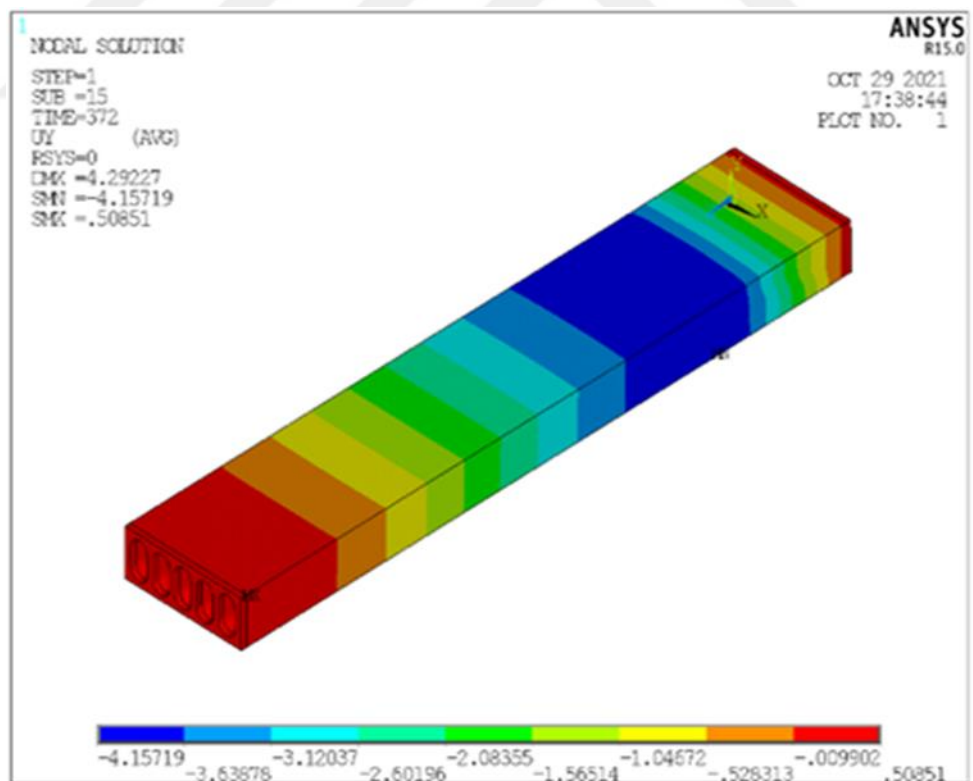
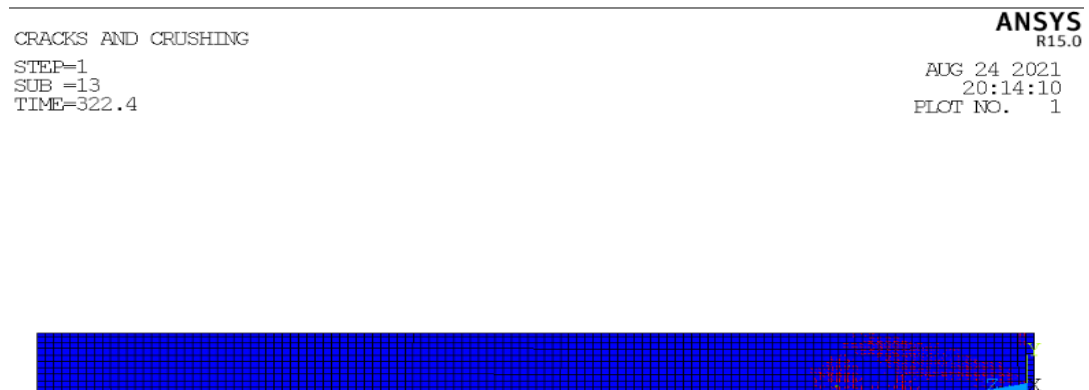
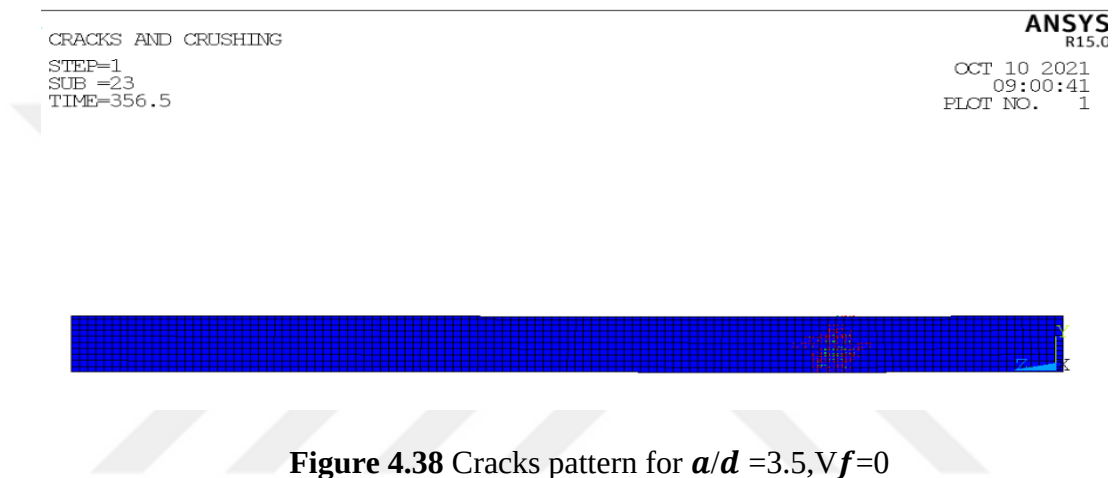


