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REHABILITATION OF DAMAGED HIGH STRENGTH REINFORCED CONCRETE CORBELS VIA BASALT FABRIC

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Adnan Hazem ALSHAWAF

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Name of the student: ADNAN HAZEM ALSHAWAF

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Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. A. Necmeddin YAZICI
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Abdulkadir ÇEVİK
Head of Department

This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assist. Prof. Dr. Mehmet Eren GÜLŞAN
Supervisor

Examining Committee Members:	Signature
Prof. Dr. Abdulkadir ÇEVİK	....
Assist. Prof. Dr. Derya BAKBAK	....
Assist. Prof. Dr. Mehmet Eren GÜLŞAN	....

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Adnan Hazem ALSHAWAF

ABSTRACT

REHABILITATION OF DAMAGED HIGH STRENGTH REINFORCED CONCRETE CORBEL VIA BASALT FABRIC

ALSHAWAF, Adnan Hazem
M.Sc. Thesis in Civil Engineering
Supervisor: Assist. Prof. Dr. Mehmet Eren GÜLŞAN
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The main aim of this thesis is to investigate the mechanical performance of heated and damaged high strength self-compacting reinforced concrete corbels after rehabilitation and strengthening with crack repair epoxy and Basalt Fiber Reinforced Polymer (BFRP) fabric. A comprehensive experimental study consisting of 18 double-sided corbels was carried out to achieve aim of thesis. All of the corbels had been damaged because of overloading after heating them to several temperature levels (250ºC, 500ºC, and 750ºC). The corbels had been produced from high strength self-compacting concrete with one concrete class (80 MPa), three different amounts of steel fiber ratios (0%, 0.5%, 1%) and two main reinforcement ratios (0.0388 and 0.0708). Shear span value for all corbels is same (90 mm). Nine of the corbels were rehabilitated with very low viscosity crack repair epoxy. However, remaining ones were strengthened by BFRP fabric in addition to repair of initial cracks. Experimental results show that rehabilitation of the corbels with BFRP fabric is much more effective as compared to repair of the corbels with only crack repair epoxy regarding improvement of mechanical properties (ductility and load carrying capacity) of them. Besides, stiffness of the corbels which were rehabilitated by BFRP fabric was nearly same with the stiffness before initial failure.

Keywords: corbels, high strength concrete, self-compacted concrete, rehabilitation, very low viscosity injection resin, Basalt fiber fabric, epoxy.

ÖZET

HASAR GÖRMÜŞ YÜKSEK MUKAVEMETLİ BETONARME KISA KONSOLLARIN BASALT KUMAŞ İLE REHABİLİTASYONU

ALSHAWAF, Adnan Hazem
Yüksek Lisans Tezi, İnşaat Mühendisliği
Tez Danışmanı: Yard. Doç. Dr. Mehmet Eren GÜLŞAN
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78 Sayfa

Bu tezin amacı ışıtılmış ve hasar görmüş yüksek mukavemetli kendiliğinden yerleşen betonla üretilmiş betonarme kısa konsolların çatlak tamir epoksisi ile tamiri ve bazalt lif takviyeli polimer (BFRP) kumaşla güçlendirilmesinden sonra oluşan mekanik performanslarını araştırmaktır. Tezin amacını başarabilmek için 18 adet çift kollu kısa konsol içeren kapsamlı bir deneysel çalışma yürütülmüştür. Çalışmadaki bütün kısa konsollar daha önceden, belirli sıcaklık seviyelerine (250^{o}C, 500^{o}C, and 750^{o}C) kadar ısıtıldıktan sonra aşırı yüklemeden ötürü hasar görmüştür. Kısa konsollar tek bir beton sınıfına (80 MPa) sahip yüksek mukavemetli kendiliğinden yerleşen betondan üretilmiştir. Kısa konsollar 3 farklı çelik lif oranına (0%, 0.5%, 1%) ve 2 farklı asal donatı oranına (0.0388 and 0.0708) sahiptir. Bütün kısa konsolların kesme açıklığı aynıdır (90 mm). Kısa konsolların 9 tanesi sadece çatlak tamir harcı ile tamir edilirken; geriye kalan kısa konsollar çatlak tamir harcı ile tamirin yanı sıra bazalt lif takviyeli polimer kumaş ile güçlendirilmiştir. Deneysel sonuçlar mekanik özelliklerin iyileştirilmesi açısından (süneklik ve yük taşıma kapasitesi), bazalt takviyeli polimer kumaş ile yapılan rehabilitasyonun sadece çatlak tamiri ile yapılan rehabilitasyona göre çok daha etkili olduğunu göstermiştir. Bunun yanında, bazalt lif katkılı polimer kumaşla tamir edilen kısa konsolların pekliği, aynı kısa konsolun ilk göçmeden önceki pekliğiyle neredeyse aynı sonuçlanmıştır.

Anahtar Kelimeler: kısa konsollar, yüksek mukavemetli beton, kendiliğinden yerleşen beton, rehabilitasyon, düşük vizkositeli enjeksiyon reçinesi, bazalt lif takviyeli kumaş, epoksi.

To My Family

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I believe if you keep your faith in God, and if you're blissful even in the smallest things, you'll see God open up new doors.

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TABLE OF CONTENTS

Page

ABSTRACT .... **iv**

ÖZET .... **v**

ACKNOWLEDGEMENT .... **viii**

TABLE OF CONTENTS .... **ix**

LIST OF TABLES .... **xi**

LIST OF FIGURES .... **xii**

CHAPTER 1 .... **1**

INTRODUCTION **1**

1.1 General 1

1.2 Research Significance 3

1.3 Aims of research 4

1.4 Thesis Layout 4

CHAPTER 2 .... **5**

LITERATURE REVIEW **5**

2.1 Introduction 5

2.2 Strengthening by using Fiber Reinforced Polymer FRP 6

2.2.1 Basalt Fiber Reinforced Polymer (BFRP) 7

2.2.2 Glass Fiber Reinforced Polymer (GFRP) 8

2.2.3 Aramid Fiber Reinforced Polymer (AFRP) 8

2.2.4 Carbon Fiber Reinforced Polymer (CFRP) 9

2.3 Previous Studies on Repaired and Strengthened Reinforced Concrete 10

2.4 Factors Affect Durability System for Rehabilitation Process 12

2.4.1 Surface preparation 13

2.4.2 Temperature 13

2.5 Studies on Strengthening of Heat Damaged Reinforced Concrete Structures........ 13

2.6 Adhesives 14

CHAPTER 3 16

EXPERIMENTAL PROGRAM 16

3.1 Introduction 16

3.2 Description of Test Specimen 16

3.4 Properties of Repairing Materials........ 19

3.5 Preparation of Specimen Surface Before Repairing........ 23

3.6 Rehabilitation Methods 25

3.6.1 Rehabilitation with very low viscosity injection resin........ 25

3.6.2 Rehabilitation with very low viscosity injection resin and basalt fiber fabric........ 27

3.7 Test Setup........ 29

CHAPTER 4 31

RESULTS AND DISCUSSION 31

4.1 Introduction 31

4.2 Corbels Rehabilitated by very low viscosity injection resin 31

4.3 Corbels rehabilitated by Basalt Fiber Fabric (BFF) 51

CHAPTER 5 72

CONCLUSION........ 72

5.1 Conclusion........ 72

5.2 Recommendations for Future Research 74

REFERENCES........ 75

LIST OF TABLES

Page

Table 3.1 Properties of selected corbels repaired by very low epoxy resin injection 17

Table 3.1 Properties of selected corbels repaired by very low epoxy resin injection (Continued) 18

Table 3.2 Properties of selected corbels repaired by very low epoxy resin injection and basalt fiber fabric 18

Table 3.2 Properties of selected corbels repaired by very low epoxy resin injection and basalt fiber fabric(Continued) 19

Table 3.3 The properties of high viscosity epoxy adhesive 20

Table 3.4 The properties of low viscosity epoxy adhesive 21

Table 3.5 The properties of very low viscosity injection resin 22

Table 3.6 The properties of basalt fiber fabric 22

Table 4.1 Experimental test results for corbels repaired with very low viscosity injection resin 33

Table 4.2 Experimental test results for rehabilitated corbels by Basalt Fiber Fabric (BFF). 53

LIST OF FIGURES

page

Figure 2.1 Basalt Fibers Reinforced Polymer (BFRP)... 7

Figure 2.2 Glass Fibers Polymer (GFRP) 8

Figure 2.3 Aramid Fibers Polymer (AFRP)... 9

Figure 2.4 Carbon Fiber Polymer (CFRP) 9

Figure 2.5 Application of carbon fiber on corbel area by wrapping........................ 11

Figure 3.1 Dimensions of the corbel. (Mohammed A. KAMIL 2016) 16

Figure 3.2 Reinforcement details of the corbel 17

Figure 3.3 Highly damaged corbel.. 23

Figure 3.4 Low damaged corbel.. 23

Figure 3.5 Surface grinding and roughening process.. 24

Figure 3.6 Using air compressor for removing small particles............................... 24

Figure 3.7 Mixing of high viscosity epoxy adhesive 25

Figure 3.8 Close the exterior cracks on the surface 25

Figure 3.9 Applied the very low viscosity injection resin....................................... 26

Figure 3.10 Grinding after injection process... 26

Figure 3.11 Surface treatment before applied the basalt fiber 27

Figure 3.12 Basalt fiber strips 28

Figure 3.13 Saturated basalt fiber with low viscosity epoxy adhesive 28

Figure 3.14 Configuration steps of bonding surface and applying the Basalt Fiber .... …29

Figure 3.15 Polishing after applied the basalt fabric... 29

Figure 3.16 Corbel Specimen Setup... 30

Figure 3.17 Injected and covered corbels with two LVDTs on the testing machine. 30

Figure 4.1 Load-deflection curve of specimen (C0-0.0-250).................................. 34

Figure 4.2 Specimen (C0-0.0-250) failure before rehabilitation.............................. 35

Figure 4.3 Specimen (C0-0.0-250) failure after rehabilitation................................ 35

Figure 4.4 Load- deflection curve of specimen (C1-0.0-500)................................. 36

Figure 4.5 Specimen (C1-0.0-500) failure before 37

Figure 4.6 Specimen (C1-0.0-500) failure after rehabilitation................................ 37

Figure 4.7 Load- deflection curve of specimen (C2-0.0-750)................................. 38

Figure 4.8 Specimen (C2-0.0-750) failure before rehabilitation.............................. 39

Figure 4.9 Specimen (C2-0.0-750) failure after rehabilitation................................ 39

Figure 4.10 Load- deflection curve of specimen (C3-0.5-250)................................ 40

Figure 4.11 Specimen (C3-0.5-250) failure before rehabilitation............................ 41

Figure 4.12 Specimen (C3-0.5-250) after rehabilitation 41

Figure 4.13 Load- deflection curve of specimen (C4-0.5-500)................................ 42

Figure 4.14 Specimen (C4-0.5-500) failure before 43

Figure 4.15 Specimen (C4-0.5-500) failure after rehabilitation.............................. 43

Figure 4.16 Load- deflection curve of specimen (C5-0.5-750)................................ 44

Figure 4.17 Specimen (C5-0.5-750) failure before rehabilitation............................ 45

Figure 4.18 Specimen (C5-0.5-750) failure after rehabilitation.............................. 45

Figure 4.19 Load- deflection curve of specimen (C6-1.0-250)................................ 46

Figure 4.20 Specimen (C6-1.0-250) failure before rehabilitation............................ 47

Figure 4.21 Specimen (C6-1.0-250) failure after rehabilitation.............................. 47

Figure 4.22 Load- deflection curve of specimen (C7-1.0-500)................................ 48

Figure 4.23 Specimen (C7-1.0-500) failure before rehabilitation............................ 49

Figure 4.24 Specimen (C7-1.0-500) failure after rehabilitation.............................. 49

Figure 4.25 Load- deflection curve of specimen (C8-1.0-750)................................ 50

Figure 4.26 Specimen (C8-1.0-750) failure before rehabilitation............................ 51

Figure 4.27 Specimen (C8-1.0-750) failure after rehabilitation.............................. 51

Figure 4.28 Load- deflection curve of specimen (C0-0.0-250)................................ 54

Figure 4.29 Specimen (C0-0.0-250) failure before rehabilitation............................ 55

Figure 4.30 Specimen (C0-0.0-250) de-bonding failure after rehabilitation 55

Figure 4.31 Load- deflection curve of specimen (C1-0.0-500)................................ 56

Figure 4.32 Specimen (C1-0.0-500) failure before rehabilitation............................ 57

Figure 4.33 Specimen (C1-0.0-500) de-bonding failure after rehabilitation 57

Figure 4.34 Load- deflection curve of specimen (C2-0.0-750)................................ 58

Figure 4.35 Specimen (C2-0.0-750) failure before rehabilitation............................ 59

Figure 4.36 Specimen (C2-0.0-750) de-bonding failure after rehabilitation 59

Figure 4.37 Load- deflection curve of specimen (C3-0.5-250)................................ 60

Figure 4.38 Specimen (C3-0.5-250) failure before rehabilitation............................ 61

Figure 4.39 Specimen (C3-0.5-250) de-bonding failure after rehabilitation 61

Figure 4.40 Load- deflection curve of specimen (C4-0.5-500)................................ 62

Figure 4.41 Specimen (C4-0.5-500) failure before rehabilitation............................ 63

Figure 4.42 Specimen (C4-0.5-500) de-bonding failure after rehabilitation 63

Figure 4.43 Load- deflection curve of specimen (C5-0.5-750)................................ 64

Figure 4.44 Specimen (C5-0.5-750) failure before rehabilitation............................ 65

Figure 4.45 Specimen (C5-0.5-750) de-bonding failure after rehabilitation 65

Figure 4.46 Load- deflection curve of specimen (C6-1.0-250)................................ 66

Figure 4.47 Specimen (C6-1.0-250) failure before rehabilitation............................ 67

Figure 4.48 Specimen (C6-1.0-250) de-bonding failure after rehabilitation 67

Figure 4.49 Load- deflection curve of specimen (C7-1.0-500)................................ 68

Figure 4.50 Specimen (C7-1.0-500) failure before rehabilitation............................ 69

Figure 4.51 Specimen (C7-1.0-500) de-bonding failure after rehabilitation 69

Figure 4.52 Load- deflection curve of specimen (C8-1.0-750)................................ 70

Figure 4.53 Specimen (C8-1.0-750) failure before rehabilitation............................ 71

Figure 4.54 Specimen (C8-1.0-750) de-bonding failure after rehabilitation 71

CHAPTER 1

INTRODUCTION

1.1 General

Concrete is the most important and general used construction material which has many advantages that make it better than other building materials. But, there are some issues that face concrete, these issues could be cracks, shear failure, corrosion effect, excessive deflections or other kinds of issues.

High strength concrete is generally a term is used when the compressive strength for the concrete higher than 41 MPa. The need of high strength concrete has regularly increased during the last years, which helps to design a new convenient sections. By diminishes the dead weight, allowing longer spans and more usable area of buildings. As well as high strength concrete is a brittle material, and as the concrete strength increases the post-peak portion of the stress-strain diagram almost vanishes or descends steeply. (Faisal et al, 1992; Khaloo et al, 1996)

Lately, reinforced concrete corbels have been usually and mostly used in structures in order to support capacious concentrated loads which are caused by reaction forces existing at the ends of beams. Corbels are mostly preferred in precast structure, especially in industrial buildings.

The corbels are short cantilever structural members that project from the face of the columns. Reinforced concrete corbels with shear-span-to-depth-ratio ≤ 1 are regarded important members to transfer loads especially in industrial buildings. These corbels could play a main role in transfering loads from supported beams to the carrying columns. (Code, 2012; Yassin, et al, 2016).

For reinforced concrete corbel, compressive strength of the concrete affects the concrete behavior. In case of high-strength reinforced concrete (HSC), corbels do not collapse suddenly because yielding of steel could notify that the member is about to damage. (Yong et al, 1994).

In case of high strength concrete corbels with steel fiber, when the concrete strength is increase the ductility is reduces , and this is a severe deficiency for the purpose of high strength concrete. An arrangement between these two mechanical properties strength and ductility for concrete mix could be achieved by adding steel fibers. Extension of fibers to concrete produces it high homogeneously, isotropic also and reconstructs it from a ordinary brittle concrete to a more ductile concrete. the usage of high strength concrete had been increased immediately by reason of the requirements for higher strength and durability.(Faisal et al, 1992)

For steel fiber reinforced concrete the fiber fails in tension only after the steel fiber breakdowns or withdraw of the cement matrix, steel fibers cannot reduce break into smaller pieces risk but it improves the remaining mechanical properties of concrete subjected to elevated temperatures(Lau et al, 2006).

On many occasions, corrosion of reinforcement may trigger off cracking and spalling of concrete, coupled with deterioration in the strength of the structure. Such situations need repairs of defected parts and occasionally need replacement a part or the whole member.

The most common reasons of concrete corbels failures are:

- Wrong assumptions in th design of the structure regarding the loading details.
- Structural faults because of bad constructing like bad quality control, and management, and supervision.
- Effects of fire, earthquakes, etc.
- Environmental effects, like chemical attacks.

Many reasons could affect the structures and cause incommodious damage or even failure. Obviously, in case of damage exposures, industrial buildings were the most popular and as was mentioned before industrial building beside precast concrete members consists mainly of the reinforced concrete corbel. With this in mind, rehabilitations and strengthening methods became more important.

Fiber-reinforced polymer (FRP) composites are structural strengthening in the civil engneering for almost 25 years. At this time, acceptance of FRP composites as a mainstream construction material has grown, and so has the number of completed FRP strengthening projects. As a result, strengthening and rehabilitaion for old or damaged reinforced concrete structures is now a most important part of the construction action in all the world. However, the use of FRP for strengthening and retrofiting is earning more reputation among design specialists over conventional rehabilitation techniques, such as installation of basalt, carbon and glass limitations elements.

FRP strengthening of old structures can contain complicated evaluation, design, and detailing techniques, seeking an exceptional understanding of the old or damaged structural conditions along with the materials used to rehabilitate the members before starting the FRP installation. The appropriateness of FRP for a rehabilitation project can be resolved by figure out what FRP is adequate for this project and the advantages it offers.

1.2 Research Significance

The main objective of this experimental study is to examination the ultimate carrying load capacity variation for corbels before and after the rehabilitation process, while every corbel had different properties and status such as; heat treatments degree and amount of damaged under vertical loading, steel fiber ratio, shear span and two methods have been utilized in this experimental study. Three types epoxy and Basalt Fiber Fabric (BFF) were used for rehabilitation methods.

Previous studies had been investigated in rehabilitation and strengthening of corbels. But, all studies were emphasized on standard corbels with ordinary types of Fiber Reinforced Polymer materials. On another hand, the first time in literature when rehabilitation of high strength damaged corbels with basalt fiber fabric (BFF) is investigated. Hence, this experimental study is original and important to explain the behavior of heat treatments damaged high strength reinforced concrete corbels with different steel fiber ratio when the corbels rehabilitated by very low viscosity injection resin epoxy and Basalt fiber fabric.

1.3 Aims of research

The objectives of this study are as follows:

- To investigate the rehabilitation compatibility methods with damaged concrete corbels
- To study the change of ultimate carrying load capacity and load-deflection of damaged concrete corbels after rehabilitation process.
- To compare two rehabilitation technique.
- To notice potential changes on modes of failure after rehabilitation.
- To observe the corbels rehabilitation outcomes when three steel fiber ratios and three degrees of heating used.

1.4 Thesis Layout

This thesis is determined to provide extra information on the structural behavior of rehabilitation of heated and damaged high strength self-compacting steel fiber reinforced concrete corbels under vertical load with and without basalt fiber fabric. This thesis consists of seven chapters

Chapter 1: This chapter contains a brief introduction about corbels, the purpose of research and the significance of research as well as an objective of the thesis and research significance are also defined within this chapter.

Chapter 2: This chapter presents the literature review for rehabilitation method, strengthening techniques, retrofitting techniques and materials that have been used for this purpose. As well as the previous investigation studies were written about strengthening for reinforced concrete corbels.

Chapter 3: In this chapter details of all materials and their properties were used this experimental study investigation. What’s more, the details of the experimental procedures are given too in this chapter.

Chapter 4: Presenting the experimental results, shows the response of the tested corbels and discusses the results and failure modes after rehabilitation process.

Chapter 5: Conclusions were presented then recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete is one of the most common material that are used in buildings. However, buildings could need rehabilitation to the original conditions for several reasons and sometimes increasing the load capacity for structural members was needed too. During the time, any structures are prone to earthquake, failing on design or require a change in design, and maybe reinforcement or concrete corrosion (Almusallam, et al, 1996).

Rehabilitation process reliance on the aim and the degree of the damage to understand the consequence of choosing this technique and how these methods can affect the rehabilitation. Many methods can be utilized to treat the failing on design or any problematic such as, upgrading the section or substitute the structure totally, reducing the structure duty or choosing the option of rehabilitation(Macdonald, 2008).The structures that made form concrete could be damaged as a result of steel reinforcement corrosion, fire attack, overloading, and mistake in design. However, to solve that issue and sustain the efficiency of the building while the building still operational, some structural members should be modified(Garden et al, 1998). In repairing or rehabilitation conditions of concrete members, many methods could be used like; injection (epoxy adhesive) applied on fresh concrete, covered by steel plates, and combined the members with another material to become a composite material.

On the first-time strengthening method, was applied in Durban, South Africa, in 1964. Where epoxy-bonded steel plates had been used to strengthen concrete beams. Where part of the reinforcement steel by accident removed during construction working. Also, four bridges strengthening with steel plates in 1975 at Swanley and 1977 at Kent, in England (Len C Hollaway, 2001).

2.2 Strengthening by using Fiber Reinforced Polymer FRP

Strengthening the structural members with externally bonded FRP maintain conducive to restore or increase strength to the structures to auxiliary the members to resist external loads and that made the demand of FPR growing by time. The FRP composing on the members surface is done by using epoxy as a glue material (Matthys, 2000). Many benefits related to composites when compared to ordinary and regular materials like reinforcements steel bars such as; lightweight, easy to transport and used, high durability, high tensile strength, easy to find in different geometric dimensions and not that expensive (Barros, et al, 2006).FRP had been made of synthetic materials graded around 5-20µm for diameters composed from long filaments placed corresponding to each other's (one-way or two-way cross) and that filaments hold thousands of individual micrometer-diameter filament (Zoghi, 2013).

