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College of Engineering

Civil Engineering Department

Rehabilitation of Damaged Reinforced Concrete Slabs Subjected to Repeated Loads Using CFRP Sheets

A Thesis Submitted to the Council of the Faculty of the College of the Engineering/University of Kerbala in Partial Fulfillment of the Requirements for the Master Degree in Civil Engineering

By:

Shurooq Dhahir Habeeb

Supervised By:

Asst. Prof. Dr: Jawad Talib Abodi

Asst. Prof. Dr. Ali Ghanim Abbas

September 2022 Safar 1443

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

يَا أَيُّهَا الَّذِينَ آمَنُوا إِذَا قِيلَ لَكُمْ تَفَسَّحُوا
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(المجادلة: من الآية 11)

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We certify that the thesis entitled **"Rehabilitation of Damaged Reinforced Concrete Slabs Subjected to Repeated Loads Using CFRP Sheets"** was prepared by **Shurooq Dhahir Habeeb** under our supervision at the Department of Civil Engineering, Faculty of Engineering, the University of Kerbala as a part of the fulfillment of the requirements for the Degree of Master of Science in Civil Engineering.

Signature: Jawad Talib

Asst. Prof. Dr: Jawad Talib Abodi

Date: 29/12/2022

Signature: Ali Gh

Asst. Prof. Dr. Ali Ghanim Abbas

Date: 29/12/2022

Examination committee certification

We certify that we have read the thesis entitled "**Rehabilitation of Damaged Reinforced Concrete Slabs Subjected to Repeated Loads Using CFRP Sheets**" and as an examining committee, we examined the student "**Shurooq Dhahir Habeeb**" in its content and in what is connected with it, and that in our opinion it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

Supervisor
Signature
Asst. Prof. Dr. Jawad Talib Abodi
Date: 29 / 12 /2022

Supervisor
Signature
Asst. Prof. Dr. Ali Ghanim Abbas
Date: 29 / 12 /2022

Member
Signature
Asst. Prof. Dr. Bahaa Hussein AL-Abbas
Date: 29 / 12 /202

Member
Signature
Asst. Prof. Dr.
Zainab Muhammad Ridha Abbdul Rasoul
Date: 29 /12 /2022

Chairman
Signature
Prof. Dr. Haider K. Ammash
Date: 29 / 12 /2022

Signature
Prof. Dr. Sadjad Ammir Hemzah
Head of the Department of Civil Engineerring
Date: 29 / 12/2022

Signature
Prof. Dr. Laith Sh. Rasheed
Dean of the Engineerring College
Date: 29/12/2022

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I certify that the thesis entitled **"Rehabilitation of Damaged Reinforced Concrete Slabs Subjected to Repeated Loads Using CFRP Sheets"** which has been submitted by **"Shurooq Dhahir Habeeb"** has been proofread and its language has been amended to meet the English style.

Signature:

Prof.Dr.Hussein Musa Kadhim

Date: 29/ 12 /2022

Abstract

This study includes rehabilitation of the damaged slabs subjected to repeated loads using external strengthening. For this purpose, ten two-way reinforced concrete (RC) slabs were constructed and tested under concentrated loads. All slabs are square in shape with the dimensions of (1050 x 1050 x 70)mm. The slabs are internally reinforced with φ8@150 mm steel bars and simply supported on the outer perimeter. Two of these slabs were tested as a reference without external strengthening and subjected to two types of concentrated loads up to failure. The first was subjected to monotonic loads and the second to repeated loads. The remaining eight slabs were divided into two groups. The first group loaded up to 50% of the damage load, and the second loaded up to 75%. Rehabilitation of both groups was done using carbon fiber-reinforced polymers (CFRP) sheets and textile- reinforced mortar (TRM) layers. Then the eight slabs were tested under repeated loads up to the failure point. The test parameters were the type of external strengthening system (CFRP or TRM), the ratio of damage in the slab (50, 75)% of the damage load, and the distribution method of the repair materials (orthogonal or parallel).The experimental results indicate the efficiency of both repair systems in rehabilitating damaged slabs and the superiority of the CFRP system by increasing the maximum load by about (41.25- 88)%, decreasing the final deflection by about (35- 69)%, and improving the structural properties compared to the reference slab. Whereas the use of TRM layers; increased the maximum load by about (9- 21.25)% and reduced the final deflection to about (8- 43.33)%. The best result was when the damaged slabs (at a ratio of 75%) were repaired using the orthogonal scheme in both repair systems (CFRP sheets and TRM layers).

Undertaking

I certify that the research work titled "**Rehabilitation of Damaged Reinforced Concrete Slabs Subjected to Repeated Loads Using CFRP Sheets**" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Signature:

Shurooq Dhahir Habeeb

Date: 29/12/ 2022

Dedication

To the one who encouraged me to persevere all my life, to the most prominent man in my life (dear father).To the one in whom I rise, and upon whom I rest, to the giving heart (My beloved mother). To those who made an effort to help me and were the best support (My husband and children).

To my friends and colleagues...To everyone who contributed even a letter to my academic life...To all of them: I dedicate this work, which I ask God Almighty to accept sincerely...

Signature:

Shurooq Dhahir Habeeb

Date: 29/12/2022

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First and foremost, I express my deepest thanks to almighty **Allah** for blessing me with the health, wisdom, perseverance, patience, understanding, and motivation needed to complete this work.

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My deepest appreciation goes to **all members and friends** at the College of Civil Engineering, University of Kerbala, who supported me in all respects during my Master's research.

Signature:

Shurooq Dhahir Habeeb

Date: 29/12/ 2022

Table of Contents

List of Tables

List of Figures

List of Abbreviations

Symbol	Description
EBR	Externally bonded reinforcement
FRP	Fiber-reinforced polymers
TRM	Textile-reinforced mortar
RC	Reinforced concrete
CFRP	Carbon fiber-reinforced polymers
LVDT	Linear variable differential transformer
ACI	American concrete institute
EBR	Externally bonded Reinforcement
GM	Grooving method
EBROG	Externally bonded reinforcement on grooves
EBRIG	Externally bonded reinforcement in grooves
FRCM	Fabric reinforced cementitious matrix
ASTM	American society for testing materials
BSI	British standars institution
Pu	Ultimate load
δu	Maximum deflection at the middle of the slab

Chapter One Introduction

Chapter One
Introduction

1.1 Background

The rehabilitation of damaged concrete members is a critical topic requiring scientific research to find appropriate repair solutions and preserve the structure from collapse instead of removing it (Waryosh and Hashim, 2020). Repair is a technical procedure for the rehabilitation of damaged elements. There are two types of repair: the first is a structural repair aimed to increase the resistance and stiffness or restore the original resistance of the structure (Jumaat et al., 2006); the second is a non-structural repair aimed to improve the appearance and function of the element.

Rehabilitation of damaged concrete slabs is a structural repair to restore the original strength and increase its stiffness after cracking (Thanoon et al., 2005). For this, it is necessary to know the causes of cracking, the applied loads, the percentage of damage, the repair technique, the materials availability, and suitability to the environmental conditions. There are many methods for repairing concrete structures, one of which is the externally bonded reinforcement (EBR) technique (Askar et al., 2022) by using fiber-reinforced polymers (FRP) or textile-reinforced mortar (TRM). FRPs are composites with high-performance mechanical properties that are fabricated by immersing fibers woven between resin layers. Recently, FRPs have been used in civil engineering works either for damaged structures rehabilitation or new structures construction (Frhaan et al., 2021).

FRPs have been used in many engineering projects and have been an essential subject for many scientific studies. Since there are some flaws in the FRP system, studies have tended to replace epoxy resin with organic materials such as modified cement mortar, a new form of external reinforcement known as TRM, which consists of one or more layers of tissue immersed in a modified cement matrix (Estevan et al., 2022).

1.2 Components of Fiber-reinforced polymers

1.2.1 Fibers

The choice of fiber often controls the properties of composite materials. Carbon, Glass, and Aramid are three major types of fibers which are used in construction. The composite is often named by the reinforcing fiber, for instance, CFRP for Carbon Fiber Reinforced Polymer. The most important properties that differ between the fiber types are stiffness and tensile strain.

1.2.2 Matrices

The fundamental purpose of a matrix is to keep the fibers together, transfer weight to them, and protect them from external influences (Uomoto et al., 2002, Günaslan et al., 2014). Thermosetting resins (thermosets) are almost exclusively used. Vinylester and epoxy are the most common matrices. Epoxy is mostly favored over Vinylester but is also more costly.

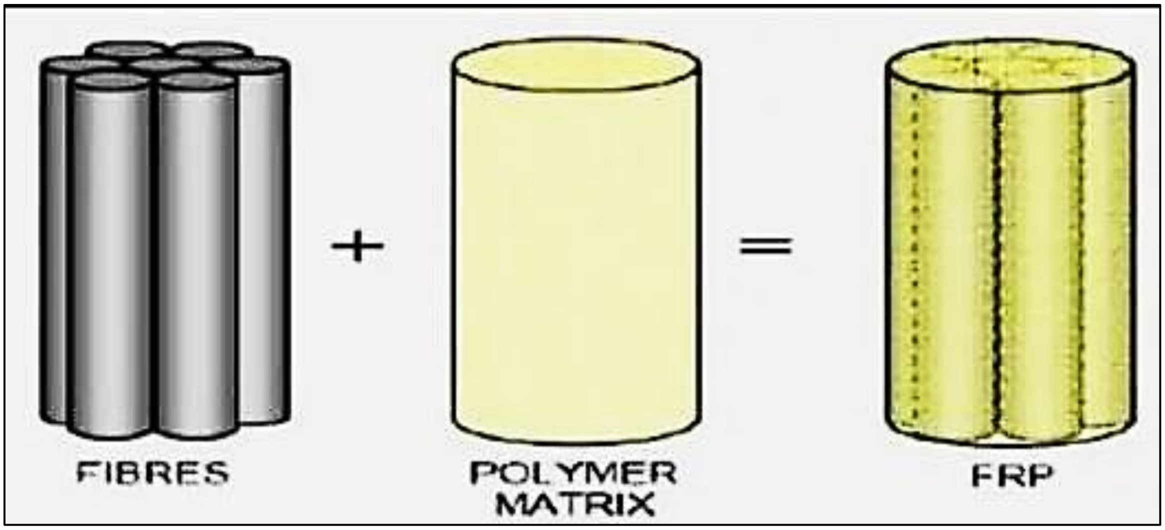


Figure 1-1: FRP Matrix (Hamakareem, 2009).

Epoxy has a pot life of around 30 minutes at 20 degree celsius but can be changed with different formulations. Epoxies have good strength, bond, creep properties, and chemical resistance.

Table 1-1: Properties of thermoset resins for FRPs (Gudonis et al., 2013).

Property	**Resin**		
	Polyesters	**Epoxy**	**Vinylester**
Density (gm/cm^3)	1.1-1.4	1.2-1.4	1.15-1.35
Tensile Strength (MPa)	34.5-104	55-130	73-81
Young's Modulus(GPa)	2.1-3.45	2.75-4.1	3.0-3.5
Poisson's ratio	0.35-0.39	0.38-0.4	0.36-0.39
Saturation, %	0.15-0.60	0.08-0.15	0.14-1.3
Coefficient of Thermal Expansion (10-6 / ℃)	55-100	45-65	50-75

1.3 Types of Fiber-reinforced polymers

Carbon, Glass, Aramid, and Basalt are the four main materials used to make fibers that are often used in the civil engineering industry: CFRP, GFRP, AFRP, and BFRP, respectively (Figure 1-2). Rebar rod, tube, sheet, beam stirrup, plate, roving, and mesh fabric are examples of FRP composites that could be used as reinforcing with concrete in various shapes. Table 1-2 shows the qualities of FRPs in comparison to traditional steel.

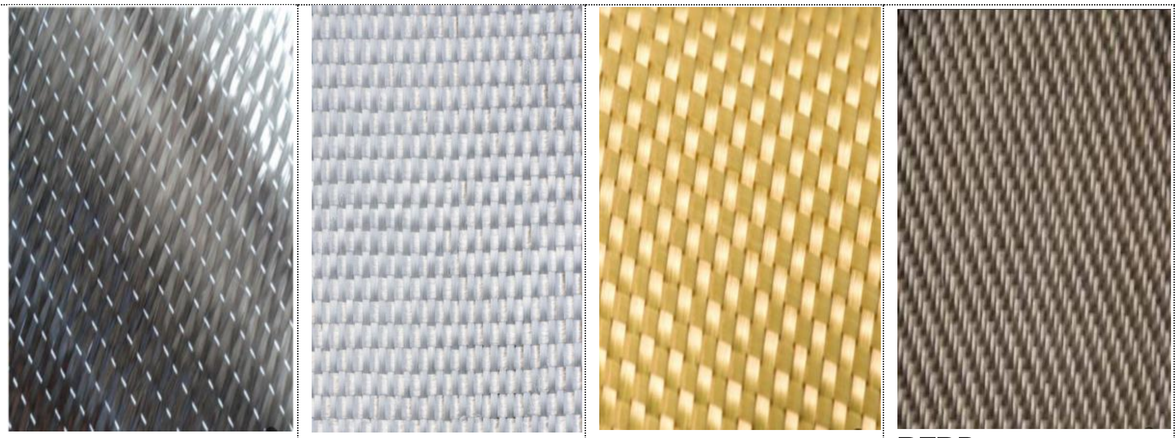


Figure 1-2: Types of Fiber-reinforced polymer sheets.

Table 1-2: Mechanical properties of FRPs types and steel(Ahmed et al., 2020).

Property	**Material Type**				
	CFRP	**GFRP**	**AFRP**	**BFRP**	**Steel**
Density (gm/cm^3)	1.5-2.01	1.25-2.5	1.25-1.45	1.9-2.1	7.85
Tensile Strength (MPa)	600-39620	483-4580	1720-3620	600-1500	483-690
Young's Modulus(GPa)	37-784	35-5.0	41-175	50-65	200
Elongation (%)	0.5-1.8	1.2-5.0	1.4-4.4	1.2-2.6	6.0-12.0
Coefficient of Linear Expansion (10-6/ ℃)	-0.9-0.0	6.0-2.0	-6.0-2.0	9.0-12.0	11.7

1.3.1 Carbon Fiber-reinforced polymers

Carbon fibers have diameters limited between 5 and 10 micrometers. The reinforcement of CFRP composite is carbon fiber that affords strength, and the matrix is generally a polymer resin, for instance, epoxy, that binds the bars. CFRP is developed to strengthen existing RC structures, such as bridges, to avoid replacing constructions that function satisfactorily for many years (Breña et al., 2001). Although CFRP can offer 50%–60% mass reduction compared with alike elements in steel, the cost is 2 to 10 times greater when the costs of materials and processing are considered, as claimed by Amran et al. (2018).

1.3.2 Glass Fiber-reinforced polymers

Glass fibers, which are also known as fiberglass and usually added at 0.5%–2.0% by weight to the composite, are referred to as fiberglass-reinforced plastic (Amran et al., 2018). The properties of GFRP rely on the features of the type of polymer matrix, reinforcing fiber, fiber content, fiber orientation, and the bonding between fiber and matrix (Correia et al., 2005). GFRP is mostly used in the construction of secondary structures, such as bridges, domes, and building frames, or nonstructural elements, such as masonry walls (Correia, 2004).

1.3.3 Aramid Fiber-reinforced polymers

Aramid fibers are synthetic high-performance fibers that are strong and heat-resistant. It has strong synthetic fibers, great strength, and elastic modulus, heat resistance, 40% lesser density than GFRP, and slightly higher cost (Saleh, 2012). AFRP is a better option given its high resistance to alkaline environments and more economical than CFRP reinforcing bars (Sakurada et al., 2006), and it is often used in concrete structures (Deák and

Czigány, 2009), but industries restrict the use of AFRP in lightly loaded structures because aramid fibers own extremely low compressive strength and high tensile strength (Saleh, 2012).

1.3.4 Basalt Fiber-reinforced polymers

Basalt fibers are materials made from extremely fine fibers with nearly 10 and 20 micrometers in diameter. These materials are composed of minerals such as plagioclase, pyroxene, and olivine (Sakurada et al., 2006, Adhikari, 2009, Balea et al., 2014), it is a new promising technology for the construction industry and an alternative to GFRP bars (Dhand et al., 2015).Considering the advantages of basalt fiber, applicable applications exist in the production of basalt–epoxy compounds, which are also feature robust load-bearing characteristics that are valuable in weighty vehicle industries and strengthening materials for structural RC members.

1.4 Components textile-reinforced mortar

TRM combines high-strength fibers in the form of textiles (with open-mesh configuration) with inorganic matrices, such as cement or hydraulic-lime-based mortars.

1.4.1 Textile fiber

Textile mesh materials used as reinforcement of TRM composite materials consist of fiber rovings arranged in two or more directions. The fiber rovings are spaced apart to allow for the formation of a mesh. Perforations between the fiber rovings enable some sort of mechanical interlock between the reinforcement and the matrix. Figure 1-1shows textiles that have been used as reinforcement in TRM systems.

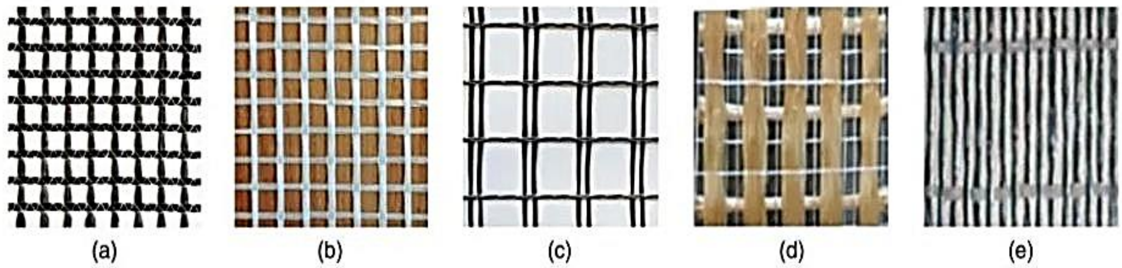


Figure 1-3: Textile fiber: : (a) carbon fiber textile; (b) glass fiber textile; (c) basalt fiber textile; (d) polyphenylene bezobisoxazole fiber textile; and (e) steel fiber textile, (Koutas et al., 2019).

The mesh size of commercially available nonmetallic textiles that are used for strengthening applications (i.e., carbon, glass, basalt, or polyphenylene bezobisoxazole fiber textiles) typically varies between 8 and 30 mm, whereas their weight is usually between 150 and 600 g/m^2, depending on the fiber material. Steel fabrics consist of unidirectional steel cords, each one comprising a number of twisted steel filaments; their density typically varies between 1 and 10 cords/cm

1.4.2 Coating

The coating of metallic textiles with polymers improves the stability of the textile material and the mechanical interlock between the textile and the matrix and the matrix. The coating of nonmetallic textiles with polymers improves the stability of the textile material and the mechanical interlock between the textile and the matrix.

1.4.3 Mortar

The composition of mortar used as matrix in TRM systems significantly affects its response as a composite material, because the impregnation of fibers with mortar is quite important for achieving a good bond between the fibers and the matrix. The mortar has to include fine granules and should have a plastic consistency, good workability, low viscosity (for easy application to vertical or steep surfaces) and sufficient shear strength (to prevent the debonding of the composite material from the substrate); hence cement-based mortars are widely used as matrix of TRM. The mechanical properties of mortar, namely the flexural strength and the bond between the matrix and the fiber rovings, can be significantly improved by adding polymers (Koutas et al., 2019).

1.4.4 The procedure of strengthening by TRM

The procedure of strengthening with TRM jacketing includes the following steps: (1) surface preparation; (2) application of a first layer of mortar at the dampened concrete surface; (3) impregnation of the textile fibers with mortar (this operation is repeated until all textile layers have been applied and covered by mortar); and (4) application of a final layer of mortar on the top of the final textile layer (Koutas et al., 2019).

1.5 Failure mechanism

1.5.1 Structural members strengthened by FRP

A significant amount of previous research has reported the common modes of failure of RC members externally strengthened with FRP (Toutanji et al., 2006, Esfahani et al., 2007). From this observation, the failure modes can be classified into two main modes which are full composite action failure modes and loss of composite action failure modes (Abdullah, 2011). Full composite action also has the following three sub-categories, schematically represented in Figure 1-4.

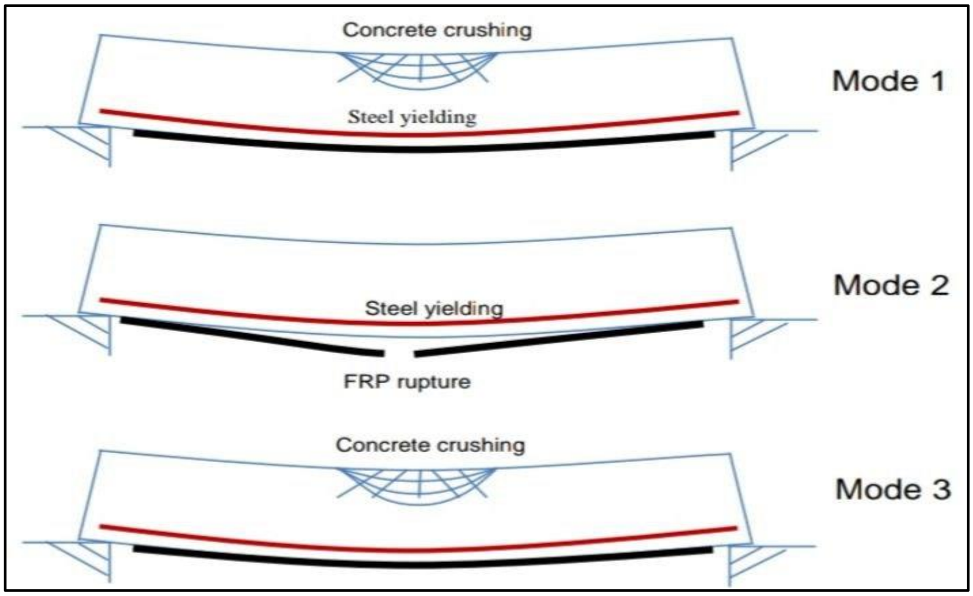


Figure 1-4: Common modes of failure of RC members externally strengthened with FRP, (Daud, 2015).

Mode 1: Steel yielding followed by concrete crushing; flexural failure may occur with yield of the steel reinforcement in tension side followed by crushing of the concrete in the compression region. In contrast, there is no damage in FRP.

Mode 2: Steel yielding followed by FRP rupture; this failure mode may occur for low ratios of both steel and FRP.

Mode 3: Concrete crushing; the RC members may fail by the crushing of the concrete in the compression region, while both reinforcement steel and the FRP are intact.

The possible failure modes for RC members that fail by loss of composite action are categorized as follows (Daud, 2015). Schematically represented in Figure 1-5.

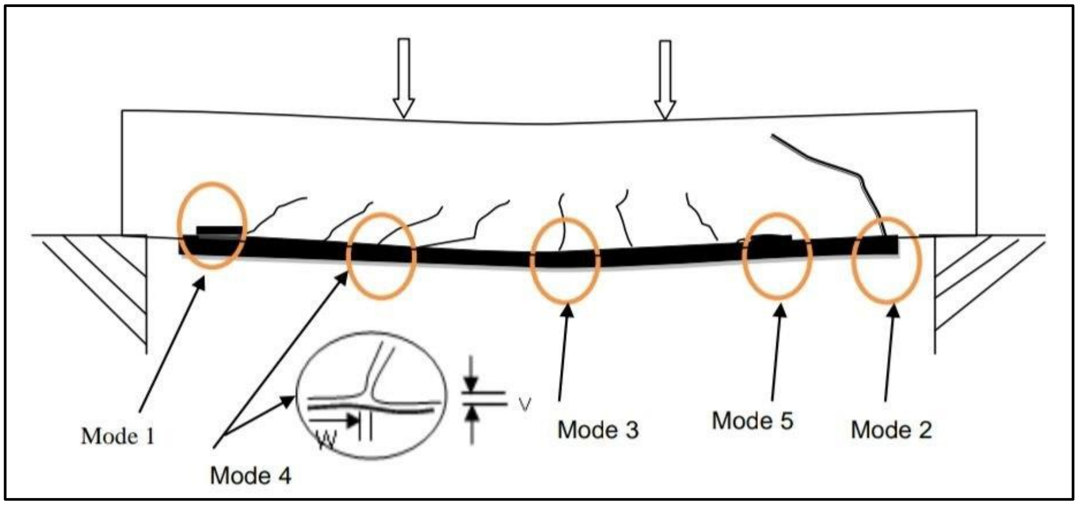


Figure 1-5: Debonding failure modes induced of flexural loading (Daud, 2015).

1- Debonding failure modes induced by flexural loading.

- Mode 1: FRP peeling- off at the outermost crack in the anchorage zone; when the shear stress in the concrete exceeds its shear strength and the outermost crack initiates, FRP separation in the anchorage zone will start.
- Mode 2: FRP plate-end shear failure; this failure type may occur as a result of shearing fracture through the concrete at the end of the FRP. The failure mechanism begins with initiation of a vertical crack in the concrete at the externally bonded plate end near to the support and then propagates as an inclined shear crack.
- Mode 3: FRP peeling – off at flexural cracks; peeling- off of the FRP causes in high moment regions far from the anchorage zone by flexural cracks in the concrete which will propagate and become wider. Thus, the shear stresses generated between the FRP and concrete surface lead to separation starting from the mid-span and propagate towards the FRP plate end

- Mode 4: FRP peeling-off occurred by shear cracking; inclined cracks in concrete created horizontal and vertical opening displacements due to dowel action effect and aggregate interlock.
- Mode 5: FRP peeling-off due to unevenness of the concrete surface; localized debonding of the FRP may increase and lead to FRP peeling off due to the roughness and unevenness of the concrete surface.

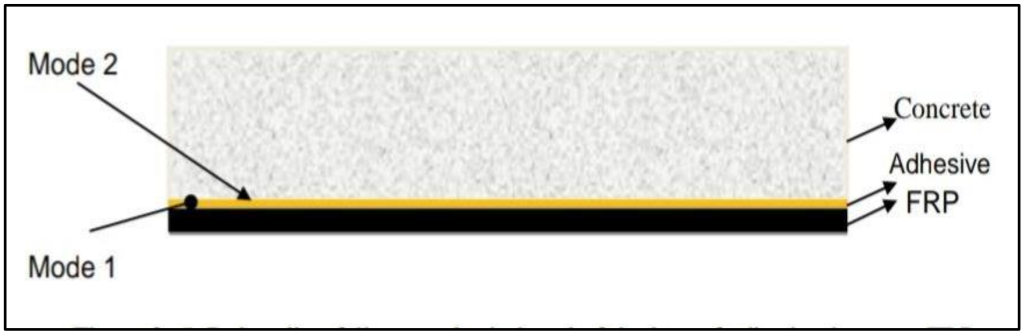


Figure 1-6: Debonding failure modes induced of the loss of adhesion between FRP and concrete substrate (Daud, 2015).

2- Debonding failure modes induced of the loss of adhesion between FRP and concrete substrate. Shown in Figure 1-6

Mode 1: Bond failure in the adhesive; the bonding failure which denotes as debonding through the FRP adhesive will occur when the strength in the adhesive is lower than the strength of concrete. However, the shear and tensile strengths of adhesive layer usually exceed those of concrete. In some cases a dramatic increase of temperature causes a pronounced drop in adhesive strength compared with concrete strength or very high tensile concrete strength.

Mode 2: Bond failure in the interfaces between concrete FRP and adhesive;in the relatively rare case where the surface conditions during the FRP application are inadequate, bond failure may occur through the adhesiveconcrete interface or FRP- adhesive. This failure type can easily be avoided by proper surface preparation for concrete and FRP.

1.5.2 Structural members strengthened by TRM

Despite the favorable characteristics of TRM composites, the adhesion property among the textile and inorganic mortars is not as effective as that of epoxy resins of FRP. Mortar particle size is too big to fit into the threads preventing them from accurately impregnating the textile. Because of this phenomenon, the stress transmission between the fibers and the matrix is not uniform, which causes "telescopic failure" or uneven slip without appreciable damage: the external textiles, in which the stress bond is highest, will rupture, whereas the internal ones which remain approximately free, will slip. The adhesive property between TRM components can be enhanced: by coating the fabric with epoxy resins before incorporating it with the modified mortar (Donnini et al., 2016, Homoro et al., 2020).