Figure 4.37 Contour plots for verification results of HCS tests ($a/d = 2.8Vf = 0.8\%$)

4.3.6 Cracks pattern

When the concrete element stress exceeds the tensile strength of concrete, cracks evolve into concrete elements. Moreover, they develop when the stress of concrete elements exceeds the concrete tensile strength in webs of HCS. Two types of cracks occur in concrete, which is: diagonal tension cracks arise diagonally toward the applied load, and cracks at sport extend toward the applied load.

As shown in Figures 4.38 to 4.42. The cracking shear failer of concrete hollow slab elements displays as a sign by the FE-based ANSYS program.



CRACKS AND CRUSHING	ANSYS
STEP=1	R15.0
SUB =19	AUG 18 2021
TIME=471.2	11:37:30
	PLOT NO. 1

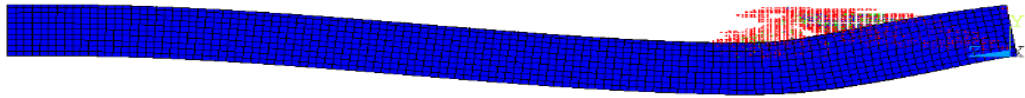


Figure 4.40 Cracks pattern for $a/d = 3.5, V_f = 1.15\%$

CRACKS AND CRUSHING	ANSYS
STEP=1	R15.0
SUB =15	SEP 13 2021
TIME=372	20:27:48
	PLOT NO. 1



Figure 4.41 Cracks pattern for $a/d = 3.5, V_f = 0.8\%$

CRACKS AND CRUSHING	ANSYS
STEP=1	R15.0
SUB =16	OCT 28 2021
TIME=396.8	21:47:42
	PLOT NO. 1

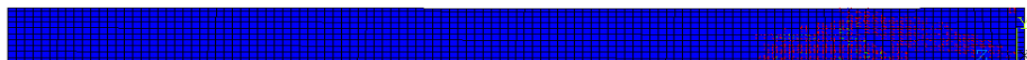


Figure 4.42 Cracks pattern for $a/d = 2.8, V_f = 1.15\%$

CHAPTER V

PARAMETRIC STUDY

5.1 Introduction

The numerical study is carried out with the help of the validated FE model. The parameters investigated in this study are.

- Reinforcement ratio
- concrete Strength
- effective depth ratio to shear span

5.2 Reinforcement Ratio

in this investigation, there were two types of steel bars utilized. The steel bar in the longitudinal and secondary direction of the top and the bottom layer was constant for all specimens $\varnothing 6\text{mm}$, $\varnothing 4\text{mm}$, with reinforcement ratio (A_s/A_c) .0037, .00175 respectively. The description of the slab specimen's reinforcement arrangement is shown in Table 4.6

Table 5.1 Reinforcement distribution

Solid and hollow slab			
Top and bottom steel reinforcement	Top and bottom steel reinforcement	$\frac{A_s}{A_c}\%$	symbol in the table
8 $\varnothing 6@55$ (main)	30 $\varnothing 4@55$ (Secondary)	0.37	1
4 $\varnothing 6@110$ (main)	15 $\varnothing 4@110$ (secondary)	0.175	2

5.3 Strength of Concrete

According to previous experimental work [Ahmed 2020,Ahmed 2021], the compressive strength is 28.6 MPa, and the compressive strength is 60.8 MPa.

