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Investigation the Structural Behaviour of Fibrous Reinforced Concrete Slab Subjected to Impact Load

A Thesis

Submitted to the College of Engineering of the University of Kerbala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

By
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بِسْمِ اللهِ الرَّحْمَنِ الرَّحِيم

إِنَّ الْأَبْرَارَ لَفِي نَعِيمٍ ﴿22﴾ عَلَى الْأَرَائِكِ يَنظُرُونَ ﴿23﴾ تَعْرِفُ فِي
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مِسْكٌ وَفِي ذَلِكَ فَلْيَتَنَافَسِ الْمُتَنَافِسُونَ ﴿26﴾

صَدَقَ اللّٰهُ العَلِيُّ العَظِيم

﴿سورة المطففين، الآيات 22 - 26﴾

Dedication

To the designer of the human civilization that is established on the unity of almighty **Allah** (SWT). To the redeemer of human volition and thought. To the seal of the prophets and the master of all beings, the **Holy Prophet Muhammad** (Peace be upon him and his Household).

I dedicate this work to **my kind family**, **my dear father**, **my beloved mother**, **my lovely wife**, **my little boy,** and **all my brothers and sisters** for their love, care, and support during this stage. Thank you, all my beloved family, for your huge support; otherwise, work would not have taken place; thanks, with all my heart.

To **my supervisors** for their valuable advice, support and patience throughout this period. Without their enormous knowledge, I would not have made this possible.

Alhussain Al-Fattehallah
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Abstract

Current research investigates experimentally the behavior of high-strength fibrous reinforced concrete slabs (HSFCS) under dynamic load. Thirteen specimens were cast during the experimental work, including one control sample. The main twelve specimens were categorized into two groups based on the slab's thickness, 70 and 100 mm.

Six different mixtures were prepared, each two samples with two different thicknesses have the same concrete mixture. Two types of fiber were used in addition to micro silica to improve the mechanical properties of HSFCS. Steel and polypropylene fibers were used with various percentages to study their effect on concrete properties under impact load.

The impact frame was designed to apply the impact load by falling 14.5 kg projectile on the center of the slab. All samples were tested under the effect of impact load. A load cell with 10 Ton capacity and a laser sensor was used to measure the impact capacity of the midspan deflection. The relations between load with time in addition to displacement with time were produced. The crack patterns were noticed and recorded. The primary parameters studied in current research were the thickness of the slab, type of fibers, percentage of fibers and height of drops for the projectile.

The results showed that the midspan displacement and impact capacity for all tested slabs under the effect of impact load tended to be larger with a percentage of (11.8% to 43.5%) and (12.1% to 24.8%) respectively with the increase in the falling height. When the slab thickness was increased, the central displacement decreased significantly with a percentage ranged between (33% to 133%) due to the increment in the stiffness of the slab, which leads to an increase in the maximum impact capacity by a percentage of (28% to 50%) compared to control specimen.

The effect of fibers was clearly monitored in the experimental results. The steel fibers have a clear effect on enhancing all concrete properties, while the polypropylene fibers improved the tensile and the flexural strength only. The presence of steel fiber leads to reduce the maximum deflection by a percentage of (13.5% to 51.2%) and increase the load capacity by (3.5% to 16.8%) compared to control samples. In contrast, the presence of polypropylene fibers increased the deflection by (1.5% to 21.2%) and reduced the maximum load by (3.6% to 7.8%). The hybrid samples showed a reasonable result, the displacement was increased compared to control samples by a percentage of (3.6% to 23%), while the load was slightly decreased by (1.1% to 5.3%) due to the reduction in compressive strength of concrete.

Also, results showed that the clamped support condition leads to high stiffness for all tested slabs and the cracks on the bottom faces of all slabs appear first, followed by cracks on the top faces. These cracks tend to take on random shapes, and directions start from the center of the bottom face of the tested slabs.

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List of Abbreviation & Notations

Symbol	Description
R.C. S	Reinforced Concrete Structures
H.S.C	High-strength concrete
H.S.F.C	High-Strength Fibrous Concrete
P.P. F	Polypropylene Fibers
S. F	Steel Fibers
CFRP	carbon fibers reinforced polymer
GGBS	Ground Granulated Blast-furnace Slag
ACI	American concrete institute
ASTM	American Society for Testing and Materials
MS	Micro Silca
kN	Kilo-Newton
MPa	Megapascals
IQs.	Iraqi specification

CHAPTER ONE

INTRODUCTION

1. CHAPTER ONE

INTRODUCTION

1.1 General

Throughout history, applications of civil engineering have improved according to humanity's demands. As a result, R.C.S "Reinforced Concrete Structures" constructions became the major part of extant structures since the invention of such technology. Various types of load combinations can be considered in the design of these structures, all of which involve dynamic loads.

Civil engineers have recently discovered the importance of dynamic loads on the concrete structures, which can be caused by the impact of ballistic tornadoes, the vibration of machines, vehicle movement, earthquake, blasts, projectile rockets, wind blowing, etc. The impact load is an essential type of dynamic load [1] which can be defined as an impulsive force acting on a body for a very short duration [2].

Experimental and numerical studies on R.C.S have been done during recent years to understand the behaviors under the effect of impact loads, with the main important goal of preventing disasters in the future. In construction field, the reinforced concrete slab is considered one of the most important elements.

The experimental research on R.C slabs under the effects of dynamic loads is very critical because the effect of dynamic load on such element is complicated, needs high accuracy. And since the explosion tests are expensive, risky, and the results are unpredictable, impact testing are generally adopted cause it more controllable and typically less costly than explosion testing.

1.2 High-Strength Fibrous Concrete (HSFC)

The term high-strength concrete (H.S.C) is generally used for concrete with a compressive strength greater than 55 MPa [3]. H.S.C is an enhanced material that is used for high-buildings, bridges, and underwater constructions. In recent years, there is a tendency to use this type of concrete because it has many advantages, such as reducing the dimensions of sections, reducing the dead weight, and increasing spans length. Adding fibers to H.S.C significantly improves ductility, minimizes shrinkage effects, and improves the mechanical properties of concrete. As is well known, concrete is a common material that is generally weak in tension and often has cracks due to plastic and dry shrinking. The addition of short discerning fibers in the concrete can enhance concrete properties and give concrete the ability to counteract these cracks. This type of concrete is called High Strength Fibrous Concrete (HSFC). The concrete mixtures containing short steel fibers showed an optimal compromise between the workability, ductility, and protection against impact [4]. Furthermore, the use of polypropylene fibers leads to high ductility for concrete slabs due to the increment in the tensile strength. Material properties provide a notable indication that HSFC may be a suitable material for protection from the high-dynamic effect resulted from impact loads.

1.3 Impact Load

Impact loading results from a collision between two bodies that occur in a small interval of time, one with a high initial speed striking another at a stationary position by generating large forces [5]. In civil engineering, the struck object is typically a structural element that must be designed to withstand and resist the effects of impact load. This load is most intense, with a low possibility of occurring during the structure’s lifetime. However, the failure caused by the impact load often results in severe damage to the structural elements because it causes severe reductions in strength and insidious damage which may grow inside the structures without detection.

Civil engineers must be capable of deciding when to take the effect of impact load into account or when it is neglected. When load intensity is small, the impact load may be ignored during the design stage, while this load could have a significant effect when the intensity of load is enough. This matter rests on the designer engineer responsible for solving these issues safely, more effectively, and more economically.

In recent years, researchers focused on the behavior of structural elements such as slabs, beams, and columns under dynamic load. More research is needed into the structural behavior of HSFC slabs, particularly the effect of impact load. The concrete slab is a simple structural element, economical, and widely used. As a result, a high-strength fibrous concrete slab was chosen in this study because it has various uses in civil engineering applications.

1.4 Failure Modes Due to Impact Load

The effect of impact load on any structure could be divided into two categories [6]:

- Local-impact response.
- Overall-impact response.

1.4.1 Local Impact Response

The local impact effects may be in the form of spalling, scabbing, penetrating, or perforation of the target [6]. Spalls are a small piece of concrete that has been volatilized from the face of structural members in the area surrounding the impact region. Scabbing involves the volatility of concrete pieces from the rear face of the target subjected to impact loads. When a rigid missile penetrates through the target completely, it is called perforation. In contrast, the depth at which a missile will enter a concrete structural member without having passed through it is known as penetration [6].

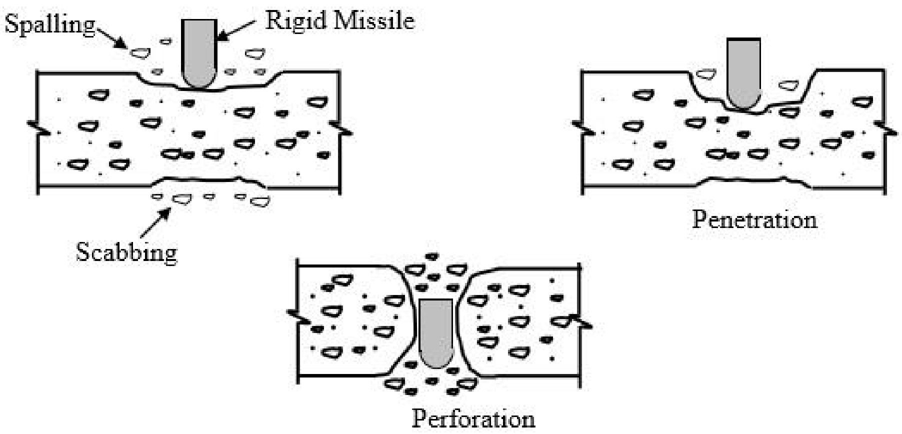


Figure 1-1 Local modes of failure [6]**.**

1.4.2 Overall Impact Response

The overall structural response includes flexural and shear deformations. If the strain energy capacity of the concrete and supports is smaller than the part of kinetic energy transmitted from the zone of penetration or perforation into the concrete, a potential flexural or shear failure will occur [6]. The dynamic response of structural elements under impact load can be determined if the load–time relationship history is known. It is necessary to consider both of the aforementioned responses when designing any concrete structural member.

1.5 Experimental Test Parameters

The current study focused on the experimental testing of reinforced concrete fibrous slabs which subjected to impact loads. The primary parameters in the current study were:

- The thickness of the slab.
- Type of fibers.
- Percentage of fibers.

1.6 Aim and Objectives

The primary objectives in the current study were:

1- Investigation the structural behavior of HSFC. slab under the effect of impact load.
2- Studying the effect of various percentages of steel and polypropylene fiber on the properties of HSFC. Slab subjected to impact load.

According to the experimental work, two important relationships had been getting from the test:

1- Load-time relationship.
2- Displacement-time relationship.

1.7 Thesis Layout

Chapter one: Includes a general introduction on HSFC and impact load and clarifies the problems that have been studied and the purpose of this research.

Chapter two: Presents a brief review of the experimental work related to current research.

Chapter Three: Presents the experimental work of this study, including the material of HSFC, the equipment, casting, and testing procedures that have been adopted in this research.

Chapter Four: Includes the results that have been obtained and the discussion of these results.

Chapter Five: Brief the conclusions for the results of impact load and recommendations for future work related to current study.

CHAPTER TWO

LITERATURE REVIEW

2. CHAPTER TWO

LITERATURE REVIEW

2.1 General

Recently, considerable attention has been focused on the effectiveness of dynamic loads applied to R.C structures. Various theoretical investigations on R.C. structures subjected to static and dynamic loads have been conducted. However, few experimental studies on the dynamic responses of reinforced concrete structures have been conducted due to two factors: cost and risk associated with experimental work. Initial research on this topic was designed to anticipate the depth of missile penetration, exit-velocity, and the structure's resistance. Robins Euler’s study in1742, Poncelet’s study in 1830, and Resel’s study in 1895 are the first examples of similar studies. Despite the advancement of R.C technology and the ongoing expansion of industrial needs, such approaches have been found to be insufficient for designing structural elements subjected to impact-load.

A dynamic load occurs when loading conditions are changing with time which are enforced on structures by either activity of humans such as machine vibrations and explosions or natural phenomena such as wind forces, earthquakes, and hurricanes. The dynamic load generates the failure in structures. The developed dynamic forces during the seismic event might cause great concern to structural integrity, as a result of the sloshing phenomenon. The structure experiences fluctuating forces due to wind gust that provokes huge dynamic motions with oscillations. Due to the dynamic loads, the structure builds up a significant level of inertia forces, and a large amount of mechanical energy is added as kinetic energy.

The majority of prior impact research has been focused on the behavior of R.C structures when hit by ballistic weapons. Particularly after the Second World War, Research in this field has significantly accelerated. The nuclear energy industry's demand for impact-resistant nuclear reactor designs has also increased. [7].

2.2 High Strength Fibrous Concrete (HSFC)

As previously defined, the term “high-strength concrete” referred to concrete with a compressive strength higher than 55 MPa [3]. High-strength concrete is treated as a brittle material that is easily cracked. Increased concrete strength diminishes its ductility, which is a significant disadvantage of using HSC. [8]. Steel fibers can be added to concrete to achieve a compromise between concrete strength and its ductility.

Previous studies on this topic showed an increase in the ductility of concrete when the fibers were added to the concrete compared to plain H.S concrete. After cracking occurs in concrete, the randomly widespread fibers stop a micro-cracking mechanism and limit the growth of the crack, which led to an increment in the strength and ductility in this type of concrete. Previous research has found that if all other parameters are held constant, the ductility of (HSFC) is significantly greater than that of normal (HSC).

The material properties for this kind of concrete indicate that HSFRC is an excellent choice to protect against the impact loads with high dynamic effects. [4].

2.3 Previous Studies on the Properties of HSFC

Najimi, Meysam in 2009 [9] study the effects of adding polypropylene (P.P) fibers to concrete. Three mixtures of concrete contain three different lengths of P.P fibers, 6mm, 12mm, and 19mm, respectively, have been studied. The volume fraction of P.P fibers for all mixtures was 2 kg/m^3. The results showed that when polypropylene fibers were added, the flexural strength was increased slightly, the crack width decreased, and the compressive strength slightly decreased compared to plain concrete (See Figures 2-1 and 2-2).

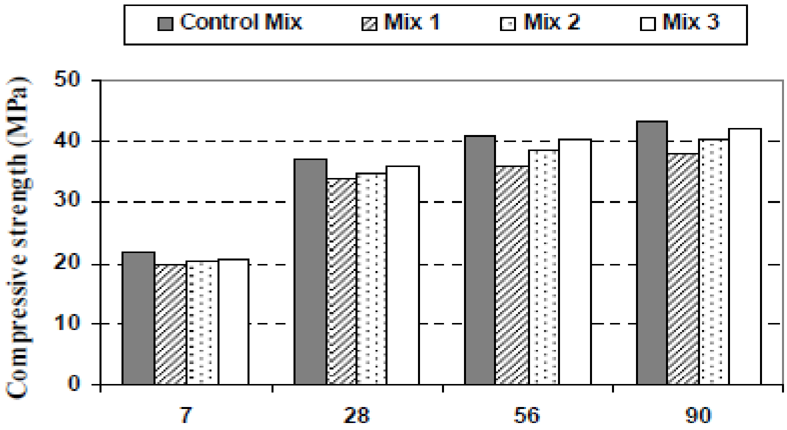


Figure 2-1 Compressive strength with concrete age [9]**.**

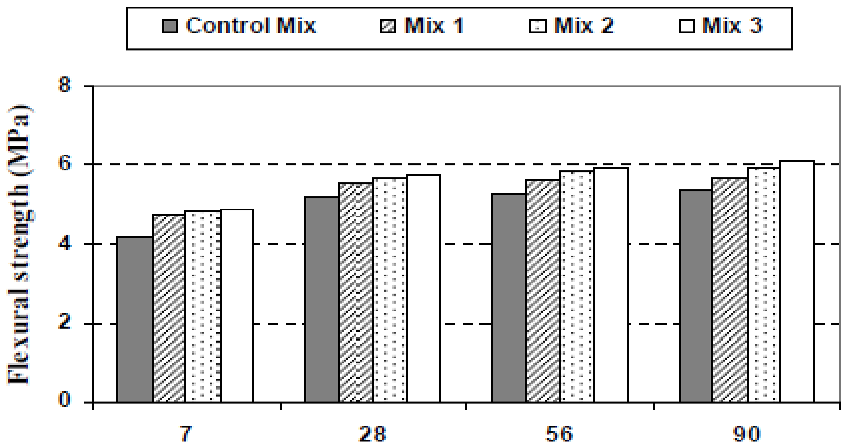


Figure 2-2 Flexural strength with concrete age [9]**.**

MR. Mehul J. Patel in 2013 [10] covers the various percentages of polypropylene fibers added to study their effect on the HSC. Experimental investigations carried out to investigate the effect of the P.P fibers on the properties of concrete. The percentages of fiber were 0%, 0.5%, 1%, and 1.5%. The results showed an increase in flexural strength, tensile strength, and shear strength compared with concrete without fiber.

Vahid Afroughsabet in 2015 [11] studied the effects of adding steel and P.P fibers to HSC and investigated their effect on the mechanical and durability properties. Four different percentages (0.25 %, 0.50 %, 0.75 %, and 1 %) of hooked end steel fiber were used, each with a 60-mm length. While the percentage of P.P fibers was (0.15 %, 0.30 % and 0.45 %). Some mixtures were carried out with the addition of steel and P.P fibers with a total percentage of 1 % by concrete volume. All the mixtures contain silica-fume (Si. F) with a percentage of 10 % as a replacement for cement. The effect of S.F, P.P fiber, and the hybridization of these fibers was investigated using a total of twelve different mixtures. The results showed a growth in flexural strength, which is produced in (Figures 2-3, 2-4 and 2-5).

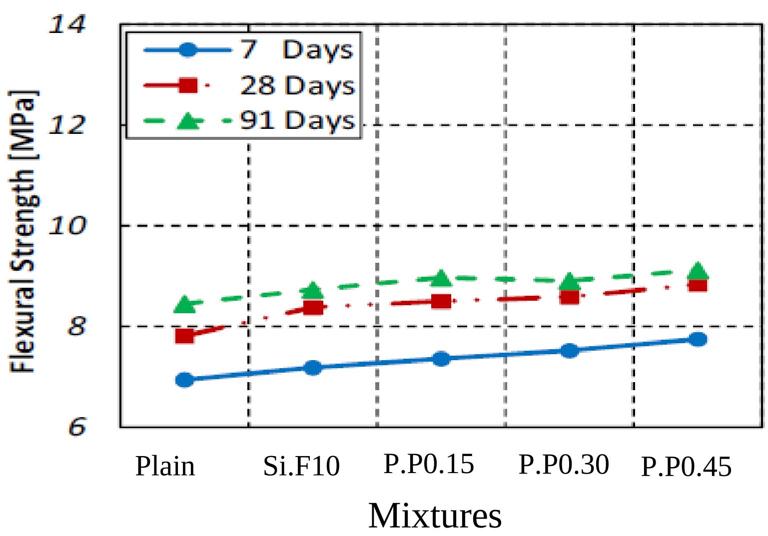


Figure 2-3 polypropylene fiber-reinforced specimens [11].

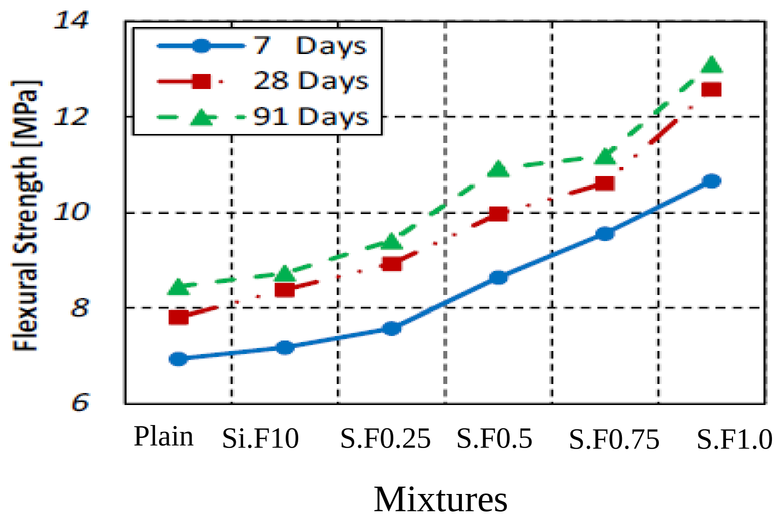


Figure 2-4 steel fiber-reinforced specimens [11].

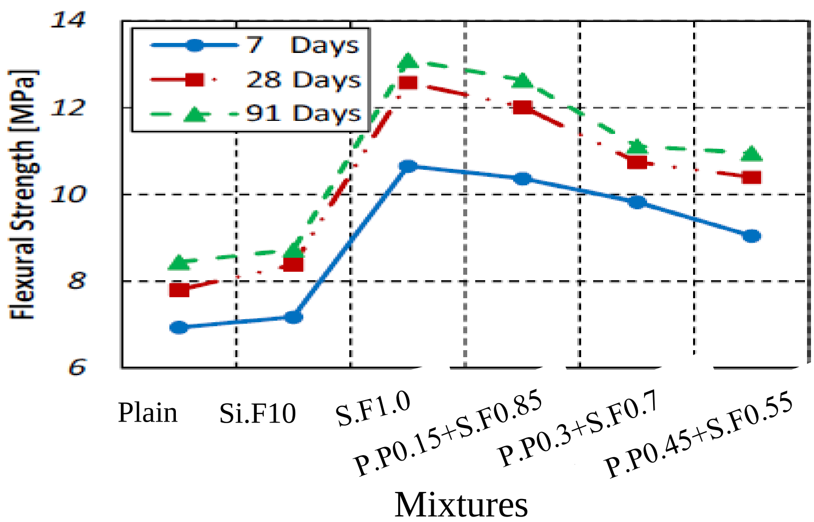


Figure 2-5 hybrid fiber-reinforced specimens [11].

According to the experimental results obtained from the tests, the following conclusions were produced:

- The 10 % percentage of silica fume improves all of the concrete's mechanical properties by (4% to 5%).
- The addition of S.F and P.P fibers improves the mechanical properties by a percentage ranged by (15% to 65%)
- The results of hybrid fiber mixture indicate that substituting P.P fiber for steel fiber results in a decrease in mechanical strength.

Hamid Gholizadeh, in 2018 [12], studied the mechanical characteristics of HSC containing S.F and P.P.F. HSC samples were carried out using a different mixing design and substitute cement by a percentage of silica fume. 24 mix design were produced. The compressive strength increased clearly with an increment in the amount of S.F. In general, it was noticed that when steel fiber was added, it enhances all the mechanical properties of concrete, increases the ductility of concrete, and decreases the cracks Significantly. After analysis of the results, the following conclusions have been produced:

- Addition of Micro-Silca up to 25 %, enhance the compressive strength by (10%) and improves the tensile strength and the fracture strength.
- Addition of S.F improves compressive-strength by (10% to 55%), in addition to enhance the tensile-strength and bending-resistance.
- Addition of P.P fibers up to 1 % decrease the compressive strength by (4% to 7%), improve the tensile strength and the bending resistance.
- Using a hybrid of steel and P.P fibers with a percentage of 1% and 1 kg/m3, respectively, enhances all three properties.

2.4 Previous Studies on Reinforced Concrete Structures Subjected to Impact-Loads

M. Zineddin and T. Krauthammer in 2007 [13] aimed to understand the dynamic behavior of R.C slabs when subjected to impact loading. Tests were performed on three different types of slabs with dimensions of 90mm x 1524mm x 3353 mm. The impact weight was dropped from three different heights: 152mm, 305 mm, and 610 mm, respectively. The impact mass dropped from a predetermined height in the center of the slabs, which weighed about 2608 Kg. The results showed that the amount of reinforcement used and the height of the drop have an effect on the response of the concrete slab.