TRM substrate failure usually occurs in three modes: (a) fibers rupturing in the specimen's center, (b) fibers rupturing close to the fastening zones, and (c) fibers slipping relative to the mortar matrix, typically close to the fastening zones. Research indicates that the effectiveness of TRM composites and failure patterns are affected by the fixing method of the substrate to the test device (De Santis et al., 2018).

Koutas et al. (2019) published a review on the reinforcement of concrete beams and slabs using textile-reinforced mortar; they pointed out that several failure modes have been reported in the literature, highlighting the intricacy of the mechanical behavior of the TRM strengthening technique. Apart from failure modes similar to those for FRP strengthening techniques, additional failure modes have been observed in most of the studies. Figure 1-7 shows schematically all the reported failure patterns. In general, an RC element strengthened in flexure with TRM may fail due to loss of the strengthening action Figure 1-7(a–f) or due to concrete failure Figure 1-7(g and h). The failure patterns can be classified as follows: (1)Slippage of the fibers within the matrix, Figure 1-7(a). (2) Debonding at the concrete–matrix interface, Figure 1-7(b). (3) Debonding at the matrix–textile interface, or interlaminar shearing, Figure 1-7(d). (4) Debonding from the concrete surface accompanied with peeling off of the concrete cover, Figure 1-7(e). (5) Fiber rupture, Figure 1-7(f). (6) Concrete crushing, Figure 1-7(g). (7) In the case of excessive flexural strengthening, shear failure of the element may precede flexural failure Figure 1-7(h).

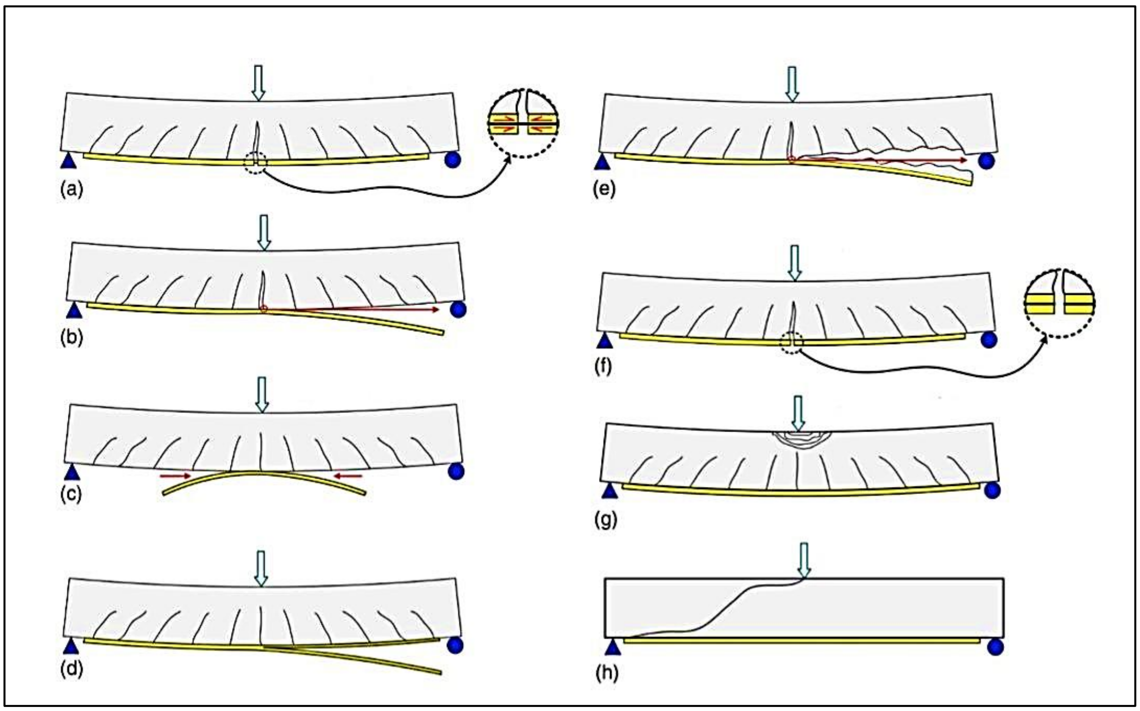


Figure 1-7: Scheme of all failures in the externally strengthened substrate by the TRM layers,(Koutas et al., 2019).

1.6 Statement of the problem

Repeated loading can lead to catastrophic failure and concrete collapse of some structures below the ultimate load level, e.g., car parks and multi-story public buildings. These buildings are exposed to loading and unloading cycles during their service life, leading to the growth of cracks, weakening the concrete strength, and reducing operational life. Funding sources are not available to replace degraded buildings. Thus, corrective measures are needed to maintain damaged buildings with an effective and inexpensive repair technique. Therefore, it is necessary to search for suitable repair methods that restore the original resistance of the building while preserving the architectural design.

1.7 Objectives and methodology of the research

The main objective is to study the structural behavior of rehabilitated slabs subjected to repeated loads. The study is concerned with the rehabilitation of damaged RC slabs subjected to repeated compression loads concentrated in the middle of the slab. The external strengthening systems used in this study are CFRP sheets and TRM layers. The methodology of the research is investigating the structural behavior of the reference slab through a monotonic load test. This test detects the ultimate load, which will be used to determine the repeated loading pattern. Also, to investigate the structural behavior of reference and rehabilitated slabs under repeated loading. This test reveals the ultimate load and structural properties, which will be used to determine the effectiveness of CFRP sheets and TRM layers.

1.8 Scope of study

The EBR technique is widely used in the structural modification of existing structures. This technique can enhance the overall strength of the structural element without changing its shape and size. According to the nature of the substrate surface, the EBR technique divides into organic and inorganic materials such as FRP and TRM, respectively. The scope of this study is to highlight: the rehabilitation of damaged two-way RC slabs subjected to repeated loads using the EBR technique, the monotonic and repeated loading patterns, CFRP sheets, and TRM layers to repair the slabs. The following paragraphs briefly explain the scope of the study:

1.8.1 Monotonic and repeated load testing

Usually, a load test of concrete structures is carried out to determine the structural behavior, investigate reinforcement, develop and implement required corrective actions, and check the ability of the structural member to bear additional loads. There are two protocols for load testing: monotonic and cyclic. The selection of the load test protocol depends on several parameters, including the required time to complete the test, charges, and the load test purpose (Gustavo et al., 2014a). The method of monotonic load testing involves applying the load gradually in equal increments till reaching the magnitude of the test load. Whereas, the repeated load test protocol includes loading the structural member periodically by applying several cycles of loading and unloading till reaching the required load, using a hydraulic jack, and recording the deflection by linear variable differential transformer (LVDT) sensors.

1.8.2 CFRP matrix

The CFRP matrix consists of longitudinally woven carbon fibers and epoxy resins to bind the carbon fibers to the damaged slab.

1.8.3 TRM matrix

The TRM matrix consists of carbon fiber woven into an orthogonal open mesh, a cement mortar, and the bonding agent between the damaged slab and the TRM matrix.

1.9 Structure of the thesis

•The first chapter briefly introduces the importance of repairing damaged reinforcement concrete slabs and provides a brief description of loading types and the repair materials used in this study.

•The second chapter shows a review of previous literature studies linked to this topic; the structural behavior of slabs subjected to monotonic and repeated loads; the characteristics of CFRP sheets and TRM layers; methods of applying external strengthening; flexural behavior of externally strengthened concrete members; and failure mechanism.

•The third chapter describes the investigated models, as well as the materials and preparation of RC slabs, and the recommended slab strengthening strategies.

•The fourth chapter, on the other hand, clarifies the experimental results and their discussion.

•The research conclusions and recommendations for further work are presented in the fifth chapter.

Chapter Two   Literature Review

Chapter Two
Literature Review

2.1 Introduction

The study aims to restore the damaged RC slabs exposed to repeated loads using CFRP sheets or TRM layers. Many previous studies dealt with repairing concrete structures using FRP and TRM composites. The second chapter provides a detailed explanation of the prior research through three axes related to the current study: (1) Structural behavior of RC slabs subjected to monotonic and repeated loads. (2) Methods of applying external strengthening. (3) Flexural behavior of externally strengthened concrete members.

2.2 Structural behavior of RC slabs subjected to monotonic and repeated loads

Usually, the loading test is used to study the structural behavior of a member, including ultimate load, ultimate deflection, and failure pattern, and investigate structural retrofit (Gustavo et al., 2014b). Al-Sulayvani and Al-Talabani (2015), evaluated the effect of CFRP strips on the strengthening and repair of circular RC slabs with openings. Thirteen circular RC slabs with dimensions of (1200 mm in diameter and 75 mm in thickness) were tested under repeated (Figure 2-1 shows the loading pattern) loading through an annular load subjected at the center of slabs. The slabs were simply supported on all edges. The experimental variables considered in this paper include the shape of openings (circle, square, and rectangular) and the strengthening schemes. The experimental results indicated that the use of CFRP strips to upgrade the circular RC slabs with openings has a significant effect on ultimate load and deflection. Depending on the CFRP strengthening scheme used, the ultimate load capacity was increased by (27–52)%. The role of CFRP strips in repairing circular slabs was found to be bigger than its role in strengthening circular.

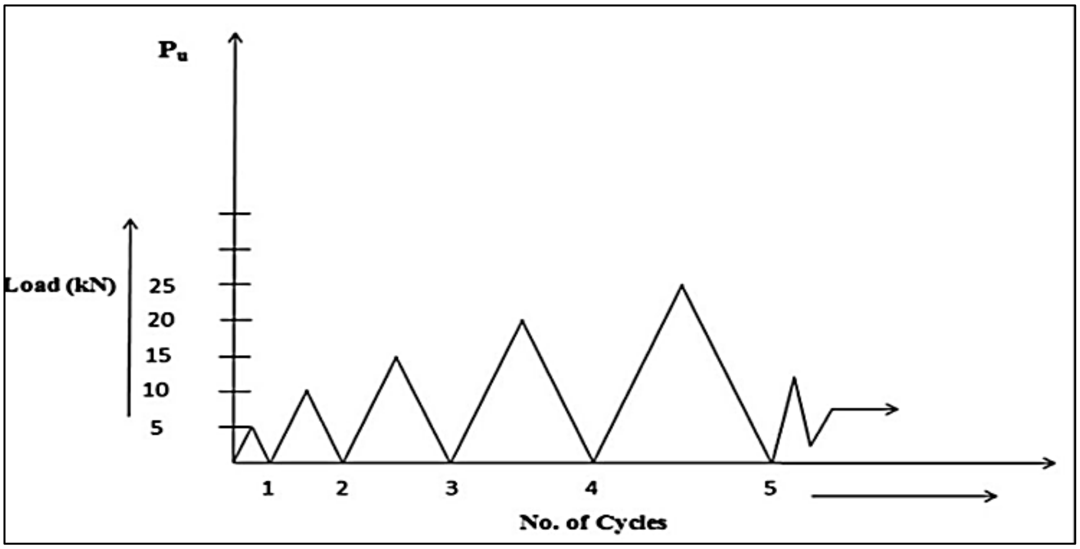


Figure 2-1: The pattern of repeated loading, adopted from Al-Sulayvani and Al-Talabani (2015).

Koutas and Bournas (2017) experimentally investigated the application of textile-reinforced mortar (TRM) as a means of increasing the flexural capacity of two-way RC slabs. The parameters examined include the number of TRM layers, the strengthening configuration (Figure 2-2), the textile fibers material (carbon versus glass), and the role of initial cracking in the slab. For this purpose, six large-scale RC slabs were built and tested up to failure under monotonic loading distributed at four points. It is concluded that TRM increases substantially the pre-cracking stiffness, the cracking load, the post-cracking stiffness, and eventually the flexural capacity of two-way RC slabs, whereas the strengthening configuration plays an important role in the effectiveness of the technique.

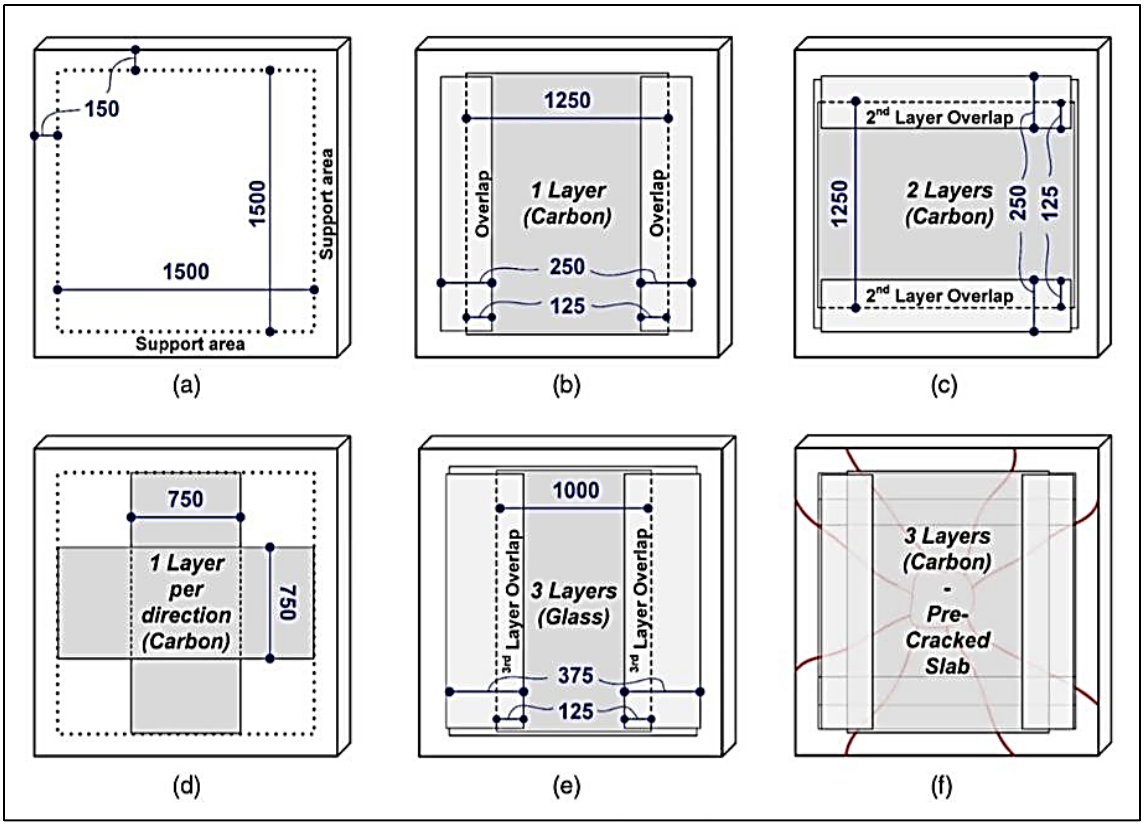
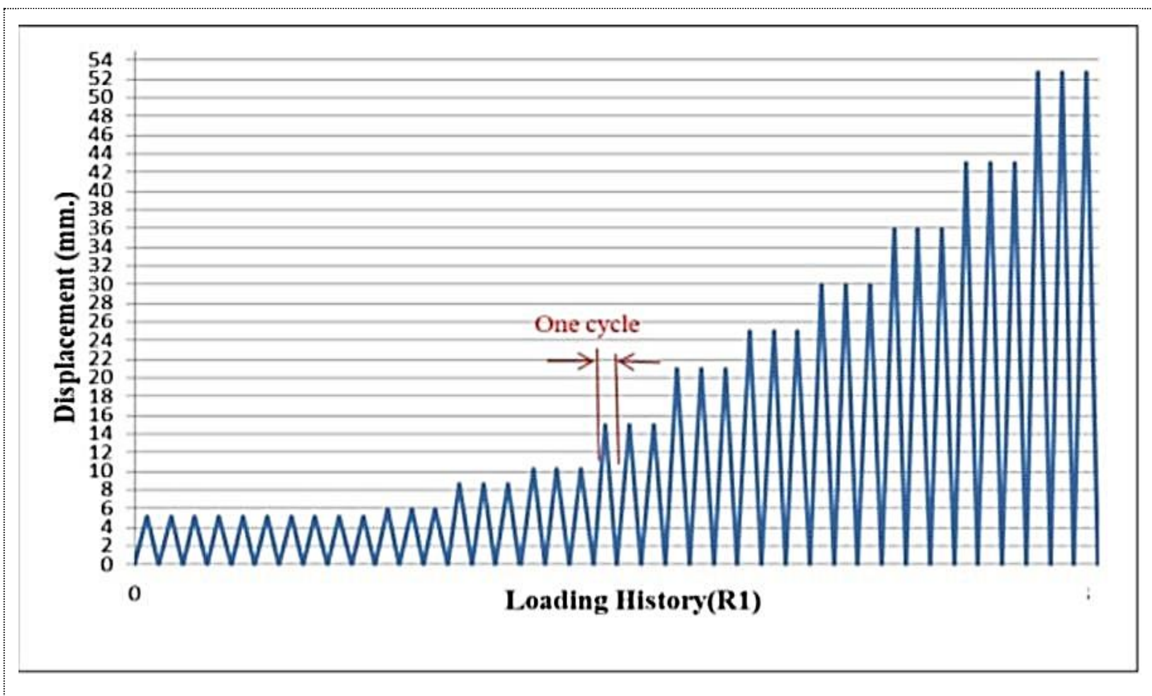


Figure 2-2: Strengthening configuration at the tensile face of tested slabs adopted from Koutas and Bournas (2017), all dimensions in mm.

Hamid and Mohammed (2018) studied the behavior of reinforced Reactive Powder Concrete (RPC) two-way slabs under static and repeated load. The experimental program included testing six simply supported RPC two-way slabs of 1000 mm length, 1000 mm width, and 70 mm thickness. All the tested specimens were identical in their material properties and reinforcement details except for their steel fiber content. In each pair, one specimen was tested under static load and the other under five cycles of repeated load (loading-unloading). For the repeated load test, applying five cycles of repeated load to the steel fiber-reinforced two-way slab specimens led to a decrease in the ultimate load capacity, ultimate deflection, ultimate strain, and absorbed energy in a comparison with the corresponding static test specimens, and that because of the loading-unloading process which causes a fluctuation of stresses and more damages in concrete.

Al-shaarbaf et al. (2020) experimentally investigated the structural behavior of RC one-way slabs under monotonic and repeated loadings. Eight specimens were propped up in their outer circumference and subjected to a centered loading in the middle. Four slabs are experimented with monotonic loading, and the other four with two patterns of a repeated loading system. The first pattern (R1) includes applying more than forty cycles of variable amplitude until the failure, while the second pattern (R2) involves more than twenty cycles of variable amplitude until failure,as shown in Figure 2-3. It was concluded that the failure pattern of the slabs during monotonic and repeated loading was similar. Increasing the number of loading cycles leads to a decrease in the ultimate load and an increase in the deflection.



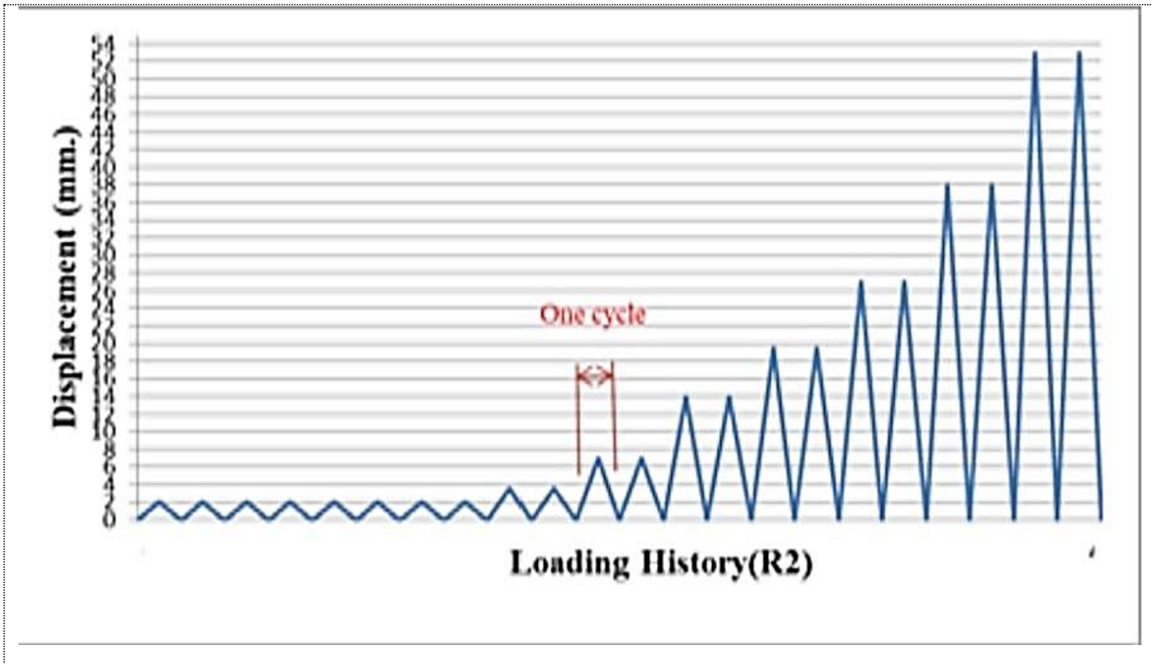


Figure 2-3:Loading historyof tested slabs under repeated load, adopted from Al-shaarbaf et al. (2020).

2.3 Methods of applying external strengthening

Concrete slabs may be subjected to loading and unloading cycles that lead to the formation of structural cracks in the concrete slab and its failure with loads less than the design capacity. FRP composites are the most commonly used type of reinforcement, repair, or rehabilitation, which can be applied to the surface of the existing concrete substrate by an externally bonded reinforcement (EBR) method (Hasan et al., 2020, Shakir and Abd, 2020, Arslan et al., 2022). The main disadvantage of this method (EBR) is the earlier removal of fiber-reinforced polymers from the concrete substrate. Many researchers presented several techniques to improve the bonding of fiber-reinforced polymers to the concrete elements, one of which is the “Grooving Method” (GM).

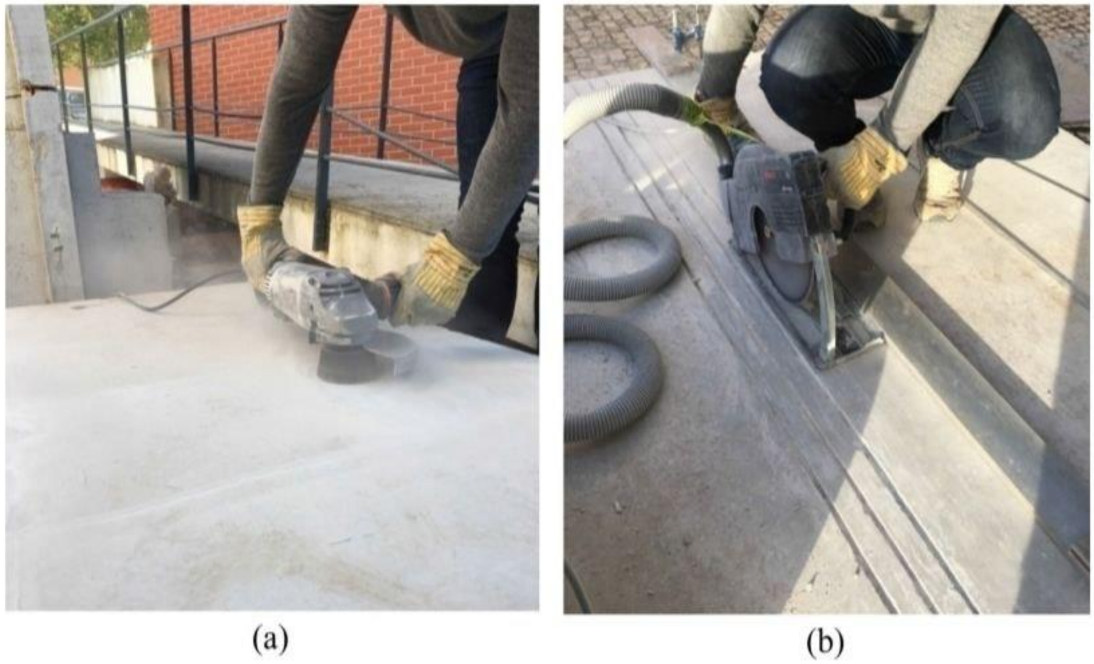


Figure 2-4:Surface prepartion; (a) EBP method, (b)in EBROG method, adopted from Torabian et al. (2020).

Torabian et al. (2020) tested five flat reinforced concrete slabs under monotonic loading to verify the performance of the EBROG technique compared to the EBR in two different bending strength configurations. All slabs were reinforced using steel shear screws to prevent occurring of the expected punching shear failure before de-bonding the FRP sheets. The results showed the efficiency of the EBROG technique in delaying the de-bonding of FRP sheets versus the EBR technique. The ultimate load of the EBROG technique-reinforced slabs increased compared to the reference slab without reinforcement and the EBR technique-reinforced slabs.

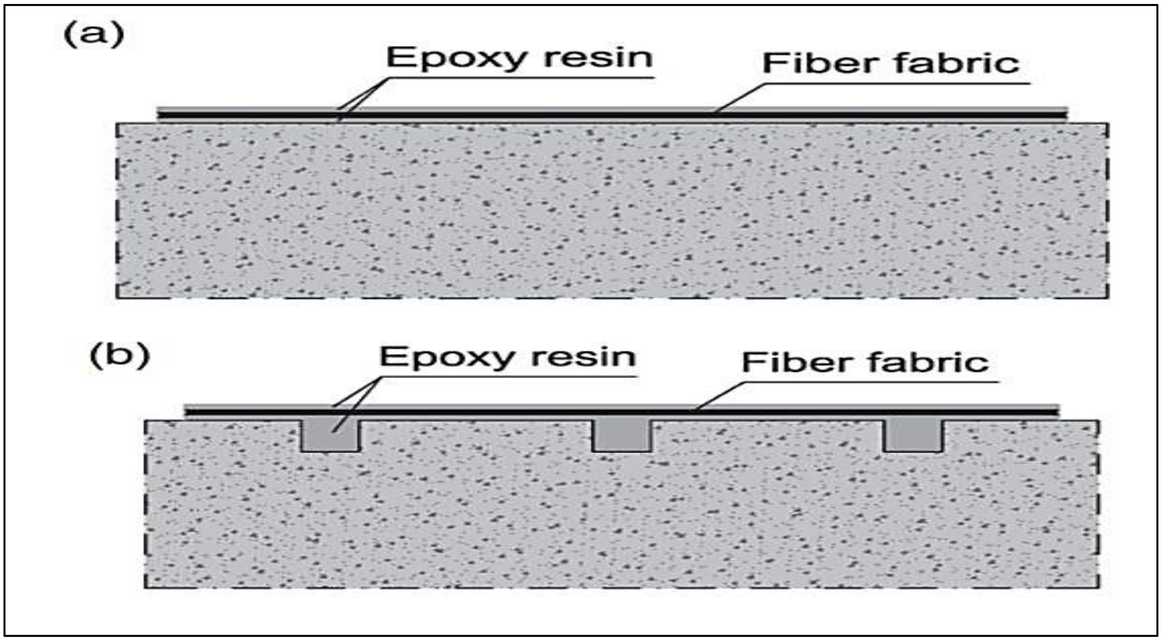


Figure 2-5 Methods for bonding of FRP on the concrete surface; (a) EBR; (b) EBROG (Torabian et al., 2020).

Amiri and Talaeitaba (2020) studied the strengthening of flat slabs with Externally Bonded Reinforcement "On Grooves" (EBROG) and "In Grooves" (EBRIG) FRP strips. 28 slabs consisting of one control and 27 strengthened were defined and analyzed nonlinearly. The EBRIG and EBROG strengthening configuration consisted of 1- or 2-layer FRP strips under slabs on 2 grooves of 4- or 8-mm width and 8, 10, or 12-mm depth. The analysis results of EBR, EBRIG, and EBROG strengthened specimens showed that the FRP strengthening of slabs in EBRIG and EBROG format, increased the punching capacity of the slab up to 60%, while EBR strengthening could increase this capacity by about 28%. The cracking load was increased by about 50% compared to EBR-strengthened specimens. Also, the EBRIG and EBROG strengthening in some of the specimens could change the slab failure from shear to shear flexure and the FRP rupture resulted in them. The grooves width and depth directly affected the cracking load, punching shear capacity, and failure type of slabs.