Fibers could be mentioned as reinforcement materials and its take a lead on rehabilitation process while the fibers inquiry the necessary conditions by transfer the load across the matrix to achieve the prospective strength and for the fibers orientation it could be in any direction that ensures strength and stiffness had been increased. Fiber composite material performance depends or can be measured by fibers dimension, formation, orientation and the mechanical properties for that fibers (Reddy, et al, 2015). Many methods that specify the way of wrap-up members in concrete structures and it was shown good results, economy and can be done fast and on short time. A Lot of studies approve the efficiency of using rehabilitation methods to restore the original load capacity of the concrete members (Leonard C Hollaway et al, 2008; Kim et al., 2012; Lima, et al, 2016; Ma et al., 2017).

Numerous kind of FRP existents and many techniques also but, if strengthen targeted one side or specific area that could affect the other sides. However, by using such as ultra-high-performance fiber reinforced concrete (UHPFRC) to improve the structural members causes variations on concrete properties (Al-Osta, et al, 2017).

The furthermost known Fiber Reinforced Polymers (FRP) had been used for strengthening in civil engineering;

2.2.1 Basalt Fiber Reinforced Polymer (BFRP)

Basalt fiber is sort of new fiber reinforced polymers (FRP) and composite material. The closest (FRP) for basalt fiber is glass they have the same chemical composition but, basalt fiber is better in strength properties, high resistance to alkaline, acidic and salt corrosion resistance(Less, 2013).

Depends on manufacture way, basalt fibers and glass fibers are alike. Crushed basalt rocks are the only raw materials imperatives for producing the fiber. It is a continuous fiber fabricated through igneous basalt rock melt drawing at about 2,700° F (1,500° C) (Babu, 2016).The price of basalt fiber is more expensive than E-glass fiber but less than S-glass, aramid or carbon fiber and as reaching throughout the world production enlarged, its cost of production should reduce subsequent (Jamshaid et al, 2016).

(Sim, et al, 2005) investigated on basalt fiber behaviors by comparing the basalt fibers with carbon and glass fibers. While all fibers had been exposed to alkali solution. However, basalt fiber and glass fiber were showed volumes loss and drop on the strengths with a loss particle on the surface when the strengths for carbon fiber still the same. Accelerated weathering test was applied to all fibers and the results as follows, the basalt fiber has been provided the best resistance than the other fiber. Nevertheless, the basalt fiber reserved around 90% of the usual temperature strength after exposure at 600 °C for 2 h while the carbon fibers and the glass fiber did not sustain the original volumetric. The fibers were exposed to flexural strengthening evaluation, the basalt fiber strengthening increased for both the yielding and the ultimate strength of the beam specimen more than 27% depending on the number of layers practical. Figure 2.1 shows the basalt fibers (BFRP).

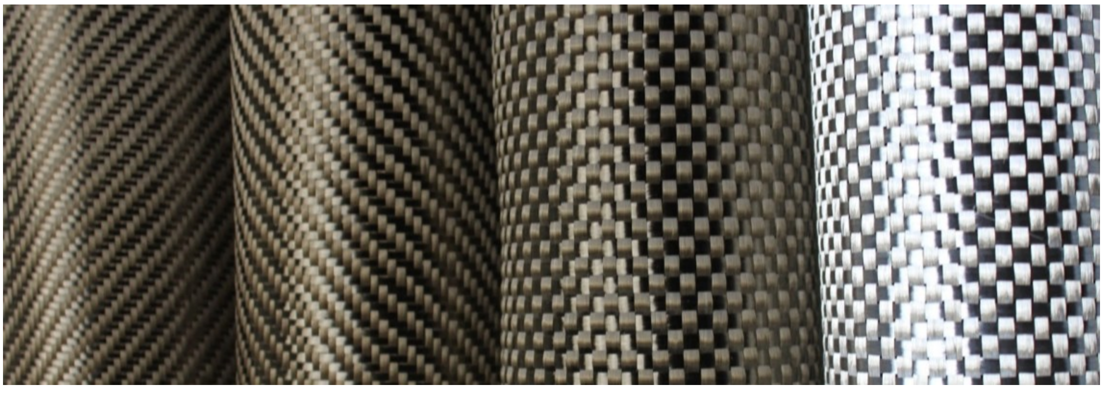

Figure 2.1 Basalt Fibers Reinforced Polymer (BFRP)

2.2.2 Glass Fiber Reinforced Polymer (GFRP)

Glass fibers are isotropic in nature and most widely used a filament. Commonly used types of glass fibers are E-Glass, S-Glass, and C-Glass. The characteristic properties of glass fiber are a High strength, not expensive, waterproof and able to resist chemicals (Günaslan, et al, 2014). Figure 2.2 shows the glass fiber reinforced polymer (GFRP)

Figure 2.2 Glass Fibers Polymer (GFRP)

2.2.3 Aramid Fiber Reinforced Polymer (AFRP)

Aramid fibers widespread but Kevlar fiber is the name that used usually. Aramid fibers are anisotropic in nature and regularly color is yellow. If glass fibers compared with aramid fibers, we can find that aramid fibers are more expensive than glass fibers. The advantages aramid fibers are; moderate stiffness, good in tension application (Cables and tendons) high tensile strength, high stiffness, high modulus and low weight and density. The most important disadvantage for aramid fibers is the lower strength in compression. The impact-resistant structure could be produced from aramid fiber. The most known classes fibers are classes Kevlar with the different engineering properties. Kevlar-29. Kevlar-49, Kevlar- 100, Kevlar-119, Kevlar-129 (Günaslan et al, 2014; Zhang, 2010). Figure 2.3 shows the aramid fibers(AFRP)

Figure 2.3 Aramid Fibers Polymer (AFRP)

2.2.4 Carbon Fiber Reinforced Polymer (CFRP)

Carbon fibers are anisotropic in nature which are formed at a temperature of 1300ºC. The advantages of carbon fibers are; High strength, excellent creep level, resistance to chemical effects, low conductivity, low density and high elastic modulus while, the most important factor related to CFRP laminate is impacted tensile strength but, carbon had disadvantages too for example; expensive and anisotropic materials and the fibers have a weak compression strength (Caprino, 1984; Günaslan et al., 2014; Meier, 1995).Figure 2 .4 normal carbon fiber polymer (CFRP).

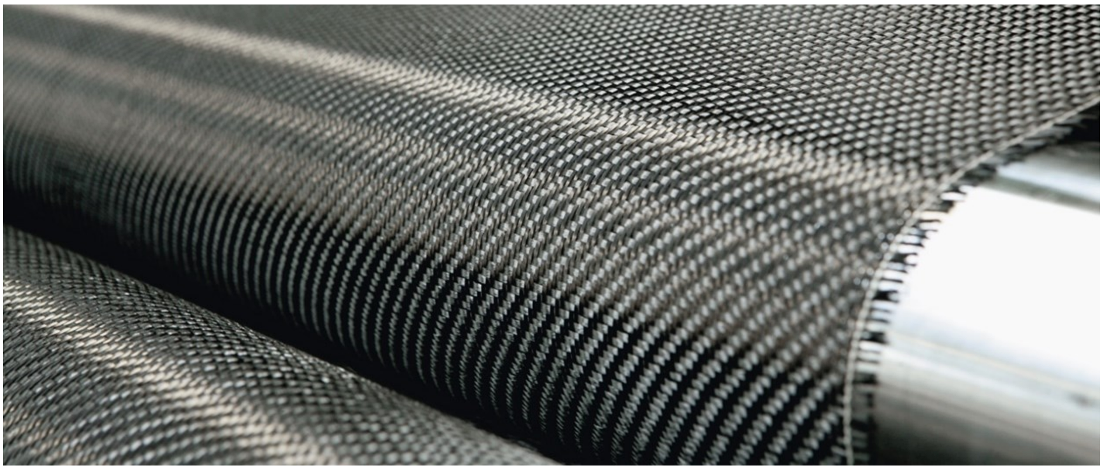

Figure 2.4 Carbon Fiber Polymer (CFRP)

2.3 Previous Studies on Repaired and Strengthened Reinforced Concrete

Many researchers had been published and focused on the behavior of concrete after rehabilitation or strengthening with FRP fabric. (Abdul-Wahab, 1989; Nijad I Fattuhi, 1994; Gulsan, et al, 2015; Ridha, 2008)those studies investigated the behavior of reinforced concrete when fibers have been added. While steel fibers and carbon fibers were used to study the effectiveness on reinforced concrete. The results showed good improvements in concrete members Characteristics.

Sometimes, using injection method enough to repair the concrete members by replace the gap between cracks and bonding the concrete (Ahmad, et al, 2013).

(Li et al, 2006)This experimental study examined the effectiveness of curing E-glass fiber reinforced by vinyl ester to repair damaged reinforced concrete. However, this method revealed in details that techniques process was resourceful to repair the member when the shear failure and flexural failure is found.

(El Maaddawy, 2008)Those researchers made a research program and the main aim is to investigate the efficiency when carbon fiber reinforced polymers were applied to improve corrosion-damaged eccentrically loaded reinforced concrete columns. However, 16 RC columns in square shapes had been cast with 1.9%. steel ratio. The test region is 125x125mm having longitudinal of the damaged specimens were incurred to accelerated corrosion that related to a steel low weight in mass about 4.25% for 30 days. The fundamental test parameters were the CFRP repair scheme (no wrap-up, full-wrap up, and partial-wrap up). After testing and calculate the results shown, strength gain had been in reverse proportional to the eccentricity ratio. Partial CFRP-wrap up has been 8% less effective than full CFRP-wrapping.

(Ivanova et al, 2016) This experimental investigates the strength improvements on short reinforced-concrete corbel when the corbel had been tested under fatigue. The aim of this study to investigate the performance of a short console exposed to influence fatigue test when certain numbers test under cycles load. Four short reinforced-concrete corbels had been tested while two corbels have been strengthened and reinforced-concrete then the corbels were exposed to static load. Furthermore, the other two rehabilitated and reinforced concrete corbels were exposed to fatigue load. In fact, the corbels are covering by carbon fiber fabrics as a reinforced. The number of cycles for the fatigue test are bounded 10 to the sixth power. After defines and equates the failure modes of the four various specimens. Definitely, the outcomes illustrated that fatigue tests are reversed the cracking of corbels and additionally that using apparently bonded carbon fiber fabrics consequentially improved the loads to 82 Percent with static loading. elucidated in Figure 2.5.

Figure 2.5 Application of carbon fiber on corbel area by wrapping

(Ozden et al, 2011)investigated the capacity and ultimate load performance of reinforced concrete corbels strengthened by GFRP overlays. In this study, 24 corbels had been tested until failure under quasi-static gravity load. Whereas the selected parameters as following; the strength of concrete, the shear span to depth ratio, AV/d ratio, corbels reinforcement, and the GFRP layers was chosen with a different orientation and different GFRP wrap up the formation. Test results concluded that GFRP wrap up with 45 degrees' fiber orientation (diagonal) was more effective than lateral wrap up. The level of tension steel strain on the onset of failure depends on the type and number of GFRP layers and the tension reinforcement ratio. The results also revealed that the level of strengthening with GFRP wrapping ranges from (40-200) %, depending on the reinforcement ratio, AV/d ratio and the orientation and number of GFRP layers used.

(Kassem, 2015) made an experiment to a (strut-and-tie) the aim for this method to determine the load carrying capacity of reinforced concrete (RC) corbels. Additionally, to the normal strut-and-tie force equilibrium demands, the projected model had been based upon secant stiffness formulation, including strain compatibility and constitutive laws of cracked RC. The suggested process evaluates the load-carrying capacity as limited by the failure modes related by nodal crushing, yielding of the longitudinal principal reinforcement, in addition to crushing or splitting of the diagonal strut. Load-carrying capacity calculations found from the aimed analysis method were in a good arrangement by corbel test results of a comprehensive database, comprising 455 test outcomes, collected from the existing literature, and from other existent corbel models. This method is demonstrated to afford extra precise estimations for behavior and capacity than the shear-friction based approach implemented by the ACI 318-11.

(Hamid, Hadi, et al, 2013) This experimental investigates retrofitting of beam-column joint. while CFRP (Carbon Fiber Reinforced Polymer) and steel plate had been used. This beam-column joint is tested till failure reach to 1.0% drift after the joint was damaged and diagonal cracks at upper crack at upper column appeared. Then, CFRP had been wrapped at corbel, the bottom of the column and top of the column. Steel plate with is gluing mandated to the two beams and the jointing system. This retrofitted beam-column joint was tested for the second time under lateral cyclic loading reach to 1.75% drift. Visual explanations show that the cracks started at the joint when 0.5% drift exposed at top of column. Damage of retrofitted beam-column joint happened inside the CFRP and can be considered as inner cracks. The results show this method was validated for this type of retrofitting method for a beam-column joint with corbel which had a very damage situation like an earthquake.

(Ahmad, et al, 2013) had been tested twelve beams to study the efficiency of wrap-up of D-region of beam corbels with CFRP. While, the study is shown that when CFRP was used to wrap up, the loading capacity was increased and energy absorption of corbel beams was increased also. However, the superficially epoxy bonded flexible CFRP effect the shear strength of RC corbels.

2.4 Factors Affect Durability System for Rehabilitation Process

Factors affect durability system for rehabilitation Process could be influenced by several parameters some of them listed below.

2.4.1 Surface preparation

The surface preparation one of the most important factor could affect the rehabilitation process because the surface should be suitable when the FRP take place. Grinding machine is a good option for make the surface rough and this technique is used in this study or by using sandblasting. Then, check if there any loose material on the surface and in FRP condition, all corner that attached to surface must be smoothed. In addition, the surface must be clean, dry and antiquated for 3-6 weeks (Assih, et al, 2015; Karakoc et al, 2001).

2.4.2 Temperature

When CFRP sheets and plates had been used the temperatures must be controlled and accomplish some demands. If not, the process might not be begun. Substrate temperature must be less than dew point in order to begin rehabilitation. Dewpoint table gives the necessary information in function of the ambient temperature of the air and relative air humidity. If temperature demands hadn't been accomplished, the temperature of the air must be modified by using air-conditions or anyway else. As well, the minimum ambient temperature of the air and substrate temperature must accomplish some demands (Savas, 2001).

2.5 Studies on Strengthening of Heat Damaged Reinforced Concrete Structures

Structure exposed to many hazards that causes failures in those structural members and fire attacks one of these hazards. Replenishing to outcomes that can both influence the security of individuals and the use. Moreover, in some excessive conditions fire could harm and collapse the constructions, mechanisms bring about fire or fire effects (Gentili, 2013).

More than a few methods had been utilized to repairing fire-damaged reinforced concrete members. The methods were covered basically eliminating damaged(burned) concrete coats and substituting by fresh concrete, a few researchers have used ordinary methods.

(De Lange, 1980)In 1980 St. Elizabeth Hospital in Holland was damaged by a powerful fire, samples had been tested ultrasonically. The epoxy injection was applied, shotcrete repair of damaged concrete surfaces to recover the structural reliability and stiffening of structural members.

(Roy, et al, 2014)studied the efficiency of various strengthening planner and methodology to strengthening short columns heat damaged reinforced concrete. This study deal with 63 heat-damaged samples had been tested under concentric compression after jacketing superficially with High Strength Fiber Reinforced Concrete (HSFRC), Ferrocement (FC) and Glass Fiber Reinforced Polymer (GFRP) jackets. It is observed that though the GFRP jacketing totally affect the improving for compressive strength and energy dissipation, on another hand the stiffness didn't improve. The samples that repaired by HSFRC and FC jacketing techniques methods presented a reduced amount of deformability contrasted with the respective heat damaged not strengthen samples. Nevertheless, the ductility of heat damaged samples wraps up by GFRP jacket increased notably, overall GFRP jacketing is observed to be a suitable technique for strengthening fire or heat damaged concrete columns.

(Lin, et al, 1995)investigated the behavior of reinforced concrete columns. The damaged samples by fire had been repaired by fresh cast-in-place concrete. The results confirmed that nearly all of repaired columns possibly will return to original stiffness and strength and some samples exceed the unheated columns.

2.6 Adhesives

The adhesive is identified as a material utilized for many purposes such as; glue FRP sheet (glue agent), deliver the load among concrete to the surface, affords a shear load path among concrete to FRP reinforcing layers and bond together multiple layers of FRP layers. FRP sheet adhesives is utilized to bond FRP laminate systems to the concrete substrate (Rizkalla, et al, 2003). Usually, every type of adhesive or resin have an appropriate FRP. This is regularly indicated by the producer the requirements regarding the configuration system. The glue agent generally guarantees the bond among the substrate to the FRP reinforcement.

There have been numerous sorts of adhesives such as PVC, epoxies, PVA, amino-plastics, and polyamides. These assortments have provided us to choose the material which has more appropriate properties. Epoxy adhesive consists basically of two components, resin, and hardener. These materials have been blended to obtainment epoxy with an unequivocal range of temperatures, weight, area or volume, and consumption (Mazzotti et al., 2016).

The physical appearance that made epoxy resins widely used in experimental study then moved the knowledge to practical life were epoxy have marvelous adhesive abilities to materials like concrete and steel, high resistance to chemicals corrosion, easy to use no wide experience is needed, high thermal movement coefficient resemble for concrete, relatively high compressive strength, relatively high tensile strength, high flexural strength and the strength highly gained around 7 days(May, 1987; Tabor, 1992).

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 Introduction

This chapter presents the experimental study for rehabilitation of high strength reinforced concrete corbels with basalt fiber reinforced polymer fabric and epoxy adhesive. The study consists of totally 18 corbels. Compressive strength of the concrete that had been used for the corbels approximately 80 MPa. Corbels were classified into two groups regarding to rehabilitation technique. Nine of the corbel's were repaired by very low epoxy resin injection and the other nine corbels were rehabilitated by basalt fiber fabric and epoxy resin injection together. Rehabilitated corbels had been constructed, heated and tested under a vertical loading by Ph.D. student, "Khamees Nayyef Abdulhaleem", in Gaziantep University laboratory. To eliminate size effect on the behavior of rehabilitated corbels, all corbels were chosen in the same shape and size. However, steel fiber and reinforcement ratio of the corbels were different from each other and they had been heated to different temperature (250°C, 500°C, and 750°C) before the loading test that lead to initial failure.

3.2 Description of Test Specimen

The width of all corbels is 150 mm. As shown in Figure 3.1 columns and corbels have the similar cross-section (150 × 150 mm). The stubs of the column extend by 160 mm and 100 mm from above and below the corbels, respectively.

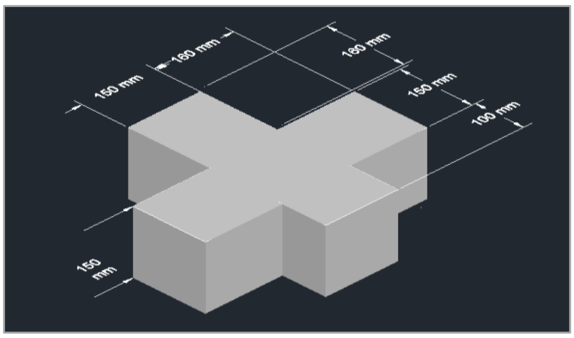

Figure 3.1 Dimensions of the corbel. (Mohammed A. KAMIL 2016)

All corbels have the same geometry and the steel reinforcement arrangement, as shown in Fig.3.2. The column parts reinforced by 4-φ10mm steel bars for longitudinal bar reinforcement, and 4-φ8mm for stirrups of them. For main reinforcement of corbels, two types of bars were used, 2-φ10mm and 2-φ14mm.

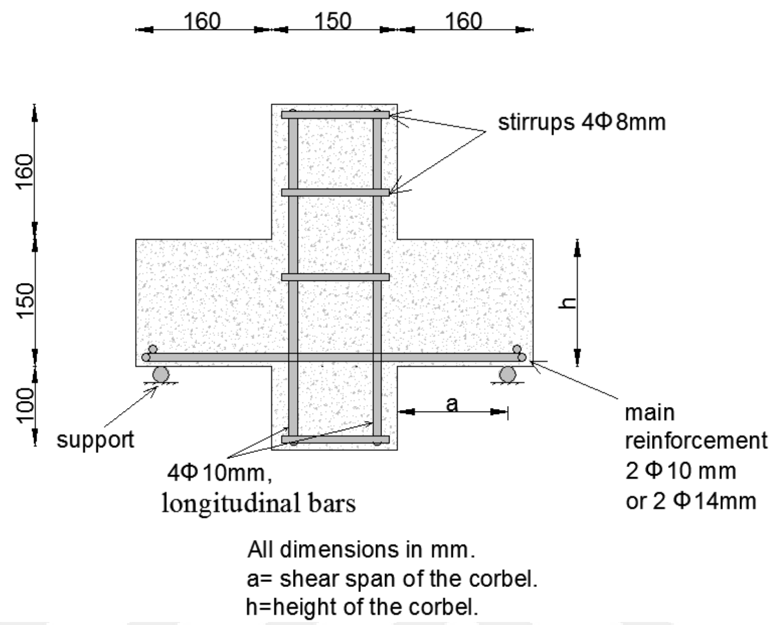

Figure 3.2 Reinforcement details of the corbel

Properties of selected corbels repaired by very low epoxy resin injection are stated in Table 3.1.

Table 3.1 Properties of selected corbels repaired by very low epoxy resin injection

Corbels name	Steel fiber ratio(%)	Heated temperature(°C)	Shear span length(mm)	Main bar diameter(mm)
C0	0	250	90	10
C1	0	500	90	10
C2	0	750	90	10
C3	0.5	250	90	10
C4	0.5	500	90	10

Table 3.1 Properties of selected corbels repaired by very low epoxy resin injection (Continued)

C5	0.5	750	90	10
C6	1	250	90	10
C7	1	500	90	10
C8	1	750	90	10

Properties of selected corbels repaired by very low epoxy resin injection and basalt fiber fabric are stated in Table 3.2.

