JULY 2017 M.Sc. in Civil Engineering MUSTAFA ABDULLA MIRWAYS SHAIKHAN

UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

REHABILITATION OF THE DAMAGED GLASS-FIBER REINFORCED CONCRETE CORBELS USING STEEL THREADED RODS

M. SC. THESIS

IN

CIVIL ENGINEERING

BY

MUSTAFA ABDULLA MIRWAYS SHAIKHAN

JULY 2017

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Civil Engineering

University of Gaziantep

Supervisor

Assist. Prof. Dr. Mehmet Eren GÜLŞAN

by

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July 2017

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REPUBLIC OF TURKEY
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

Name of the thesis: Rehabilitation of the Damaged Glass-Fiber Reinforced Concrete Corbels Using Steel Threaded Rods

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Exam date: July 7, 2017

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Mustafa Abdulla Mirways SHAIKHAN

ABSTRACT

REHABILITATION OF THE DAMAGED GLASS-FIBER REINFORCED CONCRETE CORBELS USING STEEL THREADED RODS

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M.Sc. Thesis, Civil Engineering
Supervisor: Assist. Prof. Dr. Mehmet Eren GÜLŞAN
July 2017
99 pages

The aim of this thesis is to investigate the efficiency of using threaded rods in a confinement system to rehabilitate damaged glass-fiber reinforced concrete corbels. Some of the specimens were treated with crack repair epoxy before confining for further enhancement. This study is the first experimental investigation that studies rehabilitating reinforced concrete corbels using threaded rods and confinement technique. A total of 19 double sided damaged corbels with different mechanical properties and test parameters were used in the investigation. Differences in specimens are shear span, fiber percentage, diameter of main reinforcement, and concrete strength. All corbels have the same dimensions. Four different rehabilitation styles were tried for the investigation. The rehabilitated specimens were loaded under vertical load until failure. Test results show that the proposed rehabilitation techniques enhanced the bearing capacity of the corbels and improved the ductility remarkably.

Keywords: Rehabilitation, Corbels, Load Bearing Capacity, Ductility, Threaded Steel Rods, Confinement, Glass Fiber Reinforced Concrete, Repair Epoxy.

ÖZET

HASAR GÖRMÜŞ CAM FİBER TAKVİYELİ BETONARME KISA KONSOLLARIN ÇELİK GİJONLARLA REHABİLİTASYONU ÜZERİNE BİR ARAŞTIRMA

SHAIKHAN, Mustafa Abdulla Mirways
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Tez Yöneticisi: Yrd. Doç. Dr. Mehmet Eren GÜLŞAN
Temmuz 2017
99 sayfa

Bu tezin amacı hasar görmüş cam lif takviyeli betonarme kısa konsolları güçlendirmek için gijon kullanarak oluşturulan sargı sisteminin verimliliğini araştırmaktır. Kısa konsol numunelerinin bir kısmı sargı sistemi ile iyileştirmeden önce çatlak tamir epoksisi ile tamir edilmiştir. Bu çalışma çelik gijonlarla ve sargılama tekniğiyle kısa konsolların rehabilitasyonu üzerine yapılan ilk çalışmadır. Araştırmada farklı mekanik özelliklere ve test parametrelerine sahip 19 adet 2 kollu hasar görmüş kısa konsol kullanılmıştır. Numunelerdeki farklılıklar kesme açıklığı, fiber yüzdesi, asal donatının çapı ve beton mukavemetidir. Bütün kısa konsolların boyutları aynıdır. Araştırma için 4 farklı rehabilitasyon konfigurasyonu denenmiştir. Rehabilite edilen kısa konsol numuneleri göçene kadar dikey yük altında yüklenmiştir. Deney sonuçları önerilen rehabilitasyon tekniklerinin kısa konsolların yük taşıma kapasitelerini arttırdığını ve sünekliklerini önemli ölçüde iyileştirdiğini göstermiştir.

Anahtar Kelimeler: Rehabilitasyon, Kısa Konsollar, Yük Taşıma Kapasitesi, Süneklik, Çelik Gijonlar, Sargılama, Cam Fiber Katkılı Beton, Tamir Epoksisi

To My Lovely Family

ACKNOWLEDGEMENTS

My sincerest gratitude first goes to my supervisor Assist. Prof. Dr. Mehmet Eren GÜLŞAN who expertly helped and guided me in every step I made. He was more than a supervisor for me, he was a leader and a source of motivation. He guided me always to make the right step. I will always feel grateful for him for his kind and respectable personality and sharing his knowledge and great ideas with me. Finally, I'd like to mention a great side of his nice personality which always amazed me that he is so careful about his word and he respects the time so much.

Also, I'd like to thank Prof. Dr. Abdulkadir ÇEVİK for his help and guidance, he helped me to see my path better to complete my thesis.

I would also like to thank all people who helped me during my experimental works. I might not complete my experimental works without their support.

Here, I want to thank the dearest people, my great family, my parents, brothers, and fiancé. They always encouraged me to reach my goals and motivated me at the hardest times. I'd like to say to my parents, thank you for all of the years that made me reach this level today.

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LIST OF SYMBOLS

a Shear span of corbels

A_n extra main steel provided for horizontal loads.

A_s Cross sectional area of main reinforcement

A_{vf} area of reinforcement that crosses that assumed shear plane.

b Width of corbel

d Effective depth for corbels

h Height of corbel

f'_c Cylindrical compressive strength of concrete

ρ Reinforcement ratio

ϕ Capacity Reduction Factor

V_c Shear strength supplied by the concrete

f 'c Compressive strength of the concrete

fck Compressive strength of the concrete

fcu Compressive strength of the concrete

bw Web width

d Effective depth

V_u Shear force

M_u External moment

ρ_1 Longitudinal reinforcement proportion

ρ_w Longitudinal reinforcement proportion

N_{ED} Axial force

A_c Cross section area of the member

λ Modification factor for the purpose of reducing the mechanical characteristics in the situation of light weight concrete.

Z Lever arm

fy Tensile strength of the steel

f_{ywd} Tensile strength of the steel

f_{yt} Tensile strength of the steel

V_s Shear strength supplied by shear reinforcement

V_u Vertical ultimate load

Ø Factor of safety

H/V horizontal to vertical loads ratio

CHAPTER 1

INTRODUCTION

1.1 General

Corbels are short cantilevers project from the face of the columns in order to support big concentrated loads such as loads caused by heavy precast beams -which are commonly used in industrial constructions-, corbels could be constructed monolithically with the members which are emerging from, like, columns and walls. (Layla A. Gh. Yassin et al, 2015).

Corbels are used in reinforced concrete structures and particularly in precast reinforced concrete elements that have a main function to transfer the vertical and horizontal forces to the principal members.

Commonly, corbels are designed by following one of two procedures where, the first procedure depends on the ACI code, and the second procedure, depends on Strut-and-Tie modelling (STM) –STM is a widely developing method as a design way used for shear critical structures as well as it is used for other troubled areas in concrete structures-. It is noticeable that both of the two procedures leads to get same results inside the application range of the ACI code.

Shear strength of normal strength concrete were noticed to be a function of, shear-span-to-depth ratio (*a/d*), reinforcement ratio, the strength of the concrete ($f_c^{/}$), and the ratio of the load components –horizontal and vertical- that is applied .(Kriz and Raths, 1965) and (Mattock et al. 1976).

High strength reinforced concrete (HSC) corbels have a different situation, where, the steel yields before failure occurring, but, in some situations, the failure happens before the steel yielding, however, even in this case, the failure is not expected to occur suddenly (Yook-Kong Yong and P. Balaguru, 1994).

From 1980 onward, the application of high strength concrete has steadily increased to cover all aspects of structural construction such as high-rise buildings, bridges, columns, piles etc.

1.2 Rehabilitation of Concrete

Rehabilitation of the damaged and troubled concrete structures have been a highly focused branch in the constructions field over the world, the funds spent for the purpose to rehabilitate the concrete structures passed funds of building new constructions (Chau-Khun Ma et al, 2017).

Different methods could be used for treating damages of concrete structures, for instance, decreasing the structural duty, destruction, and rebuilding of the structure completely or saving it from moreover damages by rehabilitating techniques (S. Macdonald (Ed.), 2008). Due to reasons regarding time and finance, the rapid rehabilitation methods are the most desired choice (Chau-Khun Ma et al, 2017).

Researches confirmed that using external confinement is an active technique to address the damages and recovering the primer characteristics of the concrete columns (Y.F. Wu et al, 2014), (Y.W. Zhou et al, 2015), (M. Panjehpour et al, 2016) and (A. Peled, 2007). Also, an important point to be referred to is, the confinement could recover the ductility of the failed member, according to past studies (D.S. Gu et al, 2010), (R.D. Iacobucci et al, 2003), (D.E. Lehman et al, 2001) and (D.R. Stoppenhagen et al, 1995).

Externally confinement using steel has been appointed as one of the most active techniques to rehabilitate concrete structures, the studies showed that stainless steel confining rises the plastic deformation obviously, rises the energy absorbing performance of the structure, and rises the shear strength of the member, as shown in figure (1.1).

1.3 Research Significance

The main idea of this study was to repair the corbels used in industrial constructions which widely face the problem of corbels cracking. External confinement technique was used in the study –steel confining technique- as well as injection materials (Epoxies) were used to repair the damaged parts and strengthening them up to the original limits –or higher- as an effective solution to the problem.

Figure 1.1 Steel-confined column (Source: http://www.edac.biz)

Some previous studies where about external confinement as a rehabilitation technique, steel confinement was used for the purpose of rehabilitation and strengthening concrete columns, this study will focus on steel confinement for damaged concrete corbels beside treatment with specific injection materials to repair the damaged zone and make the structures –the corbels- in safe side when they are subjected to the loads failed them previously. Therefore, this study will enrich the information about concrete corbels rehabilitation as well as steel confined technique through an experimental investigation.

1.4 Research Objectives

This research studies an experiment to rehabilitate damaged concrete corbels with different compressive strengths which were failed previously the effect of diagonal shear force.

This thesis is aiming studying the results of the using steel confining technique and injection techniques to repair and strengthen the damaged concrete corbels, we can browse the chief objectives of the research as the following points:

1- Studying the efficiency of the used techniques by studying Load – Deflection curves of the Rehabilitated specimen.
2- Studying the efficiency of the injected materials by following the occurred crack patterns.

3- To study the mechanism of load transferring within the new composite structures –Steel Confined Reinforced Concrete structures-.
4- Comparing the properties of rehabilitated specimen with those of original ones.

1.5 Thesis Layout

In Chapter 2, the literature review for Concrete Rehabilitation was presented. In addition to the previous studies made about Concrete Rehabilitation Techniques and their activity.

In chapter 3, Details of materials and their properties were presented, which were used in this experiment.

Chapter 4 gives the experimental results and shows the response of the tested corbels and discuss the cracking patterns and the effect of Steel Confinement and Injection Techniques.

In Chapter 5, conclusions are presented with recommendations for further studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Rehabilitating and Strengthening Concrete

Concrete is the most commonly used material in constructions because of its advantages that make it the favorite building material compared to other building materials. However, concrete –as any other material- has its own defeats, for example, cracks and corrosion of reinforcement steel. When the reinforcement steel is subjected to the corrosion, it is necessary to cure the affected area or replacing the whole structure –in some situations-.

Techniques of rehabilitation depend on the reason, nature and the degree of the damage, as well as depend on understanding the further results of the technique, and the durability of the used materials to resist the hardness of the structure situation.

Different ways could be used to cure faults, for example, rebuilding a section or the structure completely, destruction, reducing the structure duty or choosing the option of rehabilitation methods. (S. Macdonald (Ed.), 2008).

Strengthening of the concrete should be also regarded when a fault appears in a concrete structure, some important factors are for paying attention during strengthening as the situation of the fault, acting loads on the structure as well as the geometrical conditions of the fault zone. Occasionally, it is not possible to apply strengthening because due to difficulty of reaching the fault place that needs for strengthening.

Because of the wide need for strengthening of concrete, many studies focused on the importance of this field as well as the effective techniques could be used for this purpose.

Sometimes, using a technique to strengthen a specified side can cause a weakness in other sides. For instance, using ultra-high performance fiber reinforced concrete (UHPFRC) to enhance RC beams causes changing in ductility properties of concrete (M.A. Al-Osta et al, 2017).

When the decision of strengthening is taken, every mode of failure within the structure should be regarded. Strengthening for flexural could result a shear failure instead of the wanted capacity of load bearing. Another point to be regarded is that whole structure must be considered and not only the strengthened member, because if the strengthened member is a critical member, another member may become critical, where, the change in stiffness within a system of undetermined structure needs to analysis the all system again.

The mode of crack appeared in the RC beam determines the failure mode and the technique necessary to improve the structure, for instance, if raising the flexural strength is desired using FRP, applying will be at the tension zone. Whereas, if raising shear -as well as torsion- capacity is desired using FRP, applying will be at the faces of the RC beam. (Muhammad Imran et al, 2013).

2.2 Confinement Technique

This section is to show a literature review on techniques of confinement applied to concrete structures. Repairing failed concrete structures started to be one of the widely spreading fields in the construction sector around the world, so, different techniques were used for this purpose. Technique of confinement is one the common ways to strengthen and repair damaged concrete structures.

Confinement Technique has several types according to the used materials and the installing mode, for example: concrete confining, steel confining, ferrocement confining and fiber reinforced polymer (FRP) confining. The confining method is chosen according to the kind of the damage, the results desired and economical regards.

The addition of the externally confinement materials improves the properties of structures to resist flexural, tensile and shear forces developed in the structure. Corbels behave as deep beams which could be damaged due to shear or flexural failure.

However, the shear failure will be regarded in this study, since the developed diagonal shear is the controlling failure mode in these structures.

The techniques of rapid curing the faults of concrete structures are the most desirable because of regards about economy and time factors. Many studies have showed the efficiency of externally confinement technique as a method to recover the original capacity of the concrete columns (Yu-Fei Wu et al, 2014), (Y.W. Zhou et al, 2015), (M. Panjehpour, 2016), (A. Peled, 2007) and (A. Ilki et al, 2008).

Another important point that is referred to in some previous studies is that confinement technique could lead to recover the ductility of the damaged structure also (D.S. Gu et al, 2010), (R.D. Iacobucci, 2003), (D.E. Lehman et al, 2001) and (D.R. Stoppenhagen et al, 1995).

To exhibit the efficiency of confinement to rise concrete capacity, a study by (Mahmoud F. Belal et al, 2014) has showed that using steel jacketing can improve the capacity of column at least 20%.

Jacketing technique –as a confining method- can up the strength and ductility of RC cylindrical columns (Rahul Dubey and Pardeep Kumar, 2016).

Different jacketing ways using different materials have been depended to modify concrete members. First example, conventionally vibrated concrete (S.Z. Yuce et al, 2007). Steel is also used for the purpose of jacketing (L. Sarno et al, 2006; D.A. Bournas and T.C. Triantafillou, 2009). Another material, FRP, is a widely used in the same technique (D.A. Bournas and T.C. Triantafillou, 2009; S.K. Bhattacharyya et al, 2012; C.E. Chalioris, 2008). Also Ferrocement is used for jacketing (A.B.M.A. Kaish et al, 2012), RC jackets (E.S. Júlio et al, 2003; C.G. Karayannis et al, 2008; Eduardo N. B. S. Julio et al, 2005).

RC beams bonded using continual U jackets of carbon or glass fiber textile with epoxy combination could decrease the brittleness of the member, tensile strain of the used stirrups, the size of the cracks due to shear when the member fails. (Long Nguyen-Minh and Marian Rovňák, 2015).

2.3 Injection Technique

During the revolution of the concrete repairing technologies, injecting was appeared as an effective technique to resist the problem of cracks developed in the concrete structures. Epoxy, cementitious materials, polyesters, silicon materials and chemical materials are the widest used injecting materials.

The chief purpose of using injecting rehabilitation technique is filling the spaces of cracks and bonding the two sides of cracks (ACI Committee E706). This technique is used to close not-moving cracks, for instance, shrinkage cracks as well as settlement cracks which are stabilized. After the cracks are filled with resin, it –the resin- forms a polymer spigot which closes the spaces of cracks and protect it against water, sulphates, chlorides, carbon dioxides as well as other liquids and gases. In addition to previous advantages, the filler is also contribute in reduction of spoilage of the concrete due to freeze-thaw action and corrosion of steel. Another advantage of fillers, they could be used as a structural rehabilitation of the cracks because of the adhesive characteristics. In spite of there is many resins have strengths larger than of concrete, however, guarantying a structural rehabilitation depending on complete filling by gravity is hard. If structural rehabilitation is desired, and the situation is critical, pressure injection is the better choice (ACI Committee E706).

(Cemille A. Issa, 2007) showed the efficiency of injecting technique through an experimental study, in the experiment 15 concrete cubes was used, 6 cracked without rehabilitation, 6 with cracks bonded suing gravity filled epoxy and 3 which are crushed under compression stress. It was noticed that cracked cubes have lost their compressive strengths up to 40.93% of the original strengths, however, when the epoxy filling was applied correctly, the decrease of the strengths were changed to 8.23%.

Epoxies are preferred because of many characteristics such as the perfect adhesion to concrete, long-range resistance to hard environmental conditions, great bonding strength, and easiness of applying and lower shrinkage through curing. (Donald M. Harrison, 2003).

Epoxies are commonly consist of two parts, first, part A, which consist of the resin which is produced chemically. The wide range of used resins in the present time are produced by the reaction of Epichlorohydrin with Pisphenol A, the characteristics of the resin could be varied according to the proportion of the reactants and the procedure of the manufacturing. The other part is part B, it could be defined as the hardener of the resin, in spite of existing a large range of hardeners which could be used with the resin, and the most popular ones are Amines, Aromatic amines and Particularly

Aliphatic Amines. When the parts A and B are mixed, hardening of the epoxy begins through a chemical reaction.

2.4 Previous Studies on Rehabilitation and Strengthening of Concrete

(Bentz et al, 2010) showed the efficiency of transverse reinforcement proportion on the shear capacity of deep beam through an experimental study. The results of the experiment showed that raising the proportion from 0% to 1% leads to raising the the shear capacity 76%, whereas, raising it up from 0% to 2% results in growing the shear capacity to 82%.