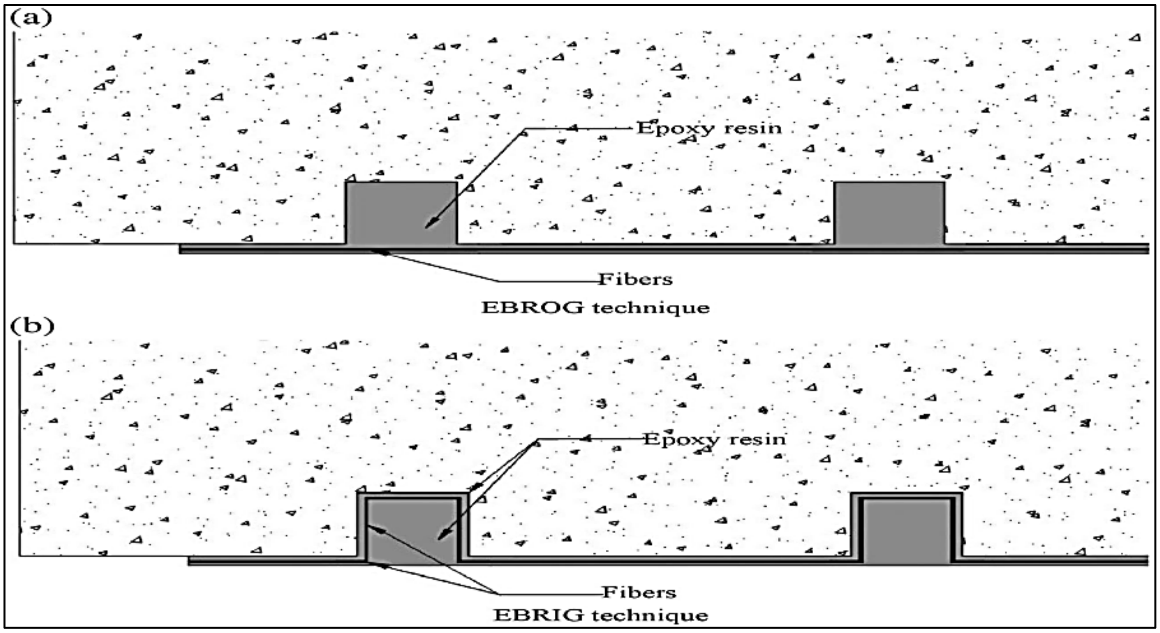


Figure 2-6 External reinforcement technique: (a) EBROG, (b)EBRIG (Saljoughian and Mostofinejad, 2020).

2.4 Flexural behavior of externally strengthened concrete members

2.4.1 Flexural behavior of FRP composites

External strengthening with CFRP can improve the flexural behavior of the RC beams and slabs (Chajes et al., 1995, Aram et al., 2008). Zhou et al. (2020) conducted a test to study the bending strength of five concrete beams strengthened externally with carbon fiber-reinforced polymer sheets. The three parameters were concrete compressive strength, sheet width, and the method of fixing CFRP sheets on test specimens. The results indicate that the effect of the width of the sheets on the external strengthening was the most prominent one, especially with the high compressive strength.

Balamurugan and Viswanathan (2020) presented an experimental study on finding an effective lamination system to increase flexural resistance in two-way slabs, including the orientations of FRP sheets, using three techniques and two types of carbon fibers (CFRP versus GFRP). Each one includes a specific direction for the distribution of FRP sheets and the percentage of coverage area. It was concluded that all the lamination systems enhanced the flexural resistance of the two-way slabs. The efficiency of the lamination system depends on orientations and distribution of the FRP sheets and adhesive force with the slab.

Mutlaq et al. (2020) studied repairing damaged slabs subjected to monotonic loads using external strengthening. 4 two-way RC slabs were constructed and tested under concentrated loads. All slabs are square with dimensions 1050 × 1050 × 70 mm, internally reinforced with steel φ8@150 mm, and supported on the outer perimeter by simple supports. One of these slabs was tested as a control and 3 strengthened by CFRP sheets. The test parameters were the damage ratio of the slab (50, 75) % of the ultimate load, and two distribution method of the repair materials, as shown in Figure 2-7 . It was concluded that The external CFRP sheets attached to the tensile faces of RC slabs increased the hardness of the slabs at all stages of loading, thus reducing the deflection in the corresponding loads. The best result was in the slabs repaired by CFRP sheets for the best shape of repairing at a ratio of load damaged (50%) by increasing ultimate load about (26.7 %) compared with unrepaired slabs.

With all of the above, two-way RC slabs with low or medium internal reinforcement suffer from flexural failure rather than shear failure. Therefore, external strengthing using FRP composites is desirable for ease of application. However, the disadvantage of using these composites in the external reinforcement of concrete structures is the fragility of the FRP composites, which can cause a ductility decrease in the repaired concrete substrate, thus the occurrence of undesirable sudden failure (Mohammed et al., 2021).

Figure 2-7: Two distribution method of the CFRP sheets adopted from Mutlaq et al. (2020).

2.4.2 Flexural behavior of TRM composites

As earlier noted, FRP has many advantages over steel; but it still has some disadvantages, such as high cost, sensitivity to high temperatures, and inapplicability in wet or cold conditions. Therefore, textile-reinforced mortar (TRM) has been presented to deal with these disadvantages. Tetta et al. (2018) suggest that using TRM is as effective as FRP when used as externally bonded reinforcement. Few research studies have been reported in the literature on using TRM to strengthen RC slabs against punching shear failure. Therefore a selection of previous works related to strengthening RC slabs, and beams will be presented here.

Schladitz et al. (2012) conducted experimental research to examine the efficiency of the TRM layers in improving the bending strength of RC slabs dimensioned (1.6 × 0.1) m externally strengthened with textile-reinforced concrete. Then, computation models were developed with dimensions (6.75 × 0.23) m to predict the maximum flexural load capacity for reinforced slabs. The results exhibited a significant increase in the ability of the slabs to bear additional loads compared to the unstrengthened slabs and a substantial decrease in deflection with increasing strengthening size at equal loading levels.

Abbas et al. (2015) investigated the influence of CFRP sheets and TRM layers strengthened on the punching resistance of RC slabs. 12 RC slabs of (600 × 600 × 90) mm dimensions subjected to quasi-static vertical load. The slab specimens were cast with two different concrete grades (grade A = 39.9 MPa and grade B = 63.2 MPa, six slabs for each of them). Two slabs of each group served as control, while the other four were strengthened by CFRP and TRM. Based on the obtained results, the following conclusions were drawn:

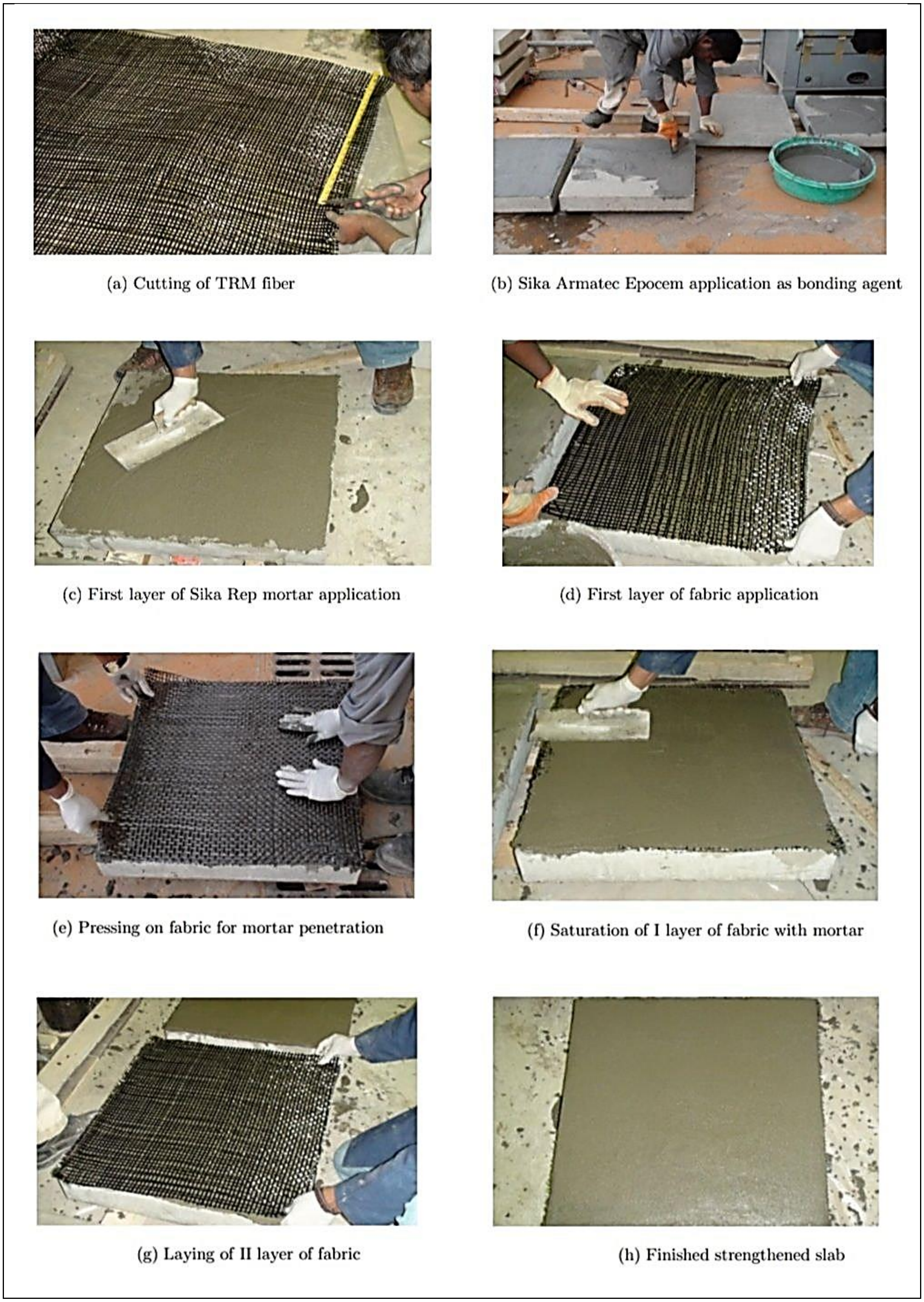
1. For slabs strengthened by CFRP, the load-carrying capacity was increased by 12.4% and 16.6% for concrete grades A and B, respectively. In addition, there is a significant improvement in the energy absorption capacity of slab specimens ranging between 65.5 and 66.1% for the two grades of concrete.

2. For slabs strengthened by TRM layers, the punching shear capacity was increased by 9.1% and 18.1% for concrete grades A and B, respectively. In addition, the improvement in the energy absorption capacity of slab specimens ranged between 22.0 and 58.7% for the two grades of concrete.

3. It was shown that the CFRP sheet was more effective than TRM layers for enhancing the punching strength of flat slabs.

Abbas et al. (2016) studied the efficiency of TRM layers in controlling the local damage in flat slabs tested under an impact load. Then, the findings were compared with that of conventional CFRP strengthening of flat slabs. Ten RC slabs of (600 × 600 × 90) mm were cast, six of them were strengthened by applying TRM and CFRP, as shown in Figure 2-8, Figure 2-9 and the other four were reference slabs. One layer of unidirectional CFRP sheet with fibers distributed along the span was used for the strengthening of RC slabs. While two layers of carbon fiber textile were used for TRM strengthening according to Al-Salloum et al. (2011) recommendations that a single layer of CFRP was found to be equivalent to two layers of textile. It was concluded that CFRP and TRM strengthening systems were effective in decreasing the local damage of flat slabs. By comparing the behavior of the two strengthening techniques, the TRM strengthening technique was slightly better.

Figure 2-8: Strengthening of slabs by CFRP sheets adopted from Abbas et al. (2016).



(a) Cutting of TRM fiber

(b) Sika Armatec Epocem application as bonding agent

(c) First layer of Sika Rep mortar application

(d) First layer of fabric application

(e) Pressing on fabric for mortar penetration

(f) Saturation of I layer of fabric with mortar

(g) Laying of II layer of fabric

(h) Finished strengthened slab

Figure 2-9: Strengthening of slabs by TRM layers adopted from Abbas et al. (2016).

Raoof and Bournas (2017) conducted experimental research to investigate the flexural performance of RC beams strengthened with TRM and FRP. The results showed that the efficiency of TRM was less than FRP in improving the flexural capacity of the beams by about (46-80) %, according to the examined parameters. Providing a coating for the dry textiles improved the effectiveness of TRM and changed the failure mode. Doubling the layers of TRM (from 1 to 3) doubles the efficacy of TRM compared to FRP.

Koutas et al. (2019) published a review on reinforcement of concrete beams and slabs using the textile-reinforced mortar; in their study indicated the efficiency of using TRM composites in improving the flexural strengthening by attaching TRM layers to the tension surface, specifically on the underside of the slab. In the bending strength of one-way slabs, not all textile fibers are used to withstand tensile forces, only the fibers parallel to the axis of the reinforced member are activated, and the perpendicular fibers contribute to closer mechanical bonding. Therefore, the TRM effectiveness in a one-way slab strengthening may be costly, while in two-way, the textile is effective in both directions.

2.5 Originality of research

In this chapter, the review of previous studies was presented and discussed to identify the gaps in knowledge as follows:

1- Some studies dealt with applying external strengthening using the GM method to strengthen concrete structures before the monotonic loading. As far as the researcher knows, there are few studies about the rehabilitation of damaged slabs using the GM method.

2- Very few scientific studies have dealt with the issue of strengthening concrete slabs before they are subjected to repeated loads using a CFRP or TRM system. Especially about the rehabilitation of the two-way RC slabs using these systems.

3- A rarity of scientific studies on the rehabilitation of damaged slabs is subjected to cyclic compressive loads.

2.6 Summary

Scientific research confirmed the effectiveness of FRP and TRM composites in strengthening concrete structures. Until the preparation of this study, little research has been performed on the rehabilitation of damaged two-way RC slabs subjected to repeated loads. The study aims to experimentally investigate the effectiveness of external strengthening using the GM method; in restoring the original resistance of damaged slabs; using CFRP sheets and TRM layers. Experiment parameters: type of repairing system (CFRT sheets and TRM layers), slab damage ratio (50, 75)% of ultimate load, and repairing configuration (orthogonal or parallel); as well as studying the structural behavior of slabs subjected to repeated loads by analyzing the results and investigating the stiffness, ductility index and toughness before and after rehabilitation. Comparison of the results to choose the best repair system, commensurates with the conditions surrounding the concrete structure.

Chapter Three Experimental work

Chapter Three

Experimental work

3.1 General

This chapter provides a detailed illustration of experimental work and a detailed description of the procedures used for: (1) Selection of materials. (2) Structural design of the concrete plates. (3) Preparation and testing of slab specimens under monotonic and cyclic compression load. (4) External repairing process. (5) Testing of rehabilitated specimens under repeated loading.

3.2 Selection of materials

Pouring of test slabs was done by using ready-made concrete consisting of (1) cement, (2) fine aggregate, (3) coarse aggregate, and (4) water. The test slabs were reinforced using steel bars of 8mm diameter. Rehabilitation of the damaged slabs was done by using CFRP sheets and TRM layers. Paragraphs below describe the properties of the materials used.

3.2.1 Cement

The ordinary Iraqi Portland cement known as Kar-Najaf was used to produce the concrete mixture. Table 3-1, Table 3-2, Table 3-3, and Table 3-4 show the chemical and physical specifications of the cement used in the concrete mix production, all of which conform to the Iraqi specification (IQS 5, 1984). All test results are according to the quality certificate of the Kar-Najaf Cement Production Factory.

Table 3-1: Test results of cement soundness.

The test name	The test result	IQS 5/2019 Requirements
Soundness Expansion (Le Chatelier)	0.5mm	10 mm (maximum)
Finenesss by Blaine	3350 cm^2/g	2800 cm^2/g (minmum)

Table 3-2: Test results of cement compressive strength.

The age	The test result	IQS 5/2019 Requirements
2 days	26.9 MPa	20.0 MPa (minmum)
28 days	47.7 MPa	42.5 MPa (minmum)

Table 3-3: Chemical properties of Portland cement

Chemical compound name	Chemical label	Actual content ratio %	IQS 5/2019 Requirements
Silicon Dioxide	SiO_2	19.76	
Aluminum Trioxide	Al_2O_3	4.62	
Ferric Oxide	Fe_2O_3	4.34	
Calcium Oxide	CaO	61.46	
Magnesium Oxide	MgO	3.29	5% (maximum)
Potassium Oxide	K_2O	0.52	/
Sodium Oxide	Na_2O	0.54	/
Sulfate	SO_3	2.43	2.8% maximum (if C3A≥ 3.5)
Chloride	Cl^-	0.027	0.1% (maximum)
Loss On Ignition	LOI	1.62	4.0% (maximum)
Insoluble Residue	IR	0.36	1.5% (maximum)
Lime Saturation Factor	LSF	93.65	
Tricalcium Silicate	C_3S	55.76	54.1 %

Dicalcim Silicate	C_2S	14.62	16.6 %
Tricalcium Aluminates	C_3A	4.9	10.8 %
Tertecalcium Aluminoferrate	C_4AF	13.19	9.1 %
Alkalis Equivalent	AE	0.89	

Table 3-4: Test results of cement setting time

Time	**The test result**	**IQS 5/2019 Requirements**
Initial Time	165 Minutes	45 Minutes (minmum)
Final Time	221 Minutes	600 Minutes (maximum)

3.2.2 Fine aggregate

The fine aggregate used in the concrete mix with a size of 4.75mm was from the local quarries. The specifications of the gradation and the proportion of harmful and soft materials are reported in Table 3-5 and Table 3-6, respectively; all results are according to the Iraqi specification (IQS 45, 1984). Gradient tests and the proportion of harmful and soft substances were conducted in the Karbala Constructional Laboratory.

Table 3-5: Sieve gradient for fine aggregate.

Sieve size (mm)	**% of passing**	**Specification limits %**
10	100	100
4.75	99	90-100
2.36	84	75-100
1.18	70	55-90
0.6	59	35-59
0.3	34	8-30
0.15	9	0.0-10

Table 3-6: The content of harmful material in the sand

Test name	Test result	Specification limits%
% of passing material from the sieve number 200mm	3.5	Maximum: 5%
The % content of sulfur salts	0.104	Maximum: 0.5%

3.2.3 Coarse aggregate

The coarse black aggregate used in the concrete mix with a size of 20mm was from the local quarries. The specifications of the gradation and the proportion of harmful and soft materials are reported in Table 3-7 and Table 3-8, respectively. All the results agreed with the Iraqi specification (IQS 45, 1984). Coarse aggregate tests were conducted by Karbala constructional Laboratory.

Table 3-7: Gradation of coarse aggregate.

Sieve size (mm)	% of passing	Specification limits%
37.5	100	100
20	99	95-100
10	44	30-60
5	4	0-10
Specific gravity	2.65	/

Table 3-8: The content of harmful material in coarse aggregat.

Test name	Test result	Specification limits%
% of passing material from the sieve number 200mm	0.19	Maximum: 3%
The % content of sulfur salts (SO_3)	0.037	Maximum: 0.1

3.2.4 Internal reinforcement

The steel used for internal reinforcement purposes was of Turkish origin (Grade 60) with a diameter of 8mm. The mechanical properties were tested at the laboratory of the University of Kerbala, as shown in Figure 3-1 and Table 3-9.

Figure 3-1: Steel bars testing a the laboratory of the University of Kerbala.

Table 3-9: Mechanical and geometrical properties of internal reinforcement.

Nominal weight (kg/m)	Nominal diameter (mm)	Actual diameter (mm)	Cross-section area (mm^2)	Yield stress (MPa)	Ultimate stress (MPa)	Elongation %	Nominal length (mm)
0.157	8	7.98	50.3	574.9	668.0	20.7	400

3.2.5 CFRP sheets

CFRP sheets are carbon fibers reinforced polymer matrix (Table 3-10) used for external laminating existing concrete structures. It consists of unidirectional woven black carbon yarn and white thermoplastic fibers in a weft direction, as shown in Figure 3-2, and epoxy resin as a binder (consisting of mixing two parts, the ratio between them 4:1).

Table 3-10: General properties of CFRP matrix.

Properties of Carbon fiber according to the product data sheet (Appendix B, page 1)	**Amount**	**Properties of Epoxy resin according to the product data sheet (Appendix B, page 5)**	**Amount**
Thickness (mm)	0.167	Compressive strength (MPa)	82
Tensile strength (MPa)	3500	Tensile strength (MPa)	33.8
Modulus of elasticity (MPa)	225000	Flexural strength (MPa)	60.6
Elongation %	1.59%	Modulus of elasticity (MPa)	3489

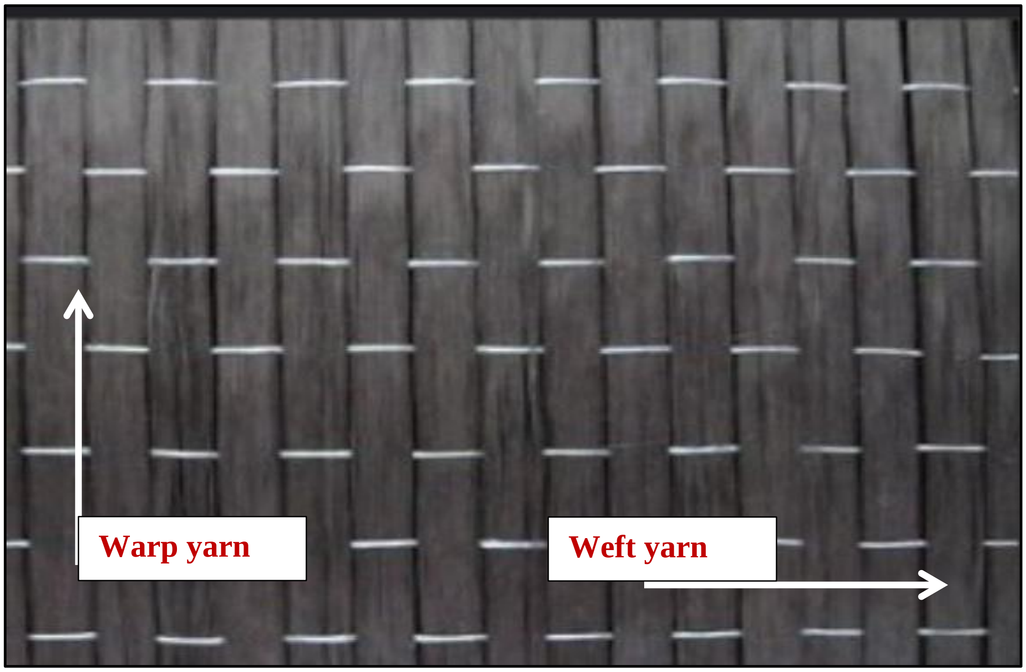


Figure 3-2: CFRP sheets: black carbon fiber in the warp direction and white thermoplastic fibers in the weft direction.

3.2.6 TRM layers

TRM layers are a composite material consisting of a carbon textile submerged between two layers of cement mortar, used for external strengthening. The textile consists of warp and weft orthogonal carbon yarns. The warp yarn is 24000 filaments (12K × 2), and the weft is 24000 (24K) filaments per tow. Filaments are in diameters between 5–8 micrometers, as shown in Figure 3-3. The mortar is composed of polymer-modified cement mixed with water (in a ratio of 1:4). The epoxy resin was used as a bonding agent between the damaged slab and the TRM matrix.

Table 3-11 shows the properties of the materials used to manufacture and bond the TRM matrix, according to the product data-sheet.

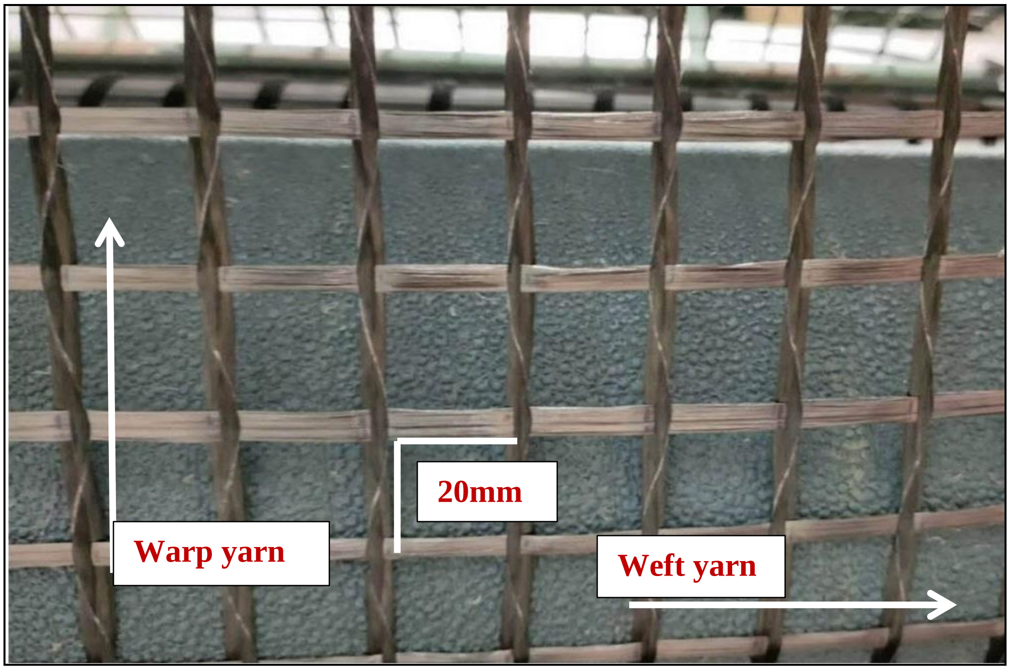


Figure 3-3: Carbon fiber textile consists of warp and weft orthogonal carbon yarns.

Table 3-11: General properties of TRM matrix.

Properties	**Amount**	
Carbon textile according to the manufacturer (Appendix B, page 9)	Weft yarn	Warp yarn
No. of filament	12k x 2	24k
Mash size (mm)	20	20
Weight (g/m^2)	160	
Tensile strength (MPa)	≥ 3000	
Modulus of Elasticity (MPa)	≥ 240000	
Elongation %	2	
Cement mortar according to the manufacturer (Appendix B, page 10)		
Compressive strength	75 N/mm^2 at 28days	
Bond strength	> 2 N/mm^2	
Flexural strength	11 N/mm^2	
Tensile strength	6 N/mm^2	

Bonding agent between the damaged slab and matrix according to the manufacturer (Appendix B, page 13)	
Compressive strength	70 N/mm^2
Bond strength	> 10 N/mm^2

3.3 Structural design of the RC slabs

This section includes: designing the slab specimens mold and calculating the weights of the concrete mixture according to the standard specifications.

3.3.1 Mold design

Ten reinforced concrete slabs are designed according to the yield line method and the ACI requirements (ACI 318R, 2019); see Appendix A. All wooden formwork was executed with internal dimensions of (1050 × 1050 × 70) mm and the same internal reinforcement ϕ8@150 mm. Figure 3-4 and Figure 3-5 show the details of the mold design and slab supported along its four sides, respectively.

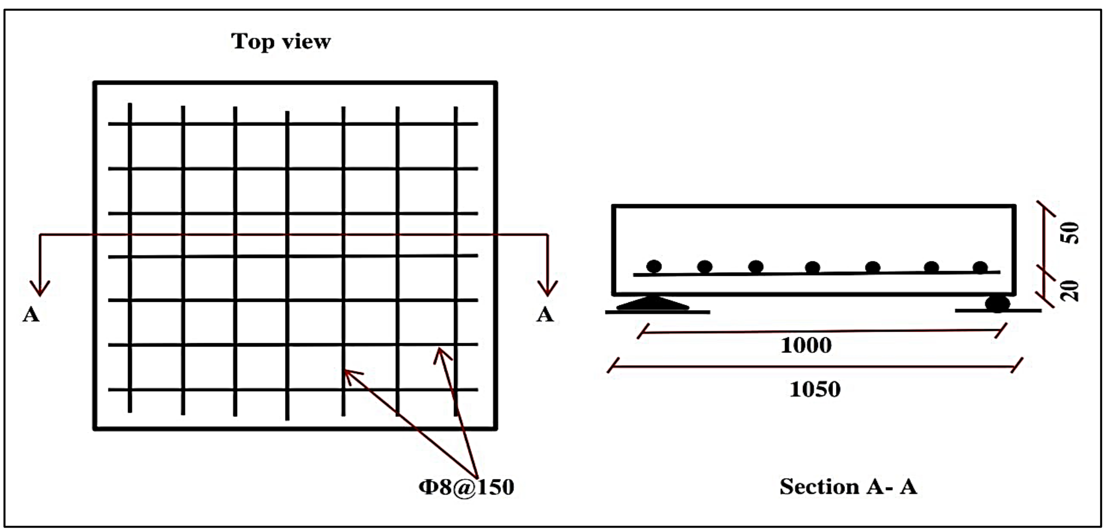


Figure 3-4:Slab geometry and reinforcement details, all dimensions in mm.