To investigate the non-linear behavior of reinforced concrete slabs (R.C.S) subjected to static and impact load, A. Ghanim, in 2009 [6], made experimental tests and numerical analyses using the “finite element method.” The experimental work was carried out by testing 15 samples of two-way R.C. Slabs. Three samples were subjected to a static load at the center of the slab. The remaining twelve samples were subjected to impact loading via a falling mass in the slab’s center. The impact test was carried out by falling a 3 kg steel ball with a diameter of 90 mm.

At lower heights, it was discovered that the central deflections of all tested slabs are proportional to the striker’s height of fall. These deflections were found to be more significant with a slight increase in the striker’s height of fall, almost a doubling of deflections was observed. The central deflections of the impact-tested slabs decreased as the ratio of tensile steel reinforcement increased. However, the rate at which the deflection decreases is slower for high steel reinforcement ratios (1.77%). Finally, it was discovered that as the number of strikes and the height of the striking object falls increases, cracks begin to form on the bottom faces of all slabs earlier than the cracks on the top faces.

In 2013, B. Batarlar [7] investigated the behavior of RC slabs subjected to an impact load with low velocity. Six R.C slabs with dimensions of 2015 mm x 2015mm x 150 mm were tested. The specimens were subjected to impact loads induced by free fall dropping weight that struck them at the middle of their area. It was determined that the impact behavior of the slabs was seriously different from the static behavior. Due to the large inertia forces generated during the impact, displacement profiles and force distributions are significantly affected [5]. (Figure 2-6) shows the final states of some samples, which show the cracks on the bottom face after the impact test with a drop weight of 210 kg.

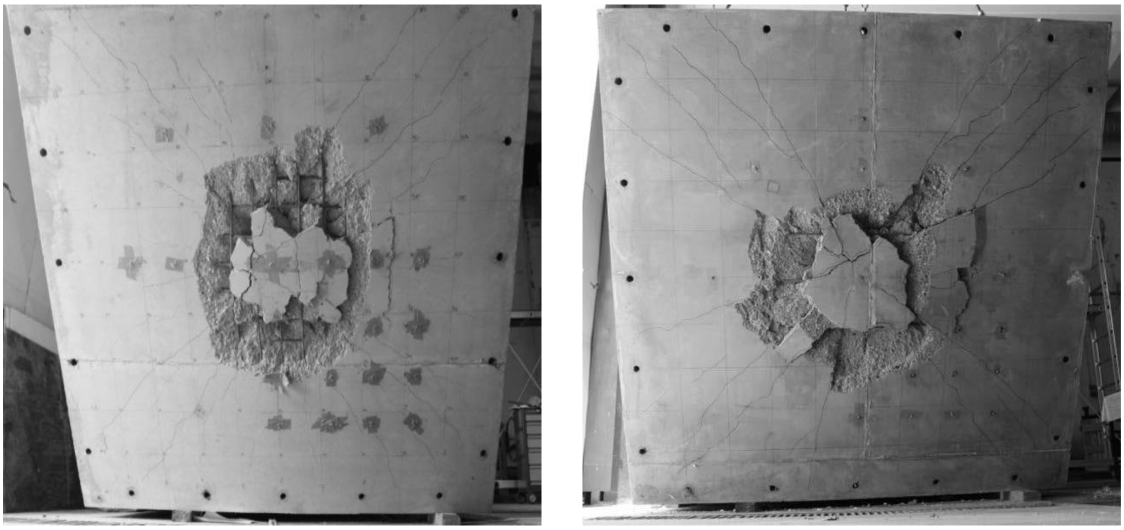


Figure 2-6 Final states of specimens **after impact test** [7]

The importance of inertia forces was demonstrated through impact tests. The impact forces were initially resisted by the slab's inertial forces, as indicated by force with time histories produced from these tests. The forces were developed on the supports under the effect of impact, and the static loads are significantly higher than those developed under static-loading. Furthermore, under static and impact loads, the direction of forces measured on the support is opposite to one another while displacement profiles match the direction of forces under the static load, impact events alter the force distribution on the specimen due to the generation of extremely high accelerations, resulting in significant inertial forces that prevent portions of the specimen from following other portions. [7]. This response lag is readily visible when displacement profiles for the same midpoint deflections are compared under static and impact conditions.

Campus, J B [14] in 2017 investigated experimentally the behavior of FRC slabs under the impact load in the form of drop weight. The program consisted of seven slabs of 600mm x 600mm x 60 mm that were cast with variable percentages of flyash and ground granulated blast-furnace slag (GGBS). Steel fibers having an aspect ratio of 70, l = 35 mm, and d = 0.5 mm) were added to all slabs at a percentage of 1%. C-clamps were used on all four sides of the slab to achieve fixed conditions. The center of the slabs was struck by a cylindrical hammer weighing 7.7 kilograms from a 700 mm height.

The strikes number required to generate the first and the final crack of failure has been recorded. The energy absorption capacity of the slabs was calculated and analyzed. The slab's initial and ultimate cracks in the failure were noted. For all slabs, the initial crack and ultimate impact strength were observed at the bottom face of the slab, while the ultimate crack at failure were determined when the reinforcement from the bottom is visible. The Number of blows required to cause the first crack ranged between (8 to 20) blows and between (73 to 575) blows to produce the ultimate impact strength.

Yılmaz, Tolga et al. [15] in 2020 examined the differences in the dynamics and modes of failure for R.C slabs under impact loads based on different types of support. The drop weight test setup was used to conduct impact load tests on nine slabs, with different support conditions made up of fixed end supports and hinged supports. The acceleration and displacement were recorded with time, as well as the impact loads that were acting on the slabs.

Nine samples were cast with a dimension of 1000 X1000 X 80 mm and a compressive strength of 25 Mpa for all samples. Two various impact energies were applied to the slabs during the experiments by dropping a hammer made of steel and having a weight of (84 kg and 102.8 kg) which falls from a height of 1.5 m. The samples were divided into groups of two samples according to support conditions. First group were fixed on all sides, second group were fixed on only three sides, third group having two adjacent sides with the fixed condition and the last group have two opposing sides with fixed support, while one specimen was deemed a reference specimen that was simply supported on all sides.

A 58% increment in the maximum acceleration, 74% in maximum displacement, and 26% in the residual displacement for R.C slabs with four hinged edges were observed compared to the same structure with all sides fixed edges. It was noticed that the cracks, which spread out from the middle of R.C slabs toward slab supports, became more intense where supports were fixed. Generally, it was determined that more cracks developed in the slabs with a higher number of fixed supports.

Batarlar, Baturay et al. [16] in 2021 studied the performance of "carbon textile reinforcement" utilized as a strengthening for R.C slabs when subjected to repeated impact loads. Five samples were tested with dimensions of (1500 X 1500 x 200) mm. Two samples were unreinforced and subjected to various impact velocities while the remaining samples were strengthened with three various carbon-textile reinforcements.

All specimens were subjected to heavy hits with the same accelerating by a drop weight of 21.60 kg, had a flat contact surface of 100 mm diameter, and a length of 380 mm. The conditions of support were fixed support at each of the four corners

It may conduct that all of the samples generated circumferential cracks, which indicated punching cone failure. Damage levels of specimens were found to differ significantly when striker velocity was increased by a significant amount. When the number of impacts until failure is taken into consideration, strengthening the slabs with carbon-textile reinforcements increased the impact capacity by a percentage of (22 % to 46%).

Yue Wang et al. [17] in 2021 investigated the dynamic response of RC slabs with two successive impacts represented by a drop hammer of 11.1 kg from three heights of 1.5, 2 and 2.1 meters. Four influences factors, including slab thickness, reinforcement ratio, impact location, and drop hammer height has been studied. The dimension of slab was 800 mm x 800 mm and three various heights of 80,100, and 120 mm.

The results showed that increasing the slab thickness and reinforcement ratio can improve the impact resistance of an RC slab by a percentage reached to (50%) and (13%) respectively, while the impact point location and drop hammer height improve impact resistance by (25%) and (58%). In addition, the RC slab will have more damage under the second impact, but the dynamic response becomes weaker. It may be because of the local damage in the concrete caused by the first impact that would weaken the propagation of vibration.

AbdulMuttalib I. Said and Enas M. Mouwainea [18] in 2021 studied experimentally the response of seven reinforced concrete slabs strengthened with CFRP sheets when subjected to high-mass low-velocity impact loads. The load was subjected at the center of the slab. The displacement recorded at center and quarter of slab. The test results showed that the adding of carbon fibers were increasing slab capacity and mitigating local damage under the impact, as the strengthening of slabs by CFRP, the increased in an impact force of the slabs about (11.9– 19.5%) and the maximum deflection at the central slabs decreased by (6.5–22%). It can be observed that the increase in the area of the CFRP layer under the impact region led to more decrease of the deflection.

CHAPTER THREE

EXPERIMENTAL WORK

3. CHAPTER THREE

EXPERIMENTAL WORK

3.1 General Introduction

Experimental work was carried to study the structural behavior of "high-strength reinforced fibrous concrete slabs" (H.S.F.R.C. Slab) under the effect of impact loads. It was conducted in the Civil Engineering Structural Laboratory at Kerbala University. The practical work consisted of testing twelve two-way concrete slabs in a clamped condition, subjected to impact load represented by a falling mass.

The test was done by using special equipment designed to read the parameters required in this test. All the frames and the equipment that were used in this work are described in this chapter. This chapter produce all the details of the tested samples and the arrangements in addition to all the material used in the casting process of all samples.

3.2 Test Specimens

Test specimens were divided into two groups according to the thickness of the slab. Each group consists of six specimens with constant dimensions (1200x1200) mm for both groups, two thickness which was 70 and 100 mm and various percentages of fibers. These dimensions were chosen to be easy to construct, move and test during the experimental work in addition to enable comparison with other researcher results.

All the specimens were tested under the effect of impact load which was represented by a projectile that hit the samples at the center from a predetermined height. Each sample was hit three times from three heights, 1.5, 1.8, and 2.1, respectively. The main variables parameters in this study will be produced in the following points:

1- Slab Thickness, the 12 samples were cast in two groups with two different thicknesses:
   - Six samples with 70 mm thickness and
   - Six samples with 100 mm thickness.
2- Type of fiber, two types of fibers has been used to enhance concrete properties:
   - Steel fibers.
   - Polypropylene fibers.
3- Percentage of fiber, the fibers were used with a different volume fraction in every two samples:
   - Steel fiber 0.5 % and 1 %.
   - Polypropylene 0.5 % and 1 %.
   - Hybrid of steel and polypropylene of 0.5 % + 0.5 %.
4- Height of drop, the projectile was dropped down freely from three different heights at the center of the tested sample:
   - 1.5 meter
   - 1.8 meter
   - 2.1 meter respectively, for each sample.

The above parameters have been chosen to investigate their dynamic effect response for high-strength fibrous reinforced concrete two-way slabs. All the details of the test specimens, including the type of test, type and percentage of fiber for this study, are shown in (Table 3-1).

Table 3-1 Details of slab specimens with (70 and 100) mm thickness

	N.	Percentage of Fiber By volume	Type of Fibers
Slab Thickness (70 and 100) mm	1	0 %	-
	2	0.5 %	Steel
	3	1 %	Steel
	4	0.5 %	Polypropylene
	5	1 %	Polypropylene
	6	(0.5 + 0.5) %	Steel + polypropylene

3.3 Materials

3.3.1 Cement

Cement is considered one of the major and basic materials in preparing concrete mixtures. In this study and during the experimental work, the most common type of cement was used which was local ordinary Portland cement produced by the Lafarge cement factory.

Lafarge cement conforms with Iraqi specifications No. (5) at 1987 (IQS No. 5/1987) [19]. The cement has been tested in the lab of the University of Kerbala. The test results, including all the physical and chemical properties of this type of cement, are shown in (Table 3-2 and Table 3-3).

Table 3-2 Lafarge ordinary cement Physical properties *

No.	Physical properties	Units	Value	I.Q.S No. 5/1987
1	**Setting time**			
	Initial	Min.	59	≥ 45
	Final	Min.	265	≤ 600
2	**Compressive strength**			
	3 Days	MPa	18.7	≥ 15
	7 Days	MPa	29.2	≥ 23

* This test was carried out by lab staff in University of Kerbala.

Table 3-3 Chemical properties of Lafarge ordinary cement *

Oxide	Chemical formula	Percentage by weight %	I.Q.S No. 5/1987
Lime	Cao	58.3	/
Silica	SiO_2	20.4	/
Alumina	Al_2O_3	3.9	/
Iron oxide	Fe_2O_3	4.5	/
Sulfate	SO_3	2.38	≤ 2. 5
Magnesia	MgO	3.81	≤ 5
Sodium oxide	Na_2O	0.25	/
Potassium oxide	K_2O	0.65	/
Insoluble residue	I.R	0.74	≤ 1.5
Loss on ignition	L.O. I	3.4	≤ 4%
Lime saturation factor	L. S. F	0.87	0.660 – 1.020
Bogue potential compound composition		% By weight	
Tri-calcium silicate (C3S)		50.8	/
Di-calcium silicate (C2S)		18.3	/
Tri-calcium aluminate (C3A)		2.1	≤ 3. 5
Tetra calcium aluminoferrite (C4AF)		12.4	/

* This test was carried out by lab staff in University of Kerbala.

3.3.2 Coarse Aggregate

In this work, black-crushed gravel from a region called Al-Niba'ai was used in a concrete mixture. Test results are shown in (Table 3-4 and Table 3-5), and the results conform to the Iraqi-Specification (No. 45)/1984 [20].

Table 3-4 Coarse aggregate sieve analysis test *

Size of Sieve (mm)	**passing Percentage %**	**I.Q.S No. 45/1984 (5-20) mm**
37.5	100	/
20	100	100
12.5	98	90 - 100
10	65	50 - 85
5	3	0 -10

* This test was carried out by lab staff in University of Kerbala.

Table 3-5 Properties for coarse aggregate *

Properties	**Value**	**IQS No.45/1984 (5-20) mm**
Sulfate's content	0.061 %	$\leq$ 0.1 %
The passing ratio from sieve No. 200	0.07 %	$\leq$ 3 %
Nominal maximum size	12.5	/
Specific gravity	2.65	/
Dry rodded density	1650 Kg/m^3	/

* This test was carried out by lab staff in University of Kerbala.

3.3.3 Fine Aggregate

In the current study, clean sand from a local region called AL-Akhaidir was used during the experimental work. The results were compared to the Iraqi standard specification No. 45 at 1984 [20]. All the details for sand properties are shown in (Table 3-6 and Table 3-7).

Table 3-6 Fine aggregate sieve analysis test *

Size of Sieve (mm)	Passing Percentage %	I.Q.S No.45/1984 Zone No. 2
10	100	100
4.75	98	90 - 100
2.36	82	75 - 100
1.18	60	55 - 90
0.6	44	35 - 59
0.3	23	8 - 30
0.15	5	0 - 10

* This test was carried out by lab staff in University of Kerbala.

Table 3-7 Properties for fine aggregate *

Properties	Value	IQS No.45/1984
Sulfate's content	0.063 %	$\leq$ 0.5 %
The passing ratio from sieve No. 200	0.4 %	$\leq$ 5 %
Fineness modulus	2.92	2.4 - 3
Specific gravity	2.6	/

* This test was carried out by lab staff in University of Kerbala.

3.3.4 Water

Normal potable water was used for mixing and concrete curing processes.

3.3.5 Superplasticizer

Mega Flow 3000, manufactured by the Conmix company, was used in concrete mixtures which is a high-performance concrete superplasticizer. This type of superplasticizer is used for ready mixed concrete, self-compacting concrete, underwater concrete, and concrete containing Silica fume, G.G.B.S (Ground Granulated Blast Slag), P.F.A (Pulverized Fuel Ash) with an extremely low w/c ratio. It is particularly useful for high-strength concrete. Mega Flow 3000 is conforming with ASTM C494 [21], Type E; BSEN 932-2 and the typical properties for this type of additive at 25 °C are shown in (Table 3-8).

Table 3-8 Mega Flow 3000 superplasticizer properties at 25 °C *[22]

Property	Test method	Value
Components	-	Single
Form of material	-	Liquid
Liquid Colour	-	Opaque
Specific Gravity	ASTM C494	1.11 ∓ 0.02
Air Entrainment	ASTM C231	Up to 1% over control mix
Chloride Content	BSEN 480-10	Nil to BSEN 934-2
pH	ASTM C494	5-7

* According to the manufactured company datasheet.

3.3.6 MegaAdd - Micro Silica

MegaAdd MS is a very fine pozzolanic material, ready to use high-performance mineral additives for use in concrete which is manufactured by Conmix company. It was used in concrete mixtures as a replacement by a specific percentage from cement (11.1 % by weight of cement). Micro silica conforms to ASTM C1240 specification [23]. The typical properties for Conmix Micro Silica are shown in (Table 3-9).

Table 3-9 MegaAdd M.S properties at 25 °C * [24]

Property of material	Test method	Values
State of material	Amorphous	Sub-micron powder
Colour	-	Grey - medium grey powder
Specific Gravity	-	2.1 – 2.4
Bulk Density	-	500 – 700 kg/m^3
<u>Chemical requirements</u> - Silicon dioxide SiO_2 - Moisture Content H_2O - Loss on ignition	-	≥ 85 % ≤ 3 % ≤ 6 %
<u>Physical requirements</u> - Specify Surface Area - Pozzolanic Activity Index, 7 days - Over size particles retained on 45 microns sieve	-	≥ 15 m^2/g ≤ 105 % of control ≤ 10 %

* According to the manufactured company datasheet.

3.3.7 Micro Steel Fibers (M.S.F)

In the current study, micro steel-fibers made in China were used. Figure 3-1 shows steel fiber shape, properties are shown in (Table 3-10).

Figure 3-1 Micro steel fibers

Table 3-10 Micro steel fiber properties * [25]

Property	Unit	Value
Shape	-	Straight
Colour	-	Gold
Fiber Length	mm	13
Fiber Diameter	mm	0.2
Fiber Density	kg/m^3	7860
Tensile Strength	MPa	2850
Aspect Ratio	-	65

* According to the manufactured company datasheet.

3.3.8 Polypropylene Fibers (P.P.F)

Polypropylene fibers were used as the second type of fiber in this study. The P.P fibers were manufactured by the sika company and conformed to EN ISO 9001 standards. (Figures 3-1 and 3-2) shows the shape of P.P fibers and the properties are shown in (Table 3-11).

Figure 3-2 Polypropylene fibers

Figure 3-3 Sika polypropylene fiber 12 mm bag

Table 3-11 Physical properties for polypropylene fibers * [26]

Property	Value or Description
Base	100 % virgin polypropylene
Colour	Natural - White
Design	Monofilament fiber
Fiber Length	12 mm
Fiber Diameter	18 micron - nominal

* According to the manufactured company datasheet.

Table 3-12 Chemical properties for polypropylene fibers * [26]

Property	Value or Description
Density	0.91 gm - nominal
Absorption	Nil
Specific Surface Area	250 sq meter per KG
Melt Point	160 °C
Ignition Point	365 °C
Thermal Conductivity	Low
Electrical Conductivity	Low
Acid Resistance	High
Alkali Resistance	100 %

* According to the manufactured company datasheet.

3.3.9 Steel Reinforcement

The steel bars that were used in this study were made in Ukraine with a grade of 40 and a diameter of 8 mm. These bars used to reinforce all tested slabs. The bars conform to ASTM-A615/2020 [27] specifications (See Table 3-14).

Table 3-13 Steel reinforcement test results *

Property	Unit	Value	ASTM-A615/2020
Nominal diameter	mm	8	-
Actual diameter	mm	7.81	-
Cross-section area	mm^2	47.9	-
Yield stress	MPa	375.5	≥ 280
Ultimate stress	MPa	526.03	≥ 420
Elongation	%	22.7	-
Nominal weight	Kg/m	0.3743	-

* This test was carried out by lab staff.

3.3.10 Steel Reinforcement Mesh

All the slabs were reinforced with Ø 8mm steel reinforcement. Two layers of reinforcement were placed. The ratio of reinforcement was taken identical for both directions of slabs. The mesh of reinforcement is shown in (Figure 3-4).

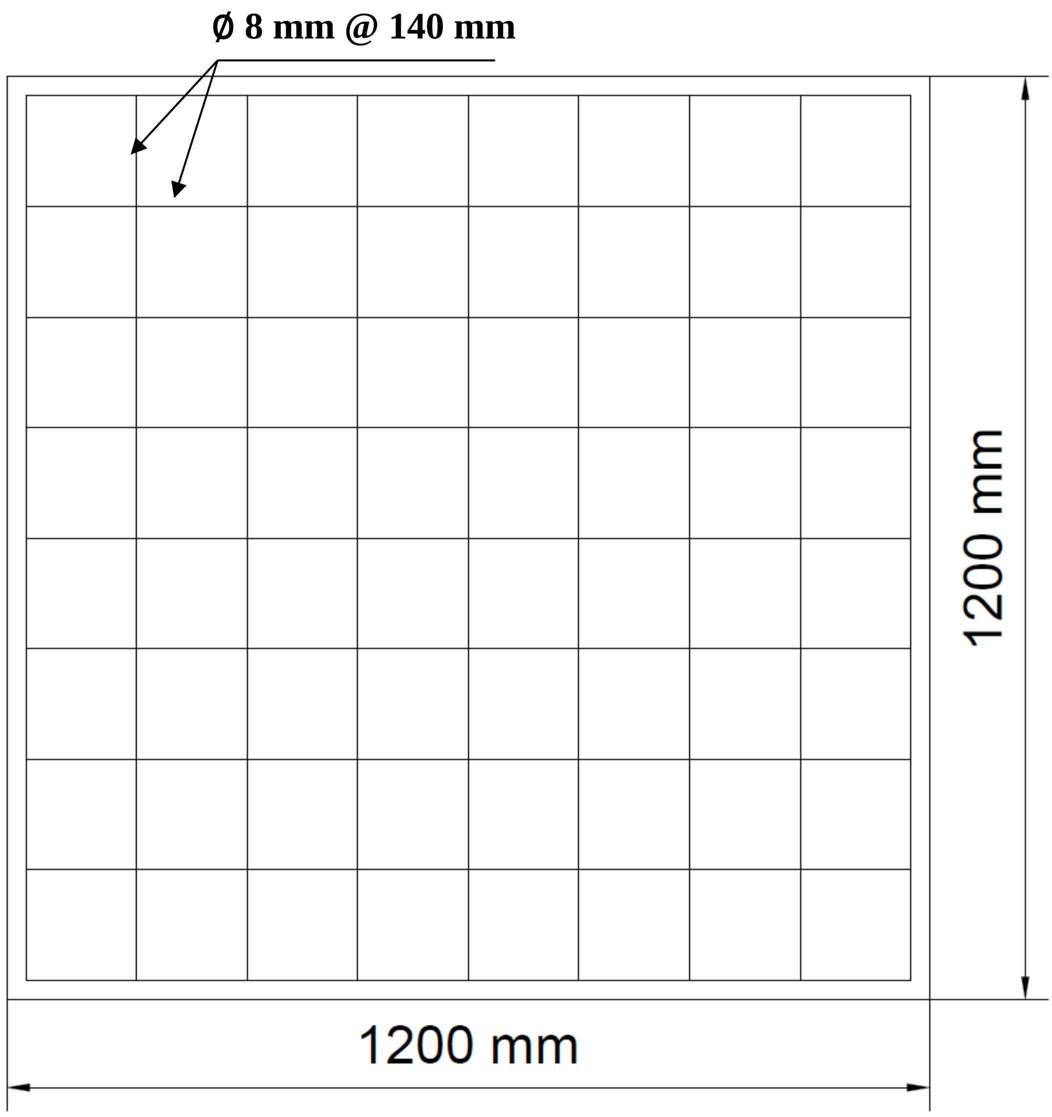


Figure 3-4 Steel reinforcement mesh

3.4 Mix Proportions

Concrete has been designed to obtain high-strength concrete with the presence of two types of fibers. In order to get suitable proportions, fifteen concrete trial mixtures were mixed. From these mixtures, six mixtures were chosen. The final proportions for one cubic meter are shown in (Table 3-14)

Table 3-14 Mix proportions per one cubic meter

Mix No.	**Mix ID**	**W/C**	**Water (kg)**	**Cement (kg)**	**M. Silca (kg)**	**F. Agg. (kg)**	**C. Agg. (kg)**	**Fiber V.F %**		**S.P %**
								S. F	**P.P. F**	
1	HS.	0.22	100	450	50	700	950	-	-	1
2	HS. S 0.5	0.22	100	450	50	700	950	0.5	-	1
3	HS. S 1	0.22	100	450	50	700	950	1	-	1
4	HS. P 0.5	0.22	100	450	50	700	950	-	0.5	1.1
5	HS. P 1	0.22	100	450	50	700	950	-	1	1.2
6	HS.H 0.5+0.5	0.22	100	450	50	700	950	0.5	0.5	1.3

- HS.: High Strength concrete without fiber.
- HS. S 0.5: High Strength concrete with 0.5% steel fibers.
- H.S S 1: High Strength concrete with 1% steel fibers.
- H.S. P 0.5: High strength concrete with 0.5 % polypropylene fibers.
- H.S. P 1: High strength concrete with 1 % polypropylene fibers.
- H.S. H 0.5+0.5: High strength concrete with hybrid 0.5 % steel and 0.5 %p.p.