(Chau-Khun Ma et al, 2017) showed that the confining technique could be used as a very efficient way to repair the concrete because of the ability to recover the original capacities of failed members.

(Guoqiang Li and Amanuel Ghebreyesus, 2006) made an experiment to examin the efficiency of UV curing E-glass fiber reinforced vinyl ester to rehabilitate failed reinforced beams, they found out that using the mentioned technique is efficient to rehabilitate shear as well as flexural failures. They also found out that making the shear rehabilitation with using this technique results in raising flexural strength.

UV curing E-glass fiber reinforced vinyl ester combinations was also employed for fast joining of composite pipes (Peck JA et al, 2004) [9], for rehabilitating of laminated beams failed due to low velocity impact (Li G, Pourmohamadian N et al, 2003) as well as for enhancing failed RC columns (Li G, Hedlund S et al, 2003).

(Jamal A. Abdalla et al, 2016) showed in their study that strengthening shear deficient reinforced concrete beams externally by aluminum alloys results in increasing shear capacity between (24%-89%) compared to the un-strengthened ones, figure (2.1).

At last 25 years, many studies about improving shear capacity of reinforced concrete beams using exteriorly bonded CFRP and GFRP combinations were presented, for example, (G.J. Al-Sulaimani et al, 1994; A. Khalifa and A. Nanni, 2000; G. Monti, 2007; A. Belarbi et al, 2012).

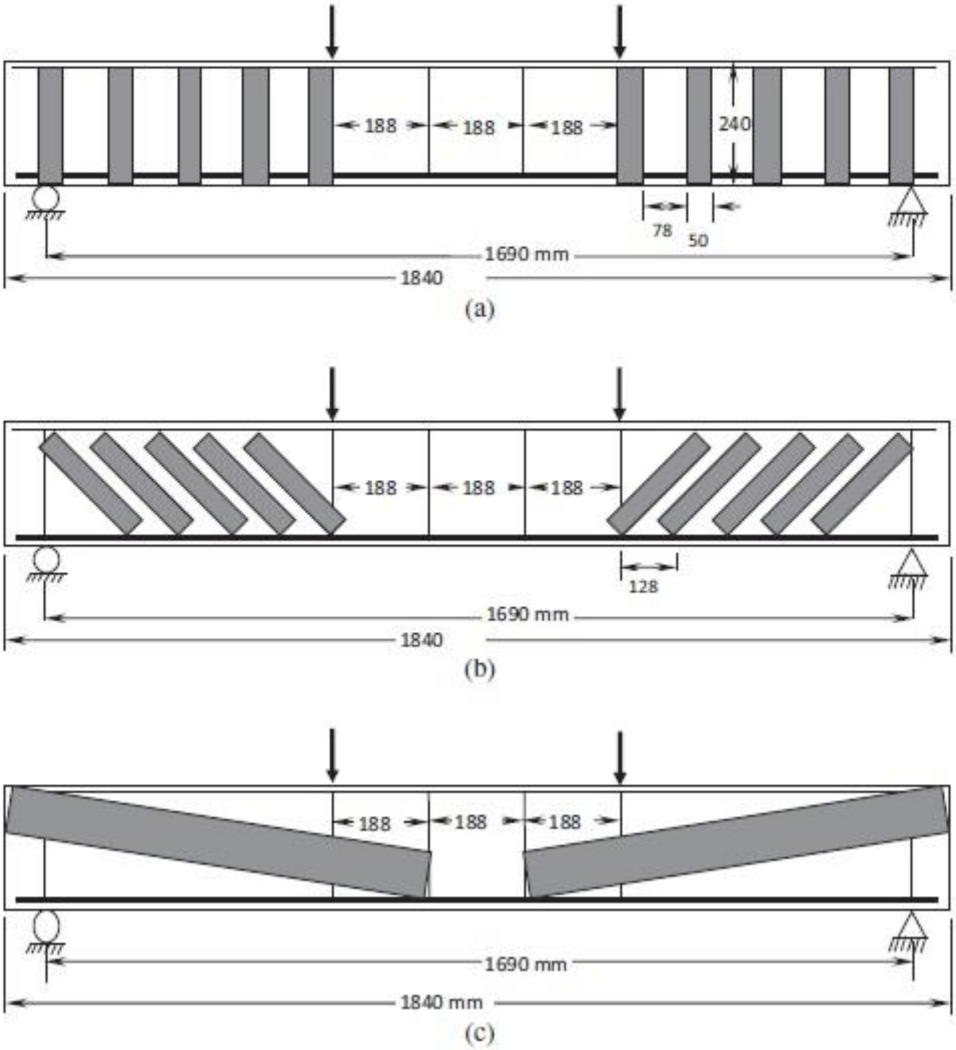


Figure 2.1 Details of three styles of strengthening with aluminum alloys

(Jamal A. Abdalla et al, 2016)

(Rahul Dubey and Pardeep Kumar, 2016) studied the efficiency of using self-compacting concrete (SCC) for jacketing cylindrical columns as a modifying extra. Basing on the results of the experimental study, they obtained that (SCC) is an efficient material for modification. They jacketed members with SCC reinforced with mild steel welded wire mesh (WWM), figure (2.2), and they obtained that the combined jackets rises the load capacity of members. Also, the ultimate strain was enhanced.

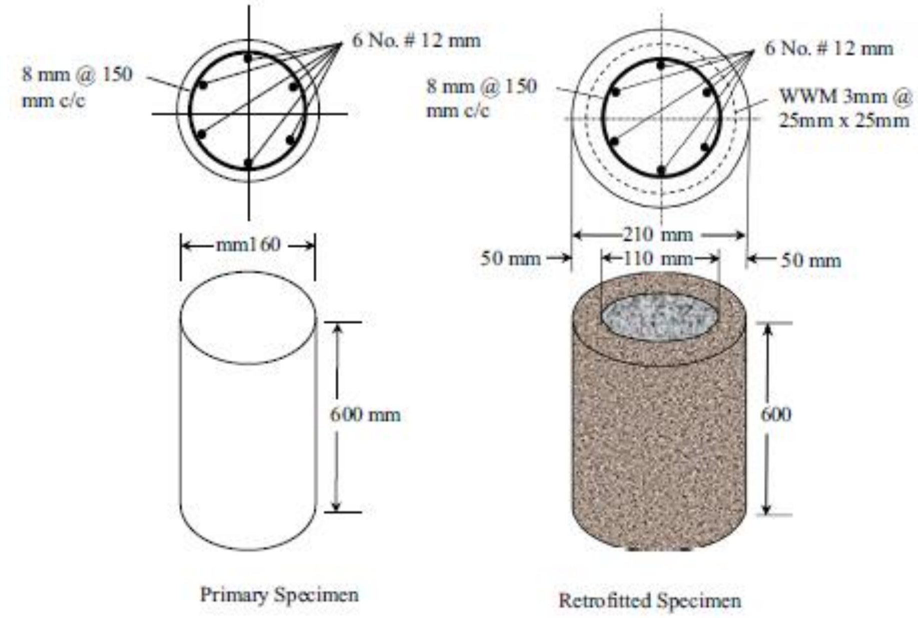


Figure 2.2 Scheme of jacketing with SCC and WWM

(Rahul Dubey and Pardeep Kumar, 2016)

(Yan Xiao et al, 2003) made a study to show the effectiveness of the partial stiffened rectilinear steel jackets to improve the shear capacity of columns. They obtained that the technique not just prevents the shear failure because of brittleness, but rises the ductility of the members seriously that makes ultimate drift ratio pass the limit of 8%.

(B.B. Adhikary, H. Mutsuyoshi, 2006) showed in their study a different techniques of improving beam strength involving exteriorly set steel stirrups, steel strips, small steel plates and steel brackets. Obtained results were that steel plates set with epoxy gained shear capacity up to 72%, whereas the exteriorly set steel stirrups gained up to 117% compared to the original member.

(Altin et al, 2005) used steel plates on the sides of reinforced concrete T-beams to rise the shear strength, the steels were bonded to the member with epoxy within the shear span of the member web. They obtained that the technique increased the member capacity, stiffness as well as ductility. Shear capacity of the member was risen between (88%-98%) compared to the original member.

While, (R.A. Barnes, G.C. Mays, 2006) showed In their study the efficiency of strengthening rectangular and T-beams using steel plates and steel links bonded by epoxy, they found out that shear capacities of rectangular sectioned members were risen between (30%-194%) while the T-sectioned members were risen between (5%-88%) compared to the un-strengthened ones.

(Zeidan et al, 2011) made an experimental study on 7 concrete beams with CFRP bars for reinforcement in order to observe their efficiency on the shear performance of the members. They obtained that raising the reinforcing proportion of 0.105% up to 0.210 results in increasing shear strength up to 11%.

(Branes, 2001) showed through a study using concrete beams, that adding steel plates to the exterior surface of the members can supply a good upgrading to the members, the provided plates which are placed to the web of the members provided them with a large shear strength, the study has examined and used two techniques to place the plates to the members, which were adhesive bonding as well as bolting.

(Ashour, 2006) made an experimental study using 12 GFRP reinforced concrete beams to examine the efficiency of the longitudinal reinforcement on the shear performance of members with varied dimensions and strengths. Normal strength concrete was used for a group of 6 samples, for each group, 3 varied depths of (200,250 and 300) mm were depended. The results of the first group referred to that raising the longitudinal reinforcement proportion for the 200 mm depth members from 0.23% up to 0.45% rises the shear strength up to 39% of the original strength. While, raising the proportion for the 250 depth members from 0.17% up to 0.71% rises the shear strength to 47%. Whereas, raising the proportion for the 300mm depth members from 0.14% up to 0.86% rises the shear strength up to 52%. In the other group of the beams, high strength concrete was used, raising the proportion of longitudinal reinforcement for 200mm depth members from 0.23% to 1.39% resulted in upgrading shear strength up to 94.4% of the original strength, while raising the proportion for the 250mm depth members from 0.17 to 1.06% rises the shear strength up to 89.7%. While, raising the proportion for the 300mm depth members from 0.28% up to 1.15% rises the strength by 20%.

(Li et al, 2013) used ferrocement confinement including diagonal renforcement as a repair method for interior beam column joints, figure (2.3). The method was used to repair the damaged cover of concrete with no increase in dimensions of the structure as well as it is used as an improvement of seismic properties of concrete. The used material for the damaged cover replacement was Ferrocement involving wire mesh and mortar, it was used in order to improve shear strength of the joints. For the purpose of reduction of the forces moved to the core of the joint, diagonal reinforcement were installed. Results referred to that the suggested method of rehabilitating could increase the joint's seismic properties by using ferrocement beside high strength mortar.

Figure 2.3 Interior beam-column joint (Li et al, 2013)

(Li et al, 2013) found that mortar is the chief effective factor that affects the improved performance of the samples. While, anchor bolts set fixing ferrosement to the concrete and the general performance. The sketch of the rehabilitation is of the specimens are as shown in figure (2.4) and figure (2.5).

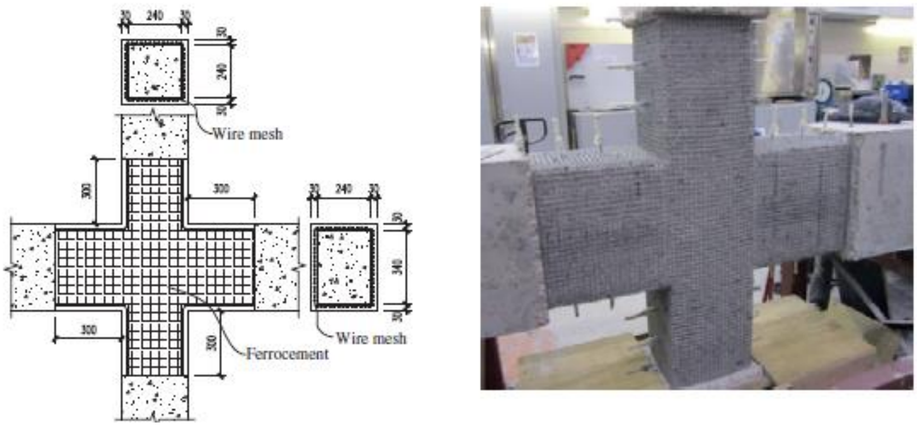


Figure 2.4 Sketch of Ferrocement wrapping (Li et al, 2013)

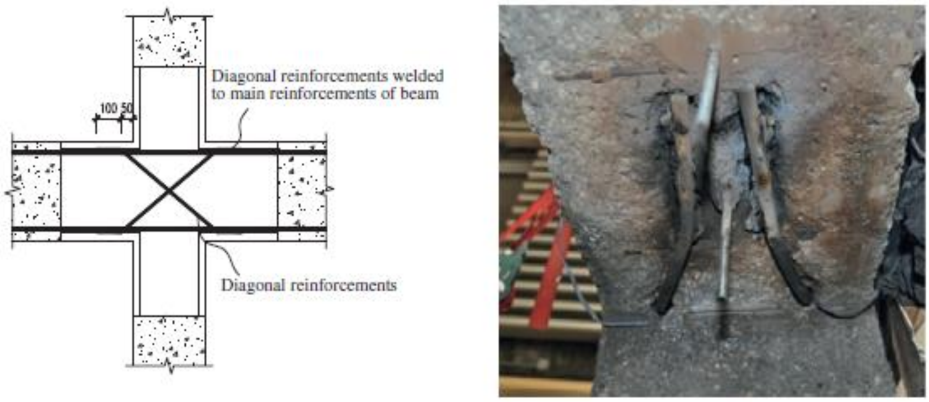


Figure 2.5 Sketch of Diagonal reinforcements (Li et al, 2013)

(Jongsung Sim et al, 2005) performed a study that deals with using basalt fiber to strengthen concrete beams by making different experiments regarding durability, mechanical characteristics and flexural improvement. Basalt fibers of 1000 MPa used made of approximately 30% carbon with 60% S-glass fiber. The test results showed that basalt fibers enhanced yield and ultimate strengths of the members up to 27% of its original strength, the upgrading proportion of the strength depends on the layers applied.

(Lee HS., 2002) reported that FRP materials are widely used for the purpose of repairing and improving the strength of the concrete members, fire resistance should be regarded when there is a probability to be subjected to high temperature –fire-conditions, where, the FRP materials lose their high strength characteristics fast under such conditions. Also, the epoxy used as matrix or at producing operation could cause seriously poisonous fumes.

(Berozashvili M., 2001) reported that basalt fibers show stronger tensile performance than E glass fibers, better strain compared to carbon fibers, also, they show a good performance regarding chemical attacks, fire as well as poisonous fumes, where they cause less poisonous fumes.

(Razaqpur et al., 2004) used CFRP bars an internally reinforcement of concrete beam in an experimental study, they showed that raising the reinforcement proportion from 0.25% up to 0.5% enhances the shear capacity by 26% of the original strength, another raising the proportion from 0.5% to 0.63% enhanced the shear strength by an additional 7.7%. Whereas, raising the proportion from 0.63% up to 0.88% improved the strength by 12%.

(D.A. Bournas and T.C. Triantafillou, 2008) presented in their study the effect of using varied near-surface mounted NSM materials of reinforcement to strengthen RC concrete columns under seismic loads, they obtained that NSM-FRP and stainless steel reinforcement could be regarded as an active solution to improve flexural capacity of the members.

In fact, using NSM reinforcement technique was appeared first in Europe for steel rebars by the recent 40s of the 20_{th} century (Asplund 1949).

(Hadi Baghi et al, 2016) studied the effectiveness of using Hybrid Composite Plates (HCP) for improving shear capacity as well as stiffness of RC beams, figure (2.6) and figure (2.7). HCPs are thin plates made by using Strain Hardening Cementitious Composites (SHCC) that reinforced with CFRP laminates. They found out that the technique is efficient to rise the shear strength of the members. The load capacity of the strengthened RC rectangular and T- beams was improved by proportions of 105% and 157% of the original ones respectively.

For the purpose of bonding CFRP laminates and the SHCC plate, openings are made within the surface of the plate and CFRP laminates are fixed into these openings and bonded to the SHCC using a suitable epoxy.

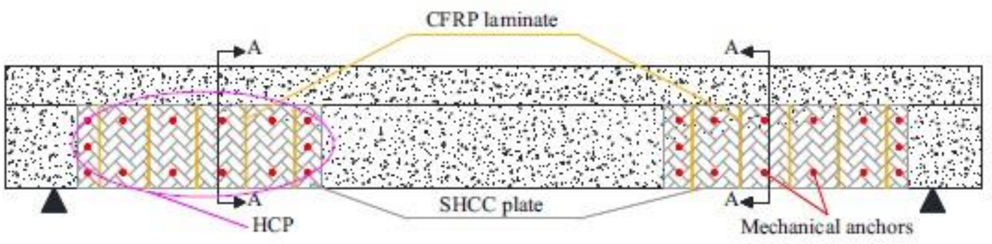


Figure 2.6 Scheme of (HCP) for shear strengthening of RC beams

(Hadi Baghi et al, 2016).

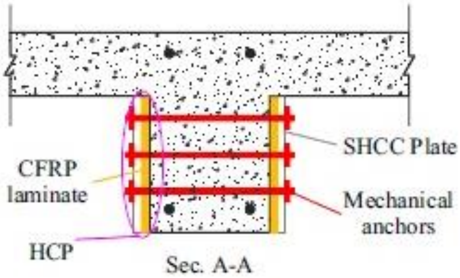


Figure 2.7 Cross sectional scheme of (HCP) for shear strengthening of RC beams (Hadi Baghi et al, 2016).

(Peter Sabol and Sergej Priganc, 2013) studied strengthening RC members using near surface mounted NSM technique, they used ATENA software to obtain the outcomes of numerical analysis, the results demonstrated the matching with the experimental results of a study by (J.A.O. Barros and S.J.E. Dias, 2006).

2.5 Shear Failure

Shear failure is a one of RC failing modes, the shear failure of RC beams is properly known as "Diagonal Tension Failure", despite of the wide studies regarding this mode, but it is not fully understood and it’s hard to expect its happening precisely. Shear stress could be developed within beams as a result of bending loads (Flexural Shear Stress) or twisting loads (Torsional Shear Stress).