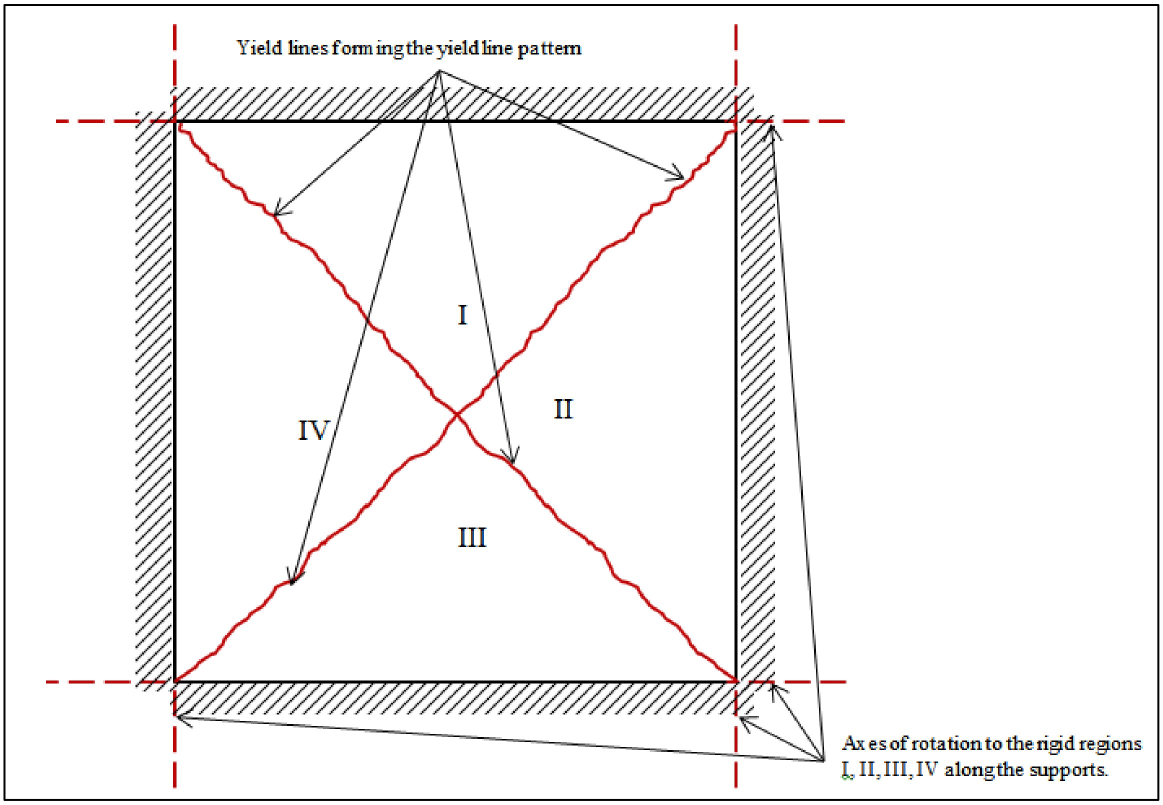


Figure 3-5:Two-way slab with simply supported edges.

3.3.2 Concrete design

Three experimental mixes were examined according to ACI recommendations (ACI 211.1, 1991) to reach the homogeneous mixture to produce a concrete with a target compressive strength of 35 MPa at 28 days. Table 3-12 represents the weights of the concrete mix components. The slabs were cast using the ready-mix prepared by the concrete-mixing plant / Al-Abbas Holy Shrine.; Figure 3-6 shows the steps of pouring the concrete slab.

Table 3-12: Weights of concrete mix components.

Cement	**Sand**	**Gravel**	**Water**
340 kg/m^3	940 kg/m^3	1020 kg/m^3	175 L/m^3

Figure 3-6: Steps for pouring concrete slabs.

3.4 Preparation and testing of slab specimens under monotonic and cyclic compression loads

After 28 days from the casting date, the slabs were painted with white emulsion and encoded with symbols, as shown in Table 3-13, supported by Figure 3-7. After that, it was divided into three groups:

1- The first group included two slabs: S1 and S2, tested under two loading types (monotonic and repeated) and employed as reference slabs without using external strengthening.

2- The second group included four slabs: S3, S4, S5, and S6, tested under monotonic loading at 50% of the ultimate load. After that, they rehabilitated using one of the repair methods (CFRP sheets and TRM layers). Then it is tested under repeated loading up to failure.

3- The third group included four slabs: S7, S8, S9, and S10, tested under monotonic loading at 75% of the ultimate load. After that, they rehabilitated using one of the repair methods. Then it is tested under repeated loading up to failure.

Table 3-13: Experimental parameters.

Group ID	**G1**		**G2**				**G3**			
Damage ratio	/	/	50% of the ultimate load				75% of the ultimate load			
Type of repair material	/	/	CFRP		TRM		CFRP		TRM	
Slab ID	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Type of scheme	/	/	I	II	I	II	I	II	I	II
Loading type	Monotonic	Repeated								

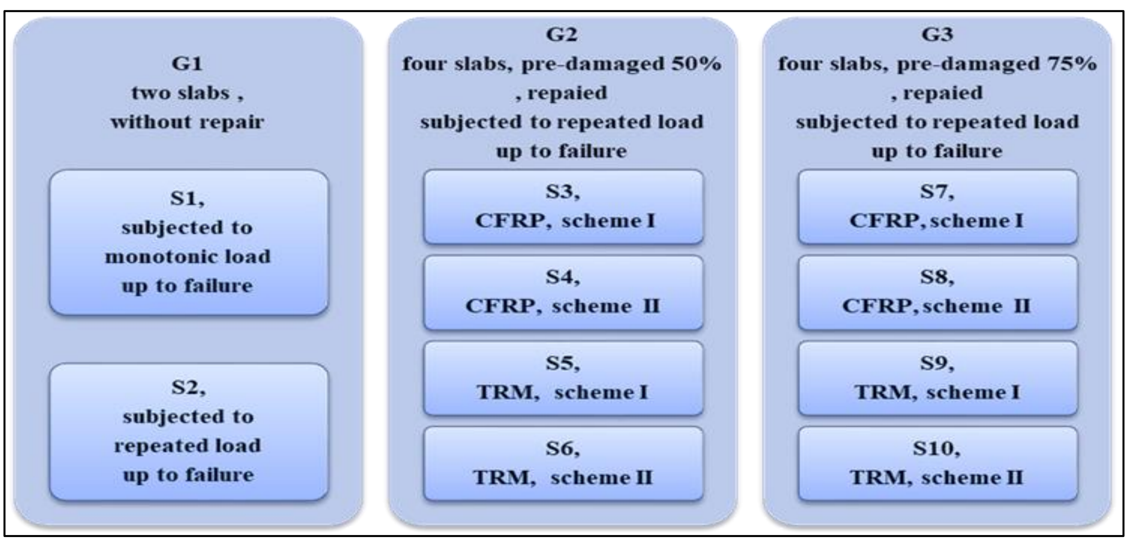


Figure 3-7:Experiment specimens chart.

3.5 Mechanical properties tests

The standard tests (compressive strength, tensile strength, and flexural strength) are employed to define the mechanical properties of concrete. The shapes of specimens used for tests were: (1) cubic to test the compressive strength; (2) cylindrical for splitting tensile strength; (3) prism for flexural strength testing, as shown in Figure 3-8. The following paragraphs describe the dimensions of the test samples and the standard specifications. All tests were conducted at the laboratory of University of Karbala.

3.5.1 Testing of the Compressive Strength

Three concrete cubes dimensioned with (150 ×150 × 150) mm, were modeled to test the compressive strength of concrete according to British specifications (BS12390-3, 2019). The test was carried out using a hydraulic press. The average value of three cubes was adopted at 28 days of age.

3.5.2 Testing of the Splitting Tensile Strength

Three concrete cylinders dimensioned with (150 × 300) mm, were modeled to test the tensile strength of concrete according to ASTM C496 / C496M (2017). The hydraulic press machine was employed to test the splitting tensile strength. The tensile strength testing was done using three cylindrial specimens after 28 days frm the day of casting the RC slabs.

3.5.3 Testing Modulus of Rupture

The prismatic specimens dimensioned with (100 × 100 × 500) mm were employed to test the flexural strength according to ASTM C78M (2021). Three simply supported prisms were tested to determine average flexural strength under three-point loading.

Figure 3-8: Mechanical properties tests : (a)numbers and shapes of specimens, (b)compressive strength, (c) splitting tensile strength, and (d) Modulus of Rupture.

3.6 Testing slabs under monotonic loading

All slabs were subjected to a concentrated load. The load was applied using a press machine (2000kN capacity) vertically attached to the stiff frame. The rate of monotonic load application was 5kN per 5min up to the ultimate load. A linear variable differential transformer (LVDT) was fixed at the bottom of a slab (at the center) to measure the central deflection. A square steel plate of (240 × 240 × 40) mm was used below the loading point to prevent local failure in the compression area. Collecting the applied loads and deflection under the slab was done by the sensitive cells connected to the control computer connected to the LabView software. Figure 3-9 shows the test steps

Figure 3-9: Multiple images represent the test stages of the slab, the steel frame ,the LVDT, and the control computer.

3.7 Testing slabs under repeated loading

Ten two-way RC slab specimens were used to conduct the experimental research. Nine of these slabs were tested under positive cyclic loading based on the result of the reference slab, which was tested monotonically, as shown in Figure 3-10. Guided by the American Concrete Institute code (ACI 437.2, 2013) and practical experience in some periodic loading cases, a cyclic loading history was proposed for specimen testing. The cyclic loading history in Figure 3-11 consists of three stages:

(1) Stage I involves applying 5kN of monotonic load every 5 minutes up to 75% of the ultimate load. (2) Stage II involves applying twenty cycles with amplitude equal to 75% of the ultimate load at a fixed frequency (5 minutes). (3) Stage III involves applying 5kN of monotonic load every 5 minutes up to failure.

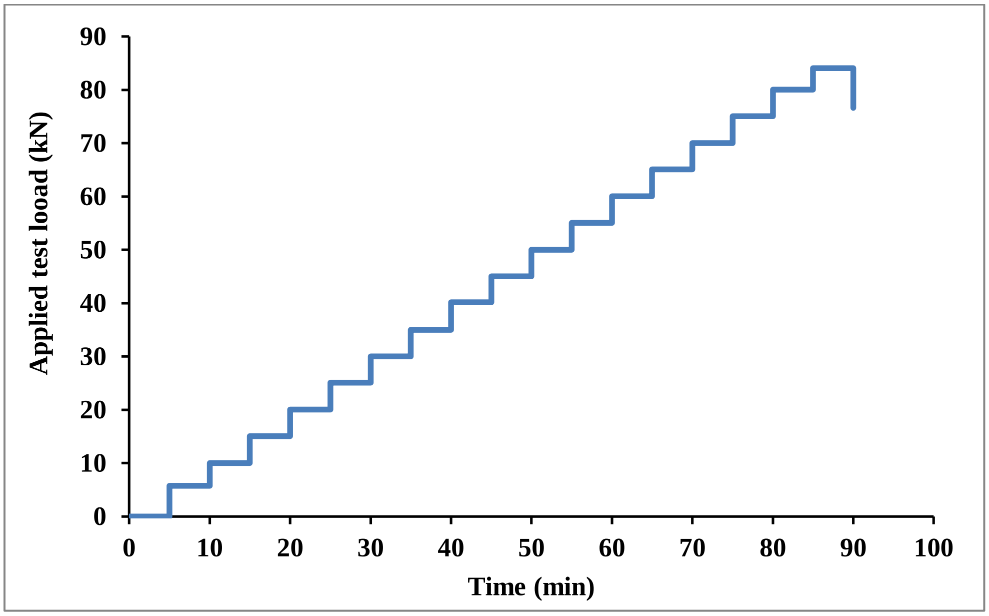


Figure 3-10: Loading history of tested slab under monotonic loading pattern.

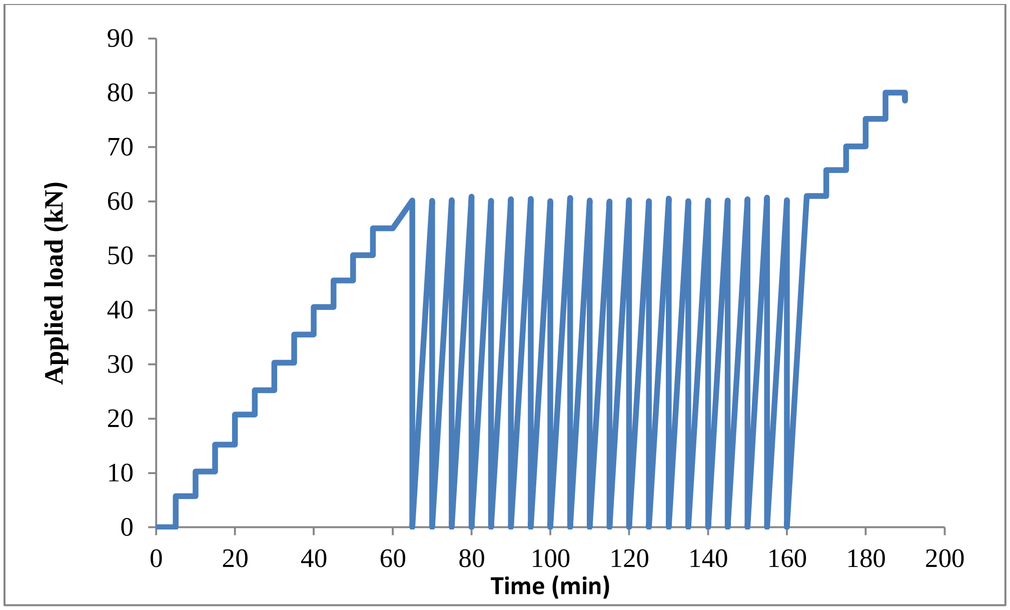


Figure 3-11: Loading history of tested slab under repeated loading pattern.

3.8 External repairing process

The EBRIG method used in the installation of CFRP sheets and TRM layers includes the formation of the groves grid. The repair material (TRM or CFRP) was externally bonded to the bottom of the slabs in an orthogonal and parallel scheme to a space of (1050 × 1050) mm, as shown in Figure 3-12.

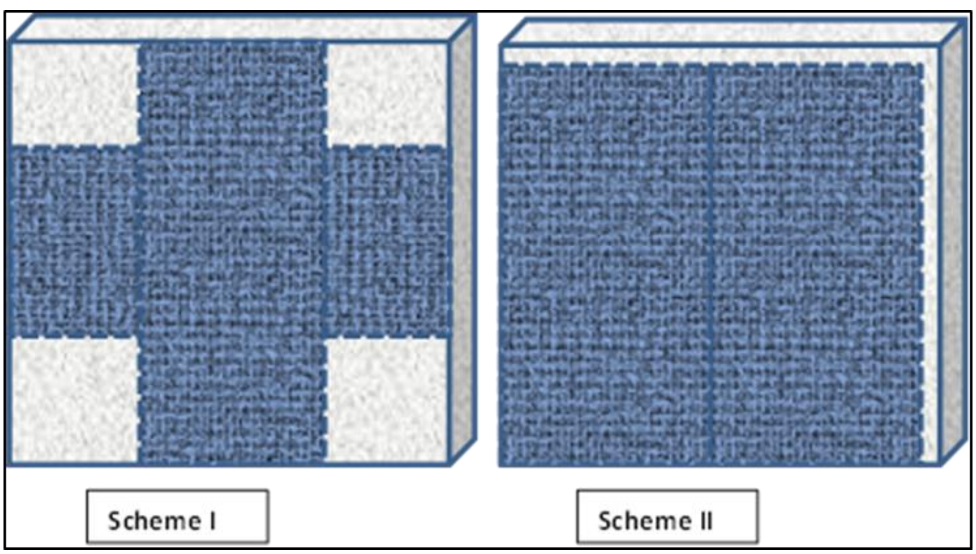


Figure 3-12: Distribution of repairing materials on the tension face of the slab.

3.8.1 Rehabilitation of damaged slabs using CFRP sheets

The CFRP repair material was glued externally to the bottom of the slabs in an orthogonal and parallel pattern to an area of (1050 ×1050) mm. The repairing procedure included the following steps:

(a) before repairing, a thin layer of concrete was removed, and figuration of grid groves with 5 mm depth and 3mm width at the tension face to improve the bond between the damaged slab and repair materials;

(b) application the first layer of epoxy resin using a brush in the quantity of approximately 1.5 kg/m^2;

(c) carefully applying the carbon fiber into epoxy resin to achieve a face free of wrinkles;

(d) finally, application of the second layer of epoxy resin to cover the carbon fiber with the using of a smooth trowel to removed air bubbles between the CFRP sheet and the damaged slab and impregnated carbon fibers with epoxy resin, as shown in Figure 3-13. The details of the orientation of the CFRP sheets on the tension face of the slab are shown in Figure 3-14. After seven days of repairing, the slabs will be ready for testing.

Removing of a light layer of concrete

Groves formation

Application of first layer of epoxy resins and fibers

Application of seconde layer of fibers

Application of seconde layer epoxy resins, scheme I

Application of epoxy resins and fibers,scheme II

Figure 3-13:Application of CFRP sheets at the tensile face of tested slabs.

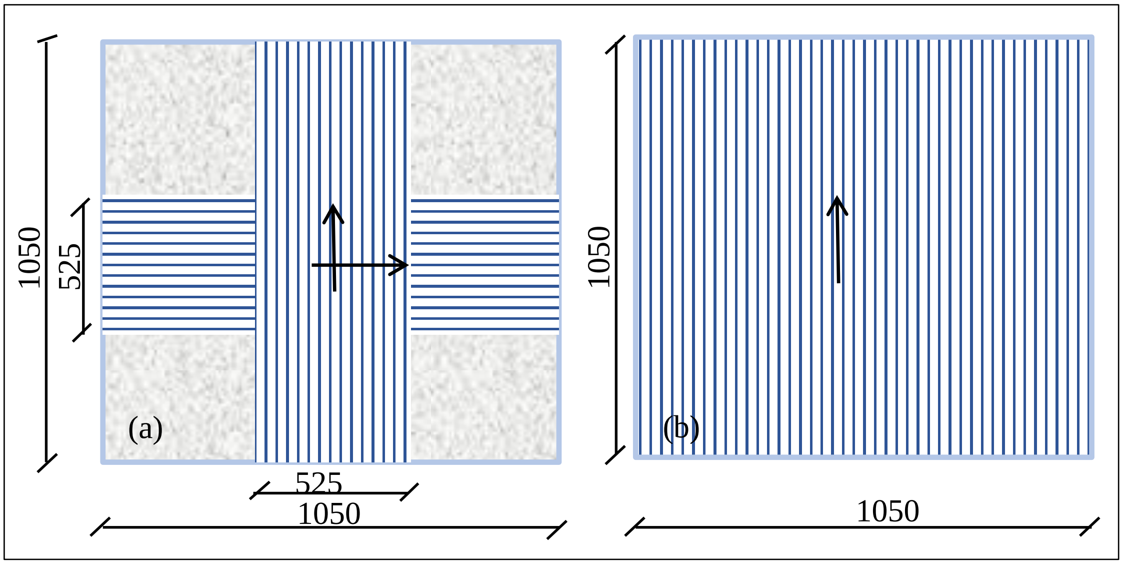


Figure 3-14: Details of the orientation of the CFRP sheets on the tension face of the slab, (a) scheme I, (b) scheme II .

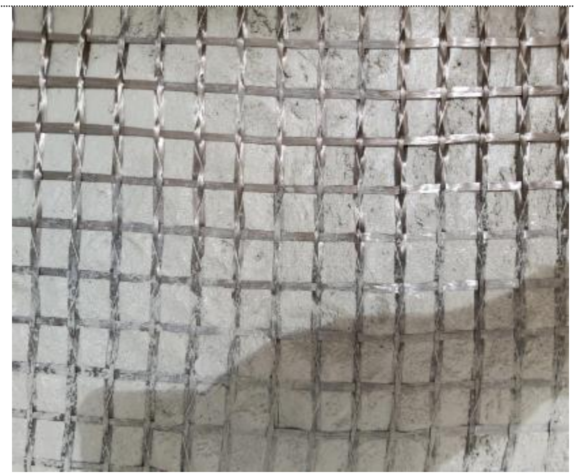
3.8.2 Rehabilitation of damaged slabs using TRM layers

The repair system using TRM consists of two layers of modified cement mortar interspersed with carbon fabric, in addition to the bonding agent between the damaged slab and the TRM matrix. The repairing steps included : (a) scraping a thin layer of concrete (0.5mm thick) and making a grid of grooves 5mm deep and 3 mm wide to receive the bonding material; (b) Applying a layer of adhesive bonding agent in an amount of approximately (0.5-1) mm thick by using a brush to bond the damaged slab with repair materials; (c) after one hour of application of adhesive bonding agent, an initial layer of mortar of 5 mm thick was applied to the surface of the damaged slab by using a hand trowel; (d) application two pieces of textile in an adjacent manner with dimensions (1050 × 1050) mm on the first layer of mortar then pressed by hand to ensure the interlocking of the textile through mortar; (e) brushing of the second layer of mortar with a thickness of 5 mm over the fabric; (f) curing of the TRM matrix with wet burlap for 28 days, then the slab will become ready for testing, as shown in Figure 3-15.

Groves formation

Applying of a layer of bonding agent

Putingt of the first layer of mortar



Putingt of a layers of textile

Putingt of the second layers of mortar

Curing of the TRM matrix with a wet burlap

Figure 3-15: Application of TRM layers at the tensile face of tested slabs.

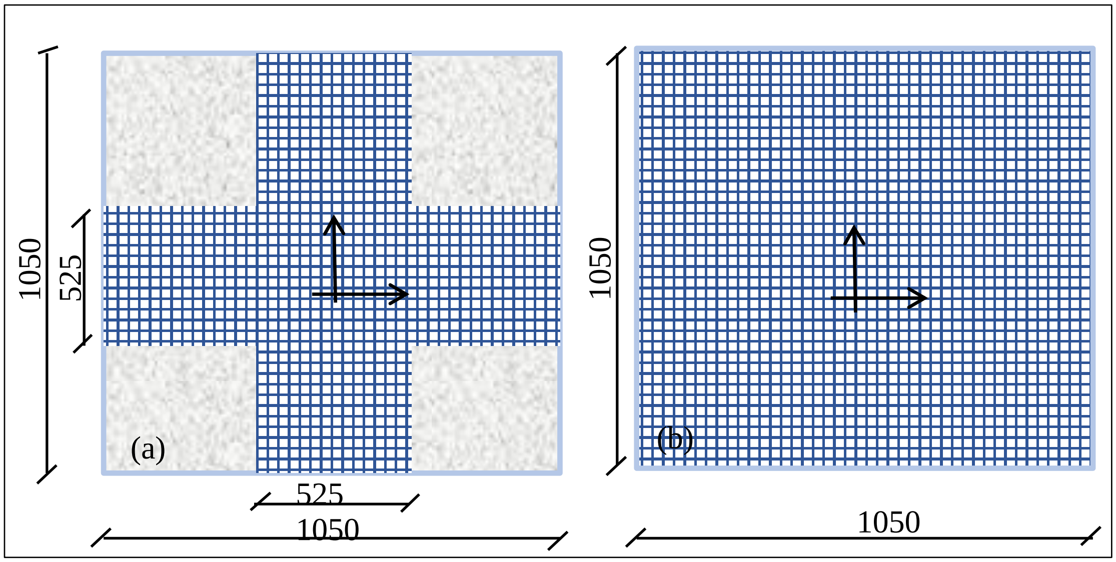


Figure 3-16: Details of the orientation of the TRM layers on the tension face of the slab, (a) scheme I, (b) scheme II .

The details of the orientation of the TRM layers on the tension face of the slab are shown in Figure 3-16.

3.9 Testing of rehabilitated specimens under repeated loading

Testing the eight rehabilitated slabs was under repeated load after the curing period. The loading pattern involved the application of 20 compression cycles (loading and unloading) up to failure. The load and deflection readings at the center of the slab were documented by the electronic software LABVIEW, as will be explained in the next chapter.

Chapter Four Results and Discussion

Chapter Four
Results and Discussion

4.1 Introduction

The principal aim of this study is to examine the efficiency of external reinforcement materials in restoring the original strength of damaged slabs subjected to repeated loads. The experiment parameters used in this study were the nature of the different external strengthening materials (CFRP, TRM), different ratios of slab damage (50%, 75%), and the distribution of the repair materials. The following paragraphs display and discuss the slabs test results: (1) mechanical testing results; (2) experimental results; (3) failure patterns; (4) load-deflection curve; (5) structural properties of rehabilitated slabs; (6) and the role of experiment parameters.

4.2 Mechanical testing results

The results of testing the mechanical properties of concrete were according to the standard specifications. Table 4-1 shows the results of three tests: compressive strength, tensile strength, and flexural strength.

Table 4-1:Mechanical properties of concrete material.

Testing type	Average of three specimens (MPa)
Compressive strength	44.2 (average values from three cubes)
Tensile strength	4.199
Flexural strength	5.044

4.3 Experimental results

The experiment results were collected using the LABVIEW program that gives the relationship between loads and deflections, which includes: (1)

the ultimate load (Pu); (2) maximum deflection at the middle of the slab (δu). The failure pattern was documented by the observed cracks, as shown in Table 4-2.

Table 4-2: Applied loads and deflection.

Slab ID	Loading type	Damaged %	Repair material	Repair scheme	Pu (kN)	δu (mm)	Observed failure
S1	Monotonic	/	/	/	84	34	A
S2	Repeated	/	/	/	80	30	
S3		50	CFRP	I	130	11.5	B
S4				II	113	9.3	
S5			TRM	I	92	27.5	C
S6				II	87	24	
S7		75	CFRP	I	150	17	B
S8				II	131	19.5	
S9			TRM	I	97	17	C
S10				II	94	27	

A: flexural, B: concrete crushing in the compressive zone and fibers rupture, C: Rupture of the carbon textile and formation of flexural cracks in the mortar of the TRM composites.

4.4 Failure patterns

The application of monotonic loads through the bearing plate led to the formation of weak flexural cracks in the middle of slab S1. The increase in applied loads led to the formation of new diagonal flexural cracks which extended to the supports. The flexural failure occurred at 84kN, while the LVDT recorded a deflection of 34mm. The reference slab S2 (tested under repeated load) failed after the development of large flexural cracks in the tension zone and the collapse of the concrete in the compression zone (it was combination of bending and punching shear), as shwon in Figure 4-1and Figure 4-2. The ultimate load and ultimate deflection were 80kN and 30mm, respectively.

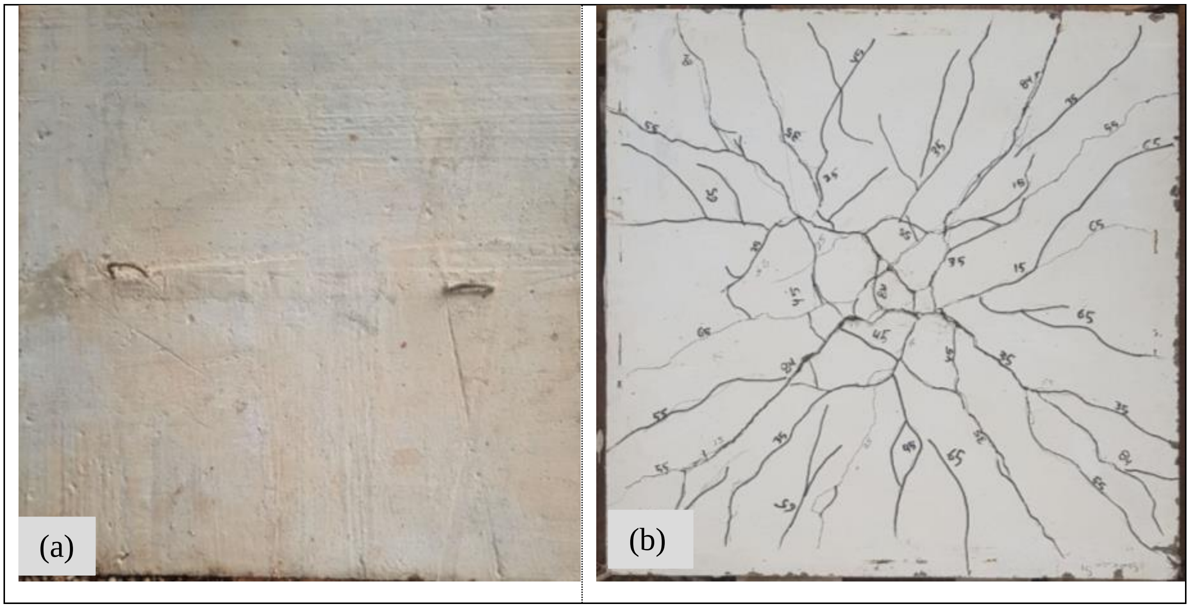


Figure 4-1: Failure pattern of slab S1, (a) tension zone, (b) compression zone.