3.5 Mixing, Casting, and Curing

All the samples were mixed by using a concrete site mixer with a capacity of 0.1 m^3. Mixing work was done outside the university to provide a large area required to control the work with thirteen specimens (12 + 1 for the trial test) with a dimension of 1200 mm x 1200 mm. All materials were weighed carefully and accurately. After that, the mixing process was normal, with adding the fibers at the final stage. The fibers were added slowly during the rotation of the mixer. This method was found to be the suitable one after a lot of trial mixes.

Special steel molds were fabricated accurately. The molds were oiled, and the steel shafts were installed and covered. Two layers of reinforcement were installed in the molds with a spacer of 15 mm. An electrical vibrator was used during the casting process then concrete was covered to prevent mixture water from evaporation and avoid the surface cracks. The oiled steel mold with shafts installation and place the reinforcement steel meshes, in addition to the mold after casting are shown in (Figure 3-5).

Figure 3-5 Casting process

After 24 hours, the molds were opened, and the samples were moved to the curing area.

3.6 Steel Molds

In this study, two steel molds were fabricated to cast the samples. Steel molds were chosen to ensure the accuracy of the slab dimensions and the precise position of the steel shafts. These shafts were fixed to the perimeter of the mold during the casting process then the shafts removed to obtain holes within the concrete samples. These holes were prepared to achieve the clamped condition by installing bolts in these holes, which are connected up and down to the test steel frame. (Figure 3-6) depicts all of these details, including dimensions.

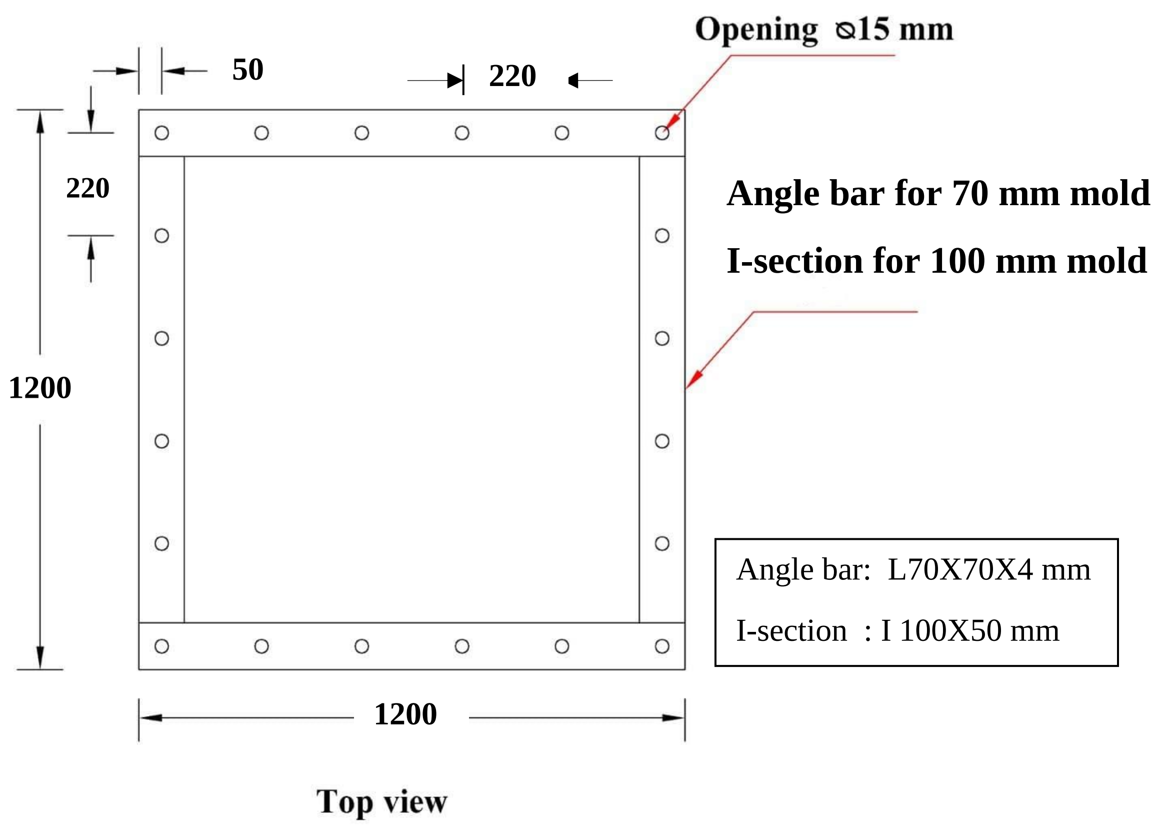


Figure 3-6 Steel molds details

The steel molds were fabricated locally, using Ukrainian steel angle bars, steel I-section, and steel sheets. According to the slab dimensions, the molds were 1200 x 1200 m in size. The height of the molds was 70 mm and 100 mm. The details of the molds and shafts are shown (Figures 3-7 and 3-8).

Figure 3-7 steel shafts installation process

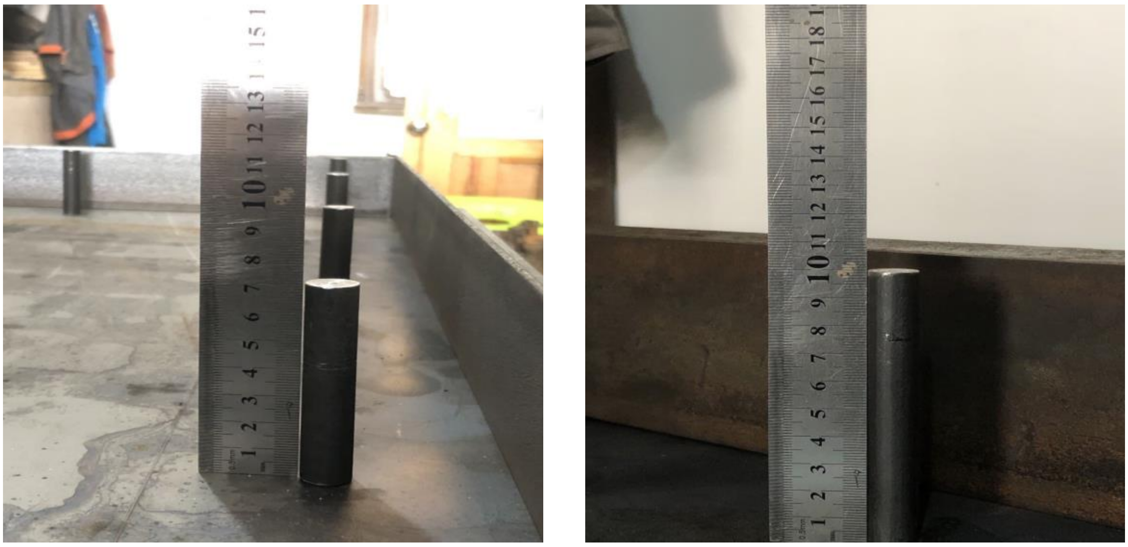


Figure 3-8 steel shafts with 70 and 100 mm

3.7 Impact Test Rig

Impact rig was made to carry out the impact test for all the samples. The impact rig consists of three parts, a supporting steel frame, impactor frame, and vertical guiding tube.

3.7.1 Supporting Steel Frame

A steel frame was fabricated to support the tested samples and achieve the clamped condition. The frame was made of steel sections. The dimension of the frame is 1200 mm x 1200 mm according to the slab dimensions. The frame consists of two steel channels (C 100x48x5.3 mm). The frame base was made of an upturned steel c-section channel with 800 mm legs fixed to the ground. The second steel channel was fixed on the top of the slab. Both C – channels have holes located exactly with the slab's holes. The two steel C – channels are fixed to the slab by twenty 15 cm black bolts throughout the slab's hole. In addition to twelve 24 cm bolts surrounding the frame, (See Figure 3-9 and 3-10).

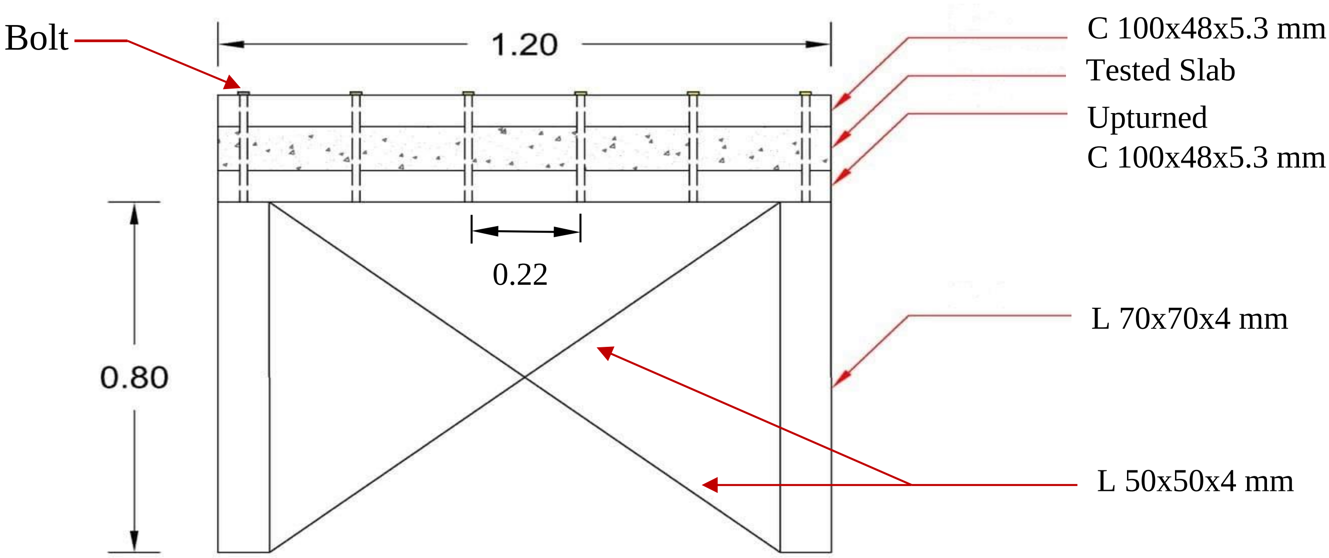


Figure 3-9 Supporting Frame details

3.7.2 Impactor Frame

The impactor frame is the top frame that is connected to the supporting frame and surrounds the guiding tube. It was fabricated from L section steel (L 50x50x4 mm) *. The impactor frame has a pyramidal shape painted with blue Colour. Figure 3-10 shows the impactor frame fixed to the supporting frame.

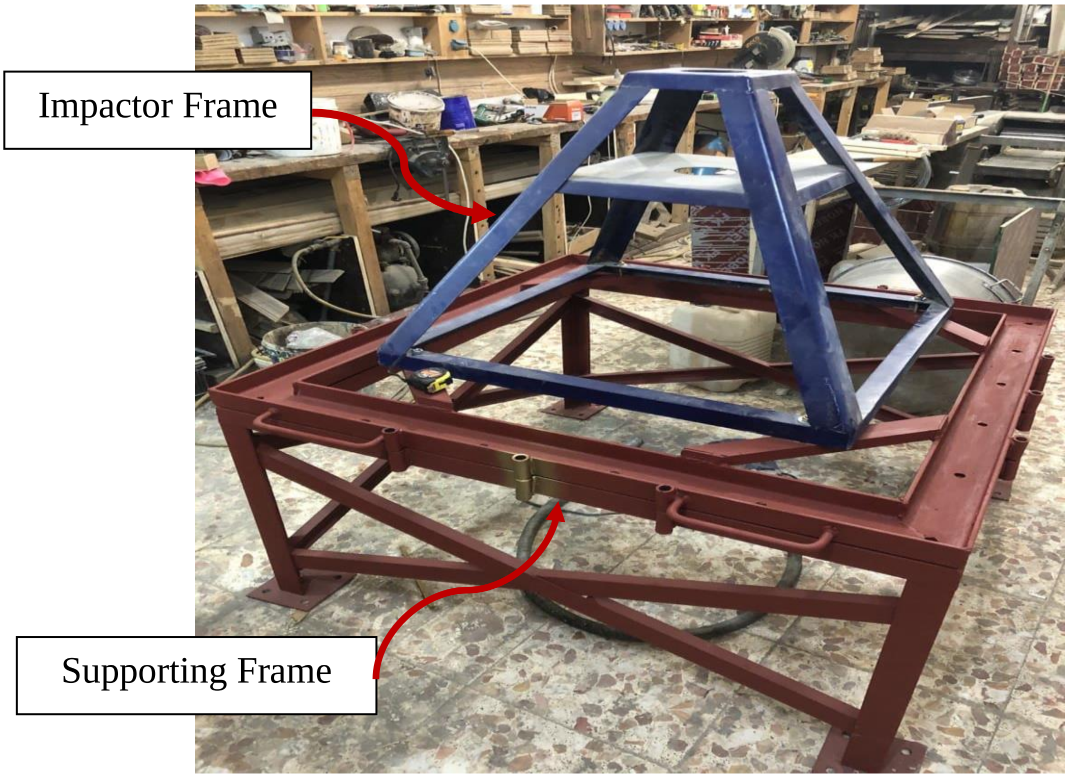


Figure 3-10 Impactor and supporting Frames

* The impactor frame manufactured by Dr. Dhafer Mohsin

3.7.3 Vertical Guiding Tube

The third part of the impact rig is the guiding tube. The primary purpose of this tube was to guide the projectile during a free fall to the center of the slab. It was made from steel with a length of 2 meters and an inner diameter of 120 mm. The tube was connected to the impactor frame and fixed vertically above the center of the tested slab.

At the top of this tube, a mechanical system has been made which works as a brake. This system was produced to hold the projectile during the test process. The tube was perforated at three heights to provide the three heights required during the test. A flexible cable was used to release the projectile from the brake system and allow it to free fall. The following figures show the guide tube connected to the impactor frame and the whole parts of the impact rig, respectively.

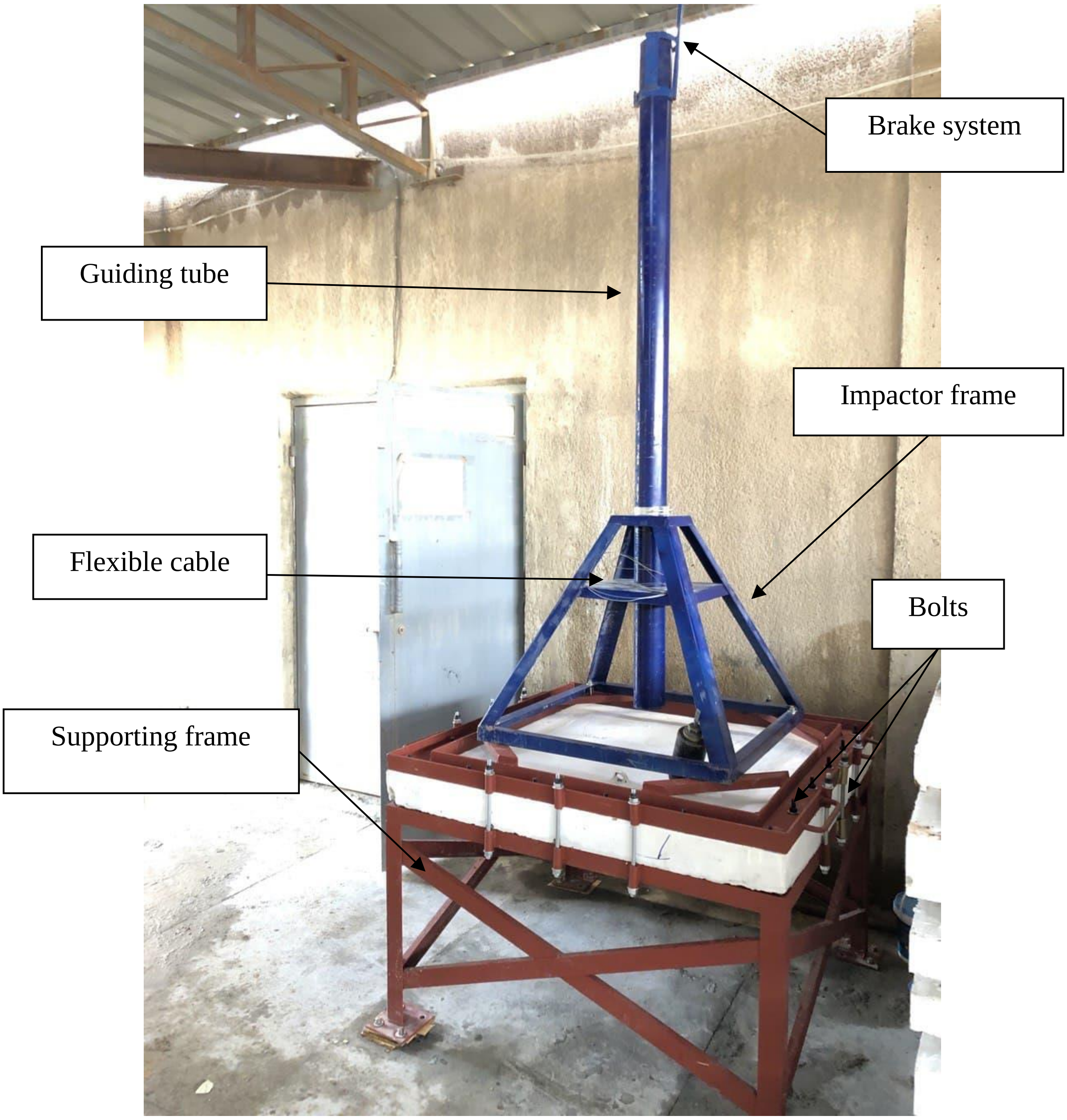


Figure 3-11 Whole parts of impact rig

3.8 Impactor Body (Projectile)

The projectile used in the current study has a mass of 14.5 kg, consisting of two parts. The first part is a steel ball of (100 mm) diameter connected to the second part of the projectile. The second part is a cylinder tube having a length of (200 mm) and a (100 mm) diameter.

The target was hit directly by this projectile by means of a falling mass at the center of the target from three predetermined height starting from 1.5 m to 2.1 m. The impactor's body is depicted in detail in the (Figure 3-12).

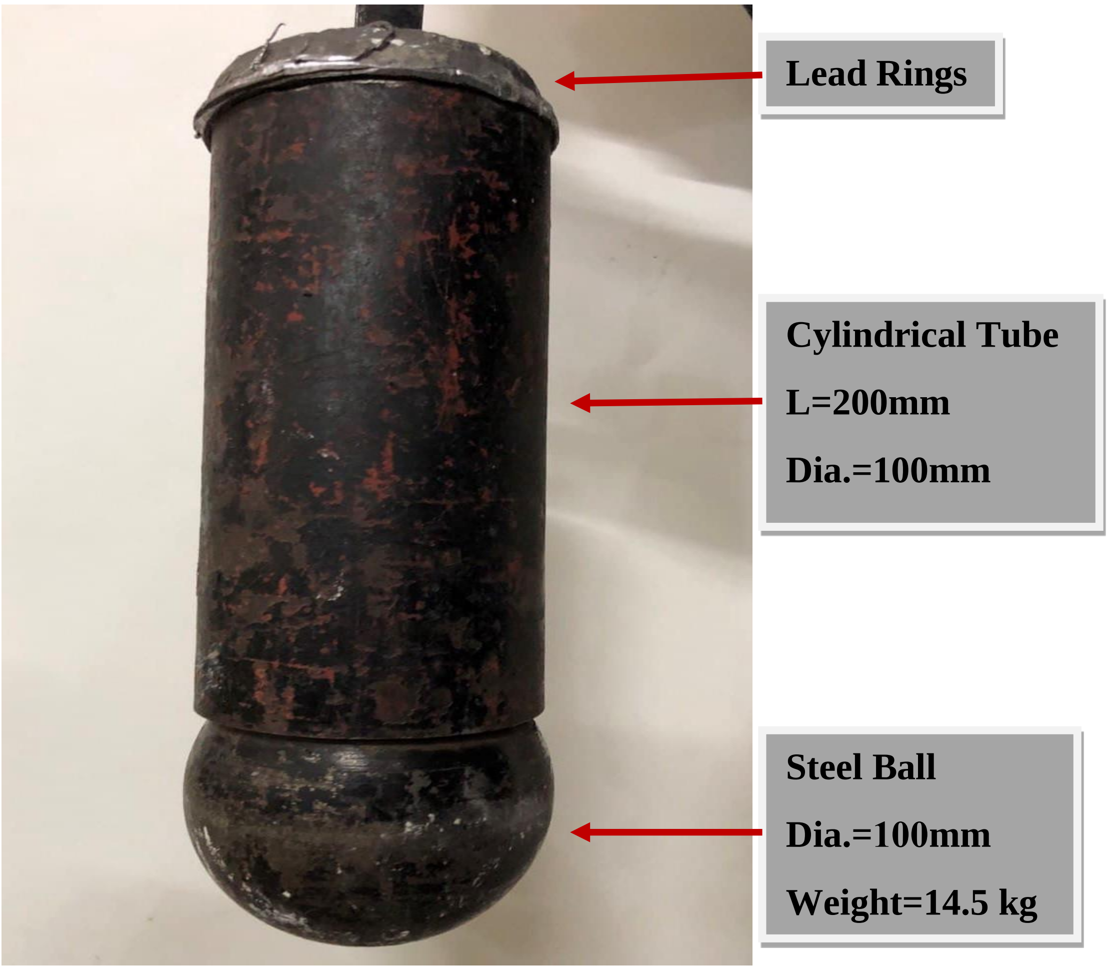


Figure 3-12 Impactor Body – Projectile

3.9 Impact Test Procedures

The impact test was carried out in the structural lab at the University of Kerbala. The frames were installed, and the samples were fixed to the frame accurately. Two types of sensors were used in this test. A Load-Cell (DYLF-102) with a capacity of 10-ton to measure the impact load (Figure 3-13) which was located in the center of the top face of slab. The projectile hit the load-cell directly, and the load cell recorded the impact load (see Figure 3-15). The second sensor was a laser sensor (LK-081- KEYENCE) that measures the displacement-time history of the impacted sample (Figure 3-14). The laser fixed under the sample and guided to the center of the slab and the two sensors were connected to the LabVIEW software, which records the data on an Excel sheet. The software was designed and programmed with a control system to record and save the data at a rate of 125,000 samples/sec (See Figure 3-15). The specifications for both sensors according to the manufacture company are shown in (Appendix B).