When diagonal tension cracks start to happen in the web of the beams without web reinforcement, they turn into a critical and unstable situation (ASCE-ACI Committee 426).

Shear failure of RC members is known of having a complex mechanism because of existing varied factors have effect of this mechanism. Many experimental and numerical studies have been done to clear that complex mechanism, especially that which is regarding diagonal tension failure of RC members that unreinforced for shear, for instance, (Kyoung-Kyu Choi et al, 2009), (Li yu et al, 2012; Tao Zhang et al, 2016).

Shear transfer mechanism is depends on different factors as the size of aggregate (Walraven JC., 1981), strength of the concrete (Vecchio FJ and Collins MP, 1986; Loov RE and Peng L., 2000).

Two very remarkable factors that affect the shear failure are size of the member as well as the a/d ratio (Span-to-Depth) ratio (CEB, 1997).

Regarding the complicated mechanism of shear resistance, codes of designing supposed the shear capacity of members from two mechanisms which are shear capacity without web reinforcement V_c and the shear capacity from web reinforcement V_s as shown in figure (2.8).

Approach	Shear Strength, Vc	Shear Strength, Vs
BS 8110 - 97	$V_c = \frac{0.79}{\gamma}\left[\left(\frac{100A_s}{b_v d}\right)^{1/3} \times \left(\frac{400}{d}\right)^{\frac{1}{4}} \times \left(\frac{f_{cu}}{25}\right)^{1/3}\right] bd$	$V_S = \frac{A_{sv}}{S_v} \times 0.95 f_y d$
EC 2 - 2004	$V_{RD,C} = \left[0.12\left(1 + \sqrt{200/d}\right)(100\rho_1 f_{ck})^{1/3} + \frac{0.1N_{ED}}{A_c}\right] bd$	$V_{RD,S} = \frac{A_{sw}}{S} Z f_{ywd}\, Cot\theta$
ACI 318 - 08	$V_c = \left[0.16\lambda\sqrt{f_c'} + 17\rho_w \frac{V_u d}{M_u}\right] b_w d$	$V_S = \frac{A_V f_{yt} d}{S}$

Figure 2.8 Varied approaches for shear designing (A. Acheampong et al, 2015)

Where:

Vc: Shear strength supplied by the concrete

f'_c, f_{ck}, f_{cu}: Compressive strength of the concrete

b_w: Web width

d: Effective depth

V_u: Shear force

M_u: External moment

ρ_1, ρ_w: Longitudinal reinforcement proportion

N_{ED}: Axial force

A_c: Cross section area of the member

λ: Modification factor for the purpose of reducing the mechanical characteristics in the situation of light weight concrete.

Z: Lever arm

f_y, $f_{ywd,}$ $f_{yt:}$ Tensile strength of the steel

V_s: Shear strength supplied by shear reinforcement

The shear crack propagation in flexural concrete members is highly affected by span-to-depth proportion (a/d) and could be regarded a chief factor that controls shear failure in these members especially members with longitudinal reinforcement without transverse reinforcement. The nature of failures are varied according to the a/d ratio, if the a/d < 2.5, the patterns of crack cross to the entire depth of the compression area and this failure is called Diagonal Tensile Failure, whereas if the a/d > 2.5 the failure will happen in the higher zone of the compression area and it is called Shear Compression Failure.

Beams, are grouped depending on the a/d ratio value, which are deep beams for (a/d < 1.0), short beams for (1.0 < a/d < 2.5) and ordinary shallow beams for (a/d > 2.5) (ASCE-ACI Committee 445, 1998). Generally, shear failure is the controlling failure mode in the deep beams. An important point has been noticed that as beams get deeper, the ultimate shear stress gets –gradually- greater than in slender beams.

It has been also recognized that, as members become deeper, the ultimate shear stress at failure becomes progressively larger than in slender beams.

Shear strength of the concrete is debatable field because that concrete is firstly a composite material, also it is a non-homogenous as well as a non-isotropic material which is cracked under low tension stresses. The effect of the (a/d) ratio is also regarded a reason of further complicating and hardening the understanding the shear mechanism (Bazant ZP, Kim JK, 1984).

The shear failure mode in the deep beams and corbels is the controlling failure mode. (Kriz and Raths, 1965) carried out an experimental work using two groups of corbels loaded differently, a group that vertically loaded and another group that vertically and horizontally loaded, the outcome of the experiment was a formula derived by them for the purpose of calculating the strength of corbels.

$$V_u = \phi\left[6.5bd\sqrt{f'_c}\left(1-0.5^{\frac{d}{a}}\right)\frac{1000\rho^{\left(\frac{1}{3}+0.4\frac{H}{V}\right)}}{10^{0.8\frac{H}{V}}}\right] \quad \text{(a)}$$

V_u: Vertical ultimate load

Ø: Factor of safety

H/V: horizontal to vertical loads ratio

a: the shear span

b: Corbel width

d: The effective depth

f 'c: Compressive strength

ρ: Steel ratio

The formula above was simplified to the following forms:

For vertically loaded corbels:

$$V_u = \phi bd\sqrt{f'_c}F_1F_2 \quad \text{(b)}$$

For combined loaded (vertically and horizontally loaded) corbels:

$$V_u = \phi bd\sqrt{f'_c}F_1F_3 \quad \text{(c)}$$

Where:

$$F_1 = 6.5\left(1-0.5\tfrac{d}{a}\right) \quad \text{(d)}$$

$$F_2 = (1000\rho)^{\frac{1}{3}} \quad \text{(e)}$$

$$F_3 = \frac{(1000\rho)^{\left(\frac{1}{3}+0.4\frac{H}{V}\right)}}{10^{0.8\frac{H}{V}}} \quad \text{(f)}$$

F_1, F_2 and F_3 values could be obtained rapidly from the table below:

Table 2.1: Values of F1, F2, and F3 calculated according to (Kriz and Raths, 1965).

Value of $F_1 = 6.5\left(1 - 0.5\frac{d}{a}\right)$

a/d	*0.00*	*0.01*	*0.02*	*0.03*	*0.04*	*0.05*	*0.06*	*0.07*	*0.08*	*0.09*
0.0	*6.50*	*6.50*	*6.50*	*6.50*	*6.50*	*6.50*	*6.50*	*6.50*	*6.50*	*6.50*
0.1	*6.49*	*6.49*	*6.48*	*6.47*	*6.45*	*6.44*	*6.41*	*6.39*	*6.36*	*6.33*
0.2	*6.30*	*6.26*	*6.22*	*6.18*	*6.14*	*6.09*	*6.05*	*6.00*	*5.95*	*5.90*
0.3	*5.85*	*5.80*	*5.75*	*5.70*	*5.65*	*5.60*	*5.55*	*5.50*	*5.45*	*5.40*
0.4	*5.35*	*5.30*	*5.25*	*5.20*	*5.15*	*5.10*	*5.06*	*5.01*	*4.97*	*4.92*
0.5	*4.87*	*4.83*	*4.79*	*4.74*	*4.70*	*4.66*	*4.61*	*4.57*	*4.53*	*4.49*
0.6	*4.45*	*4.41*	*4.37*	*4.34*	*4.30*	*4.26*	*4.22*	*4.19*	*4.15*	*4.12*
0.7	*4.08*	*4.05*	*4.02*	*3.98*	*3.95*	*3.92*	*3.89*	*3.86*	*3.83*	*3.80*
0.8	*3.77*	*3.74*	*3.71*	*3.68*	*3.65*	*3.62*	*3.60*	*3.57*	*3.54*	*3.52*
0.9	*3.49*	*3.46*	*3.44*	*3.42*	*3.39*	*3.37*	*3.34*	*3.32*	*3.30*	*3.27*

Value of $F_2 = (1000\rho)^{\frac{1}{3}}$

ρ	*F2*	ρ	*F2*	ρ	*F2*
0.0040	*1.59*	*0.0095*	*2.12*	*0.0150*	*2.47*
0.0045	*1.65*	*0.0100*	*2.15*	*0.0155*	*2.49*
0.0050	*1.71*	*0.0105*	*2.19*	*0.0160*	*2.52*
0.0055	*1.76*	*0.0110*	*2.22*	*0.0165*	*2.54*
0.0060	*1.82*	*0.0115*	*2.26*	*0.0170*	*2.57*
0.0065	*1.87*	*0.0120*	*2.29*	*0.0175*	*2.60*
0.0070	*1.91*	*0.0125*	*2.32*	*0.0180*	*2.62*

0.0075	*1.96*	*0.0130*	*2.35*	*0.0185*	*2.64*
0.0080	*2.00*	*0.0135*	*2.38*	*0.0190*	*2.67*
0.0085	*2.04*	*0.0140*	*2.41*	*0.0195*	*2.69*
0.0090	*2.08*	*0.0145*	*2.44*	*0.0200*	*2.71*

Value of $F_3 = \frac{(1000\rho)^{\left(\frac{1}{3}+0.4\frac{H}{V}\right)}}{10^{0.8\frac{H}{V}}}$

H/V ρ	*0.1*	*0.2*	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*1.0*	*1.1*	*1.2*
0.0040	*1.40*	*1.23*	*1.08*	*0.95*	*0.83*	*0.73*	*0.64*	*0.57*	*0.50*	*0.44*	*0.38*	*0.34*
0.0045	*1.46*	*1.29*	*1.14*	*1.00*	*0.89*	*0.78*	*0.69*	*0.61*	*0.54*	*0.48*	*0.42*	*0.37*
0.0050	*1.52*	*1.34*	*1.19*	*1.06*	*0.94*	*0.83*	*0.74*	*0.66*	*0.58*	*0.52*	*0.46*	*0.40*
0.0055	*1.57*	*1.40*	*1.25*	*1.11*	*0.99*	*0.88*	*0.78*	*0.70*	*0.62*	*0.55*	*0.49*	*0.44*
0.0060	*1.62*	*1.45*	*1.30*	*1.16*	*1.04*	*0.92*	*0.83*	*0.74*	*0.66*	*0.59*	*0.53*	*0.47*
0.0065	*1.67*	*1.50*	*1.34*	*1.20*	*1.08*	*0.97*	*0.87*	*0.78*	*0.70*	*0.62*	*0.56*	*0.50*
0.0070	*1.72*	*1.55*	*1.39*	*1.25*	*1.12*	*1.01*	*0.91*	*0.82*	*0.73*	*0.66*	*0.59*	*0.53*
0.0075	*1.76*	*1.59*	*1.43*	*1.29*	*1.16*	*1.05*	*0.95*	*0.85*	*0.77*	*0.69*	*0.63*	*0.56*
0.0080	*1.81*	*1.63*	*1.48*	*1.34*	*1.21*	*1.09*	*0.99*	*0.89*	*0.80*	*0.73*	*0.66*	*0.59*
0.0085	*1.85*	*1.68*	*1.52*	*1.38*	*1.25*	*1.13*	*1.02*	*0.93*	*0.84*	*0.76*	*0.69*	*0.62*
0.0090	*1.89*	*1.72*	*1.56*	*1.41*	*1.28*	*1.17*	*1.06*	*0.96*	*0.87*	*0.79*	*0.72*	*0.65*
0.0095	*1.93*	*1.75*	*1.60*	*1.45*	*1.32*	*1.20*	*1.10*	*1.00*	*0.91*	*0.83*	*0.75*	*0.68*
0.0100	*1.96*	*1.79*	*1.63*	*1.49*	*1.36*	*1.24*	*1.13*	*1.03*	*0.94*	*0.86*	*0.78*	*0.71*
0.0105	*2.00*	*1.83*	*1.67*	*1.53*	*1.40*	*1.27*	*1.16*	*1.06*	*0.97*	*0.89*	*0.81*	*0.74*
0.0110	*2.04*	*1.86*	*1.71*	*1.56*	*1.43*	*1.31*	*1.20*	*1.10*	*1.00*	*0.92*	*0.84*	*0.77*
0.0115	*2.07*	*1.90*	*1.74*	*1.60*	*1.46*	*1.34*	*1.23*	*1.13*	*1.04*	*0.96*	*0.87*	*0.80*
0.0120	*2.10*	*1.93*	*1.78*	*1.63*	*1.50*	*1.38*	*1.26*	*1.16*	*1.07*	*0.98*	*0.90*	*0.83*
0.0125	*2.14*	*1.96*	*1.81*	*1.66*	*1.53*	*1.41*	*1.30*	*1.19*	*1.10*	*1.01*	*0.93*	*0.86*
0.0130	*2.17*	*2.00*	*1.84*	*1.70*	*1.56*	*1.44*	*1.33*	*1.22*	*1.13*	*1.04*	*0.96*	*0.88*

2.6 Previous studies on Shear Strength

The primarily appeared proofs on the efficiency of the size on the longitudinally reinforced concrete members on the shear strength of these members was in the 60s of the 20_{th} century through different studies by (Leonhardt and Walther, 1962; Rüsch et al, 1962; Kani, 1967). After, many studies included the topic experimentally and theoretically, for instance, (Walraven and Lahwater, 1994; Ožbolt and Eligehausen, 1996; Karihaloo et al, 2003; Wang et al, 2006; Sherwood et al, 2007; Hassan et al, 2008), these studies proved that the size of the members affects obviously on the shear capacity of these members. The most of the experimentally studies have used similar-geometry scaled beams in tests, efficiency of the size was studied focusing on the depth of the beams.

(G. Monti and M.A. Liotta, 2005) studied using of CFRP to strengthen reinforced concrete beams against shear stresses, the results of the experimental and analytical study showed that using CFRP leads to a good performance.

(El-Sayed et al, 2006 – a) did an experimental study using 6 internally reinforced concrete beams which were reinforced using two types of longitudinal rods of FRP, which were bars of GFRP and CFRP. The study showed that raising the proportion of the bars from 1.7% up to 2.2% improved the shear capacity by 32% and 34% respectively.

(El-Sayed et al, 2006 – b) did another experimental study using 6 internally reinforced concrete beams using bars of GFRP and CFRP. The samples were different in strength of those used in study mentioned previously (El-Sayed et al, 2006 – a), the later study showed that raising the proportion of the CFRP from 0.87% up to 1.24% rises the shear strength by 34% of the original shear strength, while further raising in the proportion of the CFRP bars from 1.24% up to 1.72% results in upgrading the shear strength by further 20%. While, raising the proportion of the GFRP from 1.22% up to 1.71% results in upgrading the shear strength by 29%.

(Alkhrdaji et al, 2001) showed in their study using deep beams, that raising then proportion of the shear reinforcement from 0 to 0.39% results in upgrading the shear strength by 78% of the original strength, then they made an additional raising of the proportion from 0.39% to 0.52% which resulted in upgrading the shear strength by a further 15%.

(Tomlinson and Fam, 2014) used 9 concrete beams with BFRP reinforcement bars in their study, they found out that upgrading the proportion of the bars from 0.39% to 0.84% rises the shear capacity by 40%.

(Ramadass and Thomas, 2010) did a theoretical study to discuss the efficiency of the stirrups made of FRP on the shear capacity of concrete beams. Through the study, they noticed that shear capacity of the member reinforced with GFRP becomes enhanced by raising the proportion of vertical reinforcement (*ρv*), the study has showed that longitudinal reinforcement affects secondarily on the shear strength of the member compared to the proportion of the transverse reinforcement. It has been noticed that raising (*ρv*) from 0% to 0.5% enhances the shear strength by 130% of the original strength, while the raising in the proportion from 0% to 1% leads to upgrading the shear strength by 330%, figure (2.9).

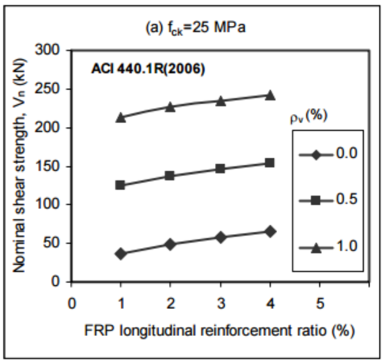


Figure 2.9 Effect of transverse reinforcement on nominal shear strength (ρ_v *%)* (Ramadass and Thomas, 2010)

(Matta et al, 2013) reported that increasing in the compressive strength from 29.6 MPa to 38.8 MPa of GFRP bars reinforced concrete beams rises the shear strength by 75% of the original strength.

(A. Claderaa and A.R. Marí, 2005) did a study to present a good vision on shear failure of high strength concrete (HSC) beams with and without transverse reinforcement, 18 RC beams were used in the experimental work. Compressive strength of the members were between 50 and 87 Mpa. The results showed that members without transverse reinforcement showed a so brittle manner. Generally, for transversely unreinforced members, the shear strength increases proportionally with the compressive strength of the concrete. For the transversely reinforced HSC, the efficiency of the used stirrups increases proportionally with the compressive strength of the HSC used.

(Tureyn and Forsch, 2002) presented a study using 6 concrete beams with internally reinforcement using longitudinal FRP rods, two kinds of the FRP have been used in the experimental study, which were, GFRP and Aramid-FRP (AFRP) bars, they found out the raising the proportion of the AFRP reinforcement from 96% to 1.92% improved the shear strength by 54% of the original strength, while raising the GFRP reinforcement with the same proportion -from 96% to 1.92%- improved the shear strength by 61%.

(Mahmoud and El-Salakawy, 2015) noticed that rising the shear strength of the concrete used in continuous FRP reinforced beams results in increasing of the interior shear span. When compressive strength was risen from 30 to 40 MPa, from 40 to 50 MPa and from 50 to 60 MPa, the shear span has been increased by 13%, 19.5% and 16.6% respectively. Then, when the strength was risen from 60 to 70 MPa and from 70 to 80 MPa, the shear span was increased by 12.6% and 5.3% respectively. Through this study, they obtained that concrete strength is changing proportionally to the shear strength of the member. They also obtained that upgrading *f 'c* of the concrete from 43 to 80 MPa rises the shear capacity of the FRP reinforced member by 38% of its previous shear capacity.

The figure (2.10) below explains how the changing in *f 'c* is not only affects in carrying load, but affects in the deflection –as a result, affects in the ductility also- of the member. Whereas, figure (2.11) explains the relation between the *f 'c* and the shear capacity of the member.

