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STRENGTHENING OF TWO WAY (NC) SLAB BY REPLACING COVER LAYER WITH DIFFERENT TYPE OF CONSTRUCTION MATERIALS

By

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ABSTRACT

Deterioration of the reinforced concrete structures with time is a widespread occurrence, this causes major the load carrying capacity to decrease. Strengthening of these structures is crucial to meet the coding standards. There are many ways to increase the capacity of an existing slab, but each method has different advantages and disadvantages. One of these ways is replacement of concrete cover layer at tension zone and using of polymer modified cement mortar (PMCM) to improvement the flexural behavior of the reinforced concrete (RC) slabs.

This study presents an experimental investigation of the behavior of Fifteen slabs simply supported with dimensions (1500*750*150)mm ,which include one control slab and fourteen strengthened slabs, were tested under four-point loading until failure. Four different types of polymer modified cement mortar, commertial namly for it (Cempatch FS ,Cempatch FL , Cempatch S , Flo-grout.2) In addition to using of the normal mortar (N) (sand + portland cement) were used as strengthening materials. The studied parameters included : type of strengthening material, thickness of cover layer (25cm,40cm) and the method connection between the cover layer with the bottom face of strengthened slab (state of the cover layer, reinforced with welded wire mesh with (1.2 mm) diameter and (25.4 mm) openings (RPMCM) or without reinforced (PMCM) just mortar).In this study the strengthening methods divide into two ways , according to the state of the cover layer : in the first way (the cover layer reinforced with wire mesh),The cover layer bonded with the bottom face of the slab by connecting the main rebar with wire mesh which is embedded in cover layer by tie wire ,while the second way (the cover layer without reinforced), the method connection between the cover

Layer with bottom face by epoxy (Sikadur-32LP). Both the two ways of strengthening showed increasing in ultimate load compared to the control specimen ,but the first way is more effective than the second way.

The experimental work concluded that a reasonable gain in the flexural strength was achieved for both the strengthening ways, with an average increase of ultimate load capacity of 80% when (RPMCM cover layer) was used and an average of 10% for the second way (PMCM cover layer) compared to their respective control slab. The highest increase in the load carrying capacity was 94% for the specimens (S1-W.) and (FL1-W.),and the increasing in the load capacity by using of ferro-cement cover (N-W.) was 64.7% , while the lowest increase in the ultimate load capacity was 3% for the specimen (N-EP.).

In general, the results showed that strengthening of the RC slabs led to an increase in the ultimate failure load, energy absorption and secant stiffness in value , while there was a decrease in the initial stiffness and ductility index.

Concluded that the improvement in the mechanical properties of the cover layer materials such as flexural and compression strength leads to improvement the flexural behavior of the RC slab, as is clear in the results above, where the mechanical properties of the materials (S and FL) are better than the normal mortar (N), this means strengthening by polymer modified cement mortar (PMCM) is more effective than the normal mortar. The increasing in the thickness of the cover layer leads to reduction of the ultimate load capacity and the effective stiffness but regarding the cracks, increasing of the thickness leads to a decrease in the number of cracks.

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LIST OF EQUATIONS

LIST OF SYMBOLS

d	Effective depth of the slab (mm)
DI	Ductility index
fsp	Tensile strength (MPa)
fr	Modulus of rupture (MPa)
f′c	Cylinder concrete compressive strength (MPa)
fcu	Cube Compressive Strength (MPa)
fy	Yield stress of steel reinforcement (MPa)
Ki	Initial stiffness (Kn/mm)
Ks	Secant stiffness (Kn/mm)
Pcr	Crack load (Kn)
Pu	Ultimate load (Kn)
Py	Yield load (Kn)
Tn	Energy absorption
Δy	Yield deflection (mm)
Δu	Maximum deflection (mm)
Ψ	Energy absorption

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standard
FRP	Fiber Reinforced Polymer
IQS	The Iraqi standards
IS	Information system
RC	Reinforced Concrete
PMCM	Polymer Modified Cement Mortar
RPMCM	Reinforced Polymer Modified Cement Mortar
N	Normal Mortar (sand + Portland cement)
EP.	Epoxy

CHAPTER ONE
INTRODUCTION

1.1 General

In the past, concrete structures were thought to have strength and durability that were almost indestructible. But recently, their degeneration and damage have become obvious[1].Before the structure has reached the end of its service life, reinforced concrete structures frequently display their susceptibility to time-dependent processes like weathering[2].

Many of the existing reinforced concrete structures (RC) were built in accordance with outdated design regulations, which do not provide the safety requirements advised by current design codes, particularly for seismic and fire aspects[3].

Older structures need to be restored or strengthened so that they satisfy the same standards needed of structures created today and in the future in order to preserve efficient serviceability[4].

Slabs are the most widely used structural components with thicknesses that are significantly less than their other dimensions. They are frequently utilized for building floors and roofs, bridge decks, tank tops and bottoms, slabs on grade (directly supported on soil), staircases, and other applications. They support and ransmit loads to the walls or beams supporting them and sometimes use flexure, shear, and torsion to directly transfer loads to the columns. In addition to supporting vertical loads, slabs also act as deep horizontal girders to resist lateral wind and earthquake loads. Their action as rigid diaphragms of great stiffness is important in restricting the lateral deformation of multi-storeyed frames. It must be kept in mind that due to accelerations caused by earthquakes, the very enormous volume and mass of the slabs attract significant lateral stresses. The maximum volume of concrete that goes into a structure is in the form of floor and roof slabs and footings. Due to this, the slightest reduction in the design depth will lead to considerable economy. Slabs can have a variety of shapes and support systems. They come in waffle, solid, and ribbed varieties. Depending on how they carry loads[5].

1.2 Flat Slab and Flat Plate

In general, there are two types of slabs: one-way and two-way. One-way slabs are slabs that typically deflect in one direction. When slabs are supported by columns arranged generally in rows or when the slab is supported on all four sides and the length, L, is less than twice the width, S, The loads on the slab are distributed among the four supports and the slab will deflect in two directions. A two-way slab is what this structure is known as. The same slab can carry larger loads when supported on four sides because such slabs' bending moments and deflections are lower than those of one-way slabs[6].

The reinforced concrete slabs with or without drops, supported generally without beams by columns with or without drops, as shown in Figure 1.1, is called flat slabs. The two-way column-supported slabs are another name for the flat slabs. In flat slabs, the beams are not provided, and the slabs are cast integrally with the columns. The flat slabs may be solid or may have recesses formed on the soffit comprises of a series of ribs in two directions[7].

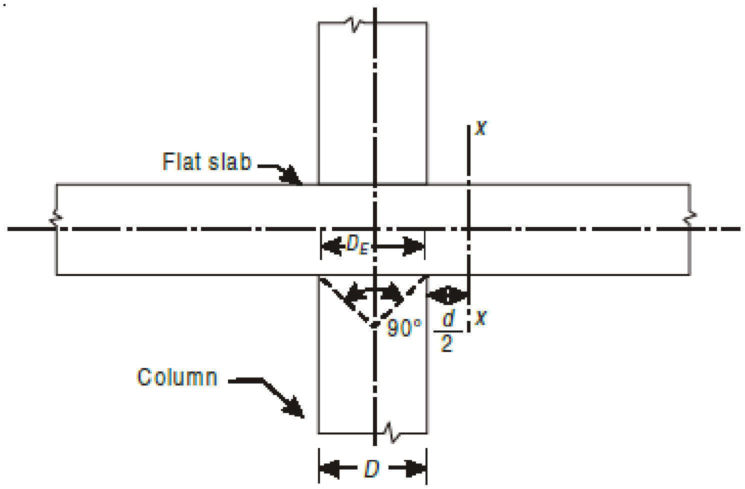


Figure 1.1 Flat slab without drop and column without column head

may be formed by removable or permanent filler blocks. The flat slabs as shown in Figure 1.1 (viz., flat slabs without drop and column without column head) are built where the span is small and the load is light. Such flat slabs are termed as flat plates. The flat slabs, as shown in Figure 1.2, (flat slabs without drop and column with column head) are constructed where, large bending moments develop round the columns. The top of column is enlarged in the shape of an inverted frustum, referred as the column head or column capital. The columns with column capital are referred as flared columns. Initially, the flat slabs were developed for heavy loads and large spans and typically using the flared column capital and often the thickened slab around the column (a drop panel). The flat slabs have long been recognized as the most economical construction for heavy service loads up to 5 kN/m2[7].

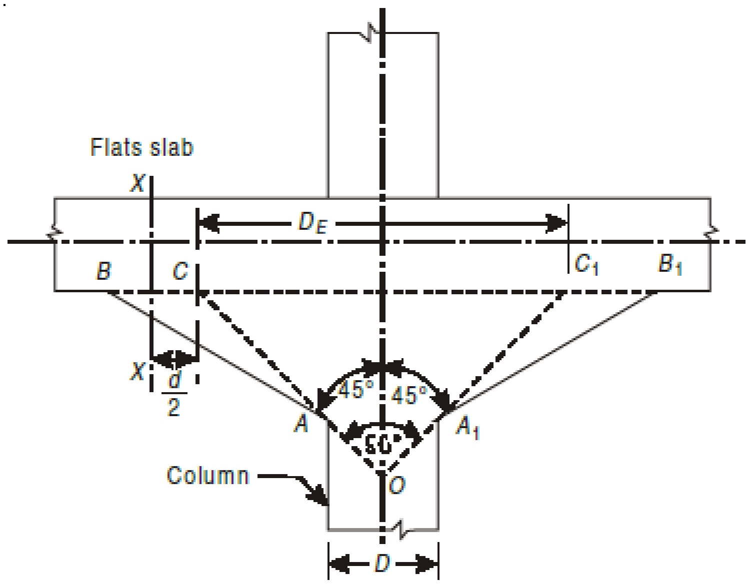


Figure 1.2 Flat slab without drop and column with column head

Flat slabs are typically many slabs that are supported directly by columns spaced regularly apart without beams. when there is a limited amount of headroom available, as in basements. Adopting flat slabs is convenient. Flat slabs are frequently utilized in garages where there is little headroom[8].

Flat plates are solid, uniform-depth slabs of concrete that don't need beams, capitals, or drop panels to distribute weight to the supporting columns. Flat plates may be built fast because of their straightforward formwork and reinforcing bar configurations. They offer the greatest freedom in the arrangement of columns and partitions and require the fewest total story heights to meet specified headroom requirements. Due to the lack of sharp corners where concrete could spall, they also offer low light obstruction and have a high fire resistance. The most popular slab system utilized today for multistory reinforced concrete hotels, motels, residential buildings, hospitals, and dorms is undoubtedly flat plates[9].

It is utilized in developed nations in places with modest floor loads, small spans, and ceilings made of plane soffits[10]. Flat plates offer a potential issue with transferring the shear at the columns' edges. In other words, the slabs could potentially be cut by the columns. Although such operations may seem pricey, it should be remembered that the straightforward formwork needed for flat plates typically results in construction that is so cost-effective that the additional expenses needed for shear heads are more than offset. Other types of floor systems, however, can be needed for large industrial weights or extensive spans [11].

1.3 Flexural Failure

Flexural failure can occur in structural elements like beams and slabs. Concrete generally has a great compression strength but a weak tension strength. Therefore, when concrete cracks under tensile stresses, the structural system may experience a number of problems. Concrete's reaction to applied loads in both compression and tension is shown by cracks. The concrete member may also become more cracked as a result of temperature and shrinkage impacts. Highly visible cracks can also ruin the appearance of the building and significantly reduce the structural member's flexure stiffness[12].

Steel reinforcement begins to yield at flexural tension failure, which is followed by concrete crushing on the compression side. The formation of cracks at the slabs' tension side that also spread to the compression side is a hallmark of this sort of failure. A further indication of flexural tension failure is excessive deflection. The failure pattern of two-way slabs is shown in Figure 1.3. Two-way slab failure can take the form of punching-shear failure, flexural failure, or a mixture of both failure modes [13]. The modes of failure of the slab are unclear when the flexural reinforcement ratio is low because the slabs may first fail in flexure before punching failure can happen[14].

Flexural cracking and a decrease in strength are potential consequences of two-way slabs' long-term deterioration and other types of damage. Additionally, cracks may expose rebars to the environment, resulting in steel corrosion. Cracks should also be kept to appropriate levels under typical service loads in order to shield structural parts from these impacts. Additionally, the random distribution of cracks has a considerable impact on the slab's flexural stiffness, and it is difficult to track the spread of cracks because stresses are transmitted in both directions. As a result of in-depth research, different retrofitting techniques have been established[15]. However, there may be drawbacks to each method. Therefore, more investigation is required to shed light on novel methods for strengthening two-way slabs.

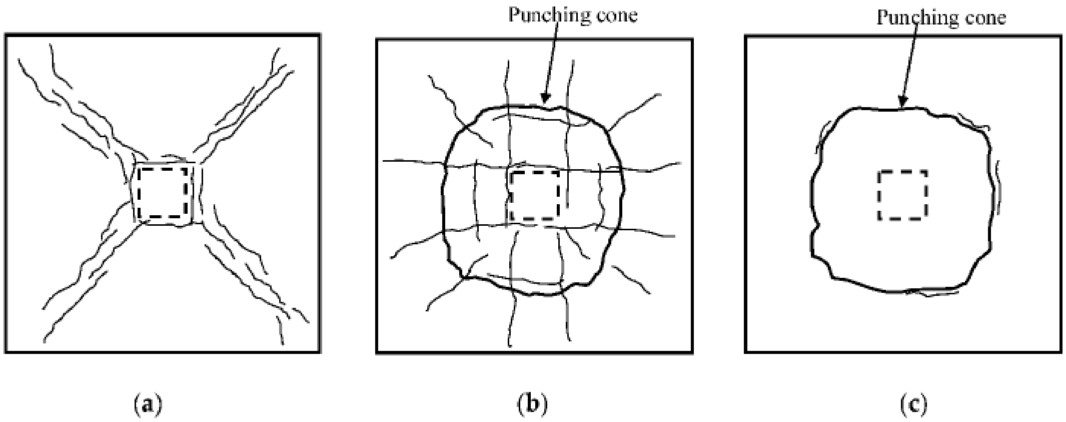


Figure 1.3 Typical cracking patterns on the tension surface of the slab:(a) Flexural failure (b) Punching shear failure of slab (c) Punching shear failure of retrofitted slab (Chen et al., 2020).

1.4 Polymer Modified Cement Mortar (PMCM)

For the past 170 years or more, portland cement-based mortar and concrete have been a common building material used all over the world. Concrete and cement mortar, however, have some drawbacks, including slow hardening, low tensile strength, significant drying shrinkage, and poor chemical resistance. Numerous attempts to employ polymers have been attempted in an effort to lessen these drawbacks. One such attempt is polymer-modified (or polymer cement) mortar or concrete, which is created by modifying regular cement mortar or concrete with polymer additives such latexes, redispersible polymer powders, water-soluble polymers, liquid resins, and monomers. The organic polymer matrix and the cement gel matrix are homogenized in the monolithic co-matrix found in polymer-modified mortars and concretes. Such a co-matrix identifies the characteristics of mortar and concrete that have undergone polymer modification. The drainage of water from the systems coupled with the hydration of the cement results in the production of a film or membrane in systems modified with latexes, redispersible polymer powders, and water-soluble polymers. Water is added to systems that have been changed with liquid resins and/or monomers, which causes the cement to hydrate and the liquid resins or monomers to polymerize[16].

1.4.1 Polymer to Cement ratios

The weight ratio of the total solids in the polymers to the total amount of cement in the modified mortar or concrete mixture is known as the polymer to cement ratio, or P/C. [17]. The properties of polymer-modified cement mortar and concrete differ from regular cement mortar and concrete in that they are more dependent on the polymer content or polymer to cement ratio than on the water to cement ratio. The maximum load for mortars with a P/C ratio of 7.5 wt% or less is rather steady, according to three-point bending tests. With extra polymer additions, flexural strength increases when the P/C ratio is between 10 and 15 weight percent. Mechanical strength is decreased by a P/C ratio more than 15 weight percent[18]. and [19]. At P/C ratios higher than 10 weight percent, continuous polymer networks form within the mortar, which accounts for the increase in tensile and flexural strength for polymer modified mortars with latex rubber[20]. Similar to how the presence of the polymer film affects the flexural strength, the delay in cement hydration is compensated[21].

1.5 Research Objectives

The objectives of this research is to study and investigate effect the replacement of concrete cover layer at tension zone of the concrete slab by using of polymer modified cement mortar (PMCM) in strengthening reinforced concrete slab in flexure. The study included the following objectives :

- Studying the effect of the variable thickness of the cover layer of the strengthened concrete slabs.
- Study the effect if the cover layer of strengthened slab reinforced with wire mesh or without reinforced (study the connection method).
- Study the effect of using different types of polymer modified cement mortar and normal mortar (ordinary Portland cement + sand) in strengthening concrete slabs.

1.6 Thesis Layouts

The structure of the present thesis is as follows:

1- Chapter One: Offers the general introduction about the concrete slabs, strengthening of the slabs , classification of the slabs and explain polymer modified cement mortar (PMCM).

2- Chapter two: Offers the methods of strengthening techniques and discuss the literature review.

3- Chapter three: This chapter presents the material properties and the experimental program, including specimen preparation, the test set-up and the instrumentation used.

4- Chapter Four: Presents analysis and discusses the obtained results from the experimental work.

5- Chapter five: This chapter provides conclusions of the study, and also highlights recommendations for future work in this field of research.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Because of the change in use or to increase the strength of degraded reinforced concrete (RC) structures, strengthening is usually necessary [22].

Structures made of reinforced concrete require strengthening. That is as a result of the continuing degradation caused by aging, poor maintenance, and external causes. Due to the time and money constraints, replacing old structures with new ones in the near future doesn't seem like a practical solution. In order to upgrade these structures, one of the strengthening methods was brought to light [23].

2.2 Necessity of Strengthening Reinforced Concrete Slabs

For taking in consideration the, analysis of the circumstances that arise when already-built concrete buildings are need to be strengthened RC components or some of their components may, for a variety of reasons, be found to be inadequate and in need of repair and/or strengthening. The following are the circumstances that call for repair or strengthening work on RC slabs[24]:

- restoring the strength and stiffness of deteriorated or damaged concrete slabs.
- reinforcement corrosion.
- reducing crack width when sustained or increasing (design/service) loads are applied.

- Retrofitting concrete members to enhance the flexural capacity and strain to failure of concrete members requested by increased loading conditions such as traffic loads or earthquakes.

- Rectifying design and construction errors such as undersized reinforcement.

- Enhancing the service life of the reinforced concrete slabs.

- Shear strengthening around the columns, for increasing the perimeter of the critical section for punching shear.

- Changes in the structural system such as cut-outs in the existing reinforced concrete slabs.

- Changes of design parameters.

- Optimization of structure regarding the reduction of deformations and of the stresses in the steel bars.

The reinforcing steel oxidizes as a result of the concrete's decreased alkalinity. Premature cracking develops as a direct result of the reinforcement's corrosion, which also results in decreased strength, stiffness, and service life as well as concrete failure, which can then result in structural collapse. The tension produced by the expansion of rusted steel undermines concrete structures as a result of the corrosion of steel reinforcing bars [25].

2.3 Strengthening Techniques for Reinforced Concrete Structures

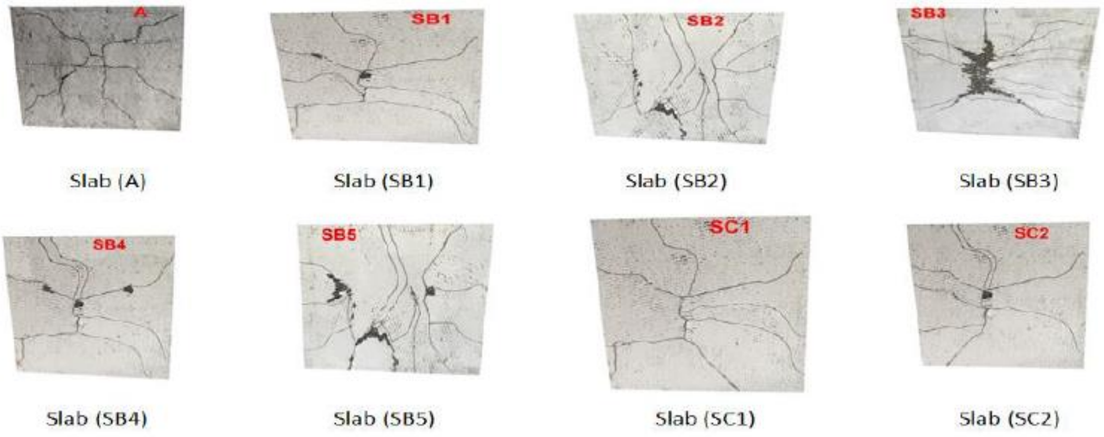
In the past, several repair and strengthening techniques were created to strengthen a particular structure or a specific portion of it so that its serviceability and strength could be restored. When the strengthening or repair of structure is done, is prudent to consider the durability aspect. In this section classic repair techniques that have been with some popularity in the past and are still in use now are analysed and presented in detail[25]. There are many techniques such as :

2.3.1 Ferrocement: Is a type of thin reinforced concrete construction in which continuous layers of relatively small-diameter wire meshes are often added for reinforcement [26].

2.3.1.1 Strengthening by the Replacement of the Concrete Cover Layer and using of the Ferrocement Cover

the strengthening method this includes: replacement of the concrete cover layer at tension zone and using the ferrocement cover . Ferrocement was a type of reinforced concrete that was first used to build boats in 1848 and was created by a Frenchman named Joseph Louis Lambot. Since the 1940s its application in the civil engineering field has widened [27].

In 2018 , Mazin [27] ,this study tested 14 simply supported two way slabs, (1) control slab, 13 strengthened slabs, and gave the experimental and analytical behavior of strengthened reinforced concrete two way slabs by steel fiber ferrocement layers. The effect of the ferrocement layers with steel fiber content of (0.25,0.5,0.75,1,1.25%), thickness of ferrocement layers, compressive strength for ferrocement mortar, and number of wire mesh layers of ferrocement was tested in the strengthened slabs. Discussion was had on the crack pattern and mid span deflection at maximum load. All of the reinforced concrete slab test specimens were made to fail in flexure and were strengthened the same way. Simply supported conditions for all slabs has beam tested under central concentrated load. For each load increment, the crack width of the slabs at mid span of the slab was measured by means of crack detection pocket microscope. Figure (2.1), shows the cracks pattern in all the slabs. The experimental results demonstrate that putting steel fiber in the ferrocement mortar, increasing the thickness of ferrocement, and ferrocement's compressive strength had a greater impact on the ultimate loads and mid span deflection of the strengthened reinforced concrete slabs. Three-dimensional nonlinear finite element analysis has been used to conduct the analytical investigation, ANSYS (Version 16.0) computer program was used in this study. The analytical output of the ANSYS program's modeling showed good agreement with the outcomes of the experiments.



Slab (A) Slab (SB1) Slab (SB2) Slab (SB3)

Slab (SB4) Slab (SB5) Slab (SC1) Slab (SC2)

Figure 2.1 Cracks pattern of slabs [27]

In 2012 , Mohammed [28] presented an experimental investigation on the flexural behavior of slabs of reinforced concrete that have been strengthened and repaired with ferrocement. 17 simply supported slabs, including 2 control slabs, 3 strengthened slabs, and 12 restored slabs, will be tested as part of the study.

For strengthened slabs the ferrocement cover was first placed at the bottom with the required number of wire mesh layers followed by placing the slab reinforcement directly on top of the ferrocement cover and then the concrete instantaneously placed (see Fig2.2 A and B). For the repaired reinforced concrete slabs (without ferrocement cover), after it was loaded up to (70%) of the failure load which was predicted by the control specimens, was then repaired by ferrocement layer which either fixed to bottom face of the slab by (10 mm) diameter bolts, placed as grid with (250×150 mm) dimension, or by epoxy resin (see Fig2.2, C and D).

The impact of the number of wire mesh layers of ferrocement on the ultimate load, mid span deflection at the ultimate load, and crack intensity were investigated in the strengthened slabs. In the repaired part the slabs were stressed to (70 %) of measured ultimate load of control slab. The effects of number of wire mesh layers, ferrocement thickness and the intensity of fractures, mid span deflection at ultimate load, and connection method between repaired slabs and ferrocement jacket on the ultimate load were all studied.

(A) (B)

(C) (D)

Figure 2.2 Steps of strengthening the slab[28]

(A) Placing the wire-mesh (B) Placing the reinforcement

(C) Placing the bolts (D) Placing the ferrocement cover.

In 2000 , Al-Kubaisy [29] investigated the flexural behaviour of the reinforced concrete slabs with the ferrocement , at tension zone cover. Figure (2.3),show the details of the strengthened slabs . The results of tests on 12 simply supported slabs are presented. The ultimate flexural load, first crack load, crack width and spacing, and the load-deflection relationship were examined in relation to the following parameters:

percentage of wire mesh reinforcement in the ferrocement cover layer, thickness of the ferrocement layer, and the type of connection between the ferrocement layer and the reinforced concrete slab. The results indicate that : the use of the ferrocement cover slightly increases the ultimate flexural load ,and increases in the first crack load. The first crack load increased with the increase in the percentage of mesh reinforcement and the ferrocement layer thickness. Considerable reduction in the cracks width and spacing (64-84) % was observed for specimens with the ferrocement layer. The presence of a cold joint between the reinforced concrete slab and the ferrocement layer lowered the ultimate flexural load by 34%, however, cracks width and spacing were reduced. Specimens cast without structural connection, provided that concrete was cast within (1-1.5) h of casting the ferrocement cover, behaved in a very similar manner to those with structural connection. For specimens with a ferrocement covering, the deflections at service load and close to ultimate load were less. The reduction in deflection was impacted by the thickness of the ferrocement layer and the type of connection .

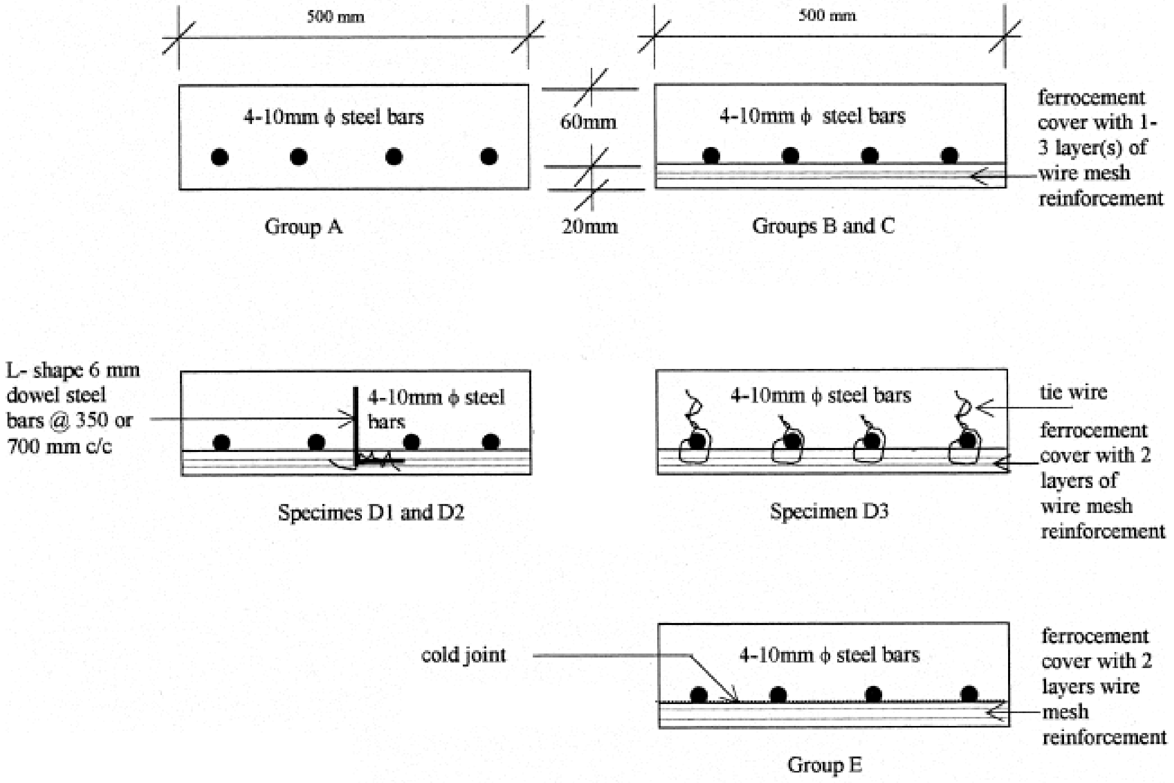
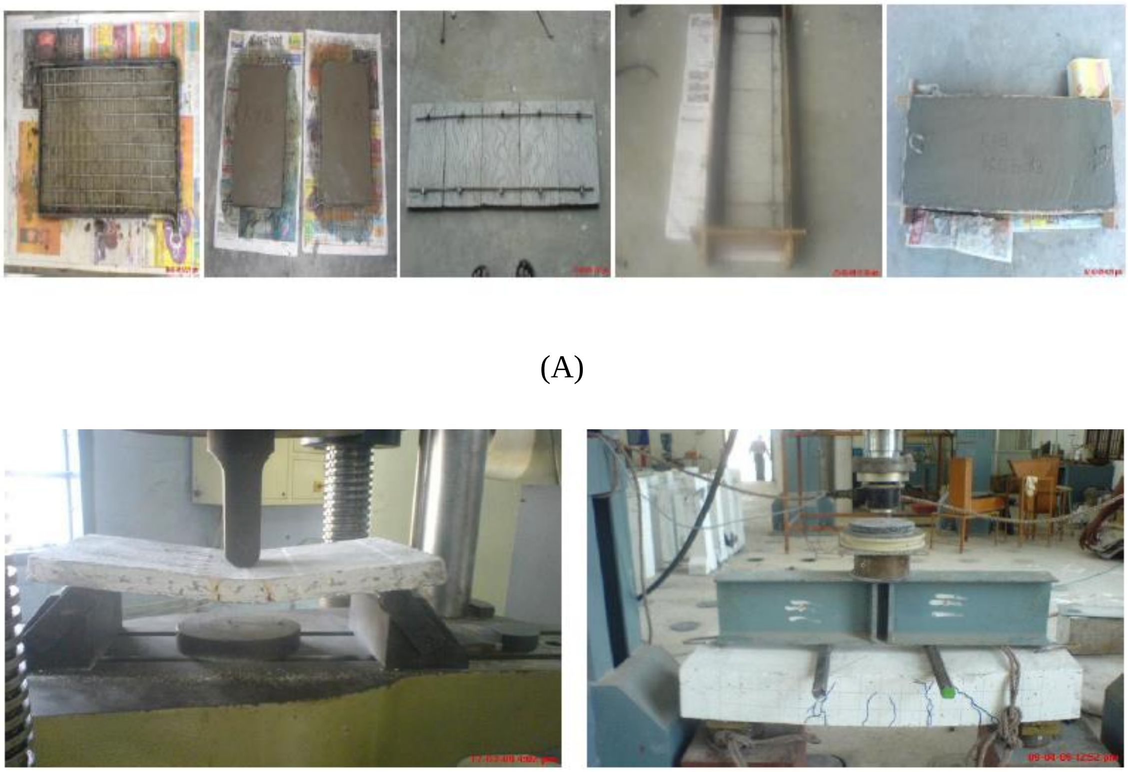


Figure 2.3 Details of strengthened slabs[29]

In 2018 K.V. Boobala Krishnan [30] The objective of this study is to understand the flexural behavior of a ferrocement composite slab under mid-third loading through an experimental program. The concept of composite slabs profited shut decking or shear connectors are well established. But still, in the countries same India, the application of same is limited due to difficulties in fabrication and also due to concerns like fire resistance durability aesthetics etc. The study aims to take use of the concept of steel –concrete composite to a similar system in which steel sheeting, is replaced by the ferrocement elements. These components will serve as long-term formwork and contribute to the slab's structural performance.Figure 2.4 , show the steps of the casting and testing setup .



(A)

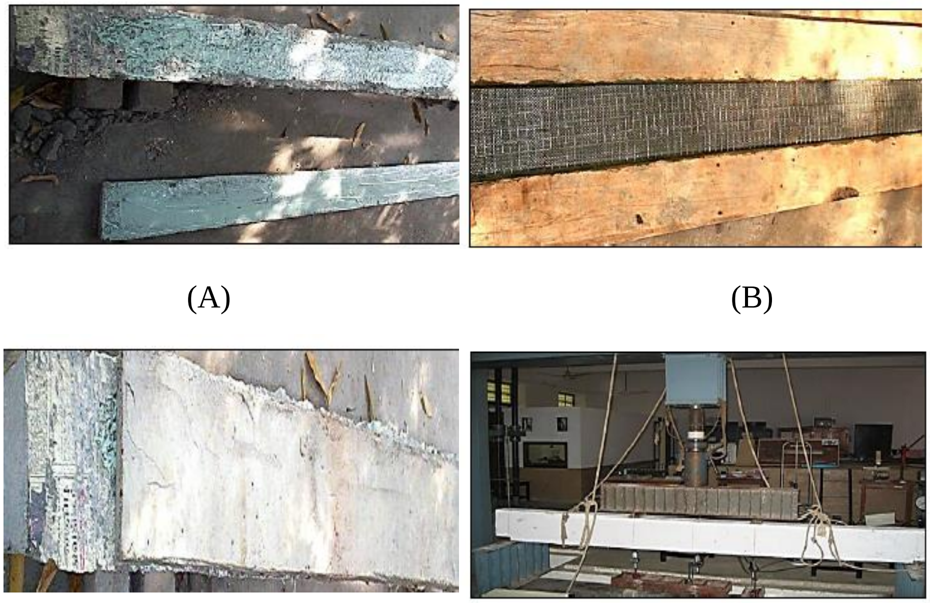
(B)

Figure 2.4 (A) Casting of the specimens (B) Test setup of slab

2.3.1.2 Ferrocement plate

casting of the ferro-cement panel separately and bonded it to the bottom side (tension zone) of the element concrete structure in order to improve the load capacity .

In 2012, Sivagurunathan. Ba and Vidivelli. Bb [31], investigated the behavior of the strengthening predamaged reinforced concrete beams by using of the ferrocement plates. This study describes the mechanical characteristics of ferrocement with three different reinforcement volume percentages. In order to improve the overall performance of reinforced concrete beams, ferrocement laminates have been introduced. Eight beams were cast and tested for flexure at 125 mm wide, 250 mm deep, and 3200 mm overall. Eight beams were used, two were used as control beams, the other six were loaded to a certain damage level, and the other two were reinforced with ferrocement laminates. Fastening of ferrocement laminates onto the surface of the predamaged beam was done by using epoxy resin adhesive. The strengthened beams were put through a flexural test once more to determine their maximum load carrying capacity. A comparative study was made between the control beam, the predamaged beams strengthened by ferrocement laminates. According to the test results, ferrocement can be used as a substitute reinforcing material for reinforced concrete beams that have been damaged by overloading. As shown in figures 2.5 (A and B), the ferrocement laminate was successfully bonded without any air gap between the two surfaces by applying a thin layer of epoxy resin COROCRETIN IHL-18 to both the surfaces of the cleaned beam surface and the laminates using a trowel.



(A) (B)

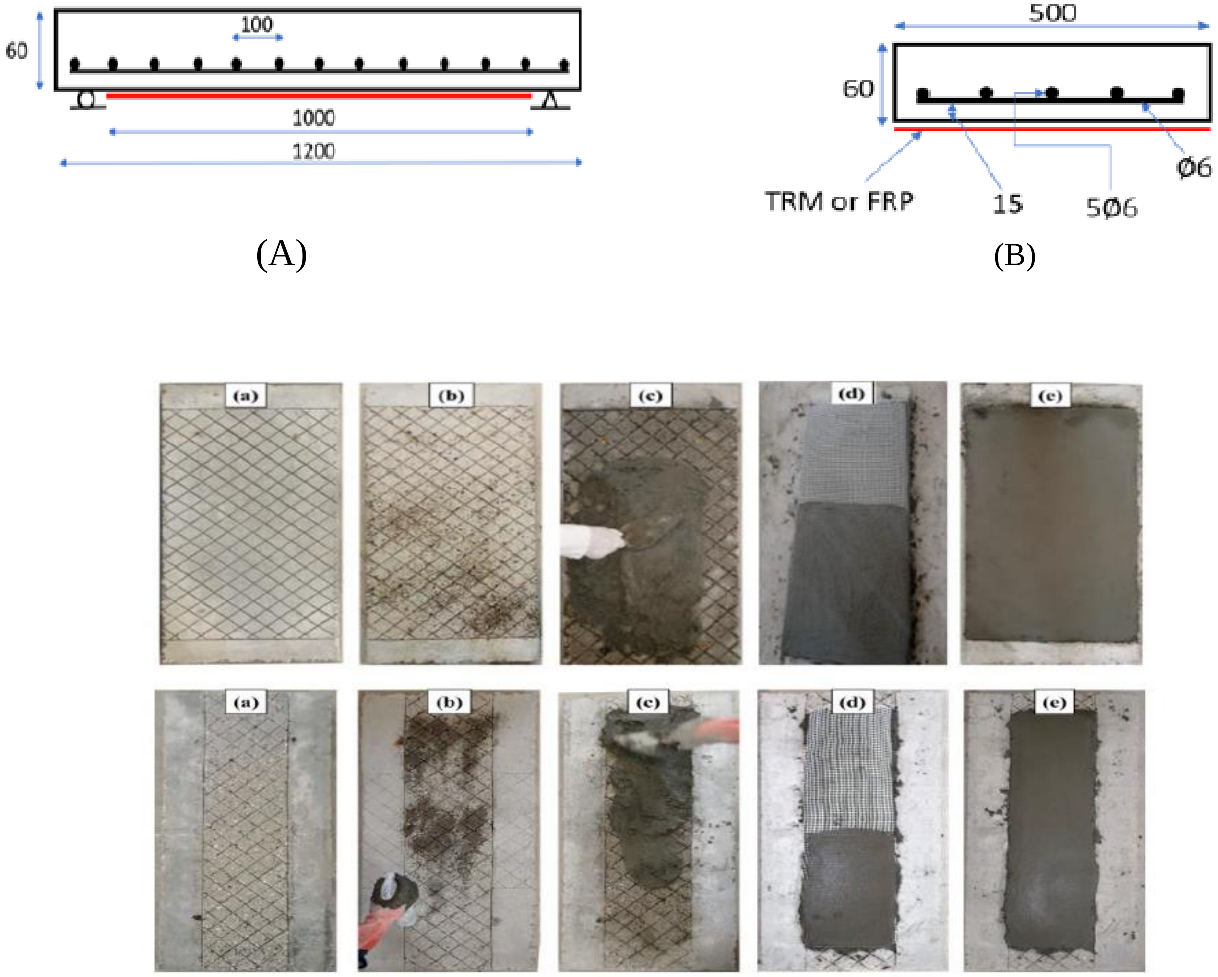
(C) (D)

Figure 2.5 Steps of the strengthening (Sivagurunthan & Vidivelli, 2012)

2.3.2 Strengthening by using Textile Reinforced Mortar (TRM) or Fabric Reinforced Cementitious Matrix (FRCM)

The TRM composite or FRCM two components make up a composite. The reinforcement mesh, which is the first component, is made of several types of fabric, including glass, carbon, Aramid, or polyparaphenylene-benzobisoxazole (PBO). The bonding agent, which is formed of mortar with a cement basis, is the second component.The FRCM composite has superior physical-durability properties such as high temperature resistance, elimination of toxic fumes in case epoxy resin is subjected to fire, and application on the wet concrete surface as the cementitious matrix is compatible with the concrete[32] . If the mortar is polymer modified, the maximum content of organic compounds (dry polymers) in the matrix is limited to (5) percent by the weight of cement. Also, the TRM is known as fiber reinforced cementitious mortar (FRCM) in North America when used as a repair material [33].

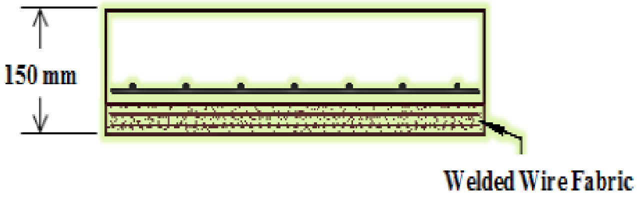
In 2021, saad [34] offered the experimental and numerical study about using of TRM for the flexural retrofitting of one-way reinforced concrete (RC) slabs . The factors that were investigated at were the number of TRM layers (one, three, five), as well as the full and partial configurations of strengthening. Eight specimens were prepared for this purpose and tested under three point loading up to failure. The result showed that the TRM increases substantially the flexural capacity of RC slabs. The highest flexural capacity increase recorded was 103 %. Also, different increases in the flexural capacity were observed as the number of retrofitting layers increased.It was also shown that the strengthening configuration plays an important role in the effectiveness of the technique. The fully covered approach showed higher loading capacity than the partial cover technique provided that the same TRM layer is applied. The ultimate moment of the strengthened specimens was then theoretically estimated and compared to the experimental result. Calculations revealed that the theoretical and experimental results were in good agreement.Details of the specimen as shown in figure 2.6.