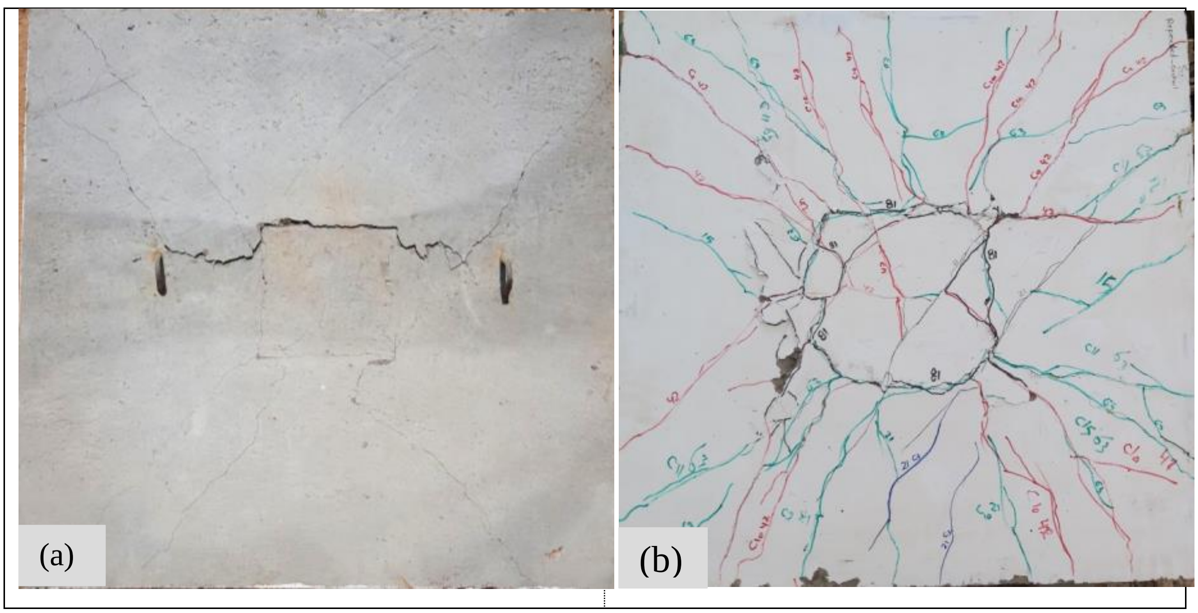


Figure 4-2: Failure pattern of slab S2, (a) collapse of the concrete in the compression zone, (b) combination of flexural and punching shear.

The test method for slabs S3 and S4 included: (1) applying monotonic loads up to 50% of ultimate load (40kN); (2) rehabilitation of the two slabs using two different CFRP sheet distribution schemes (I, II); (3) testing of slabs S3 and S4 under repeated loads until failure. The test methodology of S7 and S8 was the same as S3 and S4 except for changing the ratio of monotonic loads to 75% of ultimate load (equivalent to 60kN). The method of testing and rehabilitation slabs S5, S6, S9, and S10 using the TRM layers was similar to the CFRP sheets.

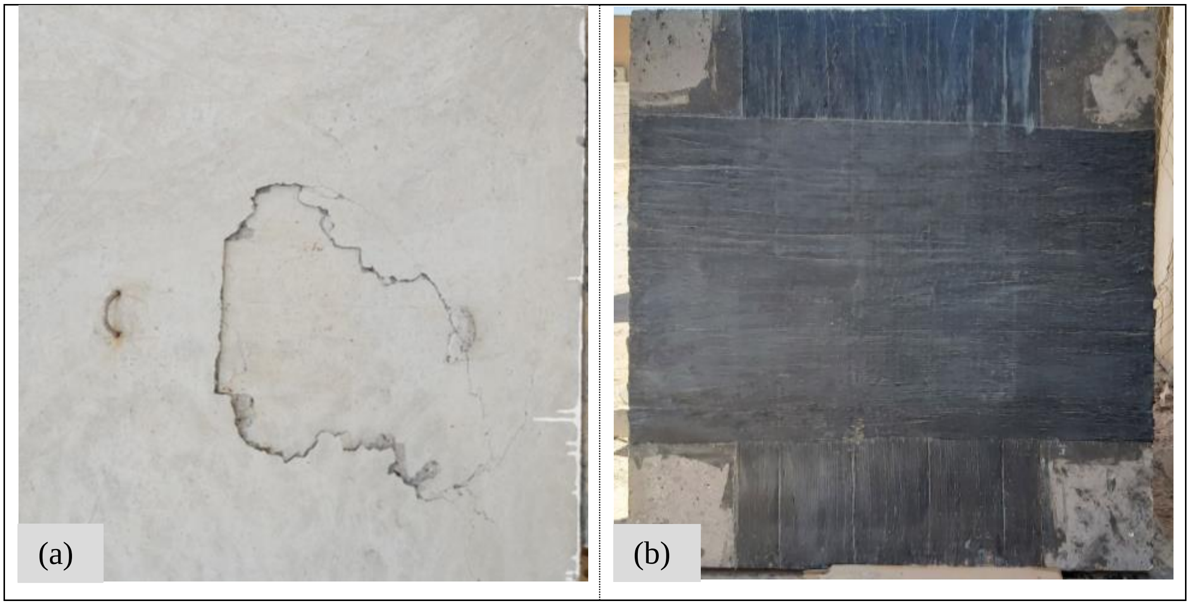


Figure 4-3: Failure pattern in slab S3, (a) tension zone, (b) compression zone.

In all the slabs rehabilitated with CFRP, a sudden failure occurred without giving precedent warnings before the collapse; in the other slabs rehabilitated using TRM, a gradual failure happened, which gave precedent warnings before the failure load. The reason is due to the nature of the bonding materials.The slabs rehabilitated with CFRP sheets failed with ultimate loads higher than the reference slab S2. The maximum recorded load for slabs S3, S4, S7, and S8 was 130, 113, 150, and 131kN, respectively. And the deflection was 11.5, 9.3, 17, and 19.5mm, respectively. The contribution of CFRP sheets in the repairing process led to an increase in the ultimate load by 63%, 41.25%, 88%, and 64%, respectively. The failure pattern was a concrete crushing in the compression zone and a rupture of a small portion of fibers near the supporters in the tension zone (only in slabs S4 and S7), as shown in Figure 4-3, Figure 4-4, Figure 4-5, Figure 4-6 and Figure 4-7.

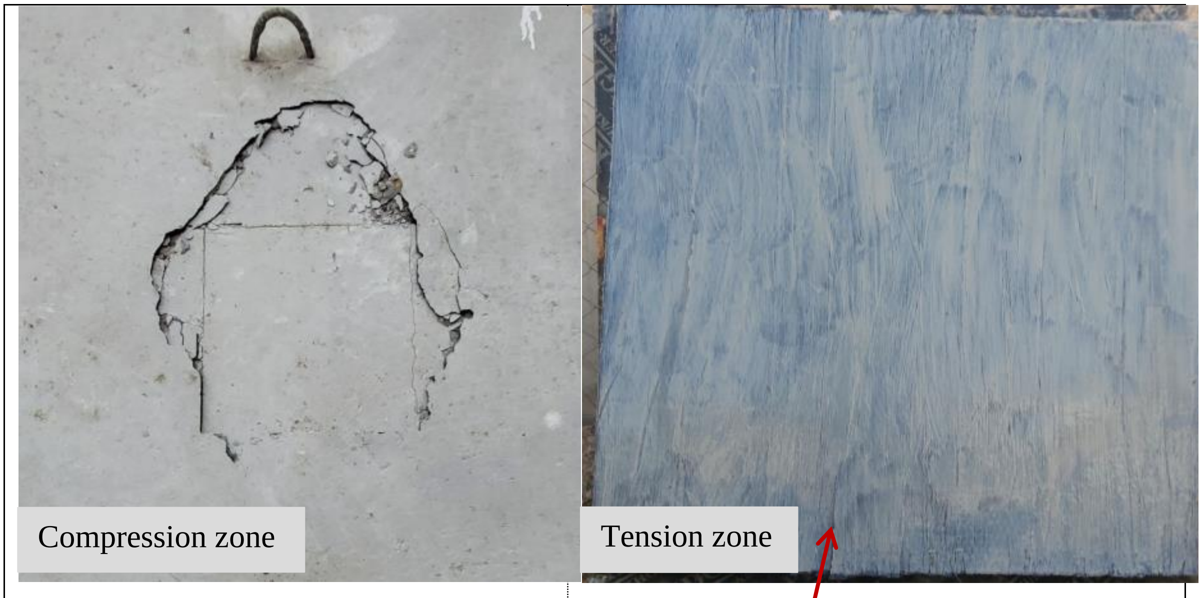


Figure 4-4: Failure pattern in slab S4, concrete crushing in the compression zone and a rupture of a small portion of fibers near the supporters in the tension zone .

Figure 4-5: Rupture of a Small portion of CFRP fibers near the supporters in the tension zone (S4).

Figure 4-6: Compression zone after repeated loading at slabs S7 and S8.

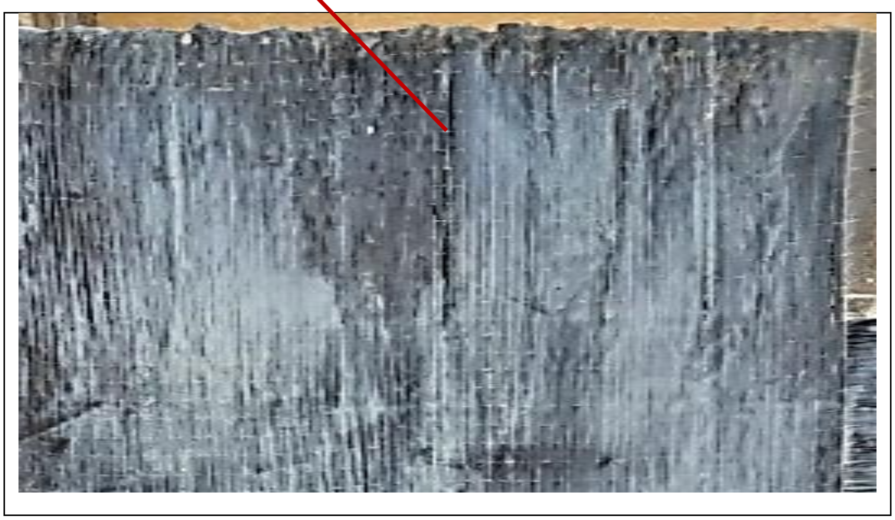


Figure 4-7: Rupture of a Small portion of CFRP fibers near the supporters in the tension zone (S7).

The sabs rehabilitated with TRM layers failed at a load slightly higher than the S2 reference slab load. The recorded ultimate load for slabs S5, S6, S9, and S10 was 92, 87, 97, and 94kN, respectively. And the deflection was 27.5, 24, 17, and 27mm, respectively. Thus, the contribution of TRM layers to the increase in flexural capacity was 15%, 9%, 21.25%, and 18%, respectively. The failure was progressive due to the gradual rupture of the carbon textile and the formation of flexural cracks in the binder of the TRM composites,as shown in Figure 4-8, Figure 4-9, Figure 4-10, Figure 4-11, Figure 4-12, Figure 4-13, Figure 4-14, and Figure 4-15.

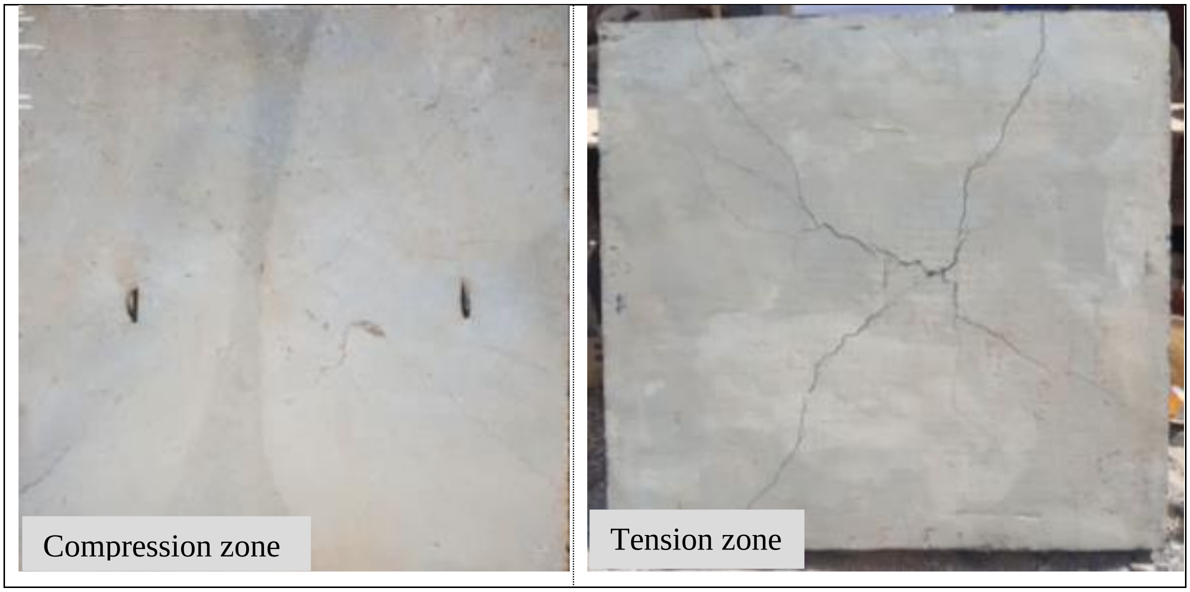


Figure 4-8: Rupture of the carbon textile and formation of flexural cracks in the mortar of the TRM composites (S5).

Figure 4-9: Details of flexural cracks in the mortar of the TRM composites (S5).

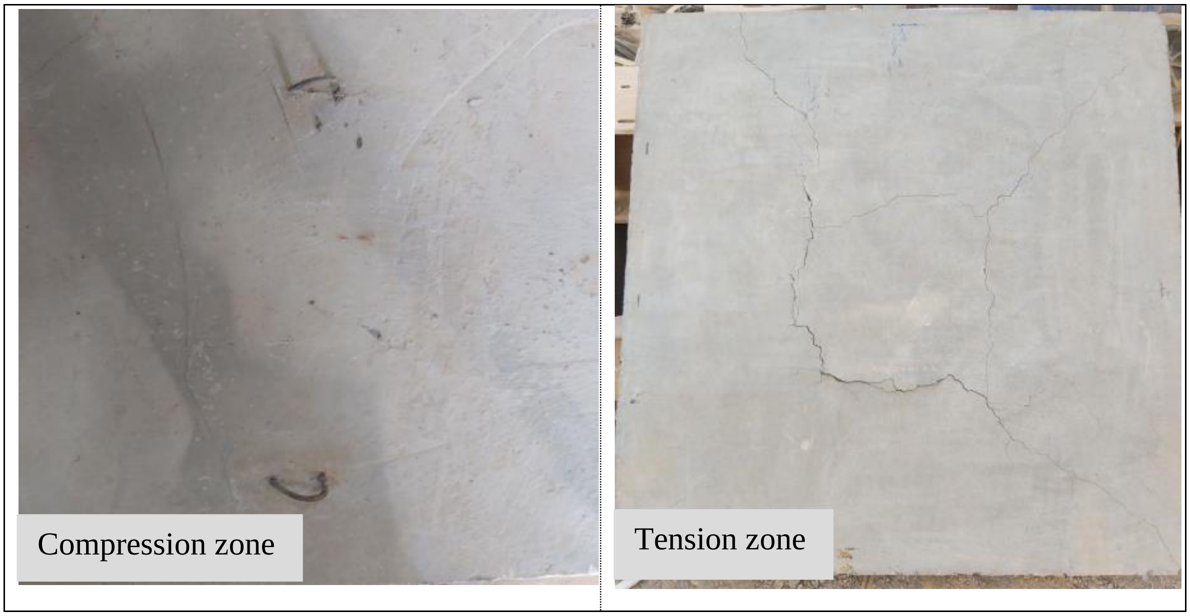


Figure 4-10: Rupture of the carbon textile and formation of flexural cracks in the mortar of the TRM composites (S6).

Figure 4-11: Details of flexural cracks in the mortar of the TRM composites (S6).

Figure 4-12: Rupture of the carbon textile and formation of flexural cracks in the mortar of the TRM composites (S9).

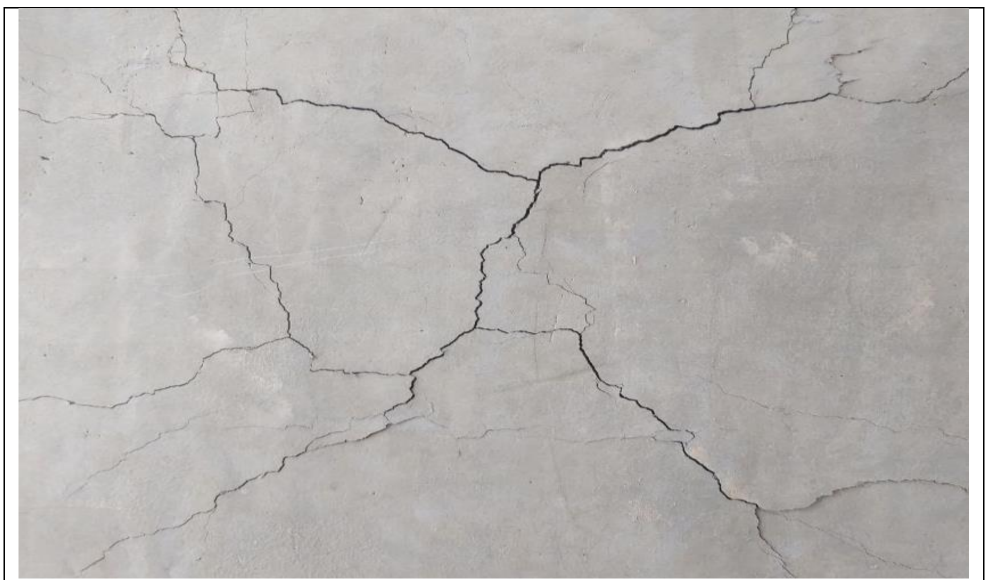


Figure 4-13: Details of flexural cracks in the mortar of the TRM composites (S9).

Figure 4-14: Rupture of the carbon textile and formation of flexural cracks in the mortar of the TRM composites (S10).

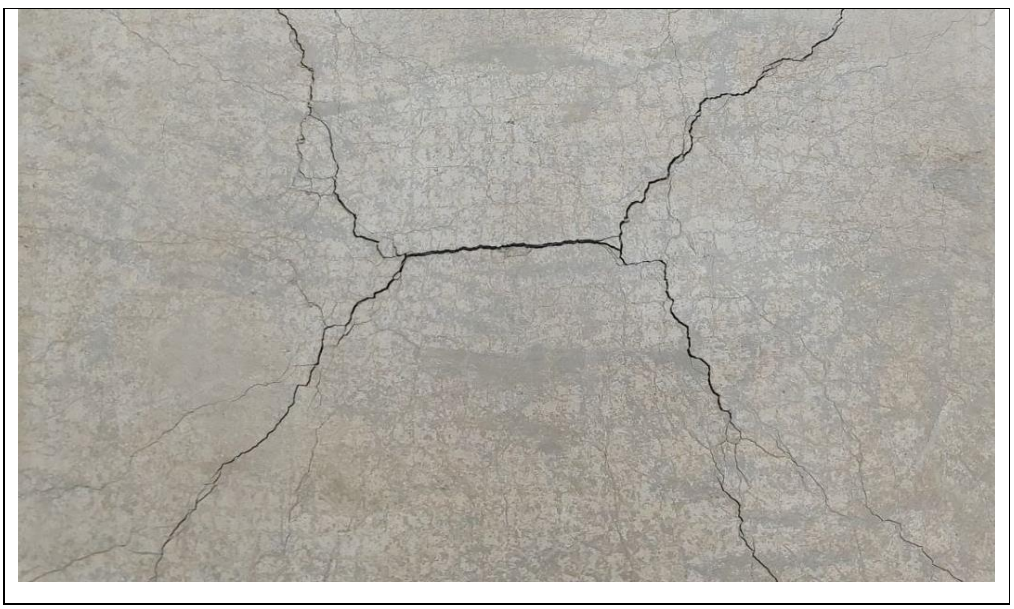


Figure 4-15: Details of flexural cracks in the mortar of the TRM composites (S10).

4.5 Load-deflection curve

The curves of load-deflection are distinguished into four zones: (1) Zone I: starting from the beginning of the loading until the appearance of the first crack, which is the stage of elastic behavior. (2) Zone II: starts from the first crack formation up to the yielding of steel reinforcement; at this zone, flexural cracks begin to appear due to loading and unloading cycles. The mouth of cracks opened during loading and closed in the unloading phase, and with the increase in the number of loading cycles, the cracks developed and remained open. (3) Zone III: the plastic behavior stage; starts from the post-yielding of steel to the ultimate load. At this stage, the cracks spread rapidly from the center of the slab toward the edges. (4) Zone IV: is the last stage; the curve begins to descend due to increasing in the deflection without additional load. Figure 4-16 represents the stages of monotonic and repeated loading. Repeated loading reduced the ultimate load of slab S2 by 5% compared to the corresponding slab S1 under monotonic loading.

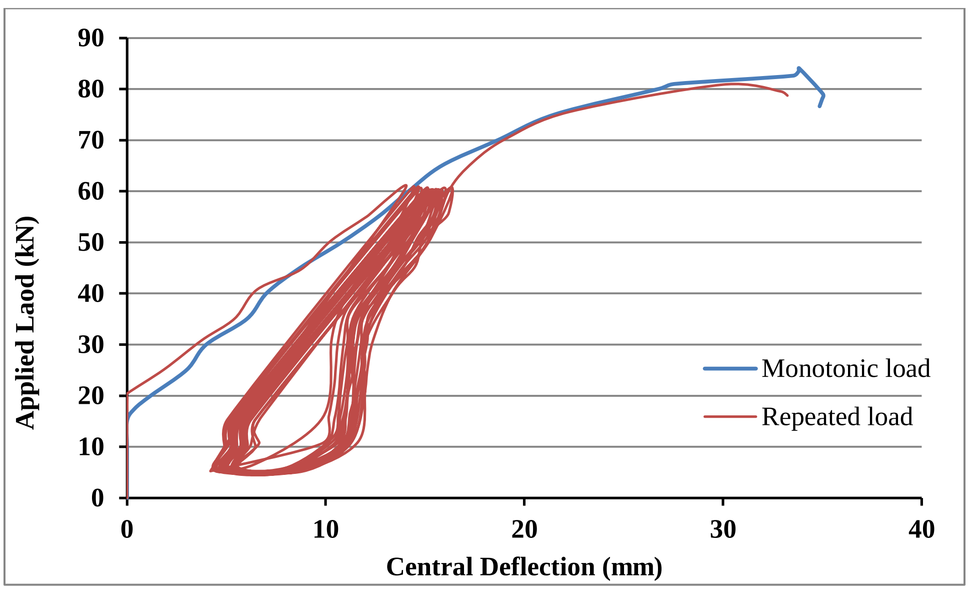


Figure 4-16: Load-deflection curve of monotonic and repeated loading.

Figure 4-17 and Figure 4-18 represents the stages of loading the rehabilitated slab S3 with CFRP sheets (scheme I) after the damage rate of 50%. The initial monotonic load for slab S3 was 40kN, and after being rehabilitated with CFRP sheets, it became 130kN. The increasing rate of loading bearing capacity was 63% compared to the reference slab S2 (without strengthening).

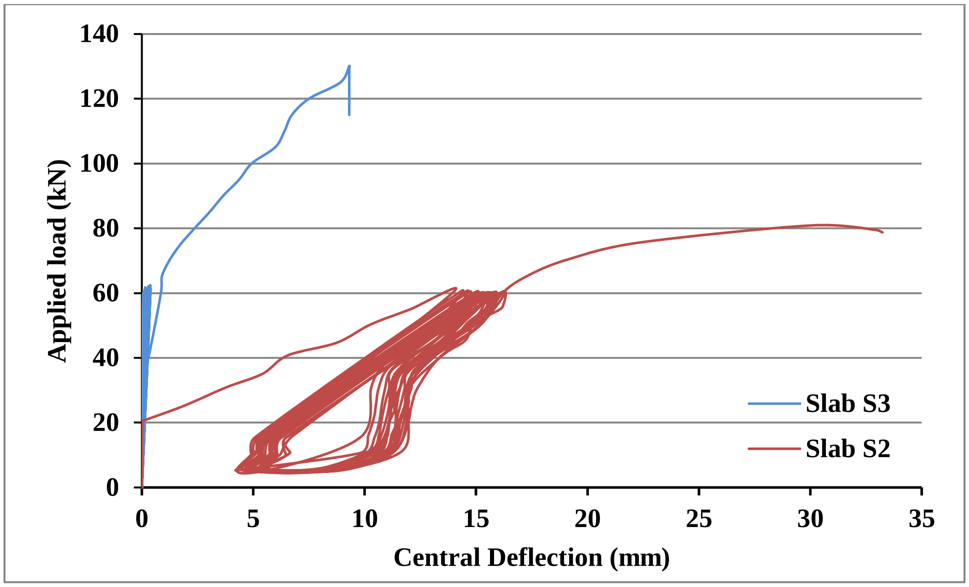


Figure 4-17: Load-deflection curve of slab S3.

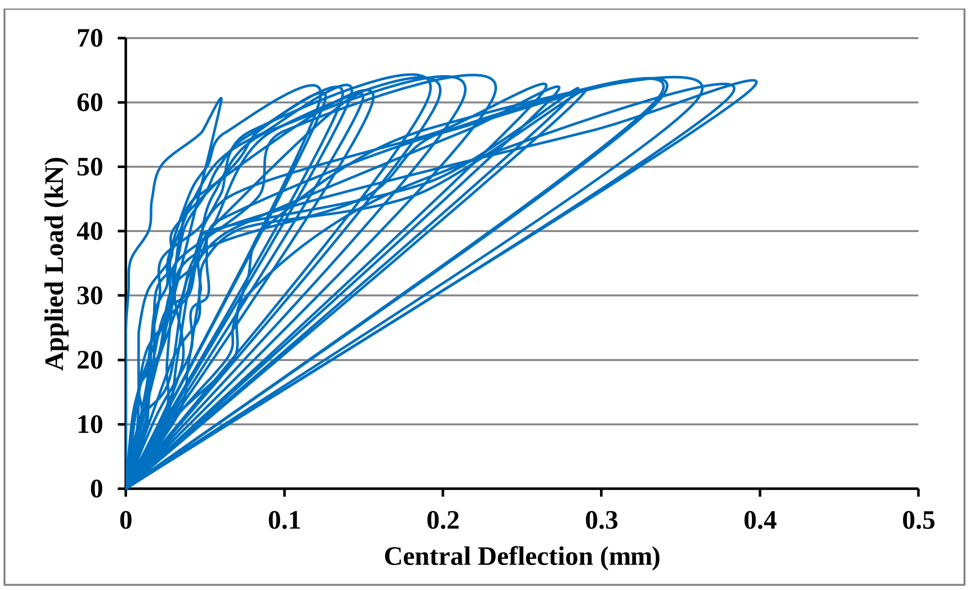


Figure 4-18: Details of applying twenty loading cycles on slab S3.

Figure 4-19 and Figure 4-20 represents the stages of loading the rehabilitated slab S4 with CFRP sheets (scheme II) after the damage rate of 50%. The initial monotonic load for slab S4 was 40kN, then increased by 41.25% (113kN) after being rehabilitated with CFRP sheets compared to the reference slab S2.