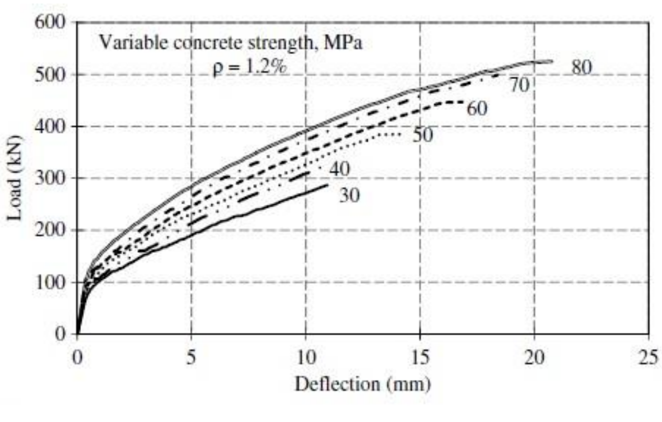


Figure 2.10 Effect of concrete strength on deflection

(Mahmoud and El-Salakawy 2016)

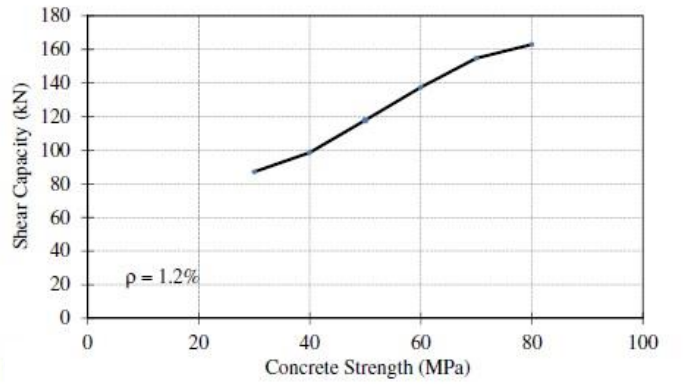


Figure 2.11 Effect of concrete strength on shear capacity (Mahmoud and El-Salakawy 2016)

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 Introduction

In this chapter, the experimental work will be shown. In order to study the efficiency of used technique, two-sided RC damaged corbels with different characteristics have been used.

19 specimens have been used in this study. Specimens were different in some characteristics. Differences were, the shear span (80, 100 and 120) mm, proportion of fiber glass (0%, 0.2% and 0.4%), the strength of the concrete (Normal Strength and High Strength), and the diameter of the bars used for reinforcement (ϕ 8 and ϕ10) mm.

For the purpose of rehabilitation, two sets of other materials were used. First set was used for injecting the cracks (High viscosity, low viscosity, and very low viscosity epoxies). The second set was used for confinment (ϕ12 mm threaded rods, L40×40×4 steel sections, steel washers, and steel nuts).

3.2 Specimen of the Test

The corbels have the same dimensions all. The corbels cross sections were (150 × 150) mm. The column parts also had the same cross sections (150 × 150) mm. The corbels are emerged by 160 mm (length) from the both sides. While, the thumb of the column stretched 100 mm from the bottom side and 160 mm from the top side. The details are shown in Figure (3.1).

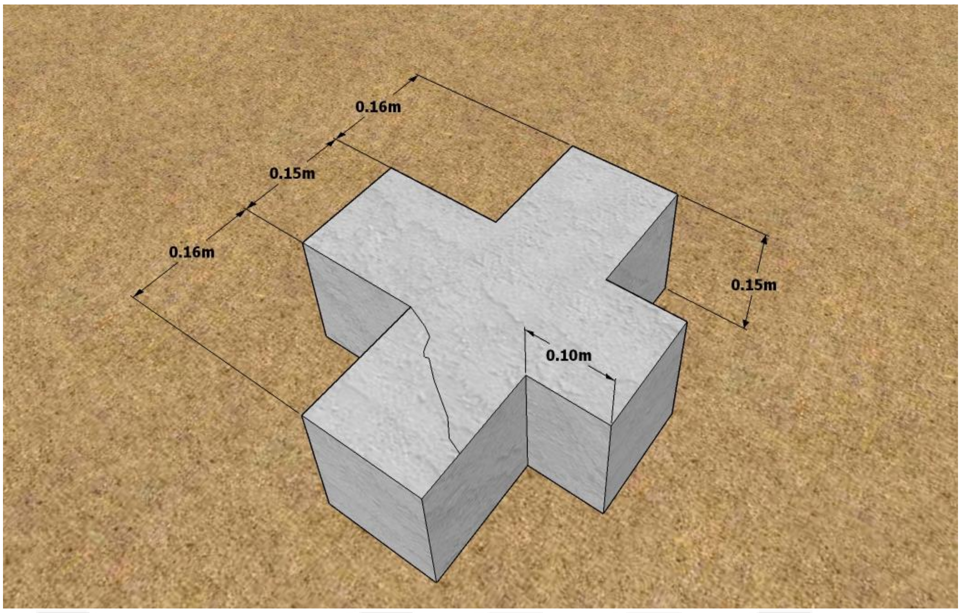


Figure 3.1 Dimension of the specimens

Threaded rods with lengths 0.2 m and 0.6 m were used. While, L40×40×4 sections with length of 27 cm have been used in the experiment, figure (3.2).

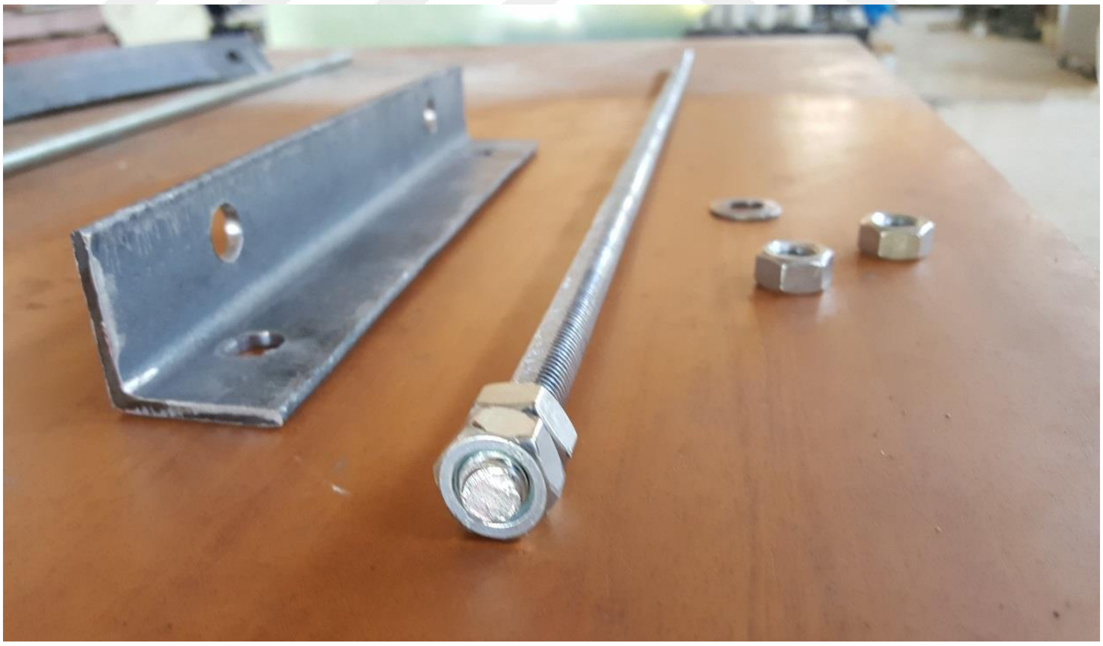


Figure 3.2 Steel Confining Elements

3.3 Properties of the Used Materials

In this section, used materials and their characteristics will be shown.

3.3.1 Injection Materials

Injection materials have been used to fill the cracks. These materials are necessary to bond the sides of the spaces of the cracks. High viscosity epoxy was used to close exterior cracks (big cracks).

Low viscosity epoxy has been used to inject large cracks (larger than 5 mm) because of the liquidity. This repair epoxy has a tensile strength of 37 MPa, and compressive strength of 52 MPa, and bond strength of larger than 4 Mpa (all the strengths are after 7 days).

The third type is very low viscosity crack repairing epoxy, and it has been used for very small cracks (smaller than 5 mm). The most important characteristics of this epoxy are, very low viscosity, high strength adhesive.

3.3.2 Confining Materials

ϕ12 mm threaded rods were used. The threaded rods have been tested, and the yield strength was 438 MPa figure (**3.3**). ST37 steel angles L40×40×4 have been used in the experimental work. Finally, commercial steel washers and nuts have been used to fix the previous parts.

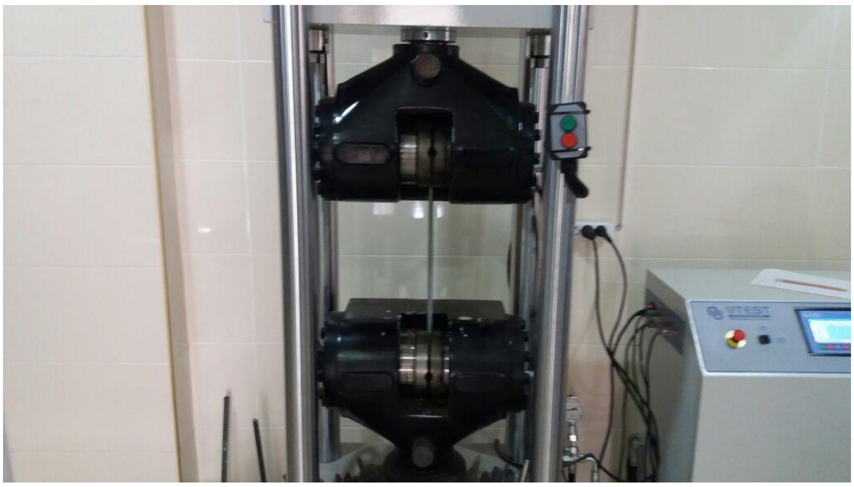
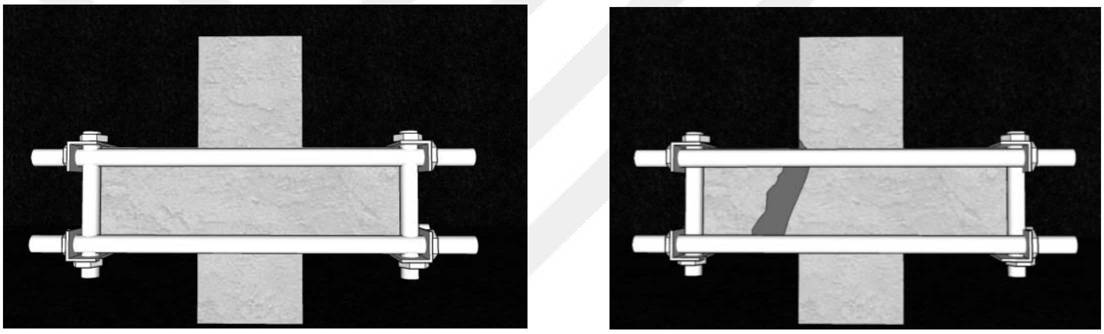


Figure 3.3 Threaded rod during tensile testing

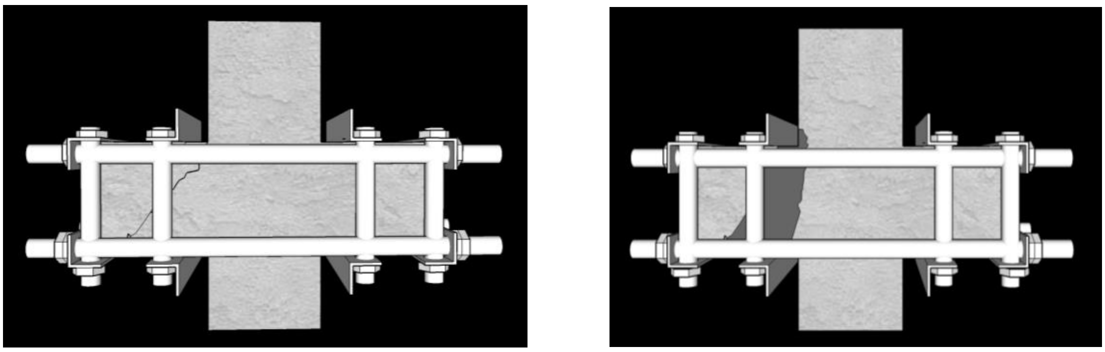
3.4 Procedure of the Specimens Preparation

Before presenting the procedures of the rehabilitation, it is important to define the styles of rehabilitation. Style-1, this style is a control style, and only one specimen rehabilitated by style-1 (control specimen), figure (**3.5**). Style-1 is confining the specimen with 4 horizontal and 4 perpendicular threaded rods, and 4 L- sections at the ends of the corbels. Style-2 (2 specimens), is repairing the specimen with three types of epoxies, and confining them with 4 horizontal and 4 perpendicular threaded rods, and 4 L -sections at the ends of the corbels. Style-3 (5 specimens), is confining the specimen with 4 horizontal and 8 perpendicular threaded rods and 8 L- sections at the ends of the corbels, figure (**3.6**). Style-4 (11 specimens), is repairing the specimen with three types of epoxies, and confining them with 4 horizontal and 8 perpendicular threaded rods and 8 L -sections at the ends of the corbels



Style-1 Style-2

Figure 3.4 Styles-1, and 2 (without middle perpendicular rods)



Style-3 Style-4

Figure 3.5 Styles-3, and 4 (with middle perpendicular rods)

3.4.1 Procedure of Repair with (High viscosity, low viscosity, and very low viscosity epoxies)

High viscosity epoxy has been used to coat the cracks exteriorly. After mixing the two parts of epoxy, it was placed to the face of the samples, figure (**3.6**). After the epoxy was hardened up, deep cracks have been cleared with compressed air. Small cracks (smaller than 6 mm) have been filled with very low viscosity epoxy using (Gravity Feed) method to rehabilitate the small cracks, figure (**3.7**). Very low viscosity epoxy could cause a leakage because of the low viscosity, and it should be controlled. After leakage controlling, figure (**3.8 - a, b**), the specimens with leakage have been cured by closing the leakage points exteriorly with High viscosity epoxy. The rest of the cracks (larger than 6 mm) have been cracked with High viscosity epoxy. Finally, another coat of High viscosity epoxy was applied in order to offset the lost mass due to damage. Then, grinding machine have been used to adjust the geometry of the corbels, figure (3.9). It is an important condition to use mask while making the grinding, because of the active dust of the epoxies that can harm the person.

Figure 3.6 High Viscosity Epoxy coated corbels

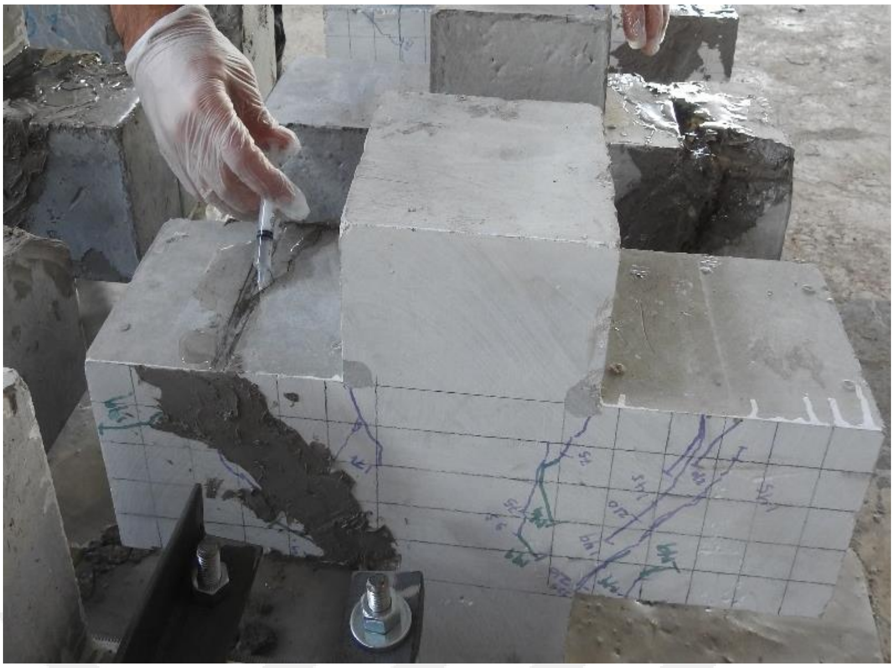


Figure 3.7 Applying the very low viscosity epoxy by (Gravity Feed method)

(a) **(b)**

Figure 3.8 Lick controlling: **(a)** Licking of the very low viscosity epoxy, **(b)** Repair of the lick using the high viscosity epoxy.

Figure 3.9 Adjusting the faces of the corbel by grinding machine

3.4.2 Steel Confining Procedure

After cutting the steel L40×40×4 sections into 27 cm pieces, holes have been made in these pieces by steel punching machine, figure (3.10). Threaded rods have been cut into 0.6 m and 0.2 m pieces. All the pieces have been installed and tightened by using nut keys, figure (3.11).

Figure 3.10 Steel punching machine

Figure 3.11 Installing the steel confinement

Threaded rods that exist in the tension zones have been provided with double nuts because of the tension stress. The ductility of the new composite –the confined concrete- is high, and the nuts will be under higher strength. So, doubling the nuts in the tension zones can be practically regarded a factor of safety, figure (**3.12**).