(A) (B)

Figure 2.6 Steps of the strengthening [34]

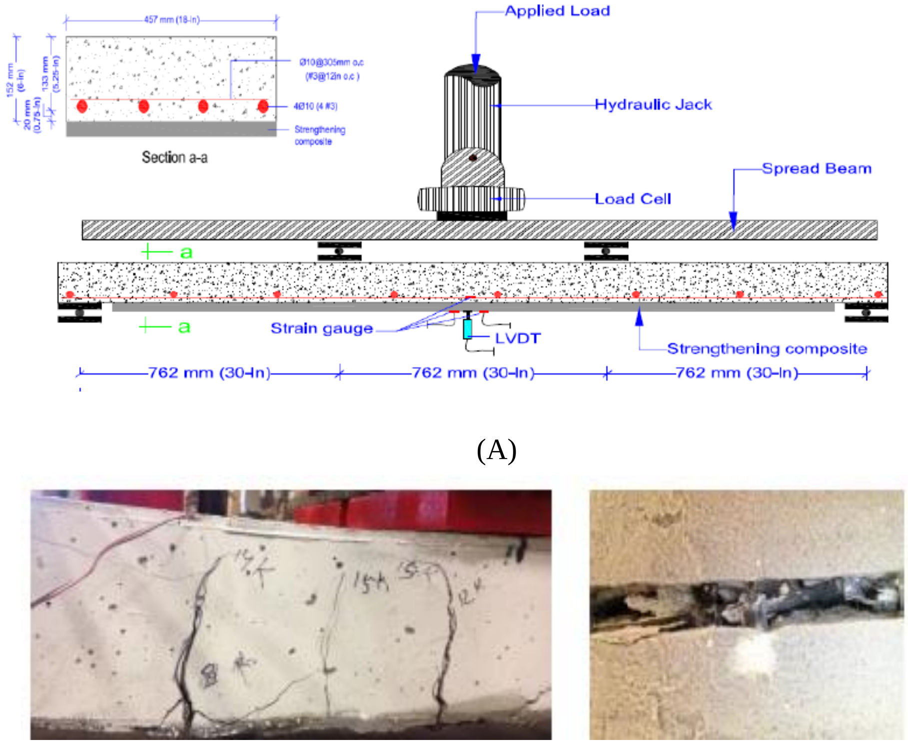
In 2017, Eyad Kadhem [1] , presented the experimental investigation of the behavior of Sixteen simply supported two way reinforced concrete slabs, which, in order to investigate the effects of various strengthening methods on their behavior, were tested until failure under the action of concentrated patch load. The overall dimensions and flexural steel reinforcement were the same for each slab. All slabs had the same dimensions (700x700x130) mm, as shown in Figure 2.7 (A). Five types of strengthening were adopted. The first and second methods include applying either near surface mounted (NSM) or near reinforcement mounted (NRM) ferrocement layers. While the third technique is applying a layer of reinforced concrete made of welded wire fabric mesh with different diameters. The fourth and fifth techniques both involve attaching CFRP rods and laminates to the slabs' bottom face. Strengthening techniques were applied on the bottom surface of fifteen slab specimens. In addition, a control slab specimen without any strengthening was used for purpose of comparison. All the strengthening techniques made an enhancement in the ultimate and cracking strength. The test results showed that carbon fiber laminates and rods significantly improve ultimate load capacity, deflection responsiveness, and cracking strength. Figure 2.7 (B), show the strengthened specimen .



(A)

Figure 2.7 Steps of the strengthening (Sayhood et al., 2017)

In 2016, Zena R. Aljazaeri [35] analyzed and evaluated the flexural behavior of simply supported one-way reinforced concrete (RC) slabs, strengthened using of three different types of the composite materials. Steel reinforced polymer system, carbon fiber grid, and polyparaphenylene benzobisoxazole (PBO) with a cementitious-based curing agent (FRCM) were the composite materials used in this study. This study's first aim was to evaluate how well these composite materials improved the flexure capacity of one-way RC slab systems in terms of the load-deflection, failure mode, and displacement ductility performance. The second aim of this study was to look at how the environmental conditioning affected the composites' stiffness and flexural performance. Figure 2.8 ,shown the details of the strengthened slab and cracks pattern .

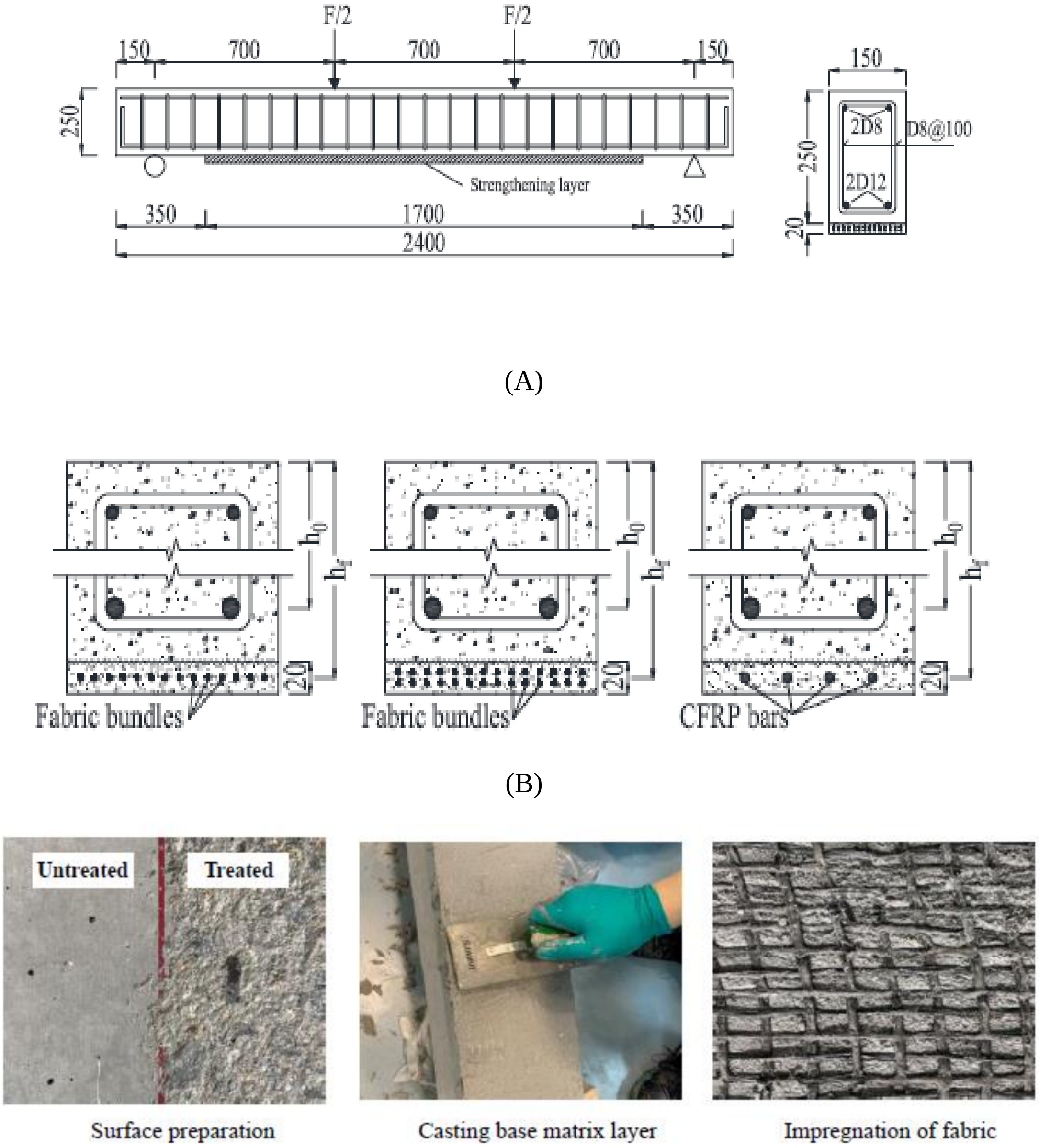


(A)

(B)

Figure 2.8 Cracks pattern (Aljazaeri & Myers, 2016)

In 2020, Xinyu Shez [36], proposed Fabric reinforced Alkali-Activated Slag (AAS) matrix ,the purpose of this study is to strengthen RC beams. Seven RC beams with and without strengthening were prepared and tested under four-point bending. Test results indicate that use of AAS matrix as replacement for conventional cement-based matrix can change the failure mode of the strengthened beams from end-debonding of strengthening layer to slippage combined with rupture of fabric. The AAS-based strengthening technique can increase the flexural stiffness and loading capacity of RC beams while also lowering the strain on the tensile reinforcements. With the exception of the samples that failed in the premature debonding, increasing the amount of fabric in the strengthening scheme increases the loading capacity of beams. In the best situation, the strengthened beams' yielding and ultimate loads are increased by 22.2% and 26.4% respectively. To further anticipate the characteristic loads of the fabric-reinforced AAS matrix-strengthened beams, an analytical model was created. It shows that the analytical model could overestimate the yielding and ultimate loads of the strengthened beams, probably due to slippage and reduced synergistic effect of fabric bundles in the strengthening system. Based on that, two efficiency factors of 0.35 and 0.25, taking account of the area of effective fabric, are obtained and recommended to estimate the yielding and ultimate loads of fabric reinforced AAS matrix-strengthened beams, respectively. The details of the strengthening steps shown in figure 2.9.



(C)

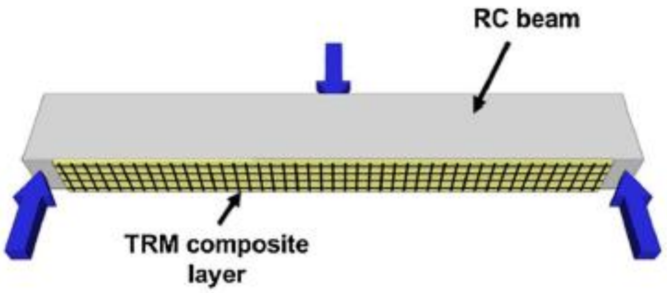
Figure 2.9 Steps of the strengthening (Shen, Chen, Li, Hancock, & Xu, 2021)

(A) Geometry and reinforcement detail RC beams

(B) Sectional view of the strengthened beams

(C) steps of application of the strengthening layer

In 2019, Lampros N. Koutas1[37], discussed in his study, a state-of-the-art review on the strength of concrete structures with TRM was covered in his work. The tensile and bond behavior of TRM is first characterized. The important parameters are then examined, and a review of studies on the use of TRM for retrofitting concrete or RC members for flexural, shear, confinement, and seismic retrofitting is presented , as shown in figure 2.10 and 2.11.



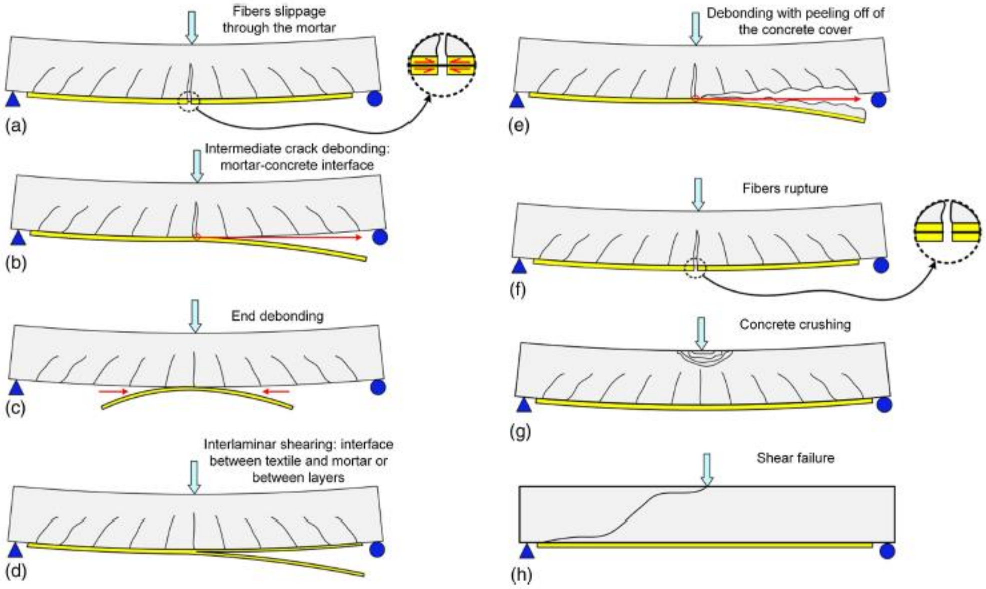


Figure 2.10 Failure modes of RC elements strengthened in flexural with TRM (Koutas, Tetta, Bournas, & Triantafillou, 2019)

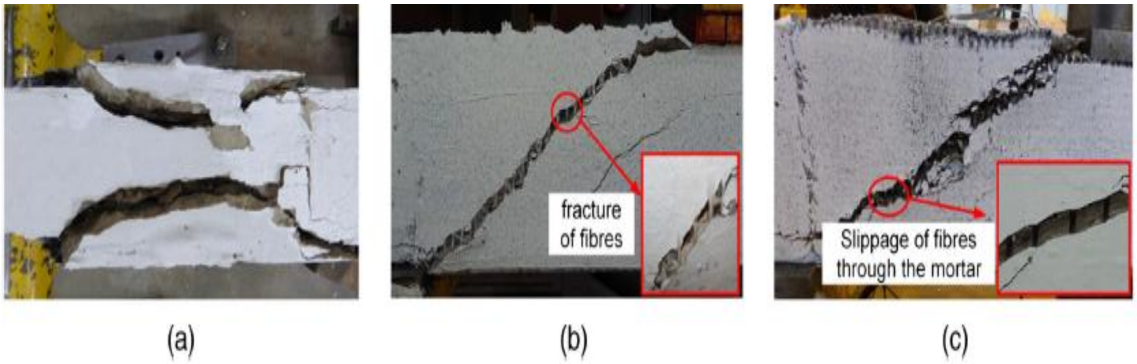
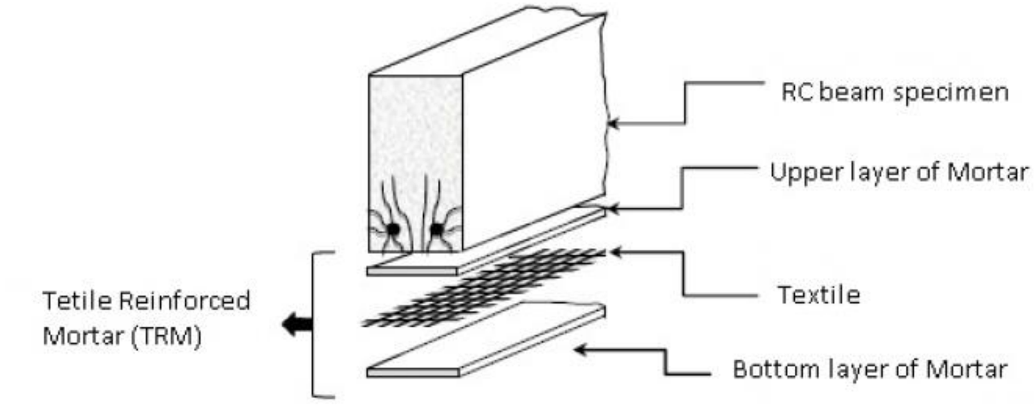


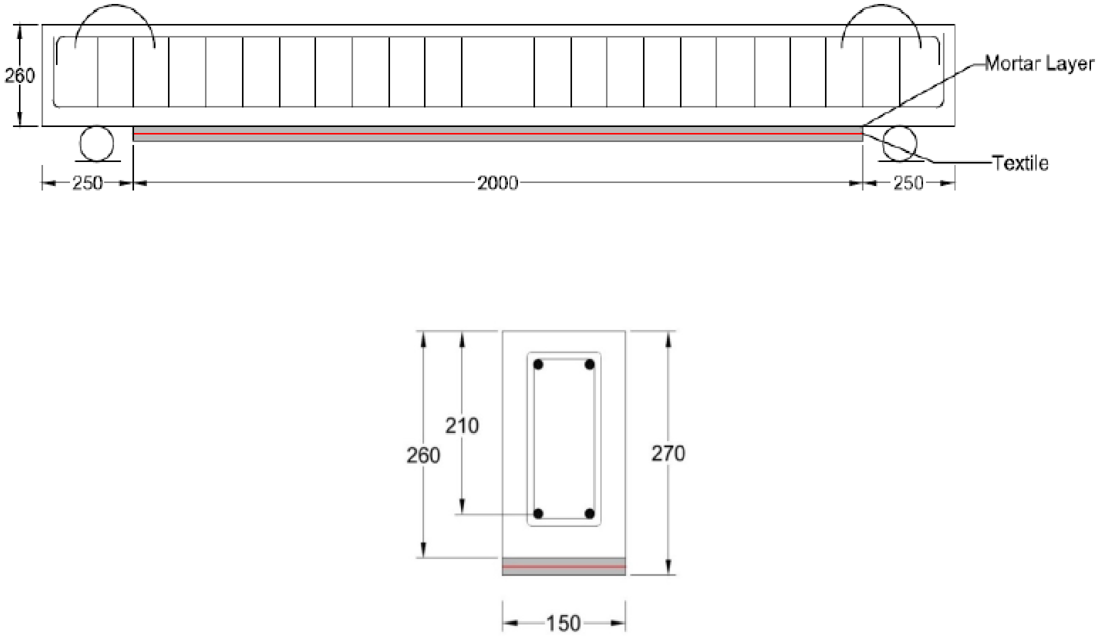
Figure 2.11 failure modes of RC beam strengthened in shear with TRM jacketing (Koutas, Tetta, Bournas, & Triantafillou, 2019)

In 2016, Muhammad shekaib [38],in this study, experimental work has been conducted to use textile reinforced mortar to increase the flexural strength of reinforced concrete (RC) beams (TRM). Two different textile types—carbon and Polyparaphenylene benzobisoxazole (PBO) were used as strengthening elements. the number of TRM layers, kind of strengthening material, type of mortar, and reinforcement ratio were among the parameters that were examined. Eighteen 18 beams were tested under four-point loading until failure. Figure 2.12, show the schematic representation of TRM system and the longitudinal and mid span cross-section of strengthened specimen.

The interfacial binding behavior between the TRM layer and concrete substrate, as well as within the TRM system, was significantly stronger in the PBO system, which resulted in higher ductility index and higher energy absorption. Moreover, during the experimentation, It was observed that the method of implementing the TRM system also takes the contractor's comfort into account, and that even less-skilled construction employees can quickly put the method into practice after seeing a few straightforward demos.



(A)



(B)

Figure 2.12 Longitudinal and mid span cross-section of strengthened specimen. (Afzal, 2016)

In 2020, Hyeong-Yeol Kim [39], investigated a numerical and experimental study about an innovative method to strengthen an reinforced concrete slab-type element in flexure using of the precast panel made of carbon (TRC). A total of five reinforced concrete slabs were fabricated to examine the flexural strengthening . Two of them were strengthened with the precast panel and grouting material and another set of two slabs was additionally strengthened by tensile steel reinforcement. Three-point bending tests were performed on the full-scale slab specimens, and the test results were compared to the theoretical solutions. In comparison to the un-strengthened specimen, the results showed that the ultimate load of the specimens strengthened with the TRC panel increased by at least 1.5 times. The application of the precast TRC panel and grouting material for the strengthening of a prototype RC structure verified its outstanding constructability. Cross-section of a full-scale slab specimen strengthened with TRC system , as shown in figure 2.13.The details of strengthening of slab specimen shown in figure 2.14.

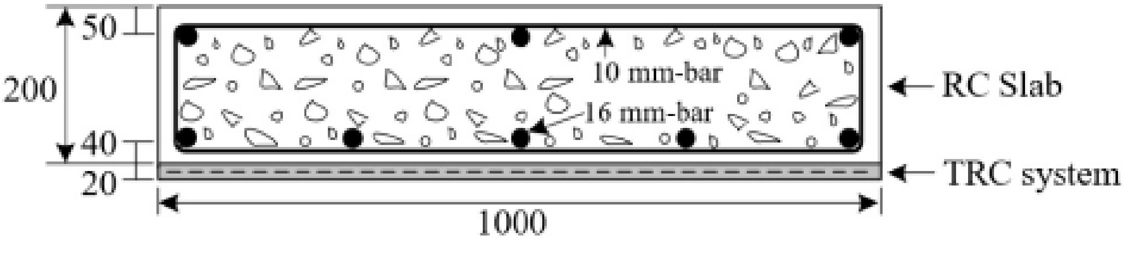


Figure 2.13 Cross-section of a full-Scale Slab Specimen Strengthened with TRC system. (Kim, You, Ryu, Ahn, & Koh, 2021)

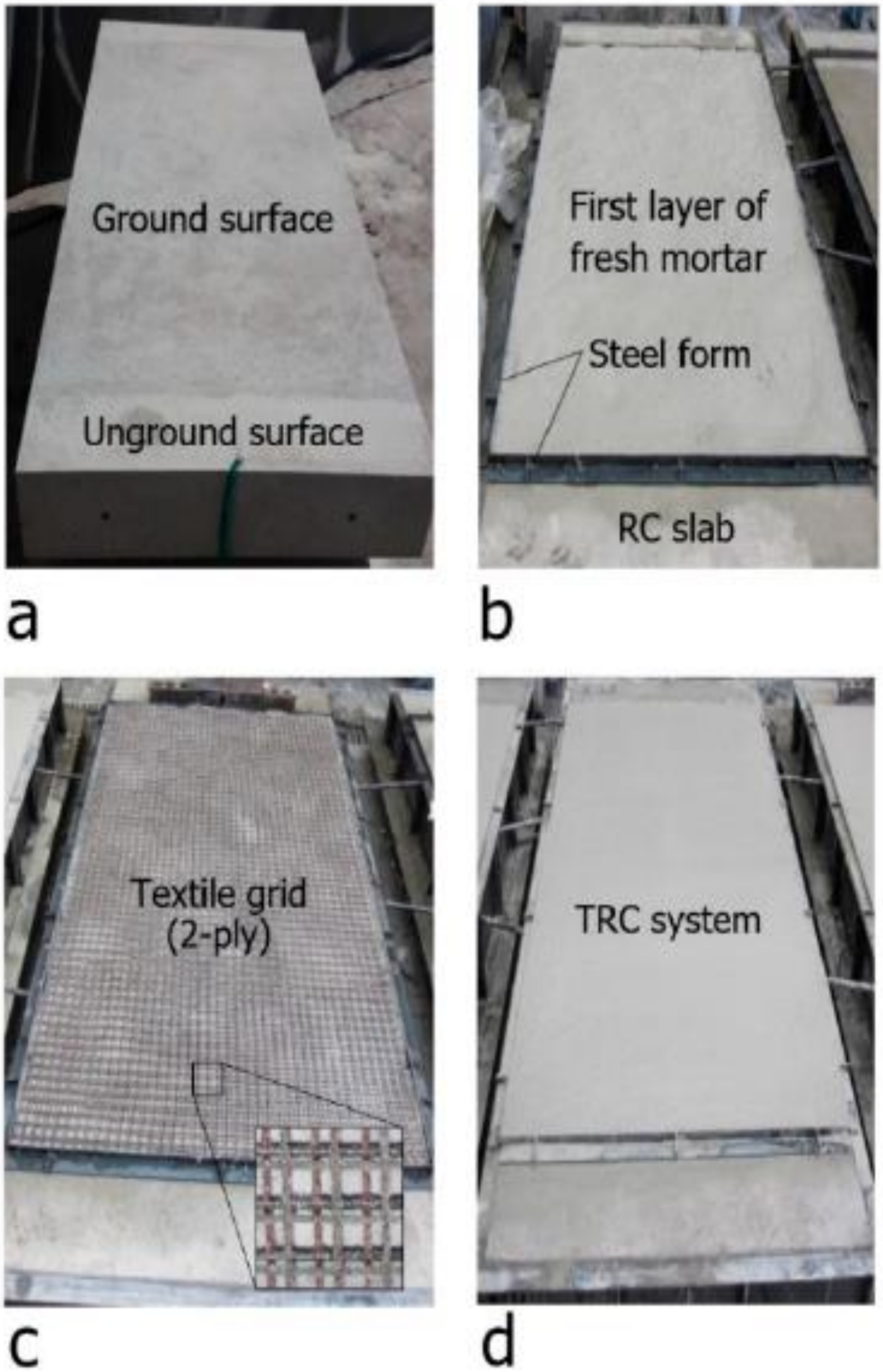
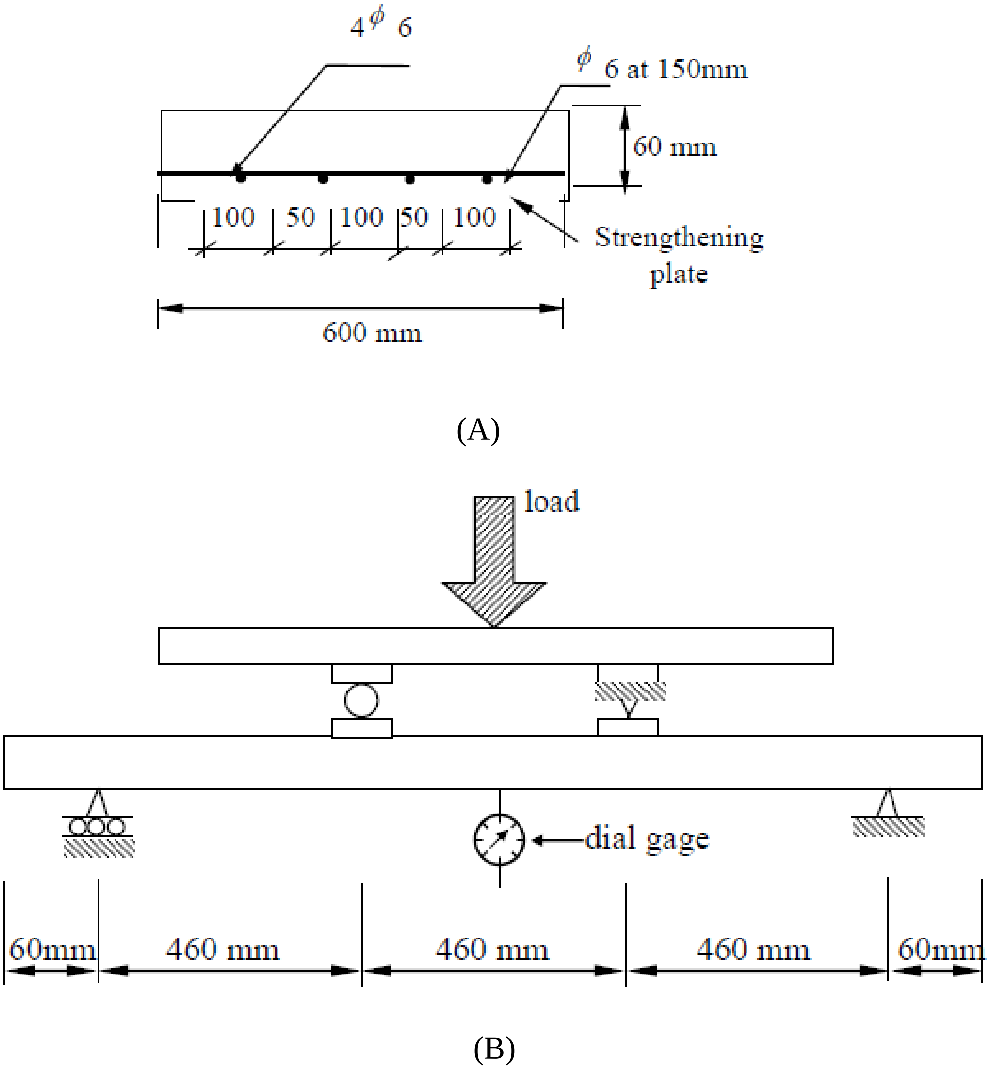


Figure 2.14 Fabrication process of a full-Scale Slab Specimen (Kim, You, Ryu, Ahn, & Koh, 2021)

2.3.3 External Plate Bonding

This technique was first used in France in the middle of the 1960s, more than 60 years ago, and is regarded by certain publications as a "classic" technique. It is frequently used to strengthen bridge constructions and involves attaching steel plates or flat steel bars to the structural elements. The bonding of the steel plates or steel flat bars to the concrete members is ensured by the use of epoxy adhesives and in some cases, additional fastening is provided by means of dowels or bolts glued to the holes drilled in the concrete members[40]. This technique is applied to strengthen RC slabs in order to increase the member's bending resistance. Therefore, to ensure bending resistance, steel flat bars or plates can be added to the bottom or top faces of a reinforced concrete slab (positive or negative bending moments zones). This method's limited applicability to relatively sound structures is one of its disadvantages. Other techniques should be taken into consideration in the event of severe concrete deterioration and significant RC member cracks. The decisive factor for the effectiveness of strengthening in this method is given by the quality of the contact layer between the concrete surface and the flat bars or steel plates. The quality of the resin adhesives represents a fundamental problem.

In 2013, Laith Shakir Rasheed[41], presented a study on the use of epoxy-bonded steel plates to enhance reinforced concrete slabs. The strengthening is intended to enhance the inherent resistance of existing slabs. The strengthened slabs have been analyzed through the experimental program done. The thickness, size, and position of steel plates are the factors that were examined in this study. The more effective parameter which enhances the overall behavior of R.C. The effect of steel plate size on slabs is greater than the impact of thickness. Slabs S3 and S5 have maximum improvements in ultimate strength of 135% percent and 79.6% percent, respectively. According to the analysis's results, stiffening R.C. slabs with steel plates can greatly increase their overall resistance. The load was applied at the one – third points for all specimens and details of specimen, as shown in figure 2.15.



(A)

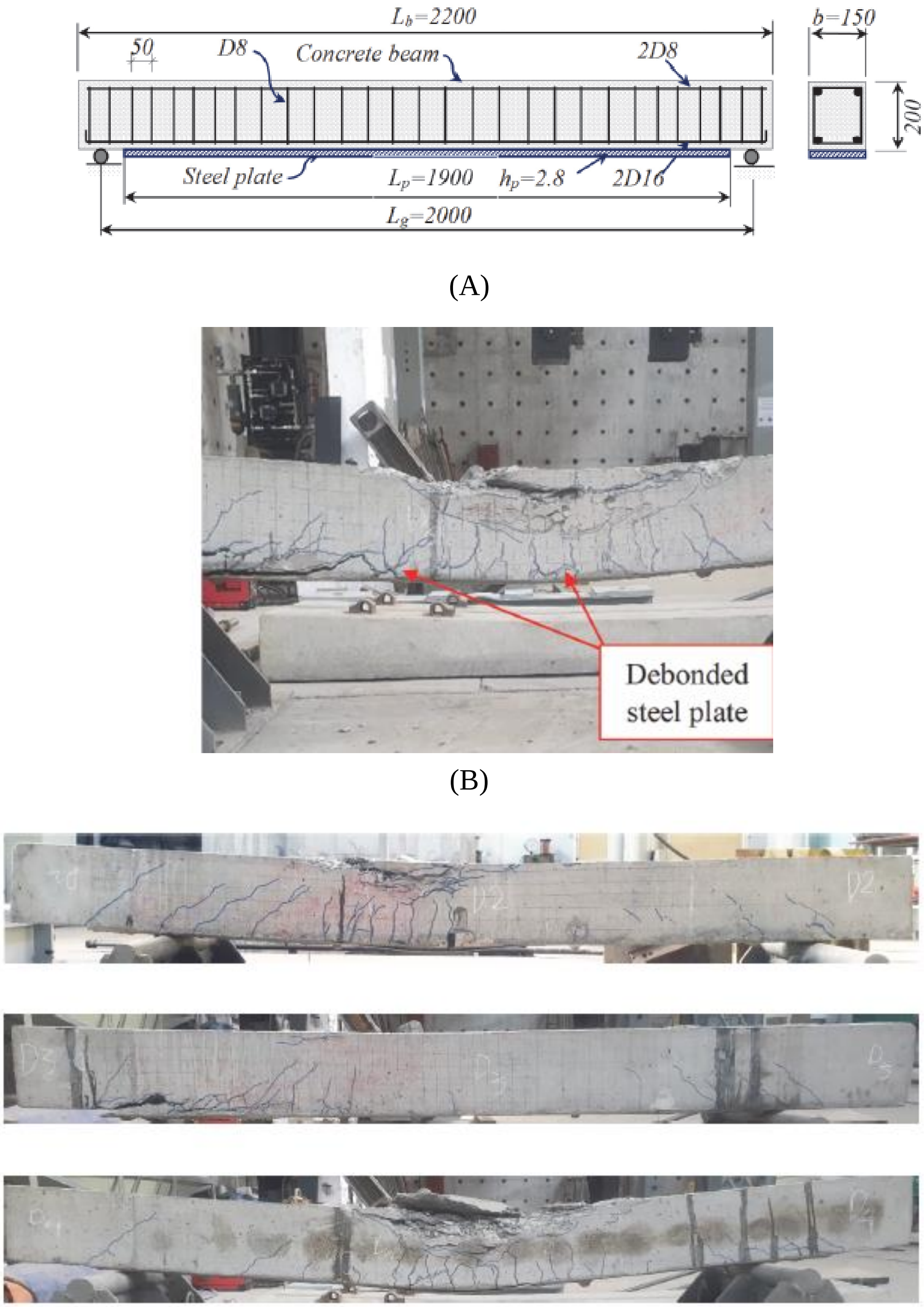
(B)

Figure 2.15 Test Layout and Specimen Geometry of Slabs. (Rasheed & Al-Azawi, 2013)

In 2022, Van-Hau Nguyen, Thanh Bui-Tien, Phe Van Pham and Long Nguyen-Ngoc[42],offered the present study investigates the ductile/brittle failure mode of reinforced concrete (RC) beams enhanced, with an external steel plate using of the experimental study and proposes a theoretical solution.

In the current experimental work, 6 RC beams with steel plate strengthening and (1) RC beam without strengthening are constructed and tested with 4-point bending loads. The rupture process of the reinforced concrete beams with external steel plates is then successfully predicted by a new theoretical model. The model is based on observed experimental results regarding crack formations, and it may be used to quantify anticipate the ductile/brittle failure mode of plate strengthened RC beams as well as the distance between vertical cracks.

The experimental analysis demonstrates that the failure mode is typically based on the random sliding of concrete and the exterior plate. There are rupture types of the test beams as shown in figure 2.16. The maximum stresses in the exterior steel are calculated from the fact that this slip is constrained between two vertical fissures. The stresses/strains in the soffit plate, fracture distances, and system failure modes predicted by the current theoretical solution are found to be in excellent agreement with those of the prior and current experimental data through result validations. This research may contribute to enhancing the design of such plate-strengthened RC beams to focus on a superior ductile performance, which has not previously been addressed.



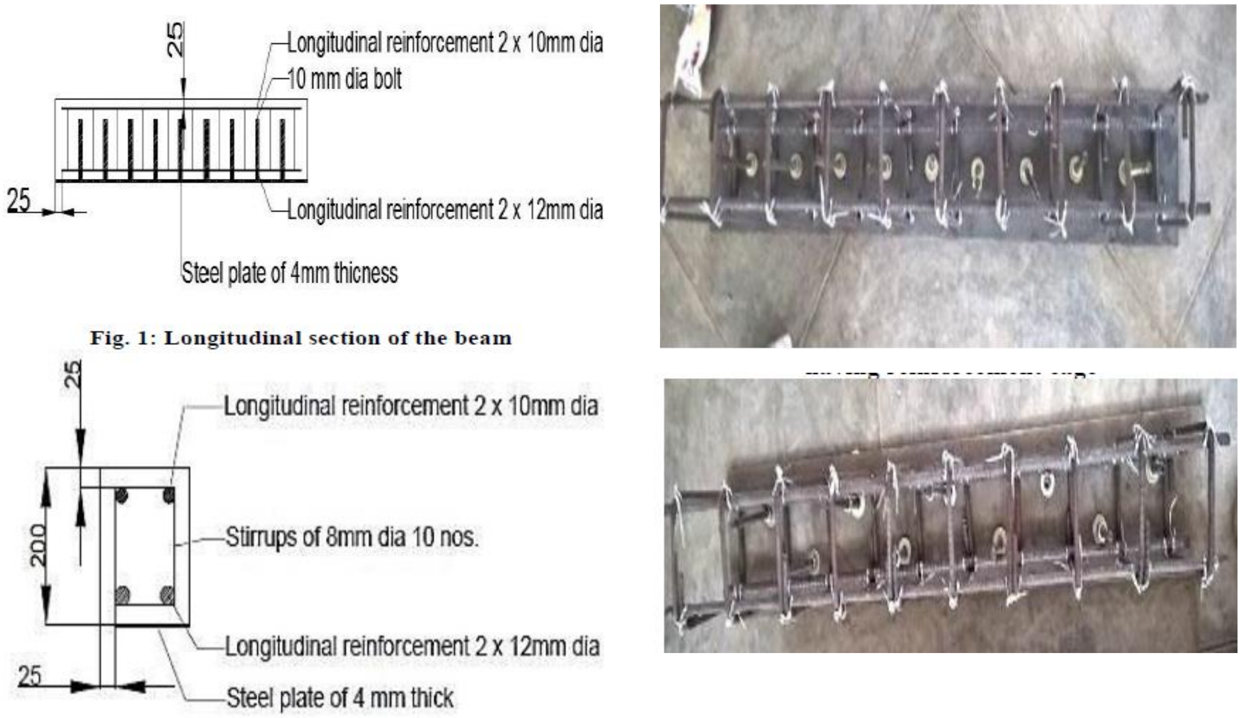
(A)

(B)

(C)

Figure 2.16 Details of testing RC beam (Nguyen-ngoc, Van, Tien, & Van, 2022)

In 2020, P. Oliver Jayaprakash, P.Sudarshan and C.Hemalatha[43],offered study on the use of single row and staggered row bolt configurations in steel plate-enhanced reinforced concrete beams, and to compare the bonding performance of different bolt arrangements under flexure. Moreover, to look into the deflection, behavior, and load-bearing ability of control and steel plate bonded beams. This study is limited by FEM analysis using ANSYS to the behaviors of conventional RC Beam and associated RC beam steel plate. Figure 2.17, show the cross section of the beam and the details of the connection method between the steel plate with the concrete beam .

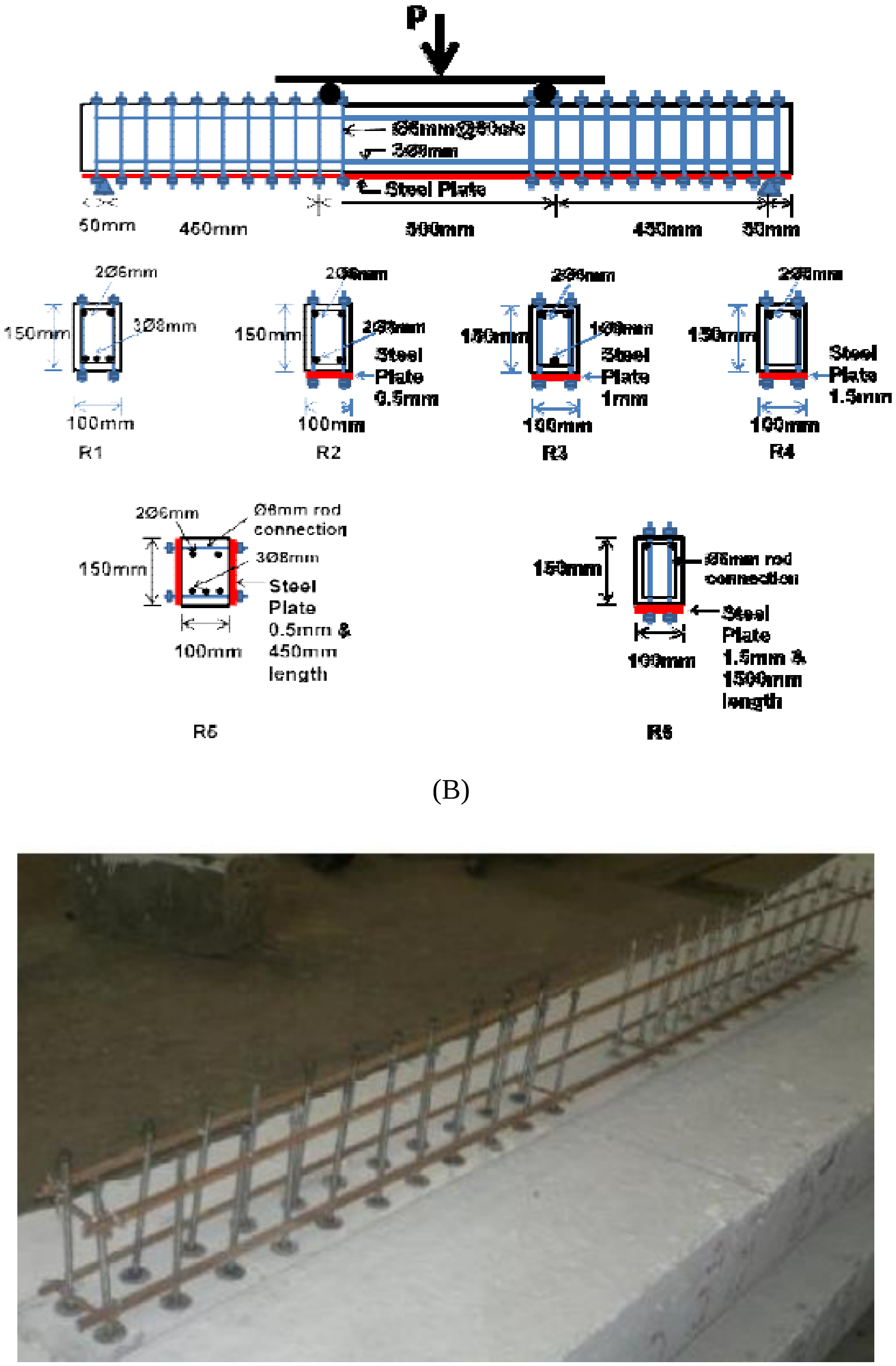


(A) (B)

Figure 2.17 Cross-section of the beam and Stagger row bolt arrangements with steel plate. (P. Oliver Jayaprakash, 6, April 2020)

In 2014, Ashraf A. Alfeehan [44], a study on the effects of replacing internal tension bars with external steel plate instead of the conventional method of bonding by glues on the ultimate strength of RC beams was reported, comparing the strengthening techniques by bonded and unbounded mechanical connection as well as the study's research results. The aim behind these procedures is to mechanically connect external steel plate with RC beams using shear connections as opposed to the usual way, which uses epoxy glues for interface bonding. Flexural testing of six concrete beams measuring (100mm *150mm *1500mm) is part of the experimental activity. The percentage of internal reinforcement replaced with exterior steel plate is one of the test variables. The techniques of bonded and unbounded beams are compared using the glue strengthening method. Results indicate that external steel plate-reinforced beams behave as a composite action up until the ultimate load and the mode of failure ,occurs by yielding of external plate, pullout or yielding the shear connectors not by separation of plate. Using external steel plates reduces central beam deflection as load capacity is increased by thickening the plates.The details of connection technique, as shown in figure (2.18).