The test procedures can be summarized in the following steps:

1- All the equipment and sensors were placed in their positions.
2- The sample was fixed to the frame.
3- The load-cell sits at the center of the top face of the slab.
4- The laser was installed below the center of the slab.
5- A cable held the projectile.
6- The cable was released to allow the free-falling.
7- The projectile hit the load cell in the center.
8- The load cell measures the impact load.
9- The laser sensor measured the resulting displacement.

Figure 3-13 Load cell and projectile during impact moment

Figure 3-14 Laser sensor (LK-081) [28]

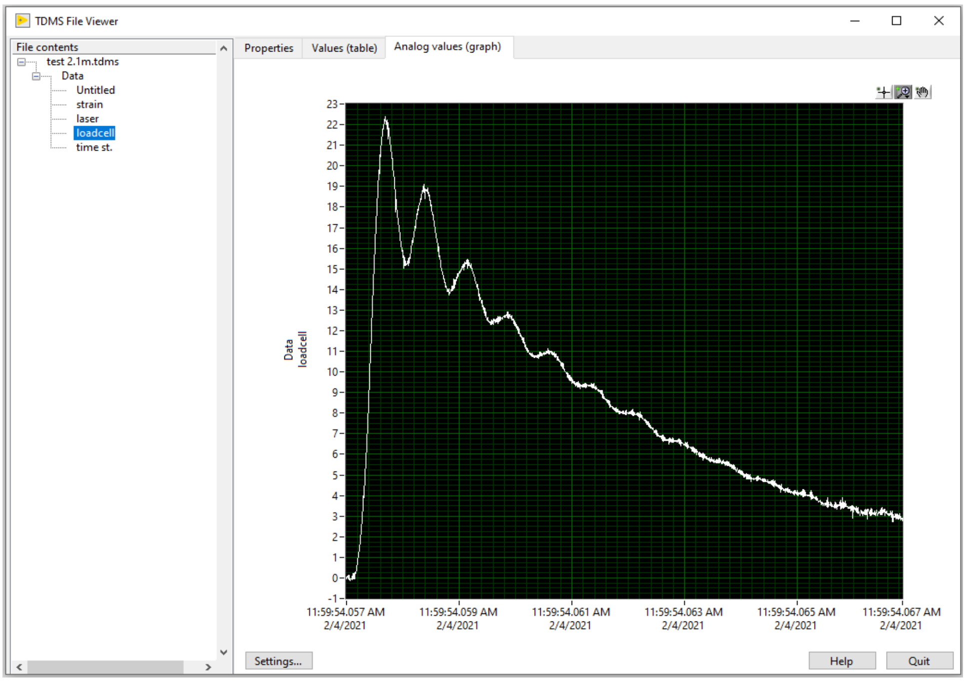


Figure 3-15 Impact waves for load in LabVIEW software

The following figure shows the impact test program, which includes three-view screens for laser sensor readings, strain readings, and load cell readings. The figures show a reading for the sensor and three readings from loadcell resulted from three hits.

Figure 3-16 Impact test program during the test

CHAPTER FOUR

RESULTS & DISCUSSION

4. CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the impact test results obtained by the experimental works on the high-strength fibrous reinforced concrete slabs (HSFCS) has been produced. As mentioned previously, thirteen specimens have been cast during the experimental work, including one test sample. Six different mixtures were prepared during the experimental work. Each two samples with two different thicknesses have the same concrete mixture. All the samples were tested under the effect of impact load represented by free fall mass in the center of the slab.

A specific equipment was used to obtain the results. A load cell with 10-Ton capacity at the center of the top face of the slab was used to record the direct impact load. An accurate laser sensor below the center of the bottom face of the slab was placed to record the midspan deflection.

This chapter shows the mechanical properties of high-strength fibrous concrete, the load-time curves, and the displacement-time curves.

4.2 Mechanical Properties of HSFC

The mechanical properties for high strength fibrous concrete that were studied in this research were:

- Compressive strength for the cube (150x150 mm).

- Compressive strength for cylinder (height: 200mm, diameter: 100 mm).

- Splitting tensile strength for cylinder (height: 200mm, diameter: 100 mm).

- Flexural strength for prism (100x100x500 mm).

4.2.1 Compressive Strength

The compressive strength was tested in the Kerbala Construction Laboratory. A compressive strength device has a capacity of 3000 KN was used (Figure 4-1). The cylinder compressive strength of high-strength fibrous concrete was tested according to C39/C39M-05 of the ASTM [29]. The compressive strengths results are shown in (Table 4-1).

Table 4-1 Compressive strength of cylinders and cubes for HSFC

Mix. No.	**Mix ID**	**Compressive Strength (MPa) at 28 Days**	
		Cubes	**Cylinders**
1	HS.	75	59
2	HS. S 0.5	78	62
3	HS. S 1	85	66
4	HS. P 0.5	62	48
5	HS. P 1	60	45
6	HS.H 0.5+0.5	64	49

The experimental results show that:

- The compressive strength was slightly increased with a percentage of (3%) compared to the control mixture (HS.) when a percentage of (0.5% steel fibers) was added.
- When the steel fiber percentage was increased to (1%), the compressive strength was increased by a percentage of (13.3%) compared to the reference one.
- The presence of polypropylene leads to a noticeable reduction in concrete compressive strength. The strength was reduced by a

percentage of (-17.3%) than the H.S. mixture when a percentage of (0.5%) from P.P. fibers were added.

- ❖ When the P.P fibers percentage was increased to (1%), the compressive strength was reduced by a percentage of (-20%).
- ❖ When a hybrid of both types of fibers was used, the compressive strength was reduced by a percentage of (14.6%).
- ❖ (Table 4-2) shows the summary of compressive strength results:

Table 4-2 Percentage of change in C.S compared to the control mixture

Mix. No.	**Mix ID**	**Compressive Strength (MPa)**	**Percentage of change**
1	HS.	75	-
2	HS. S 0.5	78	+ 3 %
3	HS. S 1	85	+ 13.3 %
4	HS. P 0.5	62	- 17.3 %
5	HS. P 1	60	- 20 %
6	HS.H 0.5+0.5	64	- 14.6 %

Figure 4-1 Compressive strength device with a capacity of 3000 KN

The cubes with a percentage of fibers were noticed to be safer during the test. The fibers work likes a thread which prevents concrete pieces from volatilizing at failure stage while the cubes without fibers were exploded, and pieces from concrete were volatilized. This goes back to the presence of S.F and P.P fibers which improve concrete properties, reduce the cracks and increase the flexibility of concrete. (Figure 4-2) shows two cubes with and without steel fibers after the crushing by the compressive strength device.

Figure 4-2 Cube containing steel fibers

4.2.2 Splitting Tensile Strength

The test was carried out in according to ASTM C496/C496M-04 [30] using a device with a capacity of 2000 KN. The cylinders with a diameter of 100 mm and a height of 200 mm were tested and the results are shown in (Figure 4-3).

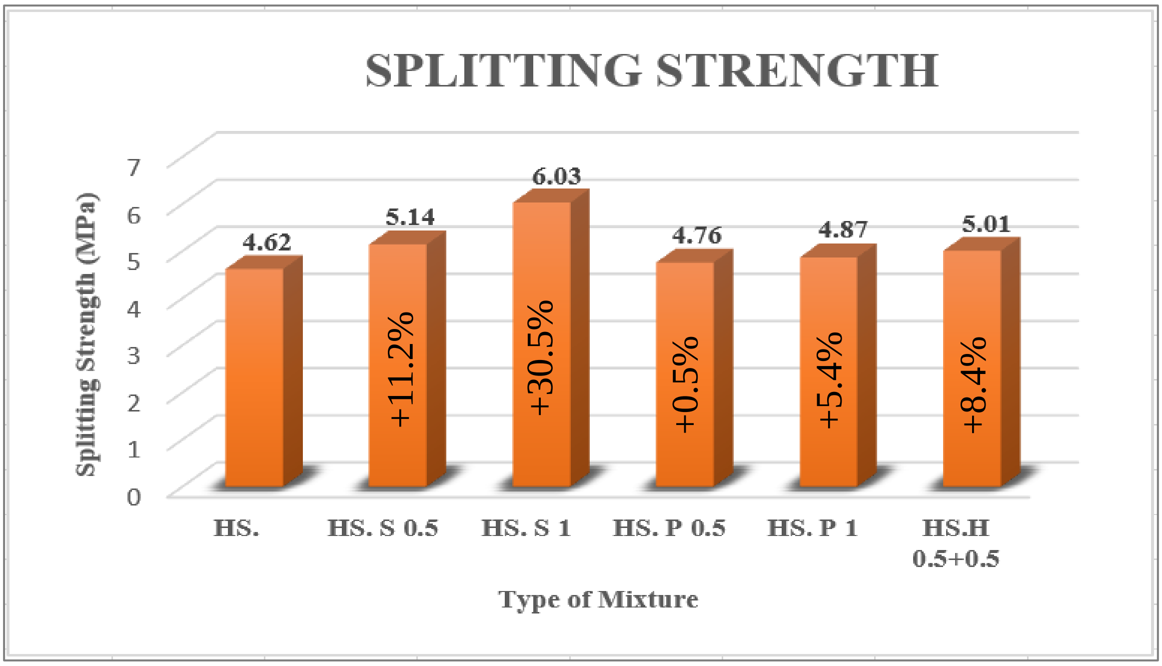


Figure 4-3 Spitting tensile test results

The results of the splitting test show:

- ❖ The splitting strength of the high strength concrete mixture without fiber was 4.62 MPa.
- ❖ The strength was increased by a percentage of (11.25%) when (0.5 %) S.F were added to the mixture compared to the control mixture.
- ❖ The strength continues to increase by a percentage of (30.52%) when (1%) steel fibers were added.
- ❖ Despite the noticeable decrease in compressive strength, the splitting strength was slightly increased with the addition of a (0.5%) percentage of polypropylene fibers.
- ❖ When a percentage of P.P fiber was increased to (1%), the splitting strength was increased by a percentage of (5.41%) compared to control mixture.
- ❖ The hybrid mixture shows a noticeable increase in splitting strength with a percentage of (8.44%) higher than the control mixture.

4.2.3 Flexural Strength

The flexural strength test were carried out using a prism with a dimension of 500x100x100 mm and was carried out using the center point loading method according to ASTM_C293 [31]. The flexural strength test results and the used device during the test of P. P 0.5 sample are shown in (Figure 4-4) and (Figure 4-5) respectively.

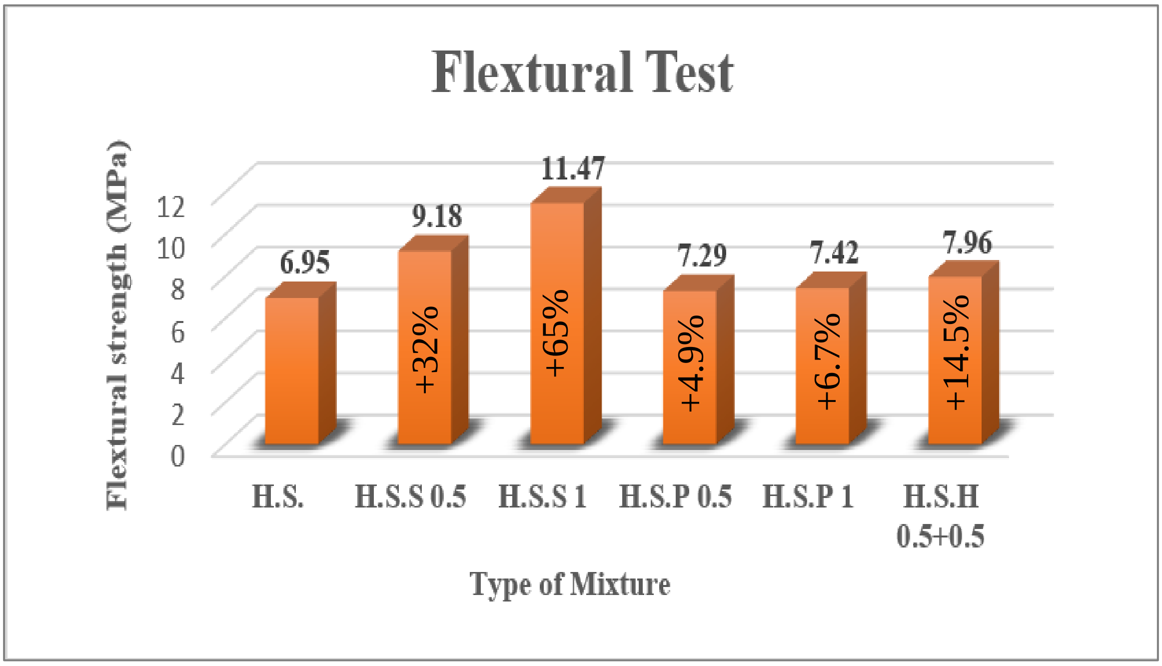


Figure 4-4 Flexural test results

- The results show that the flexural strength of the concrete increases when fibers were added. Both types of fibers increase flexural strength. The mechanical properties of concrete have depicted a gradual increase in strength as the fiber content increased [32].
- The fibers enhance the ductility of concrete.
- Although the P.P fibers decrease the compressive strength, the flexural strength was increased with the presence of P.P fibers.
- The test device was used due to the damaged of the common device.

Figure 4-5 Flexural test for P. P 0.5 sample at failure stage

4.3 Impact Test Results

4.3.1 High Strength Concrete Mixture Without Fibers – H.S

The values of peak load capacity and midspan deflection for high strength concrete mixture for both thickness of the slab for each sample are shown in (Table 4-3).

Table 4-3 Peak impact load and peak deflection for H.S mixture

H.S: High Strength Concrete without fiber					
No.	Height (m)	H.S – 70 mm		H.S – 100 mm	
		Peak Load (KN)	Peak Disp. (mm)	Peak Load (KN)	Peak Disp. (mm)
1	1.5	15.4	2.36	23.1	1.32
2	1.8	17.8	2.78	25.4	1.60
3	2.1	18.7	3.29	25.9	1.68

The load-time and displacement-time curves are shown in (Figures 4-6 and 4-7).

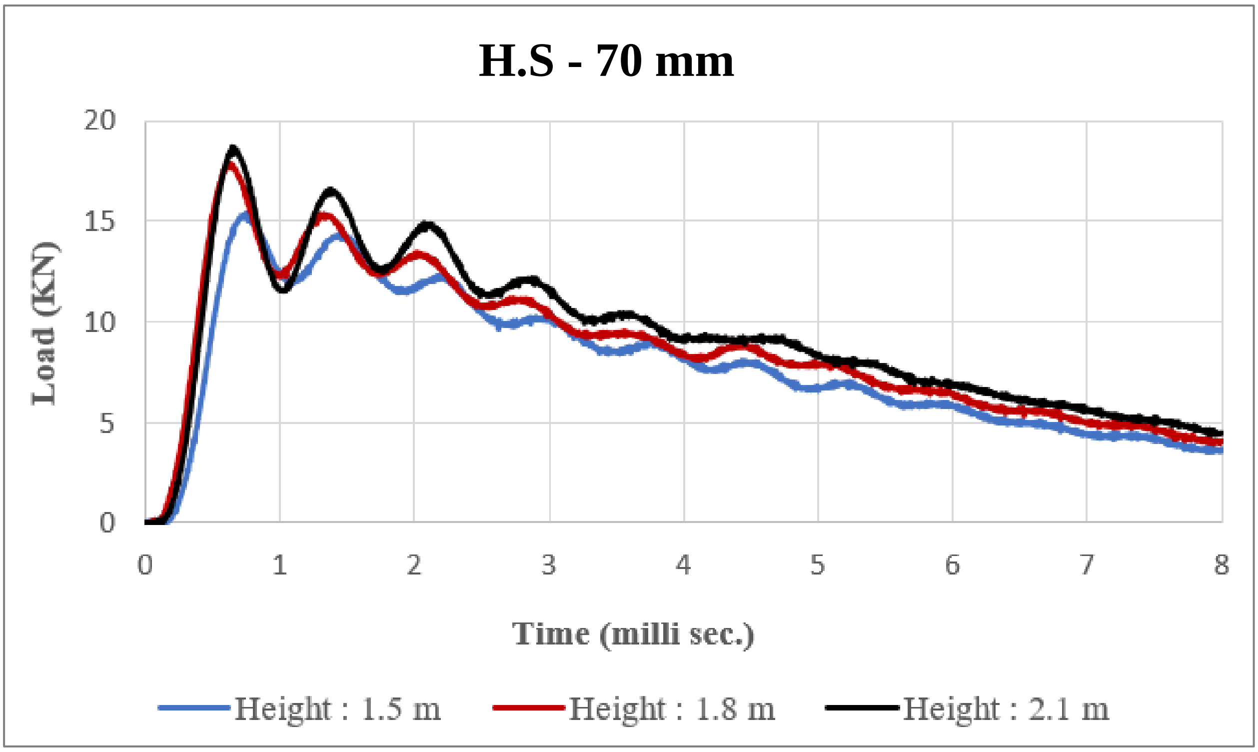


Figure 4-6 Load – Time curves for H.S mixture – 70 mm

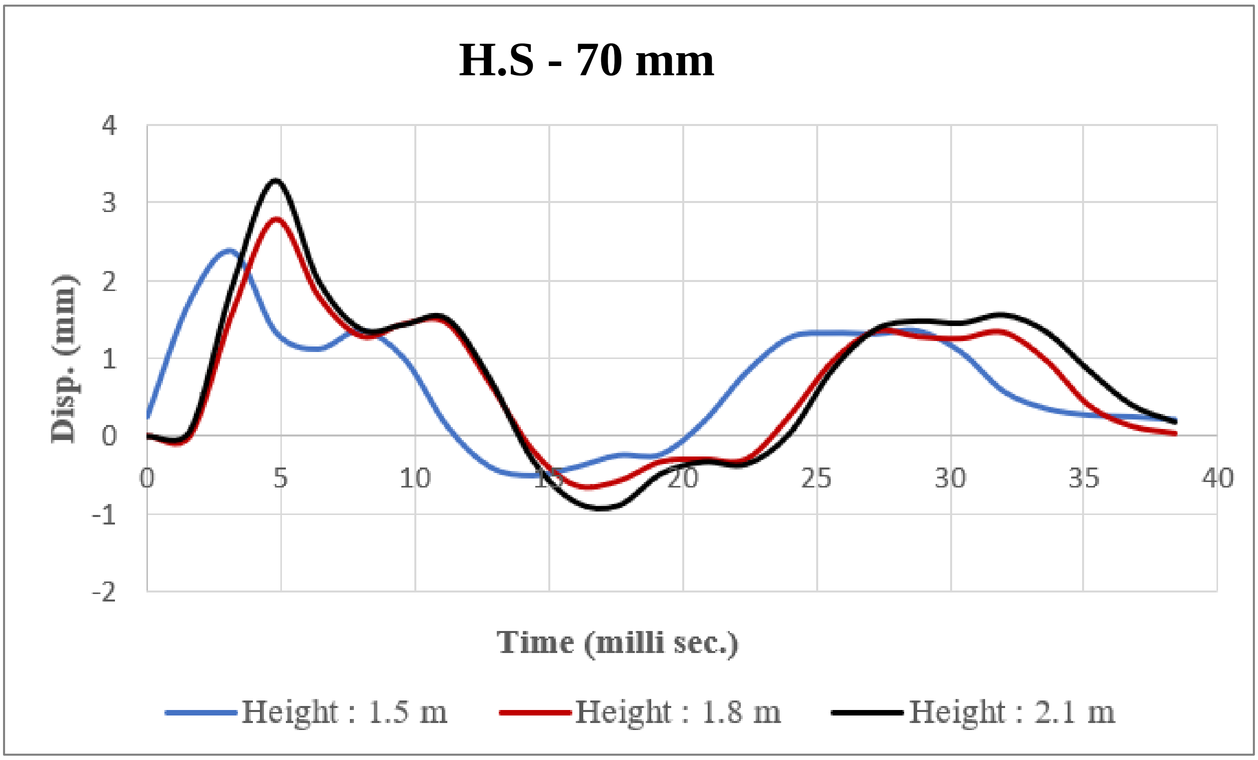


Figure 4-7 Displacement – Time curves for H.S mixture – 70 mm

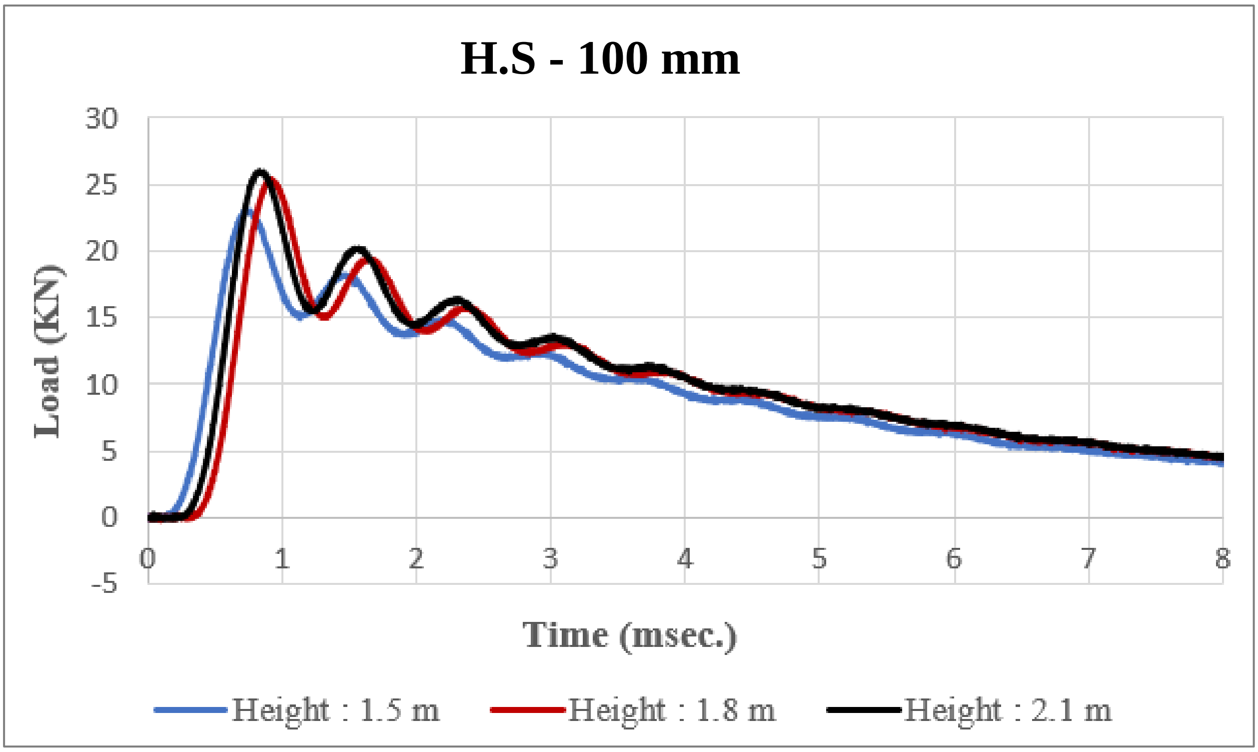


Figure 4-8 Load – Time curves for H.S mixture – 100 mm

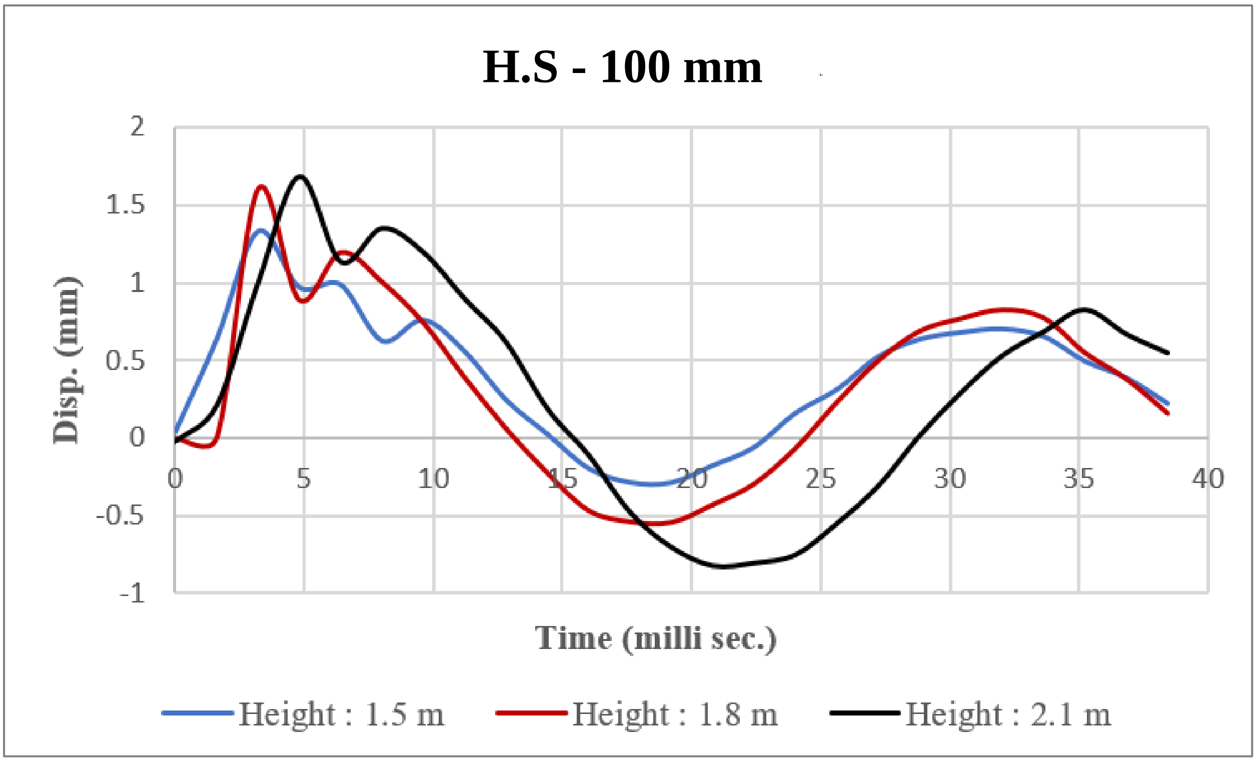


Figure 4-9 Displacement – Time curves for H.S mixture – 100 mm

According to the results, the effect of impact load height and thickness of slab is clearly noticed:

- The load was increased with the increasing in drop height for both 70 mm, and 100 mm samples due to the increment in the projectile's velocity.
- The displacement was also increased when the drop's height increased for both thicknesses of the slab.
- When the thickness of the slab was increased to 100 mm, the load was increased by a percentage of 50%, 42.7%, and 38.5%, respectively, for the three-heights, compared to the 70 mm slab, while the values of displacement were decreased compared to 70 mm slab due to the increment of slab stiffness.