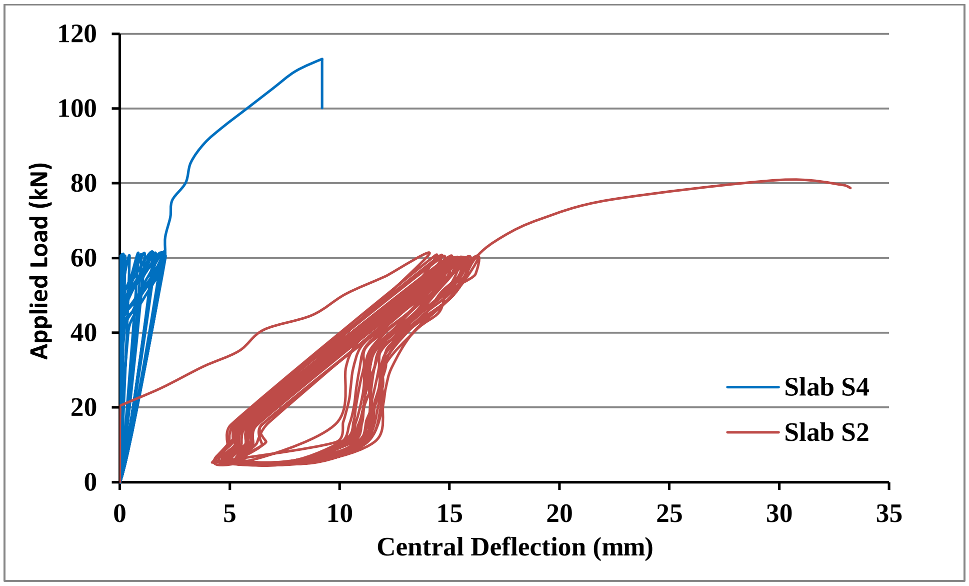


Figure 4-19: Load-deflection curve of slab S4.

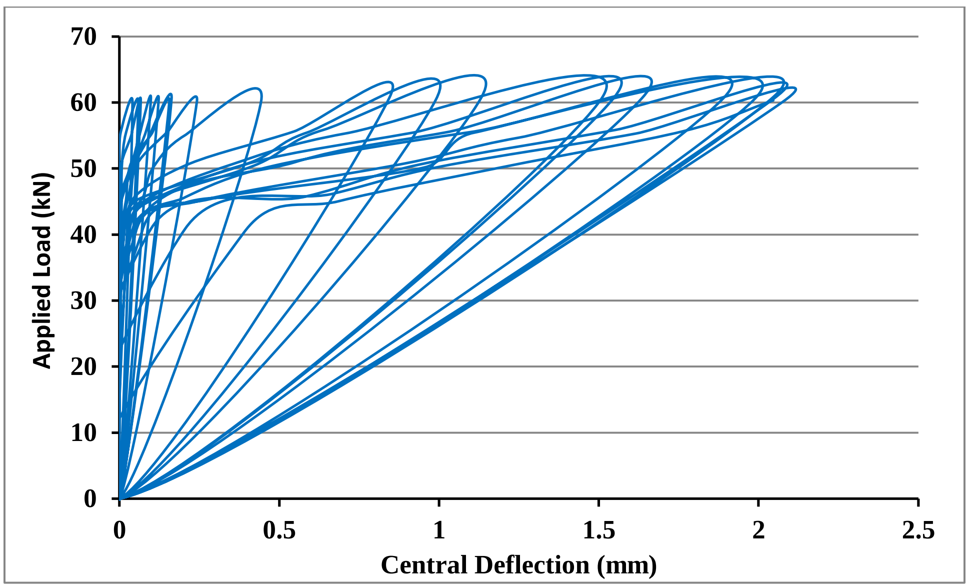


Figure 4-20: Details of applying twenty loading cycles on slab S4.

Figure 4-21and Figure 4-22 represents the stages of loading the rehabilitated slab S7 with CFRP sheets (scheme I). The initial monotonic load for slab S7 was 60kN. Then, after repairing became 150kN. The increase in bearing capacity was 88% compared with corresponding slab S2.

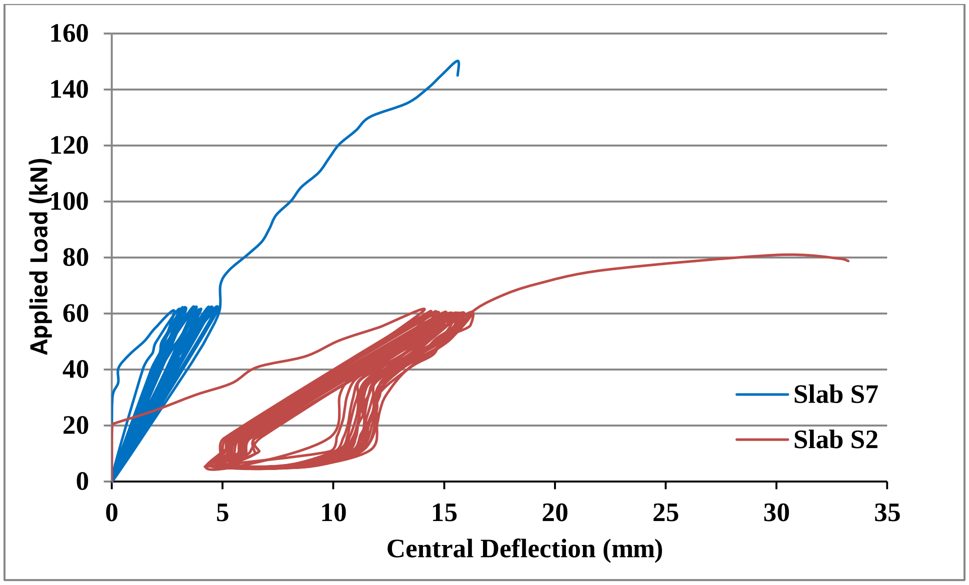


Figure 4-21: Load-deflection curve of slab S7.

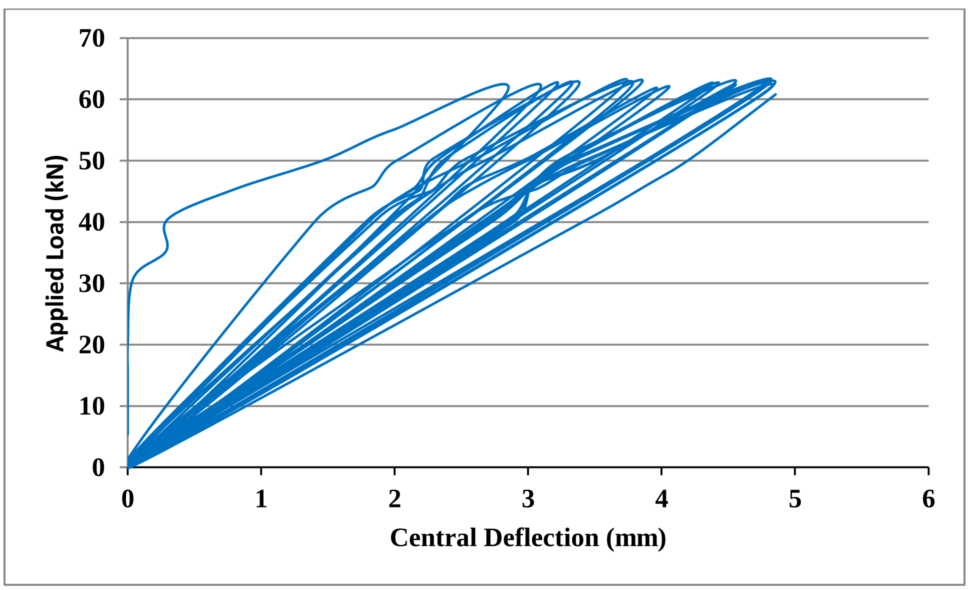


Figure 4-22: Details of applying twenty loading cycles on slab S7.

Figure 4-23 and Figure 4-24 represents the stages of loading the rehabilitated slab S8 with CFRP sheets (scheme II) after the damage rate of 75%. The initial monotonic load for slab S8 was 60kN, then increased by 64% (131kN) after being rehabilitated with CFRP sheets compared to the reference slab S2.

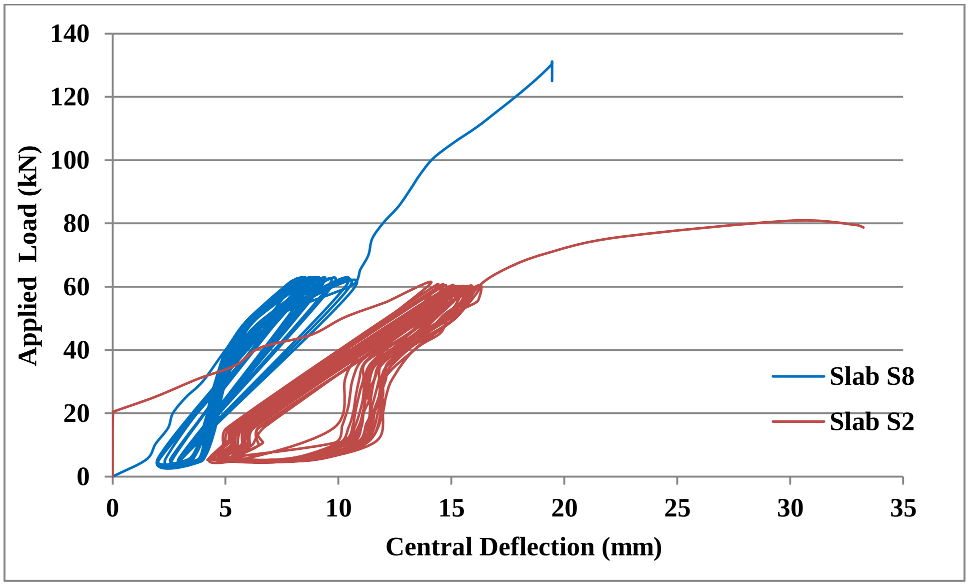


Figure 4-23: Load-deflection curve of slab S8.

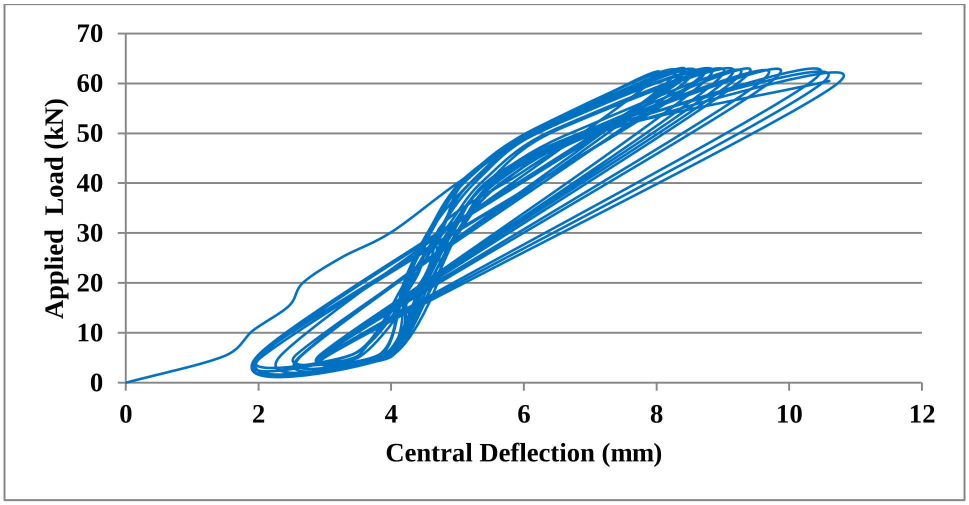


Figure 4-24: Details of applying twenty loading cycles on slab S8.

Figure 4-25and Figure 4-26 represents the stages of loading the rehabilitated slab S5 with TRM layers (scheme I) after the damage rate of 50%. The initial monotonic load for slab S5 was 40kN. Then, after being rehabilitated with TRM layers, it became 92kN. The increase in bearing capacity was 15% compared with corresponding slab S2.

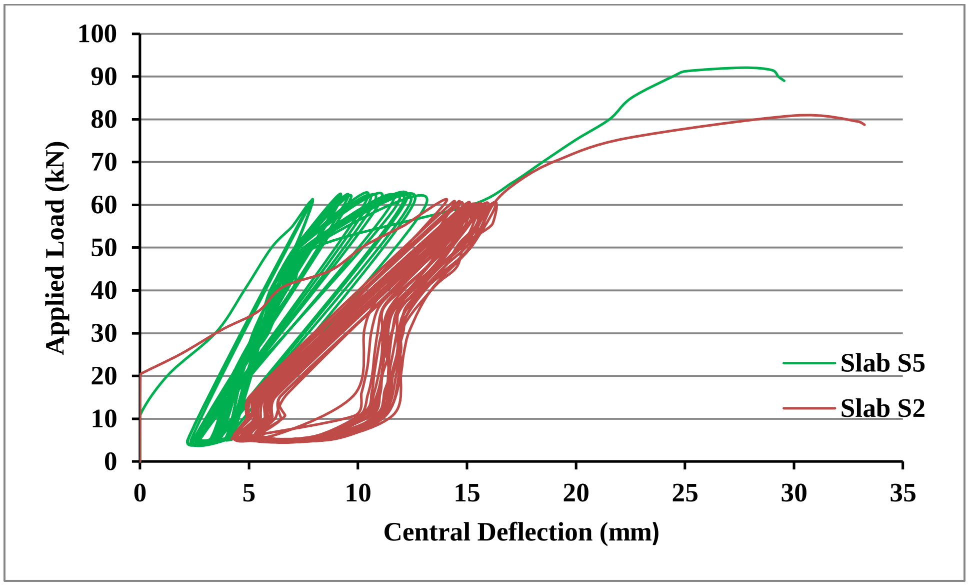


Figure 4-25: Load-deflection curve of slab S5.

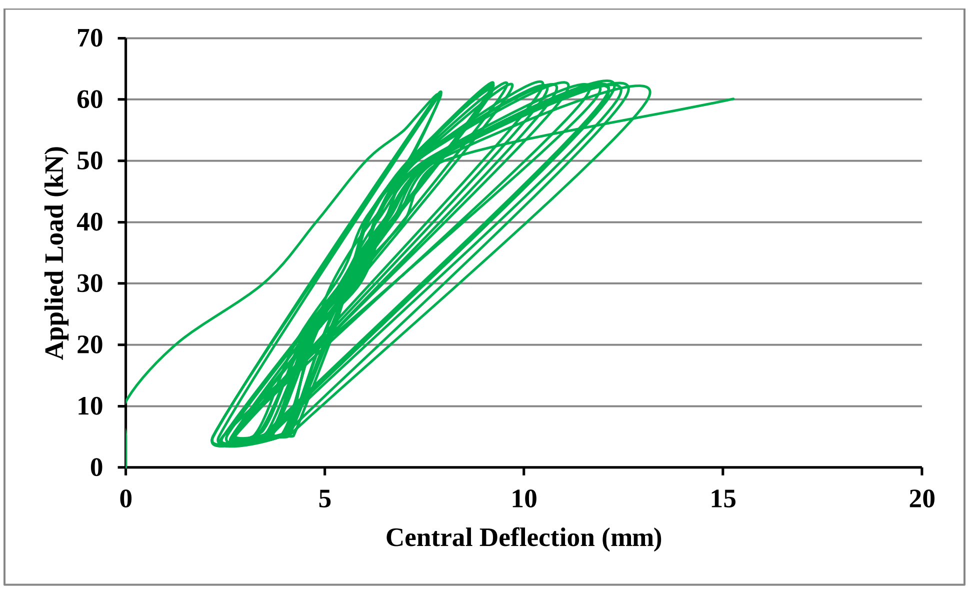


Figure 4-26: Details of applying twenty loading cycles on slab S5.

Figure 4-27and Figure 4-28 represents the stages of loading the rehabilitated slab S6 with TRM layers (scheme II) after the damage rate of 50%. The initial monotonic load for slab S6 was 40kN, then increased by 9% (87kN) after being rehabilitated with TRM layers compared to the reference slab S2.

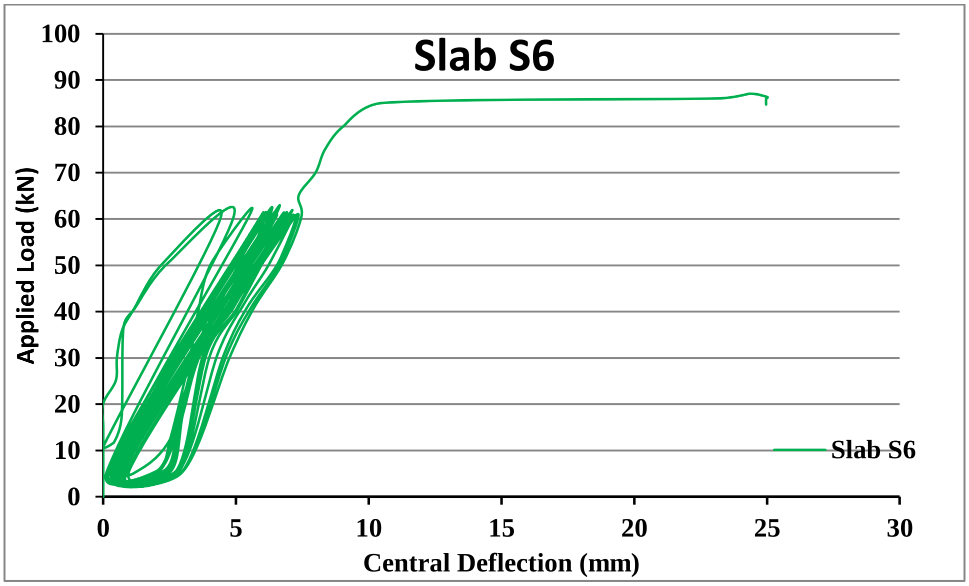


Figure 4-27: Load-deflection curve of slab S6.

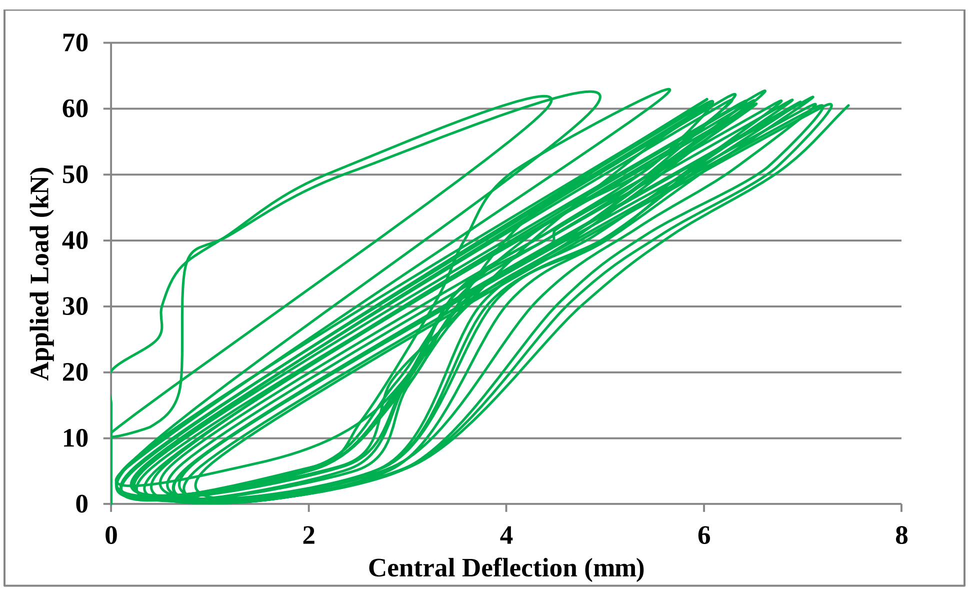


Figure 4-28: Details of applying twenty loading cycles on slab S6.

Figure 4-29 and Figure 4-30 represents the stages of loading the rehabilitated slab S9 with TRM layers (scheme I) after the damage rate of 75%. The initial monotonic load for slab S9 was 60kN. Then, after being rehabilitated with TRM layers, it became 97kN. The increase in bearing capacity was 21.25% compared with corresponding slab S2.

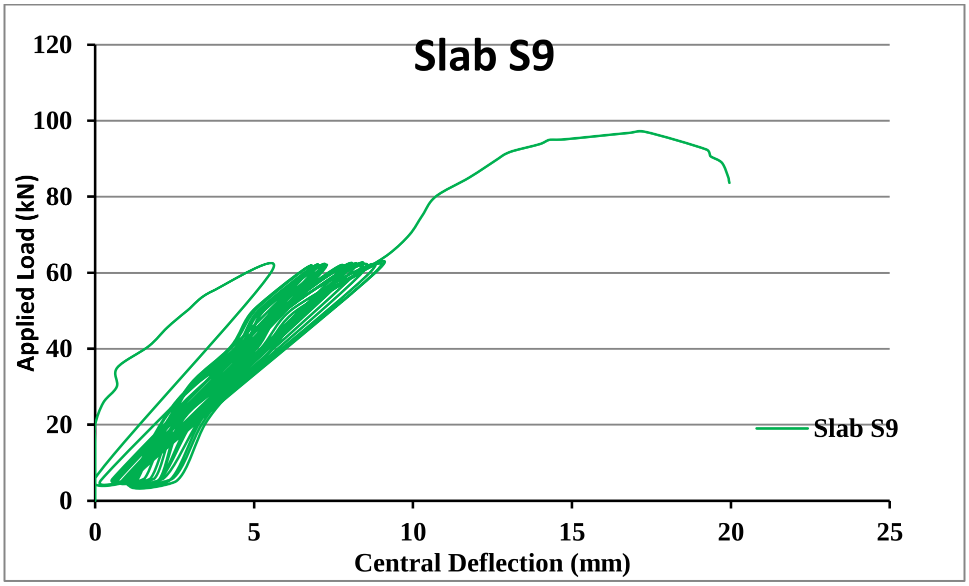


Figure 4-29: Load-deflection curve of slab S9.

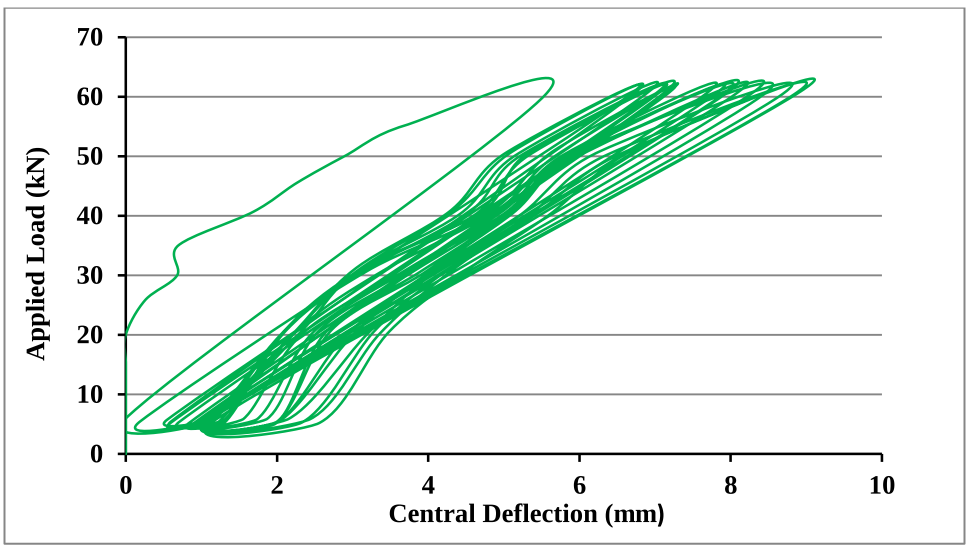


Figure 4-30: Details of applying twenty loading cycles on slab S9.

Figure 4-31and Figure 4-32 represents the stages of loading the rehabilitated slab S10 with TRM layers (scheme II) after the damage rate of 75%. The initial monotonic load for Slab S10 was 60kN. Then, after being rehabilitated with TRM layers, it became 94kN. The increase in bearing capacity was 18% compared with corresponding slab S2.

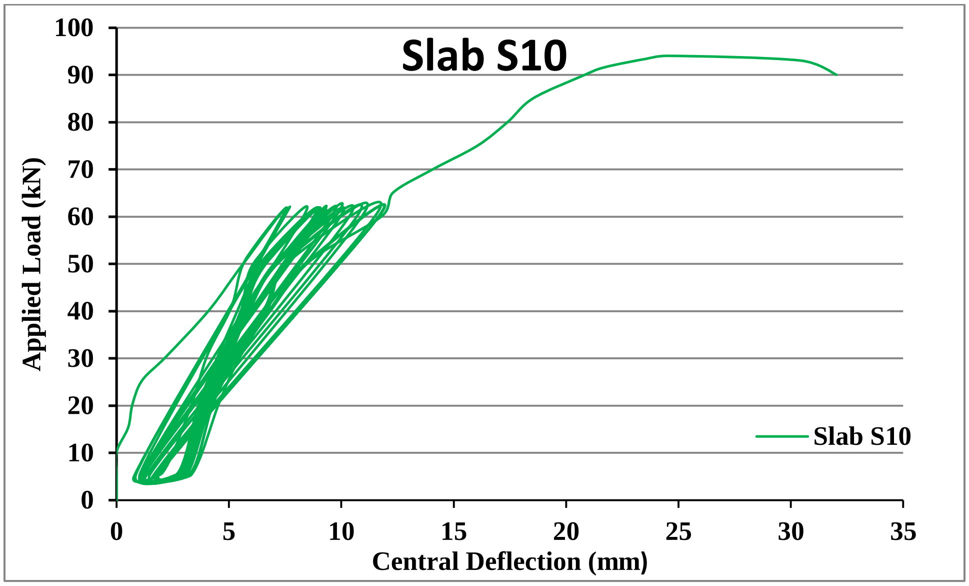


Figure 4-31: Load-deflection curve of slab S10.

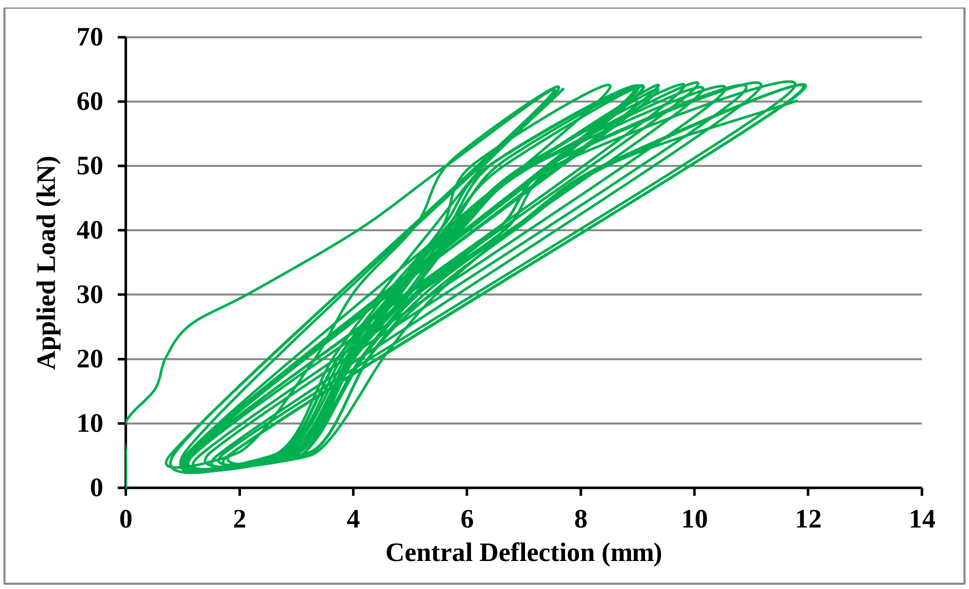


Figure 4-32: Details of applying twenty loading cycles on slab S10.

4.6 Structural properties of rehabilitated slabs

The stiffness of the rehabilitated slabs and the toughness were calculated from the load-deflection curve. Table 4-3 illustrates the test results analysis. The stiffness was calculated from the tangent of the curve. The toughness was calculated from the area under the curve. As shown in Table 4-3, the application of repair materials (CFRP or TRM) enhanced the structural properties of rehabilitated slabs compared to the reference slab S2. The rehabilitation process was sensitive to the examined parameters, such as the type of repair material, the slab damage rate, and the repairing configuration.

Table 4-3: The structural behavior of the tested slabs.

Slab ID	Stiffness (kN/mm)	% of increase in stiffness	Toughness (kN.mm)	% of increase in toughness
S2	3.5623	/	1805.389	/
S3	12.628	776.39	15822.17	254.49
S4	9.8263	1113.17	21902.4	175.84
S5	3.7256	15.133	2078.586	4.58
S6	4.0051	1097.39	21617.62	13.833
S7	9.6641	856.55	17269.41	171.29
S8	7.5534	1325.77	25740.63	112.04
S9	5.3136	434.51	9649.967	49.16
S10	4.0038	82.68	3298.084	12.39

4.6.1 Type of repair material used in the rehabilitation

The results of the experiment indicated the efficiency of the repair materials in increasing the ultimate load and decreasing the ultimate deflection, as shown in Table 4-4, Figure 4-33, and Figure 4-34, respectively.