Table 3.2 Properties of selected corbels repaired by very low epoxy resin injection and basalt fiber fabric

Corbels name	Steel fiber ratio(%)	Heated temperature(°C)	Shear span length(mm)	Main bar diameter(mm)
C0	0	250	90	14
C1	0	500	90	14
C2	0	750	90	14
C3	0.5	250	90	14
C4	0.5	500	90	14
C5	0.5	750	90	14

Table 3.2 Properties of selected corbels repaired by very low epoxy resin injection and basalt fiber fabric(Continued)

C6	1	250	90	14
C7	1	500	90	14
C8	1	750	90	14

3.4 Properties of Repairing Materials

The broken parts of damaged corbels were substituted by a high viscosity epoxy adhesive (TEKNOBOND 200). The epoxy resin consists of two components, resin and a hardener. It can be also used for bonding of FRP sheets onto wooden parts, steel or concrete surfaces, and repair the damaged concrete.

Advantages of the epoxy stated above can be listed as follows:

- Good resistance to chemical compounds attacks.
- The ability of adherence to concrete, steel, and wooden surfaces.
- Appropriate cohesion to FRP sheets.
- Mechanical strength obtained in short time.
- Can be used in overhead applications.
- Impermeability to water(Waterproof) and other liquids.
- Tension and vibration rooting resistance in the different temperatures.
- Resistant to the freeze-thaw cycle.
- Relative long process time.
- Easy to use
- High ability to resist abrasion.
- Impact absorption.

Furthermore, the mechanical and physical properties of the epoxy adhesive are shown in Table 3.3.

Table 3.3 The properties of high viscosity epoxy adhesive

Color	Gray
Density	1.5 gr/cm^3
Consumption	1.5 kg/m ^{2}for 1 mm thickness
Bond to Concrete	4.0 N/mm^2 (7 days) (TS EN 1542)
Pot Life	30 minutes (at 20°C).
Loading capability	1 day
Full strength	7 days
Application Ground Temperature	(+5°C) - (+30°C)

The fiber fabric was glued onto the surface of corbels by a low viscosity epoxy adhesive (TEKNOBOND 300). It consists of resin and hardener components. It can be also used for transfer of loads coming from the concrete corbel to BFRP fabric. Benefits and features of epoxy can be summarized as follows:

- High bonding to composite sheets at initial adhesion.
- High resistance to electric current and freeze-thaw cycle.
- Liquid impermeability.
- Easy to use
- Consummate adherence to concrete, and FRP sheets.
- Perfect chemical resistance.
- Time-consuming process.

Another function of this epoxy within the study is to close the cracks which occurred inside the damaged corbels and whose width was greater than 5mm. The mechanical and physical properties of low viscosity epoxy adhesive are shown in Table 3.4.

Table 3.4 The properties of low viscosity epoxy adhesive

Color	Component A Light Brown / Component B Transparent
Density	1.15 gr/cm3 (Component A)-1.05 gr/cm3 (Component B)
Consumption	2 kg/m 2for 1 mm thickness
Bond to Concrete	>5.3 N/mm2
Pot Life	Approx. 45 minutes at +20°C
Loading capability	1 day
Full strength	7 days
Application Ground Temperature	(+5°C) - (+30°C)

For very tiny cracks of damaged corbels, very low viscosity injection resin (Sikadur-52) epoxy was used. This cracks repair epoxy is composed of two components and can be injected into cracks regions by gravity feed method. This epoxy resin can used for repair of members of most type of structures, for example industrial and residential building, water-retaining structures, etc., by filling inner cracks of them with it. Moreover, the resin can be used in in-situ and precast concrete structures to bond the sections with each other. In this way, integrity of the structures is restored. The rein has the following advantages:

- Easy to use
- Appropriate in both, damp and dry conditions.
- Solvent-free component.
- High adhesive and mechanical strengths.
- Not brittle but very hard after hardening.
- Shrinkage-free hardening.
- Very high fluidity.

The mechanical and physical characteristics of the very low viscosity, crack repair epoxy are shown in Table 3.5.

Table 3.5 The properties of very low viscosity injection resin

Color	Part A: Transparent
	Part B: Brownish
	Part A+B mixed: Yellowish-brownish
Density	Part A: 1.1 kg/l (at +20°C) Part B: 1.0 kg/l (at +20°C) Part A+B mixed (2 : 1): 1.1 kg/l (at +20°C)
Compressive Strength	52 N/mm^2 (7 days at 23°C).
Bond to Concrete	4.0 N/mm^2 (7 days at 23°C).
Pot Life	25 minutes (at 25°C).
Flexural Strength	61 N/mm^2 (7 days at 23°C).
Tensile Strength	37 N/mm^2 (7 days at 23°C).
E-Modulus	1800N/mm^2 (7 days at 23°C).

Unidirectional basalt fiber reinforced polymer (BFRP) fabric was used for strengthening of some of the corbels. This type of fabric was selected due to its fire resistance, accessibility, smooth texture, durability, low price and high tensile strength. The mechanical properties of the fabric are specified in Table 3.6.

Table 3.6 The properties of basalt fiber fabric

Tensile Strength (MPa)	Tensile Modulus of elasticity (GPa)	Elongation (0/0)	Thickness (mm)	Polyester Yarn Density (tex)	Area weight (g/m^2)
2100	105	2.6	1.15	5.25	300

3.5 Preparation of Specimen Surface Before Repairing

The surface preparation for the concrete has a direct influence on the behavior of concrete members in rehabilitation process. In the study, some of the corbels were highly damaged as shown in Figure 3.3, but the others were not highly damaged as shown in Figure 3.4. therefore, right and suitable surface preparation were required for all corbels.

Figure 3.3 Highly damaged corbel

Figure 3.4 Low damaged corbel

Surface grinding process was achieved by ordinary grinder machine to smooth and clean the surface of corbels. The upper four corners of each corbel were rounded to reduce discontinuous regions leading to decrease in load capacity and to prevent tearing in basalt fabric by avoiding stress concentrations on the corners (see Fig. 3.5).

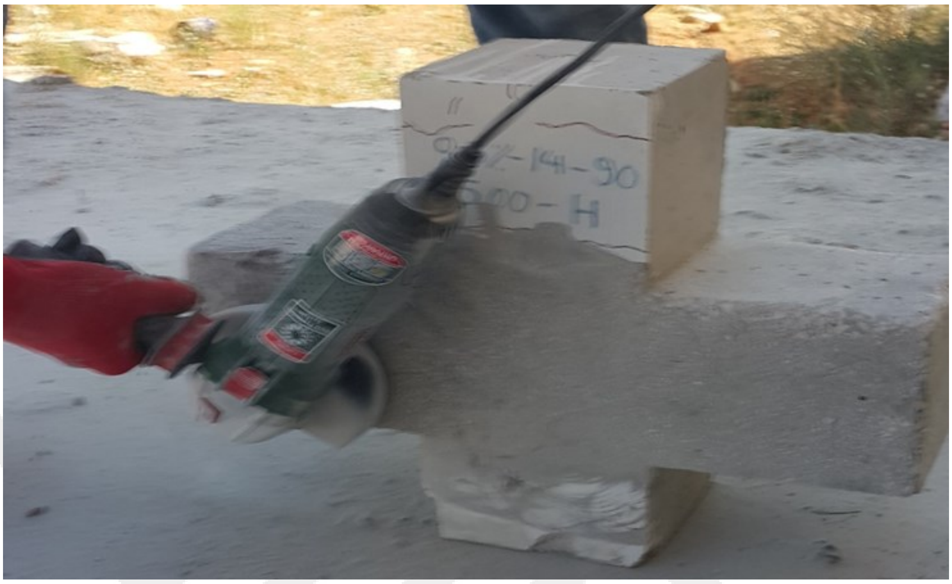

Figure 3.5 Surface grinding and roughening process

Before covering the corbel surface with BFRP fabric, small concrete particles and/or dust on the concrete surface were removed by compressed air to achieve perfect contact between the surface and the fabric (see Fig. 3.6).

Figure 3.6 Using air compressor for removing small particles

3.6 Rehabilitation Methods

In this experimental study two methods were used for rehabilitation of high strength reinforced concrete corbels. These methods are explained in the following sections.

3.6.1 Rehabilitation with very low viscosity injection resin

The high viscosity epoxy adhesive was used for substitution the loosing parts of corbels that had damaged before rehabilitation process. The high viscosity epoxy was also used for closing the exterior cracks on the surface to prevent leakage that could happen during injection of very low viscosity crack repair epoxy. The preparation of high viscosity epoxy resin adhesive is shown in Figure 3.7. The ratio of resin and harderner companents is 1:1 by weight. These companents were mixed by electric mixer with slow rotation (200 RPM) for two minutes to get a homogeneus mixture. The implementation of high viscosity epoxy adhesive on high strength reinforced concrete corbels is shown in Figure 3.8.

Figure 3.7 Mixing of high viscosity epoxy adhesive

Figure 3.8 Close the exterior cracks on the surface

After treatment of high viscosity epoxy adhesive, very low viscosity injection resin was prepared by mixing its components. These two components were mixed in a ratio of 2:1 by an electric mixer with slow rotation (maximum 250 RPM) for 3 minutes to get a homogeneous mixture according to the manufacturer's recommendations. This crack repair epoxy was injected to interior cracks of the corbels by needle injector using gravity feed method (see Fig. 3.9).

Figure 3.9 Applied the very low viscosity injection resin

The corbels were left for 7 days after injection operation to achieve target strength of the epoxy. Then grinder machine was used to clean and level the bottom surface of the corbel, which were contact with supports of the loading machine. This operation is important to obtain homogeneous load transfer mechanism during the test (see Fig. 3.10).

Figure 3.10 Grinding after injection process

3.6.2 Rehabilitation with very low viscosity injection resin and basalt fiber fabric

In this method, all corbels were repaired by very low viscosity injection resin before strengthening of corbels with basalt fiber fabric. The performance of remotely reinforced FRP can be influenced by delamination or fiber wraps of FRP if the brake width is 0.3 mm or higher. Subsequently, epoxy can be infused into those breaks that are more extensive than 0. 3mm. Inner discontinuities require pitch fixing or infusion to keep away from corrosion of the steel protection exists in the harmed solid individuals. Remain that as it may, for definite techniques and surface readiness of concrete, applicable criteria and rules can be utilized (Tureyen et al, 2002). Corbels need several treatments because of roughness of their surface due to very low viscosity injection resin and high viscosity epoxy adhesive. Therefore, the polishing machine was used to adjust the corbel surfaces and to make that surface smooth. In this way any delamination between basalt fiber fabric and the concrete surface can be prevented, as shown in Figure 3.11.

Figure 3.11 Surface treatment before applied the basalt fiber

Three strips of basalt fiber fabric were prepared with dimensions of 45cm x 20cm, 45cm x 20cm, and 140cm x 20cm for all corbel specimens (see Figure 3.12). Then the low viscosity epoxy adhesive hardener and resin were mixed by an electric mixer machine according to product data sheet for that epoxy. After that, the basalt fabric was saturated with the epoxy (see Fig. 3.13).

Fig. 3.12).

Figure 3.12 Basalt fiber strips

Figure 3.13 Saturated basalt fiber with low viscosity epoxy adhesive

The corbel surface was covered with the epoxy saturated basalt fiber fabric bi-directionally to resist vertical and horizontal stresses from loading. The fabrics were placed in a manner that fibers of them extended as parallel and transversely to the axis of corbels. Afterwards, pressure was applied with trowel to eliminate air voids, excess glue and to obtain perfect adhesion between the basalt fabric and concrete surface (see Fig. 3.14).

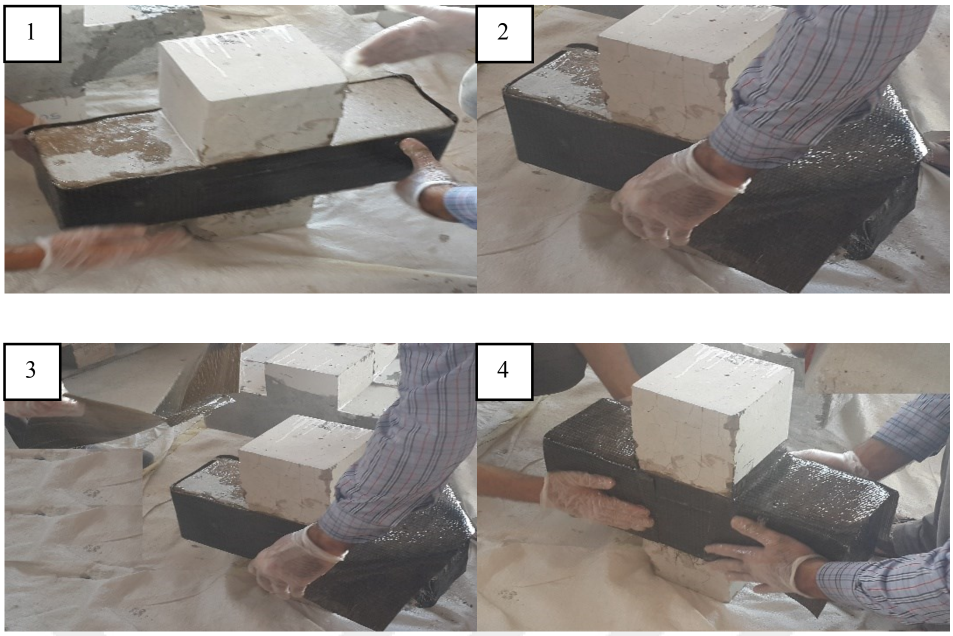

Figure 3.14 Configuration steps of bonding surface and applying the Basalt Fiber

Finally, polishing machine was used for levelling the bottom surfaces of the both corbels to ensure transfer of the load to both of supports in proper way, Figure 3.15

Figure 3.15 Polishing after applied the basalt fabric

3.7 Test Setup

All corbels were tested under vertical loading after rehabilitation process was achieved. As shown in Figure 3.16, a 500 KN capacity displacement controlled flexural testing machine was used for loading tests. Corbels were placed in inverted position to the machine. The load was applied to the top of the column part and transferred to both corbels by the supports of the machine. The machine was operated in displacement controlled mode with the rate of 0.3 mm/min, and the test data were recorded at every 0.2 s.

Figure 3.16 Corbel Specimen Setup.

Deflections of rehabilitated corbels were measured using two linear variable displacement transducers (LVDT). These LVDTs were placed to corbel-column junction for each side which correspond to tension region of all corbels. The corbel was supported by two supports; one of them allowed to rotation, while the other was not. Supports were regulated according to specified span lengths (*a*) before each test. General test configuration shown in Figure 3.17. The deflection (Δ) value was found to be average values of two LVDT readings. Measured values of loads and deflections were recorded to draw the load-deflection curves of the specimens. Moreover, in order to achieve homogeneous load distribution over the cross section of the column and to prevent premature failure, load was transferred from the machine to the column by 15 mm thickness steel plate. The raw material of the plate is transmission steel.

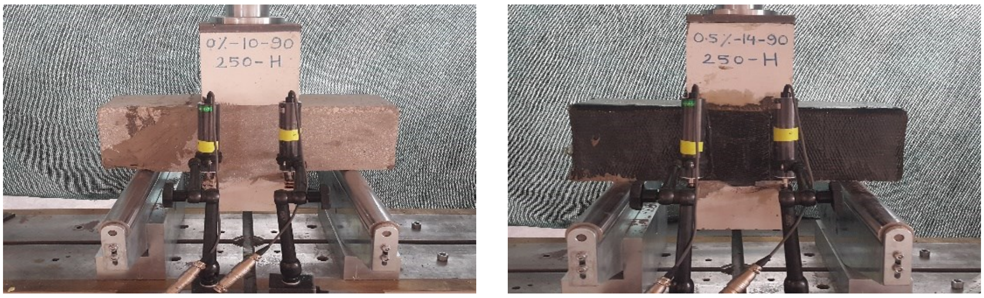

Figure 3.17 Injected and covered corbels with two LVDTs on the testing machine

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This experimental study consists of 18 corbels. All corbels were tested after and before rehabilitation process. All corbels classified into two groups. The first group of damaged corbels were repaired by very low viscosity injection resin, while the second group was repaired by basalt fiber fabric and very low viscosity injection resin. Before rehabilitation four types mode of failure had been recorded for the corbels; flexure failure happened at or near the column-corbel junction after wide yielding occur on reinforcement bars, diagonal splitting seemed as if a line spreading from the column-corbel junction to the bearing plate or the corbels was separated into more than parts, shear failure occurred between flexure and diagonal-splitting cracks and the fourth mode was shear and flexure failure together in the same concrete sample(N I Fattuhi, 1990).

This chapter presents review and discussion of each test specimen outcomes before and after rehabilitation process for example; the load-deflection responses (C.C represents control corbels and R.C represents rehabilitated corbels in the curves), the ultimate carrying load capacity, and failure modes.

4.2 Corbels Rehabilitated by very low viscosity injection resin

Nine of the corbels were rehabilitated by only very low viscosity injection resin epoxy to study the effectiveness of epoxy injection for restoring the original load capacity of the corbels. Shear span of the corbels was 90 mm in this group. Test results of the corbels in this group are presented in Table 4.1. In the table the first column represents name of the corbels. Name designation of corbels is composed of three terms; the first term shows the number of the corbels and the rest terms elucidate the steel fiber ratio and the degree of heat treatments respectively. Load carrying capacity of control corbales are represented in the second column of Table 4.1

The results of each corbel as following; peak load capacity before rehabilitation was listed in the second column and the peak load capacity after rehabilitation was listed in the third column.The results showed that ratio of load capacity after rehabilitation to the capacity of control specimens (the capacity before the first failure) varies between 0.43 and 0.99. Additionally,since the failure of high strength corbels is more brittle as compared to normal strength ones,its hard to restore the original load capacity. Therefore, the rehabilitation technique with very low viscosity injection resin epoxy was less performed for high strength corbels when heavy damaged ratio present.Comparison of original load capacity and the capacity of corbels after rehabilitation shows that performance of this method is better for the corbels that contain steel fiber. Since * PU / pu value of the corbels containing steel fiber are higher as compared to the corbels without steel fiber. As shown from Table 4.1, the average ratio of (* PU / pu) the repaired corbels reaches to 1 of their initial values when very low viscosity injection resin epoxy applied.

Deflection capability of most corbels improves after rehabilitation as compared to their deflections before repairing process. As detailed in fifth column and sixth column of Table 4.1, the deflection at peak load for most of the corbels has increased and the average values of maximum deflection before and after rehabilitation are 1.37 mm and 2.48 mm respectively. Four modes of failure had been observed before rehabilitation process which was a flexural failure, shear failure, diagonal splitting and flexural-shear failure. However, two modes of were recored for rehabilitated corbels which were shear and diagonal spilitting failure modes. The modes of failure are listed in Table 4.1. All corbel’s detail, load-deflection curve and related mode of failure are discussed in details in this chapter.

Table 4.1 Experimental test results for corbels repaired with very low viscosity injection resin

Name	P_u	$*P_U$	$*P_U/p_u$	Max.Deflection (mm)		Modes of failure	
				Before repairing	After repairing	Before repairing	After repairing
C0-0.0-250	266	98	0.43	0.551	1.116	Diagonal splitting	Diagonal splitting
C1-0.0-500	195	90	0.46	1.147	1.348	Shear failure	Shear failure
C2-0.0-750	107	59	0.55	0.979	0.954	Shear failure	Shear failure
C3-0.5-250	280	150	0.54	1.63	3.927	Shear failure	Shear failure
C4-0.5-500	235	234	1.00	1.19	3.131	Shear failure	Diagonal splitting
C5-0.5-750	267	231	0.87	1.816	2.849	Shear failure	Shear failure
C6-1.0-250	317	293	0,92	1.022	3.522	Flexural+shear failure	Diagonal splitting
C7-1.0-500	267	231	0,87	2.432	1.883	Flexural failure	Shear failure
C8-1.0-750	171	169	0,99	1.645	3.593	Shear failure	Diagonal splitting
Average			0.736	1.37	2.48		

P_u; peak load capacity before rehabilitation (kN).

$*P_U$; peak load capacity after rehabilitation (kN).

C0-0.0-250:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 10mm diameter longitudinal bar in tension side. This corbel did not contain steel fiber. Before initial loading test, the corbel had been heated until 250°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 266kN. The corbel had failed in diagonal splitting mode that occurred on the left side as a result of initial testing; as shown in Figure 4.2. After repair of the corbel with low viscosity injection resin, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 0.43 of its original capacity. However, the failure mode did not change after rehabilitation process and the mode of the repaired corbel is diagonal splitting as shown in Figure 4.3. As it can be inferred from the load-deflection curve in Figure 4.1 that the maximum deflection of the corbel is equal to 0.551 mm before rehabilitation procedure and increases to 1.116 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 98 kN. After appearance of the first cracks, the load remaines constant and the load decreases slightly until failure of the corbel.