4.3.2 High Strength With 0.5 % Steel Fiber – HS. S 0.5

The values of peak loads, peak displacements are shown in (Table 4-4). The (Figures 4-10 and 4-11) shows the curves between load with time and displacement with time for the H.S.C Slab with 0.5% steel fibers.

Table 4-4 Peak impact load and peak deflection for H.S.S 0.5

H.S.S 0.5: High Strength Concrete containing 0.5 % steel fiber					
No.	Height (m)	H.S.S 0.5 – 70 mm		H.S.S 0.5 – 100 mm	
		Peak Load (KN)	Peak Disp. (mm)	Peak Load (KN)	Peak Disp. (mm)
1	1.5	18.0	1.56	24.1	1.04
2	1.8	20.4	2.01	26.3	1.34
3	2.1	21.4	2.24	27.4	1.48

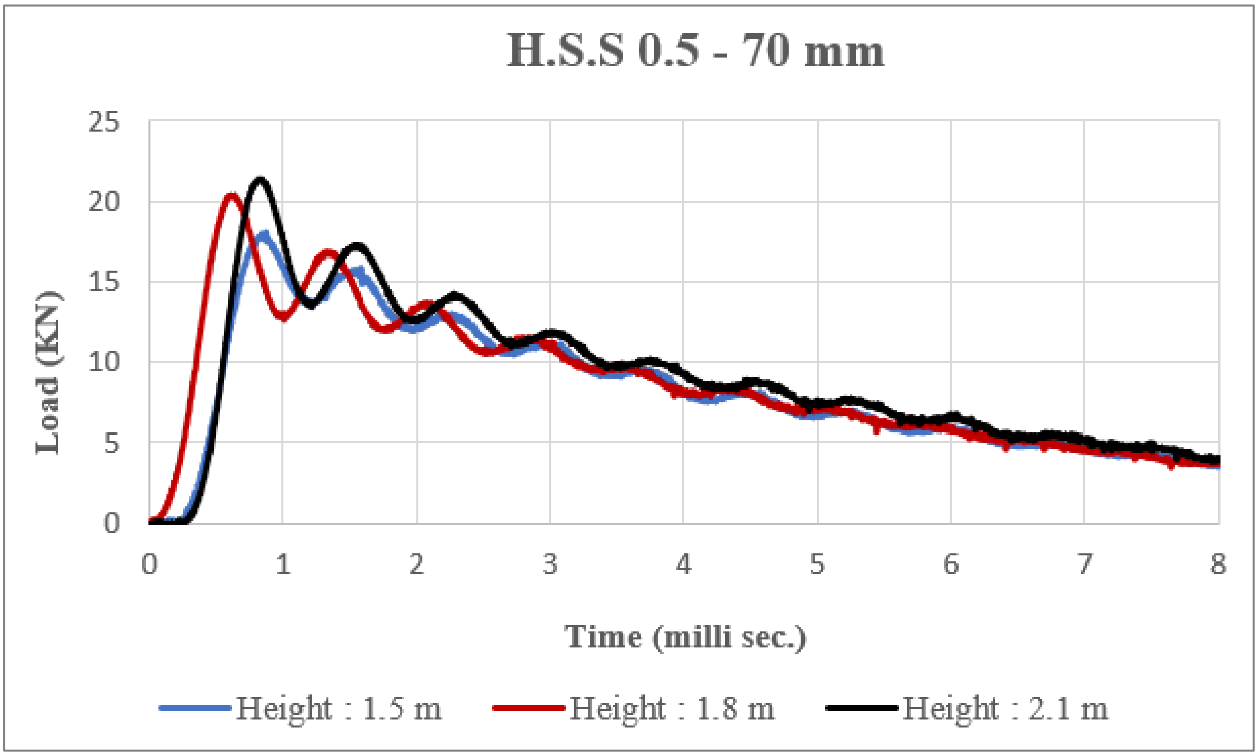


Figure 4-10 Load – Time curves for H.S.S 0.5 mixture – 70 mm

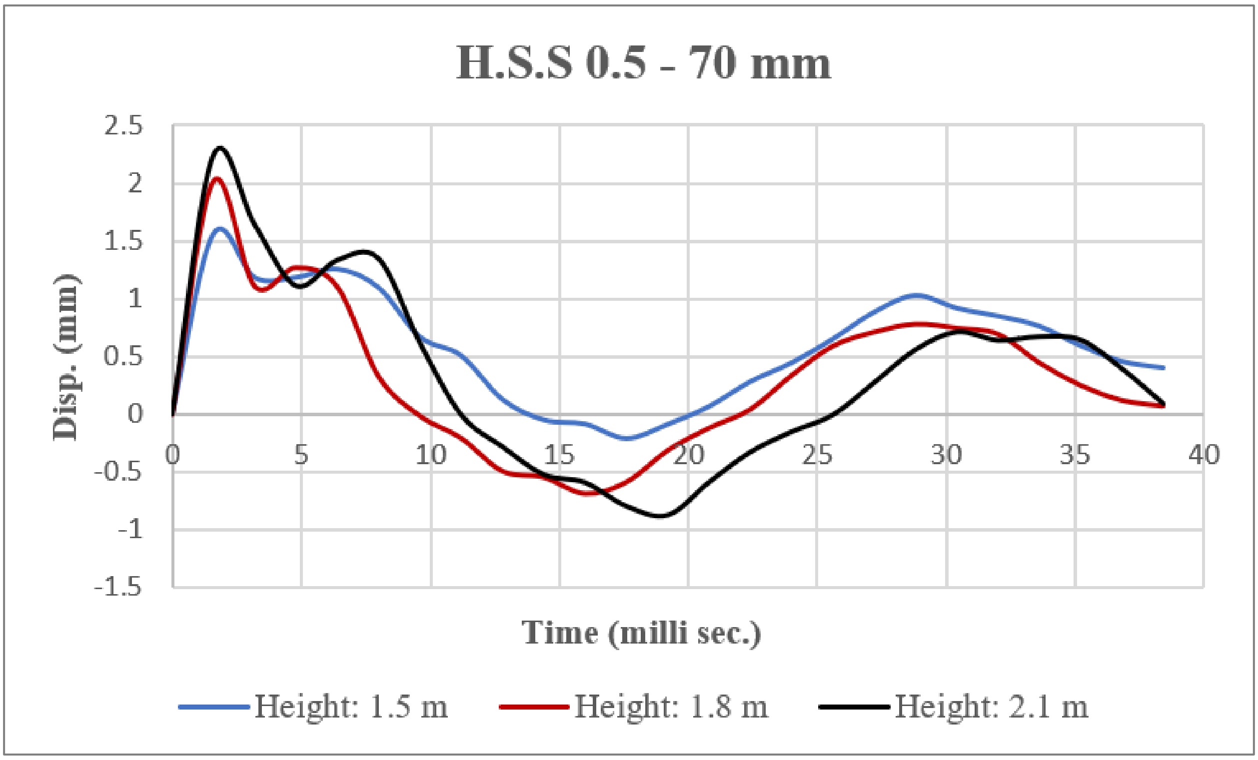


Figure 4-11 Displacement – Time curves for H.S.S 0.5 mixture – 70 mm

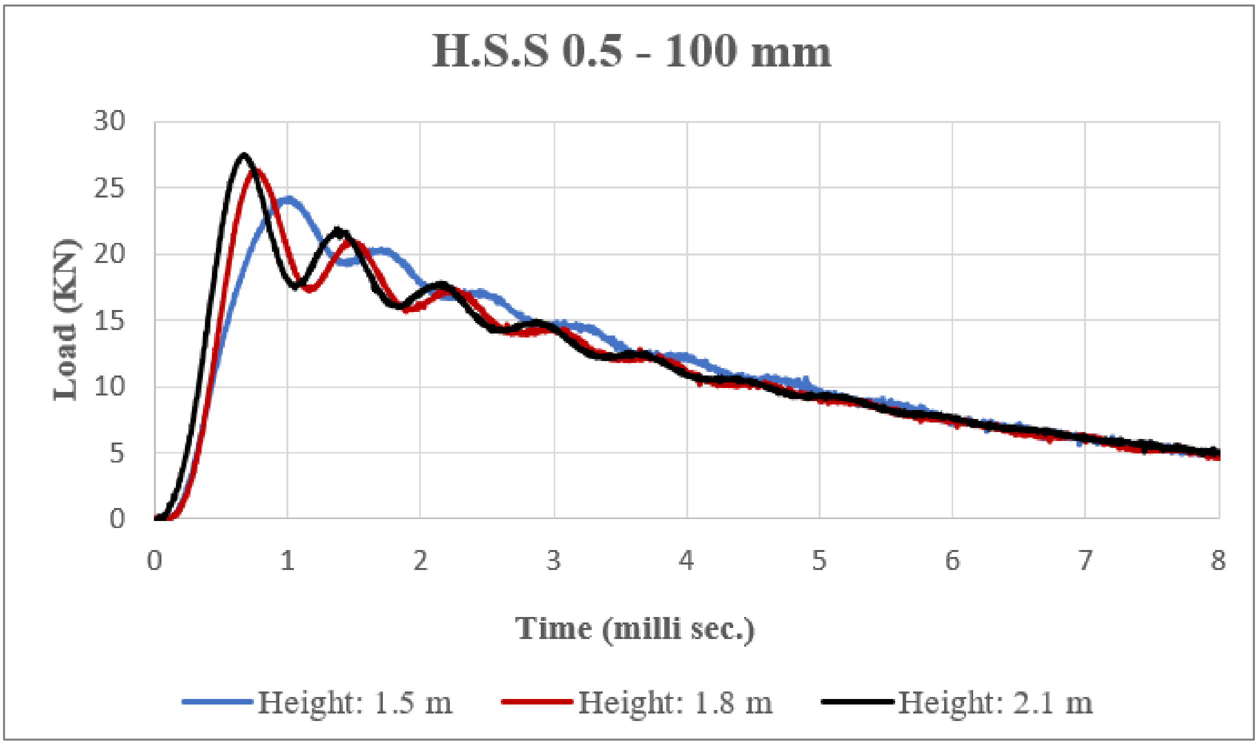


Figure 4-12 Load – Time curves for H.S.S 0.5 mixture – 100 mm

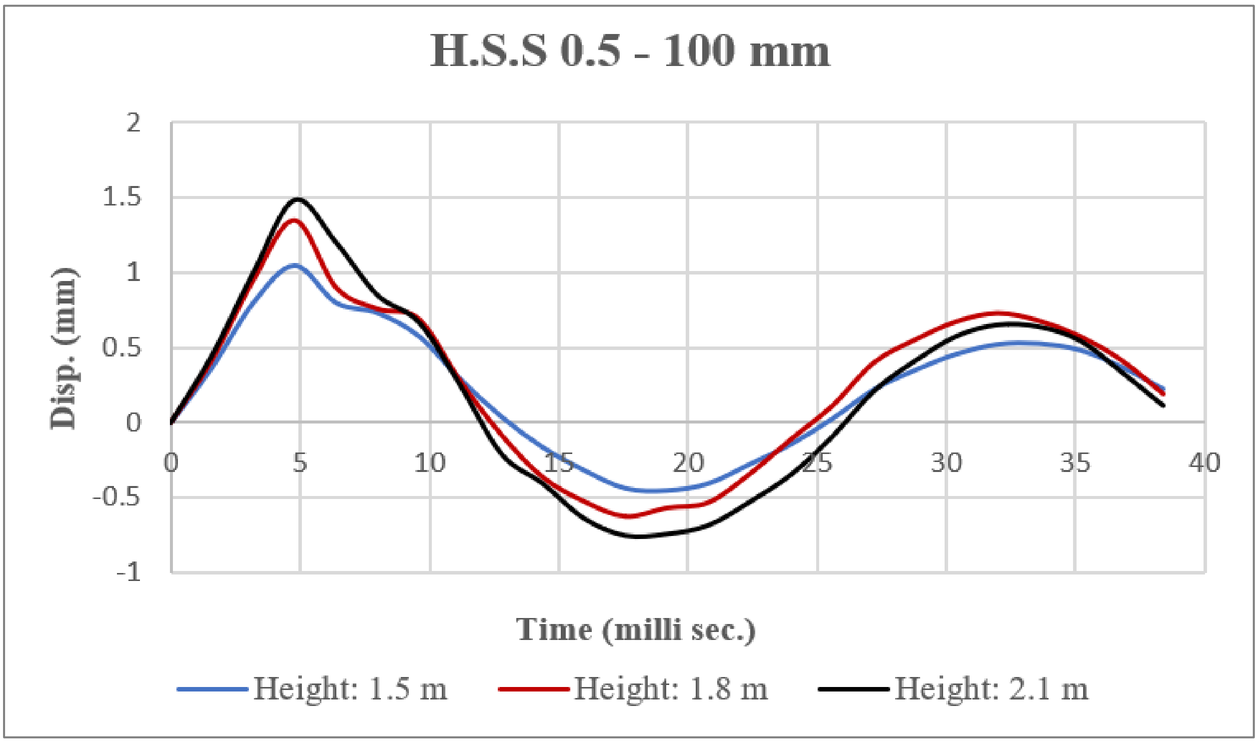


Figure 4-13 Displacement – Time curves for H.S.S 0.5 mixture – 100 mm

From the previous results, the effect of steel fibers was obviously noticed:

- The magnitude of load was increased for both thicknesses compared to the control mixture. Additionally, the displacements were decreased duo the clear enhancement in concrete strength caused by the presence of steel fibers.
- The load was obviously increased with the increasing in the height and thickness of the impacted slab.

4.3.3 High Strength With 1 % Steel Fiber – HS. S 1

The peak load capacity, peak mid-span deflection, curves of load with time, and displacement with time are shown in (Table 4-5), (Figure 4-14) and (Figure 4-15) respectively.

Table 4-5 Peak impact load and peak deflection for H.S.S 1

H.S.S 1: High Strength Concrete containing 1% steel fiber					
No.	Height (m)	H.S.S 1 – 70 mm		H.S.S 1 – 100 mm	
		Peak Load (KN)	Peak Disp. (mm)	Peak Load (KN)	Peak Disp. (mm)
1	1.5	19.4	1.85	26.5	1.39
2	1.8	20.7	2.12	28.8	1.43
3	2.1	22.1	2.40	31.4	1.58