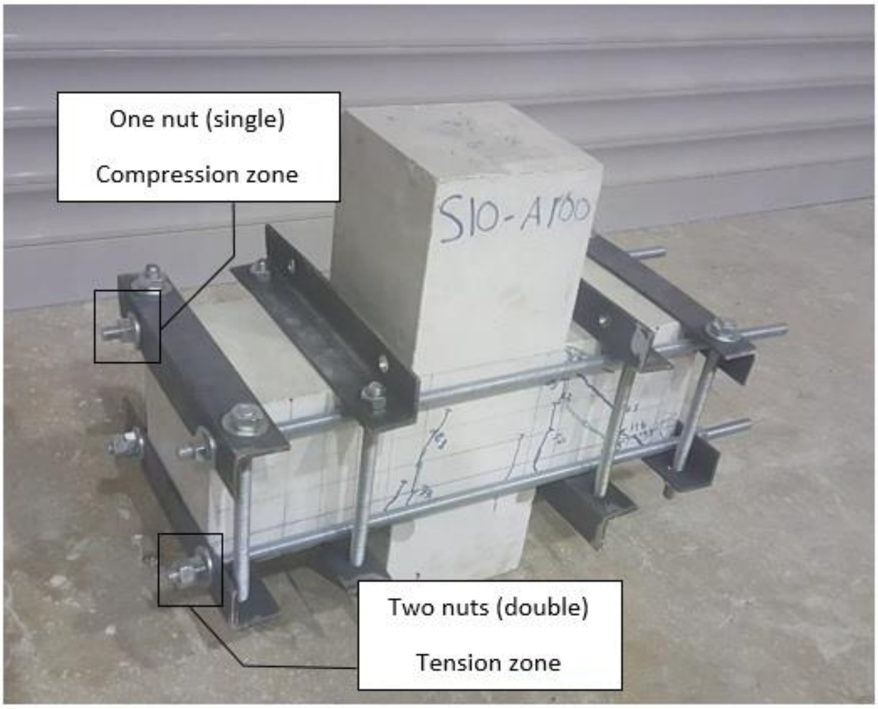


Figure 3.12 Nuts distribution according to stress zones

The middle pieces of threaded rods and the steel L- sections are placed in the mid of the shear spans. The centers of the perpendicular threaded rods must be parallel to the mid of the shear span to give the most effective performance against shear cracks, figure (**3.13**).

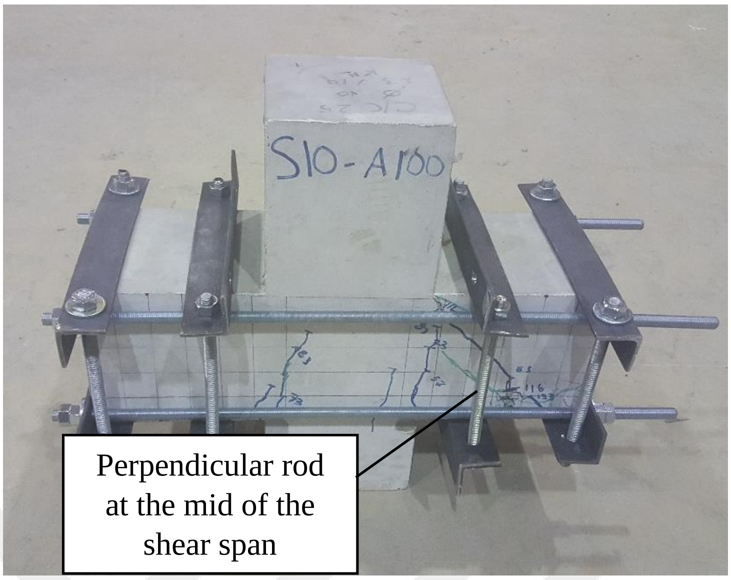


Figure 3.13 middle steel place

3.5 Properties of the original specimens

Specimens used in the experimental work were damaged in shear failure mode. All of the specimens had the same dimensions but different properties. Differences were: type of concrete, content of glass fiber GF, diameter of the steel used (ϕ8, and ϕ10) mm, and the shear span (80, 100, and 120) mm. Details are shown in Table (3.1), and Table (3.2). While, Table (**3.3**) classifies the codes of the specimens.

Table (**3.1**) Properties of the high strength concrete.

High strength concrete		
GF ratio	Cylindrical f_c (MPa)	Cubic f_c (MPa)
0.0%	92.79	102.66
0.2%	83.76	96.15
0.4%	88.26	98.69

Table (**3.2**) Properties of the normal strength concrete.

Normal strength concrete		
GF ratio	Cylindrical f_c (MPa)	Cubic f_c (MPa)
0.0%	51.34	64.50
0.2%	42.67	63.84
0.4%	46.39	66.71

Table (**3.3**) Codes of the specimens.

High strength concrete			Normal strength concrete		
GF ratio			GF ratio		
0.0%	0.2%	0.4%	0.0%	0.2%	0.4%
S10-120	S8-100-0.2%	S8-100-0.4%	S10-A100	S8-A100-0.2%	S8-A100-0.4%
S10-80	S8-80-0.2%	S8-120-0.4%	S8-A120	S8-A80-0.2%	S8-A80-0.4%
S8-120		S8-80-0.4%	S8-A80		
High strength concrete			Normal strength concrete		
GF ratio			GF ratio		
0.0%	0.2%	0.4%	0.0%	0.2%	0.4%
S8-100			S10-A120		
S8-80			S10-A80		

3.6 Procedure of the Test

Testing machine was used with bearing capacity 500 KN. The load applied from the top face of the emerged column part of the sample. The machine has been set to work in displacement controlled mode with a rate of 0.4 mm/minute, and the reading frequency has been set to 5 readings/sec. After the machine program was configured, the LVDT s has been installed to the under corners between column and corbels. The chosen location of the LVDTs are the most deflected points at the member, figure (**3.14**).

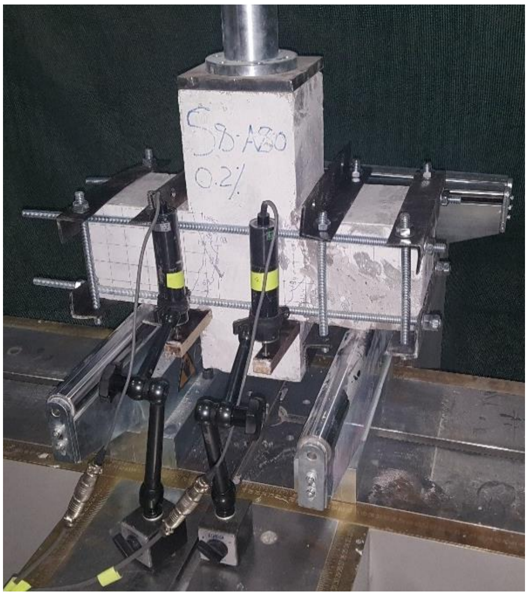


Figure 3.14 A prepared specimen to be tested

After load was applied, readings and the sample were observed until it failed, all the remarks have been noted about all the specimens during the test in order to be studied and discussed later.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, results of the 19 tested specimens will be discussed, specimens consisted of damaged corbels due to shear failure (Diagonal Tension Failure), and specimens have been divided into 4 styles according to the style of the rehabilitation techniques. Style-1 is confining the specimen with 4 horizontal and 4 perpendicular threaded rods, and 4 L- sections at the ends of the corbels. Style-2 (2 specimens), is repairing the specimen with three types of epoxies, and confining them with 4 horizontal and 4 perpendicular threaded rods, and 4 L -sections at the ends of the corbels. Style-3 (5 specimens), is confining the specimen with 4 horizontal and 8 perpendicular threaded rods and 8 L- sections at the ends of the corbels, figure (**3.6**). Style-4 (11 specimens), is repairing the specimen with three types of epoxies, and confining them with 4 horizontal and 8 perpendicular threaded rods and 8 L -sections at the ends of the corbels.

Differences in the characteristics of the specimens themselves were also existed, like, Shear span, reinforcement details, glass fiber percentage, type of the concrete. Anyhow, all the factors have been regarded, and the focus of the study was on the efficiency of the rehabilitation techniques used by making a comparison, for each specimen, between the obtained results and the old results of their failure under load carrying test. So, results will be discussed for Load-Deflection response, the ultimate carrying capacity, the ductility and the crack response. Nevertheless, the *(a/d)* ratio, (f_c'), reinforcement details and the admixtures will be seriously regarded in the discussion.

4.2 Response of Style 1 specimens (4 Steel pieces – No Epoxies)

4.1.1 Response of Specimen (S8-100-0.2%)

Specimen (S8-100-0.2%) is a rehabilitated -previously shear failed- RC corbel, and It is a control specimen .The used style of rehabilitation was Style-1. This style consists of confining the corbel using only 4 L-Sections. Figure 4.1 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 84 kN at the right side –not damaged side-. After this point, both of the old and new cracks started to grow. At 173 kN (Maximum Load), a sudden big crack occurred at the previously cracked side –left -. Then, the specimen failed strongly at the previously damaged –left- side, at deflection of 5.62 mm. The failure mode was diagonally shear failure.

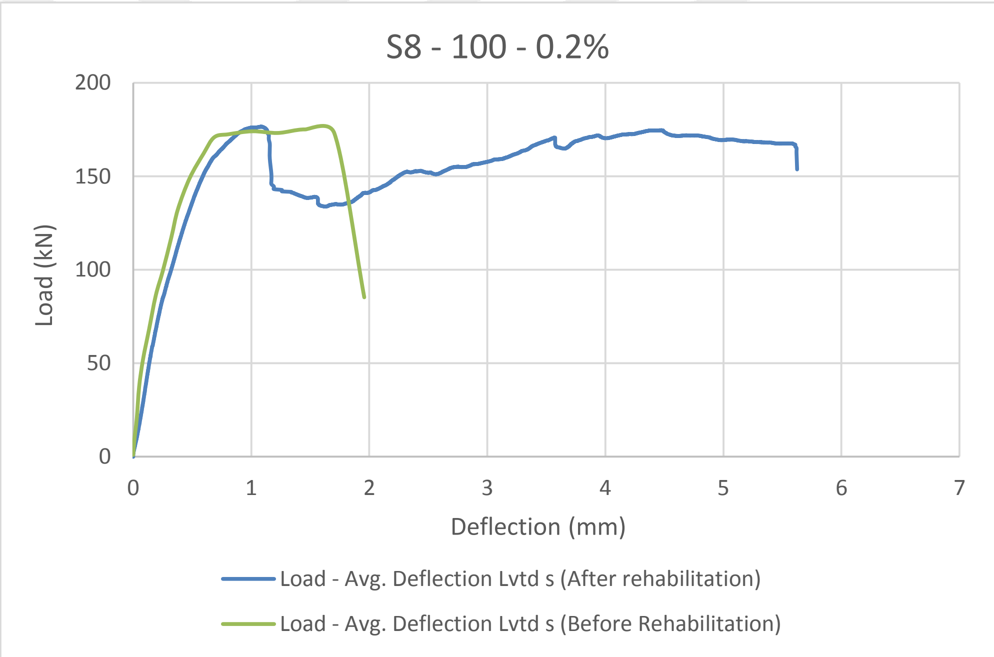


Figure 4.1 Effect of rehabilitation, style-1 (Specimen S8 - 100 - 0.2%)

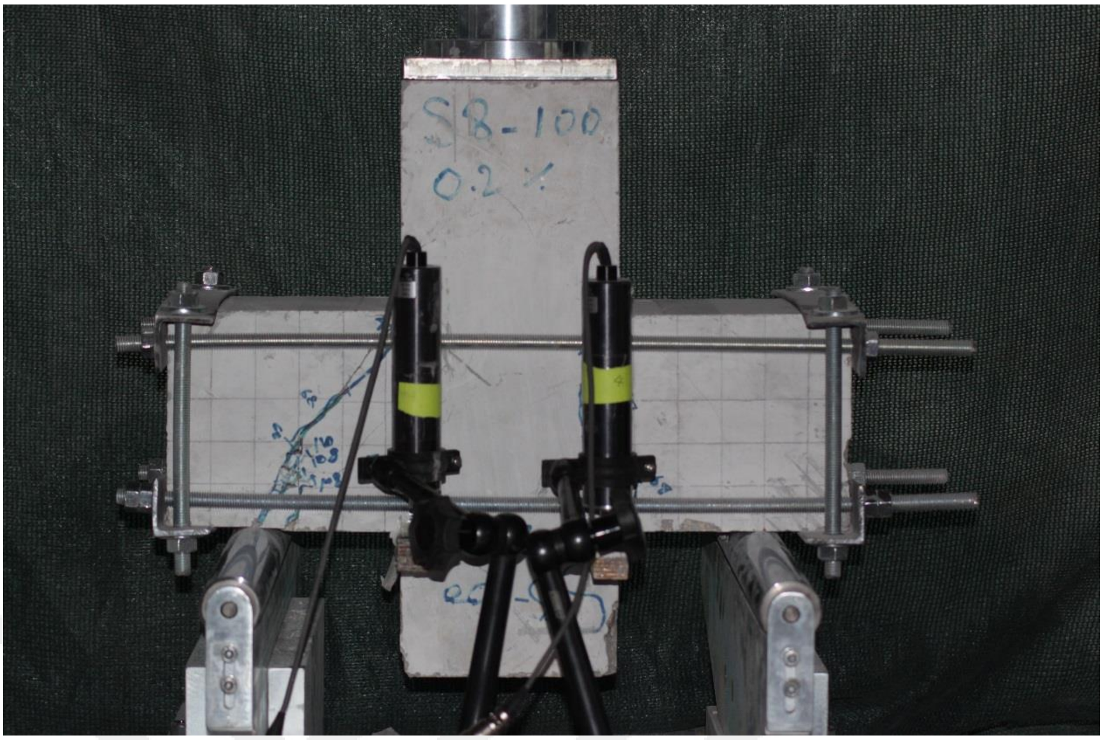


Figure 4.2 (Specimen S8 - 100 - 0.2%) in the test machine

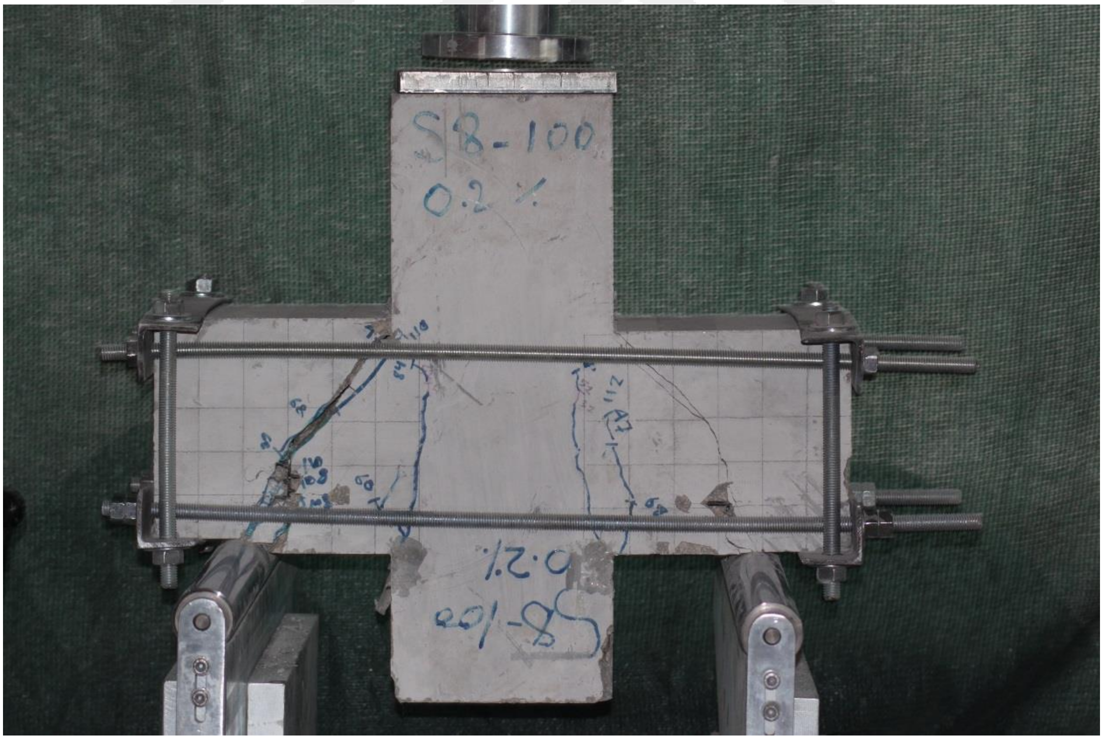


Figure 4.3 (Specimen S8 - 100 - 0.2%) after testing

Figure 4.4 Unconfined (specimen S8 - 100 - 0.2%) after testing

4.3 Response of Style-2 Specimens (4 Steel pieces – with Epoxies)

4.3.1 Response of specimen (S10-120)

Specimen (S10-120) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-2. This style consists of repairing the cracks with epoxies, then, confining the corbel using 4 L-Sections. Figure 4.5 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 74 kN at the left side –previously damaged side-. After this point, the crack started to grow. At 256 kN (Maximum Load), a sudden big crack occurred at the same side. Then, the specimen failed strongly at same side –left-, at deflection of 2.79 mm. The failure mode was diagonally shear failure.