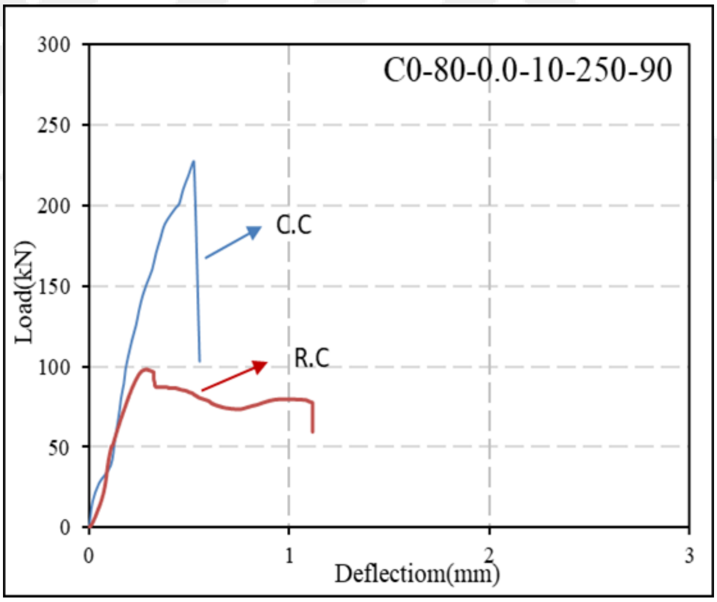

Figure 4.1 Load-deflection curve of specimen (C0-0.0-250)

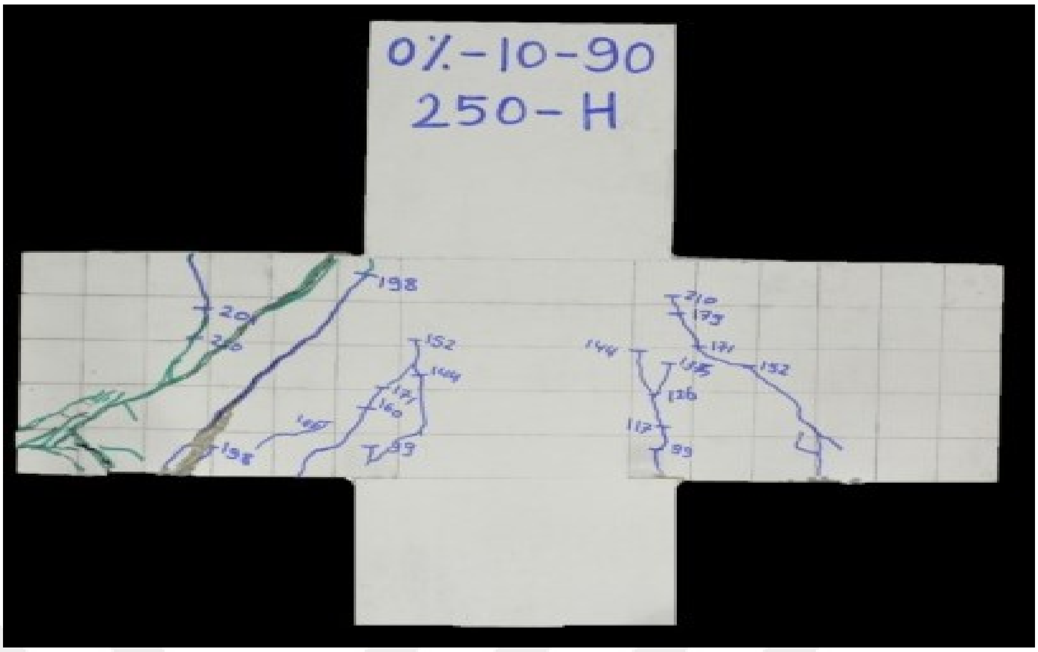

Figure 4.2 Specimen (C0-0.0-250) failure before rehabilitation

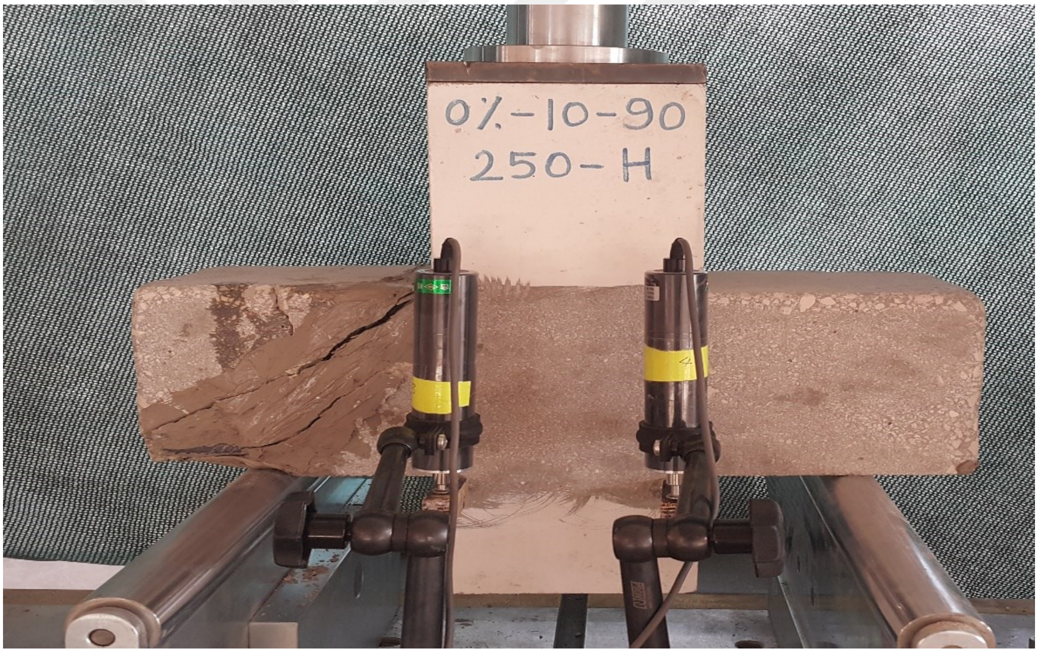

Figure 4.3 Specimen (C0-0.0-250) failure after rehabilitation

C1-0.0-500:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 10mm diameter longitudinal bar in tension side as previous corbels (C0-0.0-250). This corbel did not contain steel fiber also. Before initial loading test, the corbel had been heated until 500°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 195kN. The corbel had failed in shear mode that occurred on the left side and superficial cracks on the right side as a result of initial testing; as shown in Figure 4.5. After repair of the corbel with low viscosity injection resin, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 0.46 of its original capacity. Nevertheless, the failure mode did not change after rehabilitation process and the mode of the repaired corbel is shear failure as shown in Figure 4.6. As it can be inferred from the load-deflection curve in Figure 4.4 that the maximum deflection of the corbel is equal to 1.147 mm before rehabilitation procedure and increases to 1.348 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 90 kN. After appearance of the first cracks, the load remaines constant until failure of the corbel.

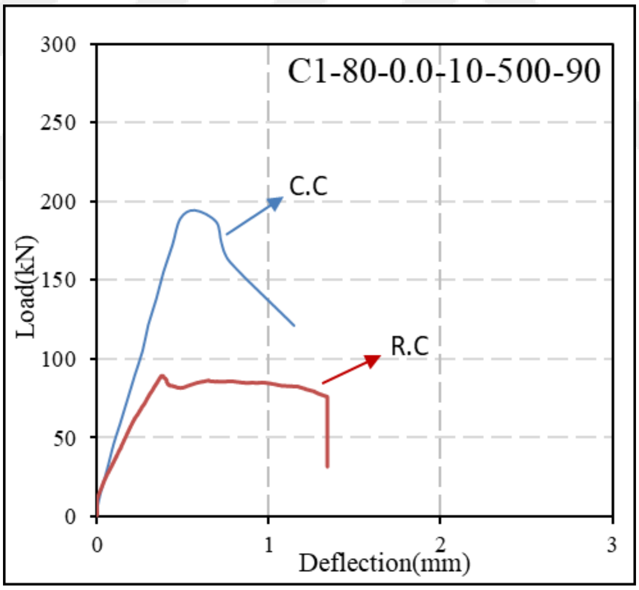

Figure 4.4 Load- deflection curve of specimen (C1-0.0-500)

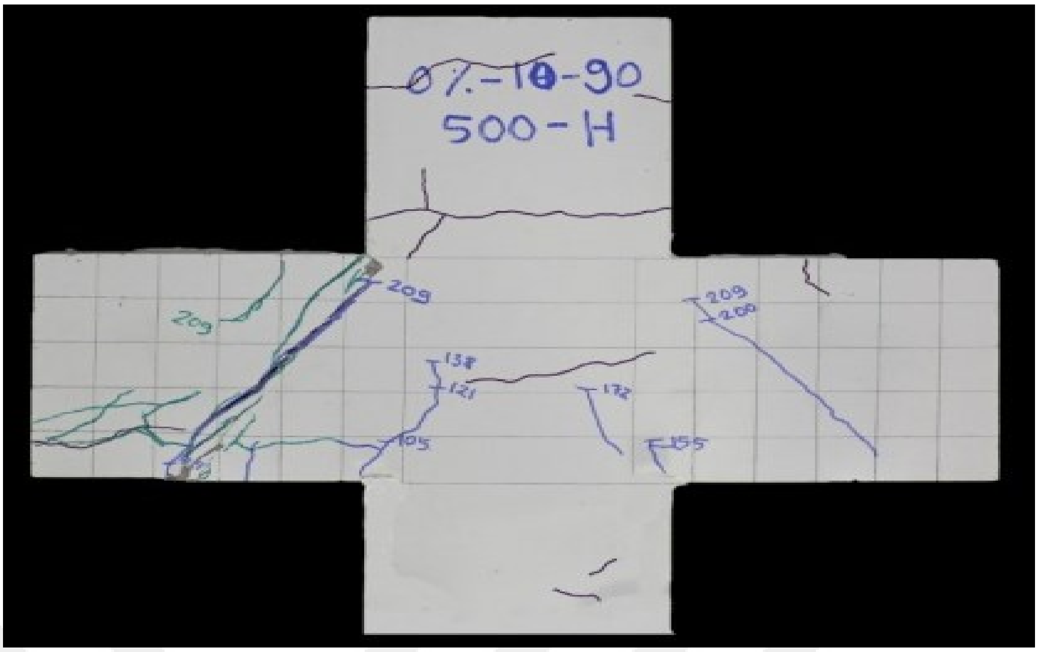

Figure 4.5 Specimen (C1-0.0-500) failure before rehabilitation

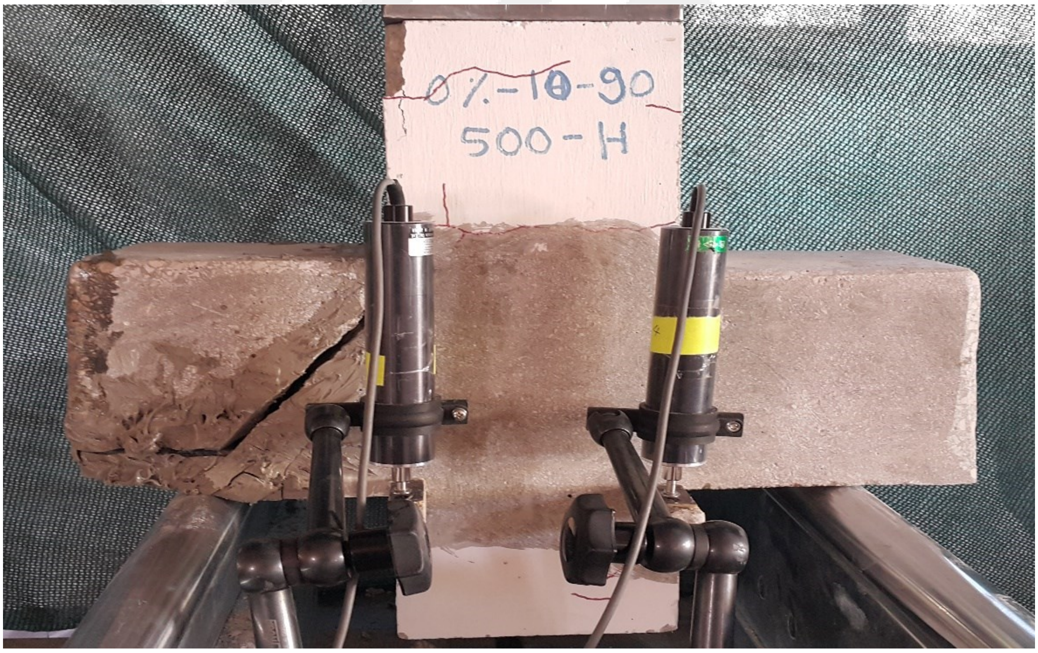

Figure 4.6 Specimen (C1-0.0-500) failure after rehabilitation

C2-0.0-750:

For this corbel, the concrete was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 10mm diameter longitudinal bar in tension side. This corbel did not contain steel fiber also. Before initial loading test, the corbel had been heated until 750°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 107kN. The corbel had failed in shear mode that occurred on the left side as a result of initial testing; as shown in Figure 4.8. After repair of the corbel with low viscosity injection resin, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 0.55 of its original capacity. However, the failure mode did not change after rehabilitation process and the mode of the repaired corbel is shear failure as shown in Figure 4.9. As it can be inferred from the load-deflection curve in Figure 4.7 that the maximum deflection of the corbel is equal to 0.979 mm before rehabilitation procedure and decreases to 0.954 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 59 kN. After appearance of the first cracks, the load decreases non-linearly until failure of the corbel.

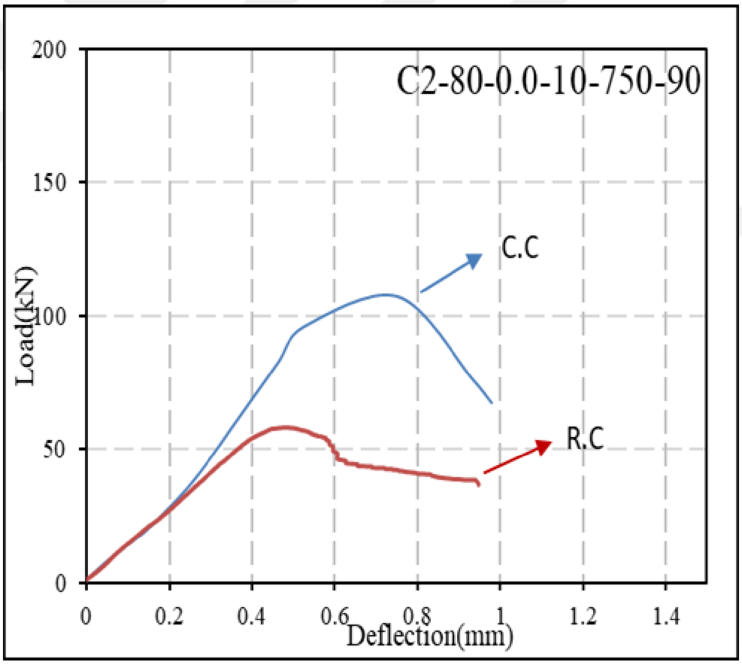

Figure 4.7 Load- deflection curve of specimen (C2-0.0-750)

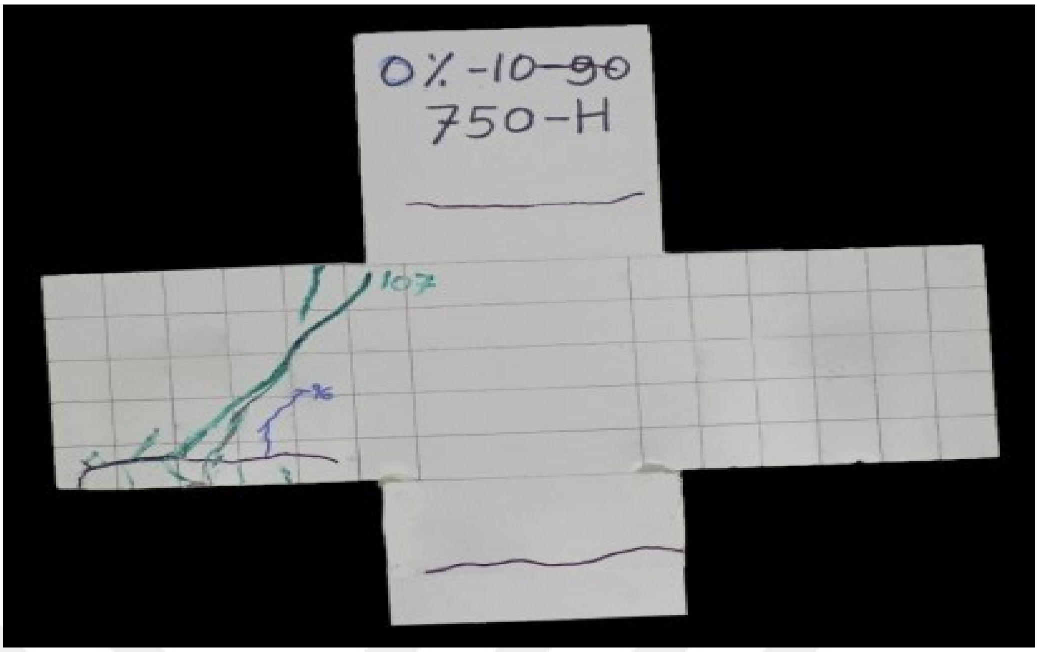

Figure 4.8 Specimen (C2-0.0-750) failure before rehabilitation

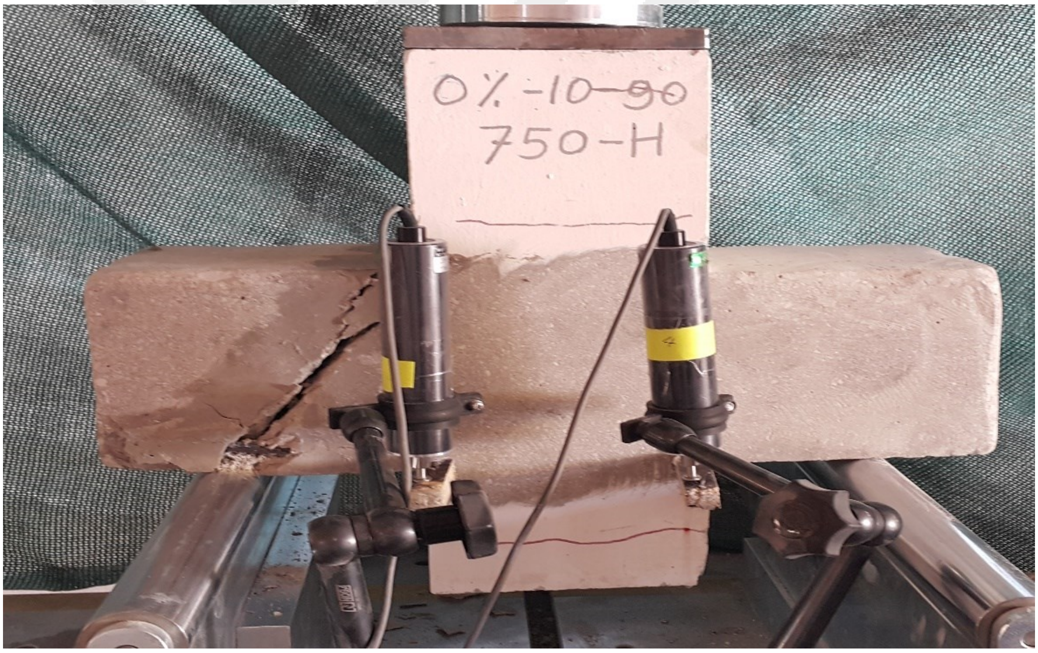

Figure 4.9 Specimen (C2-0.0-750) failure after rehabilitation

C3-0.5-250:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 10mm diameter longitudinal bar in tension side. This corbel contains 0.5% of steel fiber. Before initial loading test, the corbel had been heated until 250°C with heating rate of

5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 280kN. The corbel had failed in shear mode that occurred on the right side as a result of initial testing; as shown in Figure 4.11. After repair of the corbel with low viscosity injection resin, it was tested according to the same loading procedure the failure mode did not change after rehabilitation process and the mode of the repaired corbel is shear failure as shown in Figure 4.12. However, the load capacity didn’t show that improvement in the capacity of the corbel after rehabilitation process, while the rate of decrement was 0.54 from the initial value, but the result was increased comparing by the same corbels but without steel fiber. So, that indicates the steel fiber reduce the harm caused by heat treatments and increased the ductility. As shown from the load-deflection curve in Figure 4.10, the maximum load displacement before rehabilitation was equal to 1.63mm, the maximum load displacement after rehabilitation was equal to 3.927mm. After appearance of the first cracks, the load decreases linearly until failure of the corbel.

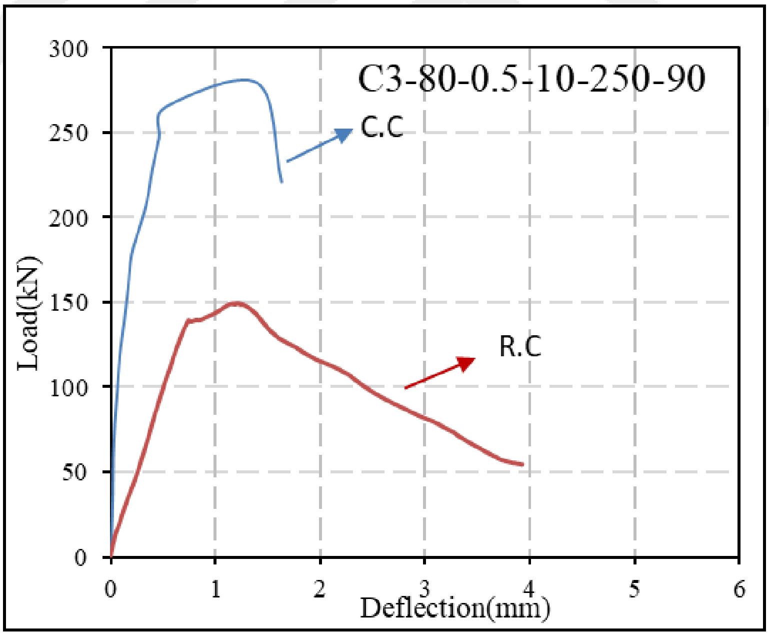

Figure 4.10 Load- deflection curve of specimen (C3-0.5-250)

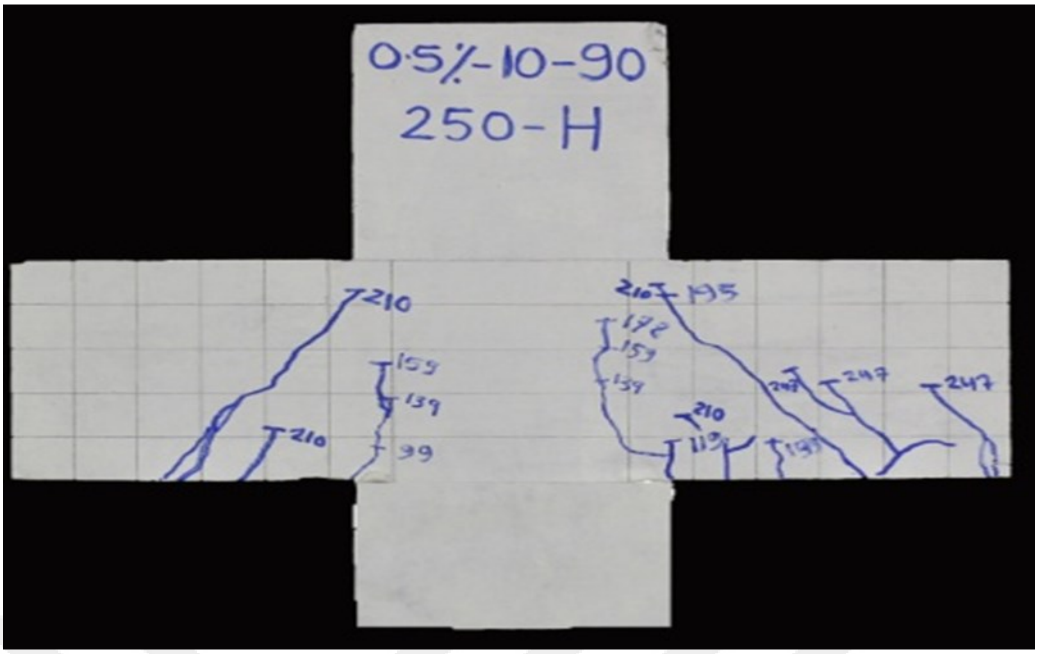

Figure 4.11 Specimen (C3-0.5-250) failure before rehabilitation

Figure 4.12 Specimen (C3-0.5-250) after rehabilitation

C4-0.5-500:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 10mm diameter longitudinal bar in tension side. This corbel contains 0.5% of steel fiber. Before initial loading test, the corbel had been heated until 500°C with heating rate of

5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 235kN. The corbel had failed in shear failure mode that occurred on the right side as a result of initial testing; as shown in Figure 4.14. After repair of the corbel with low viscosity injection resin, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 1.00 of its original capacity. For this corbels, the failure mode had been change after rehabilitation process and the mode of the repaired corbel is shear failure as shown in Figure 4.15. As it can be inferred from the load-deflection curve in Figure 4.13 that the maximum deflection of the corbel is equal to 1.19 mm before rehabilitation procedure and increases to 3.131 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 234 kN. After appearance of the first cracks, in order to steel fiber the load decreases slightly with constant drop until failure of the corbel.