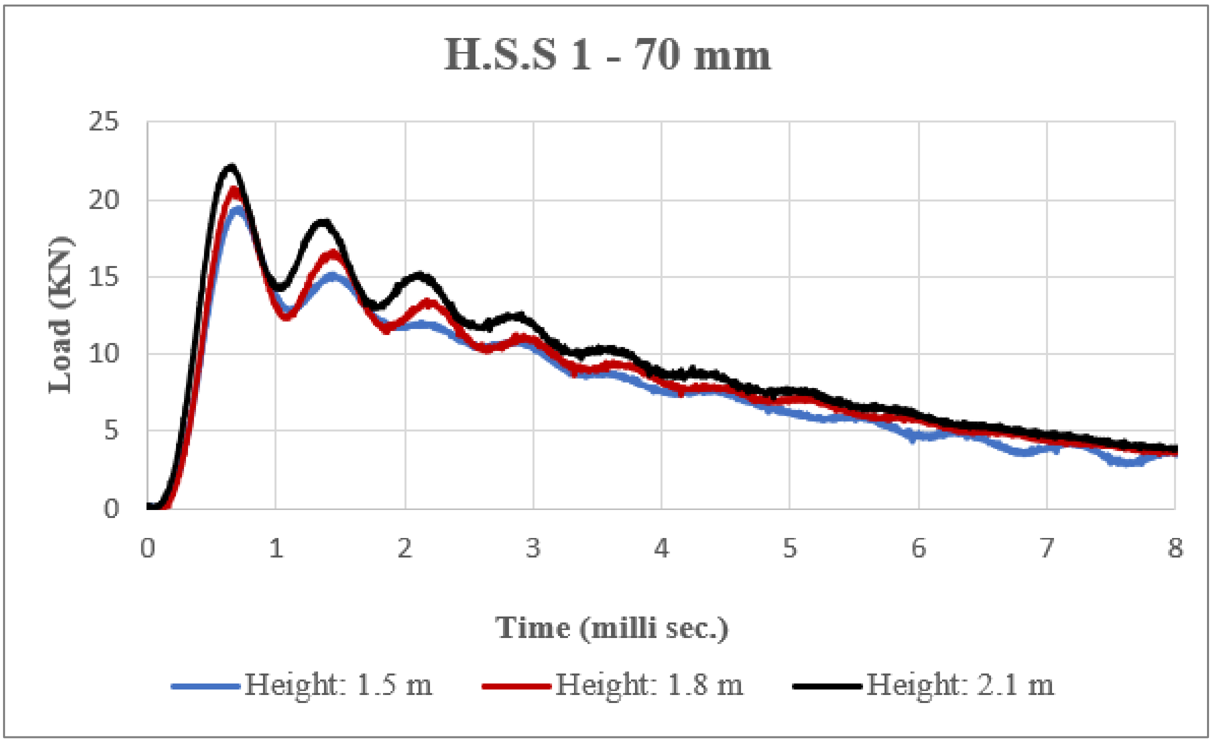


Figure 4-14 Load – Time curves for H.S.S 1 mixture – 70 mm

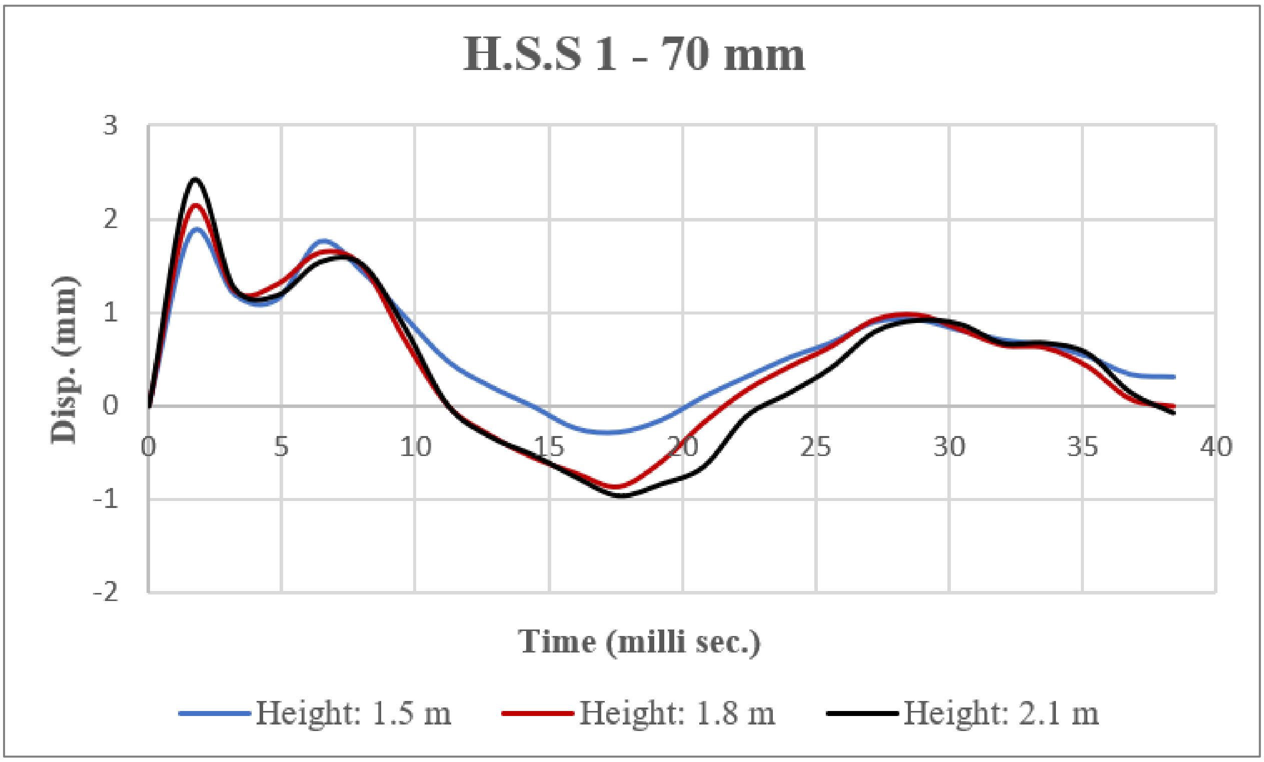


Figure 4-15 Displacement – Time curves for H.S.S 1 mixture – 70 mm

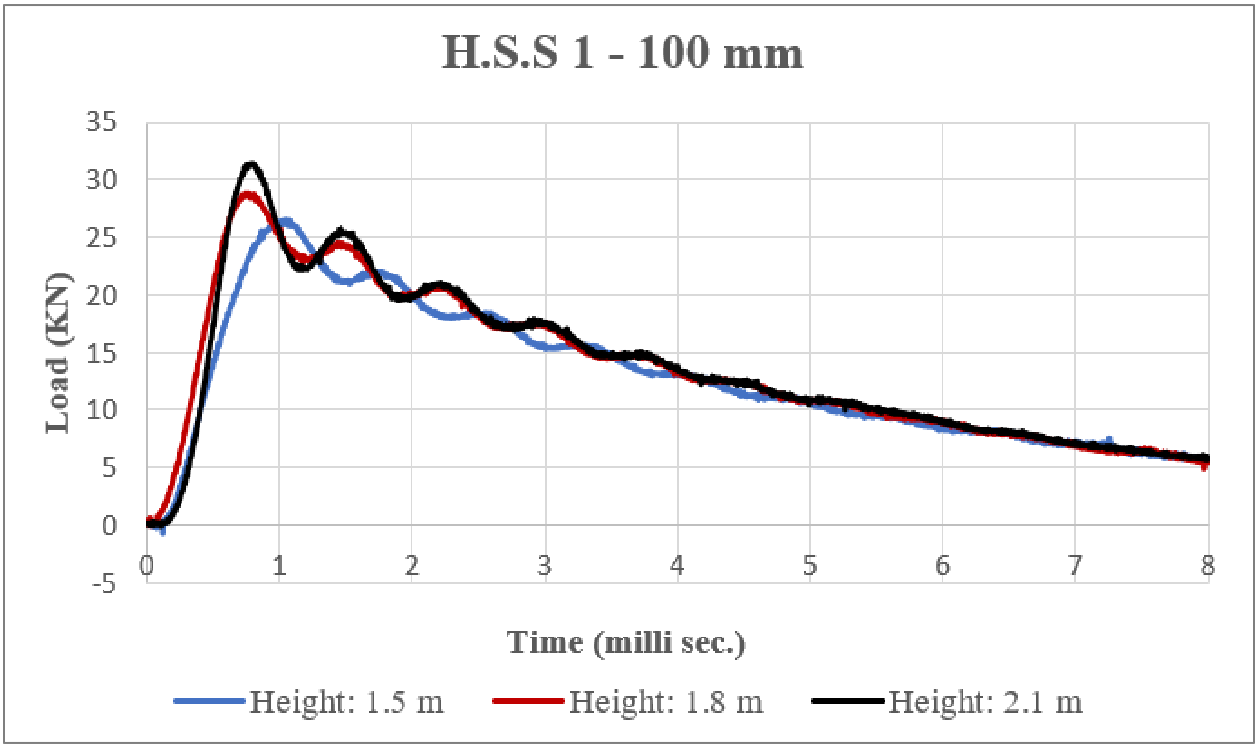


Figure 4-16 Load – Time curves for H.S.S 1 mixture – 100 mm

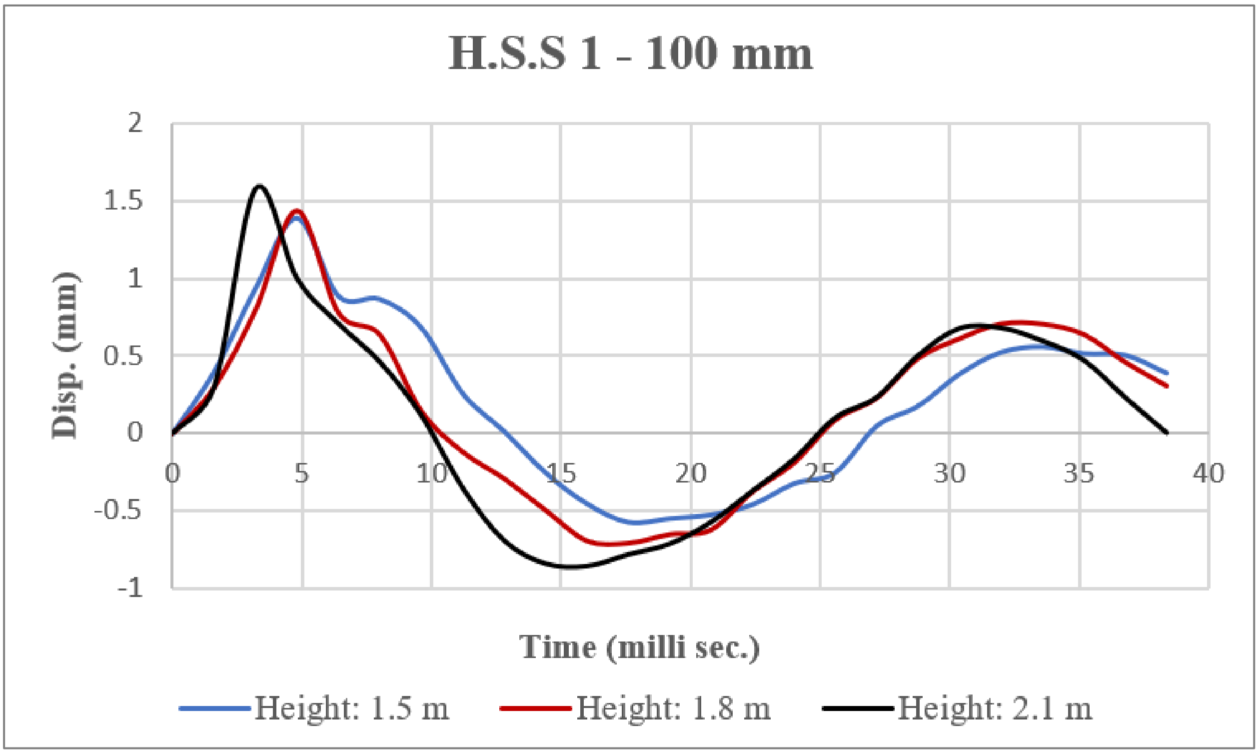


Figure 4-17 Displacement – Time curves for H.S.S 1 mixture – 100 mm

From the above results, the following points were noticed compared to the H.S.S 0.5 samples:

- When the percentage of S.F was increased to 1% by volume of concrete, the maximum impact capacities were increased for both slab thicknesses
- The load continues to increase when the height of the drop was increased.
- The maximum displacement at the center of the impacted slab was increased due to the increasing in the ductility of slab.

4.3.4 High Strength With 0.5 % Polypropylene Fiber– HS. P 0.5

The effect of P.P fibers on the values of load capacity and the midspan displacement are shown in (Table 4-6) and the resulted curves are shown in (Figures 4-18 and 4-19).

Table 4-6 Peak impact load and deflection for H.S.P 0.5

H.S.S 1: High Strength Concrete with 0.5 % polypropylene fiber					
No.	Height (m)	H.S.P 0.5 – 70 mm		H.S.P 0.5 – 100 mm	
		Peak Load (KN)	Peak Disp. (mm)	Peak Load (KN)	Peak Disp. (mm)
1	1.5	14.8	2.59	21.9	1.60
2	1.8	16.5	2.94	24.5	1.82
3	2.1	17.6	3.34	24.8	1.90

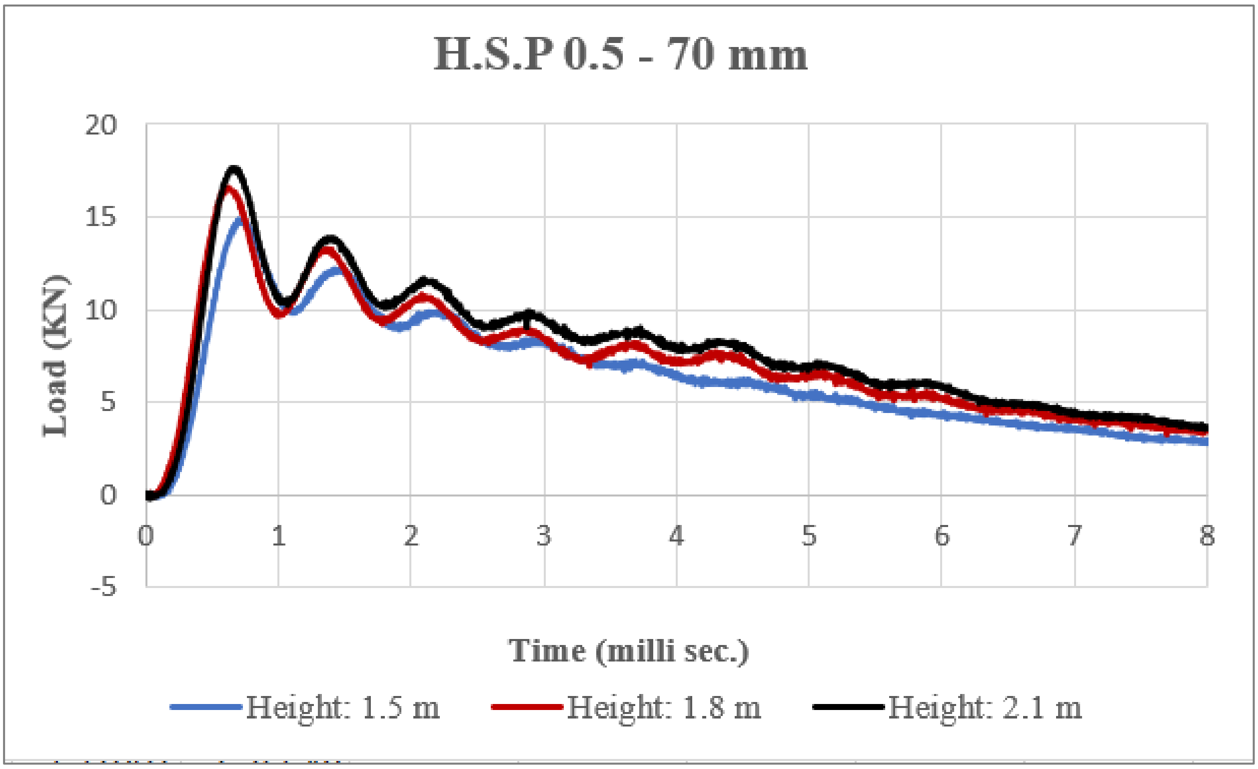


Figure 4-18 Load – Time curves for H.S.P 0.5 mixture – 70 mm

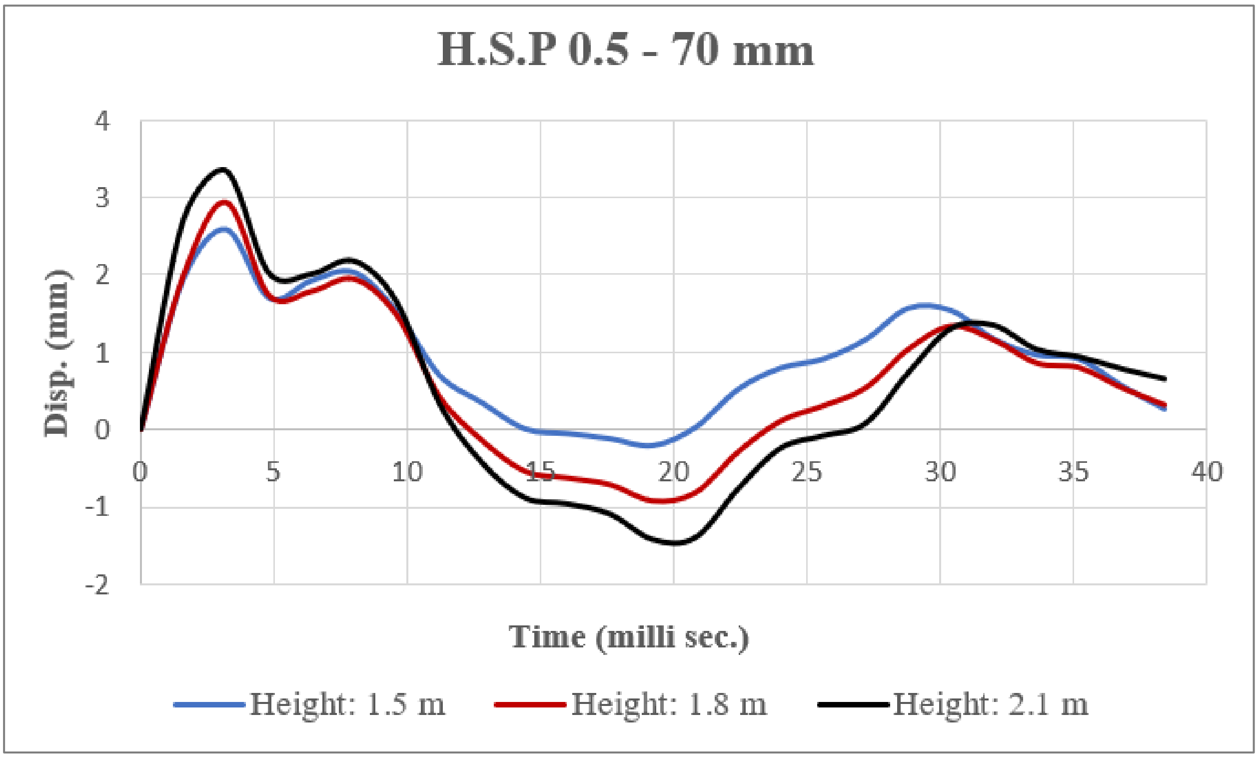


Figure 4-19 Displacement – Time curves for H.S.P 0.5 mixture – 70 mm

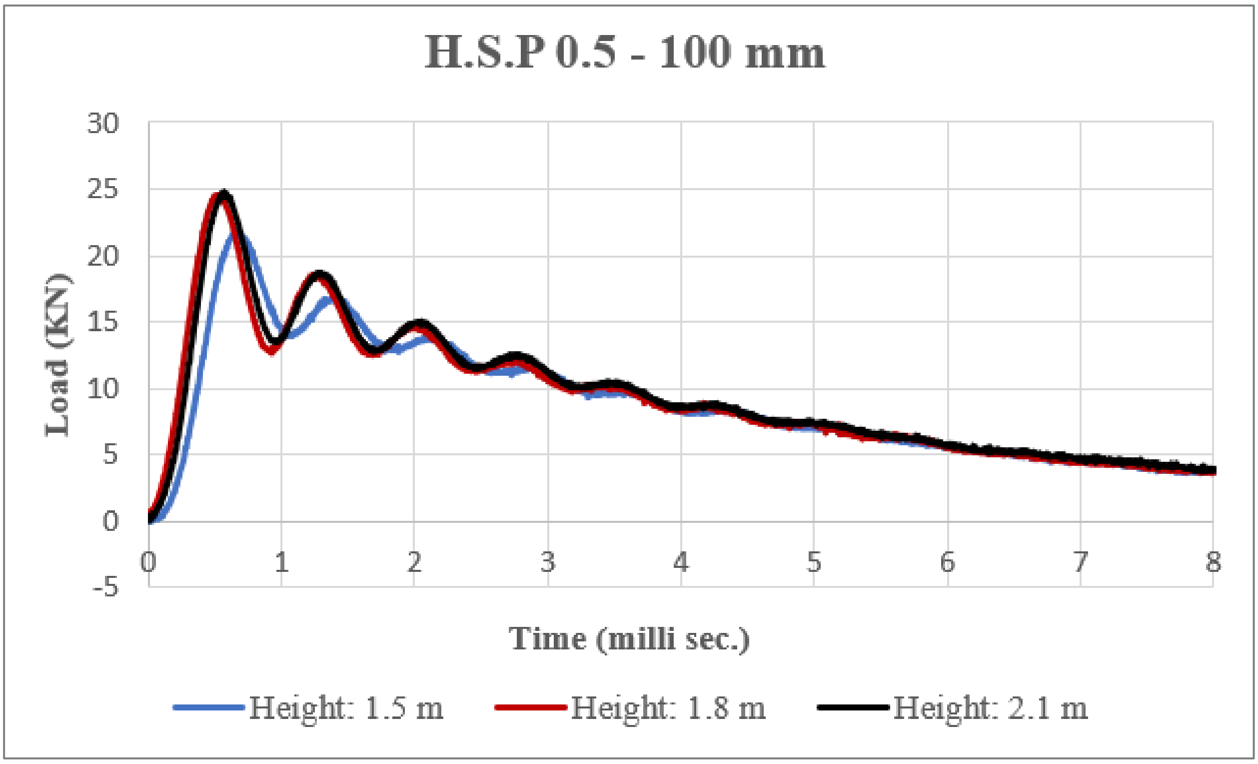


Figure 4-20 Load – Time curves for H.S.P 0.5 mixture – 100 mm

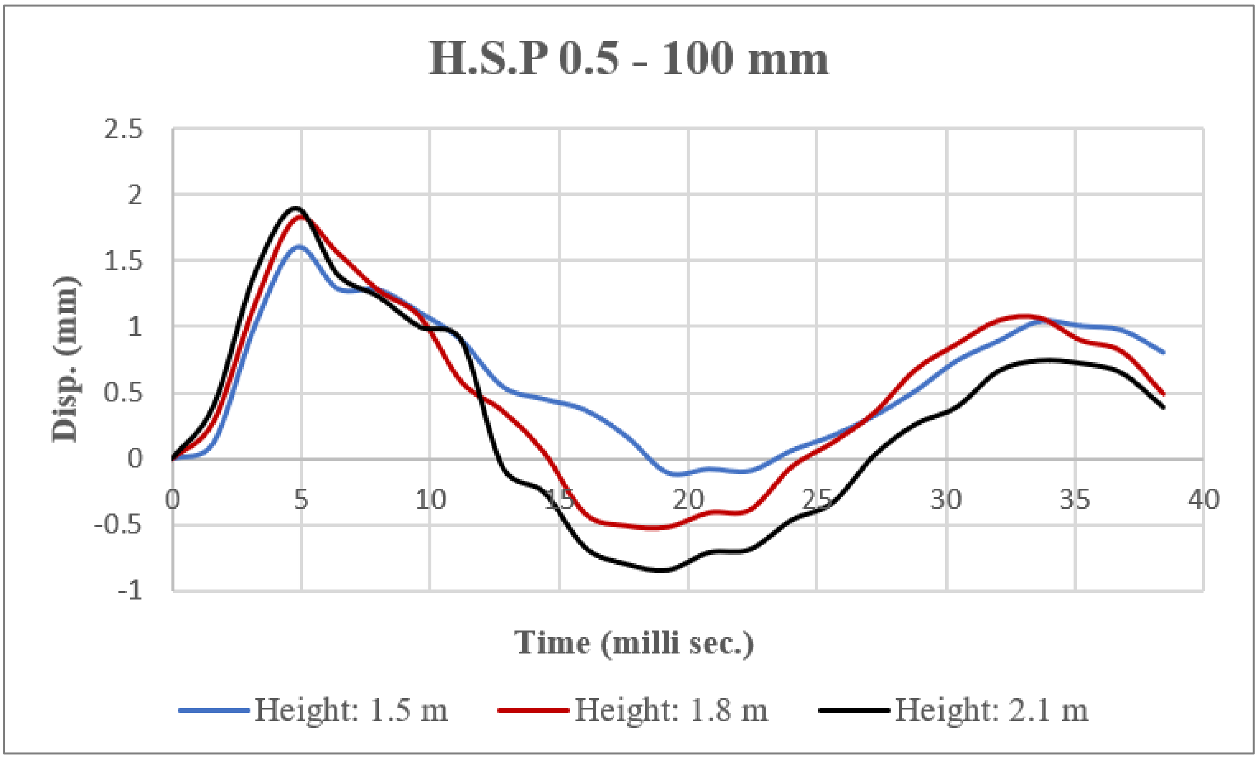


Figure 4-21 Displacement – Time curves for H.S.P 0.5 mixture – 100 mm

The results show that:

- Compared to the high strength concrete mixture without fiber (H.S), the impact load was decreased due to the noticeable decreasing in compressive strength. Although, the maximum displacement was increased higher than the control mixture due to the high ductility of the concrete slab resulting from P.P fibers presence.
- The load continues to increase with the increase in height, while the displacement continues to decrease with the increase in thickness of the slab.

4.3.5 High Strength With 1 % Polypropylene Fiber– HS. P 1

The percentage of P.P fibers was increased in this mixture to 1% by volume of concrete. Two samples were tested under impact load with two thicknesses (70 and 100 mm). The behavior of the current mixture is produced in (Figures 4-22 and 4-23). The peak impact capacity and displacement are shown in the (Table 4-7).

Table 4-7 Maximum impact load and maximum deflection for H.S.P 1

H.S.S 1: High Strength Concrete with 1 % polypropylene fiber					
No.	Height (m)	H.S.P 1 – 70 mm		H.S.P 1 – 100 mm	
		Peak Load (KN)	Peak Disp. (mm)	Peak Load (KN)	Peak Disp. (mm)
1	1.5	13.9	2.45	19.7	1.27
2	1.8	16.1	2.81	23.5	1.39
3	2.1	17.1	3.31	24.6	1.42