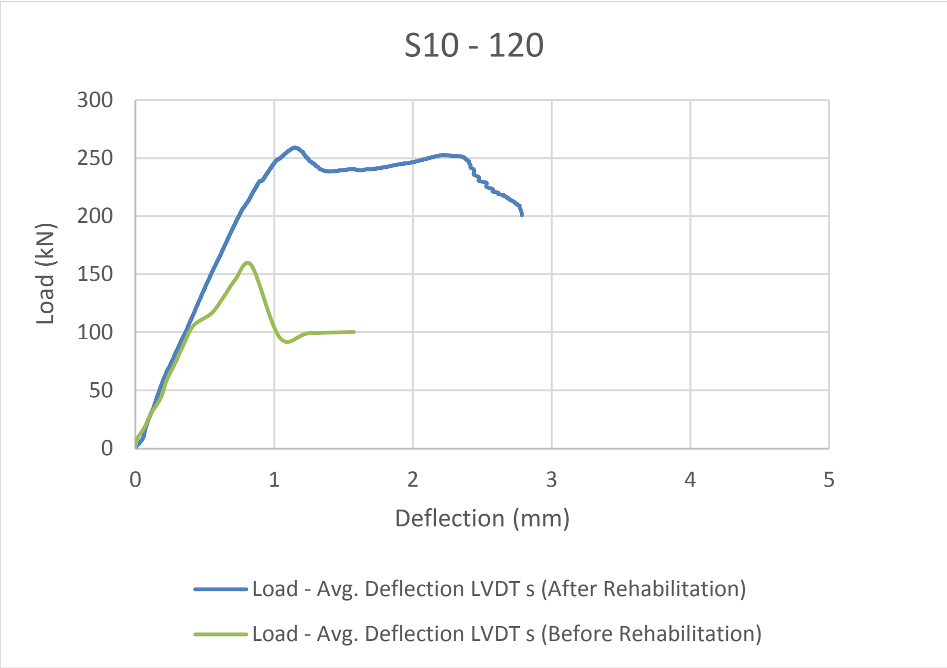


Figure 4.5 Effect of rehabilitation, style-2 (Specimen S10 – 120)

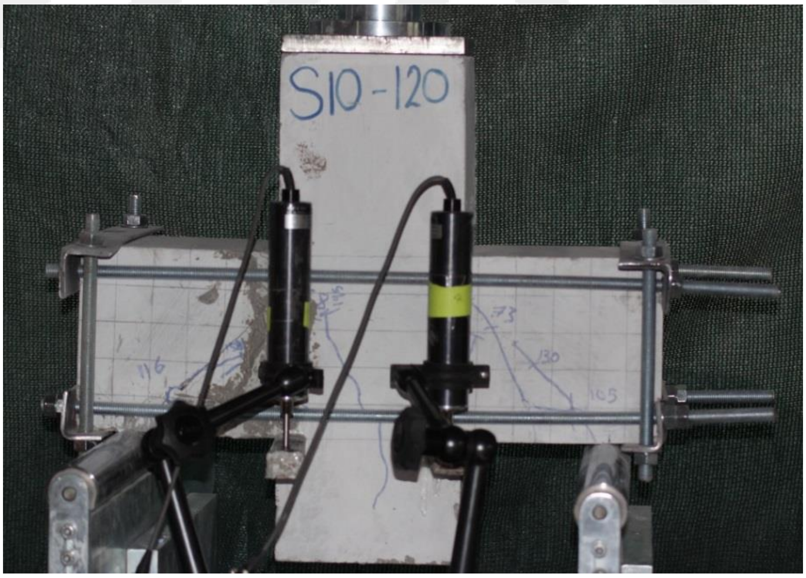


Figure 4.6 (Specimen S10 - 120) in the test machine

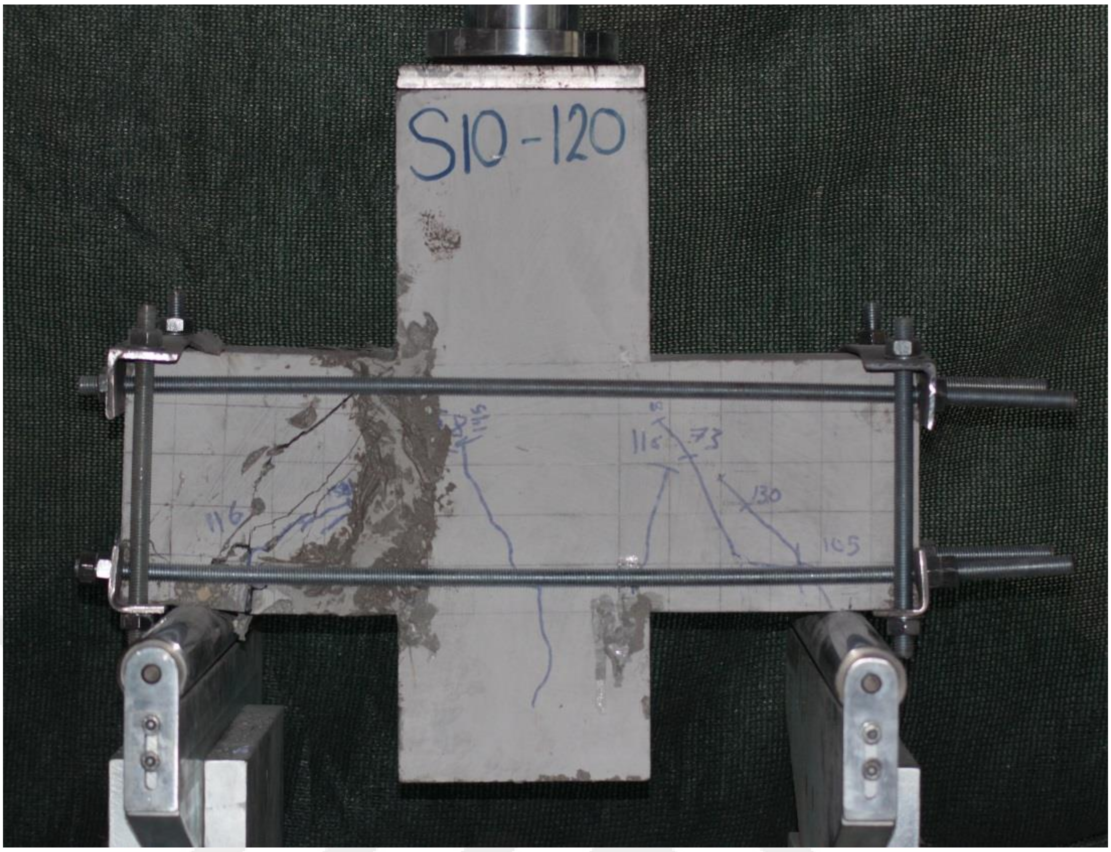


Figure 4.7 (Specimen S10 - 120) after testing

Figure 4.8 Unconfined (Specimen S10 - 120) after testing

4.3.2 Response of Specimen (S10-80)

Specimen (S10-80) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-2. This style consists of repairing the cracks with epoxies, then, confining the corbel using 4 L-Sections. Figure 4.9 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 98.2 kN at the right side –previously damaged side-. After this point, the crack started to grow. At 265 kN (Maximum Load), a sudden big crack occurred at the same side –right-. Then, the specimen failed strongly at the same side, at deflection of 4.46 mm. The failure mode was diagonally shear failure.

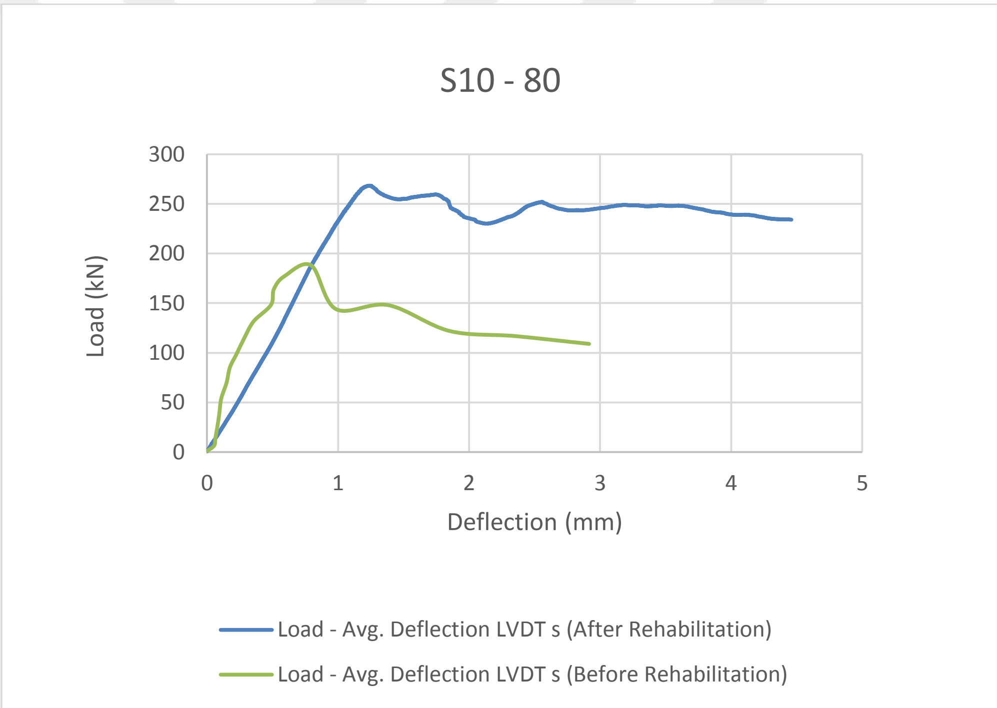


Figure 4.9 Effect of rehabilitation, style-2 (Specimen S10 - 80)

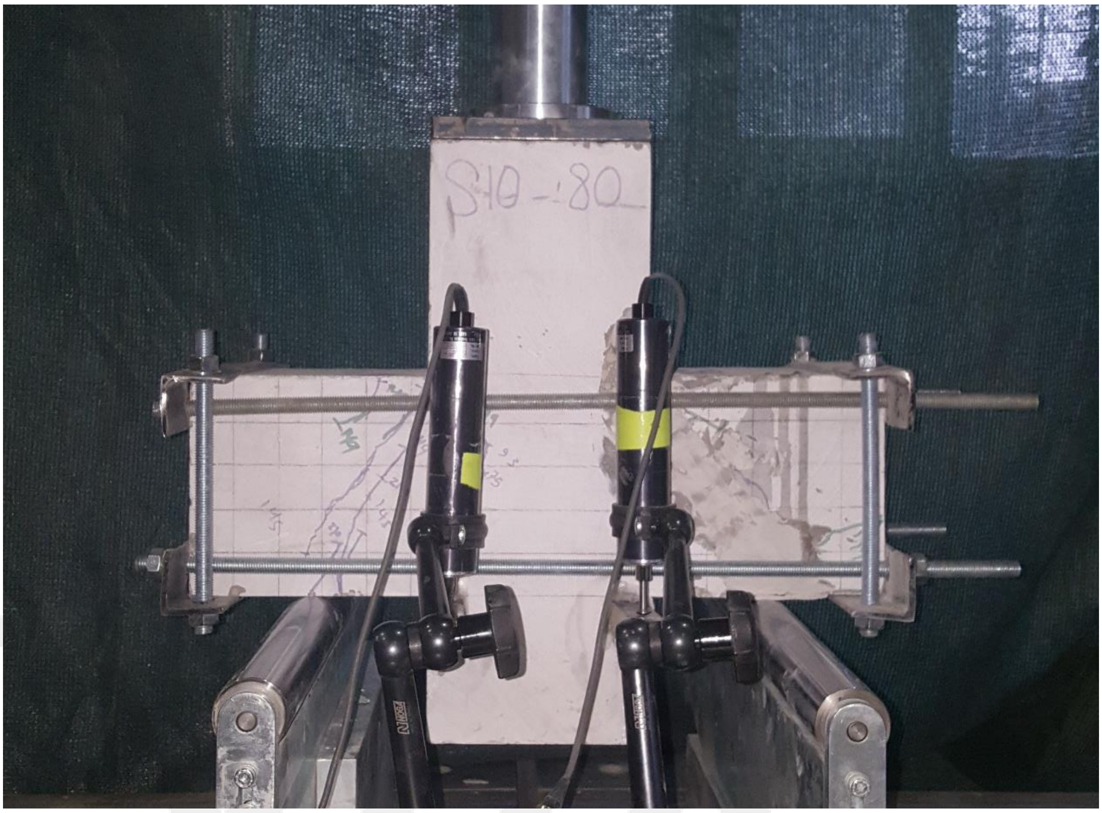


Figure 4.10 (Specimen S10 - 80) in the test machine

Figure 4.11 Unconfined (Specimen S10 - 80) after testing

4.4 Response of Style-3 Specimens (8 Steel pieces – No Epoxies)

4.4.1 Response of Specimen (S8-120)

Specimen (S8-120) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-3. This style consists of confining the corbel using only 8 L-Sections. Figure 4.12 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 106 kN at the right side –not damaged side-. After this point, both of the old and new cracks started to grow. At 200 kN (Maximum Load), a sudden big crack occurred at the previously cracked side –left -. Then, the specimen failed strongly at the previously damaged –left- side. The deflection at the failure was 6.39 mm. The failure mode was diagonally shear failure.

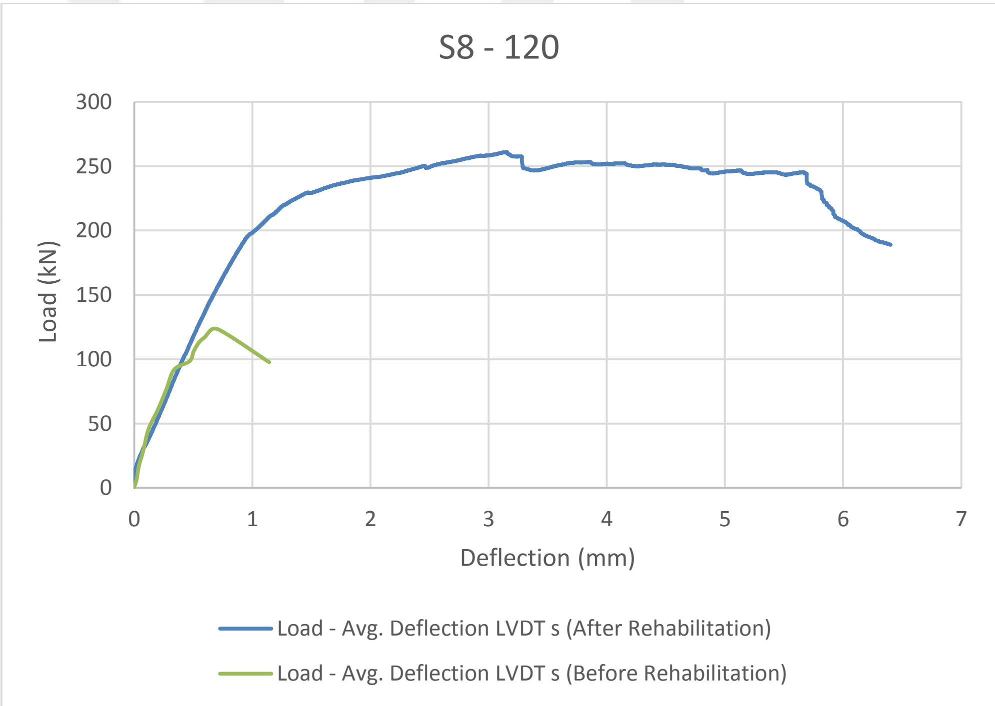


Figure 4.12 Effect of rehabilitation, style-3 (Specimen S8 - 120)

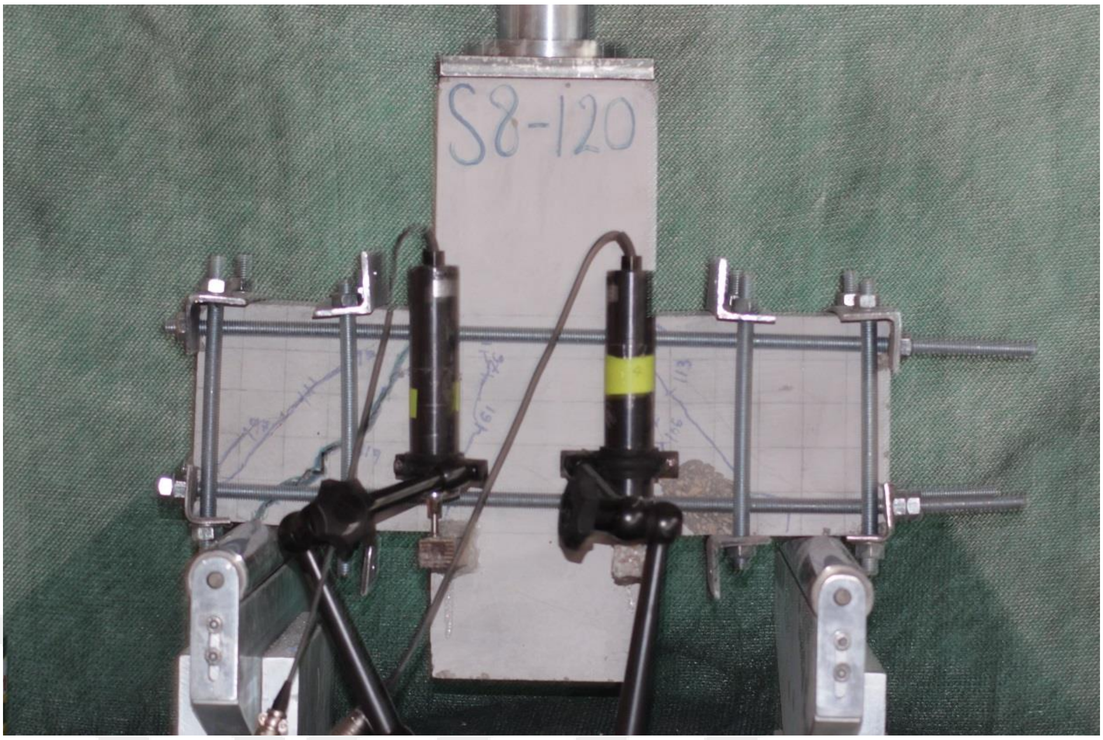


Figure 4.13 (Specimen S8 - 120) in the test machine

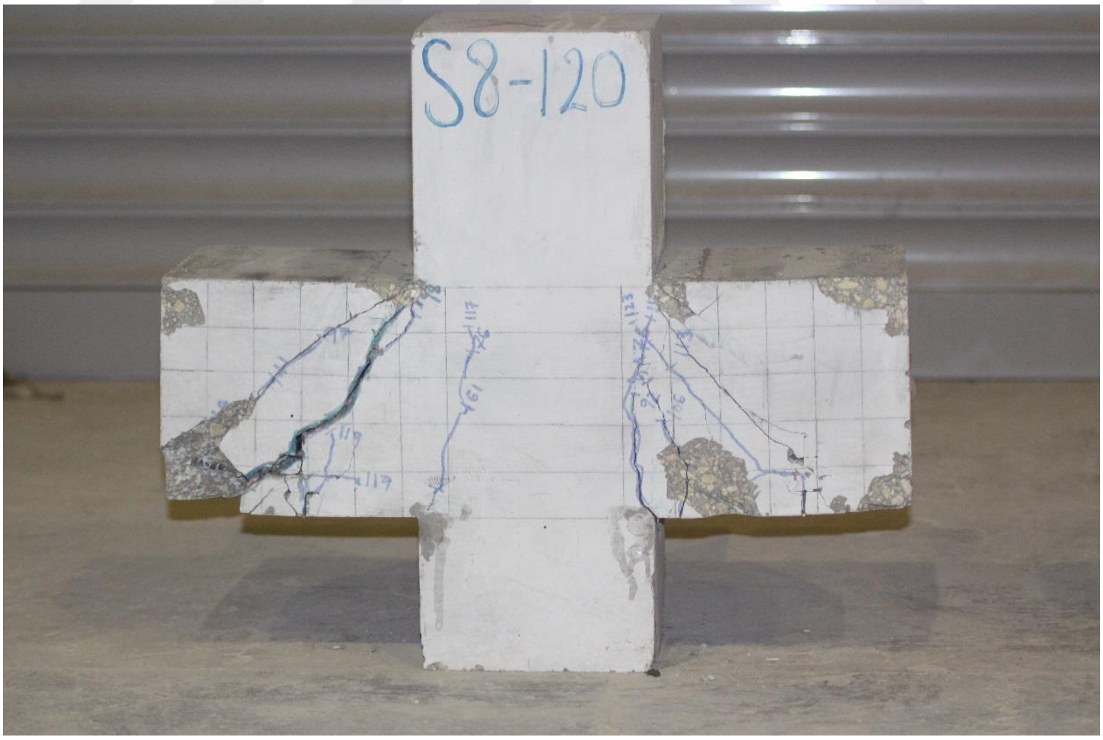


Figure 4.14 Unconfined (Specimen S8 - 120) after testing

4.4.2 Response of Specimen (S8-A100-0.2%)

Specimen (S8-A100-0.2%) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-3. This style consists of confining the corbel using only 8 L-Sections. Figure 4.15 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 126.5 kN at the right side –not damaged side-. After this point, both of the old and new cracks started to grow. At 317 kN (Maximum Load), a sudden big crack occurred at the previously cracked side –left -. Then, the specimen failed strongly at the previously damaged –left- side, at deflection of 3.27 mm. The failure mode was diagonally shear failure.