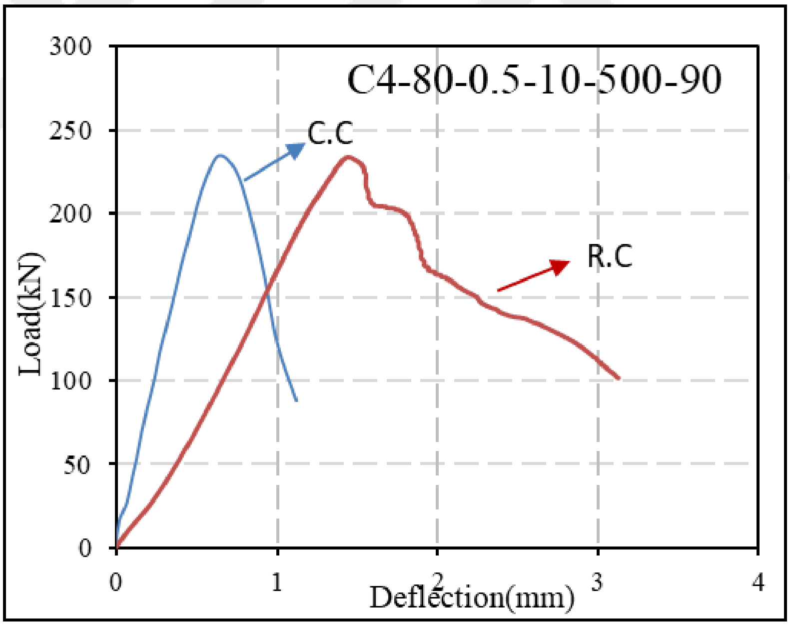

Figure 4.13 Load- deflection curve of specimen (C4-0.5-500)

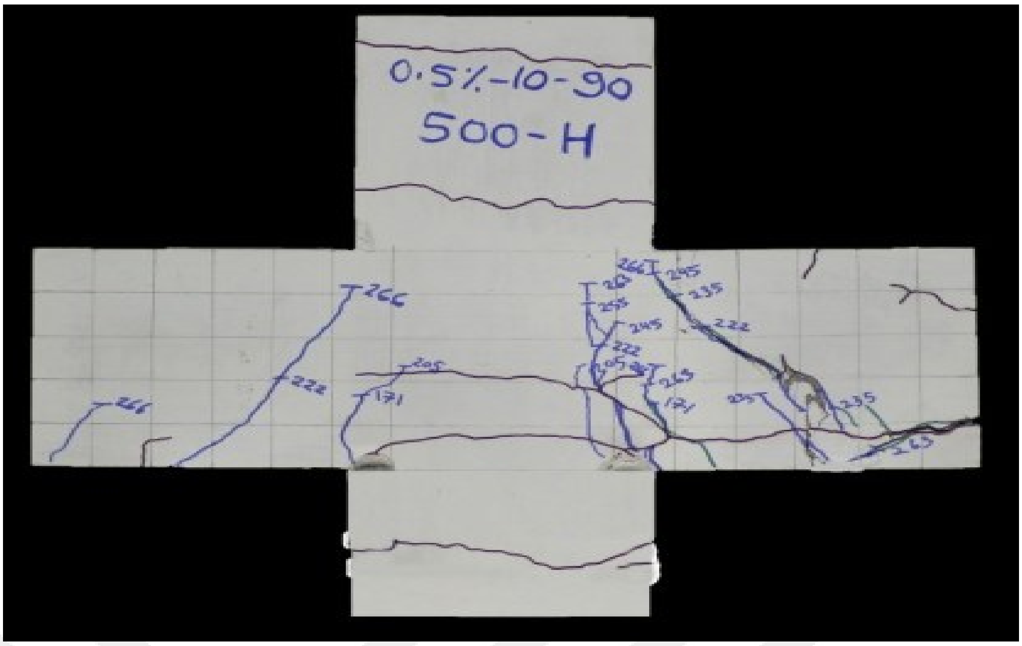

Figure 4.14 Specimen (C4-0.5-500) failure before rehabilitation

Figure 4.15 Specimen (C4-0.5-500) failure after rehabilitation

C5-0.5-750:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 10mm diameter longitudinal bar in tension side as previous corbels (C0-0.5-250). This corbel contains 0.5% of steel fiber also. Before initial loading test, the corbel had been heated until 750°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 267kN. The corbel had failed in shear mode that occurred on the right side and superficial cracks on the left side as a result of initial testing; as shown in Figure 4.17. After repair of the corbel with low viscosity injection resin, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 0.87 of its original capacity. As well as, the failure mode did not change after rehabilitation process and the mode of the repaired corbel is shear failure, but the failure pattern acquired in the left side as shown in Figure 4.18. As it can be inferred from the load-deflection curve in Figure 4.16 that the maximum deflection of the corbel is equal to 1.816 mm before rehabilitation procedure and increases to 2.849 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 231 kN. After appearance of the first cracks, since steel fiber exist the load drop regularly until failure of the corbel.

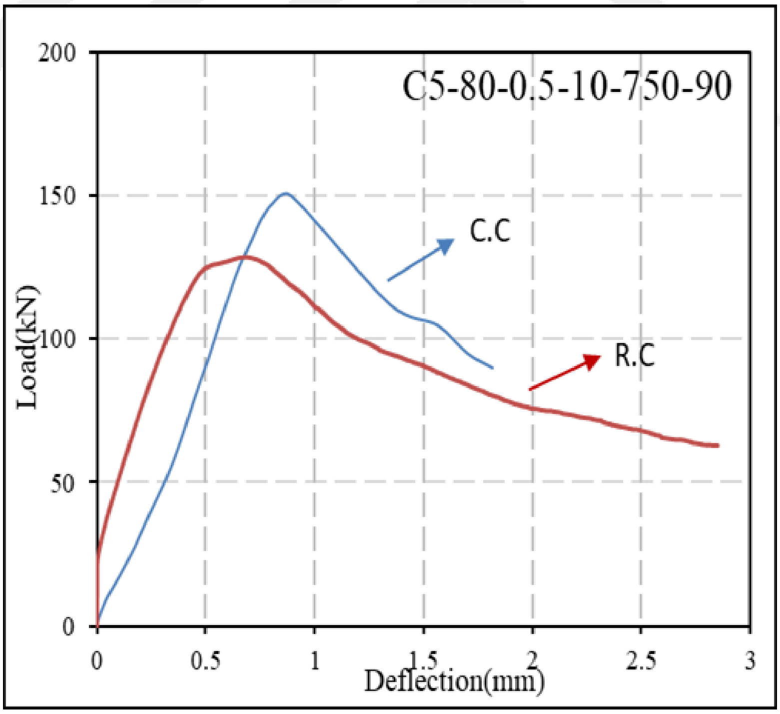

Figure 4.16 Load- deflection curve of specimen (C5-0.5-750)

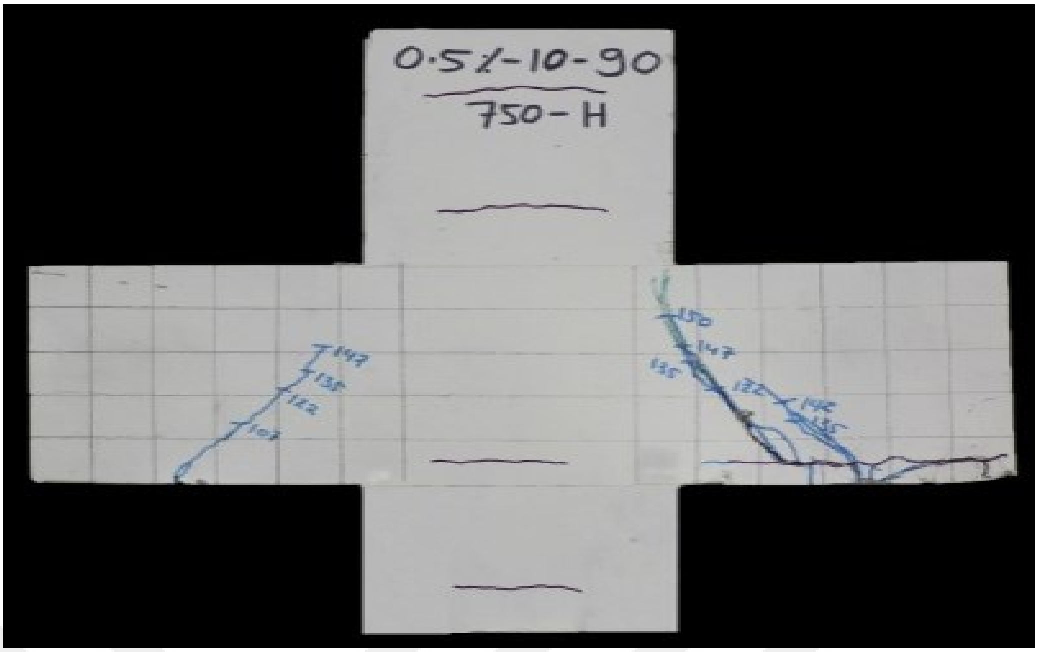

Figure 4.17 Specimen (C5-0.5-750) failure before rehabilitation

Figure 4.18 Specimen (C5-0.5-750) failure after rehabilitation

C6-1.0-250:

For this corbel, the concrete mixture had been produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 10mm diameter longitudinal bar in tension side. This corbel contains 1.0% of steel fiber. Before initial loading test, the corbel had been heated until 250°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 317kN. The corbel had failed in shear and flexural mode when the shear failure occurred on the right side and flexural failure occurred on the left side as a result of initial testing; as shown in Figure 4.20. After repair of the corbel with low viscosity injection resin, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 0.92 of its original capacity. As well as, the failure mode had been changed after rehabilitation process and the mode of the repaired corbel is diagonal splitting failure, but the failure pattern acquired in the right side only as shown in Figure 4.21. As it can be inferred from the load-deflection curve in Figure 4.19 that the maximum deflection of the corbel is equal to 1.022 mm before rehabilitation procedure and increases to 3.522 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 293 kN. After appearance of the first cracks, load decreases slightly with constant drop until failure of the corbel.

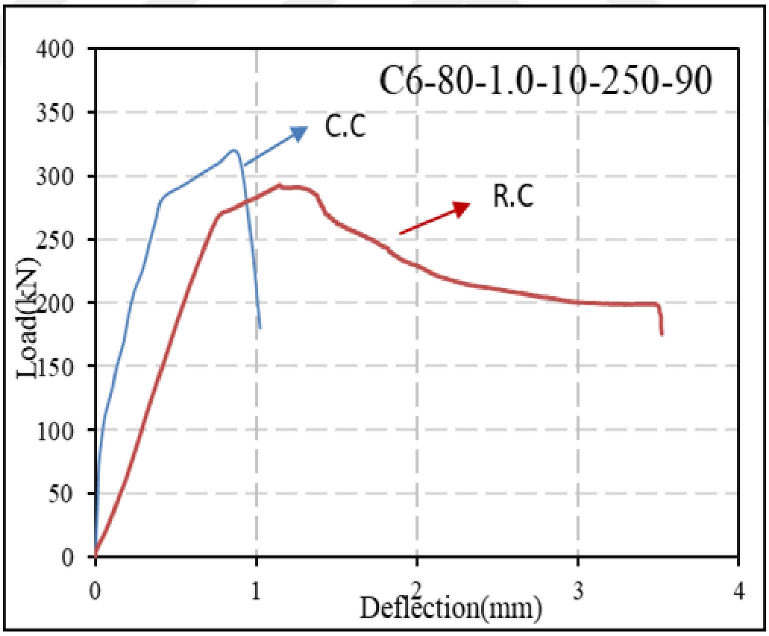

Figure 4.19 Load- deflection curve of specimen (C6-1.0-250)

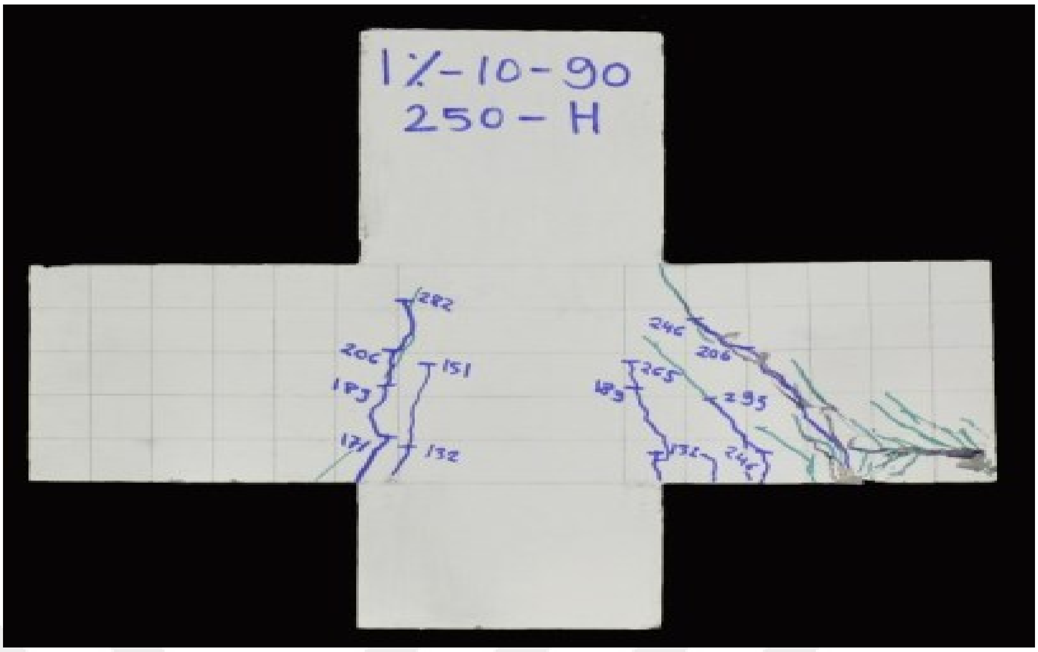

Figure 4.20 Specimen (C6-1.0-250) failure before rehabilitation

Figure 4.21 Specimen (C6-1.0-250) failure after rehabilitation

C7-1.0-500:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 10mm diameter longitudinal bar in tension side. This corbel contains 1.0% of steel fiber. Before initial loading test, the corbel had been heated until 500°C with heating rate of

5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 267kN. The corbel had failed in flexural mode that occurred on the right side and three superficial cracks on the left side as a result of initial testing; as shown in Figure 4.23. After repair of the corbel with low viscosity injection resin, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 0.87 of its original capacity. Furthermore, the failure mode had been changed after rehabilitation process and the mode of the repaired corbel is shear failure as shown in Figure 4.24. As it can be inferred from the load-deflection curve in Figure 4.22 that the maximum deflection of the corbel is equal to 2.432 mm before rehabilitation procedure and decreases to 1.883 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 231 kN. After appearance of the first cracks, the load drops suddenly then the load steel fiber was start working until failure of the corbel. As a result, this is an indicator that the very low viscosity injection resin did not affect properly.

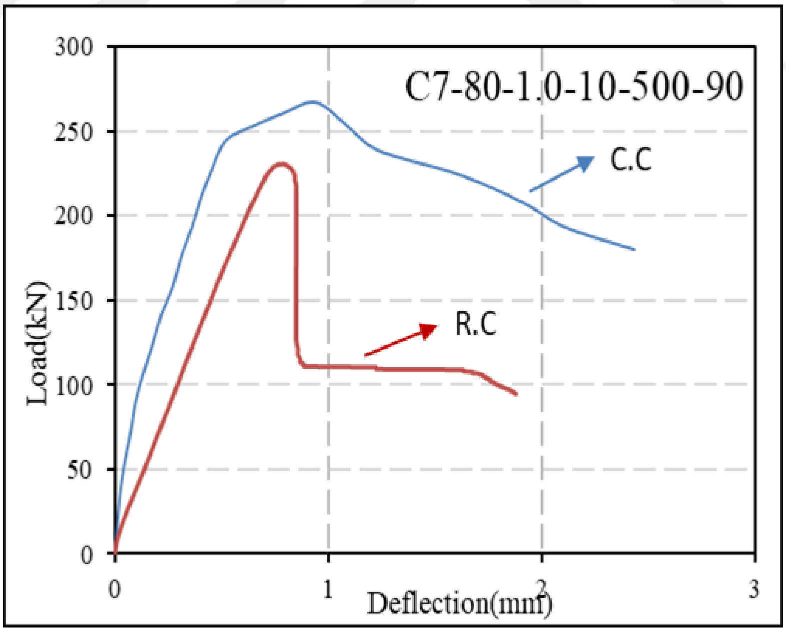

Figure 4.22 Load- deflection curve of specimen (C7-1.0-500)

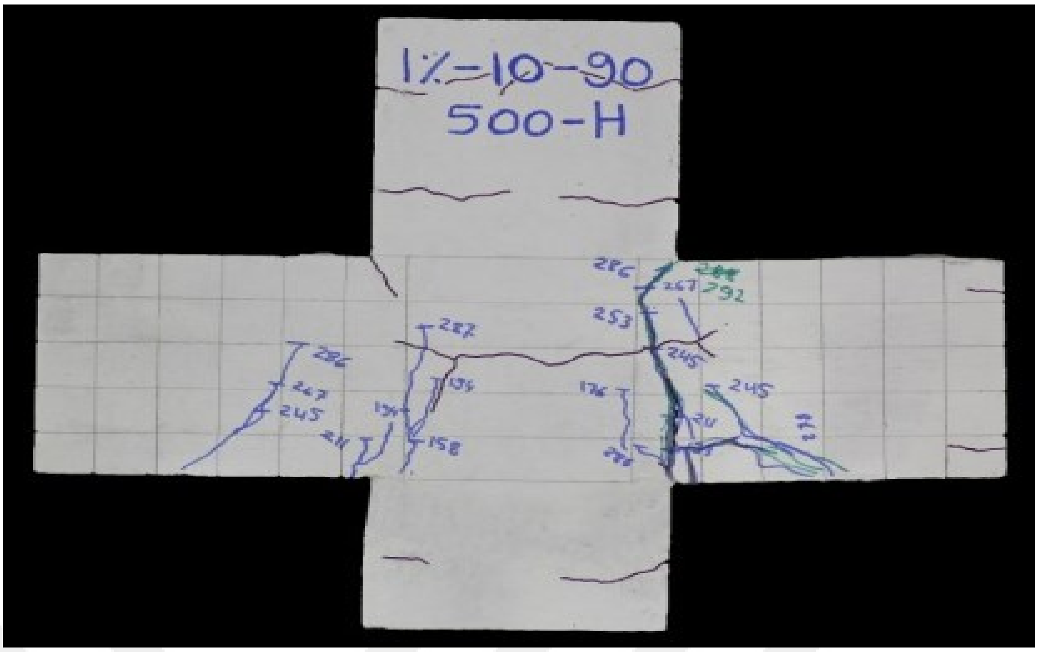

Figure 4.23 Specimen (C7-1.0-500) failure before rehabilitation

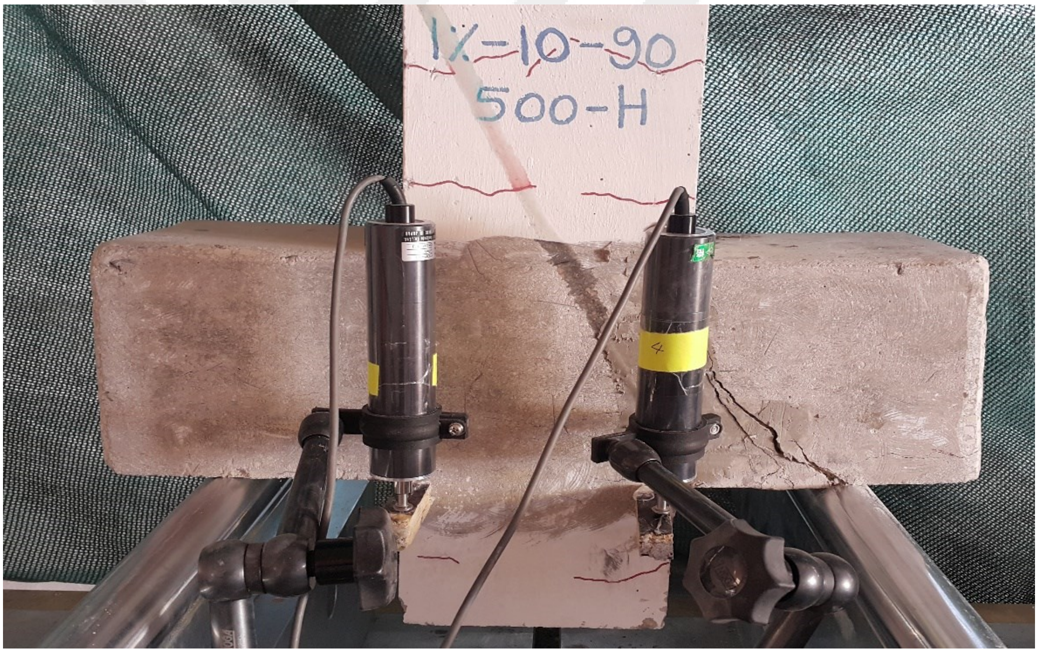

Figure 4.24 Specimen (C7-1.0-500) failure after rehabilitation

C8-1.0-750:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 10mm diameter longitudinal bar in tension side. This corbel contains 1.0% of steel fiber. Before initial loading test, the corbel had been heated until 750°C with heating rate of

5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 171kN. Therefore, the corbel had failed in shear mode that occurred on the left side and one horizontal superficial cracks on the right side as a result of initial testing; as shown in Figure 4.26. After repair of the corbel with low viscosity injection resin, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 0.99 of its original capacity. On the other hand, the failure mode had been changed after rehabilitation process and the mode of the repaired corbel is diagonal splitting failure as shown in Figure 4.27. As it can be inferred from the load-deflection curve in Figure 4.25 that the maximum deflection of the corbel is equal to 1.645 mm before rehabilitation procedure and increases to 3.593 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 169kN. After appearance of the first cracks, the load drops suddenly then the load steel fiber was start working until failure of the corbel. In addition, After appearance of the first cracks, the load decreases linearly until failure of the corbel.