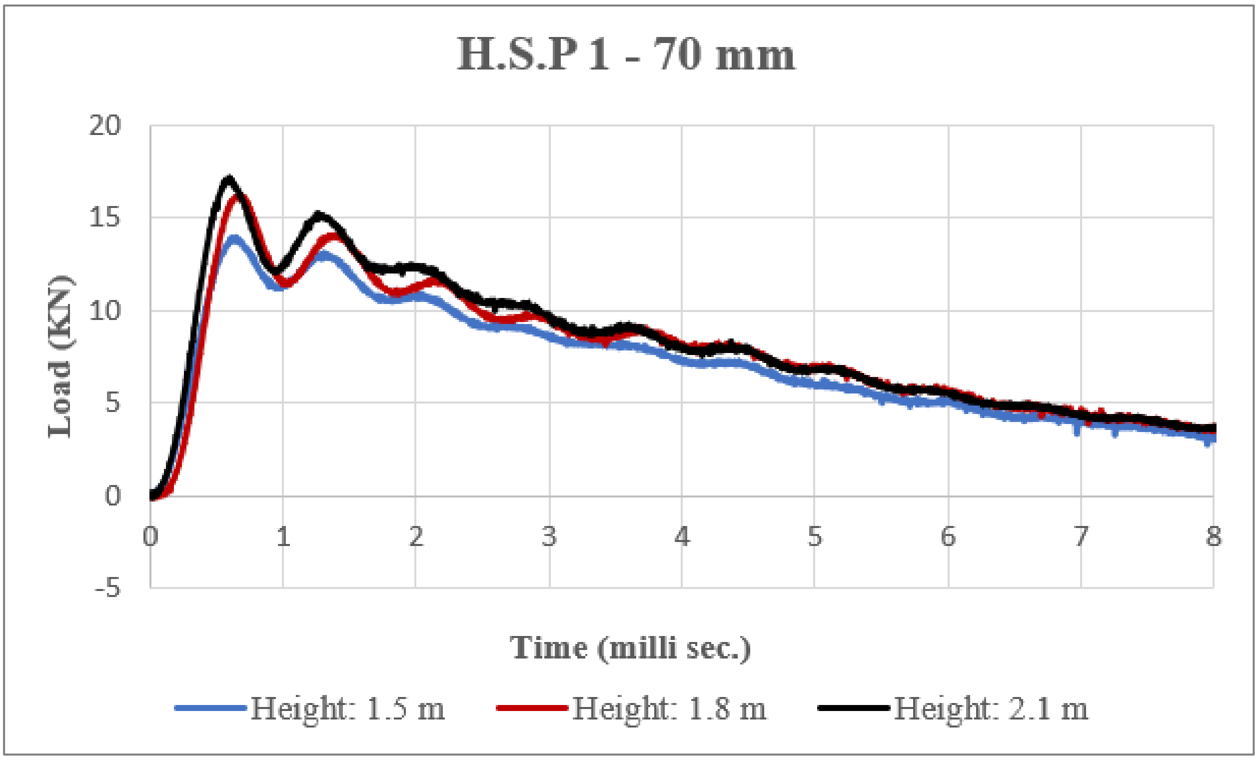


Figure 4-22 Load – Time curves for H.S.P 1 mixture – 70 mm

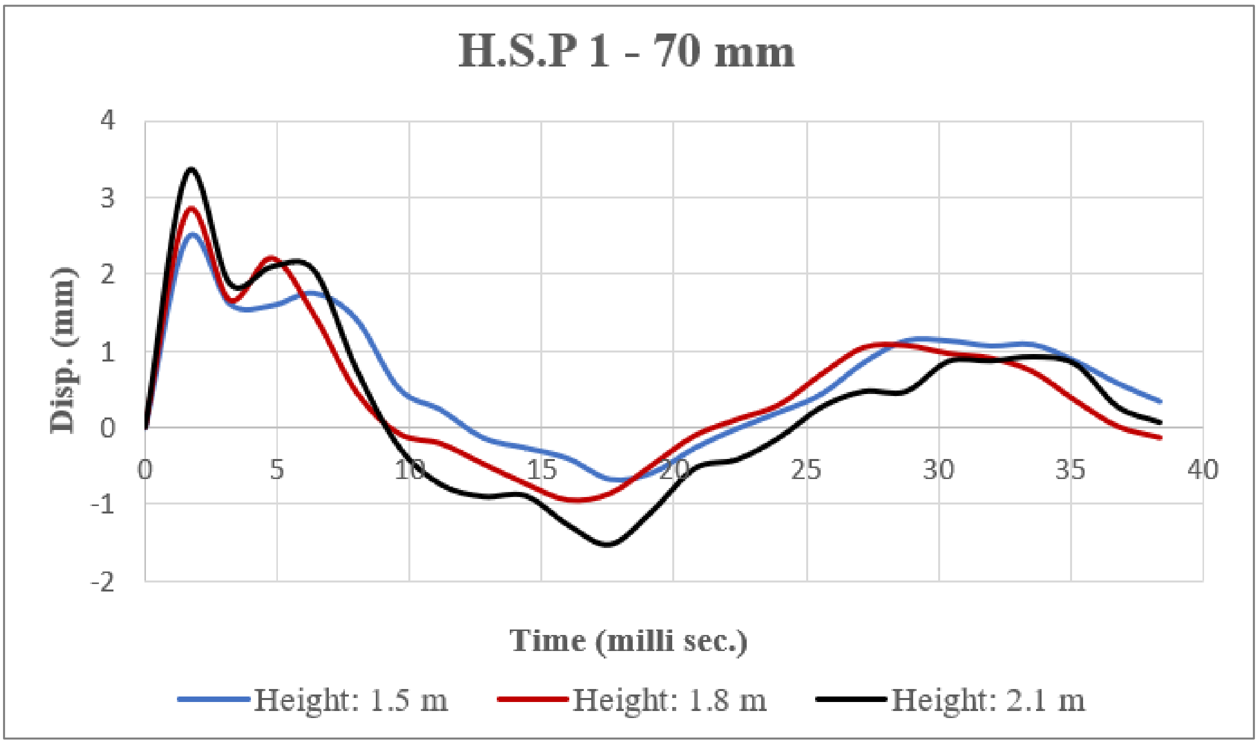


Figure 4-23 Displacement – Time curves for H.S.P 1 mixture – 70 mm

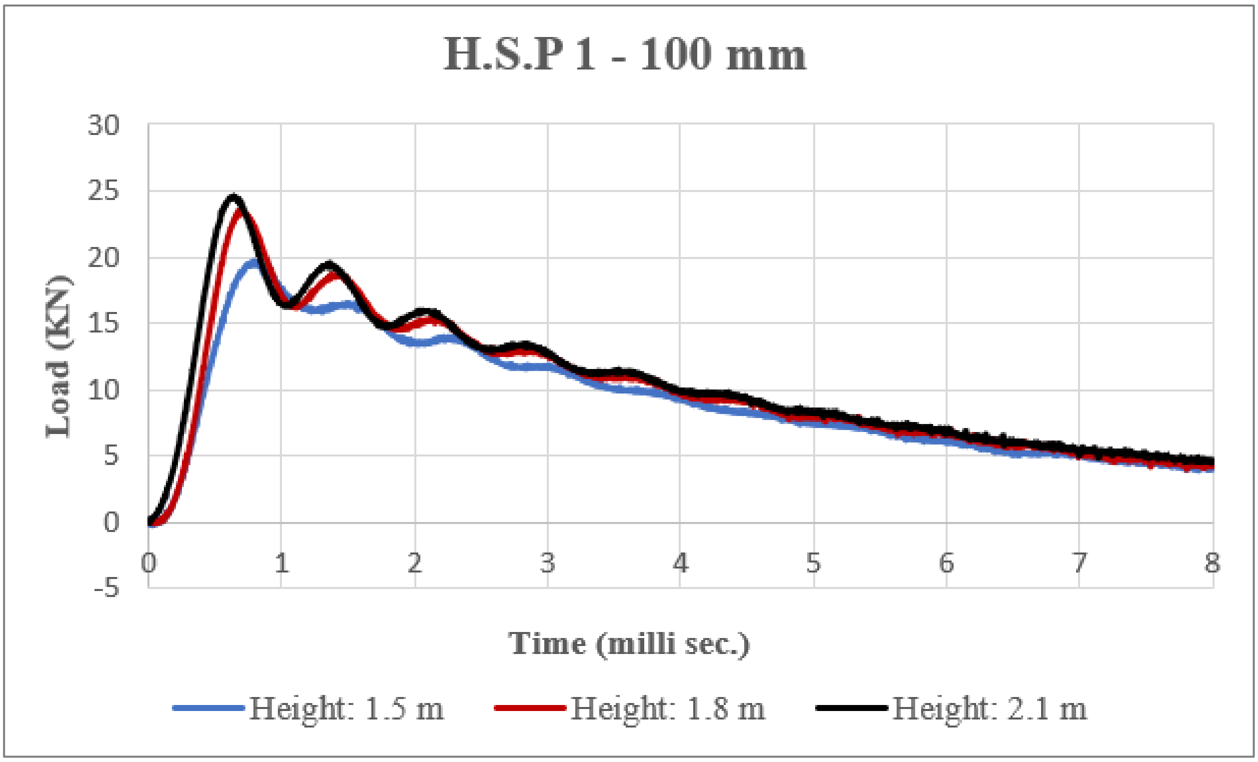


Figure 4-24 Load – Time curves for H.S.P 1 mixture – 100 mm

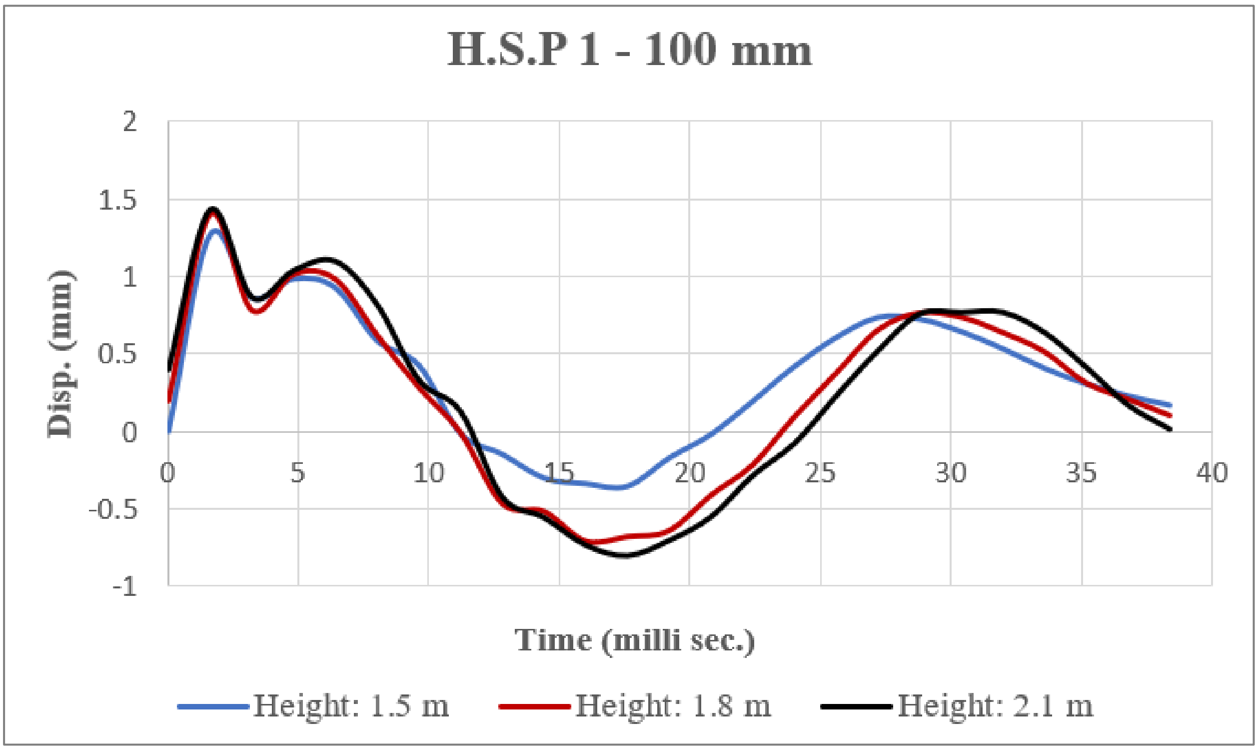


Figure 4-25 Displacement – Time curves for H.S.P 1 mixture – 100 mm

- The impact load was decreased compared to the mixture containing 0.5 % P.P fibers as a result of a decrease in the compressive strength of concrete.
- The displacement increased compared to the control concrete mixture due to the presence of P.P fibers.

4.3.6 High strength With Hybrid Fibers– HS. H 0.5+0.5

The hybrid samples contain a mix of hybrid fibers, which are steel fibers with a percentage of 0.5% and polypropylene fibers with a percentage of 0.5%. The magnitudes of impact load and displacement for both thicknesses of the slab are shown in (Table 4-8), and the (Figures 4-26 and 4-27) show to the relationships of load with time and displacement with time.

Table 4-8 Peak impact load and deflection for H.S.H 0.5+0.5

H.S.H 0.5+0.5: High Strength Concrete with Hybrid fibers					
No.	Height (m)	H.S.H – 70 mm		H.S.H – 100 mm	
		Peak Load (KN)	Peak Disp. (mm)	Peak Load (KN)	Peak Disp. (mm)
1	1.5	15.0	2.61	22.2	1.63
2	1.8	16.9	2.96	24.8	1.87
3	2.1	18.0	3.41	25.6	1.95

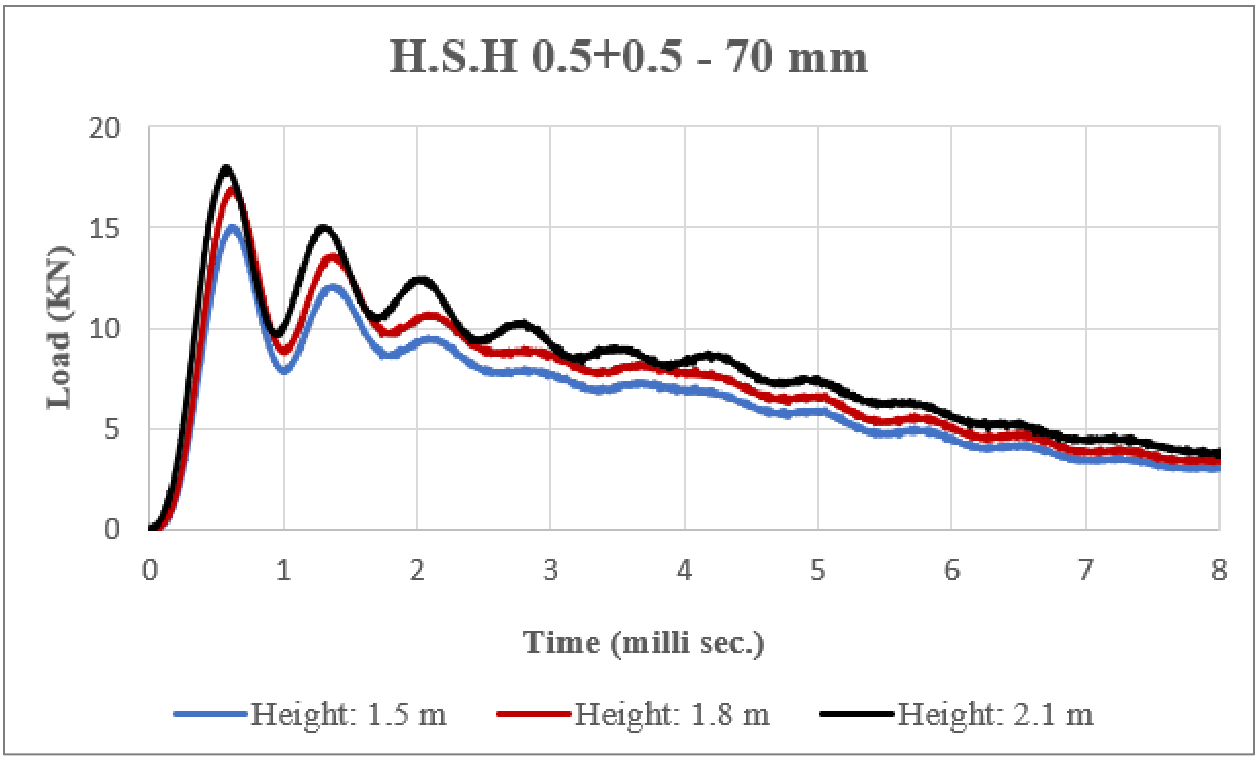


Figure 4-26 Load – Time curves for H.S.H 0.5+0.5 mixture – 70 mm

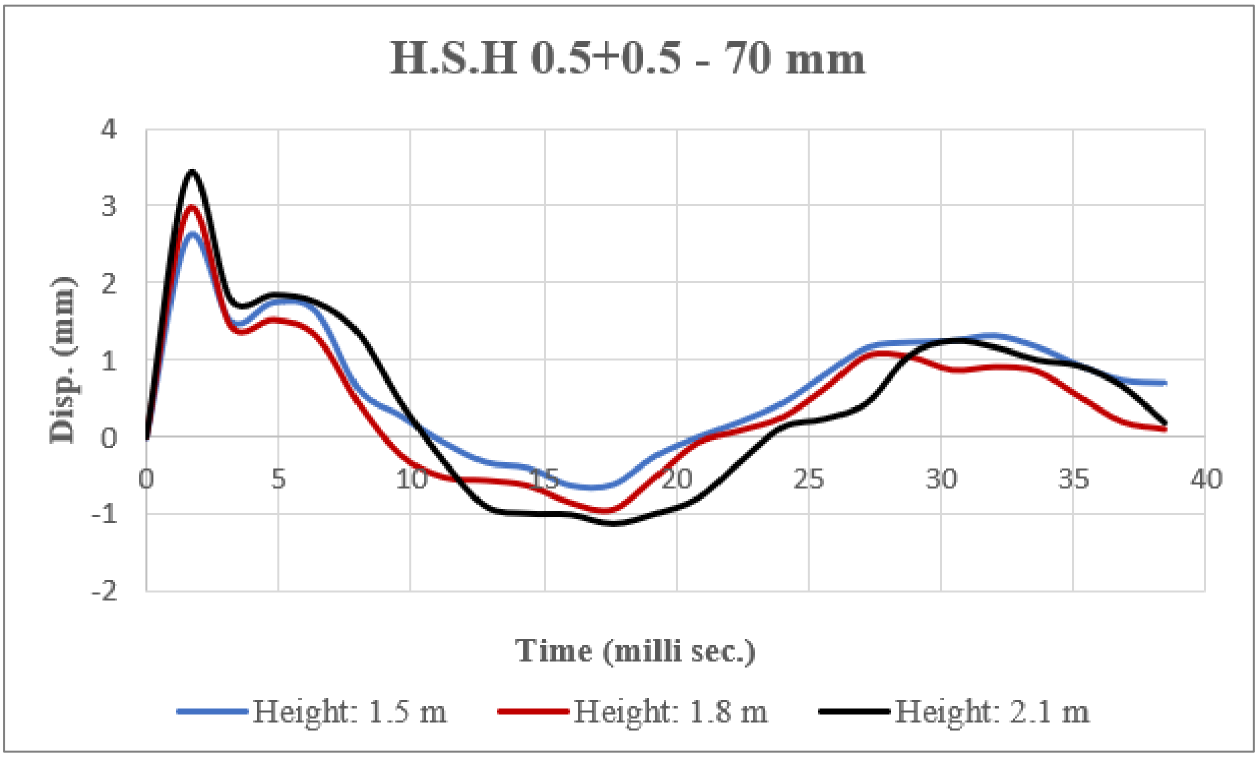


Figure 4-27 Displacement – Time curves for H.S.H 0.5+0.5 mixture – 70 mm

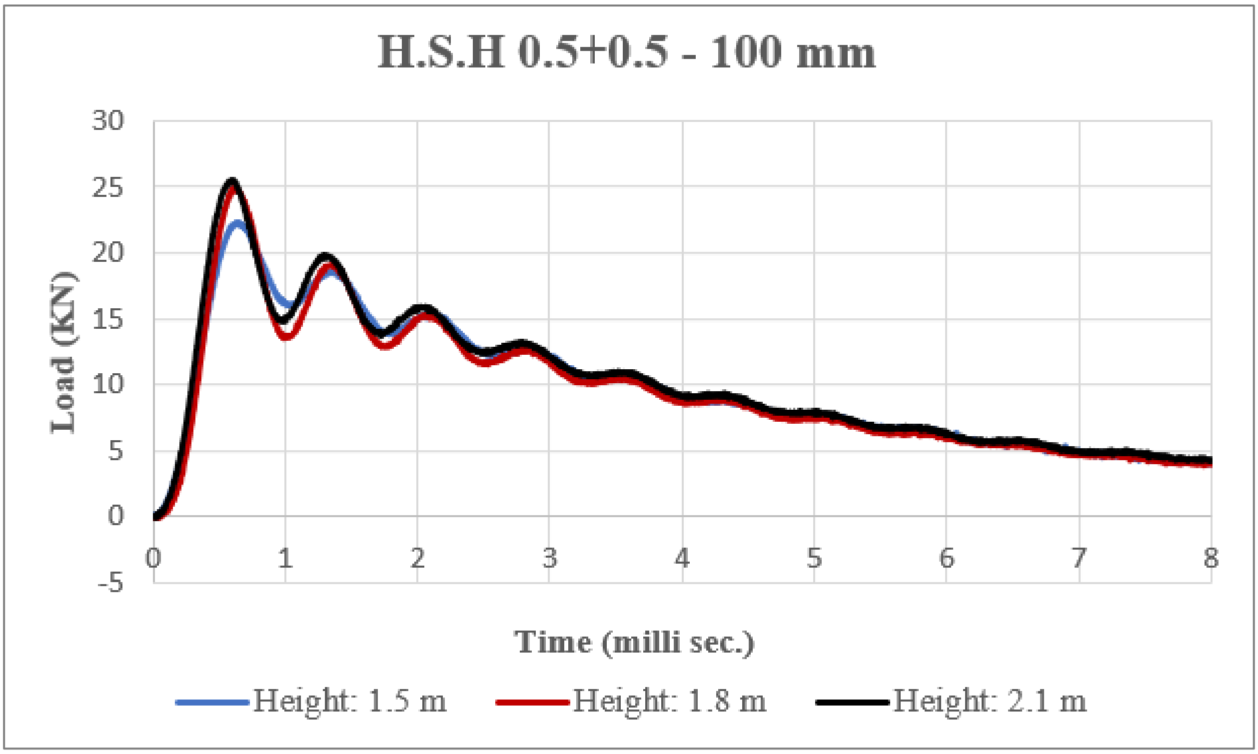


Figure 4-28 Load – Time curves for H.S.H 0.5+0.5 mixture – 100 mm

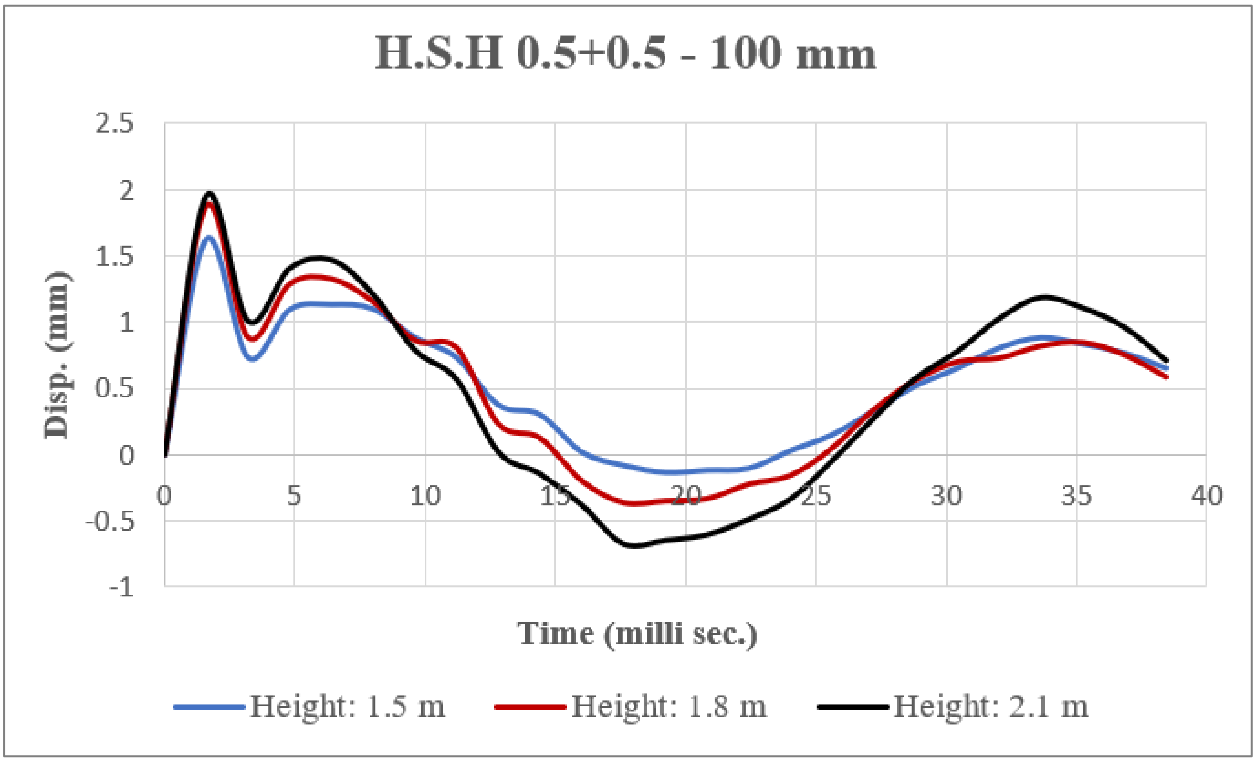
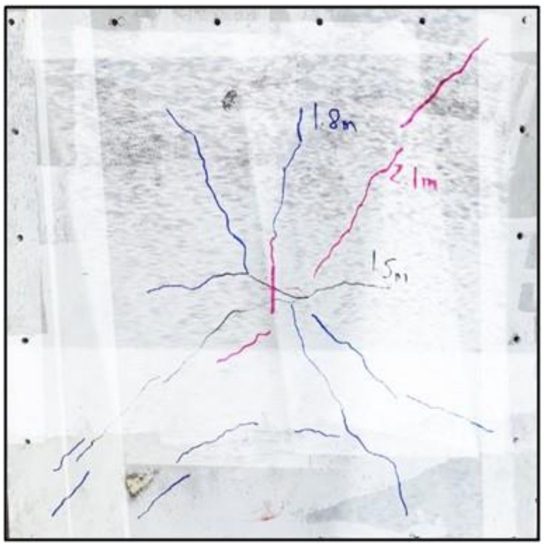


Figure 4-29 Displacement – Time curves for H.S.H 0.5+0.5 mixture – 100 mm

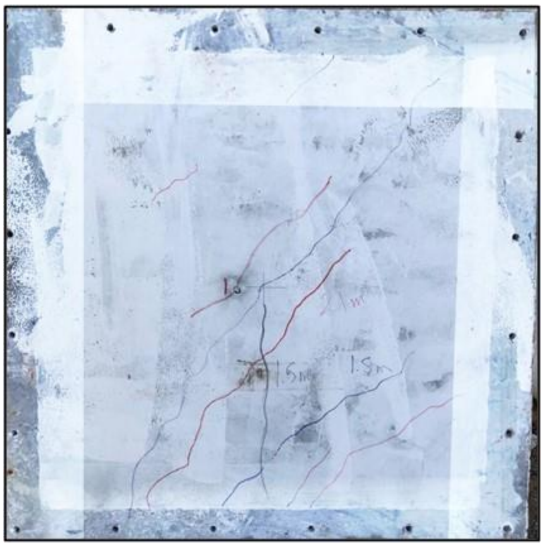
- The peak load was less than the control mixture loads due to the reduction in the strength of concrete. Despite this, the load was higher than the mixture that contains only polypropylene fibers due to the effect of steel fibers. The displacement was noticed to be higher than H.S mixture due to the effect of S.F and P.P.F.
- (Figure 4-30, 4-31,4-32 and 4-33) shows samples after the impact test and the patterns of cracks.