(A)

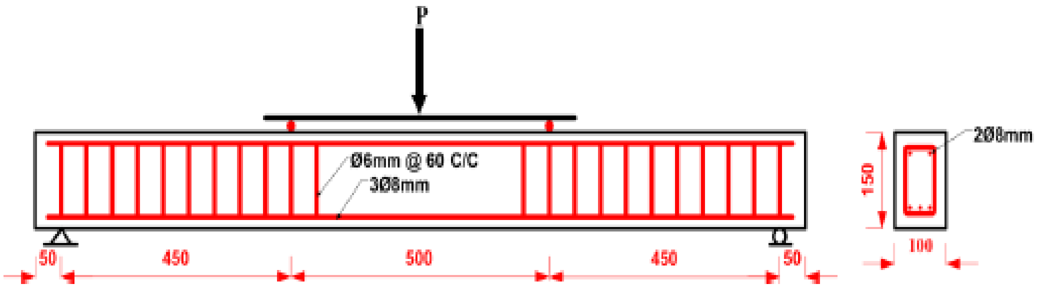


(B)

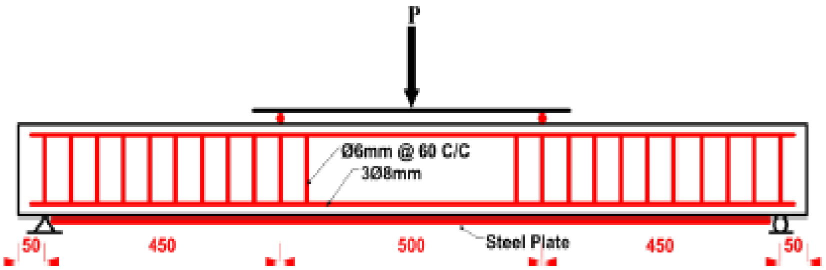
(C)

Figure 2.18 RC Beams Reinforced externally by Steel Plate (Alfeehan & Alkerwei, 2015)

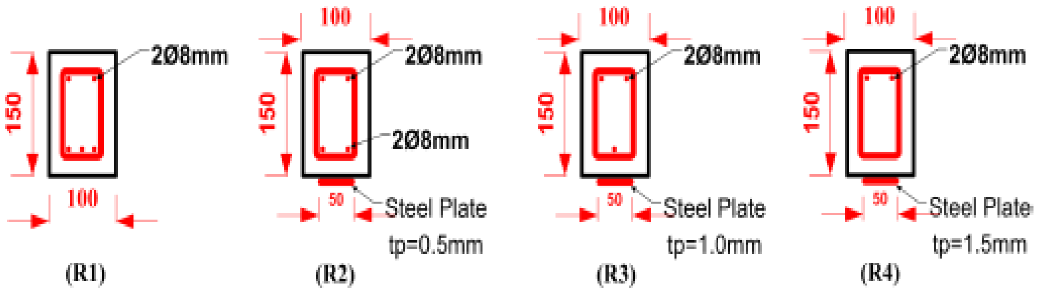
In 2011, Awadh E. Ajeel, Rana Hashim and Dina Mukheef [45] presented thorough test data on the impact of externally bonded steel plate at the tension face of a beam on the cracking pattern, structural deformations, and the ultimate strength of externally reinforced concrete beams. The experimental work include : flexural testing of (100*150*1500)mm , In order to study the reciprocal effects of increasing plate thickness against its breadth and vice versa, concrete beams were divided into two groups.The test variable included the amount of conventional (internal) reinforcement, percentage of replacing the internal reinforcement with external steel plate and the dimensions of plate. Provided the adhesive layer are chosen carefully and proper gluing techniques are followed . The results demonstrated that externally reinforced beams exhibit beam action and composite behavior up until failure and can be successfully used in place of internal reinforcement where replacement ratios of removed bars to the original tension bars are equal to 33% and 67% in which the steel plates used of wider and thiner than other used plates. However, the maximum plate thickness beyond which shear/bond failure takes place occurs before the beams reach their maximum flexural strength (premature failure).Figure 2.19, show the details of the Reinforced concrete beams, and figure 2.20, show the cracks pattern of the group one and group two.



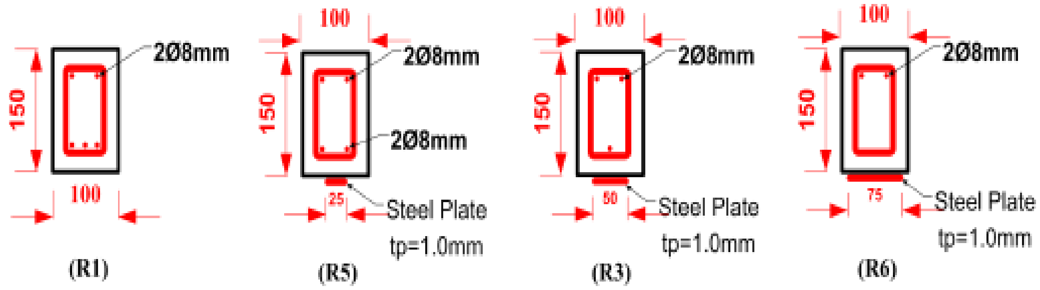
(a) Reference Beam R1



(b) Beams Reinforced Externally by Steel Plate



(c) First Group of Beams with Plate Width=50mm and Plate Thickness=0.5-1.0-1.5mm



(d) Second Group of Beams with Plate Width=25-50-75mm and Plate Thickness=1.0mm

Figure 2.19 Details of the Reinforced concrete beams (Ajeel, Ghedan, & Hamza, 2011)

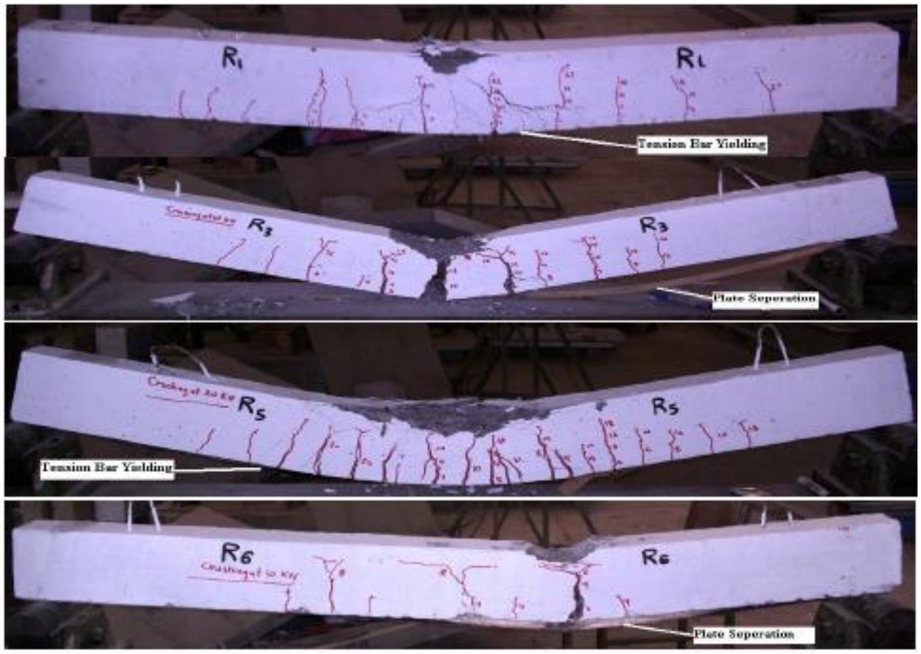


Figure 2.20 Beams specimens Figure 2.19 Details of the Reinforced concrete beams (Ajeel, Ghedan, & Hamza, 2011)

CHAPTER THREE
EXPERIMENTAL WORK

3.1 Introduction

In this chapter, the details of the experimental program are presented. It Showed of the details of materials used (cement , sand , coarse aggregate ,types of polymer modified cement mortar , steel reinforcement , wire mesh and bonding material Sikadur-32LP).Prepare the molds , casting procedures, curing , the mechanical tests (compression ,flexural and tension strength) for materials used , details of cover layer materials and explain how to replacing the cover layer .explain the connection methods between the cover layer at tension zone with the bottom face of the strengthened concrete slabs.

3.2 Material properties

3.2.1 Cement

Krista ordinary Portland cement used in this study. To protect the cement's characteristics from the effects of moisture, it was placed in a dry location. The results of the physical and chemical properties of the cement are shown in Tables 3.1 and 3.2, respectively. The tests are done in the laboratory of the Technical Institute of Amara according to the specification[46].

Table 3.1 Physical properties of the cement.

Physical Properties	Test result	Limit of IOS 5:1984
Fineness using Blaine air permeability apparatus (m^2/kg)	312	≥230
Setting time using Vicat's instruments Initial (hrs: min.) Final (hrs: min)	 130 min 4:00 hrs	 ≥45 min ≤10 hrs
Compressive strength 3 days (MPa) 7 days (MPa)	 20.6 28.4	 ≥15 ≥23

Table 3.2 Chemical composition of the cement.

Compound composition	Chemical composition	Percentage by weight	Limits of IOS 5:1984
Lime	CaO	62.45	_
Silica	SiO_2	21.00	_
Alumina	Al_2O_3	5.22	_
Iron Oxide	Fe_2O_3	3.25	_
Magnesia	MgO	2.73	≤ 5
Sulfate	SO_3	2.45	≤ 2.8
Loss on Ignition	L.O.I	3.28	≤ 4
Insoluble residue	I.R	0.85	≤ 1.5
Lime saturation factor	L.S.F	0.90	0.66-1.02
Main Compounds (Bogue's equation) percentage by weight of cement			
Tri calcium silicate (C_3S)		48.10	
Di calcium Silicate (C_2S)		20.82	
Tri calcium Aluminate (C_3A)		8.16	
Tetra calcium Alumino ferrite (C_4AF)		9.18	

3.2.2 Fine Aggregate (Sand)

All concrete mixtures have included natural sand. From the city of Basra in southern Iraq, it was brought. The maximum grain size is 4.75 mm and the modulus of fineness is 2.65. Laboratory tests for sand have been carried out according to the Iraqi specifications[47] and [48] . The results of these tests have been listed in Table 3.3 and Table 3.4.

Table 3.3 Grading of the fine aggregate.

N0	Sieve size mm	Passing(%) by weight		
		Percentage finer	Limits of IOS No. -45/1984 zone2	ASTM C33-03
1	10	100	100	100
2	4.75	99	90-100	95-100
3	2.36	96	75-100	80-100
4	1.18	69.3	55-90	50-85
5	0.60	35.2	35-59	25-60
6	0.30	15.1	8-30	5-30
7	0.15	4	0-10	0-10

Table 3.4 Physical properties of fine aggregate.

Physical properties	Test results	Limits of Iraqi specification No.45/1984
Specific gravity	2.65	----
Fineness modulus	2.74	----
Sulfate content %	0.33%	≤0.5%
Absorption %	1.5	----
Chloride content(CI)	0.072%	≤ 0.1 %
Loose bulk density kg/m^3	1645	----

3.2.3 Coarse Aggregate

Coarse aggregate from the Chilat region of eastern Amarah was used in the concrete mix in this study.A maximum size aggregate of 10 mm is used. The results indicate that, the coarse aggregate grading is within the requirements of Iraqi specification [47] and[48]. Before use, the coarse aggregate was stored in a saturated-surface dry state after being cleaned to remove the dust and dried by exposure to air. Grading and properties of the aggregate are presented in Tables 3.5 and 3.6.

Table 3.5 Grading of coarse aggregate.

N0	Sieve size (mm)	Passing(%)		
		Percentage Finer	Limits of IOS No.45/1984	ASTM C33-03
1	12	100	90-100	90-100
2	10	61	85-100	85-100
3	4.75	25	10-30	10-30
4	2.36	3	0-10	0-10

Table 3.6 Properties of coarse aggregate.

Physical properties	Test results	Limits of IOS No.45/1984
Specific gravity	2.63	-
Sulfate content(SO_3)	0.072%	≤ 0.1 %
Absorption	0.64%	-
Chloride content(CI)	0.092%	≤ 0.1 %
Loose bulk density kg/m^3	1548	-

3.2.4 Mixing Water

The reverse osmosis (R.O) water was used for casting and curing all the specimens.

3.2.5 Epoxy Adhesives

Sikadur-32 LP was used to bond the cover layer (first layer) with the bottom face of upper part of the slab. Two parts resin from component (A) and one part hardener from component (B) were combined to create epoxy, as shown in figure 3.1. At the first we must clean the surface of cover layer by brush before the painting.

Figure 3.1 Mixing epoxy components (Sikadur-32LP)

3.3 Materials of the Strengthening (Cover layer materials)

3.3.1 Polymer Modified Cement (PMC)

Is made by replacing a portion of the traditional binders with polymers. To improve properties like adhesion, toughness, flexural or tensile strength, and chemical resistance, polymers are added to ordinary mortar. In this study, four different types of polymer modified cement mortar were used, made in (Dcp) company branch Iraq, as shown in figure 3.2, named commercially as follows:

Figure 3.2 Types of polymer modified cement

3.3.1.1 Cempatch S

Is a one component polymer modified and fibre reinforced repair mortar. is a combination of powdered dry materials, particular aggregates, and fibers that, when combined with water, create a thixotropic mortar appropriate for use in vertical and overhead applications[49]. the technical Properties are presented in Tables 3.7.

Table 3.7 The technical Properties of Cempatch S

Colour	Grey & white
Compressive strength	≥ 45 MPa
Flexural strength	≥ 6.0 MPa @ 28 days ASTM C348
Tensile strength	≥ 3.0 MPa @ 28 days ASTM C307
Fresh wet density	2.1 ± 0.1 g/cm³
Change in length	Up to 0.1% @ 56 days ASTM C157
Adhesive bond	≥ 2 MPa

- **Thicknesses and Size Limitations**

Cempatch S: Can be used for sections up to (50) mm thick in overhead applications and (75) mm thick in vertical applications in a single application. Thickness should not be less than 10 mm deep in all applications.

- **Advantages**

- Polymer-modified cementitious repair mortar with controlled shrinkage.

- It only has to be added water and is simple to apply.

- Steel reinforcements and host concrete are well-protected by the material's extremely low water permeability.

- Thixotropic properties allowing extra high build for vertical and overhead applications.

- Both internal and external applications are suitable.

3.3.1.2 Cempatch FL

Is a single component polymer modified repair system. is made up of a combination of dry powders and chosen aggregates that, when combined with water, create a shrinkage-compensated, self-compacting, and free-flowing micro-concrete suitable for large-volume concrete repairs [50] .the technical Properties are presented in Tables 3.8.

Table 3.8 The technical Properties of Cempatch FL

Colour	Grey & white
Compressive strength	≥ 55 MPa
Flexural strength	≥ 13 MPa
Working time	20 – 25 min @ 20°C 12 – 17 min @ 35°C
Change in length	less than -0.02%
Initial Final	6 – 7 hr @ 25°C 9 – 10 hr @ 25°C

- **Thicknesses and Size Limitations**

Cempatch FL can be used for large repair voids at thicknesses larger than 50 mm and up to 200 mm in a single application.

- **Advantages**

- High initial and ultimate strength development.

- Very high flow, suitable for repair of steel congested areas.

- Shrinkage controlled polymer modified cementitious repair eliminates cracking.

- Easy to apply, single component, requires only addition of water.

- Extremely low permeability, providing excellent protection to steel reinforcements and host concrete.

- High bond strength, self-priming and self-compacting.

- Both internal and external applications are suitable.

- No independent primer is required.

3.3.1.3 Cempatch FS

is a single-component polymer-modified mortar for repairs. Cempatch FS is a self-compacting, high early and ultimate strength repair mortar made of a combination of dry powders and chosen aggregates that, when combined with water, make a self-compacting mortar [51].the technical Properties are presented in Tables 3.9.

Table 3.9 The technical Properties of FS

Compressive strength	> 56.0 MPa @ 28 days
Working time	≈ 20 - 25 min @ 20°C ≈ 12 – 17 min @ 35°C
Setting time	Initial Final ≈ 35 - 45 min @ 25°C ≈ 48 - 55 min @ 25°C
Mixing ratio	3.75 liter water for 25 kg Bag of Cempatch FS
Pedestrian time	≈ after 1 hr
Minimum application temperature	5°C

- **Thicknesses and Size Limitations**

Cempatch FS can be applied in a single application for portions up to 100 mm thick. 20 mm is the bare minimum thickness.

- **Advantages**

- Fast setting with high early strength development which facilitates quick return to service.

- Extremely low shrinkage which reduces any potential cracking.

- Easy to apply, single component, require only addition of water.

- Extremely low permeability providing excellent protection to steel reinforcement and host concrete.

- Self compacting. High bond strength without need for a primer.

- Suitable for internal and external applications.

3.3.1.4 Flo-Grout.2

Flo-Grout.2 is pre-mixed, pre-packed chloride free cementitious grout. It contains cement, selected additives, well graded, and non-reaactive aggregates and is designed to give excellent flow properties , shrinkage composition, frost resistance, and high compressive strength[52]. the technical Properties are presented in Tables 3.10.

Table 3.10 The technical Properties of Flo-grout.2

Colour	Grey & white
Compressive strength	≥ 30 MPa
Flexural strength	≥ 9.0 MPa @ 28 days ASTM C348
Application temperature	4 – 50°C
Expansion characteristics	Up to 3%
Fresh wet density	2.1 ± 0.05 g/cm^3
Service temperature	-20 to 200°C
Initial setting time @ 25°C	8 hr

- **Thicknesses and Size Limitations**

Flo-Grout.2 can be applied in a single layer at thickness between (10 – 100) mm, For greater thickness.

- **Advantages**

- Good non-shrinkage characteristics.

- Extremely dense and low permeability.

- High early strength development allowing for rapid installation.

- High flow can be poured or pumped into variable gap widths down to 10 mm.

- Easy to apply, single component which require only addition of water.

3.3.2 Normal mortar (sand + Portland cement)

krista Portland cement and natural sand, as shown in figure 3.3, were used in the ratio of 1:2/0.4 by weight. This mortar gives after 28-days strength of (13.43 MPa).

Figure 3.3 Krista portland cement and sand

3.3.3 Welded Wire Mesh

steel welded wire-mesh with (1.2 mm) diameter and (25.4 mm) square openings, as shown in figure 3.4 .The choice of square mesh was related to many studies stated that the type of mesh with square opening is better than any other types of mesh [53]. The mesh tested according to the method described in reference [54] to get its yield strength and it was found to be 350 MPa.

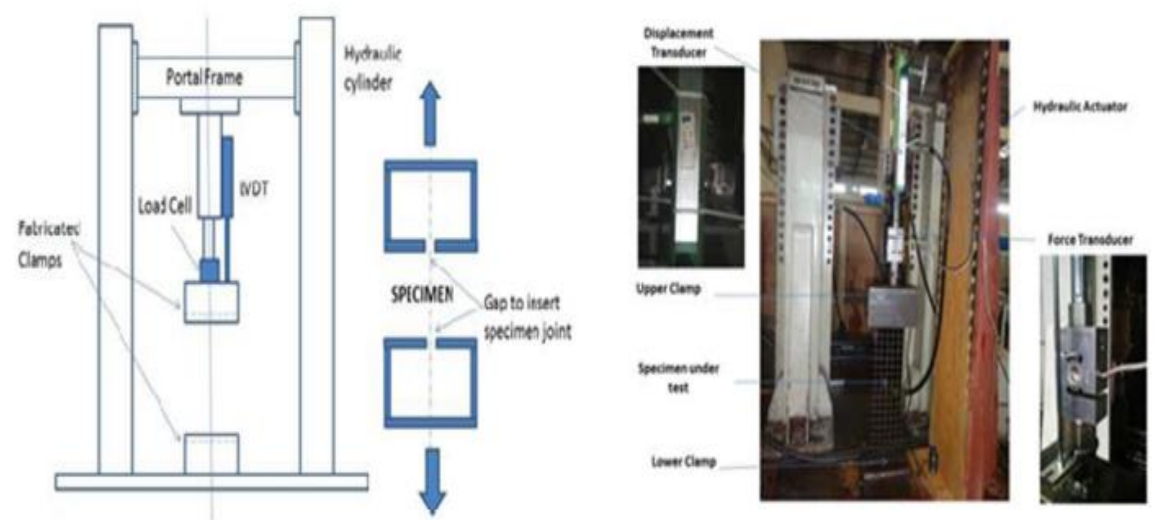


Fig.1 Schematic Test set up

Fig. 2 Laboratory Tension test set up

Figure 3.4 Test of welded wire-mesh

3.4 The Mechanical Tests of the Strengthening Materials

3.4.1 Compressive and Flexural Strength

The mechanical properties were determined at the day of testing. Six mortar prisms with dimensions of (160 mm× 40 mm×40 mm) and six mortar cubes (50×50×50) mm were tested experimentally, as shown in figure 3.5. The testing procedure was conducted based on the recommendations provided by BS EN1015-11 (1999). Results of the testing are presented in Tables 3.11 and 3.12.

Table 3.11 Results of compressive strength of cement mortar

Age	Type of Cement mortar	Cube1 Mpa	Cube2 Mpa	Cube3 Mpa	Average Mpa
At 7 days	Cempatch FS	33	31	32.6	32.2
	Cempatch FL	44	46.10	40.60	43.5
	Cempatch S	41.8	39.8	40.6	40.73
	Flo-grout.2	40.36	41.8	39	40.38
	Normal mortar	10.25	9.85	10.63	10.24
At 28 days	Cempatch FS	27.28	30.52	28.5	28.76
	Cempatch FL	38.70	37.24	39	38.31
	Cempatch S	34.50	37.30	35	35.60
	Flo-grout.2	36.70	35	34.80	35.50
	Normal mortar	12.5	13.8	14	13.43

Table 3.12 Results of flexure strength of cement mortar

Age	Type of Cement mortar	Cube1 Mpa	Cube2 Mpa	Cube3 Mpa	Average Mpa
At 7 days	Cempatch FS	4.6	4.72	5.46	4.92
	Cempatch FL	9.42	8.82	8.95	9.06
	Cempatch S	6.29	6.25	6.96	6.50
	Flo-grout.2	5.56	5.45	5.20	5.40
	Normal mortar	1.85	2.15	2.25	2.08
At 28 days	Cempatch FS	4.90	4.25	5.15	4.76
	Cempatch FL	8.50	9.40	8.75	8.88
	Cempatch S	6.20	6.18	6.80	6.40
	Flo-grout.2	5.15	5.18	5.40	5.24
	Normal mortar	1.95	2.30	2.25	2.16

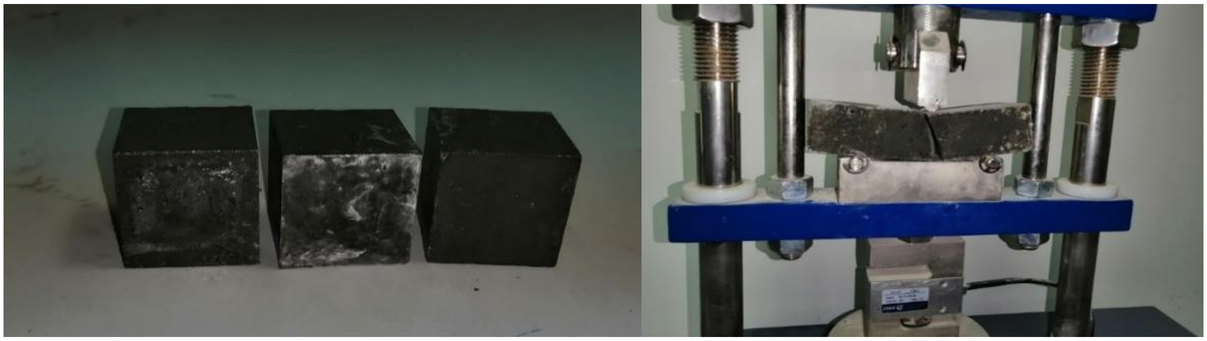


Figure 3.5 Flexural and compressive test of cover layer materials

3.5 Steel Reinforcement

Deformed steel bars with diameter 10 mm were use for both lateral and longitudinal reinforcement in all slabs.the spacing between the steel bars in both direction 160 mm . 500 mm long specimens were tested to determine the yield stress (f_y) and the ultimate strength (f_u) as shown in Fig. 3.5. The test was conducted according to (Iraqi limits 2091/1999) and[55]. The properties of the tested bars are presented in Table 3.14.

Table 3.13 Properties of Steel Reinforcement.

Nominal (mm)	Measured (mm)	Area (mm^2)	Yielding Stress (Mpa)	Ultimate Strength (Mpa)	Elongation %
10	9.68	78.5	529	634.8	13.6

Figure 3.6 Test of tensile strength

3.6 Test Variables

In this study three variables are investigated: type of the construction materials that used to cast the cover layer of the strengthened slab, thickness of the cover layer for the strengthened concrete slab and state of the cover layer : reinforced with wire mesh or without reinforced. The specimens were cast, water cured for 28 days. The main purpose behind the project is to study the flexure behavior of the strengthened concrete slabs. To this aim the experimental program examined the effect of the following variables on the strengthened concrete slabs:

3.6.1 Type of the Construction Materials (the strengthening materials)

In this study four different type of polymer modified cement commercial namly for it (cempatch FL , cempatch FS , cempatch S , flo-grout.2) ,in addition to the normal mortar (ordinary portland cement + sand) are used to cast the cover layer of the strengthened concrete slabs . the purpose of using the different type of the construction materials (different flexural and compressive strengths), to show its effect on the ultimate loads , first crack load and the deflection and knowing the effectiveness of the materials if they are effective or ineffective regarding the strengthening .

3.6.2 Thickness of the Cover Layer

casting the cover layer of the slab with thickness (25- 40)mm and study the effect of the variable thickness on the ultimate loads ,first load crack and the deflection value .

3.6.3 State of the Cover Layer (Reinforced with Wire Mesh or Without reinforced)

In this study the cover layer of the strengthened concrete slabs on two state : the first state the cover layer reinforced with one layer of wire mesh (25*25) mm . Embeded (submerged) the welded wire mesh(1) mm into the cover layer.

(polymer modified cement mortar + wire-mesh = Reinforced Polymer modified Cement Mortar (RPMCM)).

(polymer modified cement mortar (just mortar) = PMCM .

the second state of the cover layer : the cover layer without reinforced that mean the cover layer in this case just mortar .

3.7 Preparation the Materials , the Molds and the Tools before the Casting

All the materials and equipments must be prepared, to complete the casting process , As follows :

1- Prepare the wood molds (molds made of plywood).The molds must be clean and oiled to prevent the adhesive the concrete, as shown in figure 3.7 (a) . The dimensions of the molds are (length = 1500 mm , width = 750 mm and depth = 150 mm).

2- Prepare Steel Concrete Cube Molds (150 * 150 * 150)mm , six cylinder (150*300) mm , six prism molds (100*100*500)mm, as shown in figure 3.7 (b), and the cone to measure concrete slump .The molds must oiled to prevent adhesive concrete.

3- Prepare the steel reinforcement (Ø10@160 mm) , the welded wire mesh and the tiying wire, as shown in 3.7 (c).

4- Prepare the bonding material (sikadure- 32 LP).

5- Prepare the construction materials (cement , gravel , sand ,RO water) and the polymer modified cement mortar that commercial namly (cempatch FL ,cempatch FS ,cempatch S, Flo-grout2).

6- Prepare clean container and electric drill fitted with suitable paddle should be

for mixing the construction materials, as shown in figure 3.7 (d).

7- Prepare trowel to level surface of the construction materials.

(b) (a)

(d) (c)

Figure 3.7 Prepare the Tools and Molds

3.8 Casting of the Concrete Slabs

To fail in flexure, all of the reinforced concrete slab specimens were designed with the same dimensions and reinforcement. fifteen simply supported slabs were tested. The dimensions of the slabs were (length =1500 mm, width =750 mm and depth = 150 mm), as shown in figure 3.7. Each reinforced concrete slab is reinforced with Ø10@160 mm c/c as a main reinforcement in both direction .The specimens were arranged in three groups; (A-C) as follow:-

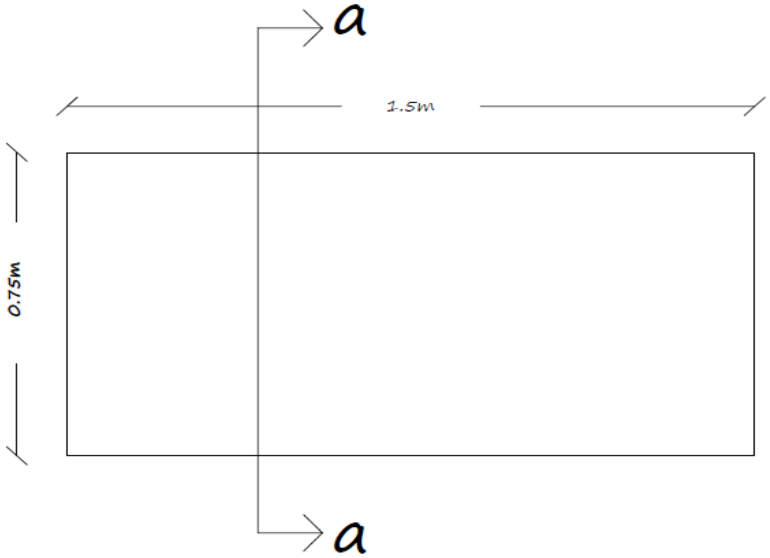


Figure 3.8 Top view of the slab specimen

3.8.1The control slab (group A)

This group consisted of one specimen; this specimen was the control slab with normal concrete cover and tested up to failure. casting of the specimen was on one stage.Section (a-a), as shown in figure 3.8.

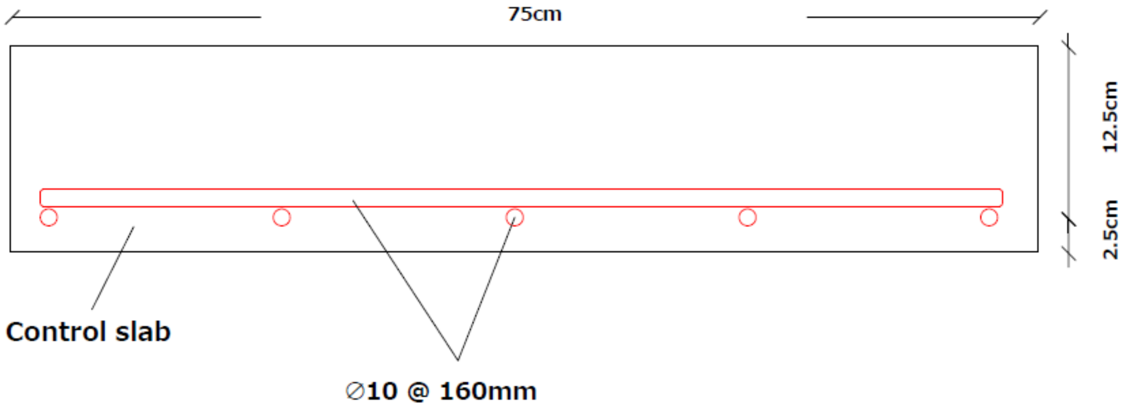


Figure 3.9 Cross section of control slab

3.8.2 The Strengthened Concrete Slabs (group B and C)

This study include Fourteen strengthened concrete slabs are divided into two groups: group (B) contains seven concrete slabs and group (C) contains seven concrete slabs also.The strengthening method is by replacement the concrete cover layer at tension zone of the slab and using of polymer modified cement mortar (PMCM) to cast the cover layer . Casting of the strengthened concrete slabs was on two stages :-

3.8.2.1 The First Stage (Casting of the Cover Layer of the Strengthened Slab)

- Prepare a clean container and use an electric drill with a suitable paddle for mixing of the consruction materials of the cover layer, then adding RO water gradually.Mixing time should be continued for 3 minutes until uniform consistency is obtained. as shown in figure 3.10 (a).

- Casting the cover layer of the slab with thickness (25- 40) mm, while the total depth remains constant (150)mm ,as shown in figure 3.10 (b), where the mortar (polymer modified cement mortar)(PMCM) and normal mortar placed at the bottom of the mold first. Four different types of (PMCM) (FL,FS,S and FLO-grout.2)were used.

(b) (a)

Figure 3.10 Casting the cover layer

- The top surface of the cover layer must be roughing in order to help in bonding with bottom face of upper part of slab, this regarding for group C.
- Curing process for the cover layer before the starting of casting the upper part of the slab and continue the curing for 28 day.There are different between group (B) and group (C), regarding the cover layer state as follow :-

*** Casting the cover of group B** : The cover layer reinforced with one layer of welded wire mesh square opening (25.4 * 25.4) mm and diameter (1) mm,as shown in figure 3.11 . Before the harding of the cover layer , by hand tryed to submerge (embeded) the welded wire mesh(1) mm into the cover layer, as shown in figure 3.12, while the rebar remains on top the surface of the cover layer ,figure 3.14 show it , thus, the cover layer is made of reinforced polymer modified cement mortar (RPMCM) . As shown in the figure 3.13, the welded wire mesh connect with rebar by tiying wire and this is the connection method between the cover layer and the bottom face of the upper part of the slab for group (B).Figure 3.15 , show the details of cross section of slab (group B).

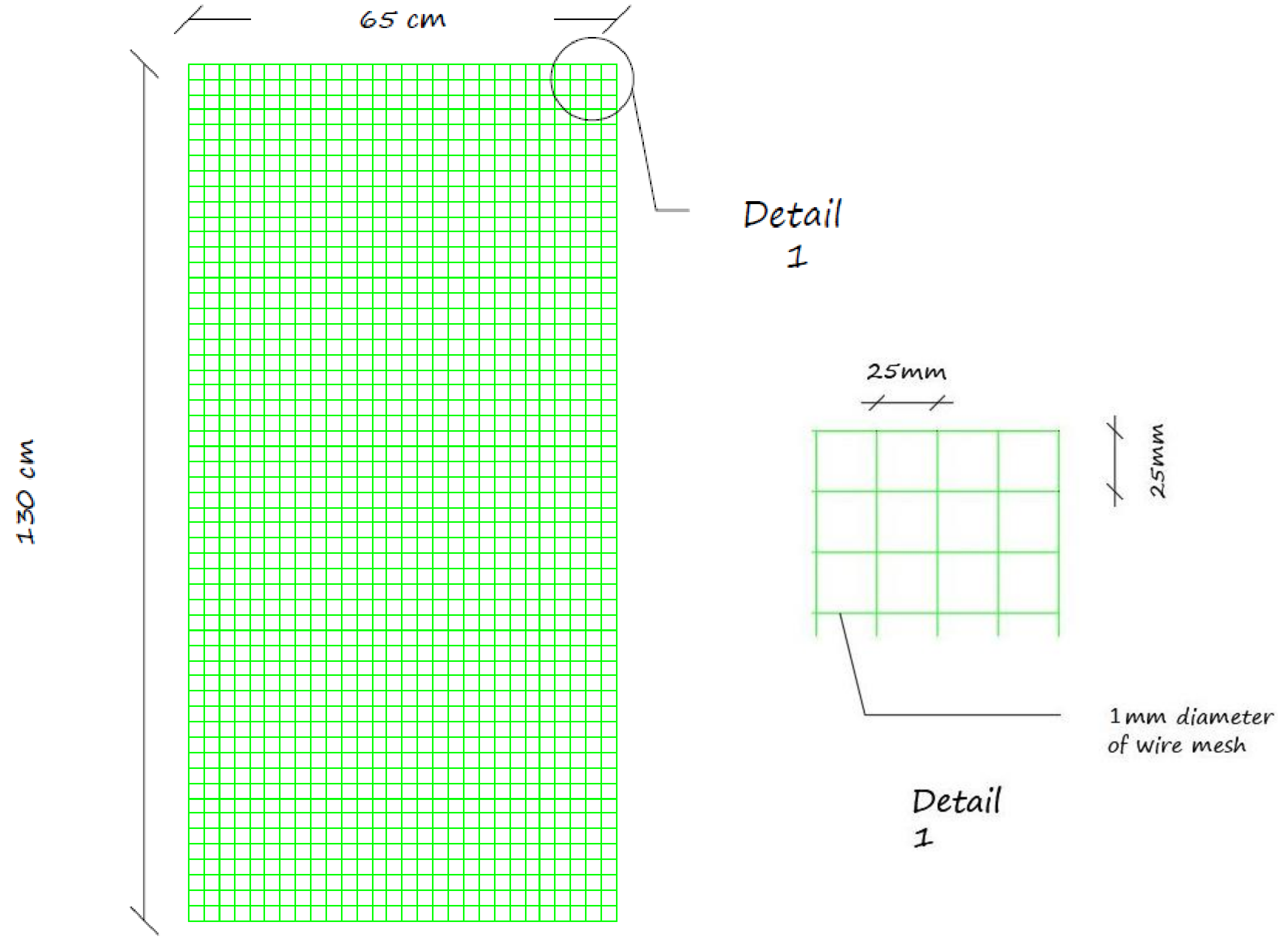


Figure 3.11 Details of the wire-mesh

Figure 3.12 Embed the wire mesh

Figure 3.13 wire mesh connect with rebar

Figure 3.14 Rebar on the top surface of cover

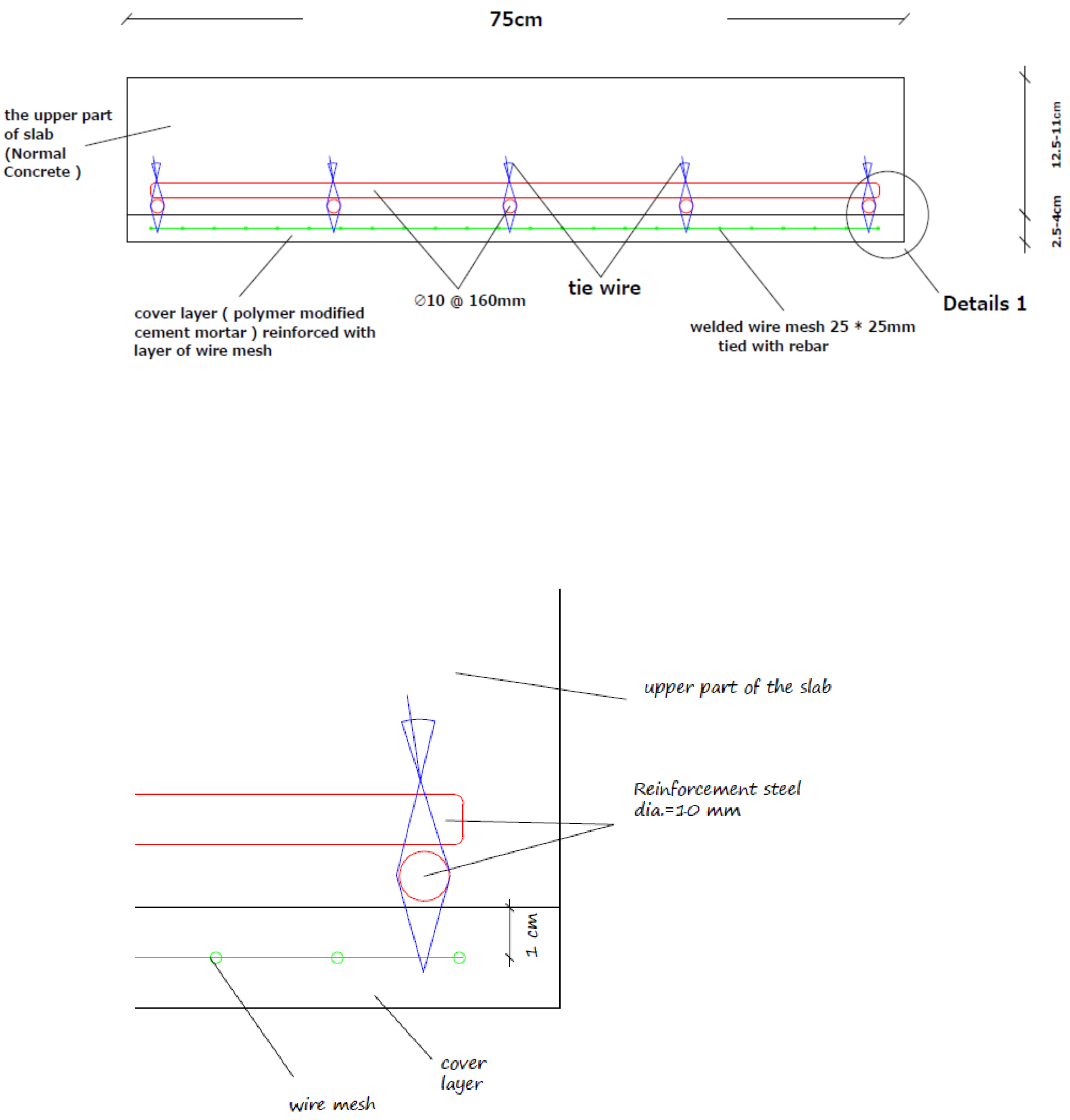


Figure 3.15 Details of cross section of slab (group B)

*** Casting the Cover of group C** : The cover layer without reinforced.That mean the cover layer just polymer cement mortar (PCM) and the connection method between the cover layer and the bottom face of the upper part of the slab by the epoxy (bonding material [sikadur-32 LP]) as shown in figure 3.14 . The top surface of the cover layer for group (C), must be roughing in order to help in bonding with upper part of the slab In addition to the bonding strength of the epoxy material . Before casting the top part of the slab, the top surface of the cover must clean and paint with epoxy ,as shown in figure 3.16.