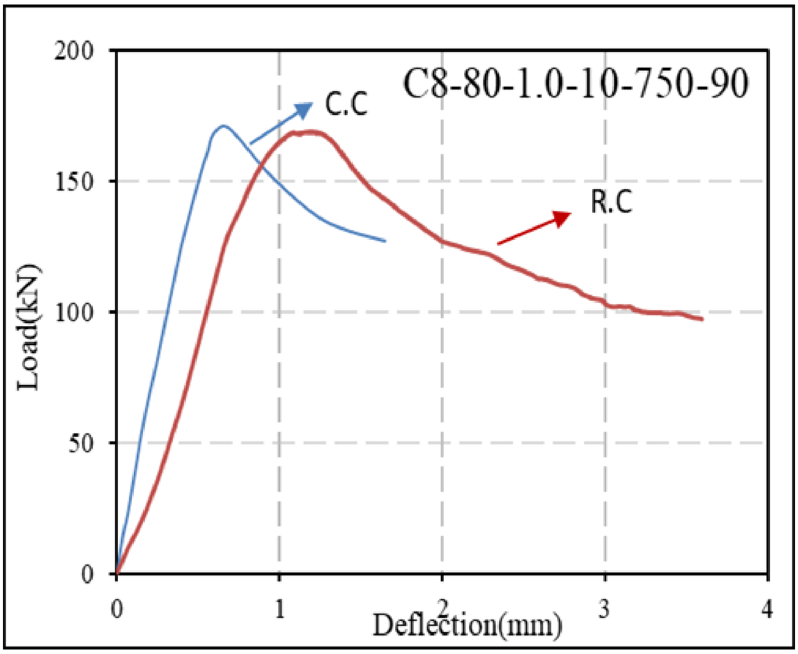

Figure 4.25 Load- deflection curve of specimen (C8-1.0-750)

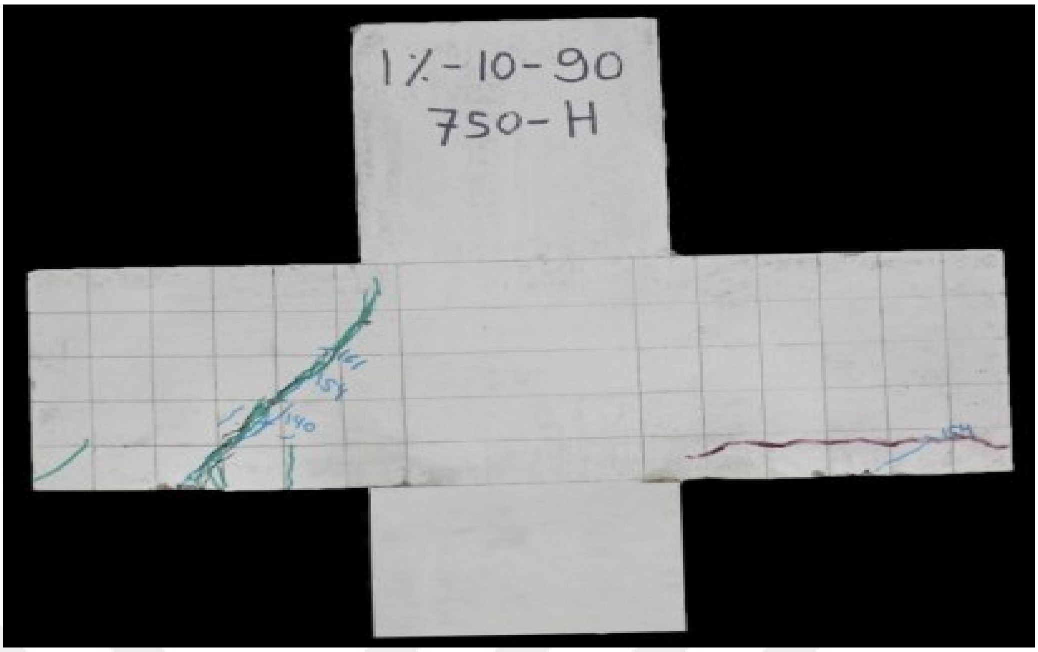

Figure 4.26 Specimen (C8-1.0-750) failure before rehabilitation

Figure 4.27 Specimen (C8-1.0-750) failure after rehabilitation

4.3 Corbels rehabilitated by Basalt Fiber Fabric (BFF)

The second group of corbels were rehabilitated by very low viscosity injection resin and basalt fiber fabric. The aim of this part is to investigate the efficiency of basalt fiber fabric for rehabilitation or strengthening the heated and damaged reinforced concrete corbels. Test results are shown in Table 4.2 in detail. The first column in the table is the name of the corbels that is composed of three terms; the first term shows the number of the corbels and the rest terms represent the steel fiber ratio and the degree of heat treatments respectively. The maximum loads carried by control corbels are listed in the second column of Table 4.2. All corbels in this group had been produced from self-compacting concrete with compressive strength value of 80 MPa. As well as corbels in this group had been reinforced with 14 mm diameter longitudinal bar in tension side. Also, the volumetric ratios of steel fiber 0.0%, 0.5% and 1.0% are used in the concrete mix design. All the corbels were exposed to heat treatments at temperatures 250°C, 500°C and 750°C and tested under vertical loading until failure occurred. After damaging, the rehabilitation process was started then, the samples had been tested under the vertical load with shear span 90mm.

As a result of loading tests, the original load capacity was recovered completely. Furthermore, load capacity after rehabilitation exceeded the original capacity. The average value of * PU / pu was 1.154. besides basalt fiber fabric increased ductility of repaired corbels much more. The average of maximum deflection value was 5.52 mm. these results prove the sufficiency and superiority of the proposed technique for the rehabilitation of highly damaged reinforced concrete corbels.

All of the corbels were wrapped up by unidirectional BFF in two directions (horizontal and vertical). Hence, the failure modes for all specimens were debonding failure in which the basalt fiber fabric was separated from the concrete surface.

Table 4.2 Experimental test results for rehabilitated corbels by Basalt Fiber Fabric (BFF).

Name	P_u	$*P_U$	$*P_U/p_u$	Max.Deflection (mm)		Modes of failure	
				Before repairing	After repairing	Before repairing	After repairing
C0-0.0-250	268	292.5	1.09	0.744	4.443	Shear failure	De-bonding
C1-0.0-500	210	246.5	1.17	1.654	3.60	Diagonal splitting	De-bonding
C2-0.0-750	113	150	1.32	1.231	7.583	Shear failure	De-bonding
C3-0.5-250	370	399.6	1.08	1.60	7.3	Shear failure	De-bonding
C4-0.5-500	251	262	1.04	2.309	6.292	Shear failure	De-bonding
C5-0.5-750	134	201	1.50	1.654	3.69	Shear failure	De-bonding
C6-1.0-250	382	430.3	1.13	2.048	6.125	Shear failure	De-bonding
C7-1.0-500	294	306	1.04	2.329	3.805	Shear failure	De-bonding
C8-1.0-750	183	187.5	1.02	1.68	6.886	Shear failure	De-bonding
Average			1.154	1.69	5.52		

P_u; peak load capacity before rehabilitation (kN).

$*P_U$; peak load capacity after rehabilitation (kN).

C0-0.0-250:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 14mm diameter longitudinal bar in tension side. This corbel did not contain steel fiber. Before initial loading test, the corbel had been heated until 250°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 268kN. The corbel had failed in shear mode with some superficial cracks that occurred on the left side and two superficial cracks on the right side as a result of initial testing; as shown in Figure 4.29. After rehabilitated of the corbel by basalt fiber fabric, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 1.09 of its original capacity. Whereas the failure mode had been changed after rehabilitation process and the mode of the strengthening corbel is debonding as shown in Figure 4.30. As it can be inferred from the load-deflection curve in Figure 4.28 that the maximum deflection of the corbel is equal to 0.744 mm before rehabilitation procedure and increases to 4.443 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 292.5 kN. Even though the first cracks did not noticed because existing of basalt fiber fabric, while the load drops suddenly the first debonding (when the basalt fiber fabric separated from corbels surface) was occurred. The load remains drops constantly until failure of the corbel.

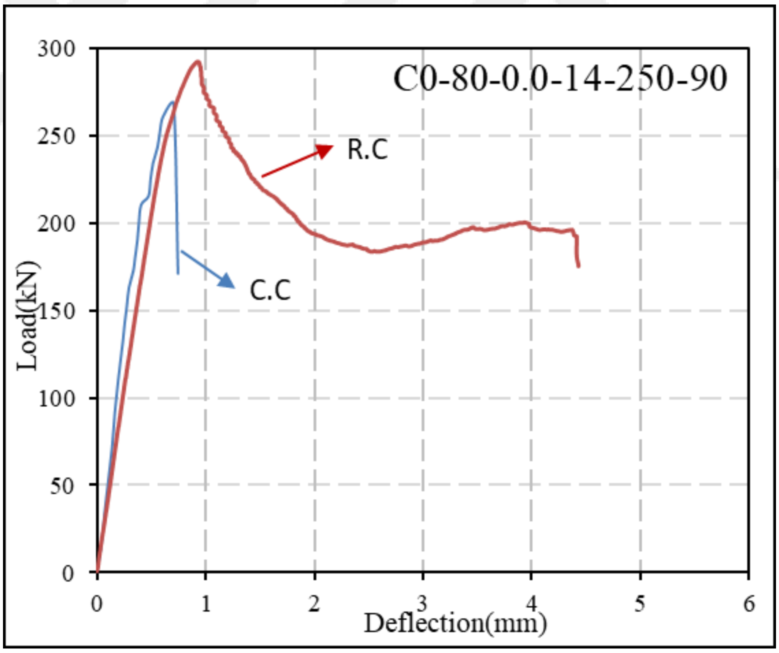

Figure 4.28 Load- deflection curve of specimen (C0-0.0-250)

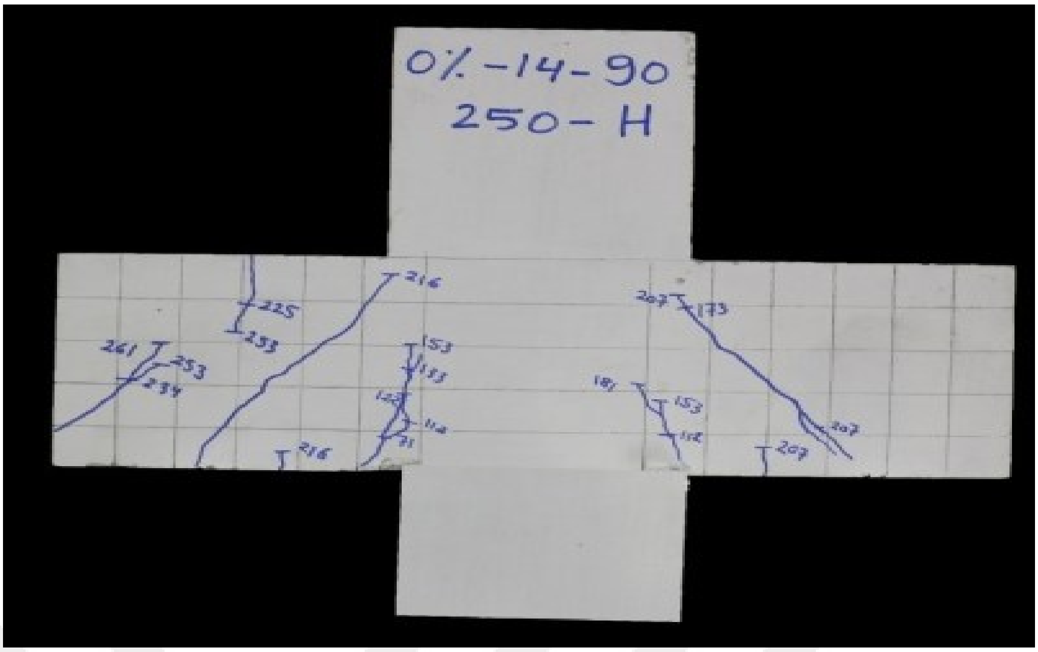

Figure 4.29 Specimen (C0-0.0-250) failure before rehabilitation

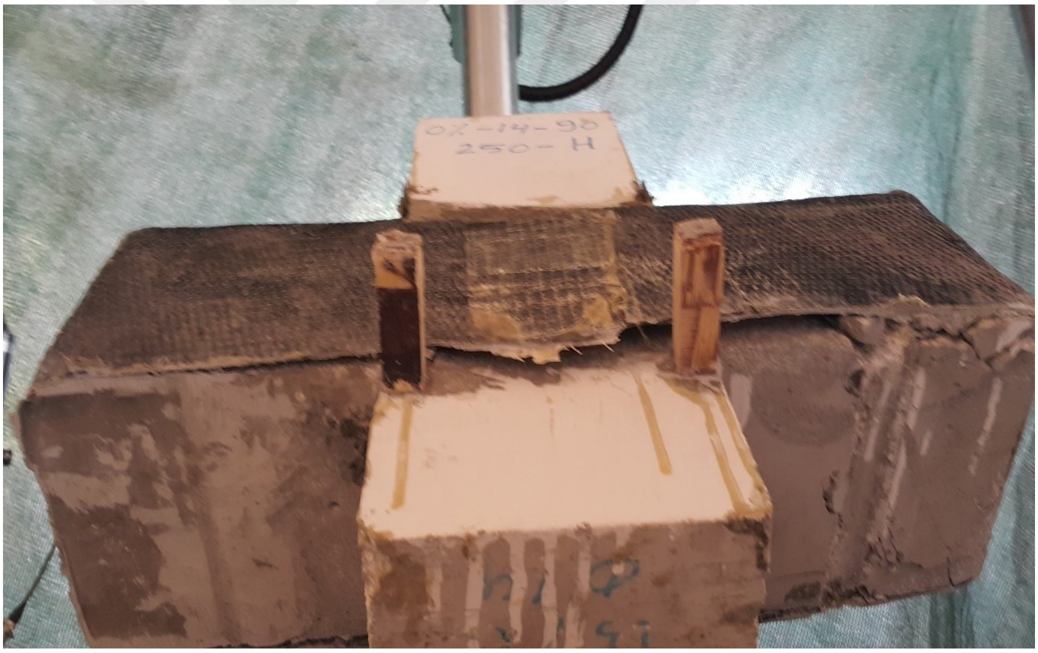

Figure 4.30 Specimen (C0-0.0-250) de-bonding failure after rehabilitation

C1-0.0-500:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. While the corbel was reinforced by two 14mm diameter longitudinal bar in tension side as previous corbels. This corbel did not contain steel fiber. Before initial loading test, the corbel had been heated until 500°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 210kN. However, the corbel had failed in diagonal splitting mode that occurred on the left side with superficial cracks on corbel column as a result of initial testing; as shown in Figure 4.32. After rehabilitated of the corbel by basalt fiber fabric, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 1.17 of its original capacity. As well as, the failure mode had been changed after rehabilitation process and the mode of the strengthening corbel is debonding as shown in Figure 4.33. As it can be inferred from the load-deflection curve in Figure 4.31 that the maximum deflection of the corbel is equal to 1.654 mm before rehabilitation procedure and increases to 3.60 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 246.5 kN. Like the previous corbels even though the first cracks did not notice because existing of basalt fiber fabric, on the other hand after first debonding was occurred the load drops suddenly. The load remains drops constantly with ductile behavior until failure of the corbel.

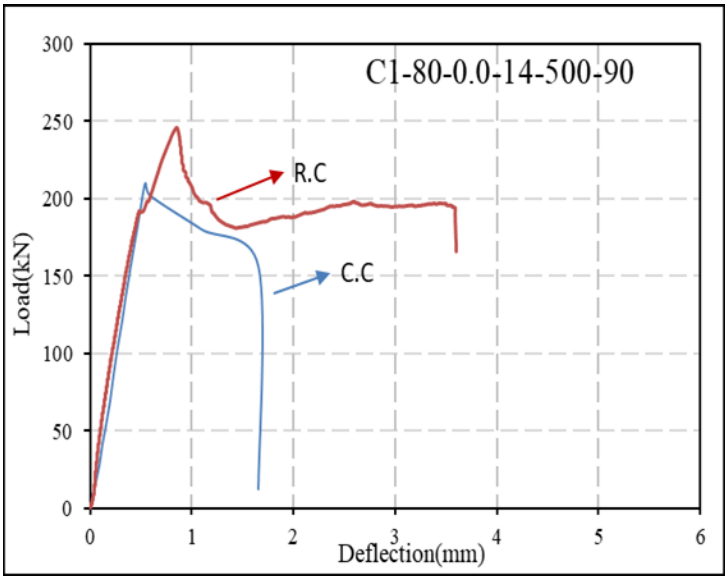

Figure 4.31 Load- deflection curve of specimen (C1-0.0-500)

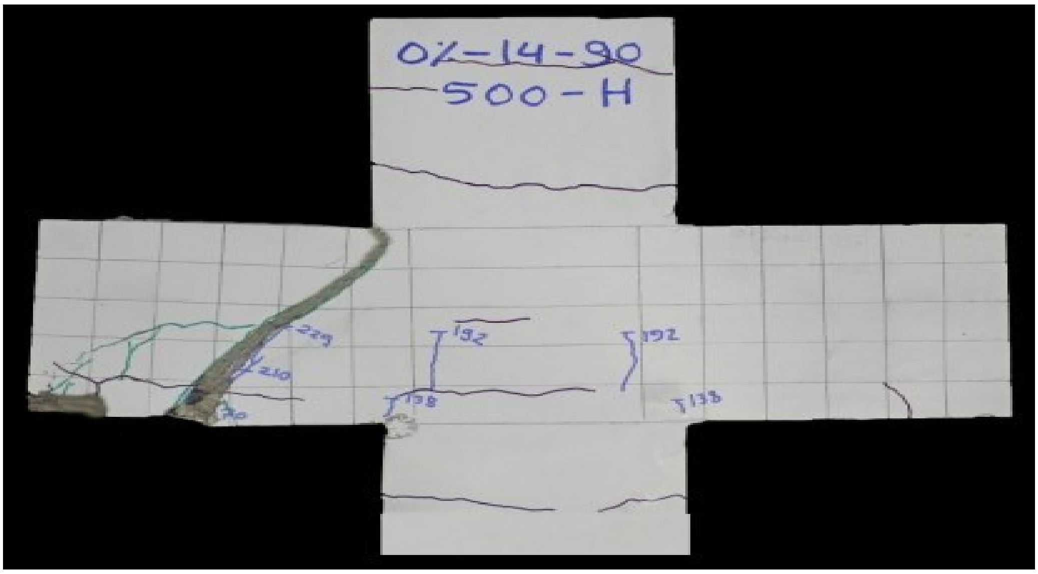

Figure 4.32 Specimen (C1-0.0-500) failure before rehabilitation

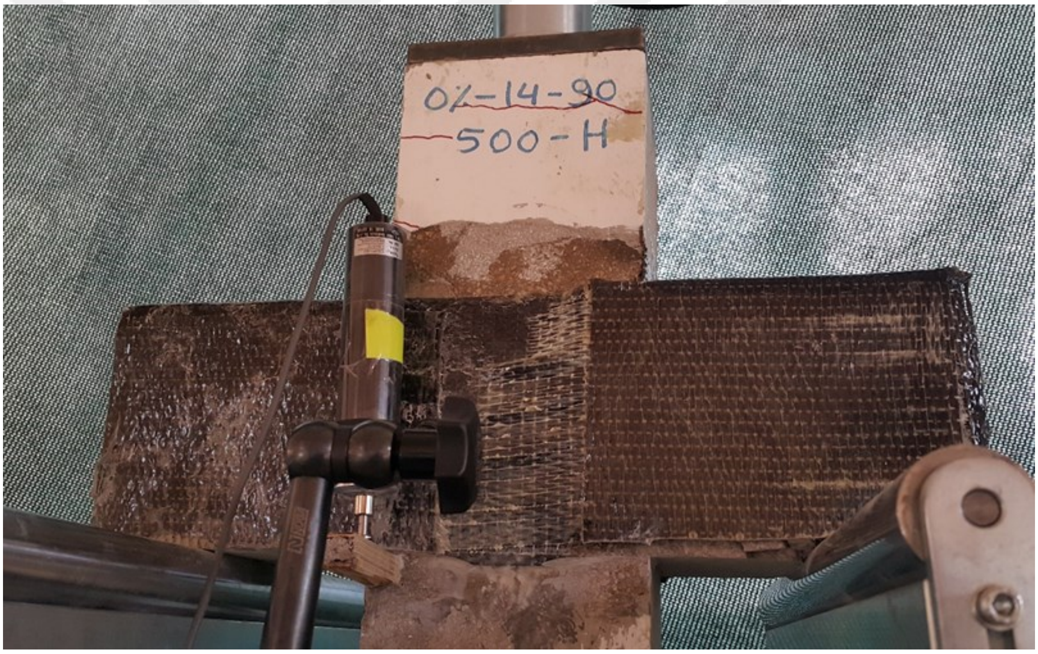

Figure 4.33 Specimen (C1-0.0-500) de-bonding failure after rehabilitation

C2-0.0-750:

For this sample, the corbel concrete was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. the corbel was reinforced by two 14mm diameter longitudinal bar in tension side. This corbel did not contain steel fiber. But before initial loading test, the corbel had been heated until 750°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 113kN. Furthermore, the corbel had failed in shear mode that occurred on the left side with superficial cracks on right side a result of initial testing; as shown in Figure 4.35. After rehabilitated of the corbel by basalt fiber fabric, it was tested according to the same loading procedure. While the load capacity of rehabilitated corbel was 1.32 of its original capacity. However, the failure mode had been changed after rehabilitation process and the mode of the strengthening corbel is debonding as shown in Figure 4.36. As it can be inferred from the load-deflection curve in Figure 4.34 that the maximum deflection of the corbel is equal to 1.231 mm before rehabilitation procedure and increases to 7.583 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 150 kN. Also for this corbels the first crack did not notice because existing of basalt fiber fabric, the sudden drops occurred after first debonding but, the basalt fiber fabric still efficient. The load comports different this time because the debonding happened before the peak load. After the peak point, the load drops fastly and in a continuous manner.