H.S 70 mm Crack patterns

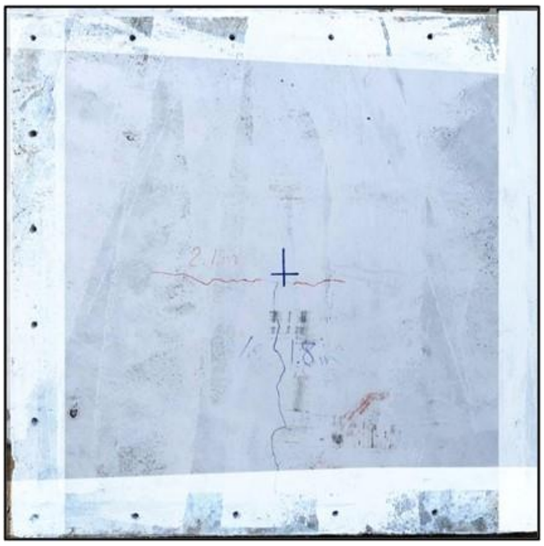


H.S.S 0.5 – 70 mm Crack patterns

Figure 4-30 H.S and H.S.S 0.5 Crack patterns

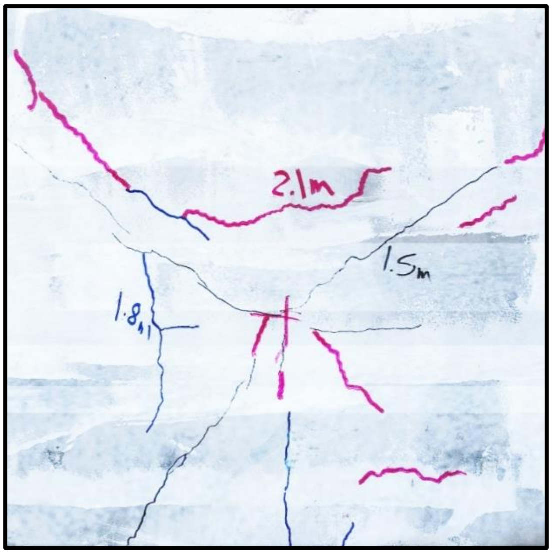


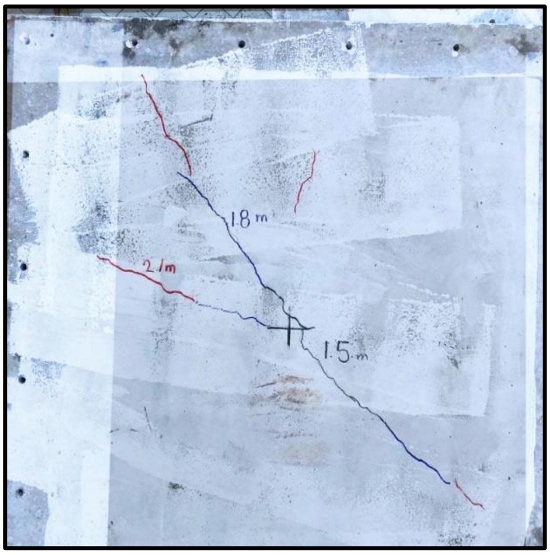
Slab 70 mm



Slab 100 mm

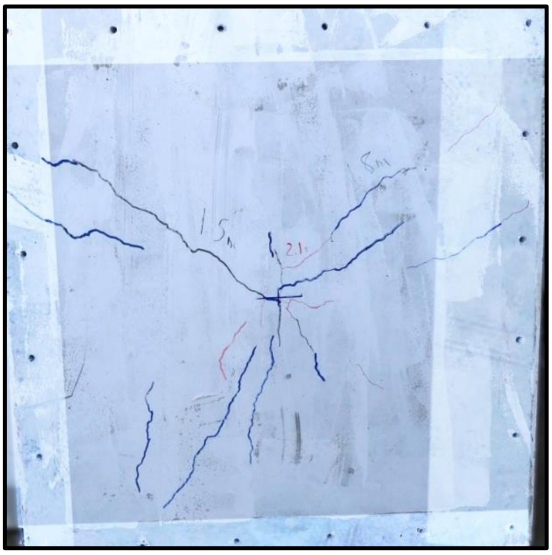
Figure 4-31 H.S.S 1 crack patterns

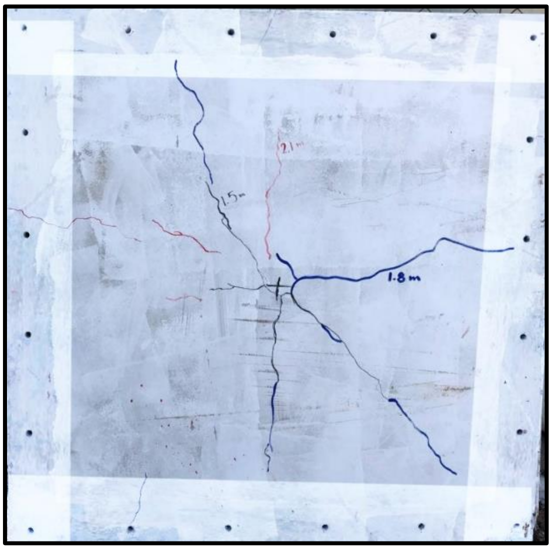




Slab 70 mm Slab 100 mm

Figure 4-32 H.S.P 0.5 crack patterns





Slab 70 mm Slab 100 mm

Figure 4-33 H.S.H crack patterns

4.4 Summary

Thorough examination of the test results, the following observations were noticed:

❖ The height of drop:

1- The peak load capacity at the center of the slabs was increased with respect to the increasing in the falling height.

2- The central deflection for all tested slabs increased with the increasing of the falling height by (11.8% to 43.5%).

❖ The presence of P.P fibers resulted in:

1- Decrease the peak load by (3.6% to 7.8%). compared to the control concrete samples, and this is because the addition of P.P fibers which significantly reduces the compressive strength of concrete by a percentage ranged between (17.3% – 20%).

2- Increase the maximum mid-span deflection of the slab, and this is due to the presence of P.P fibers, which increase the ductility of concrete.

❖ The presence of steel fibers leads to:

1- The peak load capacity was increased when the steel fiber was added by (3.6% to 7.8%).and continue to increase as the percentage of steel fiber increases which enhances all the mechanical properties of concrete.

2- The maximum deflection decreased compared to H.S samples by (13.5% to 51%) but the deflection increased when the steel fiber percentage reached 1%.

❖ The effect of hybrid fibers:

1- The maximum capacity decreased compared to the control samples due to the noticeable reduction in concrete strength resulting from the addition of P.P fibers.

2- Despite the noticeable reduction in load capacity of hybrid fiber concrete, the maximum deflection increased compared to the H.S mixture as a result of the clear enhancement in flexural strength of concrete.

- The effect of the slab thickness:

1- As a known fact, the peak load capacity increased with the increasing in slab thickness due to an increment in the stiffness of the slab.

2- In contrast, the deflection was reduced when the slab thickness increased from 70 to 100 mm.

Finally, most of the results have confirmed the findings of previous researchers in the same field as shown in the references (2,7,9,10, and others.)

Chapter Five

Conclusions & Recommendations

5. CHAPTER FIVE

CONCLUSIONS AND RECOMMMENDATIONS

5.1 Conclusions

According to the results that were obtained in the current study, conclusions can be summarized in the following points concerning each variable parameter that were studied:

1- The displacement for all the tested slabs under the effect of impact load was tended to be larger with the increasing of the falling height until 2.1 meters with a percentage of (11.8% to 43.5%).

2- The peak load capacity at the center of the impacted slabs increased when the height of the drop was increased from 1.5 to 1.8 and 2.1 meters, respectively, with a percentage of (12.1% to 24.8%).

3- When the thickness of the slab increased from 70 to 100 millimeters, the central displacement decreased significantly due to the increment in the stiffness of the slab, with a percentage ranged between (33% to 133%).

4- The increment in the stiffness of the slab, which results from the increase in thickness of the slab, leads to an increase in the maximum impact capacity for the tested slabs, and this increment ranged between (28% to 50%)

5- During the impact tests, and as the number of strikes is increased, as well as the height of the object striking the slabs, cracks on the bottom faces of all slabs appear first, followed by cracks on the top faces. These cracks have a tendency to take on random shapes, and directions start from the center of the bottom face of the tested slabs.

6- The clamped support condition leads to high stiffness for all tested slabs. The cracks were capillary, randomly speared, and increased with respect to the height of the drop.

7- Adding steel fibers enhances all the properties of concrete. While the addition of p.p fibers improves all the properties except the compressive strength which reduced by (17.3 to 20) %.

8- The presence of S.F in the concrete slab causes an increment in the strength of the slab. The midspan displacement decreased with a range of (13.5% to 51.2%) compared to the control mixture and increased slightly with the increase of fibers.

9- The peak load increased for all samples containing 0.5% steel fibers with a percentage of (3.5% to 16.8%) with respect to the control one.

10- This load increased again with the increment in fiber's percentage to 1% by volume of concrete. The impact load capacity between all the tested samples gained in the samples with 1% steel fibers which was 31.4 KN from 2.1-meter.

11- The polypropylene fibers improve the ductility of concrete, which leads to an increase in the maximum midspan displacement between (1.5% to 21.2%). The displacement kept increasing when the percentage of P.P fibers reached 1%.

12- The peak load has a slightly reduction compared to the reference slab due to the reduction in compressive strength for the samples containing polypropylene fibers. This reduction ranged between (3.6% to 7.8%).

13- The hybrid samples showed a reasonable result, the displacement increased by (3.6% to 23%) compared to control samples due to the presence of fibers, while the load slightly decreased by a percentage of (1.1% to 5.3%) due to the reduction in compressive strength of concrete.

5.2 Recommendation for Future Works

The following recommendations can be suggested as an extension for the current study:

- Advanced measuring devices can improve the final results of impact tests, such as a high-speed video camera, which can record the generation of cracks at the bottom face with time or record the moment of collision between the projectile and the slab.
- Special kind of load cell which are manufactured specially to read the impact load and can be connected to the projectile and fall with it. This type of load cell is not available locally and needs to be shipped from global markets.
- The experimental work can be developed to study the change in the following parameters:
    - The weight of the projectile.
    - The ratios of reinforcement.
    - The slab dimensions.
    - The type and length of fibers.
- Study the behavior of R.C slabs subjected to impact load and strengthen with “carbon fibers reinforced polymer” (CFRP).

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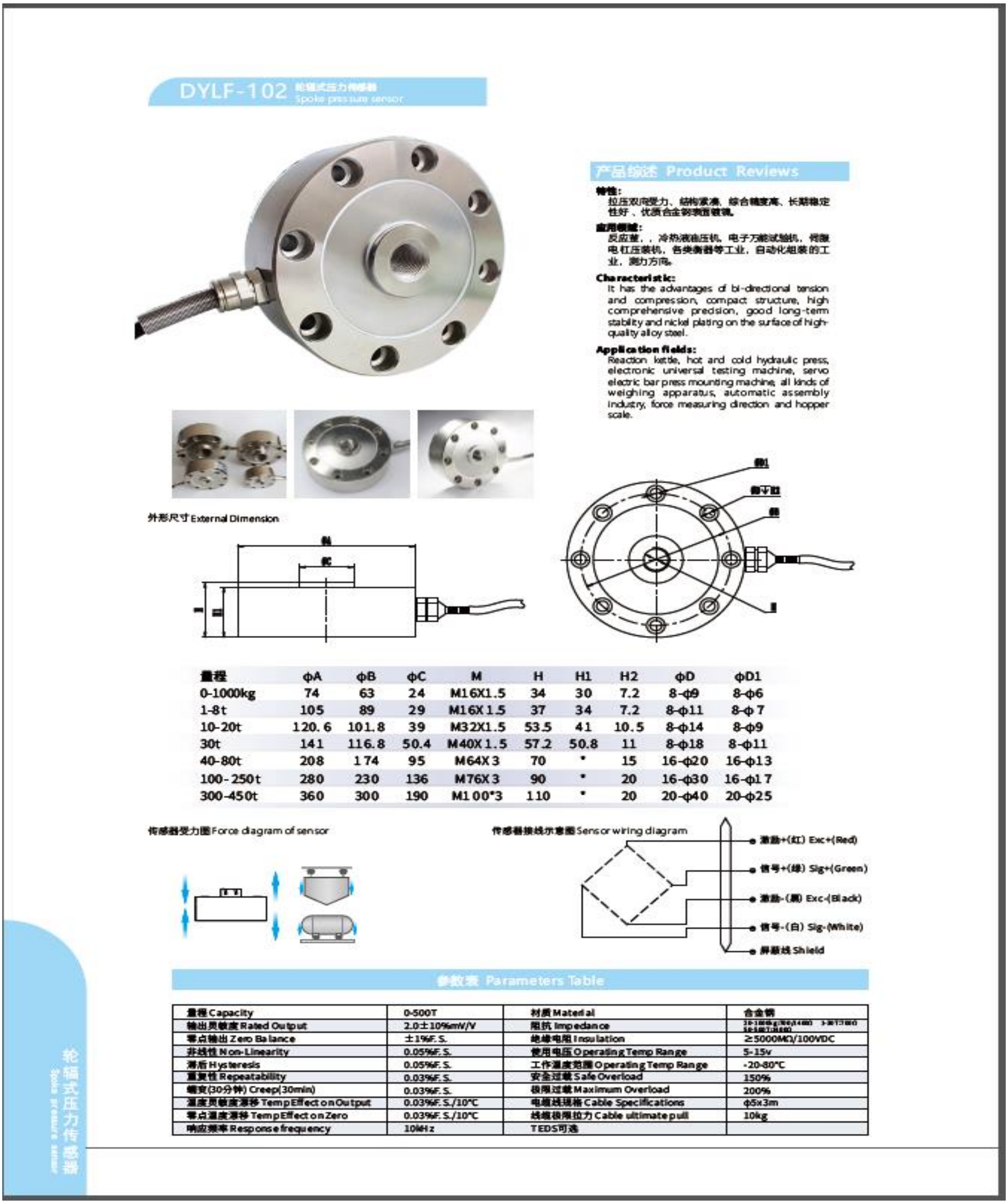
Appendix (A)



量程	φA	φB	φC	M	H	H1	H2	φD	φD1
0-1000kg	74	63	24	M16X1.5	34	30	7.2	8-φ9	8-φ6
1-8t	105	89	29	M16X1.5	37	34	7.2	8-φ11	8-φ7
10-20t	120.6	101.8	39	M32X1.5	53.5	41	10.5	8-φ14	8-φ9
30t	141	116.8	50.4	M40X1.5	57.2	50.8	11	8-φ18	8-φ11
40-80t	208	174	95	M64X3	70	*	15	16-φ20	16-φ13
100-250t	280	230	136	M76X3	90	*	20	16-φ30	16-φ17
300-450t	360	300	190	M100*3	110	*	20	20-φ40	20-φ25

参数表 Parameters Table

量程 Capacity	0-500T	材质 Material	合金钢
输出灵敏度 Rated Output	2.0±10%mV/V	阻抗 Impedance	[illegible]
零点输出 Zero Balance	±1%F.S.	绝缘电阻 Insulation	≥5000MΩ/100VDC
非线性 Non-Linearity	0.05%F.S.	使用电压 Operating Temp Range	5-15v
滞后 Hysteresis	0.05%F.S.	工作温度范围 Operating Temp Range	-20-80°C
重复性 Repeatability	0.03%F.S.	安全过载 Safe Overload	150%
蠕变(30分钟) Creep(30min)	0.03%F.S.	极限过载 Maximum Overload	200%
温度灵敏度漂移 Temp Effect on Output	0.03%F.S./10°C	电缆线规格 Cable Specifications	φ5x3m
零点温度漂移 Temp Effect on Zero	0.03%F.S./10°C	线缆极限拉力 Cable ultimate pull	10kg
响应频率 Response frequency	10kHz	TEDS可选	

Load cell specification according to manufactured company

SPECIFICATIONS

Model			LK-081
Type			Sensor head Standard Sensor head
Reference distance			80 mm 3.15"
Measuring range			±15 mm ±0.59"
Light source	Type		Visible red semiconductor laser
	Wavelength		670 nm
	Output		0.95 mW
	Laser Class	FDA (CDRH) 21CFR Part 1040.10	Class 2 Laser Product
		IEC 60825-1	
Spot diameter (at standard distance)			Approx. 70 µm 0.002756"
Linearity			±0.1% of F.S. [*1]
Repeatability			3 µm [*2] 0.000119"
Analog output	Voltage output		±5 V (3 µm 0.000119"/mV) [*3]
	Impedance		100 Ω
	Current output		4 to 20 mA (Applicable load: 350 Ωmax.)
Alarm output			NPN: 100 mA max. (40 V max.) (N.C.), Residual voltage: 1 V max.
Sampling cycle			1,024 µs
Other functions			Auto-zero, analog output holding when an alarm occurs, gain switching, response switching, span and shift adjustment of mirror surface measurement mode, changing the sampling cycle
Temperature characteristics			0.01% of F.S./°C
Rating	Power voltage		24 VDC ±10 %, Ripple (P-P) 10 % or less
	Maximum current consumption		400 mA max.
Environmental resistance	Enclosure rating		IP67
	Ambient light		Incandescent or fl uorescent lamp: 10,000 lux max.
	Ambient temperature		0 to +50 °C 32 to 122 °F (No condensation)
	Relative humidity		35 to 85 % RH (No condensation)
	Vibration resistance		10 to 55 Hz, Double amplitude 1.5 mm 0.06", 2 hours in each of the X, Y, and Z directions
Material			Aluminum die-cast
Weight			Approx. 385 g (including cable)

[*1] Linearity was obtained using KEYENCE's standard target (Zirconia block gauge: LK-031/036, LK-081/086, LK-011, White ceramic block gauge: LK-503).
[*2] Repeatability was obtained using KEYENCE's analog sensor controller (RD-50) with the number of averaging measurements set to 64.
Note: The ripple of the analog output may be 1 mV or more due to common mode noise when observed with an oscilloscope or a high-speed A/D conversion board.
[*3] When measurement is impossible, 12 V (31.2 mA) is output.

Laser specifications according to manufactured company

الخلاصة

يدرس البحث الحالي تجريبياً سلوك البلاطات الخرسانية المسلحة عالية القوة والمعززة بالألياف (HSFCS) تحت تأثير الحمل الديناميكي. تم صب ثلاث عشرة عينة خلال العمل التجريبي، بما في ذلك عينة واحدة تجريبية. تم تصنيف العينات الاثنتي عشرة الرئيسية إلى مجموعتين بناءً على سمك البلاطة 70 و100 مم.

تم تحضير ست خلطات مختلفة، كل عينتين بسمكين مختلفتين لهما نفس الخلطة الخرسانية. تم استخدام نوعين من الألياف بالإضافة إلى المايكرو سيليكا لتحسين الخواص الميكانيكية لـ HSFCS. بالإضافة الى استخدام ألياف الحديد والبولي بروبلين بنسب مختلفة لدراسة تأثيرها على خواص الخرسانة تحت تأثير الحمل الصدمي.

تم تصميم هيكل معدني خاص لتطبيق حمل الصدم والذي يتم من خلال سقوط 14.5 كجم من الجسم الساقط سقوطاً حراً على مركز البلاطة. تم اختبار جميع العينات تحت تأثير حمل الصدم حيث تم استخدام خلية تحميل بسعة 10 طن ومستشعر ليزر لقياس مقدار الحمل الصدمي وقيمة الانحراف الناتجة. تم رسم العلاقات بين الحمل مع الوقت بالإضافة إلى الانحراف مع الوقت وتسجيل أنماط الشقوق الناتجة. كانت المتغيرات الأولية التي تمت دراستها في البحث الحالي هي سمك البلاطة، نوع الألياف، نسبة الألياف وارتفاع سقوط الجسم الساقط.

أظهرت النتائج أن الانحراف المركزي ومقدار سعة الحمل الصدمي لجميع البلاطات المفحوصة تحت تأثير حمل الصدم تميل إلى أن تكون أكبر بنسبة (11.8٪ إلى 43.5٪) و (12.1٪ إلى 24.8٪) على التوالي مع الزيادة في ارتفاع السقوط. عند زيادة سمك البلاطة، انخفضت الإزاحة المركزية بشكل ملحوظ بنسب تتراوح بين (33٪ إلى 133٪) بسبب الزيادة في صلابة البلاطة، مما يؤدي إلى زيادة قدرة التأثير القصوى بنسبة (28٪ إلى 50٪) مقارنة بالعينة المرجعية.

تم رصد تأثير الألياف بوضوح في النتائج العملية. الألياف الفولاذية لها تأثير واضح في تعزيز جميع خصائص الخرسانة، بينما تعمل ألياف البولي بروبلين على تحسين قوة الشد والانثناء فقط. أدى وجود الألياف الفولاذية إلى تقليل أقصى انحراف بنسبة (13.5٪ إلى 51.2٪) وزيادة سعة الحمل بنسبة (3.5٪ إلى 16.8٪) مقارنة بالعينات المرجعية. بالمقابل، أدى وجود ألياف البولي بروبلين إلى زيادة الانحراف بنسبة (1.5٪ إلى 21.2٪) وتقليل الحمل بنسبة (3.6٪ إلى 7.8٪). أظهرت العينات الهجينة نتيجة معقولة، حيث تمت زيادة الإزاحة مقارنة بالعينات المرجعية

بنسبة (3.6٪ إلى 23٪)، بينما انخفض الحمل بشكل طفيف بنسبة (1.1٪ إلى 5.3٪) نتيجة انخفاض مقاومة الانضغاط.

كما أظهرت النتائج أن حالة الدعم المثبت تؤدي إلى صلابة عالية لجميع البلاطات المختبرة وتظهر الشقوق الموجودة في الوجوه السفلية لجميع الألواح أولاً، تليها تشققات في الوجوه العلوية. تميل هذه الشقوق إلى اتخاذ أشكال عشوائية، وتبدأ الاتجاهات من منتصف الوجه السفلي للبلاطات المختبرة.

جمهورية العراق
وزارة التعليم العالي
والبحث العلمي
جامعة كربلاء
كلية الهندسة
قسم الهندسة المدنية

التحقيق في السلوك الإنشائي للبلاطات الخرسانية المسلحة والمعززة بالألياف تحت تأثير الحمل الصدمي

رسالة مقدمة إلى
كلية الهندسة في جامعة كربلاء - قسم الهندسة المدنية كجزء من متطلبات نيل
درجة الماجستير في علوم الهندسة المدنية

من قبل

الحسين محمد عبد علي ال فتح الله

(بكالوريوس هندسة مدنية – جامعة كربلاء – 2017)

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