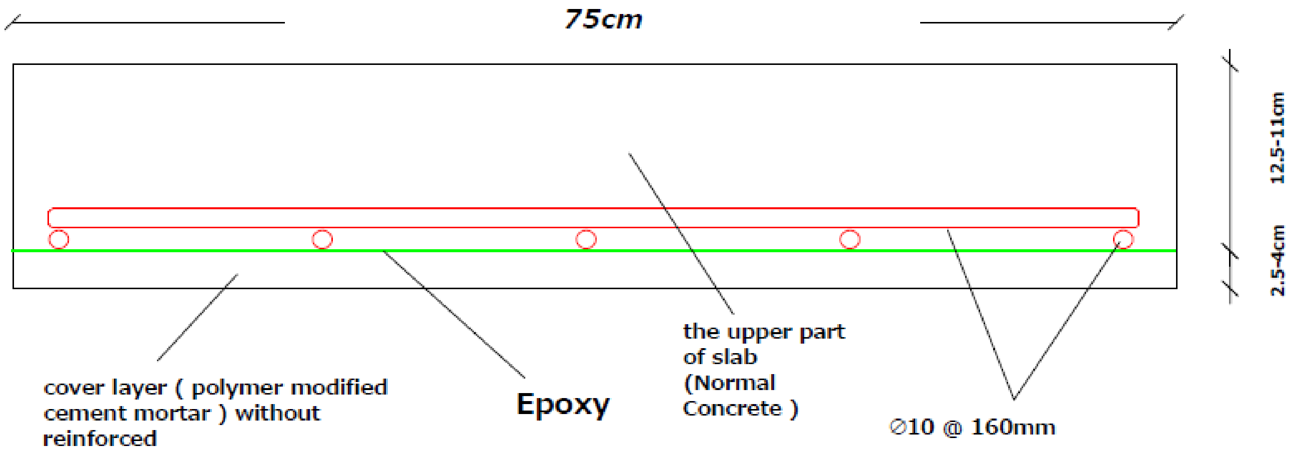


Figure 3.16 Cross section of slab (group C)

3.8.2.2 The Second Stage (Casting the upper Part of the Strengthened Slab)

Concrete was directly poured into the formwork from the concrete mixer. Casting of the upper part of the slab with thickness (125-110)mm . The slab specimens were cast using ready-mix concrete with a 23.84 MPa compressive strength. All the slabs were casted using the same transit mixer, as shown in figure 3.15, at one time. For each cubic meter, the mixture proportions were (1003) kg of gravel, (776) kg of sand, (316) kg of ordinary Portland cement and (194) leter of water. The total density was 2466 kg/m3. The water-to-cement (W:C) ratio was kept at 0.61. All specimens were cast in a horizontal position, as shown in Figure 3.16. To prevent any segregation, the concrete was compacted using hand-held vibratos. During casting, samples of concrete cubes, cylinders, and prisms were taken, as shown in Figure 3.17. Using a trowel, the concrete surface was finished and smoothed.

Figure 3.17 Mixer of concrete

Figure 3.18 Casting of the specimens

Figure 3.19 Take of concrete samples

3.9 Symbols of the Specimens

The symbols of the strengthened slabs are explained as follow:-

C.S. = control slab with (2.5cm) thickness of cover layer.

FL1-EP.

Type of cover layer material (Cempatch FL)

Thickness of cover layer (1= 25 mm)

Connection method by Epoxy

S2-W.

Type of cover layer material (Cempatch S)

Thickness of cover layer (2= 40 mm)

Connection method by tie the wiremesh with rebar

N-W.

Normal mortar (sand + cement)

without number this Mean thickness=25mm

Connection method by tie the wiremesh with rebar

Details of the slabs like group number , type of cover layer materials , thickness of the cover , method connection (state the cover layer of the strengthened slab reinforced with wire-mesh or without reinforced) and the total depth of the slab, are presented in Table 3.14.

Table 3.14 Details of the Slabs

Group NO.	SLAB	Type of Cover layer materials	Thickness Of the Cover(mm)	State of The Cover	Total depth (mm)
A	**C.S.**	**Normal concrete**	**25**	**---------**	**150**
B	**FS1-W.**	**Polymer cement mortar (Commercial name cempatch FS)**	**25**	**The cover layer reinforced With One layer Of wire mesh (RPMCM)**	**150**
	FL1-W.	**Polymer cement mortar (Commercial name cempatch FL)**	**25**		
	FL2-W.	**Polymer cement mortar (Commercial name cempatch FL)**	**40**		
	Flo grout-W.	**Polymer cement mortar (Commercial name flo-grout2)**	**25**		
	S1-W.	**Polymer cement mortar (Commercial name cempatch S)**	**25**		
	S2-W.	**Polymer cement mortar (Commercial name cempatch S)**	**40**		
	N-W.	**Normal mortar (Cement + sand)**	**25**	**Ferrocement cover**	
C	**FS1-EP.**	**Polymer cement mortar (Commercial name cempatch FS)**	**25**	**The cover layer without reinforced (PMCM)**	**150**
	FL1-EP.	**Polymer cement mortar (Commercial name cempatch FL)**	**25**		
	FL2-EP.	**Polymer cement mortar (Commercial name cempatch FL)**	**40**		
	Flo grout-EP.	**Polymer cement mortar (Commercial name flo-grout2)**	**25**		
	S1-EP.	**Polymer cement mortar (Commercial name cempatch S)**	**25**		
	FS2-EP.	**Polymer cement mortar (Commercial name cempatch FS)**	**40**		
	N-EP.	**Normal mortar**	**25**	**Normal mortar**	

3.10 Curing the Specimens

In order to reach the required compressive strength of concrete, all specimens underwent a 28-day curing process following casting. The slabs were set down in a shady location and covered with hessian cloth, as shown in figure3.18. For 28 days, the samples received two daily sprinkles of water. Before the test day, all specimens were maintained in a shady place following the curing period.R.O. water used for the curing.

Figure 3.20 Curing the Specimens

3.11 Tests of Hardened Concrete

3.11.1 Cube Compressive Strength (f_{cu})

Concrete's compressive strength was tested using cubical specimens that measured (150×150×150) mm, according to the [56]. This test was conducted in a laboratory at the College of Engineering of Missan, using a compression machine (2000 kN), as shown in Fig. 3.21. The results shown in Table 3.15.

Figure 3.21 Compressive test of specimen

3.11.2 Splitting tensile strength (f_{ct})

The splitting test was carried out according to [57], as shown in figure 3.22 .A total of six cylinders (150×300) mm, were tested. The test result shown in table 3.15 and the result calculated using the following formula:

$$f_{ct} = \frac{2P}{\pi DL} \qquad 3.1$$

Where:

f_{ct}: splitting tensile strength (N/mm^2).

P: Maximum applied load (N).

D: diameter of specimen (mm).

L: Length of the specimen (mm).

Figure 3.22 Splitting test of specimen

3.11.3 Flexural Strength Test (f_r)

The modulus of rupture was calculated in accordance with [58] . Three prisms of dimensions (100×100×500) mm, were cast for each category at the same time as the slabs were cast. This examination was carried out in the lab of the

Technical Institute of Amara. The modulus of rupture was obtained using a 100-ton machine as shown in Fig. 3.23. The expression given below is used to calculate the modulus of rupture and the results shown in table 3.15.

$$f_r = \frac{3PL}{2bd^2} \qquad 3.2$$

Where :

f_r: modulus of rupture (MPa). , b: average width of specimen (mm).

P: maximum applied load (N). , L: span length (mm).

d : average depth of specimen (mm).

Figure 3.23 Flexural test of specimen

Table 3.15 Results of mechanical properties of concrete.

Column		f_{cu} (Mpa)	f_r (Mpa)	f_{ct} (Mpa)
Category one at 7 days	Sample 1	21.50	3.55	2.45
	Sample 2	21.25	3.30	2.50
	Sample 3	20.90	3.25	2.85
	Average	21.21	3.36	2.60
Category two at 28 days	Sample 1	24.10	3.60	2.55
	Sample 2	23.82	3.52	2.90
	Sample 3	23.60	3.42	2.95
	Average	23.84	3.51	2.80

3.12 Displacement and Load Measurement

All slabs were tested under four-point flexural loading over a 1300mm clear span and equipped to measure mid- and third-of-the-span deflections. Figure 3.24 and Figure 3.25 ,show the position of LVDT, loading point on the slabs. Using an incremental loading approach, all of the slabs were tested. Linear variable displacement transducer (LVTD) was used to measure the mid and one-third of the span deflection of the slab. The deflection readings were captured using a portable electronic data logger. The loading system was assembled, and the measurement device's initial values for deflections and loads were zeroed. These conditions were then considered to represent the initial state of the slabs. After 28 days of curing, fifteen of these slabs are tested to determine their load carrying capabilities.

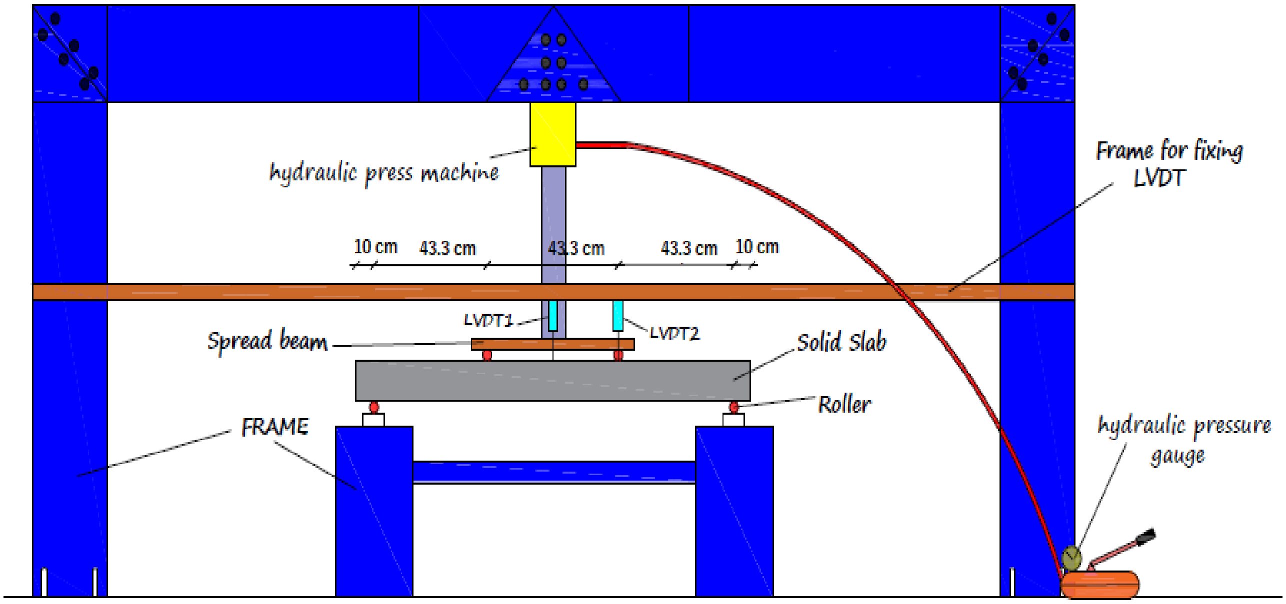


Figure 3.24 Position of LVDT and load point

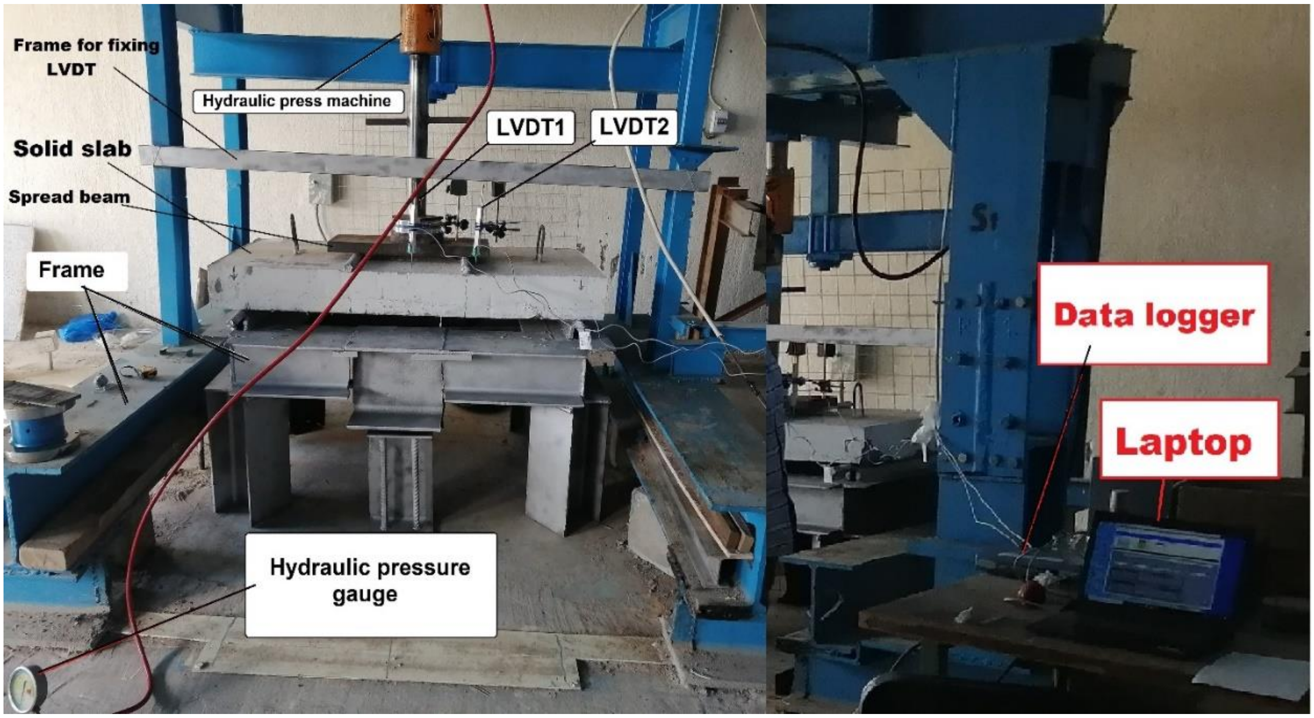
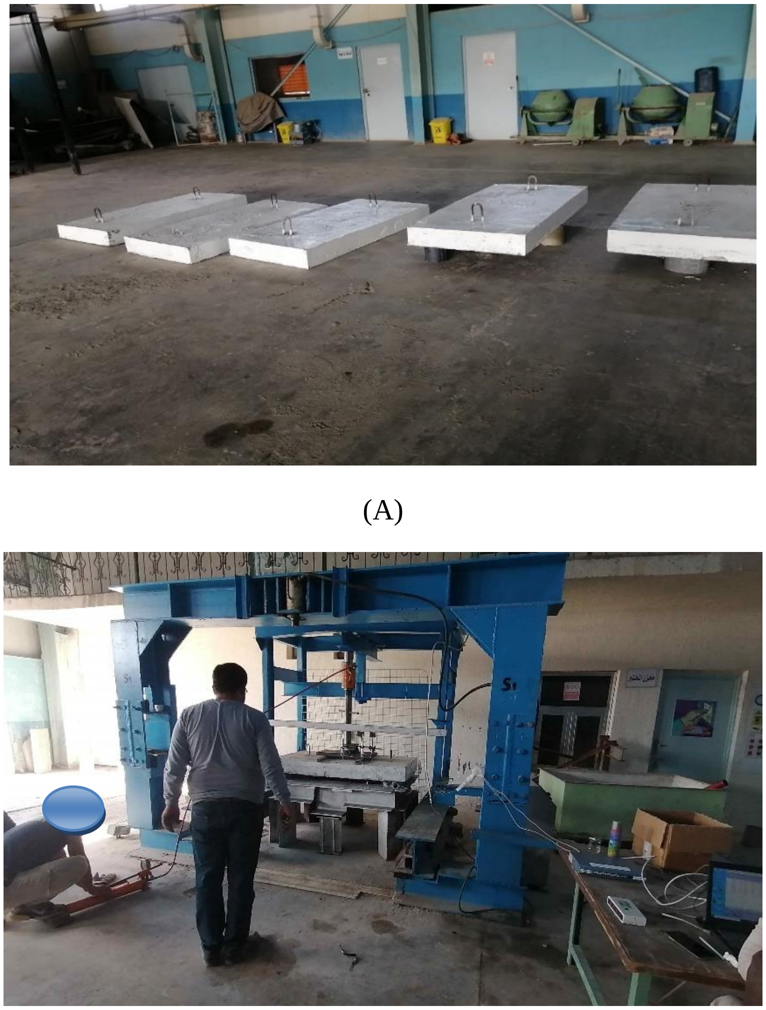


Figure 3.25 Test procedure

Figure 3.26 Specimen move by fork-lift



(A)

(B)

Figure 3.27 Prepare the specimens for testing

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 General

The results of the full-scale test specimens are illustrated and discussed in this chapter. The relationship between the load and maximum deflection of the tested specimens are plotted , Discussion includes flexural behavior and ultimate bending capacities. fifteen full-scale simply supported slabs with variable parameters were tested until failure under uniformly loading system. The main variables considered in the study are : the thickness of the cover layer, type of cover layer material (flexural and compressive strength variable for the cover materials) and the state of the cover layer reinforced with welded wire mesh or without reinforced .The test program was conducted in Structural Laboratory at the Amara technical institute in Iraq.

The name of the slab specimens were categorized based on the variable parameters

In the study, for example the specimen FL1-EP. ; (FL) is the type of cover layer material for the strengthened slab, the number (1) is the thickness of the cover layer equal 25mm , (EP.) is the method connection between the cover layer with the bottom face of the strengthened slab .

4.2 The experimental results of the Specimens

The experimental results are listed in Table 4.1. This table includes that : the load crack (Pcr),the yield load (Py), the ultimate load (Pu) , the deflection at the yield load (Δy) and ultimate load (Δu) and the increasing of the load capacity.

Analyze and discuss the results for three groups of the concrete slabs A , B and C. A complete description of load-deflection, ultimate loads, and failure characteristics are shown below.

Table 4.1 The experimental results

Group	Slab ID	Pcr (KN)	Py (KN)	Pu (KN)	Gain In Pu %	Δy (mm)	Δu (mm)	DI	Ki (kn/mm)	Ks (kn/mm)
A	C.S.	35	46	85	…….	1.50	9	6	30.66	9.44
B	FL1-W.	60	80	165	94	1.40	9.62	6.87	57.14	17.15
	FL2-W.	70	88	150	76.4	3.20	10	3.12	27.50	15
	FS1-W.	80	86	160	88	2.70	9.50	3.51	31.85	16.84
	S1-W.	70	82	165	94	1	7.67	7.67	82	21.51
	S2-W.	70	118	150	76.5	5.60	8.96	1.60	21.07	16.74
	FLO-W.	70	94	145	70.5	4.20	9.50	2.26	22.38	15.26
	N-W.	55	84	140	64.7	4.25	10.30	2.42	18.76	13.59
C	FL1-EP.	50	66	100	17.64	1.35	7	5.18	48.88	14.28
	FL2-EP.	40	49	90	5.88	1.30	9.40	7.23	37.70	9.57
	FS1-EP.	40	54	92	8.23	2.85	9	3.15	18.94	10.22
	FS2-EP.	40	60	95	11.76	2.70	8.50	3.14	22.22	11.17
	S1-EP.	45	57	98	15.29	3	10	3.33	19	9.80
	FLO-EP	40	54	95	11.76	3.20	10	3.12	16.87	9.50
	N-W.	30	53	88	3.52	3.90	12	3.07	13.58	7.33

4.3 Load–Deflection Relationship

4.3.1 The Control Slab (group A)

The experimental results for the load and the deflection of the control slab C.S. are presented in Figure 4.1.

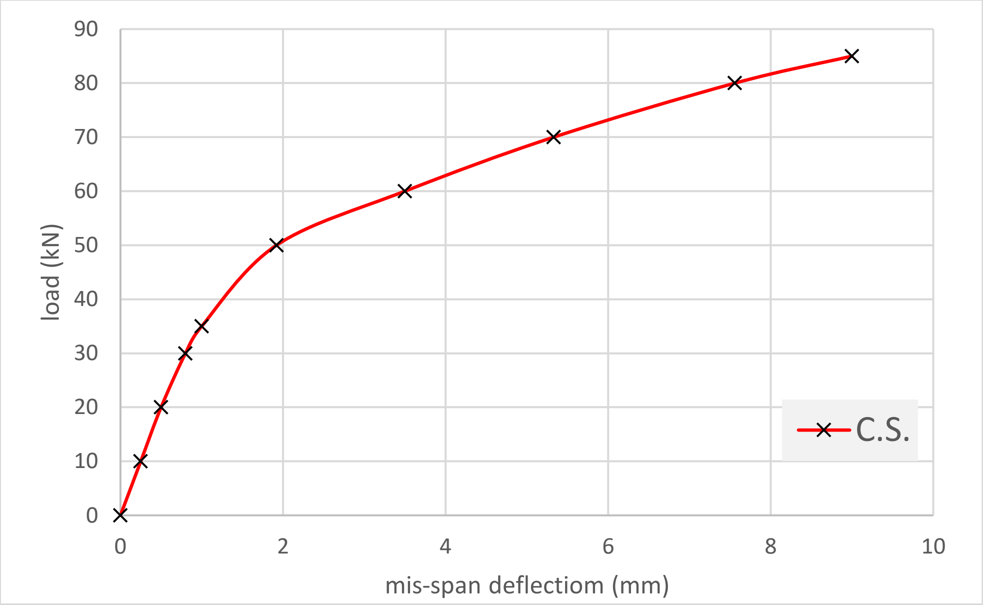


Figure 4.1 Load-Deflection Relationship for Control Slab

based on the results of Figure 4.1, The first crack in control slab appeared at the load of 35 kN , The ultimate load of the specimen was observed to be 85 kN, the yield load was equal to 46 kN/mm, and the deflection at the yield load and the ultimate load were equal to 1.5 mm and 9 mm, respectively . Appearing of the bending cracks in the tension zone of the slab and spread upwards as the load increased. Control slab failed, as expected, in a typical flexural failure mode through yielding of steel reinforcement followed by concrete crushing .

4.3.2 The Strengthened Slabs (group B)

4.3.2.1 The Specimen (FL1-W.)

based on the results of Figure 4.2, The first crack in The specimen (FL1-W.) appeared at the load of 60 kN , The ultimate load of the specimen was observed to be 165 kN, the yield load was equal 80 kN/mm, and the deflection at the yield load and the ultimate load were equal to 1.40 mm and 9.62 mm, respectively.

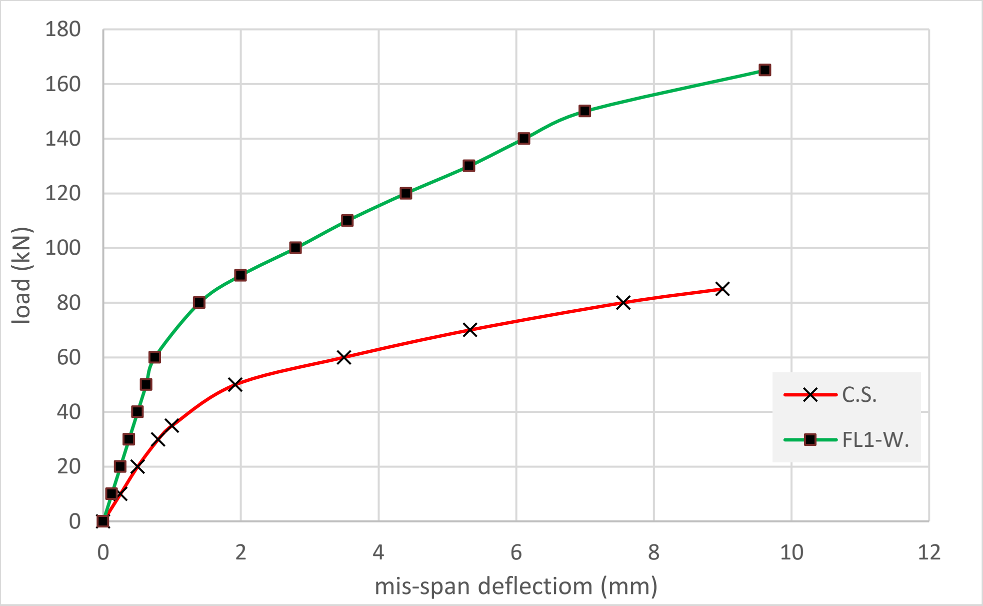


Figure 4.2 Load-Deflection Relationship between C.S. and FL1-W.

4.3.2.2 The Specimen (FL2-W.)

based on the results of Figure 4.3, The first crack in The specimen (FL2-W.) appeared at the load of 70 kN , The ultimate load of the specimen was observed to be 150 kN, the yield load was equal 88kN, and the deflection at the yield load and the ultimate load were equal to 3.20 mm and 10 mm, respectively.

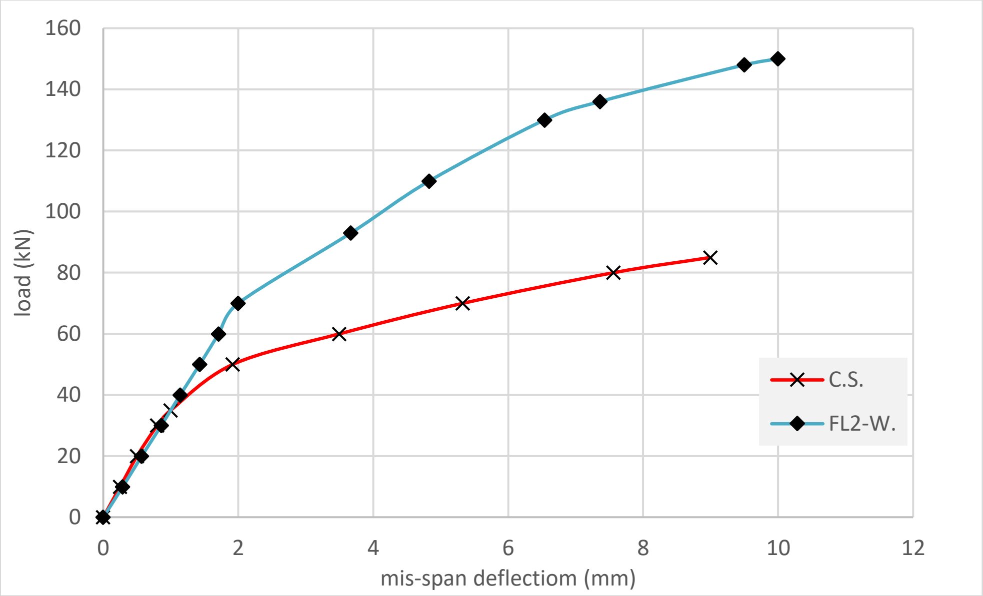


Figure 4.3 Load-Deflection Relationship between C.S. and FL2-W.

4.3.2.3 The Specimen (FS1-W.)

based on the results of Figure 4.4, The first crack in The specimen (FS1-W.) appeared at the load of 80 kN , The ultimate load of the specimen was observed to be 160 kN, the yield load was equal 86 kN, and the deflection at the yield load and the ultimate load were equal to 2.70 mm and 9.50 mm, respectively.

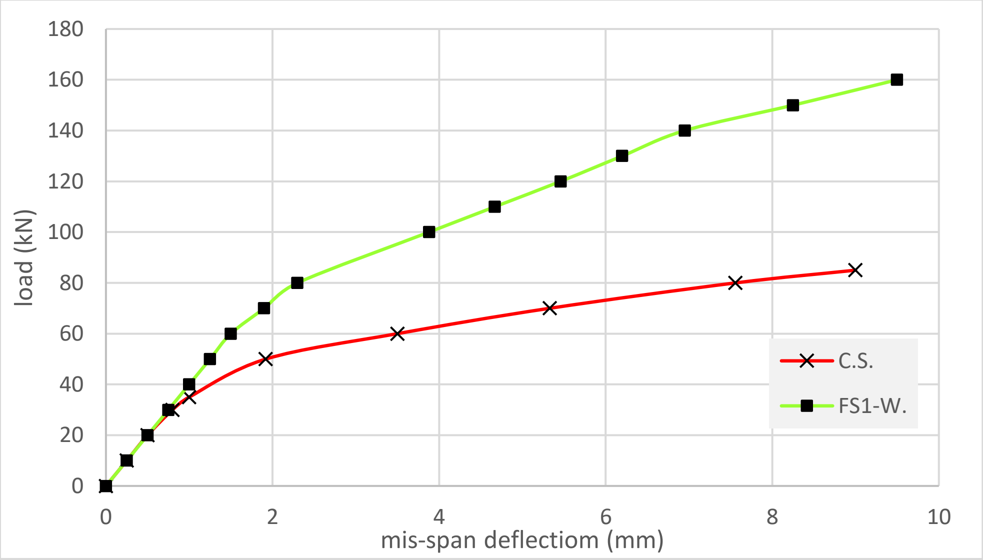


Figure 4.4 Load-Deflection Relationship between C.S. and FS1-W.

4.3.2.4 The Specimen (S1-W.)

based on the results of Figure 4.5, The first crack in The specimen (S1-W.) appeared at the load of 70 kN , The ultimate load of the specimen was observed to be 165 kN, the yield load was equal 82 kN, and the deflection at the yield load and the ultimate load were equal to 1 mm and 7.67 mm, respectively.

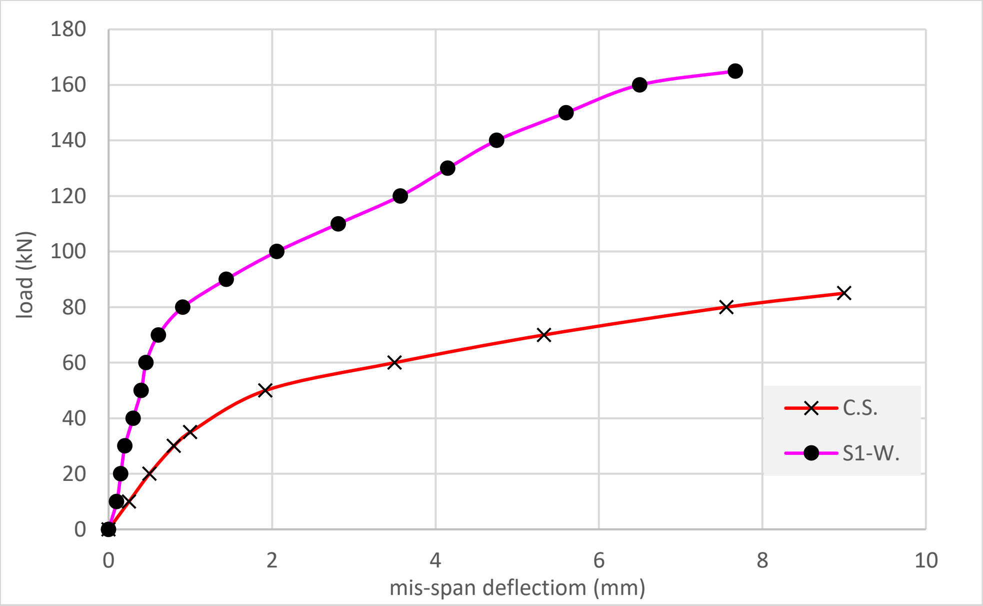


Figure 4.5 Load-Deflection Relationship between C.S. and S1-W.

4.3.2.5 The Specimen (S2-W.)

based on the results of Figure 4.6, The first crack in The specimen (S2-W.) appeared at the load of 70 kN , The ultimate load of the specimen was observed to be 150 kN, the yield load was equal 118 kN, and the deflection at the yield load and the ultimate load were equal to 5.60 mm and 8.96 mm, respectively.

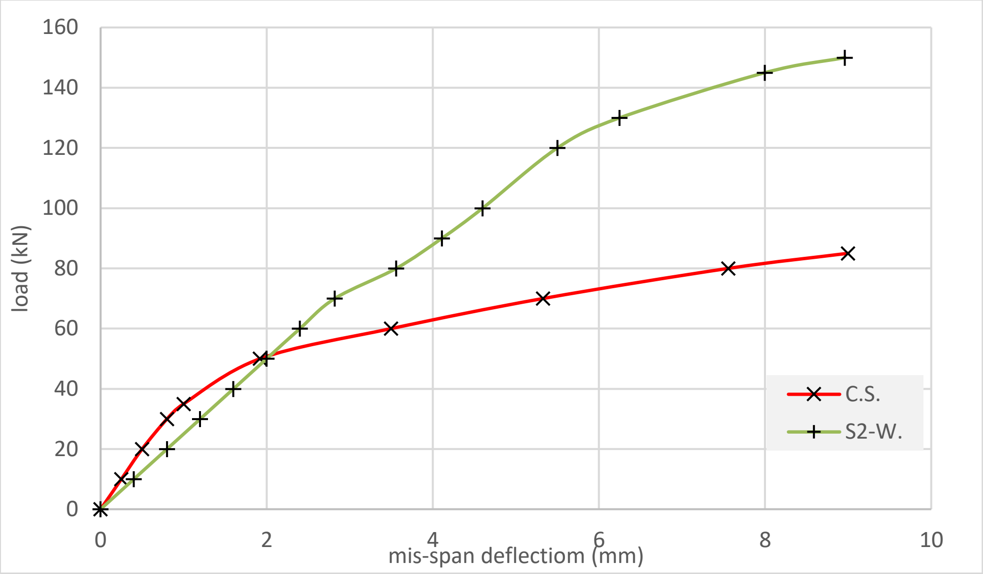


Figure 4.6 Load-Deflection Relationship between C.S. and S2-W.

4.3.2.6 The Specimen (N-W.) (Ferro-cement cover)

based on the results of Figure 4.7, The first crack in The specimen (N-W.) appeared at the load of 55 kN , The ultimate load of the specimen was observed to be 140 kN, the yield load was equal 84 kN, and the deflection at the yield load and the ultimate load were equal to 4.25 mm and 10.30 mm, respectively.

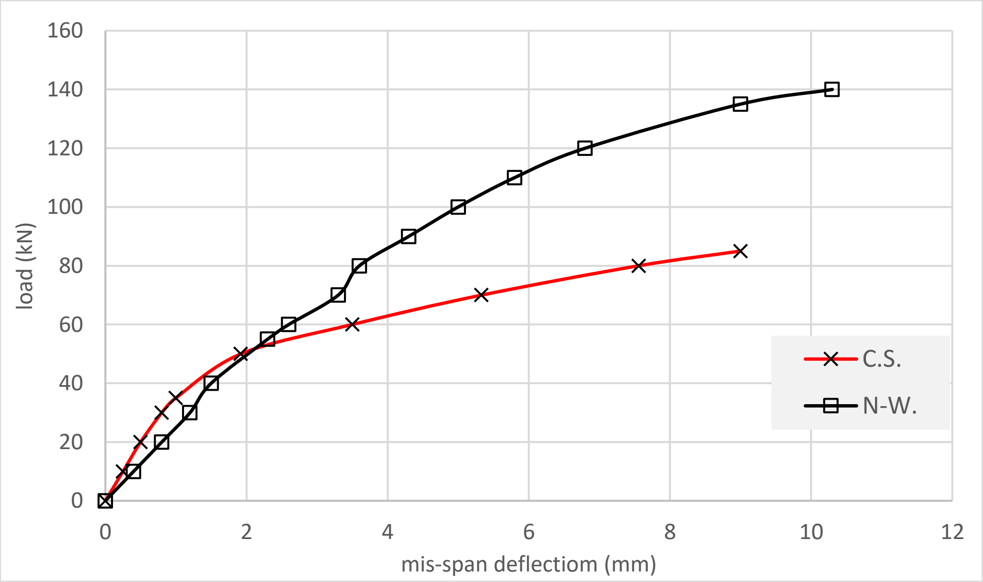


Figure 4.7 Load-Deflection Relationship between C.S. and N-W.

4.3.2.7 The Specimen (FLo grout.2-W.)

based on the results of Figure 4.8, The first crack in The specimen (FLo grout.2-W.) appeared at the load of 70 kN , The ultimate load of the specimen was observed to be 145 kN, the yield load was equal 94 kN, and the deflection at the yield load and the ultimate load were equal to 4.20 mm and 9.50 mm, respectively.

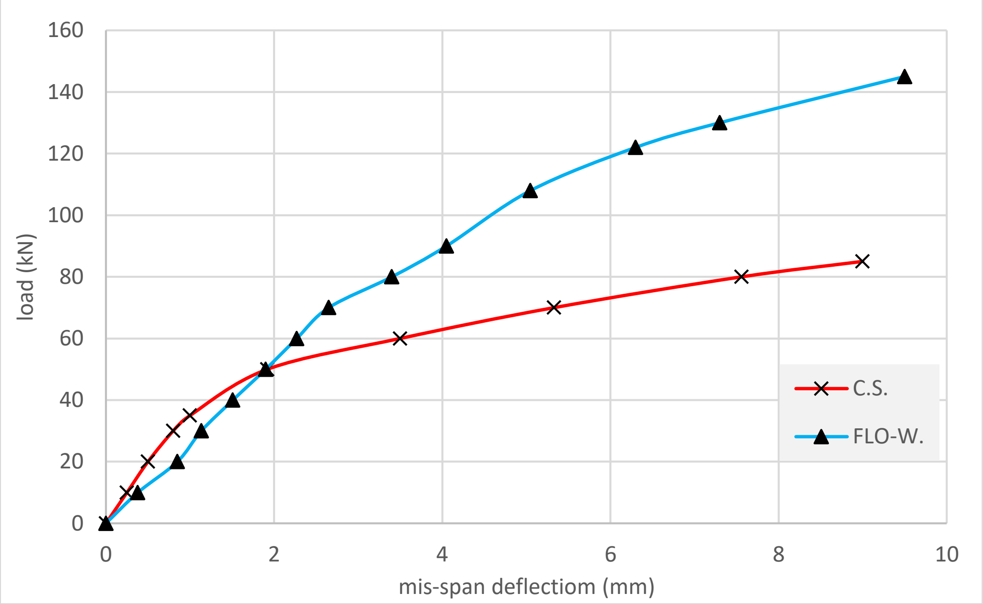


Figure 4.8 Load-Deflection relationship between C.S. and FLO-W.