One of the concrete grades used in this study for exhibiting the impact of concrete compressive strength. The 45 MPa were included in this study for HSC to explain the structural behavior.

5.4 Effective Depth Ratio to Shear Span (a/d)

The maximum load and maximum deflection of one-way slabs are influenced by the applied load position. For solid slabs, another type of shear span of 250 lengths was employed with the preceding type of shear span (a) length 500 mm, to effective depth (d) 105 mm, with a/d ratios of 4.8 and 2.4, respectively for a solid and hollow slab.

5.5 Ultimate Loads

The results of repeated experimental and FE analysis for three types of concrete (28.6, 45, and 60.8 MPa) are reported. ultimate load, deflection at ultimate load determined from FE analysis, and experimental results at the failure stage for solid slabs and HCSs D75 as shown in table 4-7

5.6 Parametric Study

5.6.1 Solid and hollow Slabs

The influence of concrete grade on the load-deflection behavior curve for solid and hollow slabs is shown in the table4.6. The different concrete grades (28.6, 40, and 60.8 MPa) were investigated. The results obtained explained that the increases in concrete stiffness caused increasing in ultimate loads with decreasing the mid-span deflection.

5.6.2 Effect of (a/d) Ratio

Two values of effective depth to shear span ratio (a/d) 4.8, 2.4, were carried out to analyze RC solid and hollow slab. The results are shown in Table 4.6 indicated that the increase of a/d ratio leads to a decrease in the ultimate load of slabs with the reduction in the deflection for the same ratio of reinforcement and ultimate capacity.

5.6.3 Effect of reinforcement ratio

The ratio of reinforcement was obtained from area steel to area concrete(A_s/A_c). Two types of this ratio were used, 0.37 and .175 corresponding's with two diameters of main steel bar reinforcement $\varnothing$ 4 mm, and $\varnothing$ 6 mm. The finding provides evidence that

the increase of reinforcement ratio caused in increasing ultimate loads and reduction in deflection of the hollow slabs and solid.

Table 5.2 The parametric study Result value of the solid and HCS

No	Specimen	Pult-(kN) EXP.	Yult (mm) EX	Pult (kN) FEM	Yult (mm) FEM
1	SS -28-4.8-1	52.46	26.75	49.86	28.34
2	SS-40-4.8-1			53.56	25.03
3	SS-60-4.8-1	71.22	17.12	66.56	20.41
4	SS-28.6-2.4-1			87.04	29.3
5	SS-40-2.4-1			108	25.84
6	SS-60-2.4-1			134.4	21.23
7	SS-28.-4.8-2			29.92	36.32
8	SS-40-4.8-2			35.36	32.82
9	SS-60-4.8-2			40.96	30.62
10	2D75-28-4.8-1	50.3	27.54	48.6	28.34
11	2D75-40-4.8-1			50.86	27.65
12	2D75-60-4.8-1	63.8	20.5	59.64	24.22
13	2D75-28-2.4-1			89.76	27.04
14	2D75-40—2.4-1			92.76	26.62
15	2D75-60-2.4-1			125.12	23.63
16	2D75-28-4.8-2			34.78	56.34
17	2D75-40-2.4-2			37.56	49.34
18	2D75-60-2.4-2			51.43	43.45
19	3D75-28-4.8-1	45.97	34.75	43.56	36.096
20	3D75-40-4.8-1			53.04	32.45
21	3D75-60-4.8-1	60.67	23.34	61.2	20.19
22	3D75-28-2.4-1			93.76	35.79
23	3D75- 40-2.4-1			98.76	32.56
24	3D75-60-2.4-1			126.4	26.65
25	3D75-28-4.8-2			31.34	54.186
26	3D75-40-4.8-2			34.45	48.18
27	3D75-60-4.8-2			47.6	40.61
28	4D75-28-4.8-1	42.46	34.67	40.08	38.05
29	4D75-40-4.8-1			48.69	34.86
30	4D75-60-4.8-1	58.91	24.95	52.02	27.51
31	4D75-28-2.4-1			84.32	38.69
32	4D75-40-2.4-1			95.2	34.64