Table 4-4: Percentage of ultimate load increase and deflection decrease.

Slab ID	**Ultimate load (kN)**	**Ultimate load increase (%)**	**Ultimate deflection (mm)**	**Ultimate deflection decrease (%)**
S1	84	/	34	/
S2	80	/	30	/
S3	130	63	11.5	62
S4	113	41.25	9.3	69
S5	92	15	27.5	8.33
S6	87	9	24	20
S7	150	88	17	43.33
S8	131	64	19.5	35
S9	97	21.25	17	43.33
S10	94	18	27	10

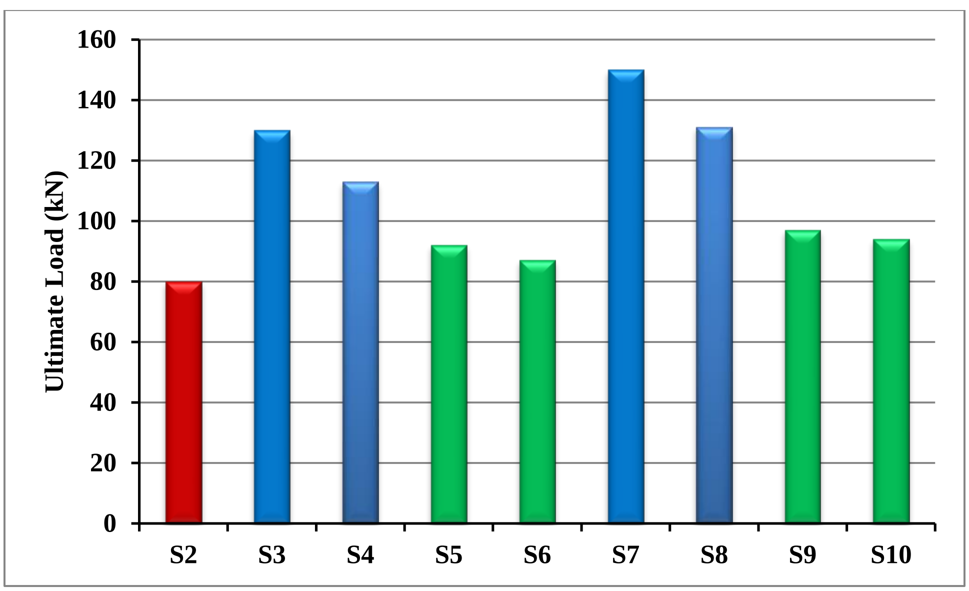


Figure 4-33: Ultimate load for test slabs under repeated loading.

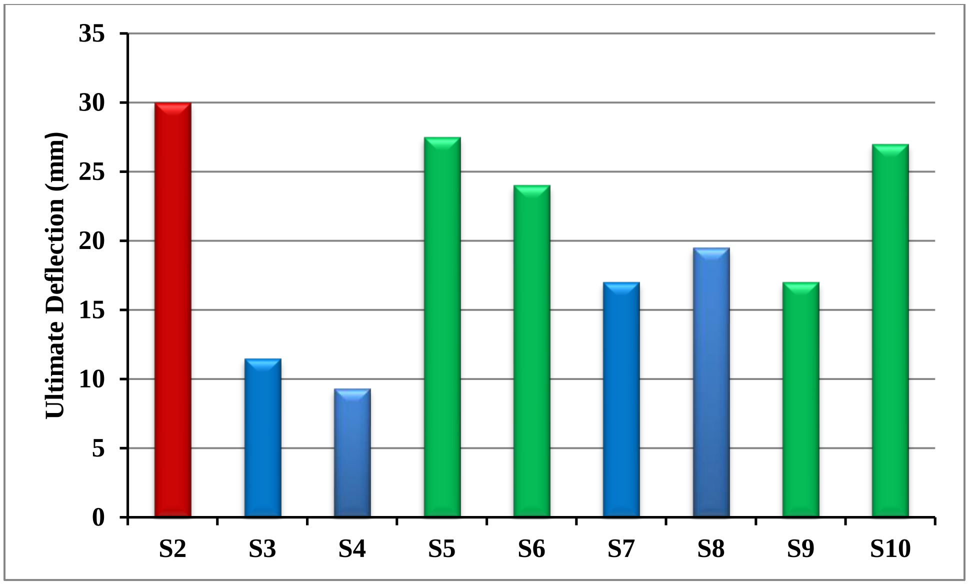


Figure 4-34:Ultimate deflection for test slabs under repeated loading.

The structural behavior of the reference slab S1 was identical to the design, and the slab failed by flexural. The bending cracks formed at the beginning of the loading at the middle of the slab; developed into diagonal cracks after yielding the internal steel rebars and concrete crushing at the compressive zone. The reference slab S2 failed in bending and shear due to concrete collapse after the yielding of the steel rebars. Repeated loading led to the fluctuation of applied pressures and additional damage to concrete.

The rehabilitated slabs with CFRP sheets failed due to the concrete crushing in the compression area and rupturing a small part of carbon fibers near the supporters after yielding the internal steel rebars. The failure occurred at a load level higher than the designed level caused by the contribution of CFRP sheets in strengthening the tensile area. The slab failure was sudden due to the brittle properties of epoxy resin.

The slabs rehabilitated with TRM layers failed at a load slightly higher than reference slab S2. The failure was progressive due to the gradual rupture of the carbon textile and the formation of flexural cracks in the binder of the TRM composites. The nature of the failure is flexible due to the properties of the modified cement used in the preparation of the mortar. The increasing rate of the ultimate load using CFRP sheets and TRM layers was about (41.25- 88)% and (9- 21.25)%, respectively, and associated with decreasing the deflection rate of the rehabilitated slabs using CFRP sheets and TRM layers by about (43.33- 69)% and (8.33- 43.33)%, respectively.

In comparison to the reference slab S2, the application of the CFRP layers increased the toughness and the stiffness by about (776- 1326)%, and (112- 254)%, respectively; As for the application of TRM layers, the above-mentioned structural properties increased by (15- 1097)%, and (4- 49)%, respectively.

Figure 4-35 shows the increase in the stiffness after using external strengthening. The stiffness in rehabilitated slabs S3, S4, S5, S6, S7, S8, S9, and S10 was about 3.56, 12.64, 9.83, 3.73, 4.05, 9.66, 7.55, 5.31, and 4.0kN/mm, respectively, whereas the stiffness of reference slab S2 was 3.56kN/mm. The reason is due to the saturation of the surface of the damaged slab with epoxy resins of a liquid consistency, which helped to close the old cracks and delay the formation of additional ones.

Toughness is a measure of energy absorption; a good balance between strength and flexibility leads to high toughness.The toughness for slabs S3, S4, S5, S6, S7, S8, S9, and S10 was 1805,15822, 21902, 2078, 21617, 17269, 25740, 9650, and 3298kN.mm, respectively, whereas the toughness of slab S2 was 1805kN.mm, as showm in Figure 4-36.

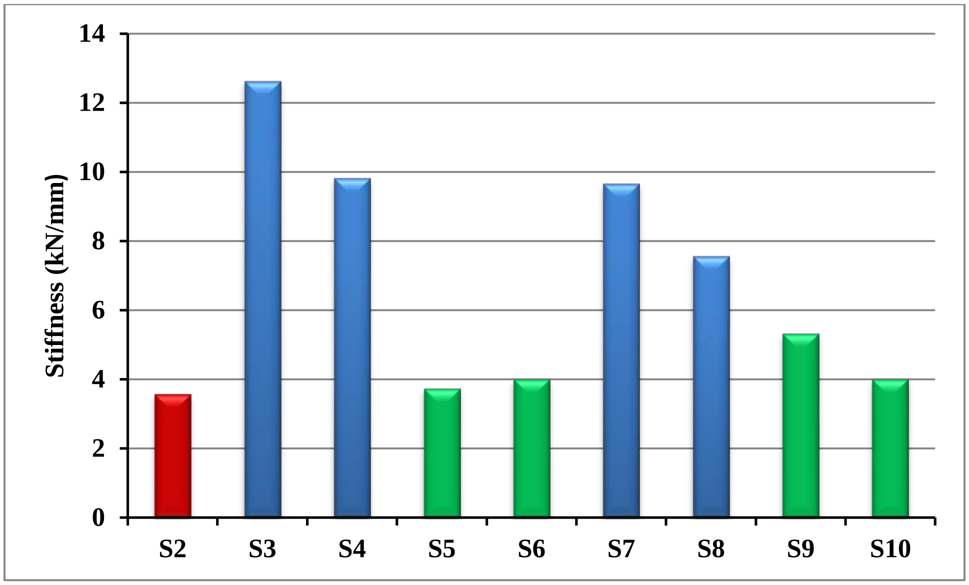


Figure 4-35:Stiffness for test slabs after repeated loading.

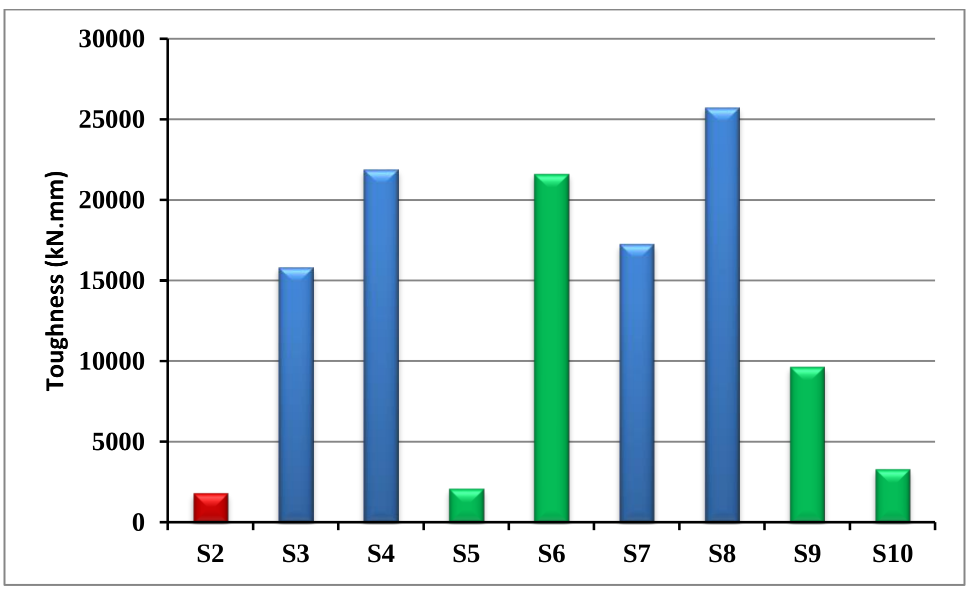


Figure 4-36:Toughenss for test slabs after repeated loading.

4.6.2 Slab damaged ratio

The percentage of slab damage affected the effectiveness of the repair materials. Experimental results showed the efficiency of CFRP sheets and TRM layers in restoring slab strength when the damage percentage was 75%. The reason may be due to the development of bending cracks and the increase in the penetration of strengthening materials through the damaged slab, thus, increasing the contribution of external strengthening in the flexural resistance. When the damage was 50%, the flexural cracks were capillary in the middle of the slab, and the internal rebar did not reach the yielding stage. At this point, the flexural strength depends on the internal reinforcement and a small part of the external strengthening.

4.6.3 Configuration of the repair materials

The comparison between slab S3 with S4 and slab S7 with S8 clarify that covering the tension face with two perpendicular pieces of carbon fiber is more effective in increasing the maximum load and decreasing the deflection. That is due to the activation of the carbon fibers in both directions, which leads to an increase in the bending resistance. In addition, the application of the carbon fiber sheets in an orthogonal scheme delay or stop the development of diagonal cracks. While the stiffness and toughness showed a slight sensitivity when changing the distribution of CFRP sheets.

Also, for slabs rehabilitated with TRM layers, the comparison between S5 with S6 and S9 with S10 shows that using the orthogonal scheme to rehabilitate the damaged slabs was more efficient than the parallel. In both, the number of TRM layers was equal. In the orthogonal one, the TRM activity concentrated below the loading area and perpendicular to the diagonal flexural cracks, which led to delaying the development of the flexural cracks, increasing the load capacity.

Chapter Five Conclusions and Suggestions

Chapter Five
Conclusions and Suggestions

5.1 Introduction

This chapter presents the conclusions obtained from laboratory work and experimental results analyzing and provides suggestions for future studies.

5.2 Conclusions

The current study presented experimental research to verify the efficiency of external strengthening systems (CFRP sheets and TRM layers) in rehabilitating damaged slabs subjected to repeated loads by three parameters: (1) the type of repair material (CFRP or TRM); (2) slab damage rate (50,75)%; (3) repairing configuration (orthogonal or parallel). The extracted results from this study point to the following conclusions:

1- As designed, the reference slab S1 (tested under static loading) failed in flexure after yielding the steel reinforcement and the development of significant flexural cracks. Applying twenty cycles of repeated load to slab S2 led to a decrease in the ultimate load capacity, the deflection, and the occurrence of bending failure in comparison with the corresponding static test specimen S1 due to the loading-unloading process that causes an inconstancy of stresses and more damage in concrete.

2- The effectiveness of the CFRP sheets in increasing the loading bearing capacity of the rehabilitated slabs was more than that of TRM layers by about (30-55)%..

3- Rehabilitation of damaged RC slabs with CFRP sheets led to an increase in the load-bearing capacity of about (41.25- 88) %, whereas the amount of increase in the slabs that were rehabilitated by TRM layers was about (9- 21.25) %.

4- Using CFRP sheets significantly reduced the final deflection of slabs subjected to repeated loads by (35- 69)%. When using TRM layers, the decrease was slight compared to the reference slab by (8- 43.33)%.

5- Four types of failure patterns were observed during the laboratory work : (a) flexural in the slab subjected to monotonic loads; (b) combination of flexural and shear in the slab subjected to repeated loads; (c) concrete crushing in the compressive zone and fibers rupture in the slabs rehabilitated with CFRP sheets subjected to repeated loads; and (d) Rupture of the carbon textile and formation of flexural cracks in the mortar of the TRM composites in the slabs rehabilitated with TRM layers subjected to repeated loads.

5- According to the experimental results, the structural properties of the damaged slabs (stiffness and toughness) improved after being rehabilitated with CFRP sheets and TRM layers. The best results were when the experimental parameters were: slab damage percentage of 75% and orthogonal scheme.

5.3 Suggestions

This study presented a new idea to rehabilitate the damaged slabs. The thought of repeated loading patterns originated from the cases of loading and unloading in buildings and multi-story car parks. The plan of this study included a specific number of tests on two-way RC slabs, two repair systems, and one method to bond the repair materials with the concrete substrate. The research proposition for future studies includes:

1- Studying the structural behavior of other types of slabs under the influence of different protocols of repeated loading.

2-Studying new methods for bonding external strengthening materials to the concrete substrate.

3- The study results can be used to guide researchers toward verifying the efficiency of TRM as a promising material in strengthening concrete structures and study the effect of other variables, such as using different types of textile (basalt, glass) and other mesh sizes (10, 12, 25) mm in addition to studying the role of the number of TRM layers.

4- To avoid concrete collapse, it should investigate the relationship between the compressive strength of the concrete substrate and the properties of the external strengthening materials.

5- The results of this study benefit those responsible for the maintenance of service and heritage buildings who are interested in the work of restoring damaged slabs without removing them.

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Appendix (A)

Designing of the concrete slabs using the (ACI 318-14) code as well as the yield line method

$As_{min} = 0.002bh$

$As_{min} = 0.002 * 1000 * 70 = 140\ mm^2/m$

$\rho_{max} = 0.85\ \beta_1\ (f_c'/f_y)(0.003/0.003+\pounds_t)$

$\beta_1 = 0.85 - (0.05/7)(fc'-28) \quad if\ fc' \geq 28$

$\beta_1 = 0.8$

$= 0.85 * 0.8 * (35/575)(0.003/0.007)$

$\rho_{max} = 0.01774$

$d = 70 - 28 = 42\ mm$

$A_{max} = \rho_{max}\, bd$

$= 0.01774 * 1000 * 42 = 745\ mm^2/m$

Let $\varphi 8@150\ mm$

$\rho = A_s/bd = 352/(1000*42) = 0.0084$

$M_u = \O \rho bd^2\ f_y(1-0.59\rho\ f_y/(f_c'))$

$= 0.9*0.0084*1000*(42)^2*575(1-0.59*0.0084(575/35)) *10^{-3} = 7kN.m$

$P_u = 8M_u = 56kN$

(Check shear) for plate (240*240*40) mm

$b_\circ = (240+42)*4 = 1128mm, \quad \lambda=1, \quad \beta=1, \quad \propto_s=40, \quad \sqrt{(fc')}\ b_\circ\ d = 282280$

$V_c = 0.17(1+(2/\beta))\lambda\sqrt{(fc')}\ b_\circ\ d = 143kN$

$V_c = 0.083((\propto_s\ d)/b_\circ) + 2)\lambda\sqrt{(fc')}\ b_\circ\ d) = 81kN$

$V_c = 0.33\lambda\sqrt{(fc')}\ b_\circ\ d = 92.5kN$

Appendices (B)

Carbon fiber

BUILDING TRUST

PRODUCT DATA SHEET

SikaWrap®-300 C

WOVEN UNIDIRECTIONAL CARBON FIBRE FABRIC, DESIGNED FOR STRUCTURAL STRENGTHENING APPLICATIONS AS PART OF THE SIKA® STRENGTHENING SYSTEM

DESCRIPTION

SikaWrap®-300 C is a unidirectional woven carbon fibre fabric with mid-range strengths, designed for installation using the dry or wet application process. Suitable for use in hot and tropical climatic conditions.

USES

SikaWrap®-300 C may only be used by experienced professionals.
Structural strengthening of reinforced concrete, masonry, brickwork and timber elements or structures, to increase flexural and shear loading capacity for:

- Improved seismic performance of masonry walls
- Replacing missing steel reinforcement
- Increasing the strength and ductility of columns
- Increasing the loading capacity of structural elements
- Enabling changes in use / alterations and refurbishment
- Correcting structural design and / or construction defects
- Increasing resistance to seismic movement
- Improving service life and durability
- Structural upgrading to comply with current standards

CHARACTERISTICS / ADVANTAGES

- Multifunctional fabric for use in many different strengthening applications
- Flexible and accommodating of different surface planes and geometry (beams, columns, chimneys, piles, walls, soffits, silos etc.)
- Low density for minimal additional weight
- Extremely cost effective in comparison to traditional strengthening techniques

APPROVALS / CERTIFICATES

- Poland: Technical Approval ITB AT-15-5604/2011: Zestaw wyrobów Sika CarboDur do wzmacniania i napraw konstrukcji betonowych.
- Poland: Technical Approval IBDiM Nr AT/2008-03-0336/1, Płaskowniki. pręty, kształtki i maty kompozytowe do wzmacniania betonu o nazwie handlowej: Zestaw materiałów Sika CarboDur® do wzmacniania konstrukcji obiektów mostowych.
- USA: ACI 440.2R-08, Guide for the Design and construction of Externally Bonded FRP Systems for strengthening concrete structures, July 2008.
- UK: Concrete Society Technical Report No. 55, Design guidance for strengthening concrete structures using fibre composite material, 2012.

PRODUCT INFORMATION

Construction	Fibre orientation Warp Weft	0° (unidirectional) Black carbon fibres 99 % White thermoplastic heat-set fibres 1 %
Fibre Type	Selected mid-range strength carbon fibres	
Packaging	**Fabric length per roll** ≥ 100 m	**Fabric width** 500 mm
Shelf life	24 months from date of production	

Storage conditions	Store in undamaged, original sealed packaging, in dry conditions at temperatures between +5 °C and +35 °C. Protect from direct sunlight.	
Dry Fibre Density	1.82 g/cm³	
Dry Fibre Thickness	0.167 mm (based on fibre content)	
Area Density	304 g/m² ± 10 g/m² (carbon fibres only)	
Dry Fibre Tensile Strength	4 000 N/mm²	(ISO 10618)
Dry Fibre Modulus of Elasticity in Tension	230 000 N/mm²	(ISO 10618)
Dry Fibre Elongation at Break	1.7 %	(ISO 10618)

TECHNICAL INFORMATION

Laminate Nominal Thickness	0.167 mm		
Laminate Nominal Cross Section	167 mm² per m width		
Laminate Tensile Strength	**Average** 3 500 N/mm²	**Characteristic** 3 200 kN/mm²	(EN 2561*) (ASTM D 3039*)
Laminate Modulus of Elasticity in Tension	**Average** 225 kN/mm²	**Characteristic** 220 kN/mm²	(EN 2561*)
	Average 220 kN/mm²	**Characteristic** 210 kN/mm²	(ASTM D 3039*)
	* modification: sample with 50 mm Values in the longitudinal direction of the fibres Single layer, minimum 27 samples per test series		
Laminate Elongation at Break in Tension	1.56 % 1.59 %		(EN 2561) (ASTM D 3039)
Tensile Resistance	**Average** 585 N/mm	**Characterstic** 534 N/mm	(EN 2561) (ASTM D 3039)
Tensile Stiffness	**Average** 37.6 MN/m 37.6 kN/m per ‰ elongation	**Characteristic** 36.7 MN/m 36.7 kN/m per ‰ elongation	(EN 2561)
	Average 36.7 MN/m 36.7 kN/m per ‰ elongation	**Characteristic** 35.1 MN/m 35.1 kN/m per ‰ elongation	(ASTM D 3039)

SYSTEMS

System Structure

The system build-up and configuration as described must be fully complied with and may not be changed.

Concrete substrate adhesive primer	Sikadur®-330
Impregnating / laminating resin	Sikadur®-330 or Sikadur®-300
Structural strengthening fabric	SikaWrap®-300 C

For detailed information on Sikadur®-330 or Sikadur®-300, together with the resin and fabric application details, please refer to the Sikadur®-330 or Sikadur®-300 Product Data Sheet and the relevant Method Statement.

APPLICATION INFORMATION

Consumption

Dry application with Sikadur®-330

First layer including primer layer	1.0 - 1.5 kg/m²
Following layers	0.8 kg/m²

Wet application with Sikadur®-300

Primer layer	0.4 - 0.6 kg/m²
Fabric layers	0.6 kg/m²

Please also refer to the relevant Method Statement for further information.

APPLICATION INSTRUCTIONS

SUBSTRATE QUALITY

Minimal substrate tensile strength: 1.0 N/mm² or as specified in the strengthening design.
Please also refer to the relevant Method Statement or further information.

SUBSTRATE PREPARATION

Concrete must be cleaned and prepared to achieve a laitance and contaminant free, open textured surface. Please also refer to the relevant Method Statement for further information.

APPLICATION METHOD / TOOLS

The fabric can be cut with special scissors or a Stanley knife (razor knife / box-cutter knife). Never fold the fabric.
SikaWrap®-300 C is applied using the dry or wet application process.
Please refer to the relevant Method Statement for details on the impregnating / laminating procedure

IMPORTANT CONSIDERATIONS

- SikaWrap®-300 C shall only be applied by trained and experienced professionals.
- A specialist structural engineer must be consulted for any structural strengthening design calculation.
- SikaWrap®-300 C fabric is coated to ensure maximum bond and durability with the Sikadur® adhesives / impregnating / laminating resins. To maintain and ensure full system compatibility, do not interchange different system components.
- SikaWrap®-300 C can be over coated with a cementitious overlay or other coatings for aesthetic and / or protective purposes. The over coating system selection is dependent on the exposure and the project specific requirements. For additional UV light protection in exposed areas use Sikagard®-550 W Elastic (G) or Sikagard®-680 SG.
- Please refer to the Method Statement of SikaWrap® manual dry application, SikaWrap® manual wet application or SikaWrap® machine wet application for further information, guidelines and limitations.

BASIS OF PRODUCT DATA

All technical data stated in this Data Sheet are based on laboratory tests. Actual measured data may vary due to circumstances beyond our control.

LOCAL RESTRICTIONS

Note that as a result of specific local regulations the declared data and recommended uses for this product may vary from country to country. Consult the local Product Data Sheet for the exact product data and uses.

ECOLOGY, HEALTH AND SAFETY

This product is an article as defined in article 3 of regulation (EC) No 1907/2006 (REACH). It contains no substances which are intended to be released from the article under normal or reasonably foreseeable conditions of use. A safety data sheet following article 31 of the same regulation is not needed to bring the product to the market, to transport or to use it. For safe use follow the instructions given in the product data sheet. Based on our current knowledge, this product does not contain SVHC (substances of very high concern) as listed in Annex XIV of the REACH regulation or on the candidate list published by the European Chemicals Agency in concentrations above 0,1 % (w/w)

LEGAL NOTES

The information, and, in particular, the recommendations relating to the application and end-use of Sika products, are given in good faith based on Sika's current knowledge and experience of the products when properly stored, handled and applied under normal conditions in accordance with Sika's recommendations. In practice, the differences in materials, substrates and actual site conditions are such that no warranty in respect of merchantability or of fitness for a particular purpose, nor any liability arising out of any legal relationship whatsoever, can be inferred either from this information, or from any written recommendations, or from any other advice offered. The user of the product must test the product's suitability for the intended application and purpose. Sika reserves the right to change the properties of its products. The proprietary rights of third parties must be observed. All orders are accepted subject to our current terms of sale and delivery. Users must always refer to the most recent issue of the local Product Data Sheet for the product concerned, copies of which will be supplied on request.

SIKA NORTHERN GULF
Bahrain / Qatar / Kuwait
Tel: +973 177 38188
sika.gulf@bh.sika.com
gcc.sika.com

SIKA SOUTHERN GULF
UAE / Oman / SIC
Tel: +971 4 439 8200
info@ae.sika.com
gcc.sika.com

SIKA SAUDI ARABIA
Riyadh / Jeddah / Dammam
Tel: +966 11 217 6532
info@sa.sika.com
gcc.sika.com

Epoxy Resin

BUILDING TRUST

PRODUCT DATA SHEET

Sikadur®-330

High-modulus, high-strength, impregnating resin

PRODUCT DESCRIPTION

Sikadur®-330 is a two-component , solvent-free, moisture-tolerant, high strength, high modulus structural epoxy adhesive.

USES

Sikadur®-330 may only be used by experienced professionals.

For use as an impregnating resin with the SikaWrap® Hex 106G, 113C, 117C, 230C and 430G Structural Strengthening Systems.

CHARACTERISTICS / ADVANTAGES

- Long pot life.
- Long open time.
- Easy to mix.
- Tolerant of moisture before, during and after cure.
- High strength, high modulus adhesive.
- Excellent adhesion to concrete, masonry, metals, wood and most structural materials.
- Fully compatible and developed specifically for the SikaWrap® Systems.
- High temperature resistance.
- High abrasion and shock resistance.
- Solvent-free, VOC compliant.

PRODUCT INFORMATION

Packaging	3.2 gal. (12 L) kit / (2) two 1.25 gal. (4.7 L) Component A pails, (2) two 0.35 gal. (1.3 L) Component B pails
Color	Light gray
Shelf Life	2 years in original, unopened container
Storage Conditions	Store dry at 40–95 °F (4–35 °C). Condition material to 65–75 °F (18–24 °C) before using.
Consistency	Non-sag paste

TECHNICAL INFORMATION

		60 °F (16 °C)	73 °F (23 °C)	90 °F (32 °C)	
Compressive Strength	8 hour	-	-	8,000 psi (55.2 MPa)	(ASTM D-695) 50 % R.H.
	1 day	8,100 psi (55.8 MPa)	10,700 psi (73.7 MPa)	10,600 psi (73.1 MPa)	
	3 day	11,200 psi (77.2 MPa)	11,100 psi (76.5 MPa)	11,000 psi (75.8 MPa)	
	7 day	11,600 psi (80.0 MPa)	11,200 psi (77.2 MPa)	11,800 psi (81.3 MPa)	
	14 day	12,400 psi (85.5 MPa)	11,800 psi (81.3 MPa)	11,900 psi (82.0 MPa)	

Flexural Strength	8,800 psi (60.6 MPa) (7 days)	(ASTM D-790) 73 °F (23 °C) 50 % R.H.
Modulus of Elasticity in Flexure	5.06 x 105 psi (3,489 MPa) (7 days)	(ASTM D-790) 73 °F (23 °C) 50 % R.H.
Tensile Strength	4,900 psi (33.8 MPa) (7 days)	(ASTM D-638) 73 °F (23 °C) 50 % R.H.
Elongation at Break	1.2 % (7 days)	(ASTM D-638) 73 °F (23 °C) 50 % R.H.
Heat Deflection Temperature	120 °F (50 °C) (7 days)	(ASTM D-648) [fiber stress loading=264 psi (1.8 MPa)]

APPLICATION INFORMATION

Mixing Ratio	Component ‘A’ : Component ‘B’ = 4 : 1 by weight
Coverage	First coat: 40-50 ft^2/gal.; Additional coats: 100 ft^2/gal.; Final coat: 160 ft^2/gal.
Pot Life	57 minutes (325 ml)
Cure Time	**Tack Free Time**: 4–5 hours

APPLICATION INSTRUCTIONS

SUBSTRATE PREPARATION

The concrete surface should be prepared to a minimum concrete surface profile (CSP-3) as defined by the ICRI-surface-profile chips. Localized out-of-plane variations, including form lines, should not exceed 1/32 in. (1 mm). Substrate must be clean, sound, and free of surface moisture. Remove dust, laitance, grease, oils, curing compounds, waxes, impregnations, foreign particles, coatings and disintegrated materials by mechanical means (i.e. sandblasting). For best results, substrate should be dry. However, a saturated surface dry condition is acceptable.