4.3.3 The Strengthened Slabs (group C)

4.3.3.1 The Specimen (FL1-EP.)

based on the results of Figure 4.9, The first crack in The specimen (FL1-EP.) appeared at the load of 50 kN , The ultimate load of the specimen was observed to be 100 kN, the yield load was equal 66 kN, and the deflection at the yield load and the ultimate load were equal to 1.35 mm and 7 mm, respectively.

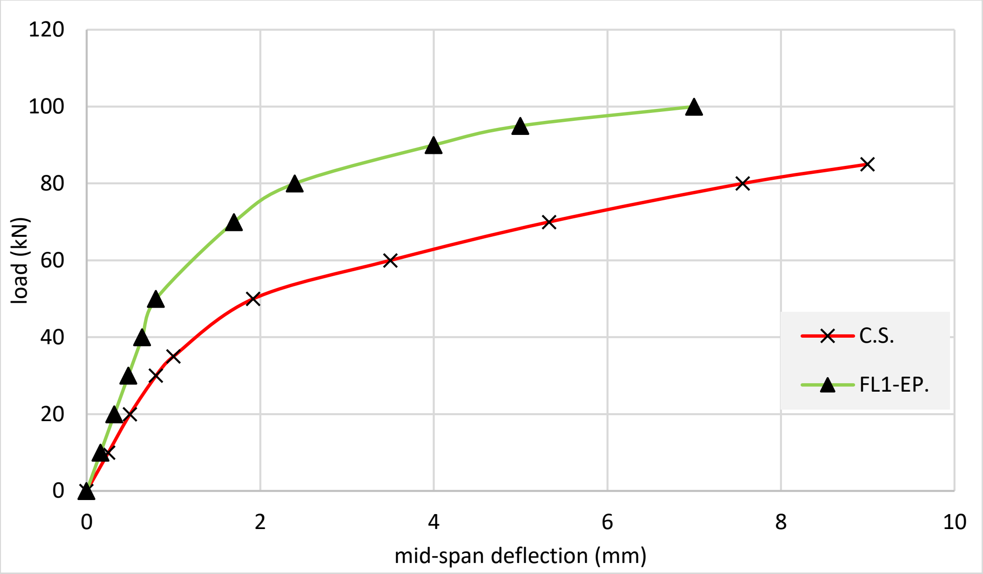


Figure 4.9 Load-Deflection Relationship between C.S. and FL1-EP.

4.3.3.2 The Specimen (FL2-EP.)

based on the results of Figure 4.10, The first crack in The specimen (FL2-EP.) appeared at the load of 40 kN , The ultimate load of the specimen was observed to be 90 kN, the yield load was equal 49 kN, and the deflection at the yield load and the ultimate load were equal to 1.30 mm and 9.40 mm, respectively.

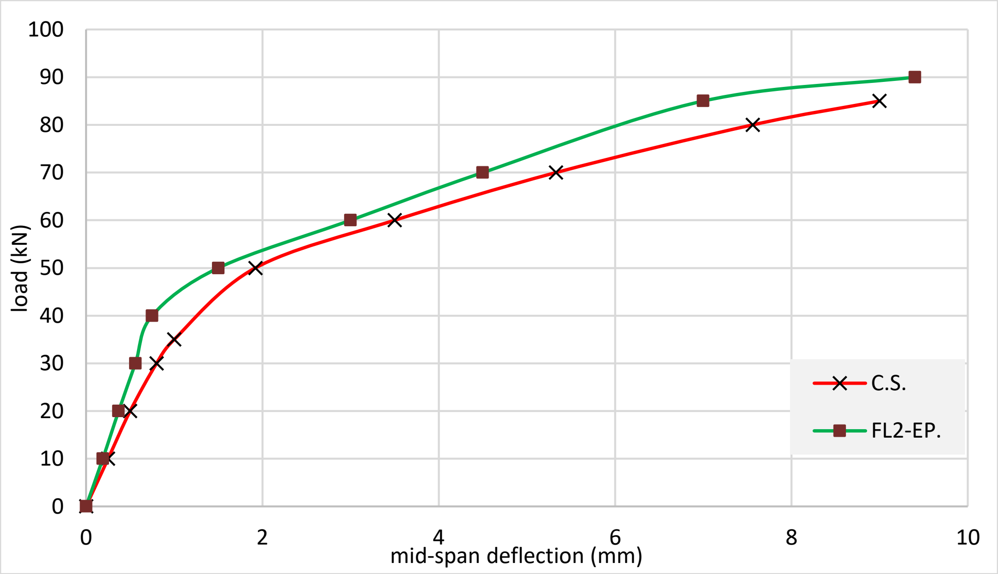


Figure 4.10 Load-Deflection Relationship between C.S. and FL2-EP.

4.3.3.3 The Specimen (FS1-EP.)

based on the results of Figure 4.11, The first crack in The specimen (FS1-EP.) appeared at the load of 40 kN , The ultimate load of the specimen was observed to be 92 kN, the yield load was equal 54 kN, and the deflection at the yield load and the ultimate load were equal to 2.85 mm and 9 mm, respectively.

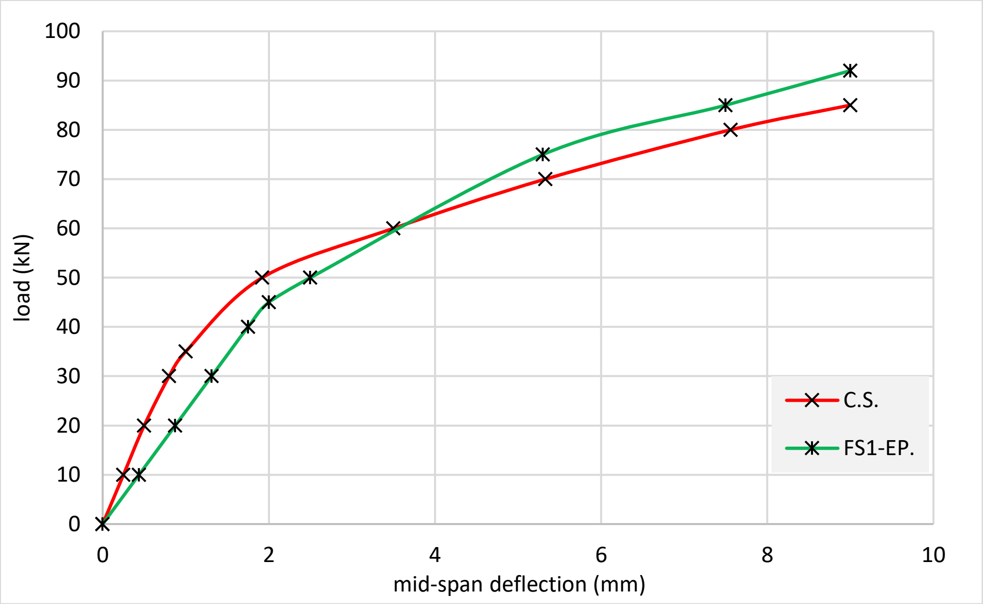


Figure 4.11 Load-Deflection Relationship between C.S. and FS1-EP.

4.3.3.4 The Specimen (FS2-EP.)

based on the results of Figure 4.12, The first crack in The specimen (FS2-EP.) appeared at the load of 40 kN , The ultimate load of the specimen was observed to be 95 kN, the yield load was equal 60 kN, and the deflection at the yield load and the ultimate load were equal to 2.70 mm and 8.50 mm, respectively.

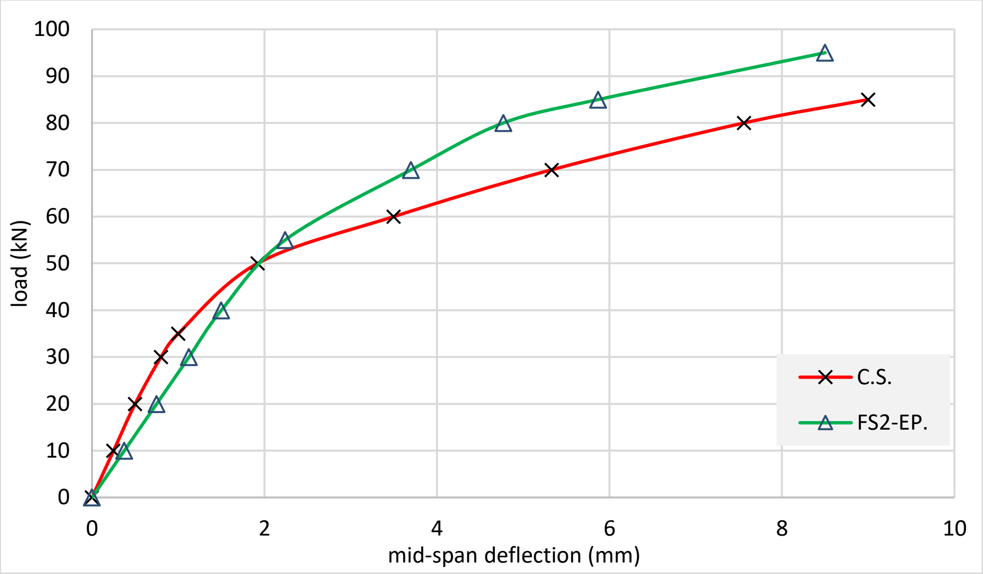


Figure 4.12 Load-Deflection Relationship between C.S. and FS2-EP.

4.3.3.5 The Specimen (S1-EP.)

based on the results of Figure 4.13, The first crack in The specimen (S1-EP.) appeared at the load of 45 kN , The ultimate load of the specimen was observed to be 98 kN, the yield load was equal 57 kN, and the deflection at the yield load and the ultimate load were equal to 3 mm and 10 mm, respectively.

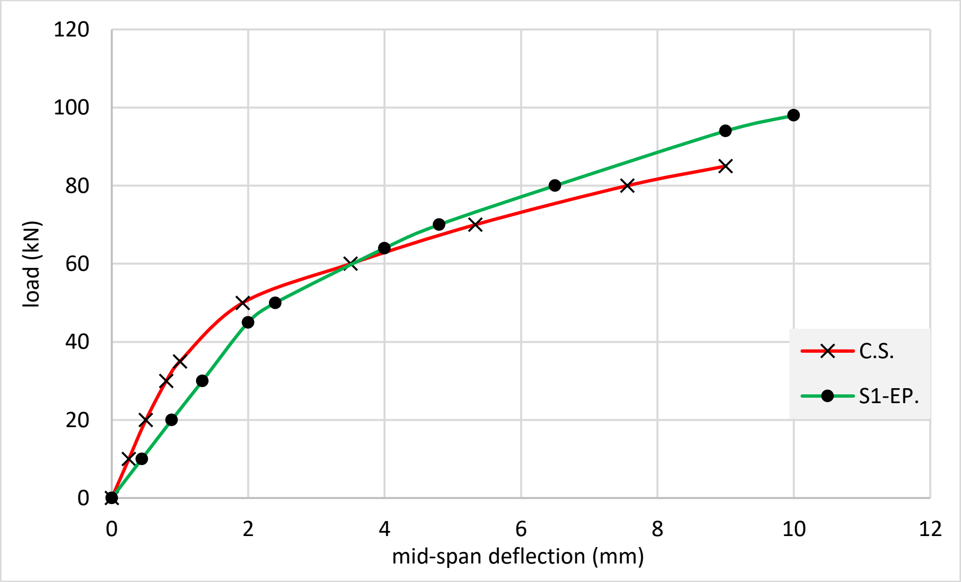


Figure 4.13 Load-Deflection Relationship between C.S. and S1-EP.

4.3.3.6 The Specimen (N-EP.)

based on the results of Figure 4.14, The first crack in The specimen (N-EP.) appeared at the load of 30 kN , The ultimate load of the specimen was observed to be 88 kN, the yield load was equal 53 kN, and the deflection at the yield load and the ultimate load were equal to 3.90 mm and 12 mm, respectively.

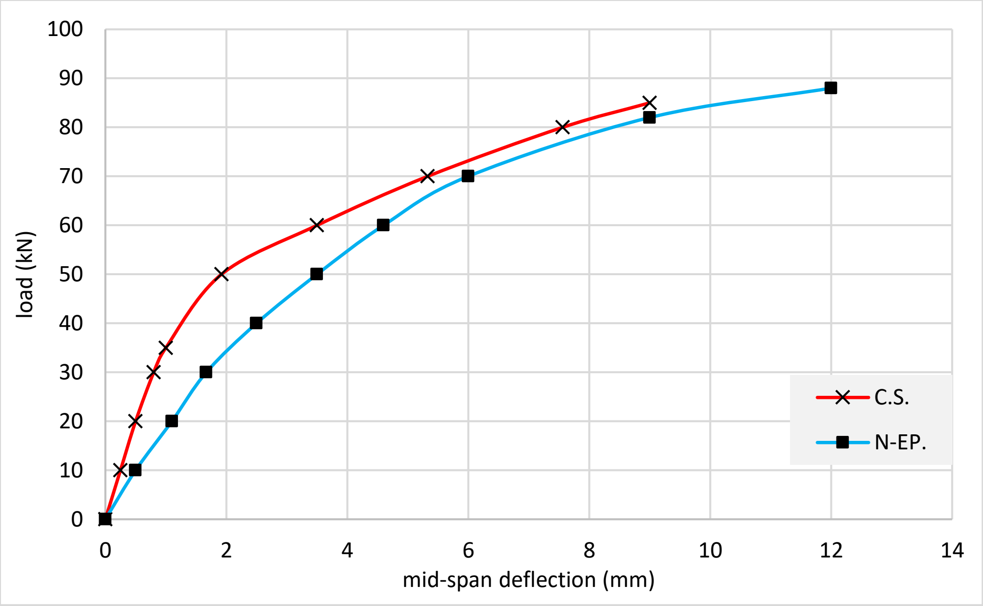


Figure 4.14 Load-Deflection Relationship between C.S. and N-EP.

4.3.3.7 The Specimen (Flo grout.2-EP.)

based on the results of Figure 4.15, The first crack in The specimen (Flo grout.2-EP.) appeared at the load of 40 kN , The ultimate load of the specimen was observed to be 95 kN, the yield load was equal 54 kN, and the deflection at the yield load and the ultimate load were equal to 3.20 mm and 10 mm, respectively.

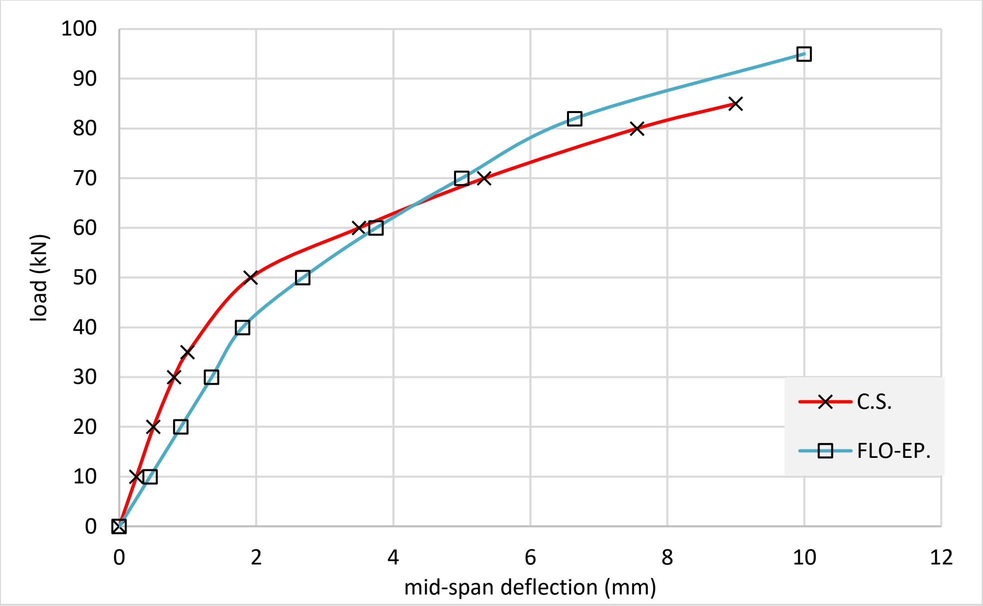


Figure 4.15 Load-Deflection Relationship between C.S. and FLO-EP.

4.4 Discussion of Test Results

The following discussions are made on the observed ultimate load carrying capacities and the deformational characteristics in terms of the deflection at mid span, ductility index and energy absorption .

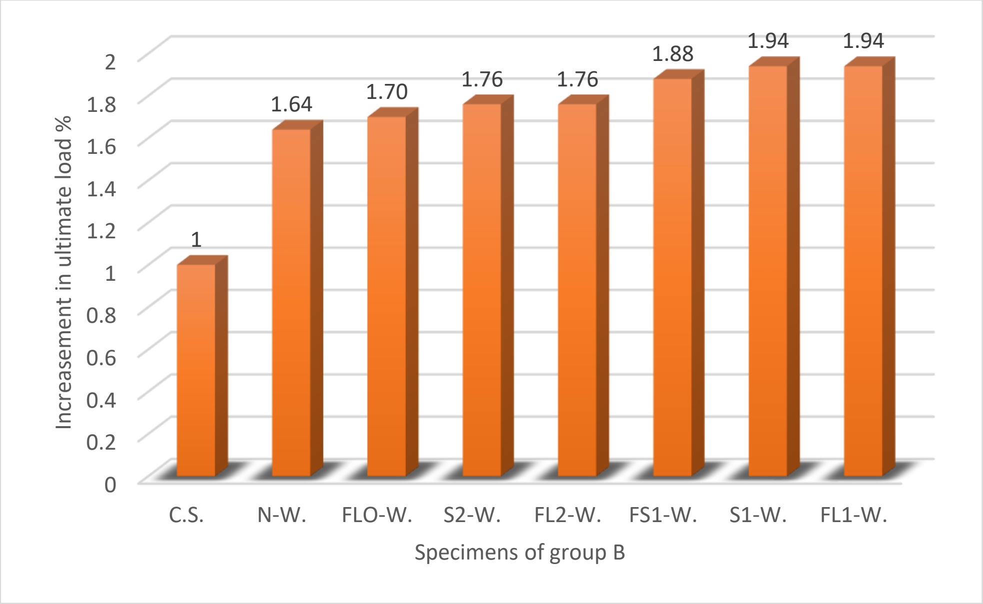
4.4.1 The Increasement in Ultimate Load

The increasement of the ultimate load and gain in (Pu) for all concrete slabs are recorded and presented in Table 4.1. The ultimate failure load of the control slab was 85 kN. Figure 4.16 (a and b) depicts the load versus mid-span deflection for strengthened slabs of group (B) Compared with control slab .From this figure, it is observed that the increments/gains in Pu were: Both of the specimens (FL2-W.),(S2-W.) showed an increase about 76.5% in ultimate load capacity, the specimen (FS1-W.) recorded an increase about 88%, the specimen (N-W.) it observed an increase about 64.7% ,the increasment in ultimate load of the specimen (FLO-W.) was 70.5% kN . While the two specimens (FL1-W.) and (S1-W.) it observed that the maximum increasement in ultimate load was 94% compared to the control slab. The failure load characteristic of the slabs (FL1-W.) , (S1-W.) was the best among all the slabs.This is for group B.

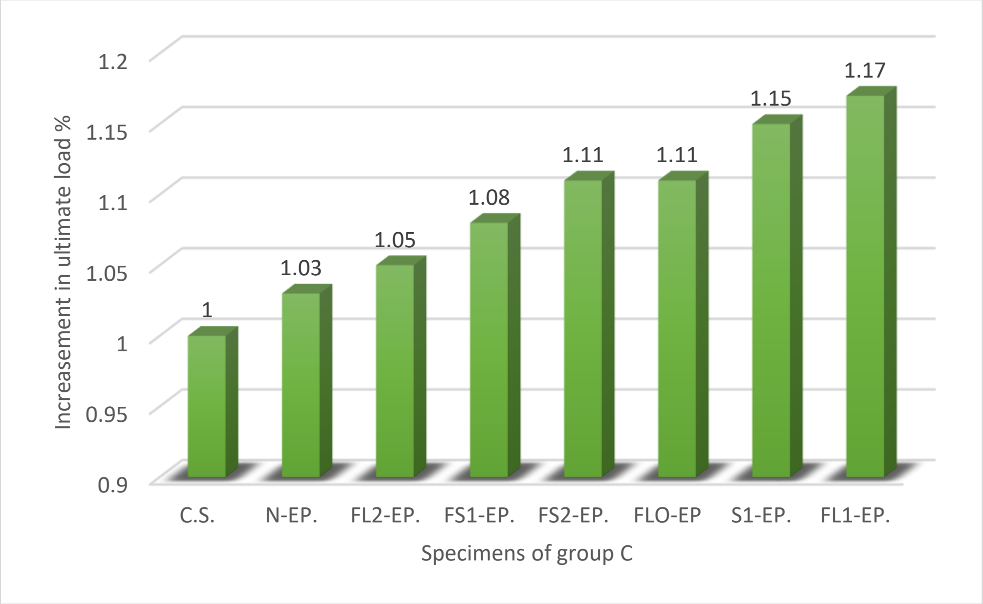
Regarding the strengthened slabs of group (B) , the rate of increasement in ultimate load was as follows : Specimen(FL1-EP.) showed an increase of about 17.64%

in the ultimate load capacity whereas, specimen (FL2-EP.) showed an increase

of about 5.88% , (FS2-EP.) and (FLO-EP.) as shown in table 4.1 Similarly, specimen (FS1-EP.) showed an increase of about 8.23 % in ultimate load capacity, whereas specimen (S1-EP.) showed an increase of about 15.29 and the specimen (N-EP.) recorded an increase of about 3.52% compared to the control slab . Both the two methods of strengthening for the concrete slabs showed considerable increment in ultimate load compared to the control slab .



(a) Increasement in ultimate load of group B



(b) Increasement in ultimate load of group C

Figure 4.16 Increasement in ultimate load of the strengthened slabs

4.4.2 Flexural Stiffness

Based on the load-deflection curve as shown in figure 4.36 and 4.37, initial stiffness and secant stiffness (effective stiffness) were computed by dividing the maximum applied load (Pu) by the yield deflection (Δy) in the case of initial stiffness or the maximum deflection (Δu) in the case of secant stiffness. The equations used 4. 1 and 4.2.

INITIAL FLEXURAL STIFFNESS = PY / ΔY ………...…. 4. 1

SECANT FLEXURAL STIFFNESS =PU/ ΔU ……………. 4. 2

Stiffness is calculated using the Priestley study [59], as illustrated in Figure 4.17. The results that are presented in Table 4.2.

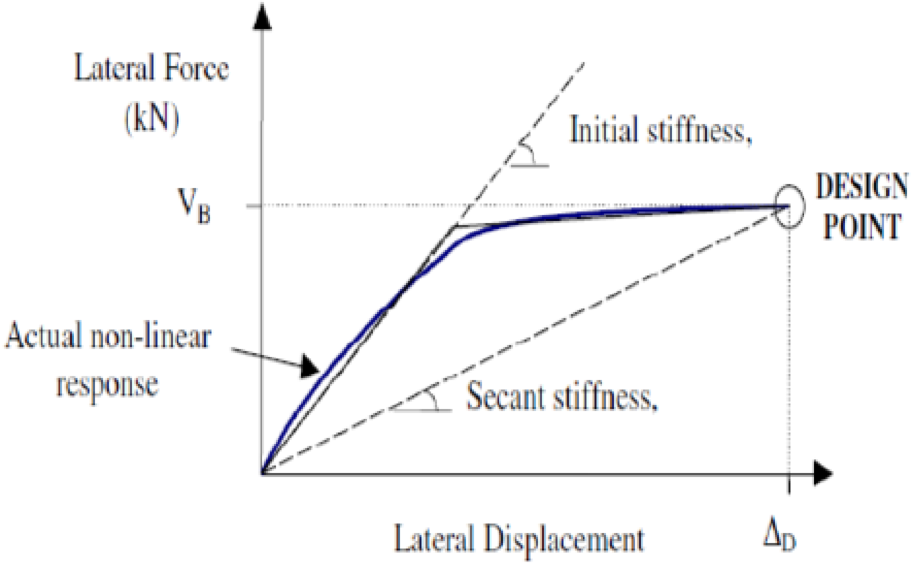


Figure 4.17 The calculation method of Initial and Secant stiffness [59]

Table 4.2 The values of initial and Secant stiffness

Group	Slab ID	Initial Stiffness Ki (kn/mm)	Variation in initial stiffness%	Secant stiffness Ks (kn/mm)	Variation in Secant stiffness%
A	C.S.	30.66	0	9.44	0
B	FL1-W.	57.14	86.36	17.15	81.67
	FL2-W.	27.50	- 10.30	15	58.89
	FS1-W.	31.85	3.88	16.84	78.38
	S1-W.	82	167.44	21.51	127.86
	S2-W.	21.07	- 31.50	16.74	77.33
	N-W.	18.76	- 38.81	13.59	43.96
	FLO-W.	22.38	- 27.00	15.26	61.65
C	FL1-EP.	48.88	59.42	14.28	51.27
	FL2-EP.	37.70	22.96	9.57	1.37
	FS1-EP.	18.94	- 38.22	10.22	8.26
	FS2-EP.	22.22	- 27.52	11.17	18.32
	S1-EP.	19	- 38.03	9.80	3.81
	N-EP.	13.58	- 55.70	7.33	- 22.35
	FLO- EP	16.87	- 44.97	9.50	0.63

4.4.3Ductility Index

Ductility refers to the ability of reinforced concrete members to withstand significant deflection before failing figure 4.18 . The load deflection curve yields the ductility index (D.I), which is equal to the ratio of the maximum deflection (Δu) to the yield deflection (Δy). The values of the ductility index for the concrete slabs , as shown in table 4.3 below. As is clear from the results, the ductility index values decreased with the strengthening except the specimens (FL1-W.),(S1-W.) and (FL2-EP.).

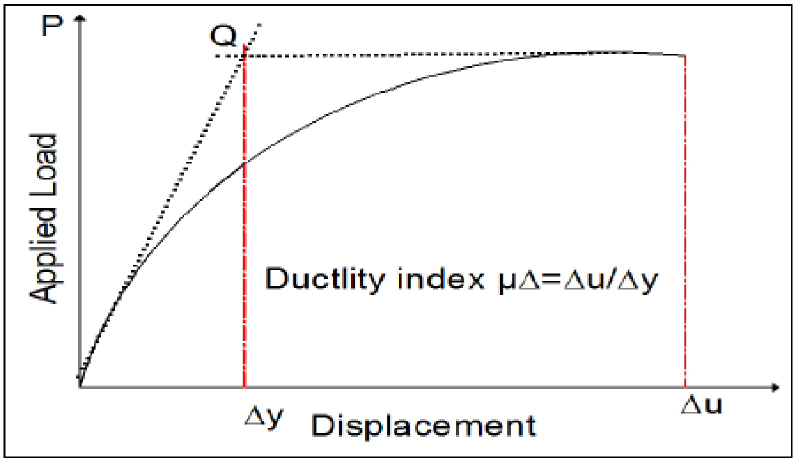


Figure 4. 18 Show the ductility index calculation [60]

Table 4.3 Ductility indices for slabs specimens

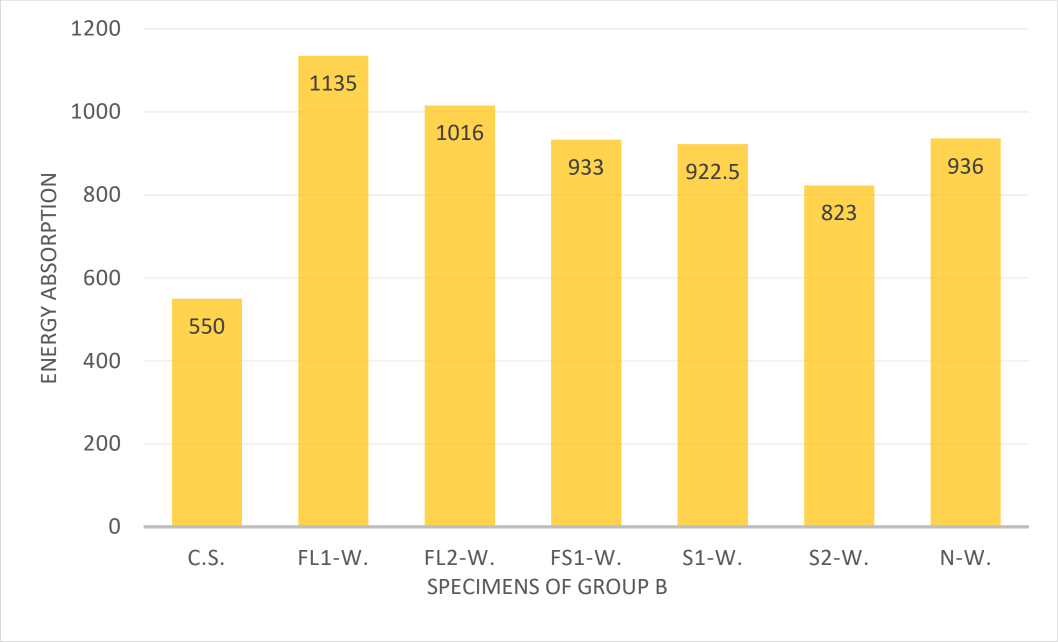
Group	I.D. Slab	Ductility Index (D.I)	Variation in Ductility index %
A	C.S.	6	0
B	FL1-W.	6.87	14.33
	FL2-W.	3.12	- 48
	FS1-W.	3.51	- 41.5
	S1-W.	7.67	24.33
	S2-W.	1.60	- 73.33
	N-W.	2.42	- 59.66
	FLO-W.	2.26	- 62.33
C	FL1-EP.	5.18	- 13.66
	FL2-EP.	7.23	20.50
	FS1-EP.	3.15	- 47.50
	FS2-EP.	3.14	- 47.66
	S1-EP.	3.33	- 44.50
	N-EP.	3.07	- 48.83
	FLO-	3.12	- 48

4.4.4Energy-Absorption

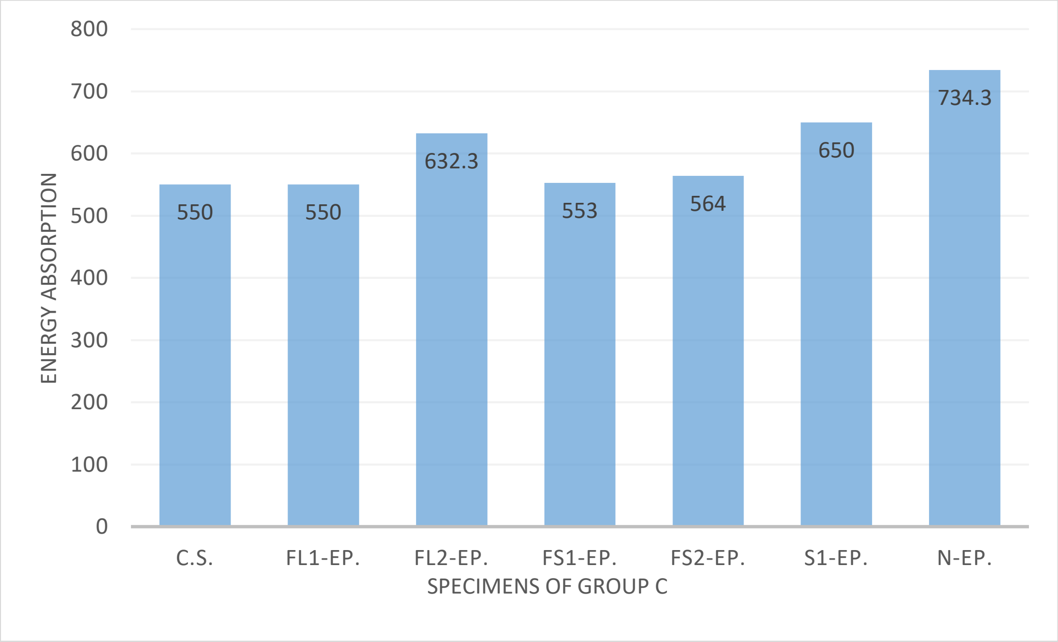
The area under the load-deflection curve is used to calculate energy absorption. The energy absorption Ψ data for all concrete slabs were listed in Table 4.4, which showed a significant increase in energy absorption Ψ. A noticeable increase in the energy absorption was observed when using the (RPMCM) cover system as compared to that when using (PMCM) cover. The reference slab recorded energy absorption of 550 kN.mm. The energy absorption increased with increasing the compressive and flexural strength of the cover layer materials and especially the slabs of (group B) due to the presence of wire-mesh in the cover layer, where slabs (FL1-W.),(FL2-W.), (FS1-W.),(S1-W.),(S2-W.),(N-W.) and (FLO-W.) achieved an energy absorption of 1135, 1016, 933,922.5,823,936 and 874.6 kN.mm respectively. While the slabs of (group C), the values are different, there is an equal value in energy absorption like specimen (FL1-EP.), and there a slight increase in the values compared with reference slab like the two specimens (FS1-EP.) and (FS2-EP.), where the increasing ratio (0.5%) and (2.5%), but regarding the remainder slabs (FL2-EP.),(S1-EP.),(N-EP.) and (FLO-EP.) are greater than the reference slab by (14.9%),(18%),(33.5) and (15.9) respectively. The bar charts in Figure 4.19 (A-B), show the values of the energy absorption (Ψ) for the strengthened specimens.

Table 4.4 The Energy Absorption Data of Concrete Slabs

Group	I.D. Slab	Energy Absorption kN.mm	Variation in Energy Absorption%
A	C.S.	550	0
B	FL1-W.	1135	106.3
	FL2-W.	1016	84.7
	FS1-W.	933	69.6
	S1-W.	922.5	67.7
	S2-W.	823	49.6
	N-W.	936	70.1
	FLO-W.	874.6	59
C	FL1-EP.	550	0
	FL2-EP.	632.30	14.9
	FS1-EP.	553	0.5
	FS2-EP.	564	2.5
	S1-EP.	650	18
	N-EP.	734.30	33.5
	FLO-EP.	637.57	15.9



(A)



(B)

Figure 4.19 Comparison the energy absorption of slabs

4.5 Failure Modes and Crack Pattern

4.5.1 Control Slab

Control slab failed as expected in a typical flexural failure mode through yielding of longitudinal steel reinforcement followed by concrete crushing at the top third-span of the slab. The cracks start in the bottom face of the slab at a load level of 35 kN. As shown in Figure 4.20, these cracks are parallel to the first crack, which extended at the free vertical edge of the slab upward to the slab compression face. Finally, the specimen crashed at a failure ultimate load of 85 kN, (see Table 4.1).

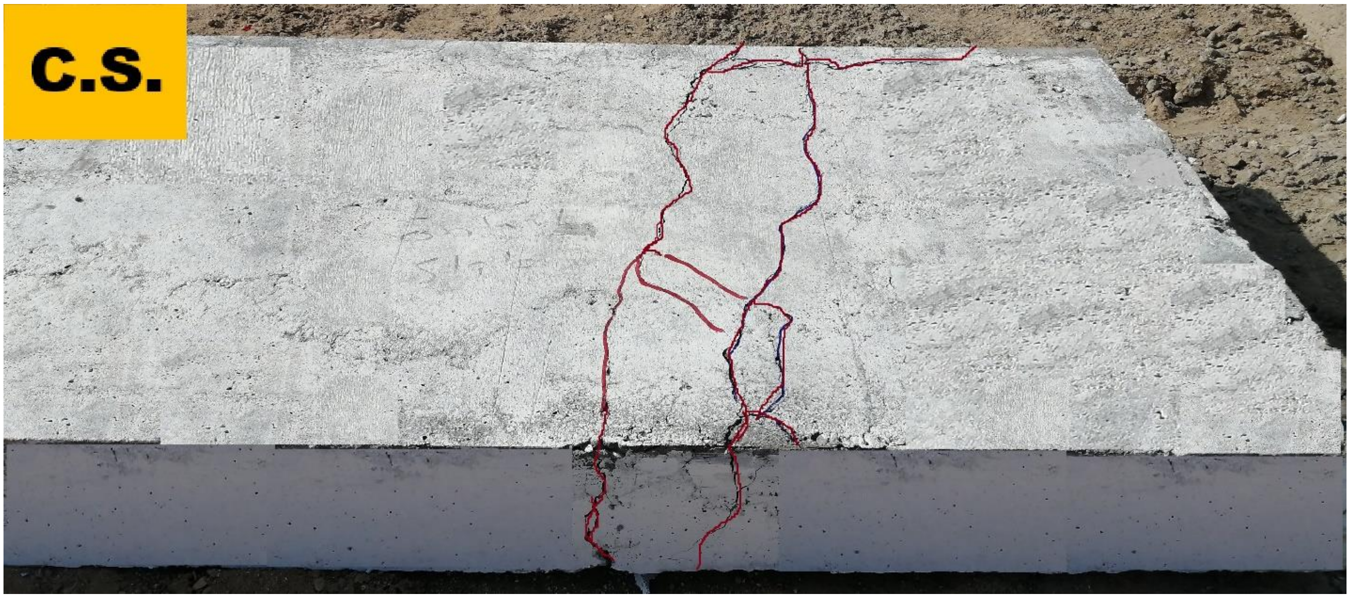


Figure 4.20 Mode of failure and crack patterns for specimen C.S.

4.5.2 The Strengthened Slabs of group B

Failure of the slab occurs when the cover layer is partially debonding at the tension zone followed by concrete crushing at the compressive zone, then the cover layer is rupture, and this happens gradually when the loading increases. The number of concrete capillary cracks are few and thicker compared to the cracks in the slabs of group (C), due to the presence of wire-mesh in the cover layer. The cracks initially occur in the cover layer and are capillary and parallel to the distributed load. When the load increases, the cracks increase. Some the cracks in the cover layer do not extend upward and penetrate the top part of the concrete slab , while the cracks in the slab of group (c) extend and penetrate the slab.

4.5.2.1 The Specimen FL1-W.

The first crack in the specimen (FL1-W.), appeared at the load of 60 kN. failed in flexural-shear.There is one main crack that penetrate the slab and is responsible for the failure, as shown in figure 4.21 and it is located in the first third of clear space. The cover layer is partial debonding. The specimen crashed at a failure ultimate load of 165 kN.

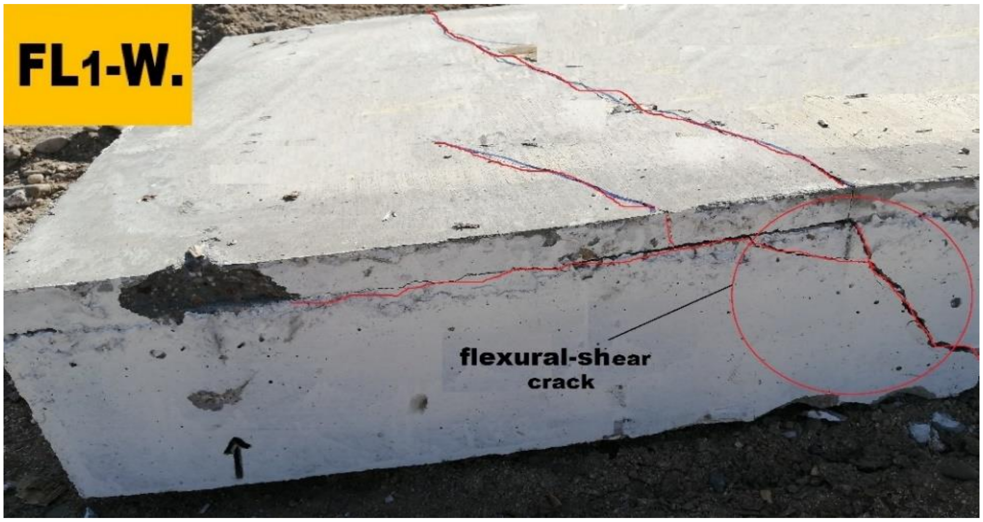


Figure 4.21 Mode of failure and crack patterns for specimen FL1-W.

4.5.2.2 The Specimen FL2-W.

The cracks initially occur in the concrete cover layer and was capillary and parallel to the load. When the load increases, the cracks increase. The first crack in the specimen (FL2-W.) appeared at the load of 70 KN. Failed in flexural.The number of capillary cracks are eight. There are two main cracks that penetrates the slab and are responsible for the failure as shown in figure 4.22, located below the load (middle of the clear span). The cover layer is not debonding. The specimen crashed at a failure ultimate load of 150 KN.