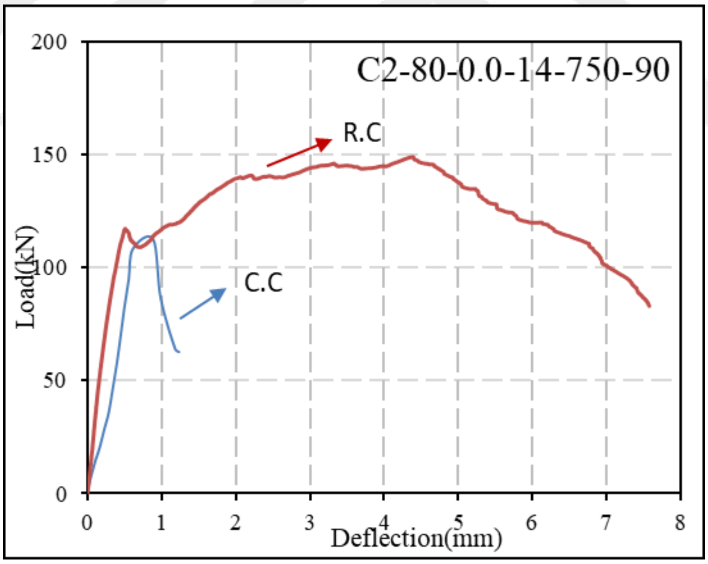

Figure 4.34 Load- deflection curve of specimen (C2-0.0-750)

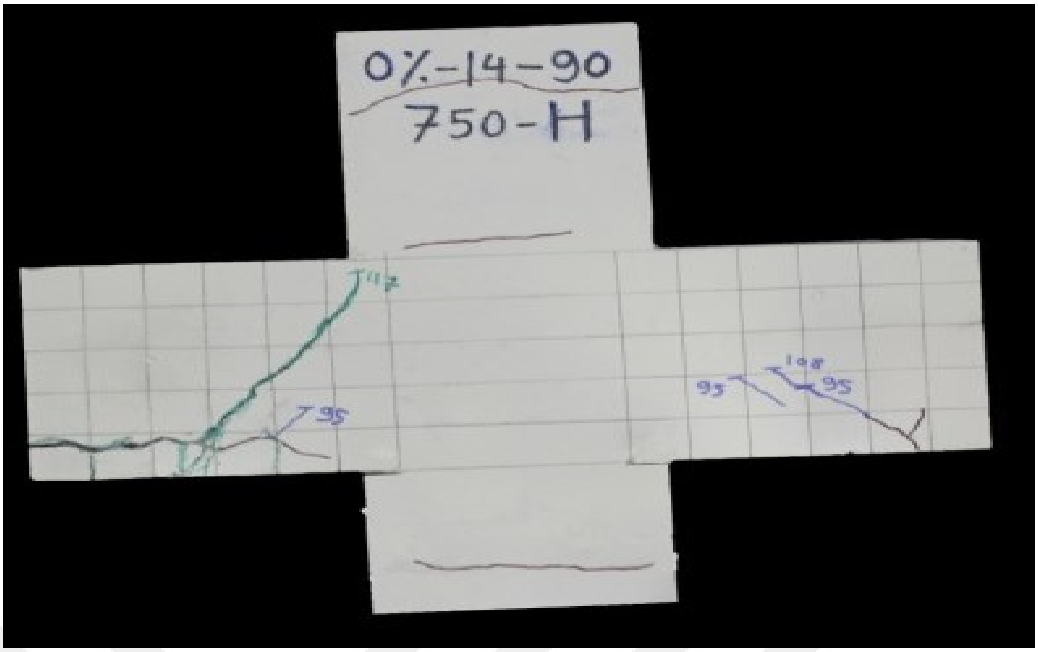

Figure 4.35 Specimen (C2-0.0-750) failure before rehabilitation

Figure 4.36 Specimen (C2-0.0-750) de-bonding failure after rehabilitation

C3-0.5-250:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. The corbel was reinforced by two 14mm diameter longitudinal bar in tension side as previous corbels (C2-0.0-750) but this corbel was contained 0.5% of steel fiber. Before initial loading test, the corbel had been heated until 250°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 370kN. The corbel had failed in shear mode with some superficial cracks that occurred on the left side and two superficial cracks on the right side as a result of initial testing; as shown in Figure 4.38. After rehabilitated of the corbel by basalt fiber fabric, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 1.08 of its original capacity. Whereas the failure mode had been changed after rehabilitation process and the mode of the strengthening corbel is debonding as shown in Figure 4.39. As it can be inferred from the load-deflection curve in Figure 4.37 that the maximum deflection of the corbel is equal to 1.60 mm before rehabilitation procedure and increases to 7.3 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 399.6 kN. Since the first cracks did not notice because existing of basalt fiber fabric the sudden drops in load was occurred after first debonding. The load remains drops constantly until failure of the corbel.

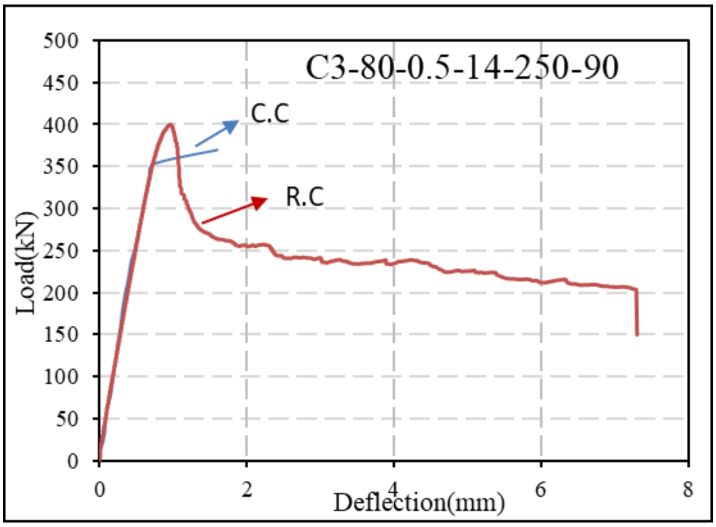

Figure 4.37 Load- deflection curve of specimen (C3-0.5-250)

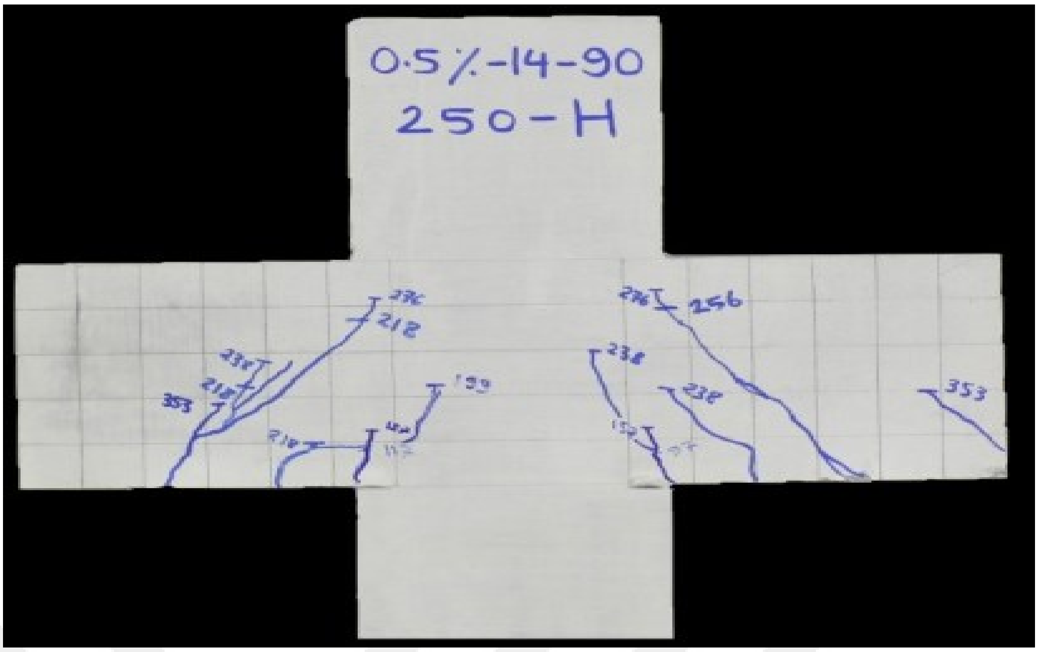

Figure 4.38 Specimen (C3-0.5-250) failure before rehabilitation

Figure 4.39 Specimen (C3-0.5-250) de-bonding failure after rehabilitation

C4-0.5-500:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. However, the corbel was reinforced by two 14mm diameter longitudinal bar in tension side while this corbel was contained 0.5% of steel fiber. Before initial loading test, the corbel had been heated until 500°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel.

In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 251kN. Furthermore, the corbel was failed in shear mode that occurred on the left and right side as a result of initial testing; as shown in Figure 4.41. After rehabilitated of the corbel by basalt fiber fabric, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 1.04 of its original capacity. However, the failure mode had been changed after rehabilitation process and the mode of the strengthening corbel is debonding as shown in Figure 4.42. As it can be inferred from the load-deflection curve in Figure 4.40 that the maximum deflection of the corbel is equal to 2.309 mm before rehabilitation procedure and increases to 2.309 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 262 kN. Like the previous corbels even though the first cracks did not noticed because existing of basalt fiber fabric, on the other hand after first debonding was occurred the load drops suddenly. The load remains drops constant with ductile behaviour until failure of the corbel.

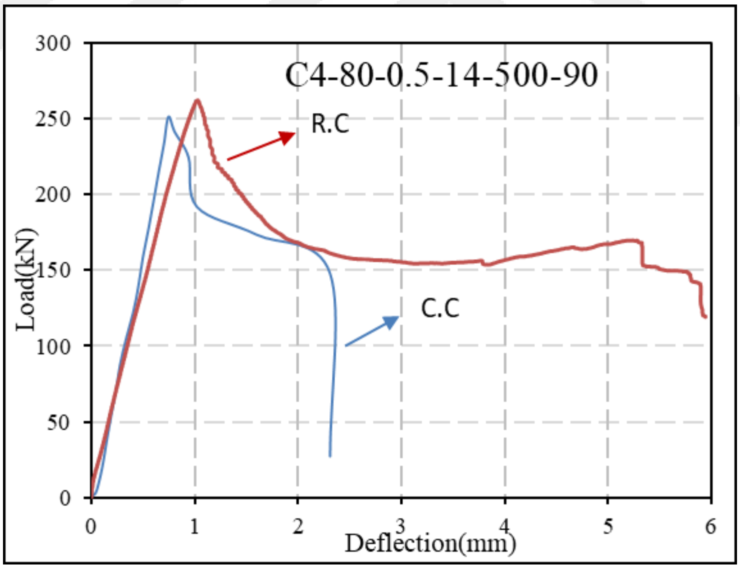

Figure 4.40 Load- deflection curve of specimen (C4-0.5-500)

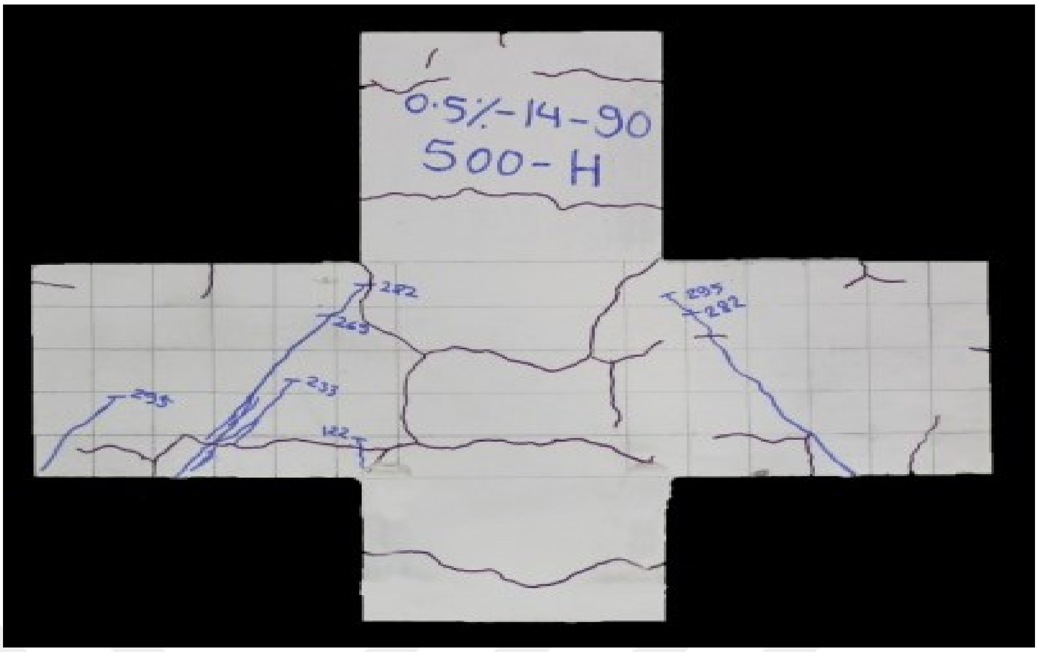

Figure 4.41 Specimen (C4-0.5-500) failure before rehabilitation

Figure 4.42 Specimen (C4-0.5-500) de-bonding failure after rehabilitation

C5-0.5-750:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. Also, the corbel was reinforced by two 14mm diameter longitudinal bar in tension side. This corbel was contained 0.5% of steel fiber. Before initial loading test, the corbel had been heated until 750°C with heating rate of

5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 134kN. The corbel had failed in shear mode that occurred on the left side and superficial horizontal crack on the right side as a result of initial testing; as shown in Figure 4.44. After rehabilitated of the corbel by basalt fiber fabric, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 1.50 of its original capacity. However, the failure mode had been changed after rehabilitation process and the mode of the strengthening corbel is debonding as shown in Figure 4.45. As it can be inferred from the load-deflection curve in Figure 4.43 that the maximum deflection of the corbel is equal to 1.654 mm before rehabilitation procedure and increases to 3.69 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 201 kN. As well as, the first cracks did not noticed because existing of basalt fiber fabric, in addition of first debonding the load drops at second debonding then the load remains constant until failure of the corbel.

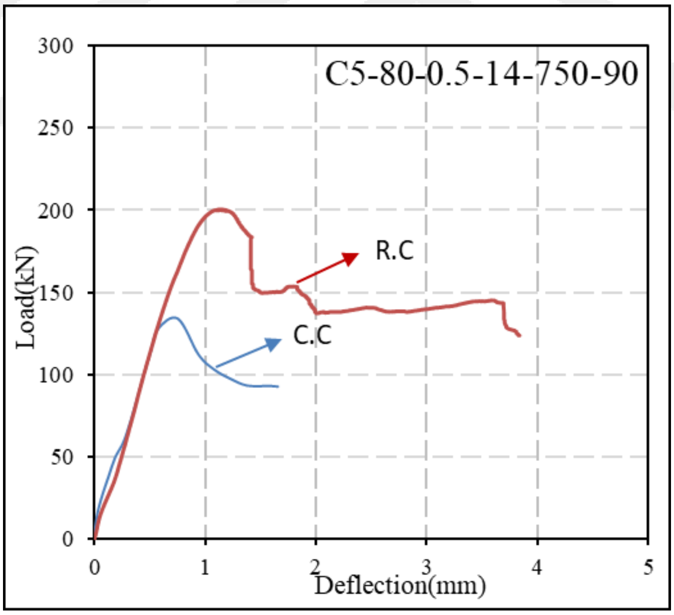

Figure 4.43 Load- deflection curve of specimen (C5-0.5-750)

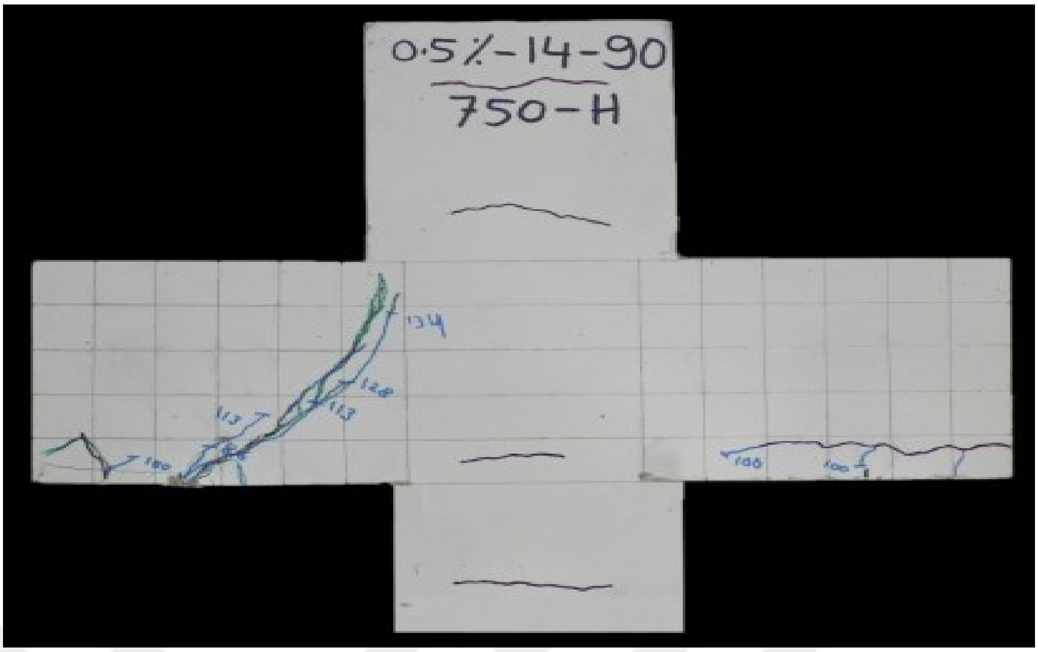

Figure 4.44 Specimen (C5-0.5-750) failure before rehabilitation

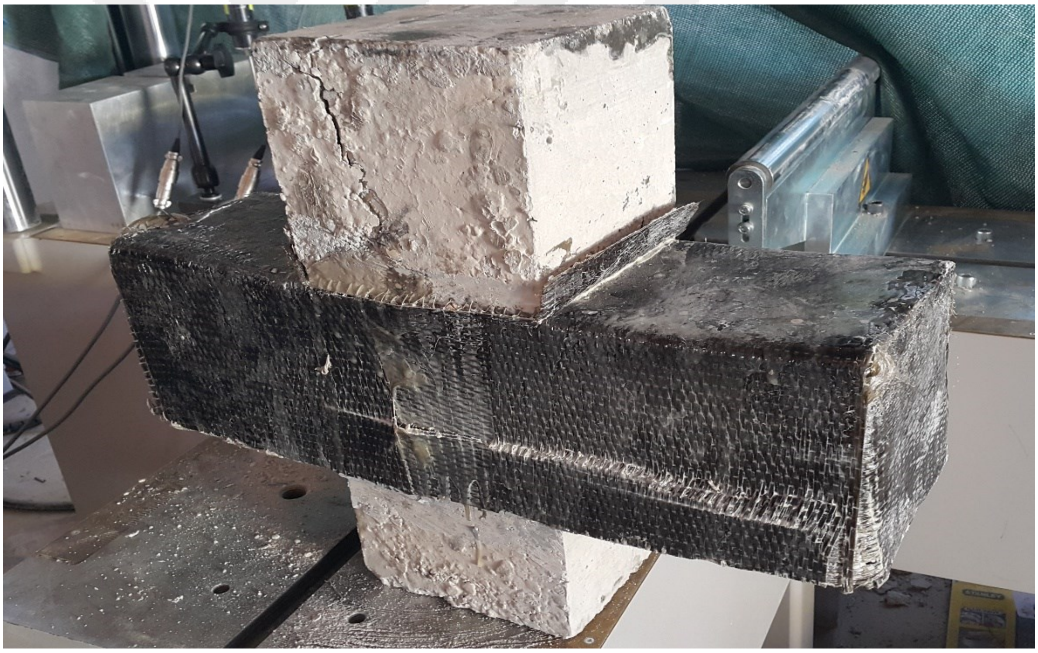

Figure 4.45 Specimen (C5-0.5-750) de-bonding failure after rehabilitation

C6-1.0-250:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. the corbel was reinforced by two 14mm diameter longitudinal bar in tension side and this corbel was contained 1.0% of steel fiber. Before initial loading test, the corbel had been heated until 250°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 382kN. The corbel had failed in shear mode that occurred on the right side and superficial shear crack on the left side as a result of initial testing; as shown in Figure 4.47. After rehabilitated of the corbel by basalt fiber fabric, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 1.13 of its original capacity. Moreover, the failure mode had been changed after rehabilitation process and the mode of the strengthening corbel is debonding as shown in Figure 4.48. As it can be inferred from the load-deflection curve in Figure 4.46 that the maximum deflection of the corbel is equal to 2.048 mm before rehabilitation procedure and increases to 6.125 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 430.3 kN. As same as the previous corbels even though the first cracks did not noticed because existing of basalt fiber fabric, on the other hand after first debonding was occurred the load drops suddenly. The load remains drops constant with ductile behaviour until failure of the corbel.