MIXING

Pre-mix each component. Mix entire unit, do not batch. Pour contents of part B to part A. Mix thoroughly for 5 minutes with a 1/2 inch “Jiffy” mixer mounted on a rotary drill and set at a slow speed (400–600 rpm) until uniformly blended. Mix only that quantity that can be used within its pot life.

APPLICATION METHOD / TOOLS

Dry Lay-Up: When installing a SikaWrap® Hex fabric in the dry lay-up process apply the mixed Sikadur®-330 epoxy resin directly onto the substrate at a rate of 40–50 ft.2/gal. (0.95–1.18 m^2/L). Coverage rate will depend on the actual surface profile. This equates to a thickness of approximately 32–40 mils. Carefully place the fabric into the applied resin with gloved hands and smooth out. Work out any irregularities or air pockets with a plastic laminating roller. Let the resin squeeze out between the rovings of the fabric. If more than one layer of fabric is required, apply additional Sikadur®-330 at a rate of 100 ft²/gal. (2.37 m2/L) and repeat as described above. This equates to a thickness of approximately 16 mils. Add a final layer of Sikadur®-330 onto the exposed surface at a rate of 160 ft²/gal. (3.79 m²/L). This equates to a thickness of approximately 10 mils.

Wet Lay-Up: When installing a SikaWrap® Hex fabric vertically or overhead in the wet lay-up process, mixed Sikadur®-330 can be applied to the substrate as a primer/tack coat to prevent the impregnated fabric from sliding down the concrete. Due to its mixed viscosity, do not use Sikadur®-330 with an automatic fabric saturating device. Consult the SikaWrap® Hex fabric technical data sheet for information on saturating/impregnating fabric in a wet lay-up installation.

CLEANING OF TOOLS

Clean all equipment immediately with Sika® Colma Cleaner. Cured material can only be removed mechanically.

LIMITATIONS

- Minimum age of concrete is 21–28 days, depending on curing and drying conditions.
- All repairs required to achieve a level surface must be performed prior to application.
- Do not apply or cure Sikadur®-330 in direct sunlight.
- Minimum substrate temperature 40 °F (4 °C). Maximum application temperature 95 °C (35 °C)
- Do not thin with solvents.
- Material is a vapor barrier after cure.
- Do not encapsulate saturated concrete in areas of freezing and thawing.
- Color of Sikadur®-330 may alter due to variations in lighting and/or UV exposure.
- Due to its mixed viscosity, do not use Sikadur®-330 with an automatic saturating device. Fabric must be saturated/impregnated manually when the wet lay-up process is used.
- At low temperatures and/or high relative humidity, a slight oily residue (blush) may form on the surface of the cured epoxy. If an additional layer of fabric, or a coating is to be applied onto the cured epoxy. This residue must first be removed to ensure adequate bond. The residue can be removed with either a solvent wipe (e.g. MEK) or with water and detergent. In both cases, the surface should be wiped dry prior to application of the next layer or coating.
- Not an aesthetic product. Color may alter due to variations in lighting and/or UV exposure.

BASIS OF PRODUCT DATA

Results may differ based upon statistical variations depending upon mixing methods and equipment, temperature, application methods, test methods, actual site conditions and curing conditions.

OTHER RESTRICTIONS

See Legal Disclaimer.

ENVIRONMENTAL, HEALTH AND SAFETY

For further information and advice regarding transportation, handling, storage and disposal of chemical products, user should refer to the actual Safety Data Sheets containing physical, environmental, toxicological and other safety related data. User must read the current actual Safety Data Sheets before using any products. In case of an emergency, call CHEMTREC at 1-800-424-9300, International 703-527-3887.

LEGAL DISCLAIMER

- **KEEP CONTAINER TIGHTLY CLOSED**
- **KEEP OUT OF REACH OF CHILDREN**
- **NOT FOR INTERNAL CONSUMPTION**
- **FOR INDUSTRIAL USE ONLY**
- **FOR PROFESSIONAL USE ONLY**

Prior to each use of any product of Sika Corporation, its subsidiaries or affiliates ("SIKA"), the user must always read and follow the warnings and instructions on the product's most current product label, Product Data Sheet and Safety Data Sheet which are available at usa.sika.com or by calling SIKA's Technical Service Department at 1-800-933-7452. Nothing contained in any SIKA literature or materials relieves the user of the obligation to read and follow the warnings and instructions for each SIKA product as set forth in the current product label, Product Data Sheet and Safety Data Sheet prior to use of the SIKA product.

SIKA warrants this product for one year from date of installation to be free from manufacturing defects and to meet the technical properties on the current Product Data Sheet if used as directed within the product's shelf life. User determines suitability of product for intended use and assumes all risks. User's and/or buyer's sole remedy shall be limited to the purchase price or replacement of this product exclusive of any labor costs. **NO OTHER WARRANTIES EXPRESS OR IMPLIED SHALL APPLY INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. SIKA SHALL NOT BE LIABLE UNDER ANY LEGAL THEORY FOR SPECIAL OR CONSEQUENTIAL DAMAGES. SIKA SHALL NOT BE RESPONSIBLE FOR THE USE OF THIS PRODUCT IN A MANNER TO INFRINGE ON ANY PATENT OR ANY OTHER INTELLECTUAL PROPERTY RIGHTS HELD BY OTHERS.**

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Sika Corporation
201 Polito Avenue
Lyndhurst, NJ 07071
Phone: +1-800-933-7452
Fax: +1-201-933-6225
usa.sika.com

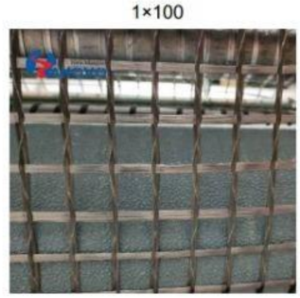
Sika Mexicana S.A. de C.V.
Carretera Libre Celaya Km. 8.5
Fracc. Industrial Balvanera
Corregidora, Queretaro
C.P. 76920
Phone: 52 442 2385800
Fax: 52 442 2250537

Carbon Textile

JIANGSU HANOVO NEW MATERIAL CO., LTD
ADD:No.20-38 Huanshi, Wuyao Town,
Rugao,Jiangsu P.R., CHINA
Tel: +86 513 87036085; Web:www.hanovo.com.cn

CARBON FIBER MESH GRID DATA SHEET

Product Properties	Units	CF3030
Physical Properties		
Material		12k*2/24k Carbon Fiber
Weaving Style		Plain
Aperture Size - MD	mm	20 ± 1
Aperture Size - CD	mm	20± 1
Density	g/m2	160 ±10
Mechanical Index Properties		
Tensile Strength	Mpa	≥3000
Elastic Modulus	Mpa	$\geq 2.4*10^5$
Elongation	%	2
Physical Properties		
Roll Dimensions(width×length)	m	1×100



Note: The right is reserved to make changes without notice.

Cement Mortar

MSASA
Construction Solutions for Africa

CONMIX

ReCon HS

High Strength Cementitious Structural Repair Mortar

DESCRIPTION

ReCon HS is a ready to use single component, polymer modified non-shrink repair mortar containing fibers and silica fume. It contains specially selected ingredients to provide high strength, fine, smooth repaired surfaces.

USES

ReCon HS is suitable for spray or trowel applications with high build characteristics. Typical applications include, but are not restricted to:

- Repairs to reinforced or prestressed concrete elements
- Repair of honeycomb, cavities, plugging tie holes
- Repairs in marine environments
- Can also be used as dry pack mortar of various consistencies by adjusting the water content of the mix

ADVANTAGES

- Maintains durability of the structure
- Easy to apply
- Can be used for repairs in contact with potable water
- Low permeable mortar
- Gives excellent resistance to attack by aggressive elements
- Inhibits carbonation significantly
- Excellent adhesion and mechanical strengths
- Contains no chlorides or salts that may cause corrosion

TYPICAL PROPERTIES at 25°C with W/P ratio at 0.14

PROPERTY	TEST METHOD	VALUE	
Component	-	Single	
Form	-	Powder	
Colour	-	Grey	
Fresh Wet Density	BSEN 12350-6	2.30 kg/ltr +/- 0.05	
Working Time	-	20 mins	
Compressive Strength	ASTM C109	1 day	40 N/mm²
		28 days	75 N/mm²
Bond Strength	ASTM D4541	> 2 N/mm² at 28 days	
Flexural Strength	BS 6319-3	11 N/mm² at 28 days	
Tensile Strength	BS 6319-7	6 N/mm² at 28 days	
Water Absorption (ISAT)	BS 1881-208	< 0.01 ml/m²/sec at 2 hrs	
Water Permeability	BSEN 12390-8	< 8mm	
Rapid Chloride Permeability	ASTM C1202	< 650 coulombs	
Drying Shrinkage	ASTM C157	< 500 microstrain at 28 days	

SURFACE PREPARATION

The area to be repaired should be clearly marked and saw cut to a depth of at least 5 mm to avoid feather edges. The surface should be clean and sound. Remove dirt, dust, oil, grease, laitance, sealers, release agents, curing compounds and paints. Exposed rebar should be cleaned by suitable means and protected with **ReCon Zinc** or **ReCon ST.**

CON MIX

ReCon HS

PRIMING	Priming is generally not required. Surfaces to receive **ReCon HS** should be well saturated with water prior to application and excess water is to be removed before the application of **ReCon HS.** In some critical cases appropriate bonding agent form **FitBond** range can be used.
MIXING	**ReCon HS** is mixed with water to yield a stiff but easily workable mortar. The amount of water to be added is 3.50 ltrs for 25 kg bag. Mix using a heavy duty slow speed drill machine attached with a paddle for at least 3 minutes to ensure a homogeneous lump free material is achieved. Do not try to remix the mortar after it loses its workability by the addition of extra water.
APPLICATION	**ReCon HS** can be applied by hand, trowel or spray. Care should be taken to ensure that the repair material is applied behind the steel reinforcements. If sagging occurs, remove material and start again at reduced thickness. The surface can be finished with a steel, wooden or plastic float. A sponge float may be used to achieve a rough texture. Do not over work the surface. **ReCon HS** is formulated for spray and trowel applications.
APPLICATION THICKNESS	5 mm to 50 mm in a single layer for horizontal surface 5 mm to 20 mm in a single layer for vertical surface 5 mm to 15 mm in a single layer for overhead surface
CURING	To prevent rapid surface drying and crazing, repair mortar should be cured by spreading wet burlap or moist hessian over the surface. Alternatively curing compound from **JetCure** range can be used.
PACK SIZE	10 kg and 25 kg bag
YIELD	12ltr / 25kg bag
COVERAGE	1m² /bag at 12 mm thickness
LIMITATIONS	At temperatures above 35°C it is recommended that measures are taken to reduce material placing temperatures. These include: storing materials and equipment under cool shade and away from direct sunlight. Avoid installation during the hottest part of the day. Ensure that water temperature is kept below 20°C.
GENERAL INFORMATION	**Shelf Life** 12 months from date of manufacture when stored under warehouse conditions in original unopened packing. Extreme temperature / humidity may reduce shelf life. **Cleaning** Clean all equipment and tools with water immediately after use. Hardened material can be removed mechanically.

CONMIX

ReCon HS

HEALTH and SAFETY	**PPE's**	Gloves, goggles and suitable mask must be worn.
	Precautions	Contact with skin, eyes etc. must be avoided.
	Hazard	It is considered as non-hazardous for transportation.
	Disposal	Do not reuse bags. To be disposed off as per local rules and regulations.
	Additional Information	Refer MSDS. (Available on request)

TECHNICAL SERVICE **CONMIX Technical Services** are available on request for onsite support to assist in the correct use of its products.

MSASA
Construction Solutions for Africa

CAPE TOWN
Tel: +27 (0)87 231 0253
Unit 5 | M5 Freeway Park
Upper Camp Rd | Maitland | 7405
Cape Town | South Africa

JOHANNESBURG
Tel: +27 (0)82 785 8529
64 Maple Street | Pomona
Kempton Park | Johannesburg | 1619
South Africa

Email: info@msasa.co.za | www.msasa.co.za

Manufacturer:
CONMIX LTD.
P.O. Box 5936, Sharjah
United Arab Emirates
Tel: +971 6 5314155
Fax: +971 6 5314332
Email: conmix@conmix.com

Sales Office:
Tel: +971 6 5682422
Fax: +971 6 5681442
www.conmix.com

ISO9001 CERTIFIED VINÇOTTE

Bonding agent between the damaged slab and matrix

Construction Chemicals

CON MIX

FitBond EA

Epoxy Bonding Agent for Old to New Concrete

DESCRIPTION

FitBond EA is a two component solvent free epoxy resin bonding agent.

STANDARDS

ASTM C881-Type I, II, and V, Grade 1 Class B and C

USES

FitBond EA is used as a bonding agent between old and new concrete, screeds, mortars, steel to concrete, wood to concrete, etc. When used as part of a concrete repair system, **FitBond EA** will act as a barrier to prevent the migration of chlorides from the parent concrete into the repaired area. It can be used to fix kerbstones on concrete slabs.

ADVANTAGES

- Solvent Free, high build, non-toxic
- Long pot life suitable where formwork or additional reinforcement has to be installed
- Unaffected by moisture, can be applied on dry or damp substrates
- Exhibits high mechanical strength
- Easy to apply
- Exceeds the tensile strength of the parent concrete

TYPICAL PROPERTIES at 25°C

PROPERTY	TEST METHOD	VALUE
Component	-	Two: Part A- Base Part B- Hardener
Form	-	Liquid
Colour	-	Grey when mixed
Viscosity	ASTM C881	8-10 poise
Pot Life	-	2-3 hours
Track Free Time	-	6-8 hours
Max. Overlay Time	-	5-6 hours
Compressive Strength	BS 6319-2	70 N/mm²
Flexural Strength	BS 6319-3	30 N/mm²
Pull Out Strength	ASTM D 4541	> 2.5 N/mm² (Concrete Failure)
Bond Strength	ASTM C 882	> 10 N/mm²
Toxicity	-	Non-Toxic

SURFACE PREPARATION

Surfaces to recieve **FitBond EA** should be clean and free from loose particles, dust, oil, curing membranes, paint, grease, corrosion deposits etc. Roughen the surface and expose aggregates by light scabbling or gritblasting. Oil and grease deposits should be removed by steam cleaning, detergent scrubbing or a proprietary degreaser.

MIXING

Stir the base and hardener components of **FitBond EA** separately before mixing together. Transfer the contents of the hardener into the base tin container and mix thoroughly using a slow speed drill fitted with a paddle for about 2 minutes until a uniform consistency is obtained. The sides of the mixing container should then be scrapped and mixing should continue for a further 1 minute.

CONMIX

FitBond EA

APPLICATION	Apply **FitBond EA** as soon as the mixing process is complete. Apply by brush, roller or spray. Apply to the prepared surfaces ensuring uniform thickness. Ensure that it is well brushed into the damp surface. New concrete or screed should be placed while the bonding agent is tacky. Ensure the applied **FitBond EA** is protected from contamination during this time. For difficult access areas like congested reinforcement, sprayable version of **FitBond EA** can be used. Consult Conmix for details.	
PACK SIZE	6 ltr set	
COVERAGE	4-5 m²/ltr/coat at 200 microns wft. Coverage depends on substrate porosity and texture.	
GENERAL INFORMATION	**Shelf Life**	12 months from date of manufacture when stored under warehouse conditions in original unopened packing. Extreme temperature / humidity may reduce shelf life.
	Cleaning	Clean all equipments and tools with **Conmix Cleaner** immediately after use. Hardened material can be removed mechanically.
HEALTH and SAFETY	**PPE's**	Gloves, goggles and suitable mask must be worn.
	Precautions	Contact with skin, eyes, etc. should be avoided. If swallowed seek medical attention immediately.
	Hazard	Regarded as non-hazardous for transportation.
	Disposal	Do not reuse containers. To be disposed off as per local rules and regulations.
	Additional Information	Refer MSDS. (Available on request.)
TECHNICAL SERVICE	**CONMIX Technical Services** are available on request for onsite support to assist in the correct use of its products.	

Manufacturer:
CONMIX LTD.
P.O. Box 5936, Sharjah
United Arab Emirates
Tel: +971 6 5314155
Fax: +971 6 5314332
Email: conmix@conmix.com

Sales Office:
Tel: +971 6 5682422
Fax: +971 6 5681442
www.conmix.com

ISO9001 CERTIFIED VINÇOTTE

Appendix (C)

Figure B-2: Steps of application CFRP sheets.

Figure B-4: Steps of application TRM layers.

- C2

Figure B-5: TRM layers application steps.

- C3

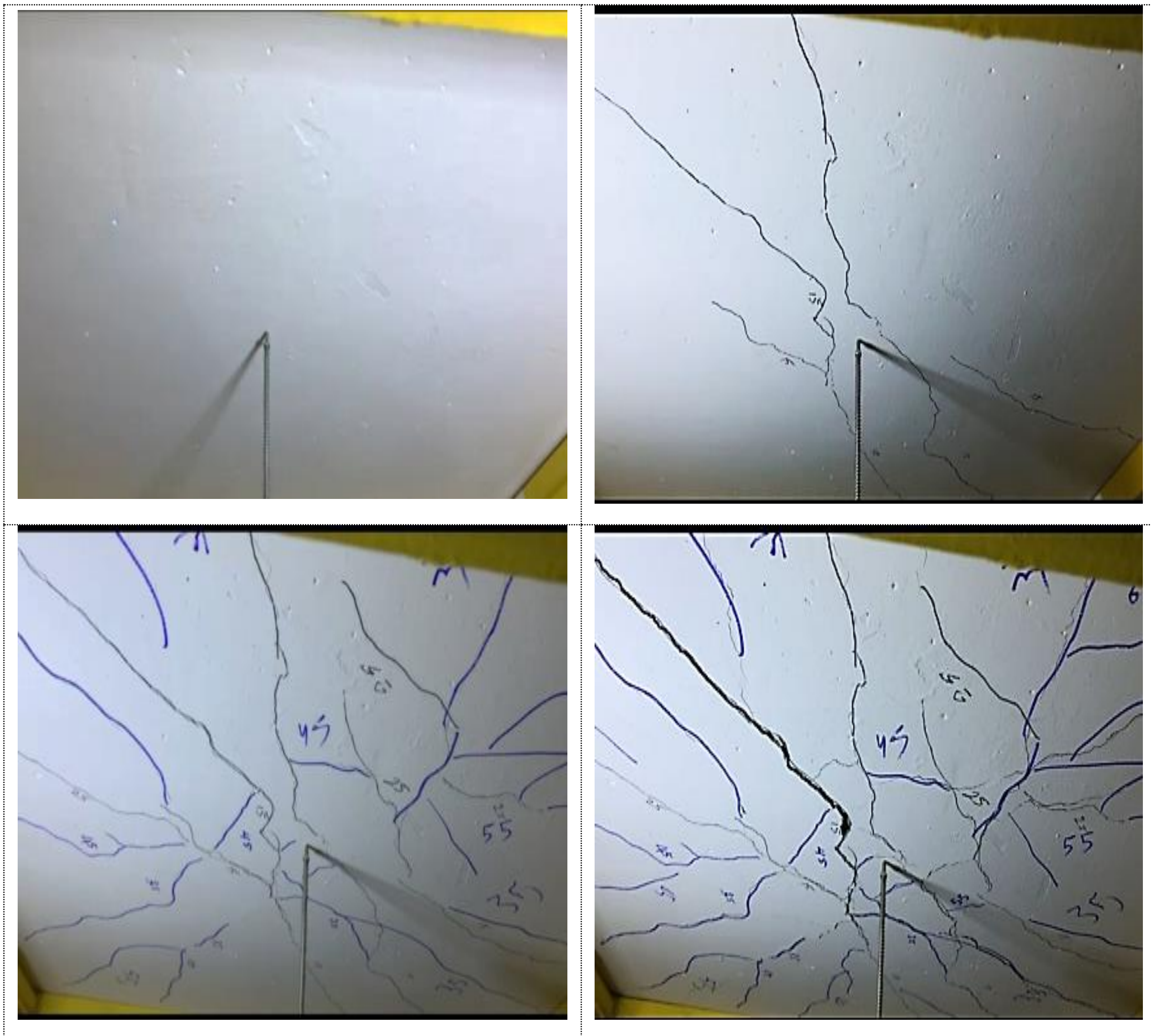


Figure B-7: Tension surface of slab S1 under monotonic loading.

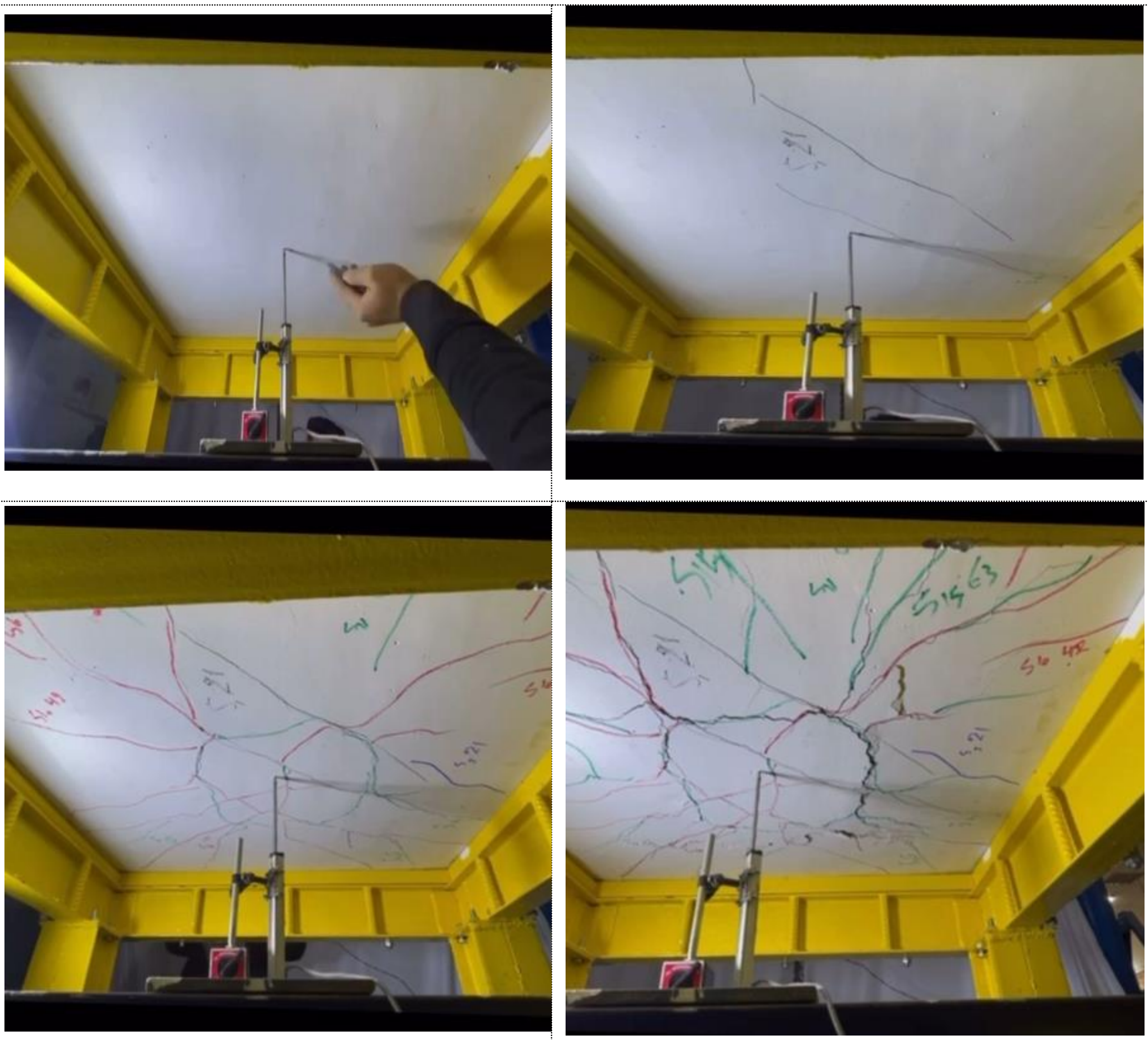


Figure B-8: Tension surface of slab S2 under repeated loading.

الخلاصة

تضمنت هذه الدراسة اعادة تأهيل البلاطات المتضررة التي تعرضت لأحمال متكررة بأستخدام التقوية الخارجية. لهذا الغرض، تم صب وأختبار عشرة بلاطات خرسانية مسلحة ثنائية الاتجاه تحت أحمال ضغط مركزة ؛ جميع البلاطات كانت مربعة الشكل بأبعاد (1050× 1050 × 70) ملم؛ تم تسليح البلاطات داخليا بالفولاذ φ8@150 ملم واساندها في محيطها الخارجي بواسطة مساند بسيطة؛ أختبرت اثنتان من هذه البلاطات كبلاطات مرجعية بدون تقوية خارجية وتعرضت لنوعين من الأحمال الانضغاط حتى الفشل: الاولى تعرضت لاحمال رتيبة، والثانية لاحمال متكررة؛ البلاطات الثمانية المتبقية مقسمة الى مجموعتين: الاولى تم تحميلها بمستوى تحميل بنسبة 50%، والثانية 75% من الحمولة القصوى على الترتيب؛ تم اعادة تاهيل كلا المجموعتين باستخدام صفائح البوليمرات المقواة بالياف الكاربون (CFRP) وطبقات الملاط المقوى بالنسيج (TRM)؛ ثم تم اختبار البلاطات الثمانية باحمال متكررة الى حد الفشل. كانت متغيرات الاختبار: نوع نظام التعزيز الخارجي (CFRP , TRM)، نسبة تضرر البلاطة (50 , 75) %، وطريقة توزيع مواد الاصلاح (متعامد , متوازي). أشارت النتائج التجريبية الى كفاءة نظامي الاصلاح في اعادة تأهيل البلاطات المتضررة وتفوق نظام CFRP من خلال زيادة الحمولة القصوى بنسبة (41.25- 88)% وتقليل الانحراف النهائي بنسبة (35 -69)% وتحسين الخواص الانشائية مقارنة بالبلاطة المرجعية. في حين ان استخدام طبقات TRM، ادى الى زيادة الحمولة القصوى بنسبة (9 -21.25)% وتقليل الانحراف النهائي بنسبة (8- 43.33)%. كانت افضل النتائج عندما تم اعادة تأهيل البلاطات المتضررة بنسبة 75% باستخدام التوزيع المتعامد في كل من انظمة الاصلاح صفائح البوليمرات المقواة بالياف الكاربون (CFRP) وطبقات الملاط المقوى بالنسيج (TRM).

جمهورية العراق

وزارة التعليم العالي و البحث العلمي

جامعة كربلاء

كلية الهندسة

قسم الهندسة المدنية

أعادة تأهيل البلاطات الخرسانية المتضررة تحت تاثير الأحمال المتكررة باستخدام الألياف الكاربونية

رسالة مقدمة الى مجلس كلية الهندسة / جامعة كربلاء وهي جزء من متطلبات نيل درجة الماجستير في علوم الهندسة المدنية

من قبل: شروق ظاهر حبيب

باشراف:

أ.م.د جواد طالب عبودي

أ.م.د علي غانم عباس