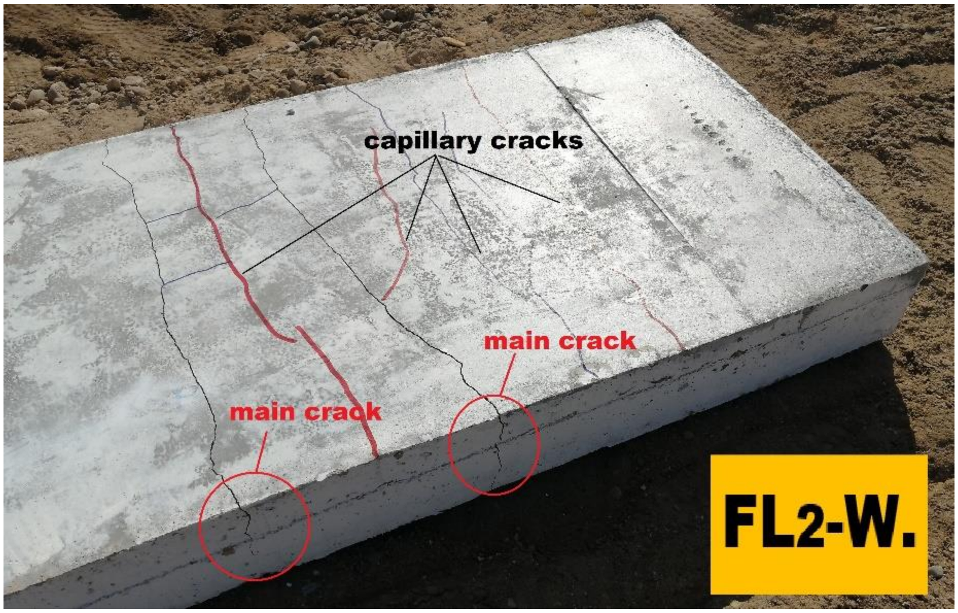
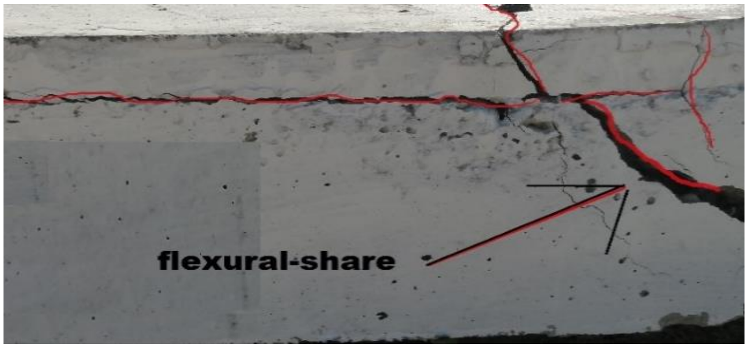


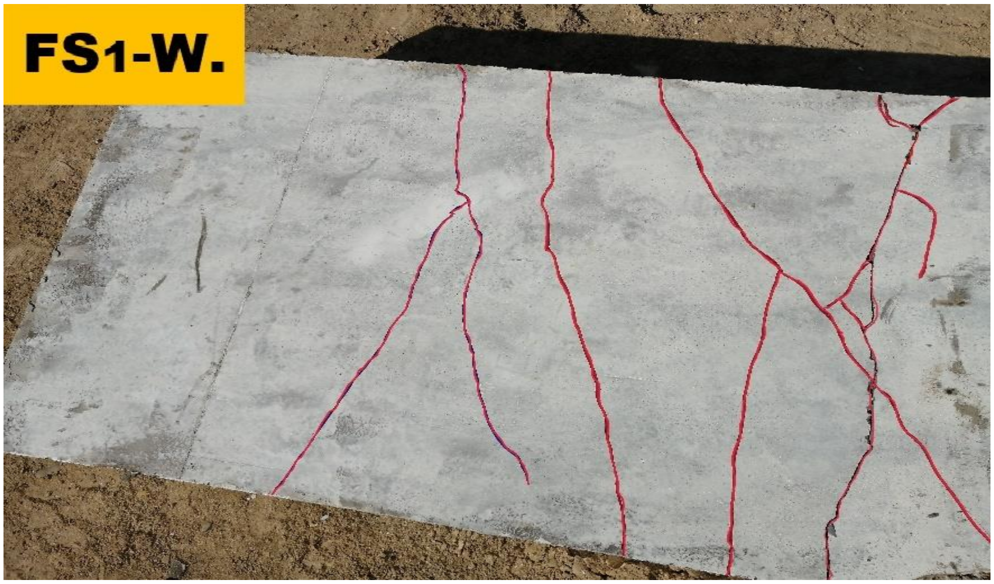
Figure 4.22 Mode of failure and crack patterns for specimen FL2-W.

4.5.2.3 The Specimen FS1-W.

flexural cracks propagated at the bottom face of the slab extending to the slab free edges and expanded.The first crack in the specimen (FS1-W.) appeared at the load of 80 kN. Failed in flexural-shear. The number of capillary cracks is nine. There is one main crack that penetrate the slab and is responsible for the failure, as shown in figure 4.23 .The cover layer is partial debonding . The specimen crashed at a failure ultimate load of 160 kN.



(a) Side view



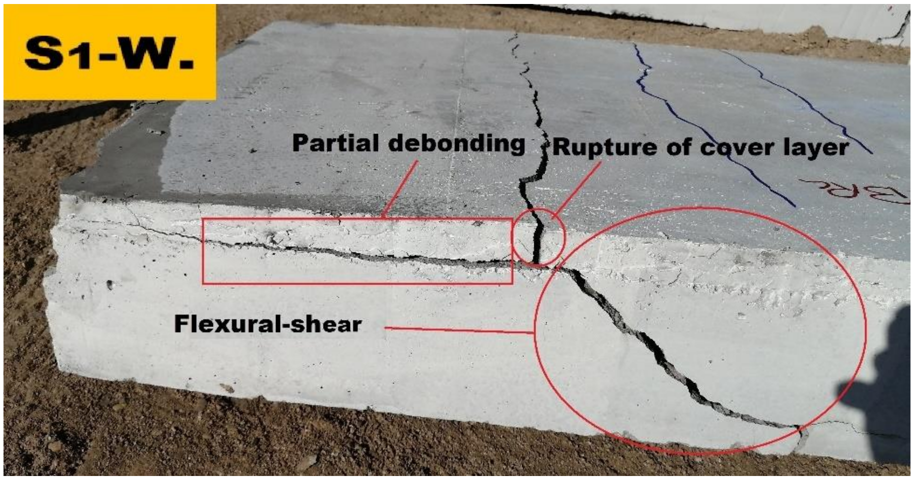
(b) Top view

Figure 4.23 Mode of failure and crack patterns for specimen FS1-W.

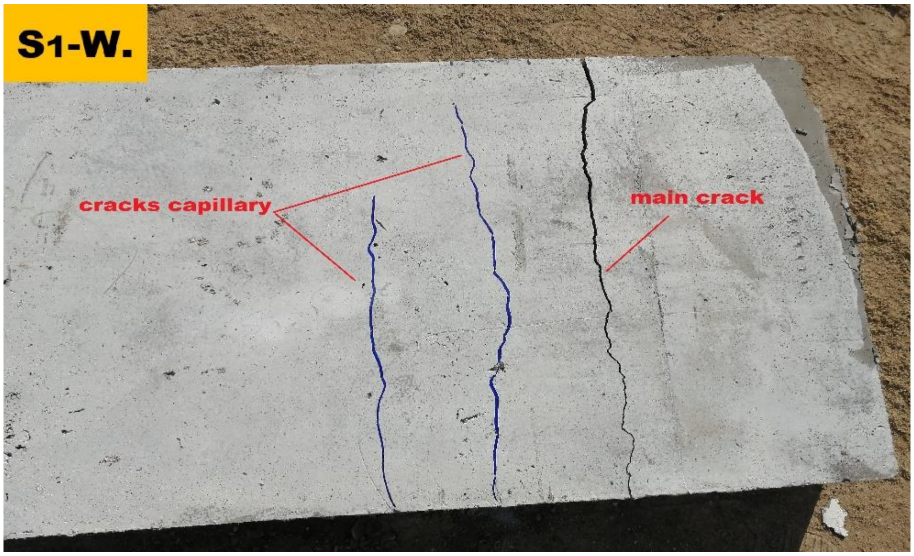
4.5.2.4 The Specimen S1-W.

The first crack in the specimen (S1-W.) appeared at the load of 70 kN. Failed in flexural-shear .The number of capillary cracks are two. There is one main crack that penetrate the slab and is responsible for the failure as shown in figure

4.24.The cover layer is partial debonding .The specimen crashed at a failure ultimate load of 165 kN.



(a) Side view

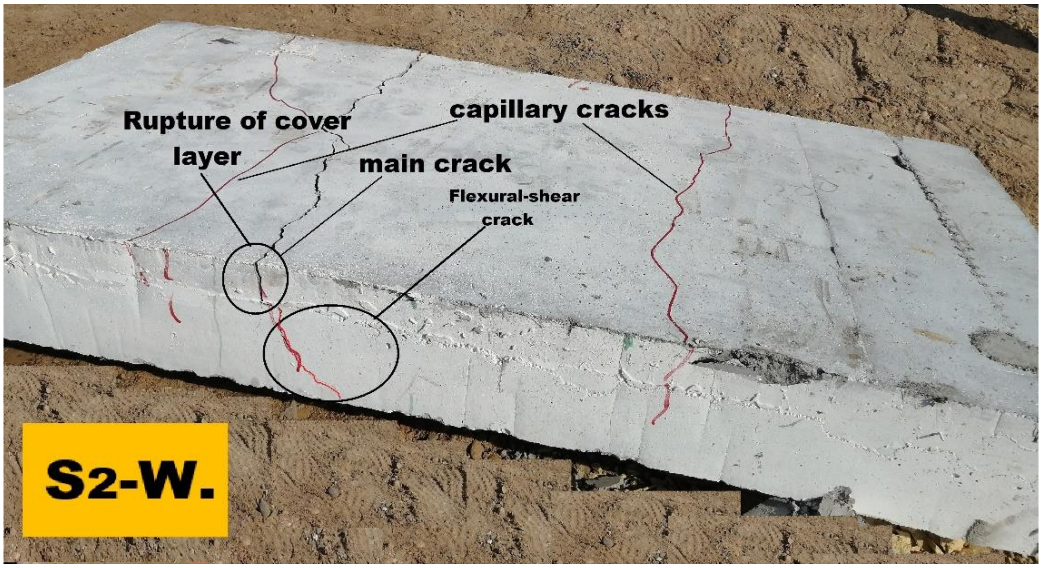


(b) Top view

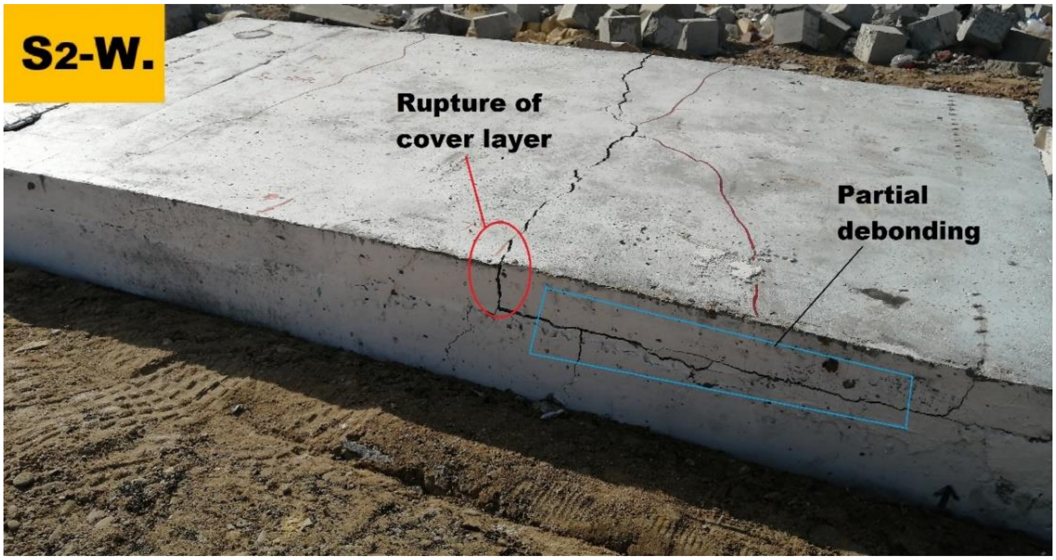
Figure 4.24 Mode of failure and crack patterns for specimen S1-W.

4.5.2.5 The Specimen S2-W.

The first crack in the specimen (S1-W.) appeared at the load of 70 kN. Failed in flexural-shear.The number of capillary cracks are three. There is one main crack that penetrate the slab and is responsible for the failure as shown in figure 4.25.The cover layer is partial debonding . The specimen crashed at a failure ultimate load of 150 kN.



(a) Front side view



(b) Back side view

Figure 4.25 Mode of failure and crack patterns for specimen S2-W.

4.5.2.5 The Specimen Flo grout.2-W.

The first crack in the specimen (FLO-W.) appeared at the load of 70 kN. failed in flexural-shear .The number of capillary cracks are seven. There is one main crack that penetrate the slab and is responsible for the failure as shown in figure 4.26.The cover layer is partial debonding . The specimen crashed at a failure ultimate load of 145 kN.

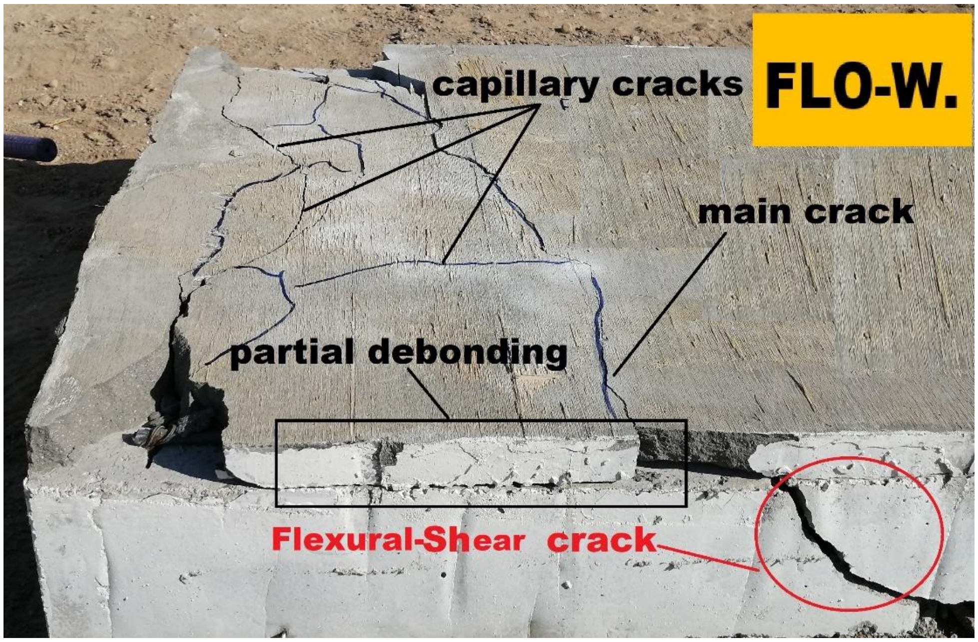


Figure 4.26 Mode of failure and crack patterns for specimen FLO-W.

4.5.2.6 The Specimen N-W. (Ferro-cement cover layer)

The first crack in the specimen (N-W.) appeared at the load of 70 kN. failed in flexural.The number of capillary cracks are eight. There is one main crack that penetrate the slab and is responsible for the failure as shown in figure 4.27.The cover layer is partial debonding . Before the ultimate failure of the specimen, multiple cracks were observed.The specimen crashed at a failure ultimate load of 145 kN. The capillary cracks that do not penetrate the slab, penetrating the cover layer only.

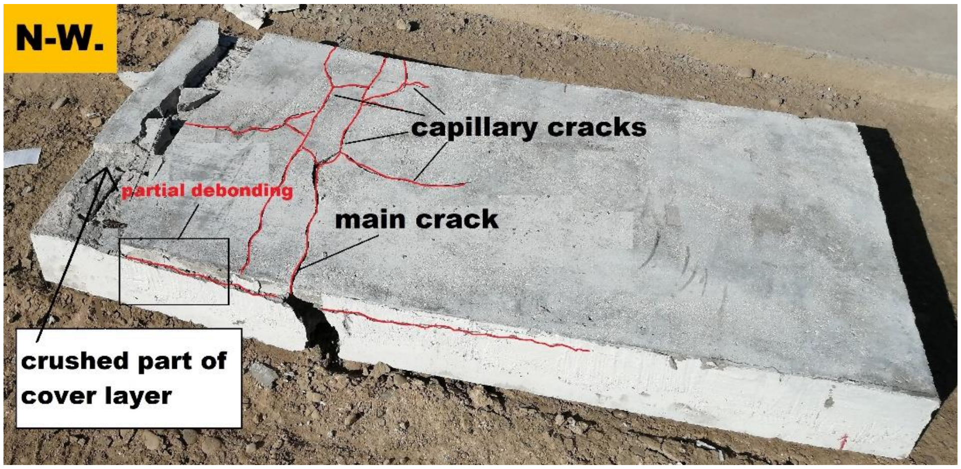


Figure 4.27 Mode of failure and crack patterns for specimen N-W.

4.5.3 The Strengthened Slabs of group C

Each slab was loaded until failure. All specimens in this group exhibited a similar mode of failure and the mode is flexural failure like the control specimen except the specimens (FL1-EP.),(N-EP.) and (FLO-EP.), the mode failure of it flexural-shear. group (C) contains seven concrete slabs .The cover layer at tension zone without reinforced ,that mean the cover layer just polymer modified cement mortar(PMCM) and the connection method between the cover layer and the bottom face of the upper part by epoxy.

The cracks initially occur in the concrete cover layer and are capillary, parallel to the distributed load. When the load increases, the cracks increase and spread in all directions, and the width of the crack increases so that it penetrates the concrete slab without separating the cover layer due to the adhesion force due to the epoxy material (bonding material sikadur-32 LP). In general, the failure mode of this group is similar in terms of crack shape and crack spread. Most of the main cracks (failure cracks) are in the mid-span of the slab, under the applied load, and these cracks extend upwards and penetrate the concrete slab. the number of cracks in this group is more than the cracks of group C.

Mode failure of the specimens of this group as follow :-

4.5.3.1 The Specimen FL1-EP.

Specimen FL1-EP. failed in flexural-shear. flexural cracks propagated at the bottom face of the slab extending to the slab free edges and expanded. The longitudinal rebars yielded, and the concrete crushed reached its ultimate strain in the compression zone at the top of the slab. the cracks start in the bottom face of the slab at a load level of 35 kN. Crack propagation and crack size are continuously increasing as the load on the specimen continued to increase. The specimen crashed at a failure ultimate load of 100 kN. The cracks are parallel to the applied load. There are two main cracks, as shown in figure 4.28, that penetrate the concrete slab. The other cracks are capillary.

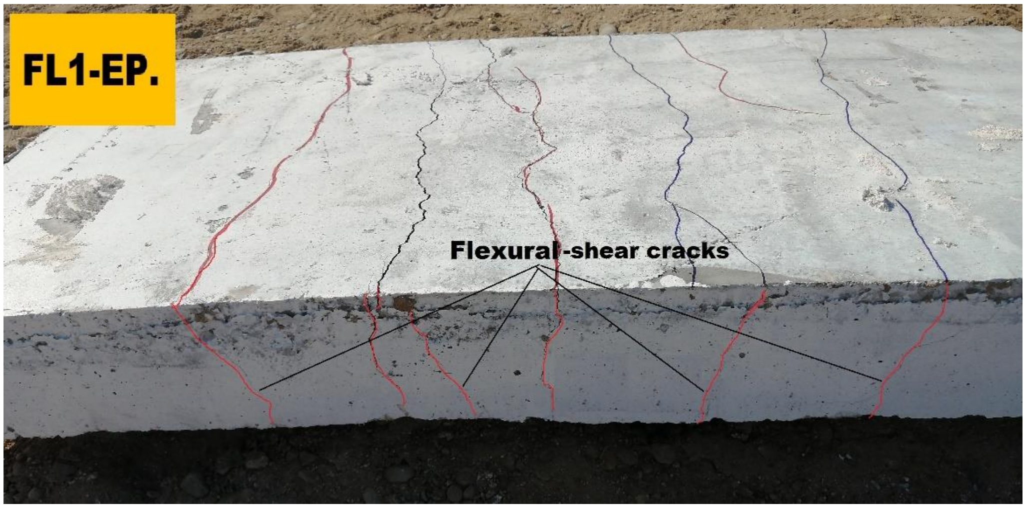


Figure 4.28 Mode of failure and crack patterns for specimen FL1-EP.

4.5.3.2 The Specimen FS2-EP.

Specimen FS2-EP,the number of capillary cracks is eight. Parallel and perpendicular to the applied load. There is a main crack that penetrates the slab and is responsible for the failure as shown in figure 4.29, located below the load (one third of the clear span). The concrete cover layer was not separated due to the adhesion force between the cover layer and the top of the concrete slab.

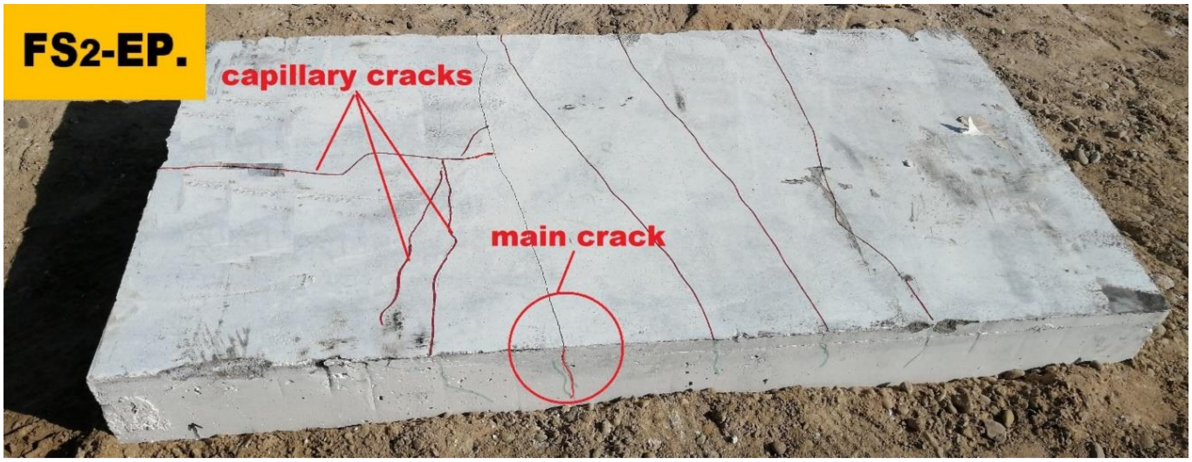


Figure 4.29 Mode of failure and crack patterns for specimen FS2-EP.

4.5.3.3 The Specimen FL2-EP.

The first crack in the specimen (FL2-EP.) appeared at the load of 40 kN. Failed in flexure. flexural cracks propagated at the bottom face of the slab, as shown in figure 4.30 . Number of cracks is three, parallel to the applied load and located in the middle of the clear span of the concrete slab. There are no cracks in the other directions.The specimen crashed at a failure ultimate load of 90 KN.

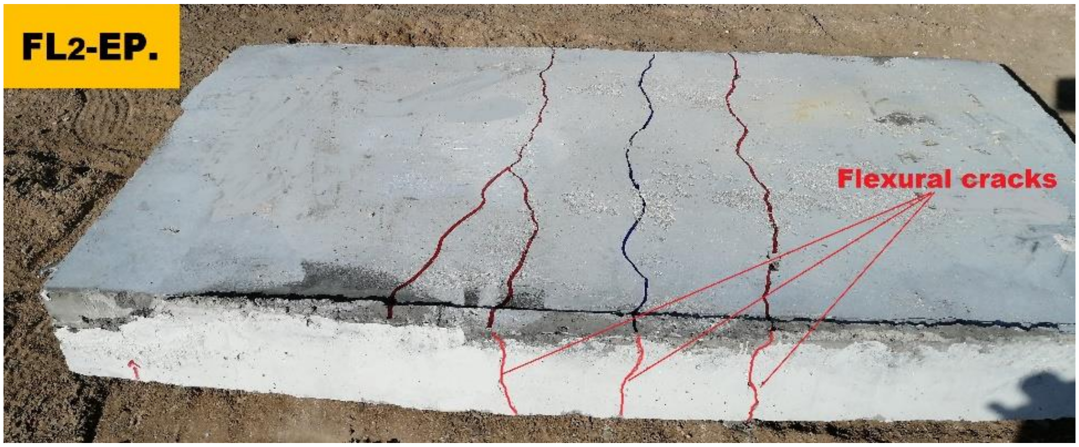


Figure 4.30 Mode of Failure and Crack Patterns for Specimen FL2-EP.

4.5.3.4 The Specimen S1-EP.

The first crack in the specimen (S1-EP.) appeared at the load of 45 kN. Failed in flexure. The number of capillary cracks is seven, Parallel and perpendicular to the applied load. There is one main crack that penetrate the slab and is responsible for the failure as shown in figure 4.31, located below the load.The concrete cover layer is not separated due to the adhesion force between the cover layer and the top part of the concrete slab. The specimen crashed at a failure ultimate load of 98 kN.

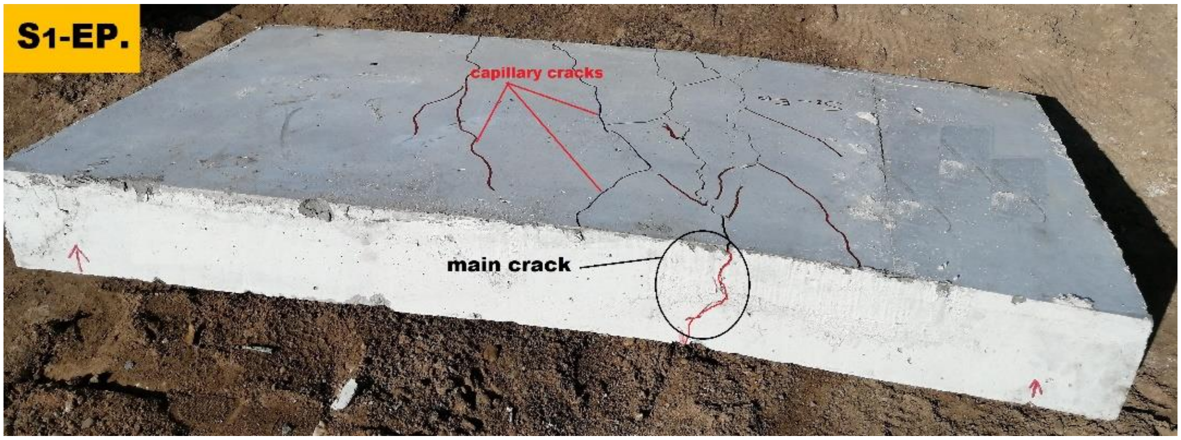


Figure 4.31 Mode of Failure and Crack Patterns for Specimen S1-EP.

4.5.3.5 The Specimen FLO-EP

The first crack in the specimen (FLO-EP.) appeared at the load of 40 kN. Failed in flexural-shear.The number of capillary cracks is four, Parallel and perpendicular to the applied load. There are three main cracks that penetrates the slab and is responsible for the failure, as shown in figure 4.32, located below the load (mid span of the clear span). The concrete cover layer is not separated due to the adhesion force between the cover layer and the bottom face of the concrete slab. The specimen crashed at a failure ultimate load of 95 kN.

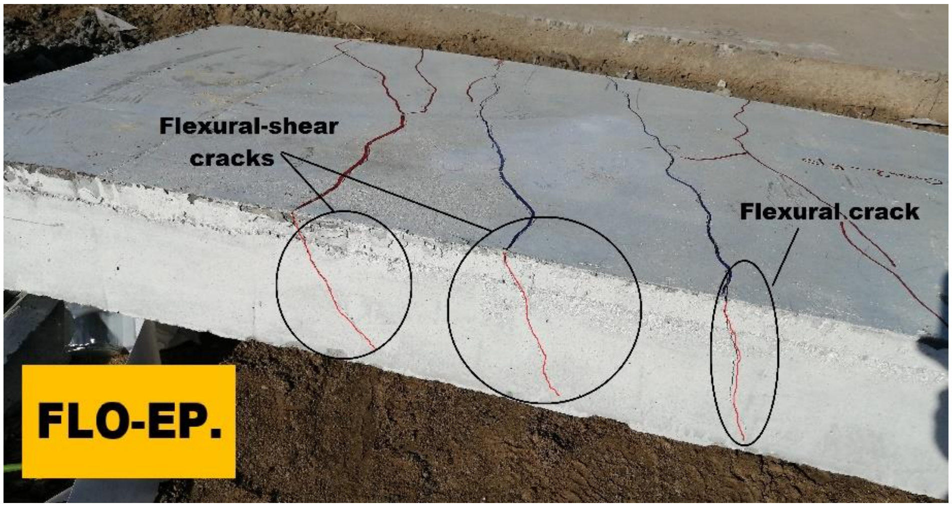
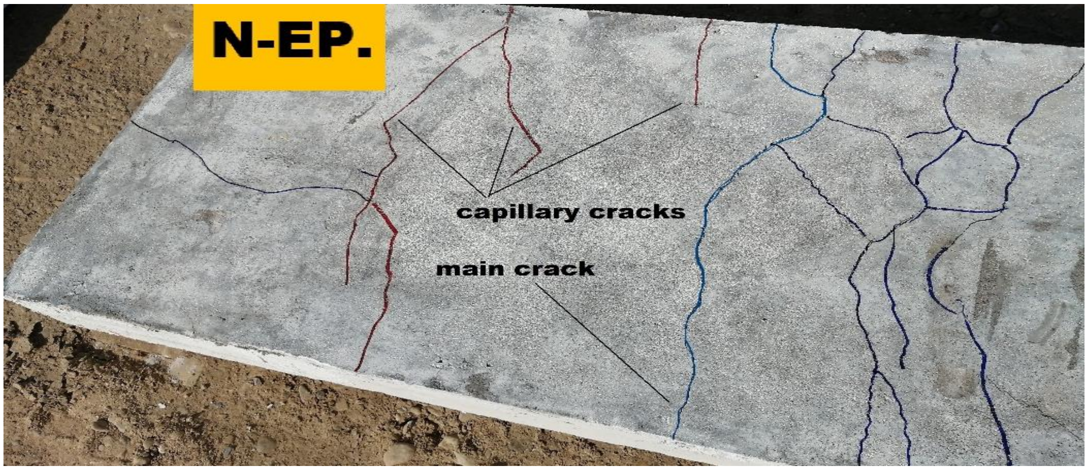


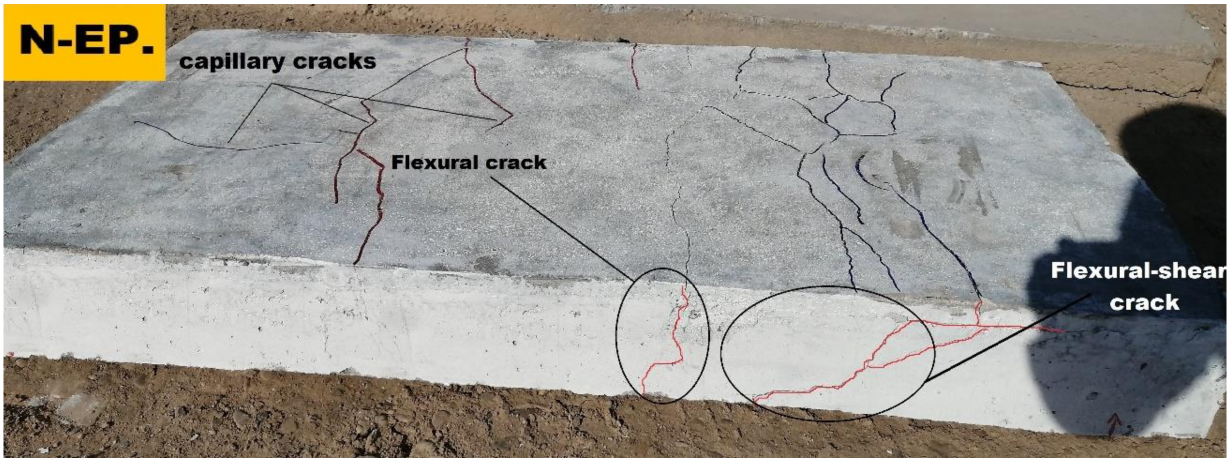
Figure 4.32 Mode of Failure and Crack Patterns for Specimen FLO-EP.

4.5.3.6 The Specimen N-EP

The first crack in The specimen (N-EP.) appeared at the load of 30 kN. failed in flexural-shear .There are many capillary cracks.The number of capillary cracks is sixteen, Parallel and inclined to the applied load. There is a main crack that penetrates the slab and is responsible for the failure as shown in figure 4.33, located below the load (mid span of the clear span). The concrete cover layer is not separated due to the adhesion force between the cover layer and the bottom face of the concrete slab. The specimen crashed at a failure ultimate load of 88 kN.



(a)



(b)

Figure 4.33 Mode of Failure and Crack Patterns for Specimen N-EP.

4.5.3.7 The Specimen FS1-EP

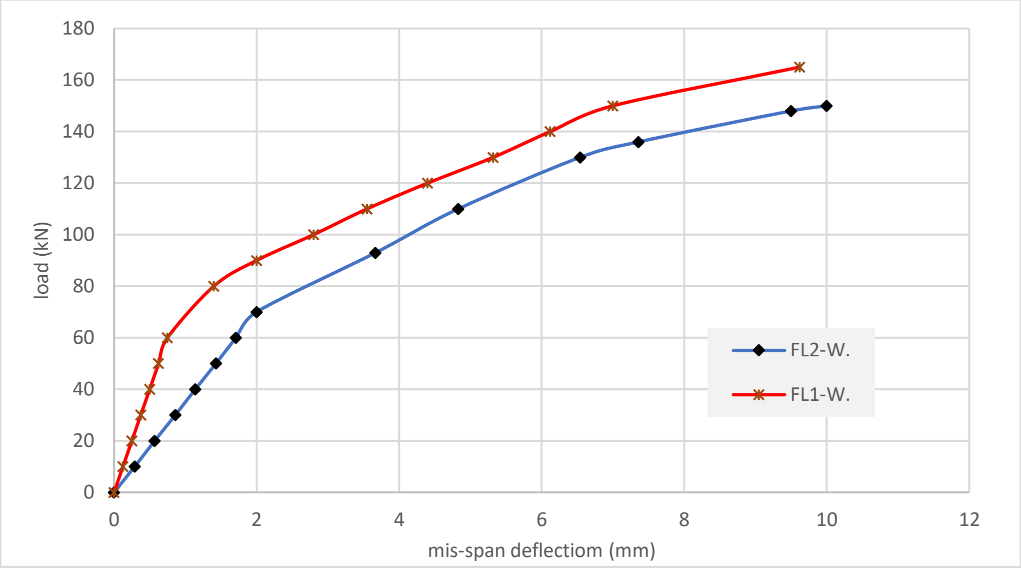
Specimen FS1-EP. failed in flexural-shear. The cracks start in the bottom face of the slab at a load level of 40 kN. Crack propagation and crack size were continuously increasing as the load on the specimen continued to increase. The specimen crashed at a failure ultimate load of 92 kN. The cracks are parallel to the applied load. There is a main crack, as shown in figure 4.34.There are parallel, perpendicular and inclined concrete capillary cracks with respect to the applied load capillary.The capillary cracks that do not penetrate the slab, penetrating the cover layer only.

Figure 4.34 Mode of Failure and Crack Patterns for Specimen FS1-EP.

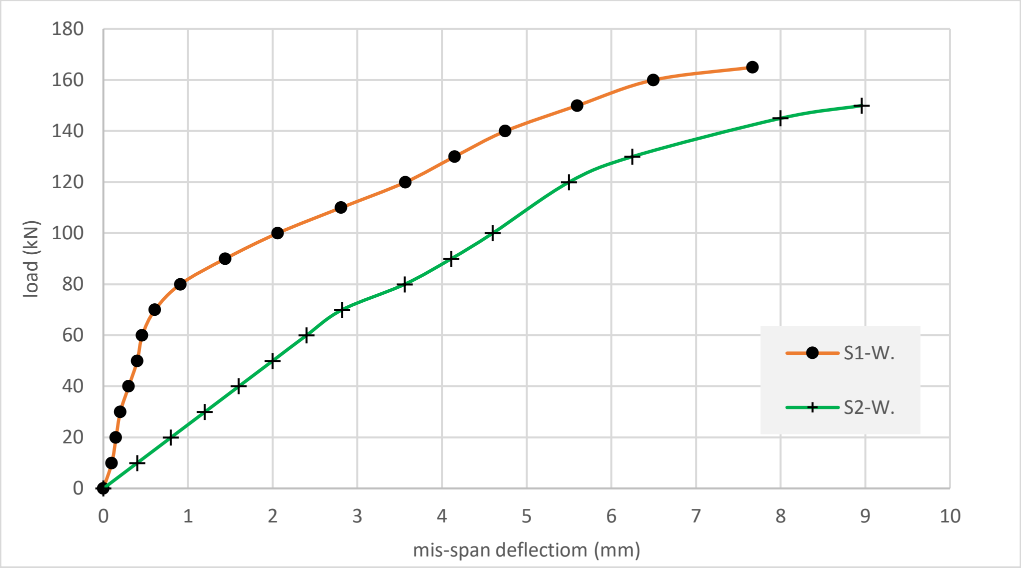
4.6 Parameters Studied

4.6.1 Effect of Increasing the Cover Layer Thickness

The thickness of the cover layer for the strengthened slab is one of the variable parameters considered in this full scale experimental program. Compare the results by studying the figure 4.35, that shows the mid span deflection curves for the concrete slabs (FL1-W.),(FL2-W.),(S1-W.),(S2-W.),(FL1-EP.),(FL2-EP.),(FS1-EP.) and (FS2-EP.),every two specimens consecutive that are with the same type of cover layer material and the same state of the cover layer (reinforced with wire mesh or without reinforced).

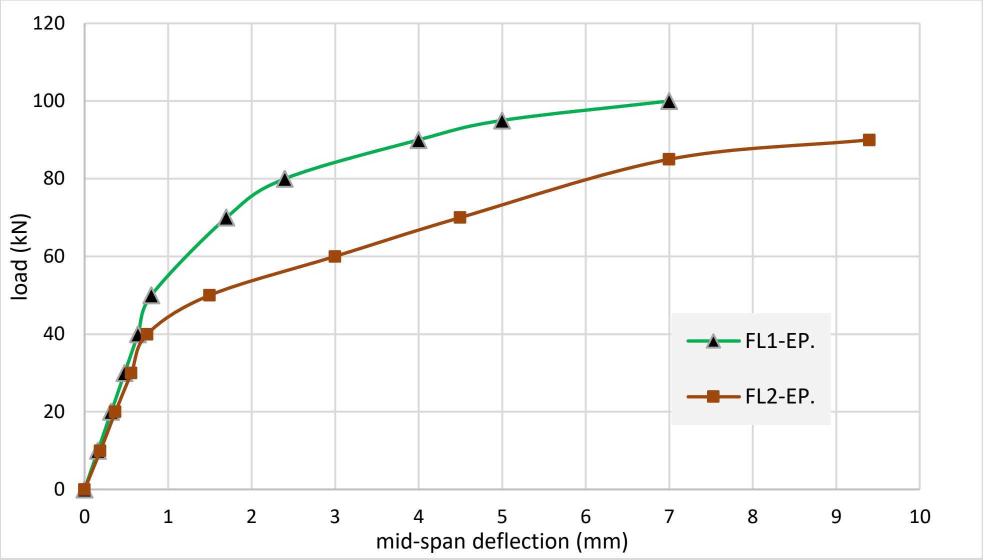


(a)

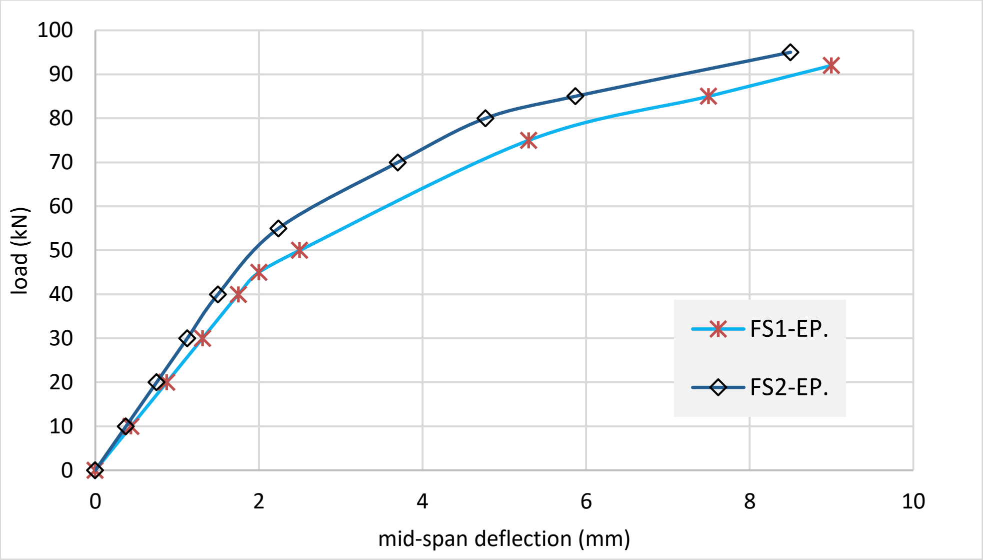


(b)

Figure 4.35 Comparison by the Variable Thickness of the Cover Layer



(c)



(d)

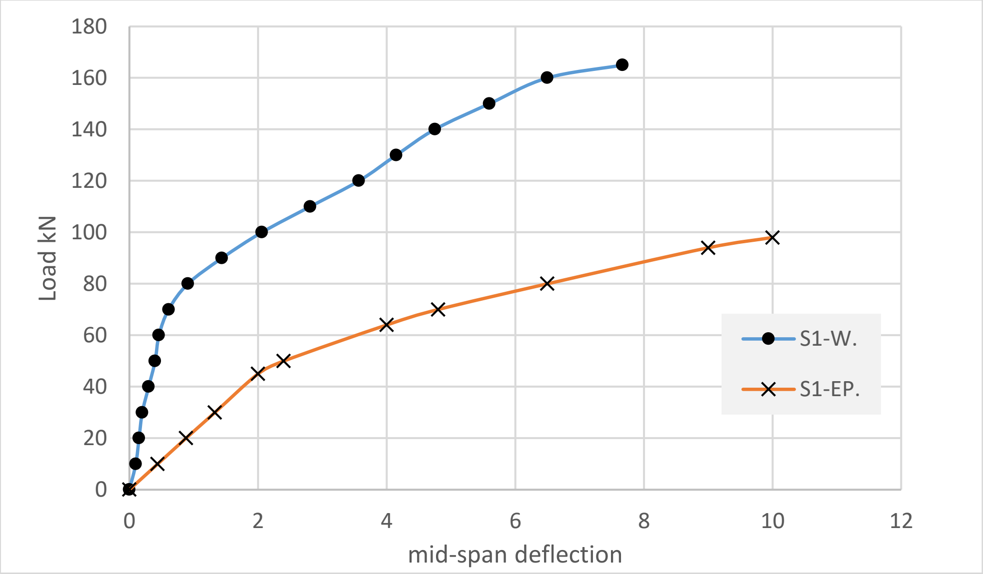
Figure 4.35 Comparison by the Variable Thickness of the Cover Layer

In general, from the results in table 4.1, for the specimens mentioned above, concluded that increasing the thickness of the cover layer leads to reduction of the ultimate load capacity and the effective stiffness . Regarding the cracks, increasing the thickness leads to a decrease in the number of cracks.