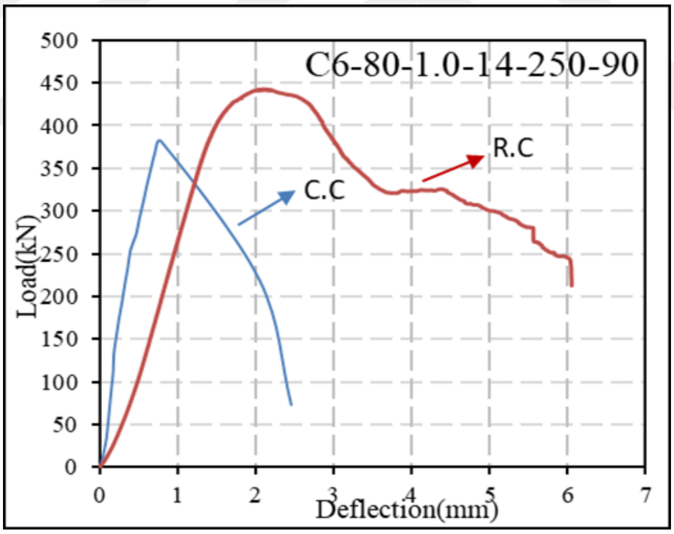

Figure 4.46 Load- deflection curve of specimen (C6-1.0-250)

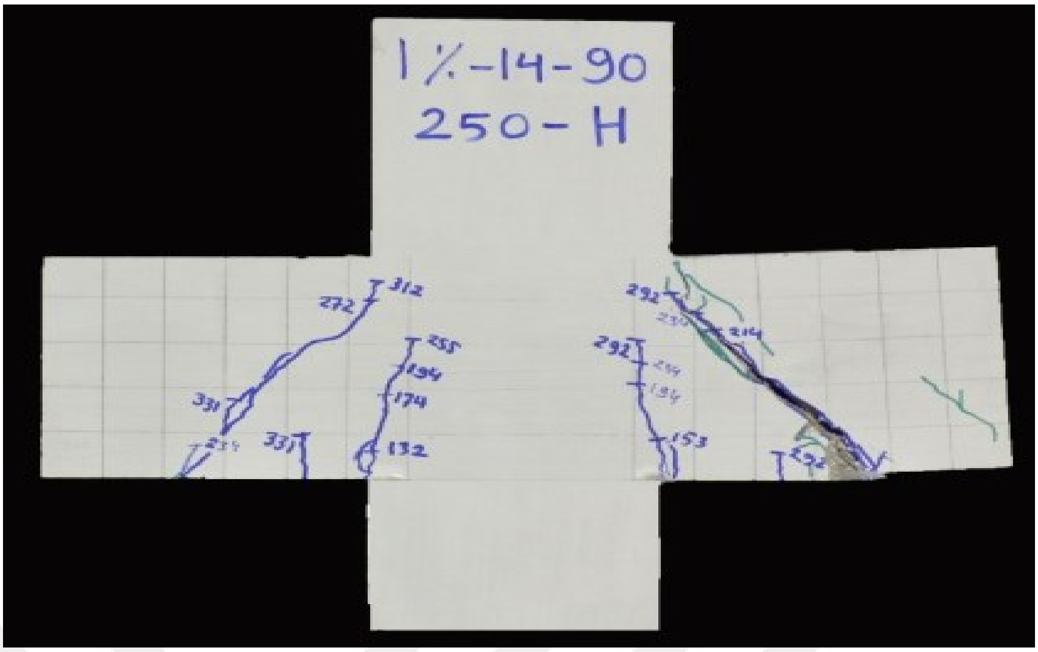

Figure 4.47 Specimen (C6-1.0-250) failure before rehabilitation

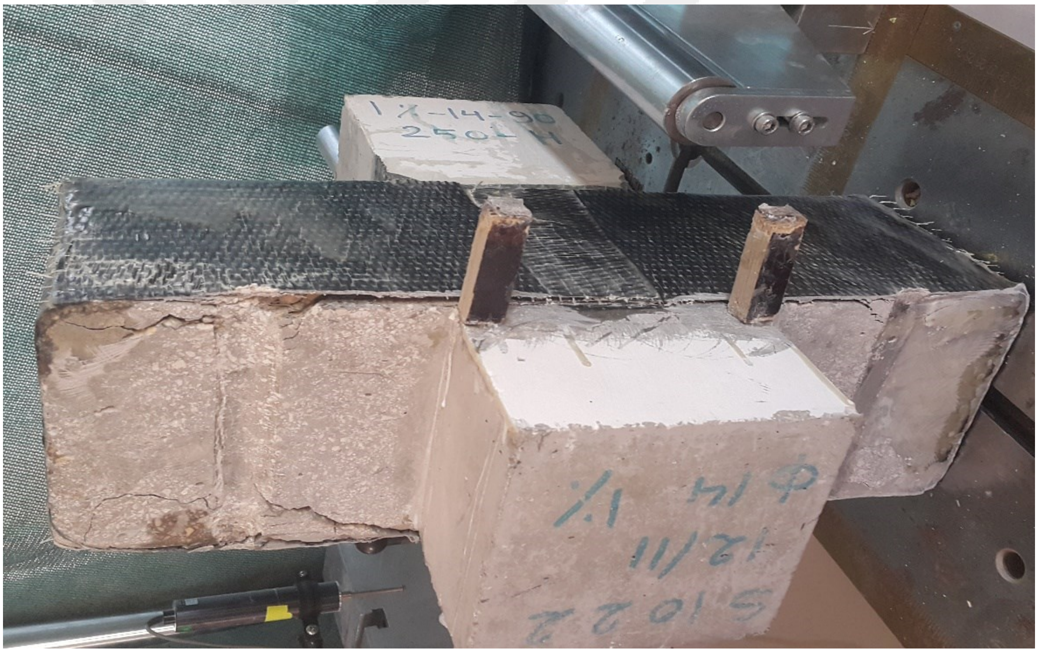

Figure 4.48 Specimen (C6-1.0-250) de-bonding failure after rehabilitation

C7-1.0-500:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. However, the corbel was reinforced by two 14mm diameter longitudinal bar in tension side while this corbel was contained 1.0% of steel fiber. Before initial loading test, the corbel had been heated until 500°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel.

In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 294kN. Furthermore, the corbel was failed in shear mode that occurred on the left and superficial shear crack on the right side as a result of initial testing; as shown in Figure 4.50. After rehabilitated of the corbel by basalt fiber fabric, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 1.04 of its original capacity. However, the failure mode had been changed after rehabilitation process and the mode of the strengthening corbel is debonding as shown in Figure 4.51. As it can be inferred from the load-deflection curve in Figure 4.49 that the maximum deflection of the corbel is equal to 2.329 mm before rehabilitation procedure and increases to 3.805 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 306 kN. Even though the first cracks did not noticed because existing of basalt fiber fabric. After first debonding was occurred the load drops suddenly then the load remains drops constant with ductile behaviour until failure of the corbel.

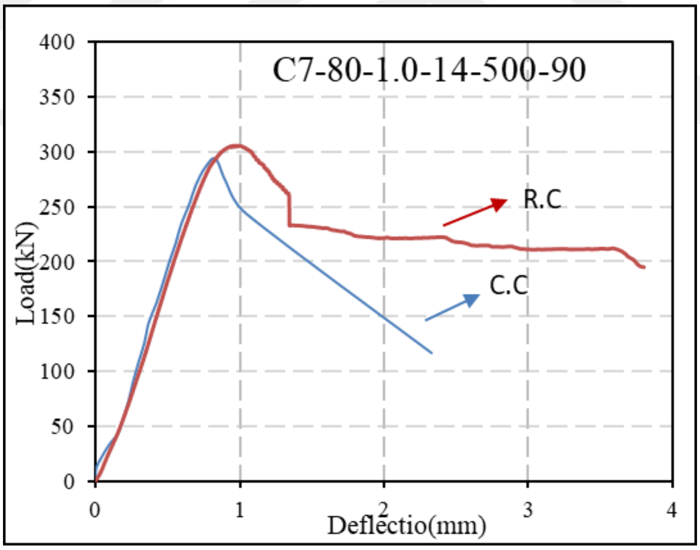

Figure 4.49 Load- deflection curve of specimen (C7-1.0-500)

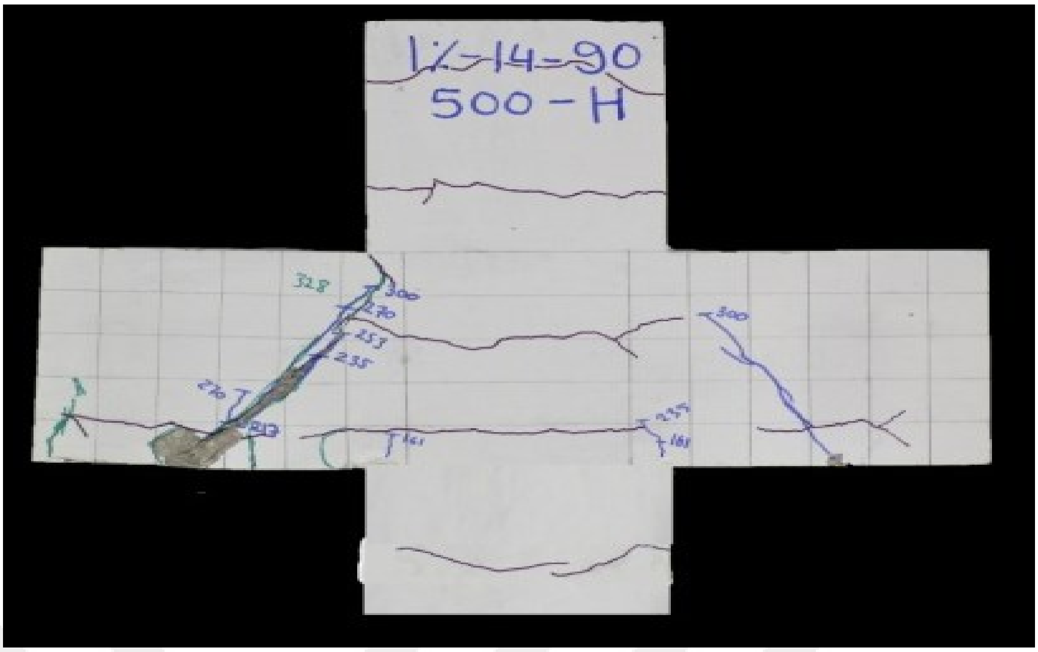

Figure 4.50 Specimen (C7-1.0-500) failure before rehabilitation

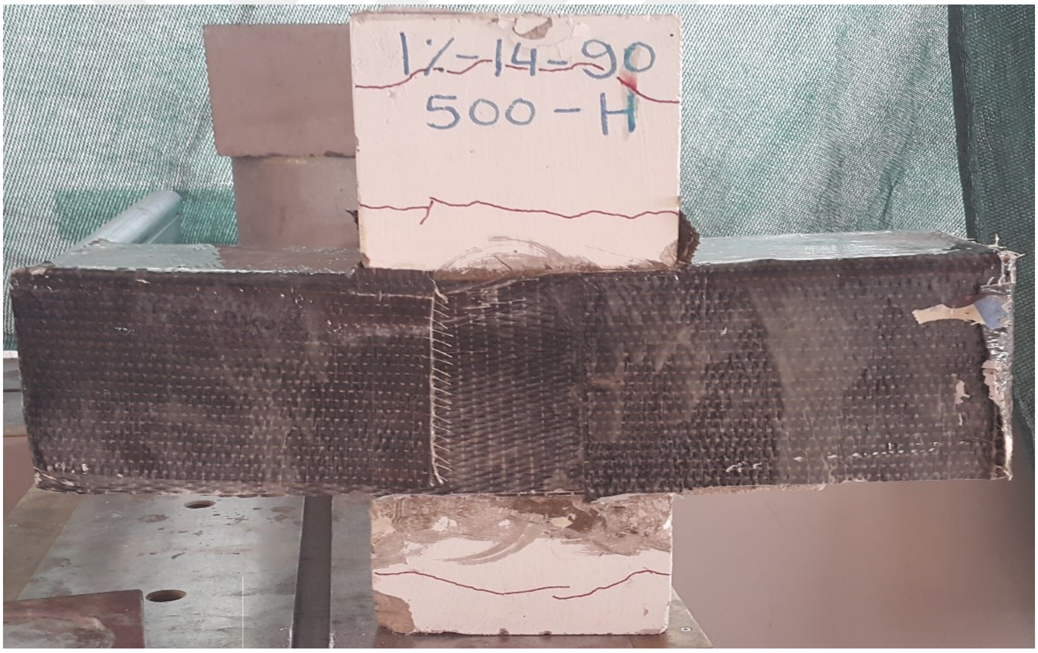

Figure 4.51 Specimen (C7-1.0-500) de-bonding failure after rehabilitation

C8-1.0-750:

This corbel was produced from high-strength self-compacting concrete, with compressive strength value of 80 MPa. the corbel was reinforced by two 14mm diameter longitudinal bar in tension side and this corbel was contained 1.0% of steel fiber. Before initial loading test, the corbel had been heated until 750°C with heating rate of 5°C/min by an electric furnace. Shear span was 90 mm for each corbel. In the initial test, the corbel had been loaded vertically until failure and the original capacity of the corbel was 183kN. The corbel had failed in shear mode that occurred on the right side and superficial horizontal crack on the left side as a result of initial testing; as shown in Figure 4.53. However, after rehabilitated of the corbel by basalt fiber fabric, it was tested according to the same loading procedure. Load capacity of rehabilitated corbel was 1.02 of its original capacity. Moreover, the failure mode had been changed after rehabilitation process and the mode of the strengthening corbel is debonding as shown in Figure 4.54. As it can be inferred from the load-deflection curve in Figure 4.52 that the maximum deflection of the corbel is equal to 1.68 mm before rehabilitation procedure and increases to 6.886 mm after rehabilitation procedure. It can be also observed from the curve of rehabilitated corbel (R.C) that the ultimate load capacity reaches to the value of 187.5 kN. As same as the previous corbels even though the first cracks did not notice because existing of basalt fiber fabric, on the other hand after first debonding was occurred the load drops suddenly. The load remains drops constant with ductile behavior until failure of the corbel.

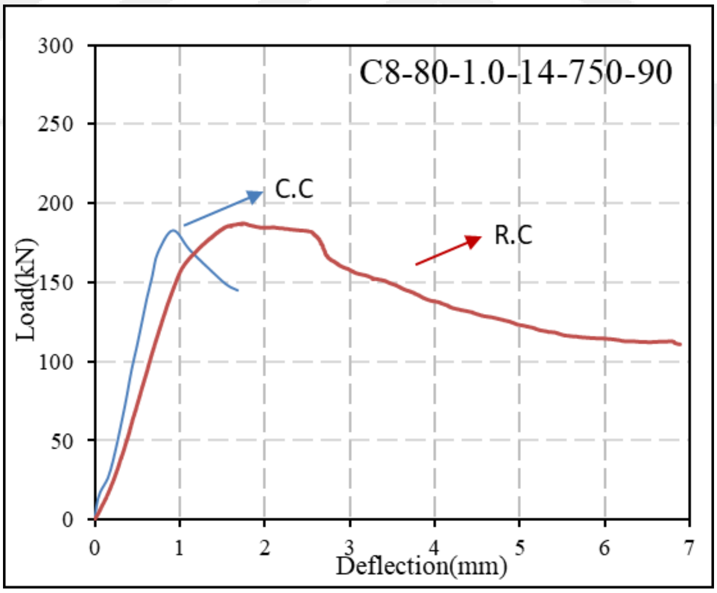

Figure 4.52 Load- deflection curve of specimen (C8-1.0-750)

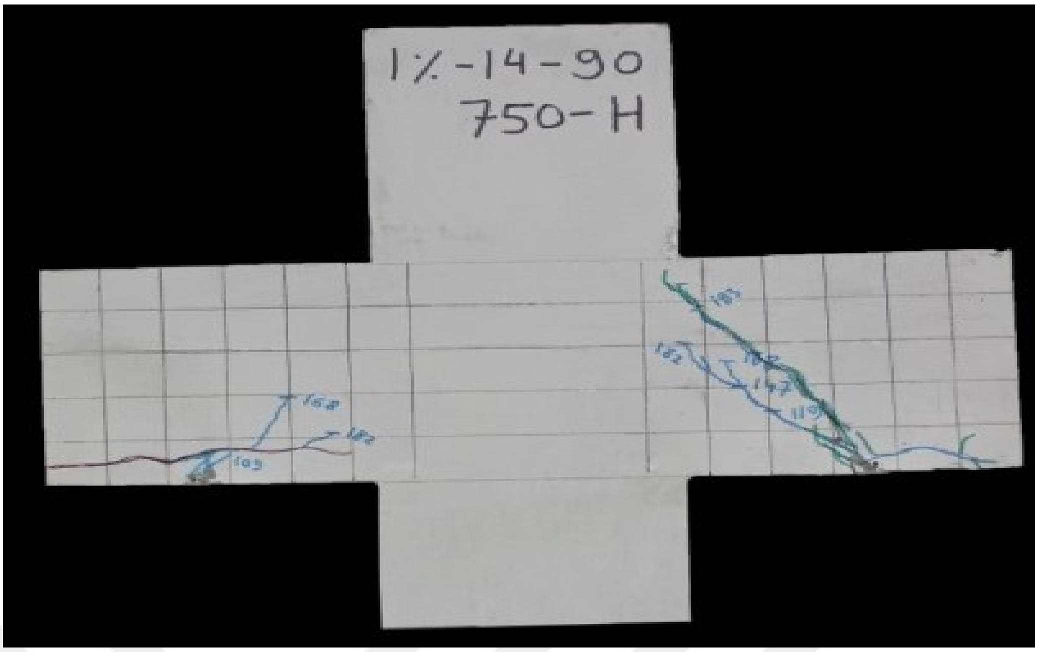

Figure 4.53 Specimen (C8-1.0-750) failure before rehabilitation

Figure 4.54 Specimen (C8-1.0-750) de-bonding failure after rehabilitation

CHAPTER 5

CONCLUSION

5.1 Conclusion

Corbels are very important structural members that are used in different constructions especially huge ones like industrial structures. Corbels are generally used in precast construction, and due to the importance of this element, several studies had been focused on the behavior of the corbels. In this study, the corbels could damage or exposed to fire attack and many reasons what lead us to rehabilitate the structural members. Huge numbers of researchers studied methods to return the damaged corbels to his original conditions. While in this experimental study an original technique is examined to restore the carrying load capacity for damaged corbels. Furthermore, very low viscosity injection resin epoxy and basalt fiber fabric had been used for the rehabilitation process. The efficiency of this method was investigated for the first time in literature. This experimental study was including and evaluating the related outputs of rehabilitated corbels which were exposed to elevated temperatures and damaged with multiple parameters such as, steel fiber ratio, different heat treatments, and steel bar reinforcements. The following subjects are presented in this thesis;

- A literature review contains past studies on rehabilitation methods and repairing methods for concrete structures.
- An experimental study on rehabilitation of high strength concrete corbels with 2-φ10mm steel bar as the main reinforcement by very low viscosity injection resin epoxy. And an experimental study on rehabilitation and strengthening high strength concrete corbels with 2-φ14mm steel bar as the main reinforcement by very low viscosity injection resin epoxy and basalt fiber fabric(BFF).
- The results of the experimental study.
- Discussion of the obtained results and explaining them.

depends on outcome results of this experimental study investigation following conclusions can be summarized.

- The results of rehabilitation using very low viscosity injection resin epoxy were not satisfying when steel fiber was 0%.
- When micro inner cracks are existent, the effectiveness of rehabilitation by very low viscosity injection resin epoxy becomes decreased, and this may be due to the injected epoxy couldn’t reach all of the cracks.
- In the high-strength concrete case, rehabilitation using only very low viscosity injection resin epoxy will not make a difference in tensile strength. This could be because the original tensile strength of the corbel -before the rehabilitation- is higher than the epoxy’s tensile strength.
- When high strength concrete corbels with steel fibers are rehabilitated by very low viscosity injection resin epoxy, the load capacity becomes close to the original values -before rehabilitation.
- The effectiveness of this rehabilitation method depends on the previous strength for specimens while basalt fabric works until debonding occur as a mode of failure, so for high strength concrete the strength after the rehabilitation is satisfied and when the carrying load is not very high the chance to restore the original value with adequate increment also.
- The de-bonding in the BFRP was happened for all corbels because the epoxy didn’t provide a perfect glue cohesion material.
- The corbels rehabilitated by very low viscosity injection resin epoxy and basalt fiber fabric recovered to 1.154 of the original corbel’s maximum carrying load capacity with a massive increase in ductility.
- The basalt fiber fabric is better as a rehabilitated material compared to very low viscosity injection resin epoxy.

- Stiffness returned back to the original value with slightly increments when the basalt fabric method was applied unlikely for the corbels that only injected method was applied.

5.2 Recommendations for Future Research

While the outcomes from this experimental study had gave significant information about the use of three different type of epoxy materials and basalt fiber fabric together to considered as one composite material, for rehabilitation the heated and damaged reinforcements concrete corbels, but still need more further investigation.

Support this experimental study with the theoretical study is desirable for clarification the structural behavior and compare the results with more parameters, different steel fiber ratio or different kinds of fiber like the basalt fiber that can add it to the mix design. In this study, the influence of parameters like the elevated temperature and the steel fiber ratio had been studied under a vertical loading on two rehabilitation methods. The study can be extended by the consideration of parameters other than temperature and steel fiber ratio, that affect the mechanical behavior of reinforced concrete corbels.

Change the glue material (low viscosity epoxy adhesive) that was used to wrap the BFF maybe can prevent the De-bonding and allowed to basalt fiber fabric the capability to failure concurrence with the concrete

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