Table 5.2 (cont)			
33	4D75-60-2.4-1	115.6	27.77
34	4D75-28-4.8-2	69.24	28.42
35	4D75- 40-4.8-2	56.45	28.42
36	4D75-60-4.8-2	36.72	47.77

5.6.4 Effect of size of hollow core slab

The size of the diameter opening is an effective factor in the ultimate load of the RC HCS. For this verification experimental work, the researchers used many specimens (NS,3D50,3D63,2D75,3D75,4D75) .The results are evident in the experimental and FE models show that the maximum ultimate load and minimum deflection can do by using the smallest diameter of opening as shown in table 4.6. Another explanation increases in concrete grade from NSC to HSC, lead to a reduction in the maximum load and an increase in deflection for HCSs.

The amount of ultimate load has a substantial effect by reinforcement and a/d ratios. The increases of concrete grade from NSC to HSC, lead to a decrease in the maximum load and an increase in deflection for HCSs.

It noted from this study Reinforcement, compressive strength and a/d ratios have a significant impact on increasing or decreasing the amount of ultimate load. also, the amount of ultimate load increase when the strength of the concrete and reinforcement ratio increases. Show these results peak load-deflection decreases when the reinforcement ratio and compressive strength increase, and increase the shear-span-to-effective depth ratio (a/d) decrease the amount of ultimate load

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

In this chapter, conclusions constructed on the FE numerical analysis carried out in the previous section of the dissertation using the FE software are summarized and presented. The conclusions can be written concerning the results obtained for FE model hollow slab. Additionally, the recommendations for future work are presented futuristic ideas for the development of the research work of RC hollow slab. The study with numerical findings is given in earlier chapters based on the FE approach established using FE computer software. It can be proven that the computational FE-models validated in this study are helpful and sufficient for evaluating FRC hollow slabs. According to nonlinear FE studies of RC hollow slab, the current study work's FE-model is capable of simulating the performance of RC and FRC hollow slab. The load-deflection response and ultimate load behavior in concrete RC hollow slab are in excellent agreement with the experimental data acquired from laboratory testing, according to the results of the FE analytical experiments conducted for the two examples investigated.

6.2 Conclusions

The following conclusions can be drawn from the results obtained by the FE model of the hollow slab model.

1. Inclusion of the fibers in the concrete matrix increased the shear strength gradually as the fiber content increased. Optimization reaches the best state when using a fiber content of 1.15% to 1.5% the highest shear resistance can be obtained
2. The addition of fibers leads to a decrease in deformations at all stages of loading due to the stiffness change of the material.

3. The relationship between the applied load and deflection of HCSs was linear during the early stages of loading up to the maximum load capacity.
4. Increasing the proportion of polypropylene added enhances the experimental conclusion reliability that Adding fibers to concrete increases the efficiency of prestressing by increasing the bonding between the ropes and concrete.

6.3 Recommendations and Future Works

The review of past research studies and analysis, a technique used in this dissertation has offered a beneficial vision for the future use of FE software as a method of RC hollow beam analysis. To ensure that the FE model produces findings that can be used for research, each numerical model must be calibrated using properly crafted experimental data, which contributes to the FE model's correctness. Based on the findings of this research, the following suggestions for possible extension and improvement of the present model can be made.

1. Dynamic and impact loads are major topics that may be tackled with nonlinear FE analysis of RC hollow beams using ANSYS software.
2. Other aspects besides the examined ones stated in this work, such as specimen size, the existence of openings, can be evaluated and investigated in RC hollow slabs under various forms of stress.
3. Nonlinear FE is used to investigate various composite RC hollow slabs.
4. Analysis of continuous post-tensioned RC hollow slabs.
5. The FE model employed in this work may be adapted to evaluate prestressed concrete hollow slabs under flexure load.
6. The FE model used in this work may be used to analyze steel fiber RC hollow members under the sheer load of enhancing shear strength in a deeply hollow slab.

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