4.6.2 State of the Cover Layer of the Strengthened Slabs (Reinforced with welded Wire Mesh or without Reinforced)

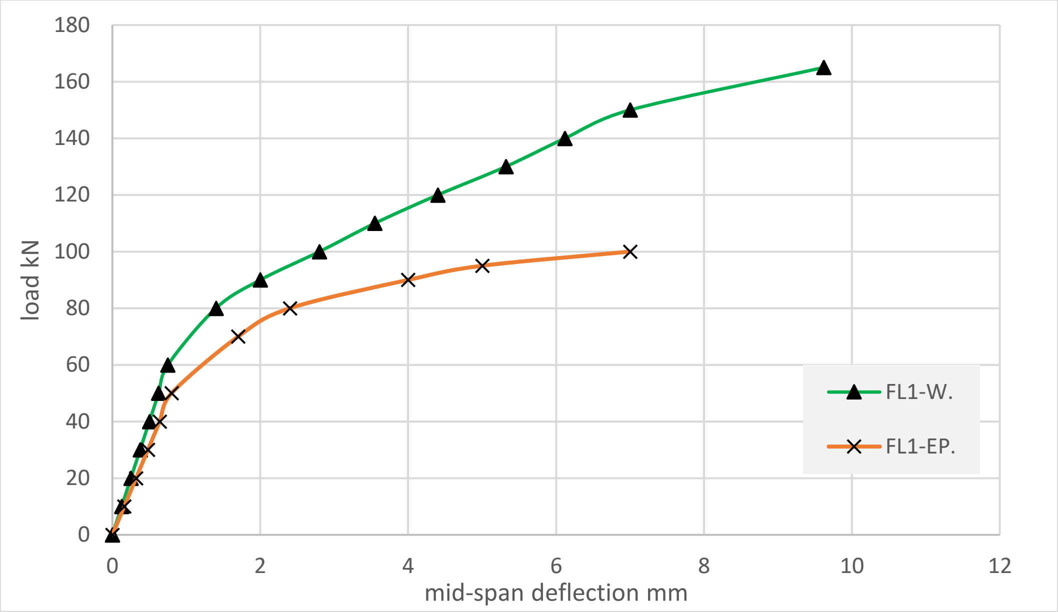
In this study, the concrete slab strengthened by two methods, the first method: replacing the concrete cover layer at the tension zone and using of polymer modified cement mortar and reinforced the cover with welded wire mesh, (RPMCM),(the cover layer consist of reinforced polymer modified cement mortar).

The second method: replacing the concrete cover layer at tension zone and using of polymer modified cement mortar without reinforced, that mean the cover layer consist of mortar only (PMCM). In general, using of the two way led to the strengthening of the slabs, but by studying of the results in the table 4.1 and comparing them with each other, it becomes clear the first method exhibited greater stiffness, ultimate load and ductility than the second method , because of wire mesh presence which these increase of steel area that resist bending load. .Figure 4.36, shows the compartion between the two methods .



(a)

Figure 4.36 Comparison by the State of the Cover Layer

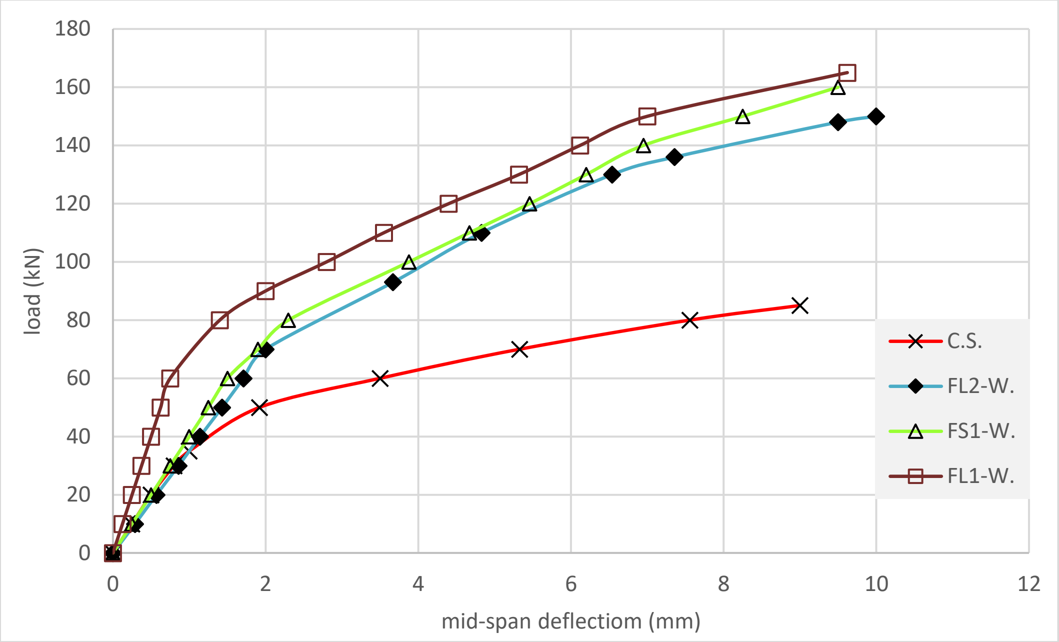


(b)

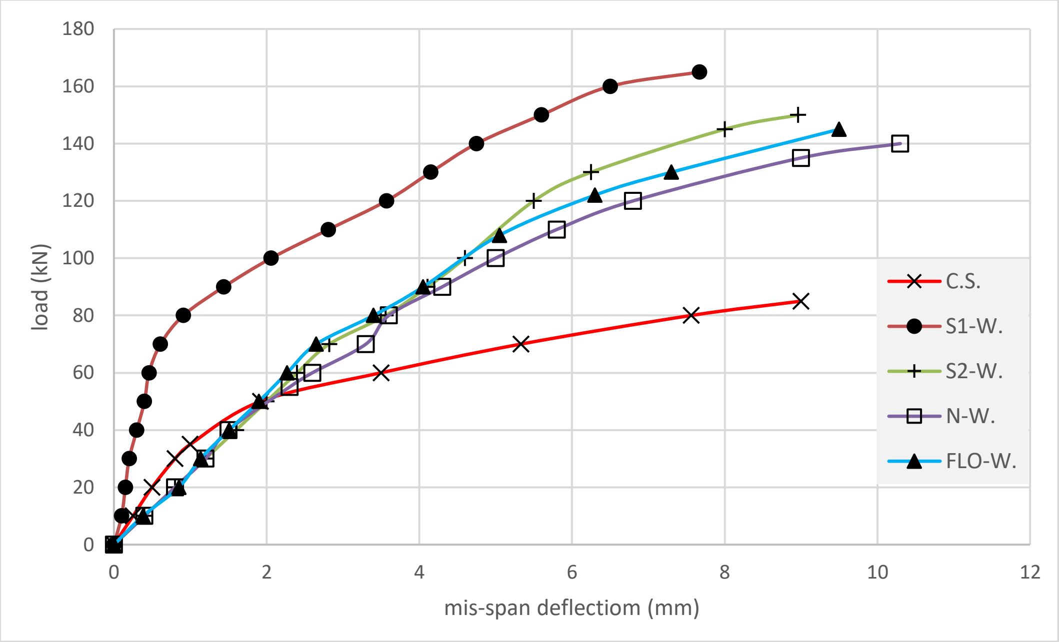
Figure 4.36 Comparison by the State of the Cover Layer

4.6.3 Type of the Cover Layer Materials

There is a detailed explanation in chapter three on the mechanical and physical properties of the strengthening materials. By studying the values of flexural and compressive strengths in table 3.11 and 3.12 and compared it with the values of ultimate load in table 4.1 and effective stiffness in table 4.2 ,conclude the increase in flexural and compressive strength of the cover layer materials leads to an improvement the flexural behavior of the strengthened concrete slab ,as shown in figure 4.37 and 4.38.

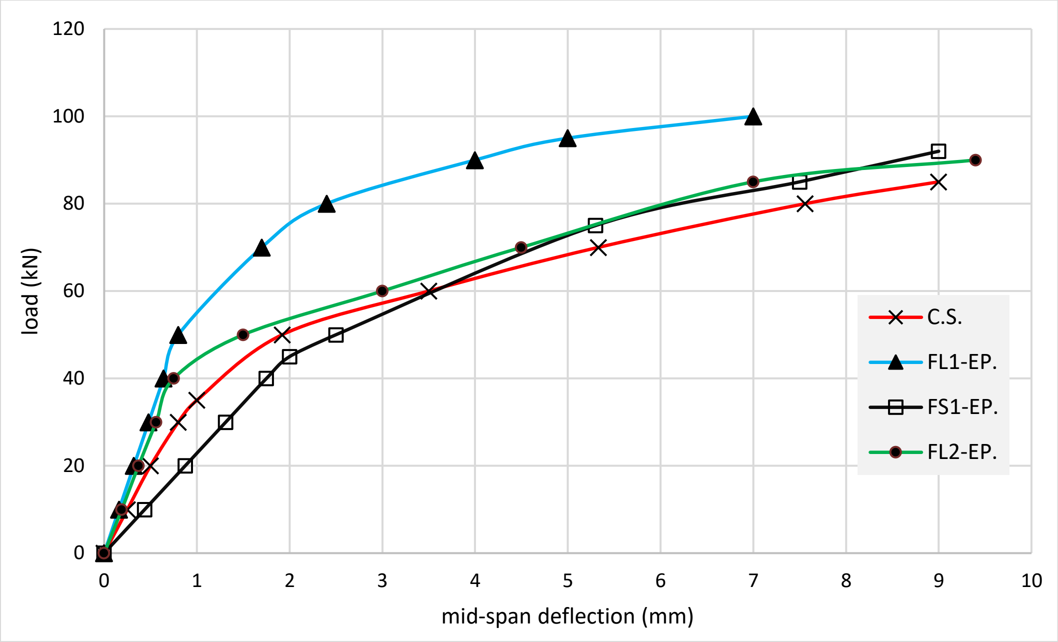


(a)

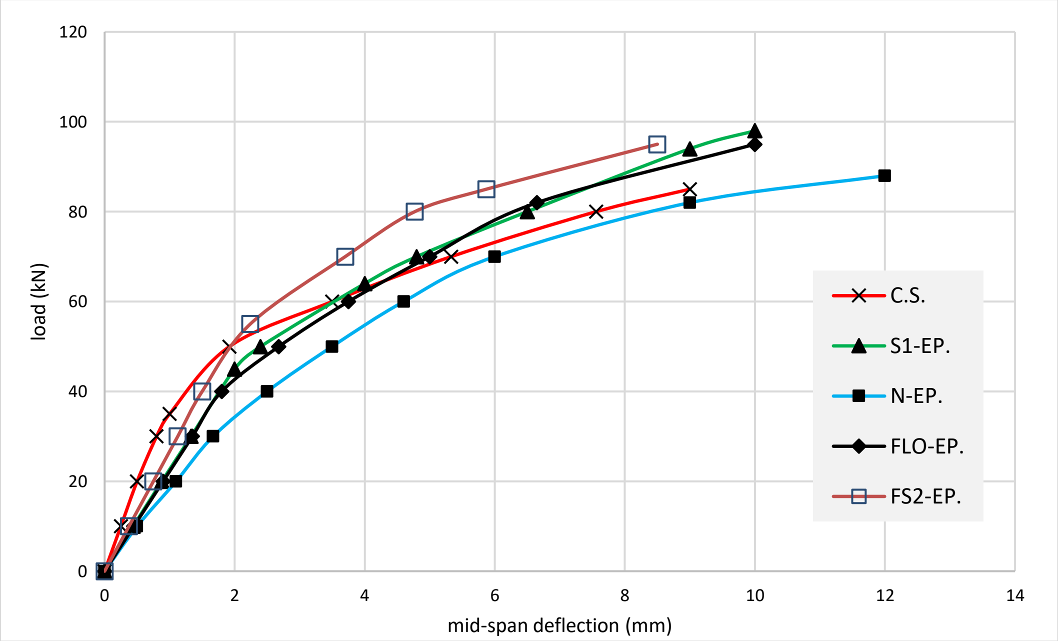


(b)

Figure 4.37 Comparison on Load Versus Mid-span Deflection for Specimens of group B



(a)



(b)

Figure 4.38 Comparison on Load Versus Mid-span Deflection for Specimens of group C

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Based on the investigated variables in this research, different conclusion points concerning the structure behavior of the strengthened concrete slab specimens are drawn:

1- Both the two methods of the strengthening show increment in ultimate load compared to the control specimen ,but the first method (strengthening by cover layer consist of RPMCM) is more effective than the second method (strengthening by cover layer consist of PMCM).

2- The high flexural and compressive strength of the cover layer materials leads to an improvement the flexural behavior of the strengthened concrete slab.

3- Specimens with (RPMCM) cover ,show higher stiffness and higher cracking moment than those with ferro-cement cover and (PMCM) cover (the cover layer just mortar).

4- The cracks in (RPMCM) cover less and thicker than the cracks in (PMCM) cover due to the presence of wire-mesh in the cover layer.

5- The effect of increasing the thickness of cover layer for strengthened slab has not significantly increased the load capacity of the strengthened slab. However, the increase in thickness of the cover layer led to reduce the number of the cracks.

5.2 Recommendations for Future Studies

1- Replacement of the cover layer at compression zone of the slab with different type of construction materials.

2- Use two and three layers of wire-mesh for reinforcing the cover layer of the strengthened slab.

3- Casting specimens of slabs without cover layer and compare it with other specimens with cover layer.

4- Casting of the upper part of the strengthened slab and then cast the cover layer

(invert the steps as in this study) .

5- Using of two method for connection (epoxy & tie wire) between the cover layer and the upper part of the strengthened slab together (at same time) .

6- Study of the effect of fires on slab samples.

7- Study the flexural behavior of reinforced concrete beam included replacement of the cover layer at tension zone by other construction materials.

8- Using of (flo-grout.2) as bonding material for connect between the cover layer and the upper part of the strengthened slab.

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APPENDIX A

Cempatch FL

Shrinkage compensated free flowing micro concrete

Description

Cempatch FL is a single component polymer modified repair system. Cempatch FL is composed of a blend of dry powders and selected aggregates which when mixed with water produce a shrinkage compensated, self compacting and free flowing micro-concrete suitable for large volume concrete repairs.

Applications

Repair of all types of structural concrete elements such as walls, columns, beams and floors.

Advantages

- High initial and ultimate strength development.
- Very high flow, suitable for repair of steel congested areas.
- Shrinkage controlled polymer modified cementitious repair eliminates cracking.
- Easy to apply, single component, requires only addition of water.
- Extremely low permeability, providing excellent protection to steel reinforcements and host concrete.
- Self compacting and self priming, with high bond strength.
- Suitable for internal and external applications.
- No independent primer is required.

Standards

Cempatch FL complies with the requirements of EN 1504-3 as a structural repair product Class R4 for principles 3.2, 7.1 and 7.2.

Method of Use

Substrate Preparation

All damaged and weak concrete shall be cut back to reach sound concrete or to a minimum depth of application. Corroded steel reinforcement should be grit blasted to remove all rust traces. Steel loss up to 25% of original section shall be compensated, where loss of section exceeds 25%, steel reinforcement shall be replaced.

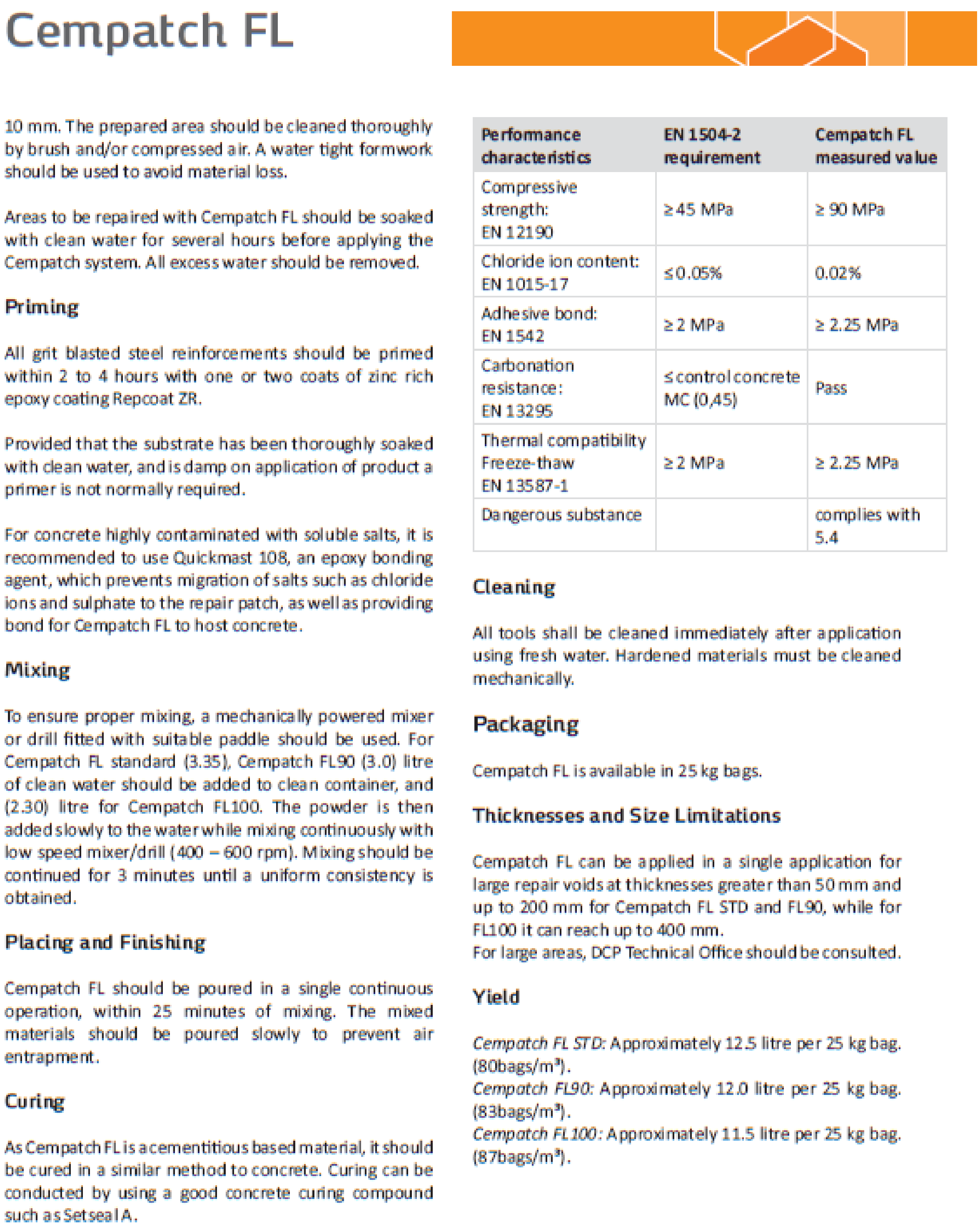
Remove all concrete form around exposed steel reinforcements by 20 mm thickness. The perimeters of the repair area should be saw cut to a minimum depth of

Technical Properties:

Colour:	Grey & white		
Compressive strength: BS EN 12390-3	**Cempatch FL**		
	STD	**90**	**100**
@ 1 day	> 27 MPa	> 35 MPa	> 40 MPa
@ 3 days	> 42 MPa	> 55 MPa	> 60 MPa
@ 7 days	> 52 MPa	> 70 MPa	> 80 MPa
@ 28 days	> 62 MPa	> 80 MPa	> 90 MPa
Flexural strength: BS6319, Part 3: 1998	**Cempatch FL**		
	STD	**90**	**100**
@ 28 days	≥ 9 MPa	≥ 11 MPa	≥ 13 MPa
Length change: ASTM C157	**Cempatch FL**		
	STD	**90**	**100**
@ 56 days	up to 0.008%	up to 0.01%	less than -0.02%
Working time:	20 – 25 min @ 20°C 12 – 17 min @ 35°C		
Setting time: BS4550 :			
Initial	6 – 7 hr @ 25°C		
Final	9 – 10 hr @ 25°C		
Water penetration: DIN1048	≤ 10 mm		
Mixing ratio:	**Cempatch FL STD** 3.35 litre of water for 25 kg bag of Cempatch FL STD **Cempatch FL90** 3 litre of water for 25 kg bag of Cempatch FL90 **Cempatch FL100** 2.30 litre of water for 25 kg bag of Cempatch FL100		
Minimum application temperature:	5°C		

Note: Cempatch FL is available in 3 ranges.
Compressive strength results are evaluated by using 150 mm cubes.
Compressive strength and Flexural strength @ 1 day are under restrain.
Compressive strength and Flexural strength @ 3, 7 & 28 days are under wet cure.

APPENDIX A



Cempatch FL

10 mm. The prepared area should be cleaned thoroughly by brush and/or compressed air. A water tight formwork should be used to avoid material loss.

Areas to be repaired with Cempatch FL should be soaked with clean water for several hours before applying the Cempatch system. All excess water should be removed.

Priming

All grit blasted steel reinforcements should be primed within 2 to 4 hours with one or two coats of zinc rich epoxy coating Repcoat ZR.

Provided that the substrate has been thoroughly soaked with clean water, and is damp on application of product a primer is not normally required.

For concrete highly contaminated with soluble salts, it is recommended to use Quickmast 108, an epoxy bonding agent, which prevents migration of salts such as chloride ions and sulphate to the repair patch, as well as providing bond for Cempatch FL to host concrete.

Mixing

To ensure proper mixing, a mechanically powered mixer or drill fitted with suitable paddle should be used. For Cempatch FL standard (3.35), Cempatch FL90 (3.0) litre of clean water should be added to clean container, and (2.30) litre for Cempatch FL100. The powder is then added slowly to the water while mixing continuously with low speed mixer/drill (400 – 600 rpm). Mixing should be continued for 3 minutes until a uniform consistency is obtained.

Placing and Finishing

Cempatch FL should be poured in a single continuous operation, within 25 minutes of mixing. The mixed materials should be poured slowly to prevent air entrapment.

Curing

As Cempatch FL is a cementitious based material, it should be cured in a similar method to concrete. Curing can be conducted by using a good concrete curing compound such as Setseal A.

Performance characteristics	EN 1504-2 requirement	Cempatch FL measured value
Compressive strength: EN 12190	≥ 45 MPa	≥ 90 MPa
Chloride ion content: EN 1015-17	≤ 0.05%	0.02%
Adhesive bond: EN 1542	≥ 2 MPa	≥ 2.25 MPa
Carbonation resistance: EN 13295	≤ control concrete MC (0,45)	Pass
Thermal compatibility Freeze-thaw EN 13587-1	≥ 2 MPa	≥ 2.25 MPa
Dangerous substance		complies with 5.4

Cleaning

All tools shall be cleaned immediately after application using fresh water. Hardened materials must be cleaned mechanically.

Packaging

Cempatch FL is available in 25 kg bags.

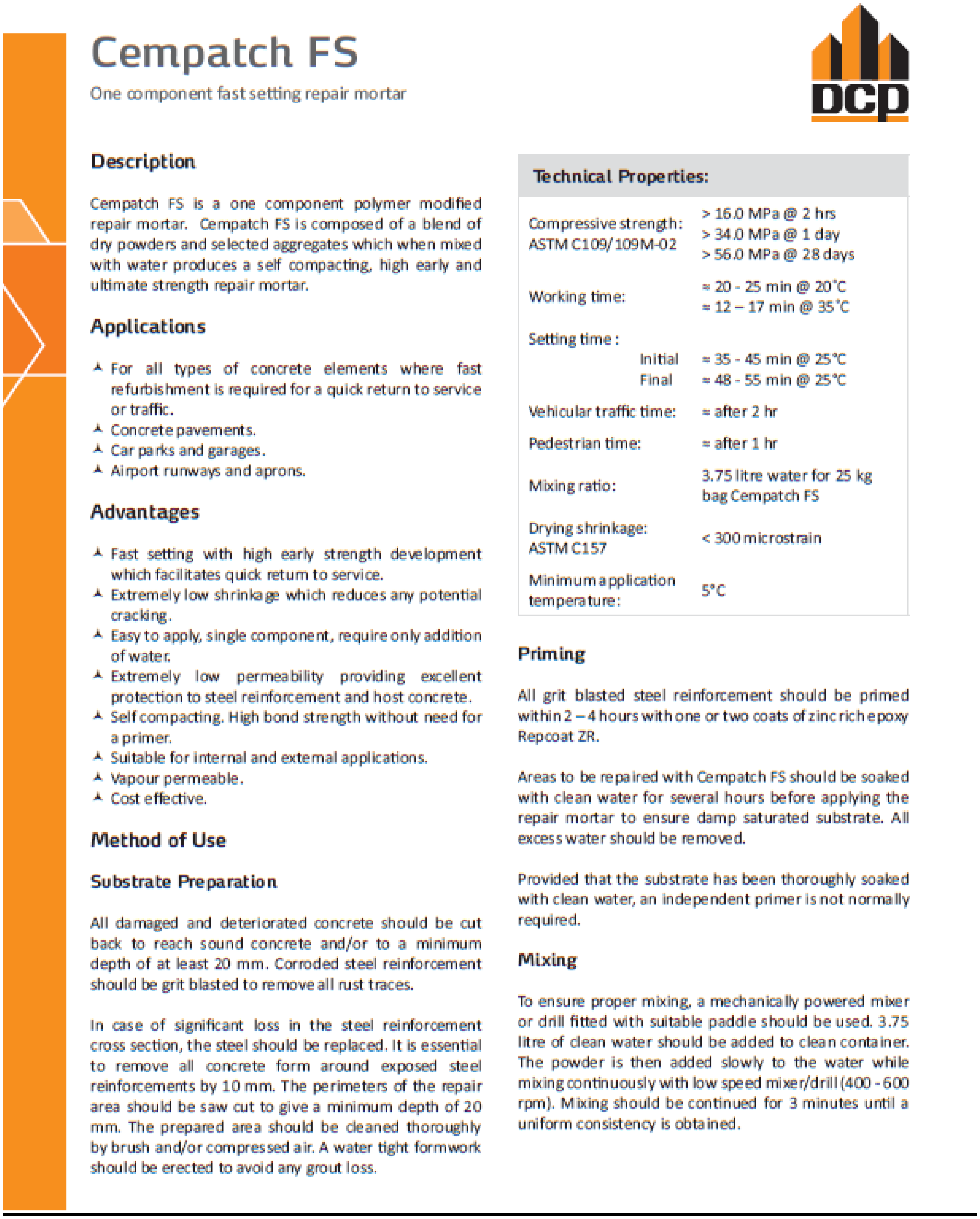
Thicknesses and Size Limitations

Cempatch FL can be applied in a single application for large repair voids at thicknesses greater than 50 mm and up to 200 mm for Cempatch FL STD and FL90, while for FL100 it can reach up to 400 mm.
For large areas, DCP Technical Office should be consulted.

Yield

Cempatch FL STD: Approximately 12.5 litre per 25 kg bag. (80bags/m^3).
Cempatch FL90: Approximately 12.0 litre per 25 kg bag. (83bags/m^3).
Cempatch FL100: Approximately 11.5 litre per 25 kg bag. (87bags/m^3).

APPENDIX B



Cempatch FS

One component fast setting repair mortar

Description

Cempatch FS is a one component polymer modified repair mortar. Cempatch FS is composed of a blend of dry powders and selected aggregates which when mixed with water produces a self compacting, high early and ultimate strength repair mortar.

Applications

- For all types of concrete elements where fast refurbishment is required for a quick return to service or traffic.
- Concrete pavements.
- Car parks and garages.
- Airport runways and aprons.

Advantages

- Fast setting with high early strength development which facilitates quick return to service.
- Extremely low shrinkage which reduces any potential cracking.
- Easy to apply, single component, require only addition of water.
- Extremely low permeability providing excellent protection to steel reinforcement and host concrete.
- Self compacting. High bond strength without need for a primer.
- Suitable for internal and external applications.
- Vapour permeable.
- Cost effective.

Method of Use

Substrate Preparation

All damaged and deteriorated concrete should be cut back to reach sound concrete and/or to a minimum depth of at least 20 mm. Corroded steel reinforcement should be grit blasted to remove all rust traces.

In case of significant loss in the steel reinforcement cross section, the steel should be replaced. It is essential to remove all concrete form around exposed steel reinforcements by 10 mm. The perimeters of the repair area should be saw cut to give a minimum depth of 20 mm. The prepared area should be cleaned thoroughly by brush and/or compressed air. A water tight formwork should be erected to avoid any grout loss.

Technical Properties:

Compressive strength: ASTM C109/109M-02	> 16.0 MPa @ 2 hrs > 34.0 MPa @ 1 day > 56.0 MPa @ 28 days
Working time:	≈ 20 - 25 min @ 20˚C ≈ 12 – 17 min @ 35˚C
Setting time :	
Initial	≈ 35 - 45 min @ 25°C
Final	≈ 48 - 55 min @ 25°C
Vehicular traffic time:	≈ after 2 hr
Pedestrian time:	≈ after 1 hr
Mixing ratio:	3.75 litre water for 25 kg bag Cempatch FS
Drying shrinkage: ASTM C157	< 300 microstrain
Minimum application temperature:	5°C

Priming

All grit blasted steel reinforcement should be primed within 2 – 4 hours with one or two coats of zinc rich epoxy Repcoat ZR.

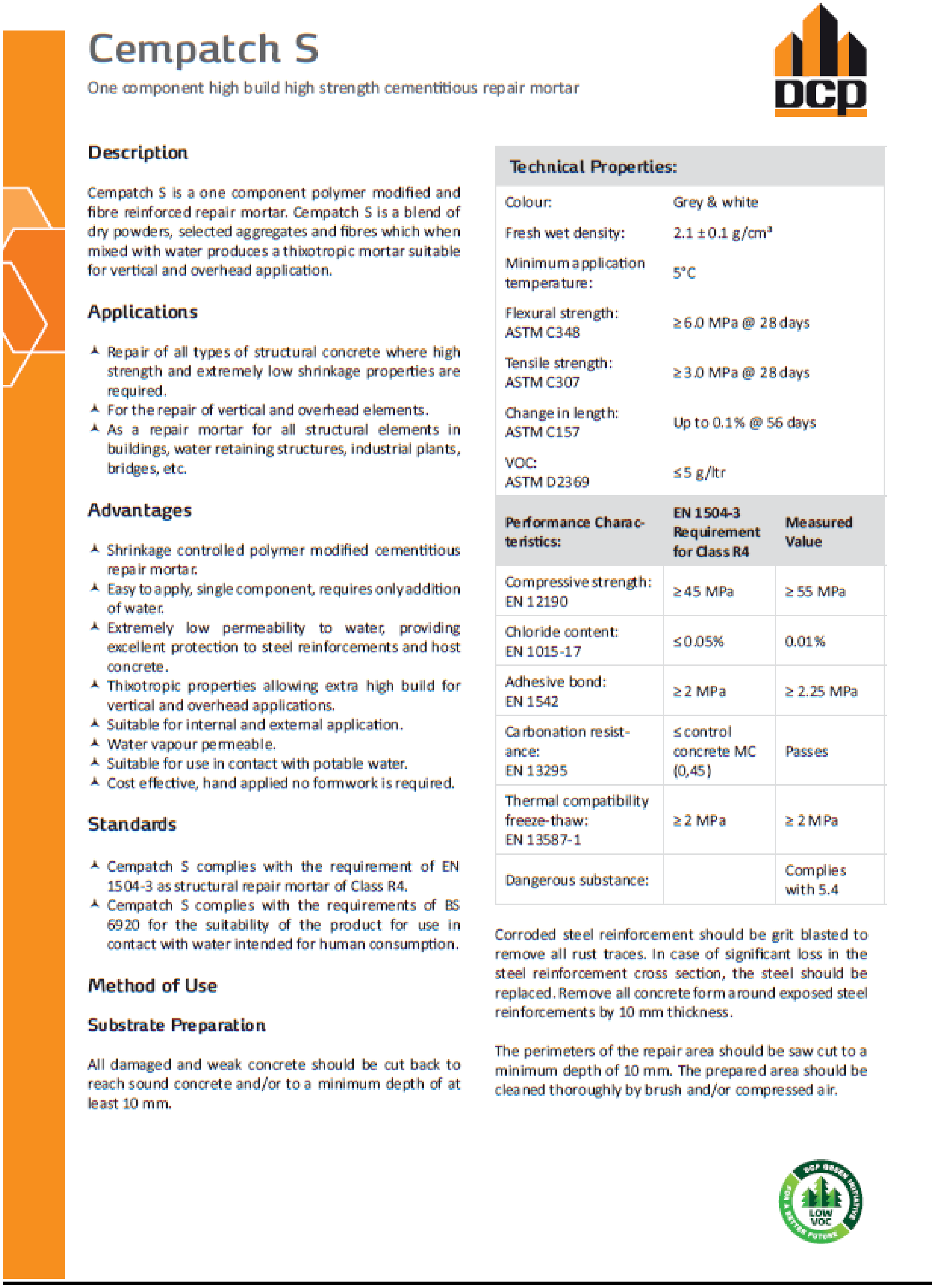
Areas to be repaired with Cempatch FS should be soaked with clean water for several hours before applying the repair mortar to ensure damp saturated substrate. All excess water should be removed.

Provided that the substrate has been thoroughly soaked with clean water, an independent primer is not normally required.

Mixing

To ensure proper mixing, a mechanically powered mixer or drill fitted with suitable paddle should be used. 3.75 litre of clean water should be added to clean container. The powder is then added slowly to the water while mixing continuously with low speed mixer/drill (400 - 600 rpm). Mixing should be continued for 3 minutes until a uniform consistency is obtained.

APPENDIX C



Cempatch S

One component high build high strength cementitious repair mortar

Description

Cempatch S is a one component polymer modified and fibre reinforced repair mortar. Cempatch S is a blend of dry powders, selected aggregates and fibres which when mixed with water produces a thixotropic mortar suitable for vertical and overhead application.

Applications

- Repair of all types of structural concrete where high strength and extremely low shrinkage properties are required.
- For the repair of vertical and overhead elements.
- As a repair mortar for all structural elements in buildings, water retaining structures, industrial plants, bridges, etc.

Advantages

- Shrinkage controlled polymer modified cementitious repair mortar.
- Easy to apply, single component, requires only addition of water.
- Extremely low permeability to water, providing excellent protection to steel reinforcements and host concrete.
- Thixotropic properties allowing extra high build for vertical and overhead applications.
- Suitable for internal and external application.
- Water vapour permeable.
- Suitable for use in contact with potable water.
- Cost effective, hand applied no formwork is required.

Standards

- Cempatch S complies with the requirement of EN 1504-3 as structural repair mortar of Class R4.
- Cempatch S complies with the requirements of BS 6920 for the suitability of the product for use in contact with water intended for human consumption.

Method of Use

Substrate Preparation

All damaged and weak concrete should be cut back to reach sound concrete and/or to a minimum depth of at least 10 mm.

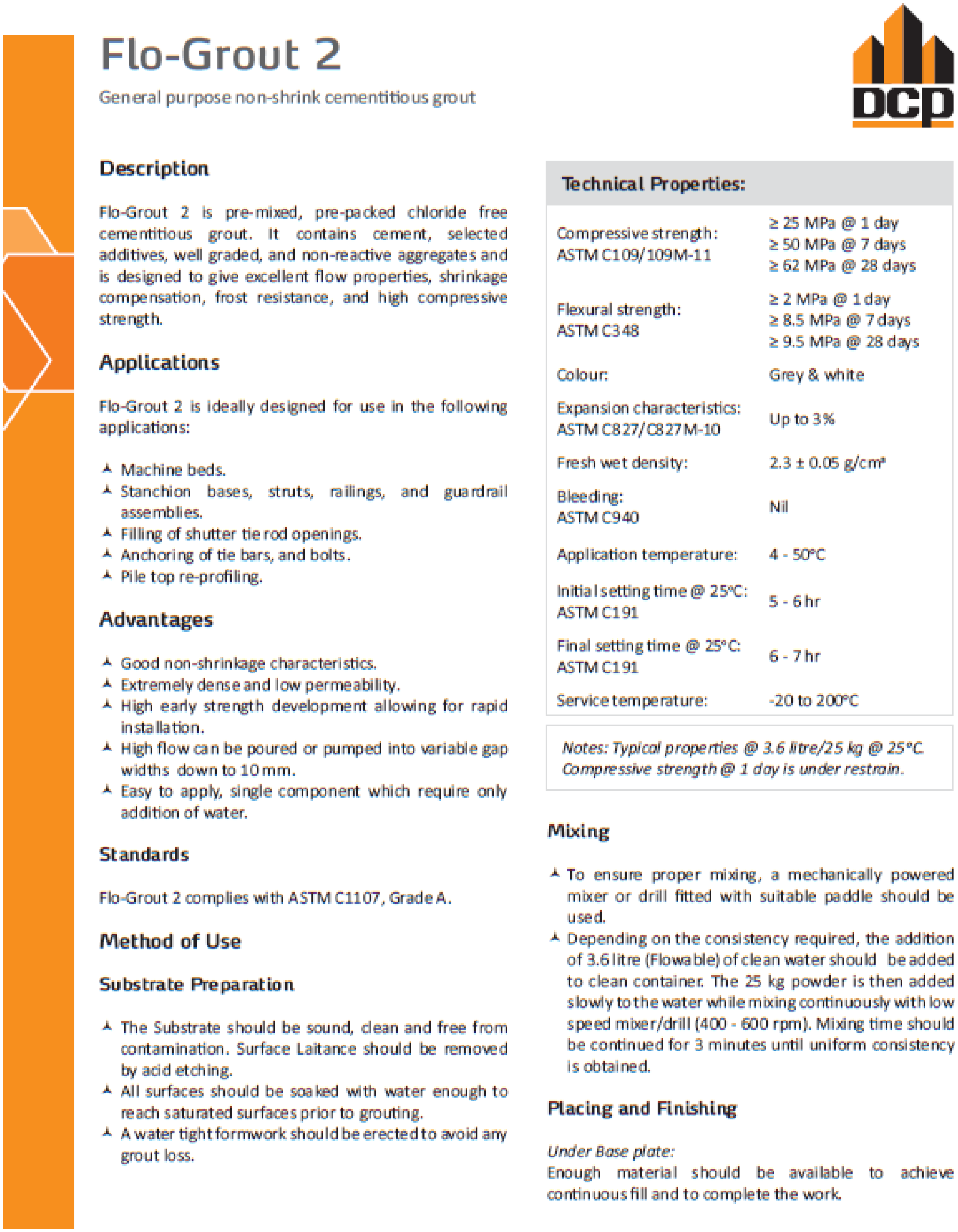
Technical Properties:	
Colour:	Grey & white
Fresh wet density:	2.1 ± 0.1 g/cm³
Minimum application temperature:	5°C
Flexural strength: ASTM C348	≥ 6.0 MPa @ 28 days
Tensile strength: ASTM C307	≥ 3.0 MPa @ 28 days
Change in length: ASTM C157	Up to 0.1% @ 56 days
VOC: ASTM D2369	≤ 5 g/ltr

Performance Characteristics:	EN 1504-3 Requirement for Class R4	Measured Value
Compressive strength: EN 12190	≥ 45 MPa	≥ 55 MPa
Chloride content: EN 1015-17	≤ 0.05%	0.01%
Adhesive bond: EN 1542	≥ 2 MPa	≥ 2.25 MPa
Carbonation resistance: EN 13295	≤ control concrete MC (0,45)	Passes
Thermal compatibility freeze-thaw: EN 13587-1	≥ 2 MPa	≥ 2 MPa
Dangerous substance:		Complies with 5.4

Corroded steel reinforcement should be grit blasted to remove all rust traces. In case of significant loss in the steel reinforcement cross section, the steel should be replaced. Remove all concrete form around exposed steel reinforcements by 10 mm thickness.