Figure 4.15 Effect of rehabilitation, style-3 (Specimen S8 - A100 - 0.2%)

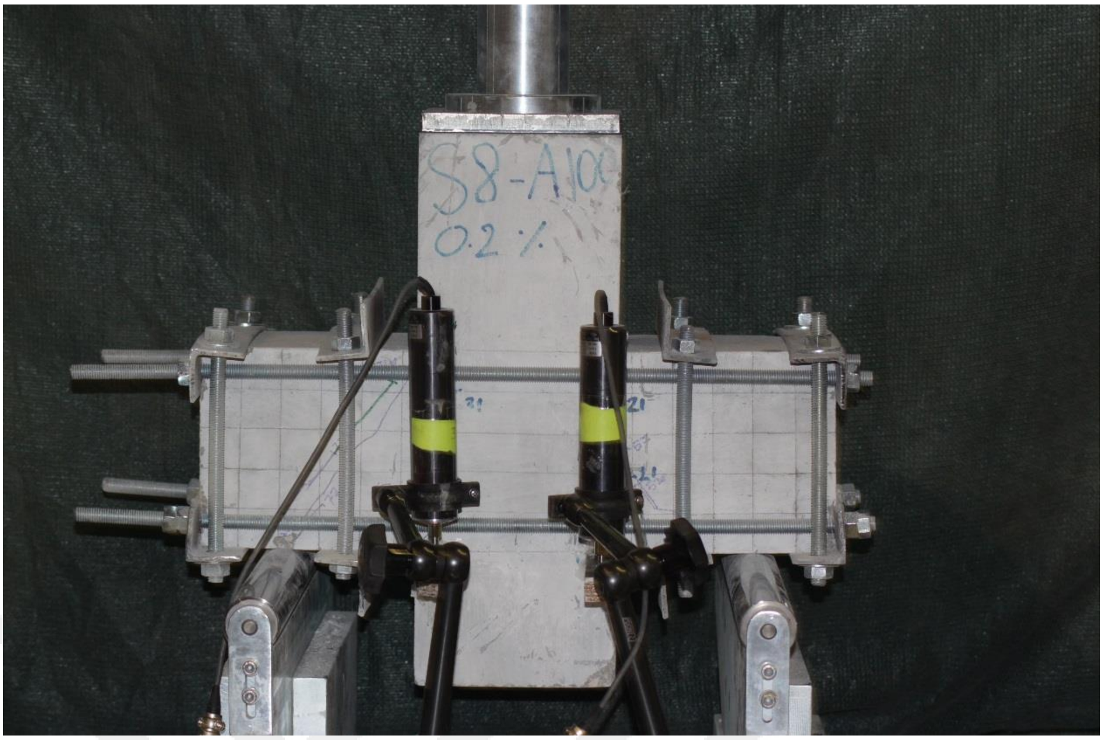


Figure 4.16 (Specimen S8 - A100 - 0.2%) in the test machine

Figure 4.17 Unconfined (Specimen S8 - 100 - 0.2%) after testing

4.4.3 Response of Specimen (S8-A100-0.4%)

Specimen (S8-100-0.4%) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-3. This style consists of confining the corbel using only 4 L-Sections. Figure 4.18 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 118 kN at the right side –not damaged side-. After this point, both of the old and new cracks started to grow. At 270 kN (Maximum Load), a sudden big crack occurred at the previously cracked side –left -. Then, the specimen failed strongly at the previously damaged –left- side. The deflection at the failure was 6.61 mm. The failure mode was diagonally shear failure.

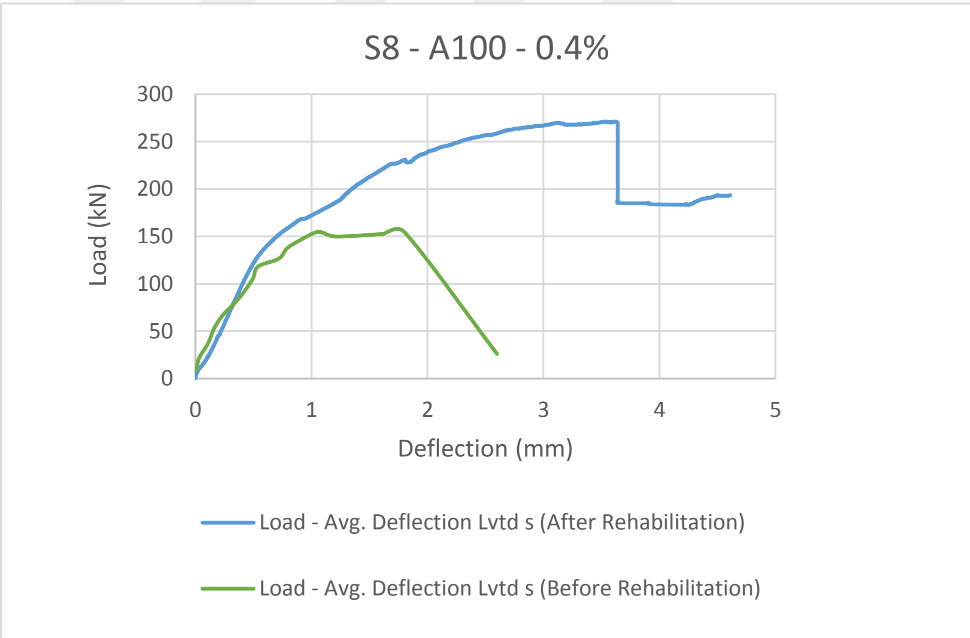


Figure 4.18 Effect of rehabilitation, style-3 (Specimen S8 - 100 - 0.4%)

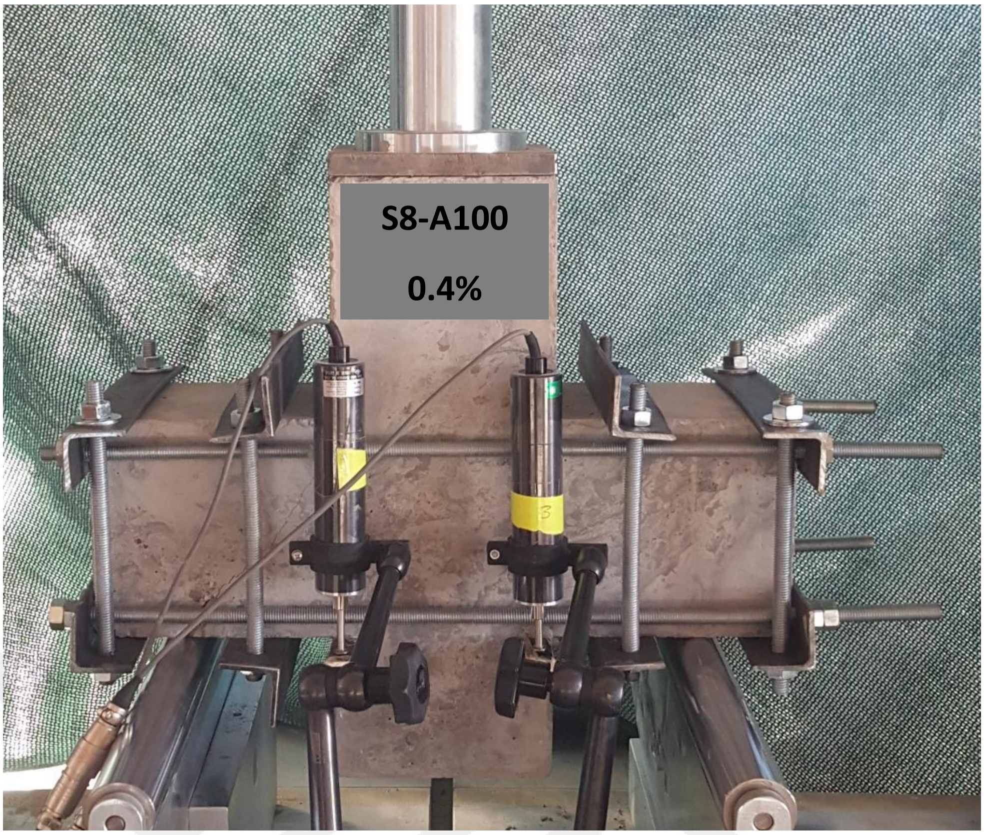


Figure 4.19 (Specimen S8 - A100 - 0.4%) in the test machine

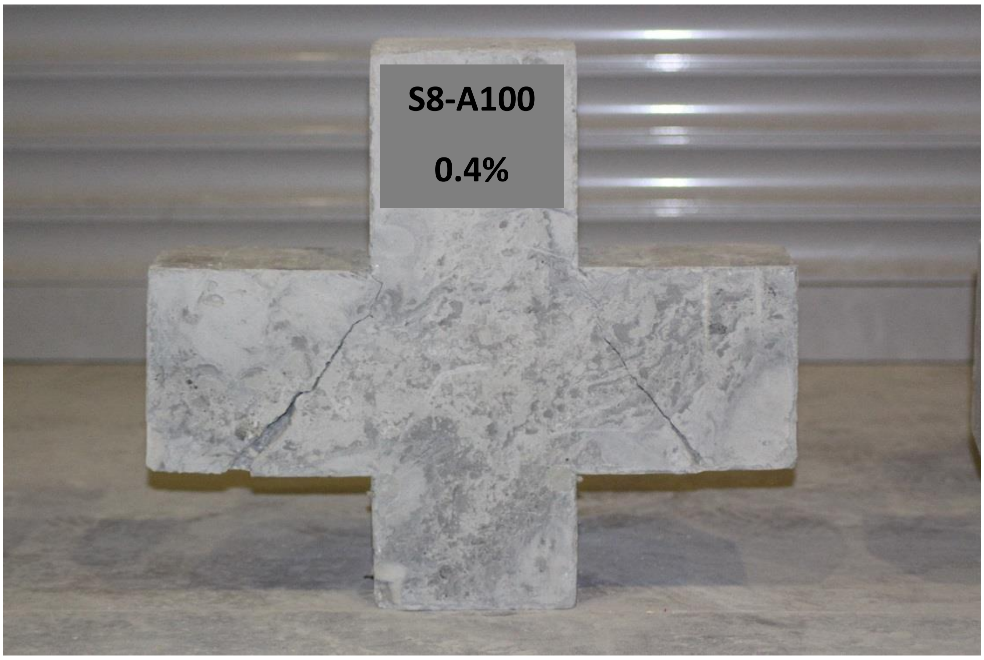


Figure 4.20 Unconfined (Specimen S8 - A100 - 0.4%) after testing

4.4.4 Response of Specimen (S8-80-0.2%)

Specimen (S8-80-0.2%) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-3. This style consists of confining the corbel using 8 L-Sections. Figure 4.21 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 142 kN at the right side –previously damaged side-. After this point, both of the old and new cracks started to grow. At 340 kN, a sudden big crack occurred at the right side. At 359 (Maximum Load), the crack began to grow seriously. The deflection at the failure was 2.91 mm. The failure mode was diagonally shear failure.

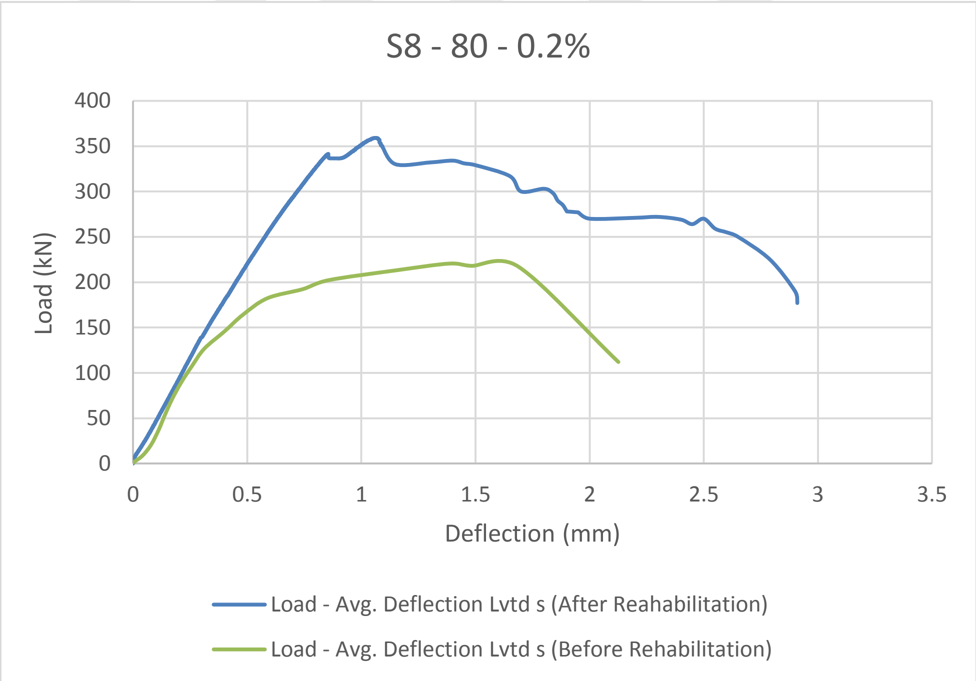


Figure 4.21 Effect of rehabilitation, style-3 (Specimen S8 - 80 - 0.2%)

Figure 4.22 (Specimen S8 - 80 - 0.2%) in the test machine

Figure 4.23 Unconfined (Specimen S8 - 80 - 0.2%) after testing

4.4.5 Response of Specimen (S10-A100)

Specimen (S10-A100) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-3. This style consists of confining the corbel using 8 L-Sections. Figure 4.24 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 117 kN at the left side –not damaged side-. After this point, both of the old and new cracks started to grow. At 235 kN, a sudden big crack occurred at the right side –previously damaged side-. At 288 (Maximum Load), another sudden crack happened at the left side. The deflection at the failure was 5.42 mm. The failure mode was diagonally shear failure.

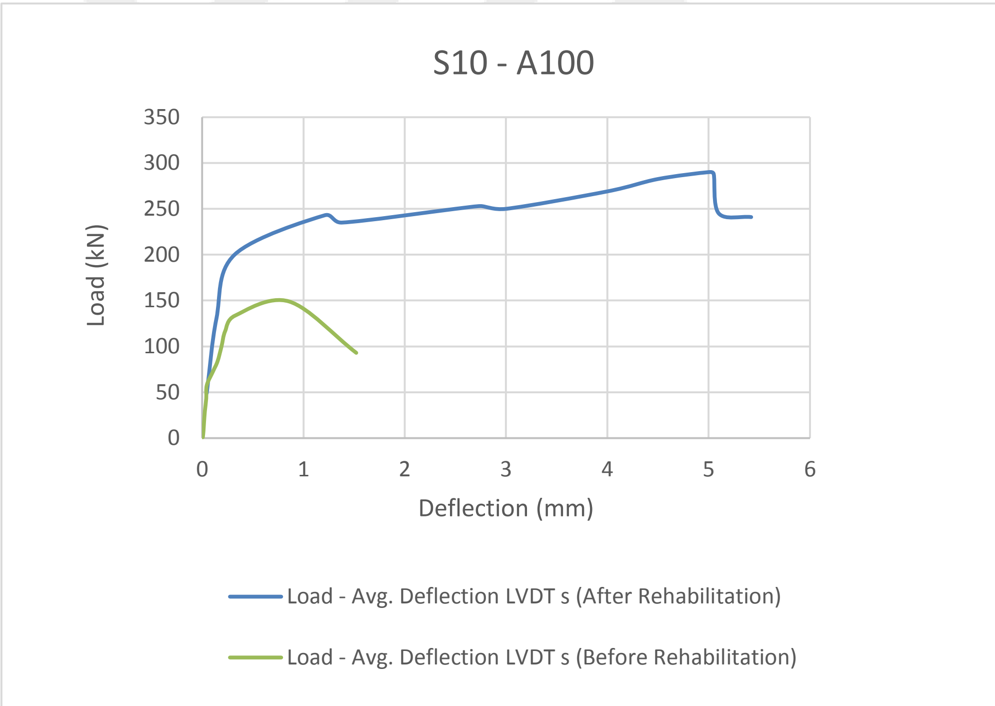


Figure 4.24 Effect of rehabilitation, style-3 (Specimen S10 - A100)