The perimeters of the repair area should be saw cut to a minimum depth of 10 mm. The prepared area should be cleaned thoroughly by brush and/or compressed air.

APPENDIX D



Flo-Grout 2

General purpose non-shrink cementitious grout

Description

Flo-Grout 2 is pre-mixed, pre-packed chloride free cementitious grout. It contains cement, selected additives, well graded, and non-reactive aggregates and is designed to give excellent flow properties, shrinkage compensation, frost resistance, and high compressive strength.

Applications

Flo-Grout 2 is ideally designed for use in the following applications:

- Machine beds.
- Stanchion bases, struts, railings, and guardrail assemblies.
- Filling of shutter tie rod openings.
- Anchoring of tie bars, and bolts.
- Pile top re-profiling.

Advantages

- Good non-shrinkage characteristics.
- Extremely dense and low permeability.
- High early strength development allowing for rapid installation.
- High flow can be poured or pumped into variable gap widths down to 10 mm.
- Easy to apply, single component which require only addition of water.

Standards

Flo-Grout 2 complies with ASTM C1107, Grade A.

Method of Use

Substrate Preparation

- The Substrate should be sound, clean and free from contamination. Surface Laitance should be removed by acid etching.
- All surfaces should be soaked with water enough to reach saturated surfaces prior to grouting.
- A water tight formwork should be erected to avoid any grout loss.

Technical Properties:

Compressive strength: ASTM C109/109M-11	≥ 25 MPa @ 1 day ≥ 50 MPa @ 7 days ≥ 62 MPa @ 28 days
Flexural strength: ASTM C348	≥ 2 MPa @ 1 day ≥ 8.5 MPa @ 7 days ≥ 9.5 MPa @ 28 days
Colour:	Grey & white
Expansion characteristics: ASTM C827/C827M-10	Up to 3%
Fresh wet density:	2.3 ± 0.05 g/cm^3
Bleeding: ASTM C940	Nil
Application temperature:	4 - 50°C
Initial setting time @ 25°C: ASTM C191	5 - 6 hr
Final setting time @ 25°C: ASTM C191	6 - 7 hr
Service temperature:	-20 to 200°C

Notes: Typical properties @ 3.6 litre/25 kg @ 25°C
Compressive strength @ 1 day is under restrain.

Mixing

- To ensure proper mixing, a mechanically powered mixer or drill fitted with suitable paddle should be used.
- Depending on the consistency required, the addition of 3.6 litre (Flowable) of clean water should be added to clean container. The 25 kg powder is then added slowly to the water while mixing continuously with low speed mixer/drill (400 - 600 rpm). Mixing time should be continued for 3 minutes until uniform consistency is obtained.

Placing and Finishing

Under Base plate:
Enough material should be available to achieve continuous fill and to complete the work.

APPENDIX D

Flo-Grout 2

Pouring of the mixed grout should be started from one side only to avoid air entrapment. To obtain maximum flow distance, a side shutter feed between 100 mm to 250 mm high should be erected and used to build the required head.

Formwork:
As the mixed grout posses high fluidity characteristics, all formwork and shutters should be water tight. This can be obtained by sealing underneath the formwork and at the joints by using an appropriate mastic. The unrestrained areas should be kept to a minimum due to the expansive nature of Flo-Grout 2.

Curing

Since Flo-Grout 2 is a cementitious based material, it should be treated in a manner similar to concrete. Curing can be conducted by either using concrete curing compound such as Setseal 22 or by using wet hessian and polyethylene.

Notes:

- At low temperatures (below 8°C), warm water is recommended to achieve the early strength. And the formwork is recommended to be kept longer time.
- At high temperatures (35°C and above), cold water (less than 20°C) must be used for mixing.

Cleaning

All tools should be cleaned immediately after finishing by clean water. Hardened materials can be cleaned mechanically.

Packaging

Flo-Grout 2 is available in 25 kg and 50 kg bags.

Thicknesses and Size Limitations

Flo-Grout 2 can be applied in a single layer at thickness between 10 - 120 mm. For greater thickness, an 8 - 12 mm washed aggregate should be added at a ratio of 14 - 15 kg of washed aggregate to 25 kg of Flo-Grout 2 and 28 - 30 kg of washed aggregate to 50 kg of Flo-Grout 2.

However, Flo-Grout 2WWA are available in 25 kg bags, where the mixing water is about 2.3 litre per bag to get a flowable consistency.

Yield

Approximately 12 - 13 litre per 25 kg bag and 24 - 26 litre per 50 kg bag.

Storage

Flo-Grout 2 has a shelf life of 12 months from date of manufacture if stored at temperatures between 2°C and 50°C.

If these conditions are exceeded, DCP Technical Department should be contacted for advise.

Cautions

Health and Safety

Since it is powder containing Portland cement and sand, Flo-Grout 2 may cause irritation to skin or eyes.
In case of accidental contact with eyes, immediately flush with plenty of water for at least 10 minutes and seek medical advise.

For further information refer to the Material Safety Data Sheet.

Fire

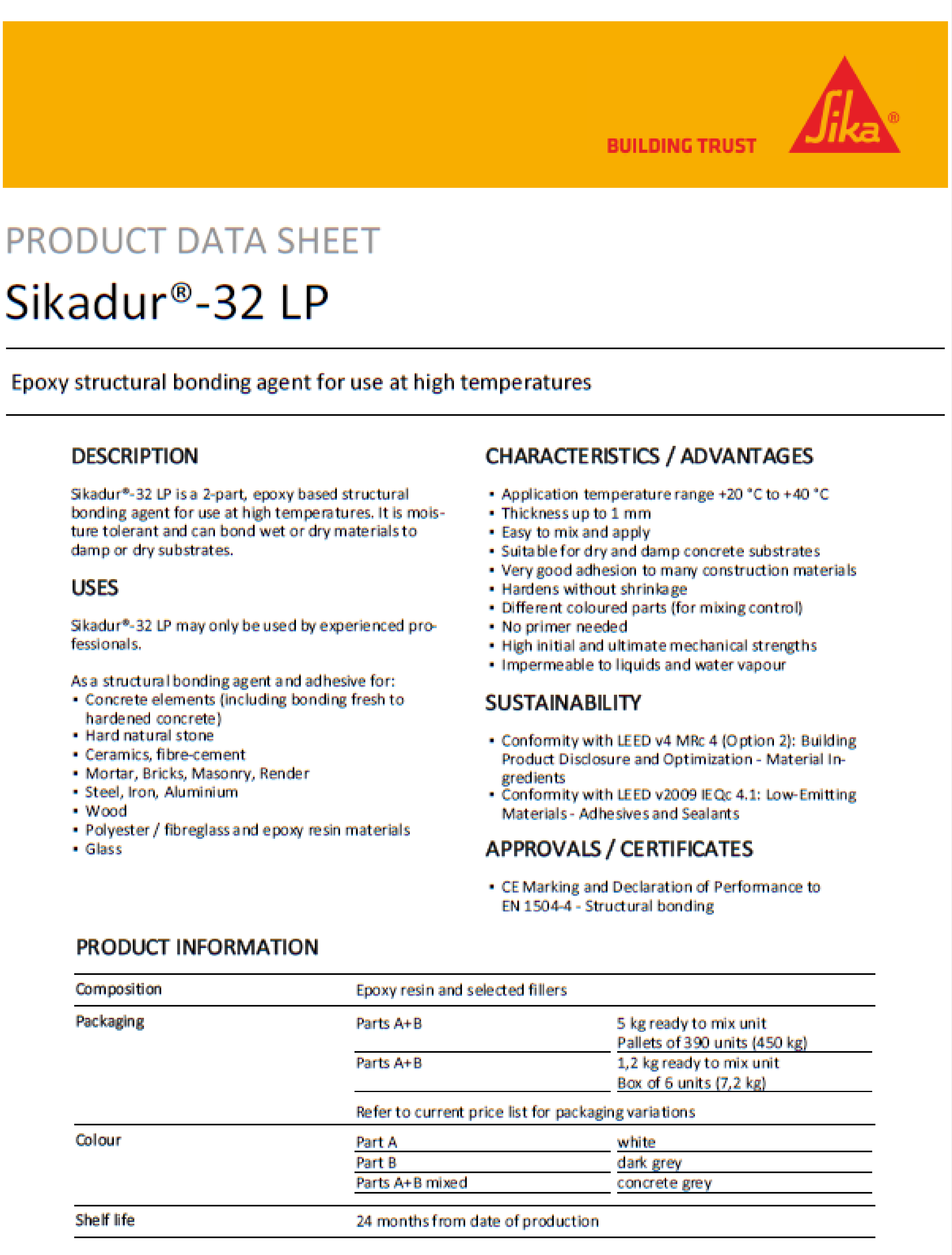
Flo-Grout 2 is nonflammable.

More from Don Construction Products

A wide range of construction chemical products are manufactured by DCP which include:

- Concrete admixtures.
- Surface treatments
- Grouts and anchors.
- Concrete repair.
- Flooring systems.
- Protective coatings.
- Sealants.
- Waterproofing.
- Adhesives.
- Tile adhesives and grouts.
- Building products.
- Structural strengthening.

APPENDIX E



BUILDING TRUST

PRODUCT DATA SHEET

Sikadur®-32 LP

Epoxy structural bonding agent for use at high temperatures

DESCRIPTION

Sikadur®-32 LP is a 2-part, epoxy based structural bonding agent for use at high temperatures. It is moisture tolerant and can bond wet or dry materials to damp or dry substrates.

USES

Sikadur®-32 LP may only be used by experienced professionals.

As a structural bonding agent and adhesive for:
- Concrete elements (including bonding fresh to hardened concrete)
- Hard natural stone
- Ceramics, fibre-cement
- Mortar, Bricks, Masonry, Render
- Steel, Iron, Aluminium
- Wood
- Polyester / fibreglass and epoxy resin materials
- Glass

CHARACTERISTICS / ADVANTAGES

- Application temperature range +20 °C to +40 °C
- Thickness up to 1 mm
- Easy to mix and apply
- Suitable for dry and damp concrete substrates
- Very good adhesion to many construction materials
- Hardens without shrinkage
- Different coloured parts (for mixing control)
- No primer needed
- High initial and ultimate mechanical strengths
- Impermeable to liquids and water vapour

SUSTAINABILITY

- Conformity with LEED v4 MRc 4 (Option 2): Building Product Disclosure and Optimization - Material Ingredients
- Conformity with LEED v2009 IEQc 4.1: Low-Emitting Materials - Adhesives and Sealants

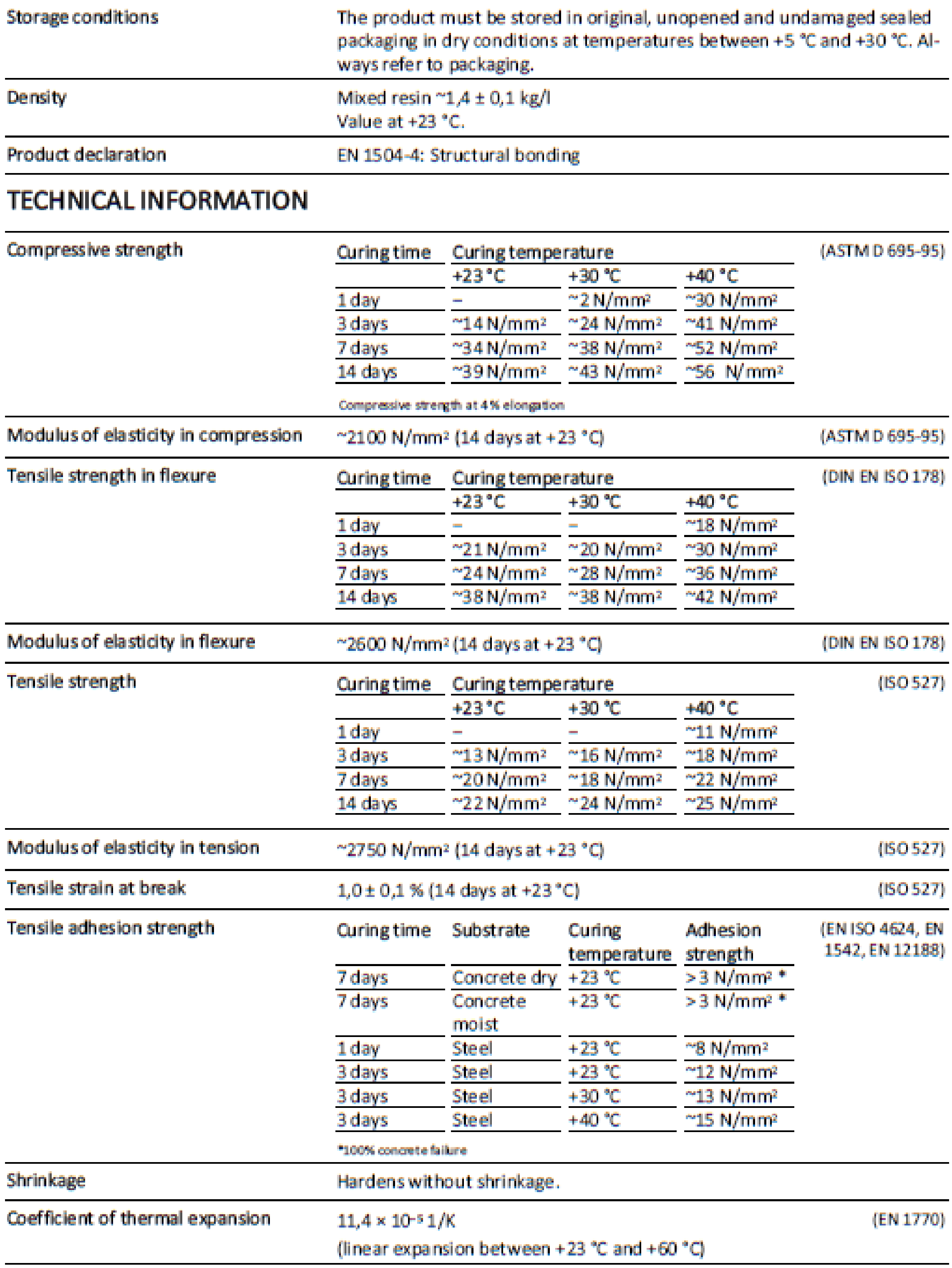
APPROVALS / CERTIFICATES

- CE Marking and Declaration of Performance to EN 1504-4 - Structural bonding

PRODUCT INFORMATION

Composition	Epoxy resin and selected fillers	
Packaging	Parts A+B	5 kg ready to mix unit Pallets of 390 units (450 kg)
	Parts A+B	1,2 kg ready to mix unit Box of 6 units (7,2 kg)
	Refer to current price list for packaging variations	
Colour	Part A	white
	Part B	dark grey
	Parts A+B mixed	concrete grey
Shelf life	24 months from date of production	

APPENDIX E



Storage conditions	The product must be stored in original, unopened and undamaged sealed packaging in dry conditions at temperatures between +5 °C and +30 °C. Always refer to packaging.
Density	Mixed resin ~1,4 ± 0,1 kg/l Value at +23 °C.
Product declaration	EN 1504-4: Structural bonding

TECHNICAL INFORMATION

Compressive strength (ASTM D 695-95)

Curing time	Curing temperature		
	+23 °C	+30 °C	+40 °C
1 day	–	~2 N/mm²	~30 N/mm²
3 days	~14 N/mm²	~24 N/mm²	~41 N/mm²
7 days	~34 N/mm²	~38 N/mm²	~52 N/mm²
14 days	~39 N/mm²	~43 N/mm²	~56 N/mm²

Compressive strength at 4 % elongation

Modulus of elasticity in compression: ~2100 N/mm² (14 days at +23 °C) (ASTM D 695-95)

Tensile strength in flexure (DIN EN ISO 178)

Curing time	Curing temperature		
	+23 °C	+30 °C	+40 °C
1 day	–	–	~18 N/mm²
3 days	~21 N/mm²	~20 N/mm²	~30 N/mm²
7 days	~24 N/mm²	~28 N/mm²	~36 N/mm²
14 days	~38 N/mm²	~38 N/mm²	~42 N/mm²

Modulus of elasticity in flexure: ~2600 N/mm² (14 days at +23 °C) (DIN EN ISO 178)

Tensile strength (ISO 527)

Curing time	Curing temperature		
	+23 °C	+30 °C	+40 °C
1 day	–	–	~11 N/mm²
3 days	~13 N/mm²	~16 N/mm²	~18 N/mm²
7 days	~20 N/mm²	~18 N/mm²	~22 N/mm²
14 days	~22 N/mm²	~24 N/mm²	~25 N/mm²

Modulus of elasticity in tension: ~2750 N/mm² (14 days at +23 °C) (ISO 527)

Tensile strain at break: 1,0 ± 0,1 % (14 days at +23 °C) (ISO 527)

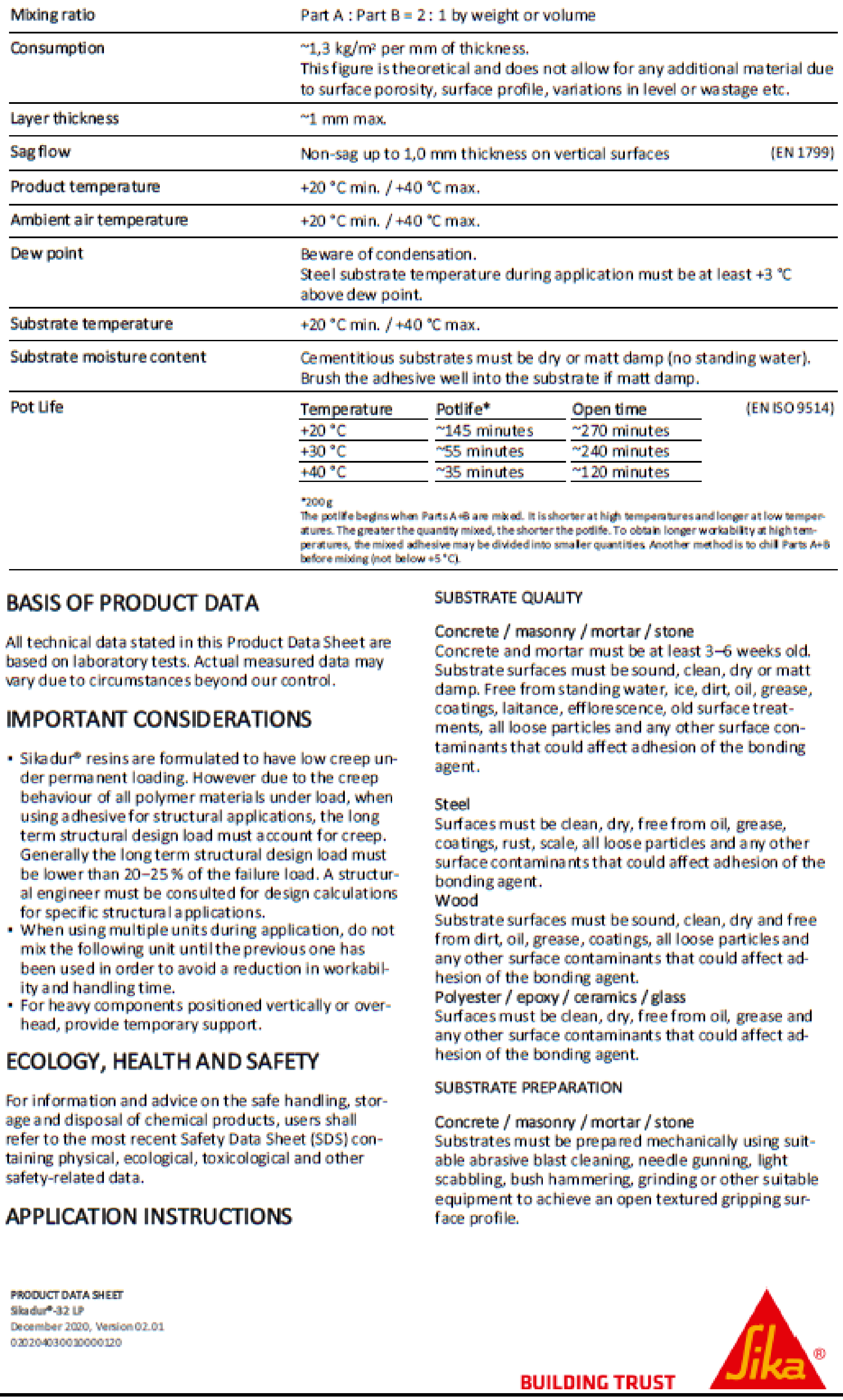
Tensile adhesion strength (EN ISO 4624, EN 1542, EN 12188)

Curing time	Substrate	Curing temperature	Adhesion strength
7 days	Concrete dry	+23 °C	> 3 N/mm² *
7 days	Concrete moist	+23 °C	> 3 N/mm² *
1 day	Steel	+23 °C	~8 N/mm²
3 days	Steel	+23 °C	~12 N/mm²
3 days	Steel	+30 °C	~13 N/mm²
3 days	Steel	+40 °C	~15 N/mm²

*100% concrete failure

Shrinkage	Hardens without shrinkage.	
Coefficient of thermal expansion	$11,4 \times 10^{-5}$ 1/K (linear expansion between +23 °C and +60 °C)	(EN 1770)

APPENDIX E



Mixing ratio	Part A : Part B = 2 : 1 by weight or volume
Consumption	~1,3 kg/m² per mm of thickness. This figure is theoretical and does not allow for any additional material due to surface porosity, surface profile, variations in level or wastage etc.
Layer thickness	~1 mm max.
Sag flow	Non-sag up to 1,0 mm thickness on vertical surfaces (EN 1799)
Product temperature	+20 °C min. / +40 °C max.
Ambient air temperature	+20 °C min. / +40 °C max.
Dew point	Beware of condensation. Steel substrate temperature during application must be at least +3 °C above dew point.
Substrate temperature	+20 °C min. / +40 °C max.
Substrate moisture content	Cementitious substrates must be dry or matt damp (no standing water). Brush the adhesive well into the substrate if matt damp.
Pot Life	(EN ISO 9514)

Temperature	Potlife*	Open time
+20 °C	~145 minutes	~270 minutes
+30 °C	~55 minutes	~240 minutes
+40 °C	~35 minutes	~120 minutes

*200 g
The potlife begins when Parts A+B are mixed. It is shorter at high temperatures and longer at low temperatures. The greater the quantity mixed, the shorter the potlife. To obtain longer workability at high temperatures, the mixed adhesive may be divided into smaller quantities. Another method is to chill Parts A+B before mixing (not below +5 °C).

BASIS OF PRODUCT DATA

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

IMPORTANT CONSIDERATIONS

- Sikadur® resins are formulated to have low creep under permanent loading. However due to the creep behaviour of all polymer materials under load, when using adhesive for structural applications, the long term structural design load must account for creep. Generally the long term structural design load must be lower than 20–25 % of the failure load. A structural engineer must be consulted for design calculations for specific structural applications.
- When using multiple units during application, do not mix the following unit until the previous one has been used in order to avoid a reduction in workability and handling time.
- For heavy components positioned vertically or overhead, provide temporary support.

ECOLOGY, HEALTH AND SAFETY

For information and advice on the safe handling, storage and disposal of chemical products, users shall refer to the most recent Safety Data Sheet (SDS) containing physical, ecological, toxicological and other safety-related data.

APPLICATION INSTRUCTIONS

SUBSTRATE QUALITY

Concrete / masonry / mortar / stone
Concrete and mortar must be at least 3–6 weeks old. Substrate surfaces must be sound, clean, dry or matt damp. Free from standing water, ice, dirt, oil, grease, coatings, laitance, efflorescence, old surface treatments, all loose particles and any other surface contaminants that could affect adhesion of the bonding agent.

Steel
Surfaces must be clean, dry, free from oil, grease, coatings, rust, scale, all loose particles and any other surface contaminants that could affect adhesion of the bonding agent.

Wood
Substrate surfaces must be sound, clean, dry and free from dirt, oil, grease, coatings, all loose particles and any other surface contaminants that could affect adhesion of the bonding agent.

Polyester / epoxy / ceramics / glass
Surfaces must be clean, dry, free from oil, grease and any other surface contaminants that could affect adhesion of the bonding agent.

SUBSTRATE PREPARATION

Concrete / masonry / mortar / stone
Substrates must be prepared mechanically using suitable abrasive blast cleaning, needle gunning, light scabbling, bush hammering, grinding or other suitable equipment to achieve an open textured gripping surface profile.

APPENDIX F

All slabs were designed according to ACI318-14 Code. The steps of analysis of the reference slab as follows:

Data

fy =529 Mpa , f'c$_{avg}$=23.84 Mpa

slab dimension = 1500 × 750 mm

t$_s$(h)=150 mm

1- Check the minimum thichness

$h)_{min.} = \frac{L}{20} \times (0.4 + \frac{fy}{700}) \longrightarrow h)_{min.} = \frac{1500}{20} \times (0.4 + \frac{529}{700})$

$h)_{min.} =$ 86.67 mm < 150 mm O.K

2- Calculate area of the steel reinforcement

A_S bar $= \frac{\Pi}{4} d2 = \frac{\Pi \times 100}{4} = 78.5 mm^2$

$d = h - cover - \frac{db}{2} = 150 - 20 - \frac{10}{2} = 125$ mm

$\rho\ max = 0.75 \times \rho_b = 0.75 \times 0.017 = 0.012$

$\rho\ b = 0.85 \times \beta_1 \times \frac{f'c}{fy} \times \frac{600}{600+fy} = 0.017$

$fc' < 28\ MPa \rightarrow \beta 1 = 0.85$

$\rho\ min = \frac{0.0018 \times 420}{fy}\ for\ fy > 420$ Mpa

$\rho\ min = \frac{0.0018 \times 420}{529} = 0.0014$

In both direction :

A_S total = $\frac{\text{AS bar} \times 1500}{spacing} = \frac{78.5 \times 1000}{150} = 523.30\ mm^2$

$\rho = \frac{\text{AS total}}{b \times d} = \frac{523.30}{750 \times 125} = 0.004$

$\rho > \rho\ min$ and $\rho < \rho\ max$ ok

$a = \frac{\text{As} \times \text{fy}}{0.85 \times \text{f'c} \times \text{b}} = \frac{523.30 \times 529}{0.85 \times 23.84 \times 1000} = 13.66\ mm$

No. of bars $= \frac{\text{As)required}}{\text{As)one bar}} = \frac{523.30}{78.5} = 6.66 \approx 7$ bars for one meter

In long direction (10 Ø10)*bars will be used*

In short direction (5Ø10) bars will be used

$Spacing\ (S) = \frac{long\ span}{No.of\ bars - 1} = \frac{1500}{9} = 160$ mm ok

$M_u = Ø \times As \times fy\ (d - \frac{a}{2}) \times 10^{-6} = 0.9 \times 523.30 \times 529(125 - \frac{13.66}{2}) \times 10^{-6} = 29$ Kn.m

$Mu = \frac{wu \times l^2}{8} \rightarrow \quad 29 = \frac{wu \times 1.3^2}{8} \rightarrow$ Wu = 137.27 Kn

Wu = 1.2 WD + 1.6 WL → $\quad 29 = 1.2 \times (2.5 \times 0.15) + 1.6 \times$ WL

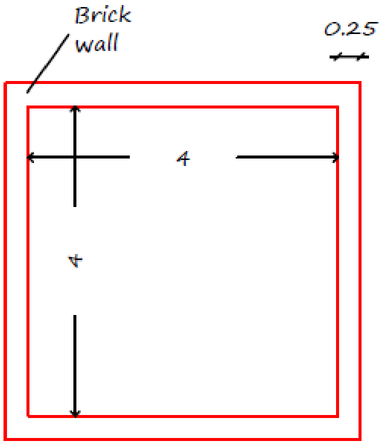
∴ WL = 85.5 Kn

APPENDIX G

Cost difference between strengthened slab and unstrengthened slab

The difference between the cost of pouring the strengthened slab and ordinary slab (without strengthened), is the cost difference between the normal concrete cover layer and the cover layer made (composed) of polymer modified cement mortar because the upper part of the slab, whether it is strengthened or without strengthened, is the same details in terms of quantity and quantity of reinforcing steel. As an example, the cost of the strengthened slab by the first way (by RPMCM cover) and the second way (by PMCM cover), will be calculated and compared it with the slab without strengthened , as below :

Note : thickness of the cover layer = 2.5 cm.



Dimensions of the room = 4 * 4 m
width of the brick wall = 0.25 m
depth (thickness) of the concrete slab (ceiling) = 150 mm

-Area of the slab = $4.5 \times 4.5 = 20.25\ \mathit{square\ meter}$.

1- The cost of casting the normal concrete cover layer as below :

- Cost of one cubic meter of normal concrete = 90000 IQD (61.64 USD).

- Volume of the cover layer of the slab for room = $4.5 \times 4.5 \times 0.025 = 0.5$ m3.

$\therefore$ The cost = $0.5 \times 90000 = 45000\ IQD$. Casting the ordinary slab (without strengthening) was on one stage,while the strengthened slab was on two stages.

2- (A) Cost the cover layer of the strengthened slab by (RPMCM)

-To complete the pouring of the cover layer for strengthened slab , we need two labour. The wages of each laborer is 25,000 IQD.

- Wages of two laborer = 2× 25000 = 50,000 IQD (34.24 USD).

Appendix G Table 1 Cost of the polymer modified cement

NO.	Product Name	Unit	Price per unit (USD)
1	Cempatch FL (1bag = 25 kg)	kg	16 $
2	Cempatch FS (1bag = 25 kg)	kg	20 $
3	Cempatch S (1bag = 25 kg)	kg	14 $
4	Flo-grout.2 (1bag = 25 kg)	kg	10 $

∴ (Average the price of one bag = 15 $)

- ❖ Price of one square meter of wire mesh (with 25.4 mm square opening) = 5000 IQD (3.42 USD).
- ❖ Each one bag cast (1.125 m2), with thickness 2.5cm , this mean cost of casting one meter = 13.33 $ (≈ 19500 IQD).

- ❖ this mean cost of one meter of **RPMCM** cover layer = 19500 + **5000** = 24500 IQD.

∴ The total cost = area of the room × 24500 + Wages of two laborer

$$= 20.25 \times 24500 + 50000 = 546{,}125\ IQD \text{ (374 USD)}$$

(B) - Cost the ferrocement cover layer of the strengthened slab (N-W.)

∵ Cost of one meter of normal mortar (sand+Portland cement) = 1000 IQD.

∵ Cost of one meter of ferro-cement = cost of one meter wire mesh + cost one meter of normal mortar

= 5000 + 1000 = 6000 IQD (4.10 USD)

∴ The total cost = area of the room × 24500 + Wages of two laborer

$$= 20.25 \times 6000 + 50000 = \ 171{,}500\ IQD$$ (117.46 USD)

3- Cost the cover layer of the strengthened slab by second way (by PMCM cover)

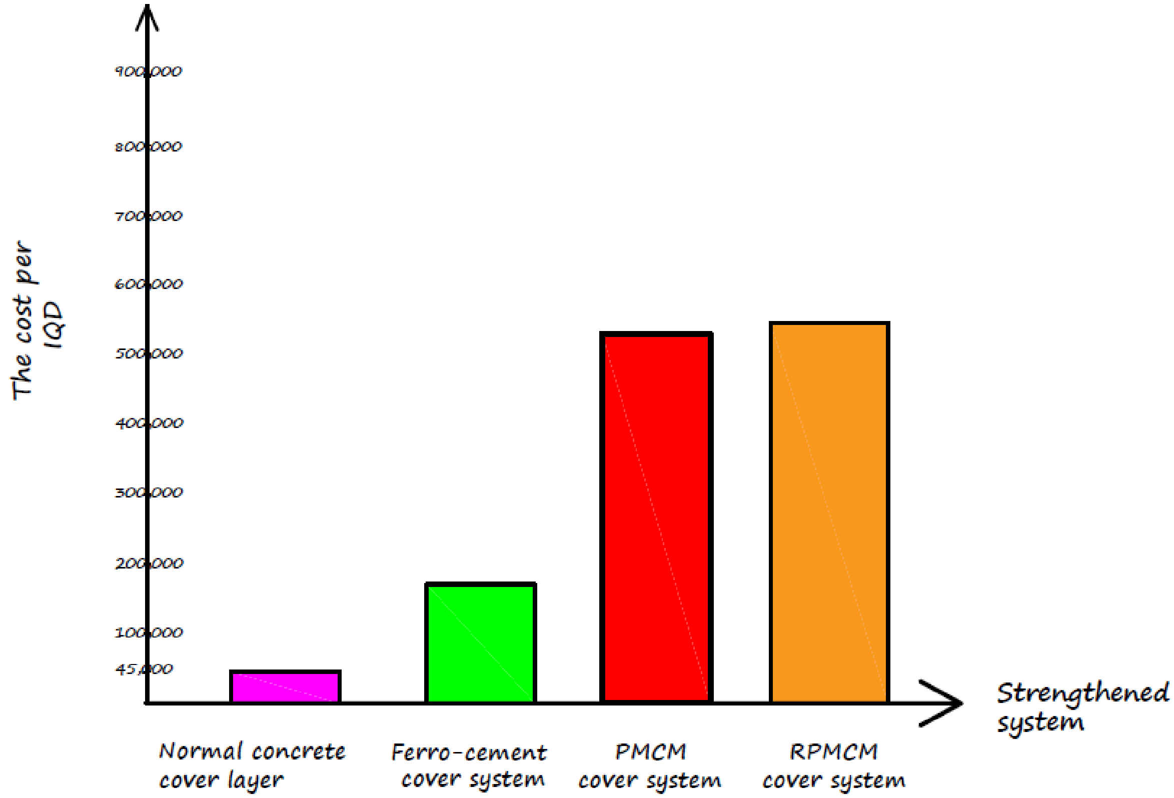
Appendix G Table 2 Cost of Sika-dur 32 LP

NO.	Product Name	Unit	Price per unit (USD)
1	Sika-dur 32 LP (5 kg)	kg	58.21 $

- Each one bag cast (1.125 m2), with thickness 2.5cm , this mean cost of casting one meter = 13.33 $ (≈ 19500 IQD).
- Cost of one square meter of epoxy (sika-dur 32 LP) = 4200 IQD (2.87 USD).
- this mean cost of one meter of **PMCM** cover layer = 19500 + **4200** = 23700 IQD.

∴ The total cost = area of the room × 23700 + Wages of two laborer

$$= 20.25 \times 23700 + 50000 = 530{,}000\ IQD$$ (363 USD)



Appendix G Figure 1: Cost comparison between the normal concrete cover system and others systems

Note : (The cost used here is changed to IQD based on the currency exchange rate available on date 28/9/2022).

الخلاصة

يعد تدهور الهياكل الخرسانية المسلحة مع مرور الوقت أمرًا شائعًا ، مما يؤدي إلى انخفاض كبير في القدرة على تحمل الأحمال. تقوية هذه الهياكل أمر بالغ الأهمية لتلبية المعايير القياسية. هناك العديد من الطرق لزيادة قدرة البلاطة، ولكن لكل طريقة مزايا وعيوب مختلفة. تتمثل إحدى هذه الطرق في استبدال طبقة الغطاء الخرساني في منطقة الشد واستخدام مونة الأسمنت المُحسنة بالبوليمر (PMCM) لتحسين السلوك المرن للبلاطات الخرسانة المسلحة .

يتناول هذا البحث دراسة عملية لسلوك خمسة عشر بلاطة بسيطة الاسناد بألابعاد (1500 * 750 * 150) ملم، والتي تشمل بلاطة مرجعية واحدة وأربعة عشر بلاطة مقواة ، تم اختبارها تحت تحميل من أربع نقاط حتى الفشل. تم استخدام أربعة أنواع مختلفة من مونة الأسمنت المُحسنة بالبوليمر ، الاسم التجاري لها (Cempatch FS ، Cempatch FL ، Cempatch S ، Flo-grout.2) كمواد تقوية بالإضافة إلى استخدام المونة الاعتيادية (N) (الرمل + الأسمنت البورتلاندي). تضمنت المتغيرات المدروسة : نوع مادة التقوية ، سمك طبقة الغطاء (25 ملم ، 40 ملم) وطريقة التوصيل بين طبقة الغطاء بالسطح السفلي للبلاطة المقواة (حالة طبقة الغطاء ، مقواة بشبكة سلكية ذات قطر (1.2 ملم.) و (25.4 ملم) مربعة الفتحات (RPMCM) أو بدون مونة مسلحة (PMCM)). في هذه الدراسة تُقسم طرق التقوية إلى طريقتين حسب حالة طبقة الغطاء: في الطريقة الأولى تكون طبقة الغطاء مقواة بشبكة سلكية اي طبقة الغطاء مرتبطة بالوجه السفلي للبلاطة عن طريق ربط حديد التسليح الرئيسي مع المشبك الحديدي المغروس في طبقة الغطاء بواسطة سلك الربط ، بينما الطريقة الثانية تكون طبقة الغطاء غير مقواة (غير مسلحة) و طريقة التوصيل بين طبقة الغطاء مع الوجه السفلي للبلاطة بواسطة الإيبوكسي (Sikadur-32LP).

كلا طريقتي التقوية اظهرت زيادة في الحمل الاقصى مقارنتةً بالبلاطة المرجعية ولكن الطريقة الاولى اكثر فعالية من الثانية. خلص العمل التجريبي إلى أنه تم تحقيق زيادة في مقاومة الانحناء لكلا طريقتي التقوية ، بمتوسط زيادة في قدرة الحمل النهائي بنسبة 80٪ عند استخدام الطريقة الاولى (طبقة تغطية RPMCM) ومتوسط زيادة 10٪ للطريقة الثانية (طبقة غطاء PMCM) مقارنة بالبلاطة المرجعية. أعلى زيادة في القدرة الاستيعابية للحمل 94٪ للنماذج (S1-W.) و(FL1-W.), والزيادة في القدرة الاستيعابية للحمل عند استخدام غطاء الفيروسمنت كانت 64.7% للنموذج (N-W.), بينما الزيادة الاقل في القدرة الاستيعابية للحمل كانت للنموذج (N-EP.).

بصورة عامة اظهرت النتائج بأن تقوية البلاطة الخرسانية ادت الى زيادة حمل الفشل الاقصى وزيادة طاقة الامتصاص والصلابة القاطعة , بينما انخفضت الصلابة الاولية و مؤشر الليونة.

نستنتج أن التحسن في الخواص الميكانيكية لمواد طبقة الغطاء مثل مقاومة المرونة والضغط يؤدي إلى تحسين السلوك المرن للبلاطة الخرسانية المسلحة ، كما هو واضح في النتائج أعلاه ، حيث الخواص

الميكانيكية للمواد (S و FL,...الخ) أفضل من الصفات الميكانيكية للمونة الاعتيادية (N) ، وهذا يعني أن التقوية باستخدام المونة الأسمنتية المُحسنة بالبوليمر (PMCM) يكون أكثر فعالية من المونة العادية.

ان زيادة سمك طبقة الغطاء يؤدي إلى تقليل سعة الحمل القصوى والصلابة الفعالة ، ولكن فيما يتعلق بالشقوق فان زيادة السماكة يؤدي إلى انخفاض عدد الشقوق.

وزارة التعليم العالي والبحث العلمي

جامعة ميسان / كلية الهندسة

قسم الهندسة المدنية

تقوية البلاطة الخرسانية الاعتيادية ثنائية التحميل بواسطة استبدال طبقة الغطاء بأستخدام مواد انشائية مختلفة

من قبل

علي ماهر شنيشل

بكلوريوس الهندسة المدنية, 2013

اطروحة
مقدمه الى كلية الهندسه جامعة ميسان
كجزء من متطلبات الحصول على درجة الماجستير
في علوم الهندسة المدنية
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