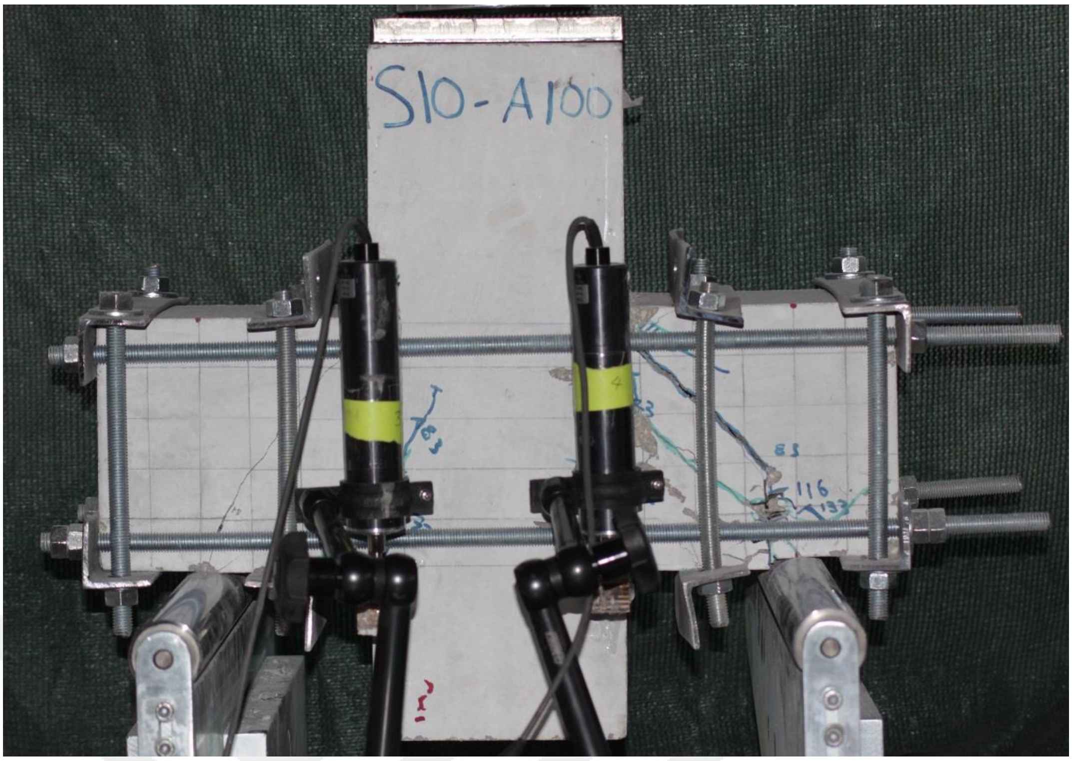


Figure 4.25 (Specimen S8 - A100) in the test machine

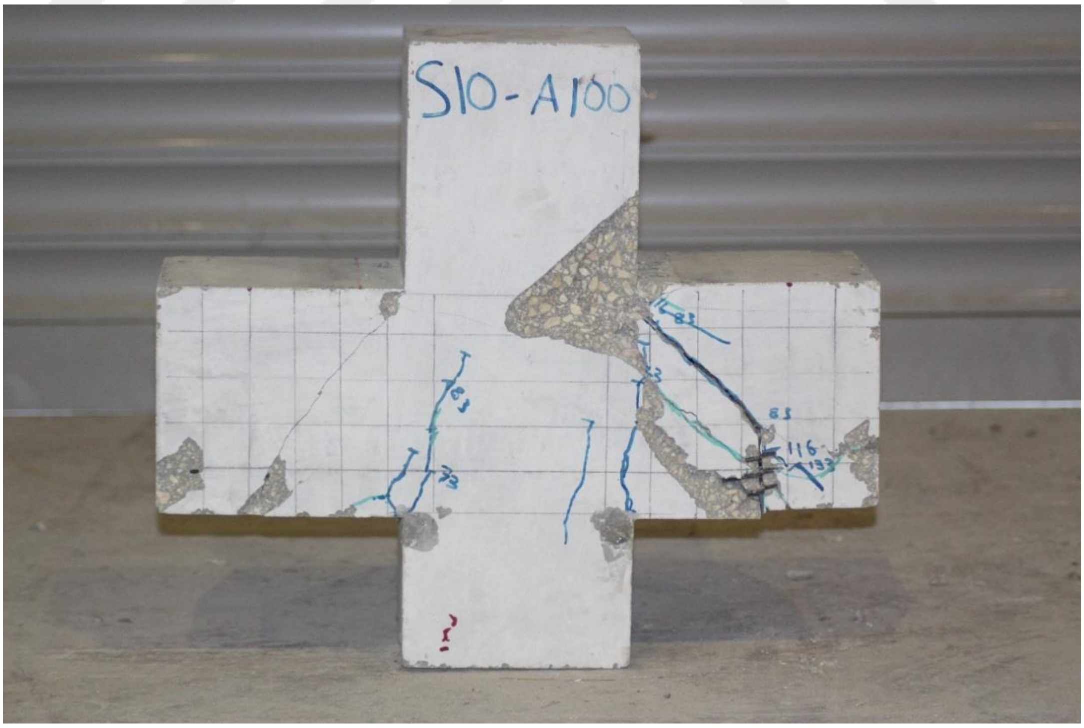


Figure 4.26 Unconfined (Specimen S8 - A100) after testing

4.5 Response of Style-4 Specimens (8 Steel pieces – with Epoxies)

4.5.1 Response of Specimen (S8-A120)

Specimen (S8-A120) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.27 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 81.5 kN at the right side –previously damaged side-. At 191 kN, a sudden crack occurred at the same side. At 243 (Maximum Load), the crack started to grow seriously. The deflection at the failure was 7.2 mm. The failure mode of the both sides was diagonally shear failure.

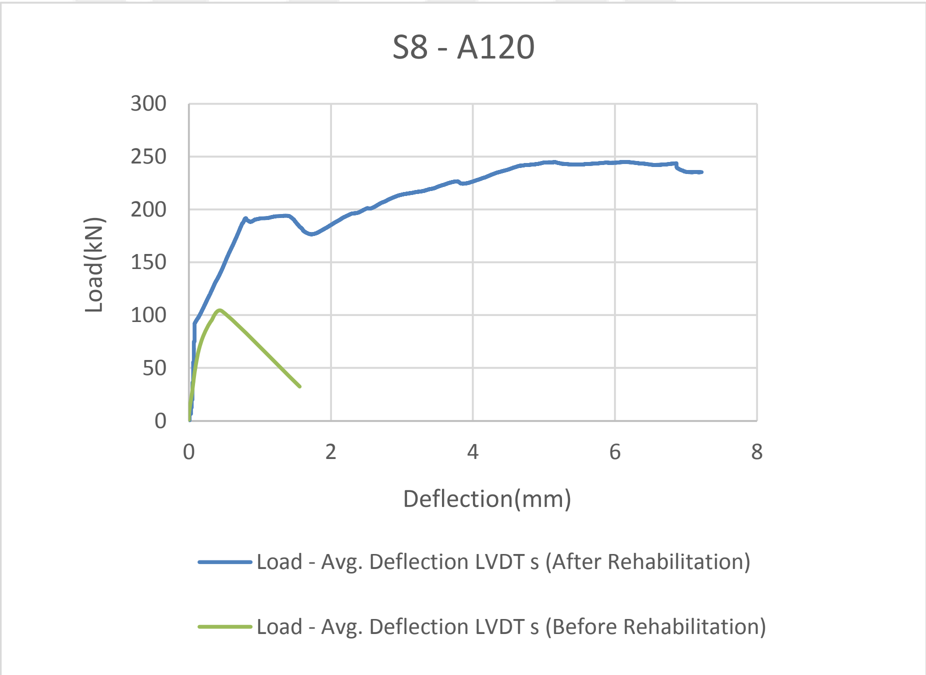


Figure 4.27 Effect of rehabilitation, style-4 (Specimen S8 - A120)

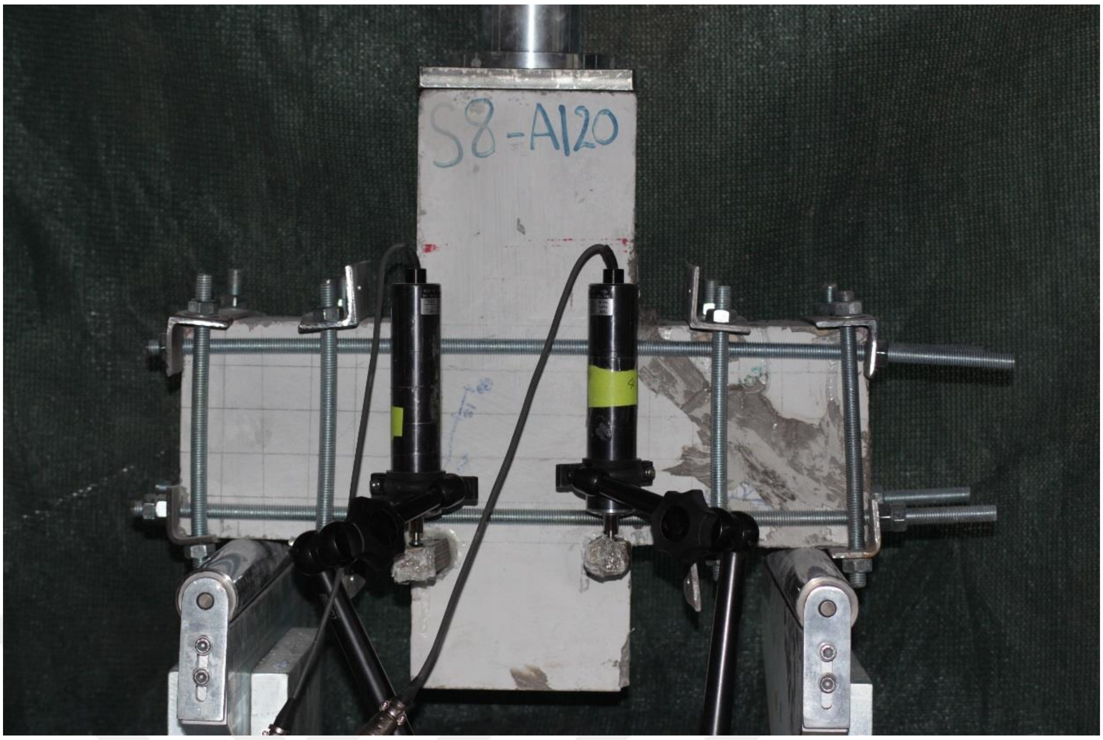


Figure 4.28 (Specimen S8 - A120) in the test machine

Figure 4.29 Unconfined (Specimen S8 - A120) after testing

4.5.2 Response of Specimen (S8-120-0.4%)

Specimen (S8-120-0.4%) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.30 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 75.3 kN at the right and left sides respectively – both were previously damaged -. At 150 kN, a sudden crack occurred at the same side. At 205 (Maximum Load), the crack started to grow seriously until it failed at the right side. The deflection at the failure was 9.45 mm. The failure mode of the both sides was diagonally shear failure.

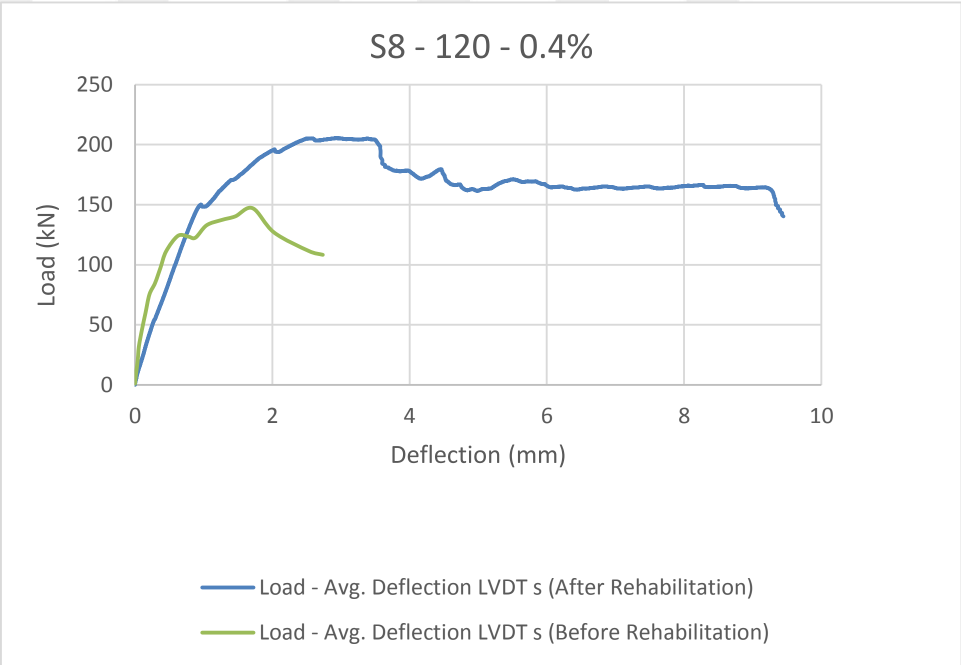


Figure 4.30 Effect of rehabilitation, style-4 (Specimen S8 - 120 - 0.4%)

Figure 4.31 (Specimen S8 - 120 - 0.4%) in the test machine

Figure 4.32 Unconfined (Specimen S8 - 120 - 0.4%) after testing

4.5.3 Response of Specimen (S8-100)

Specimen (S8-100) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.33 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 60 kN at the right side -previously damaged -. At 248 kN, a sudden crack occurred at the same side. At 291 (Maximum Load), the crack started to grow seriously until it failed at the same side. The deflection at the failure was 5.24 mm. The failure mode was diagonally shear failure.

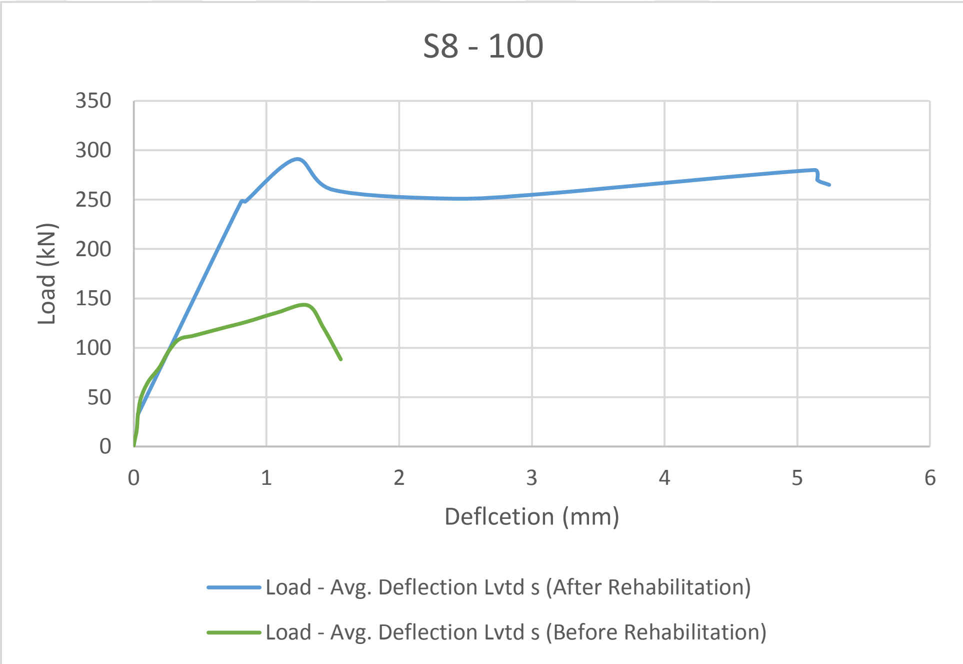


Figure 4.33 Effect of rehabilitation, style-4 (Specimen S8 – 100)

Figure 4.34 (Specimen S8 - 100) in the test machine

Figure 4.35 Unconfined (Specimen S8 - 100) after testing

4.5.4 Response of Specimen (S8-100-0.4%)

Specimen (S8-100-0.4%) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.36 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 100.6 kN at the left side. After this point, the crack started to grow. At 295 kN (Maximum Load), a sudden big crack occurred at the same side –left -. Later, the specimen failed strongly at the same side. The deflection at the failure was 7.81 mm. The failure mode was diagonally shear failure.

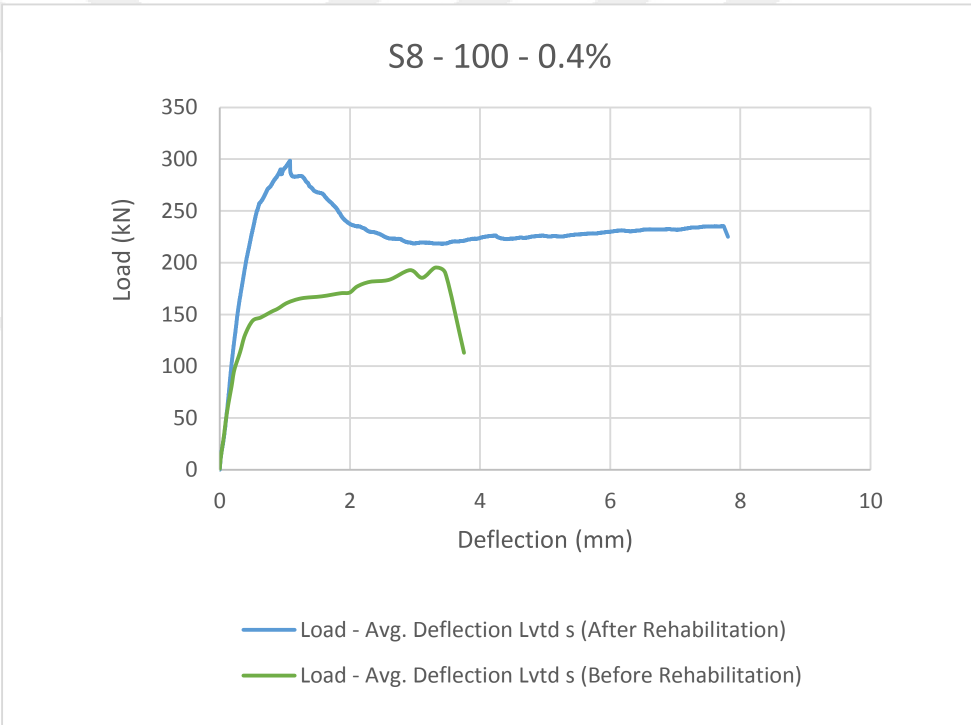


Figure 4.36 Effect of rehabilitation, style-4 (Specimen S8 - 100 - 0.4%)

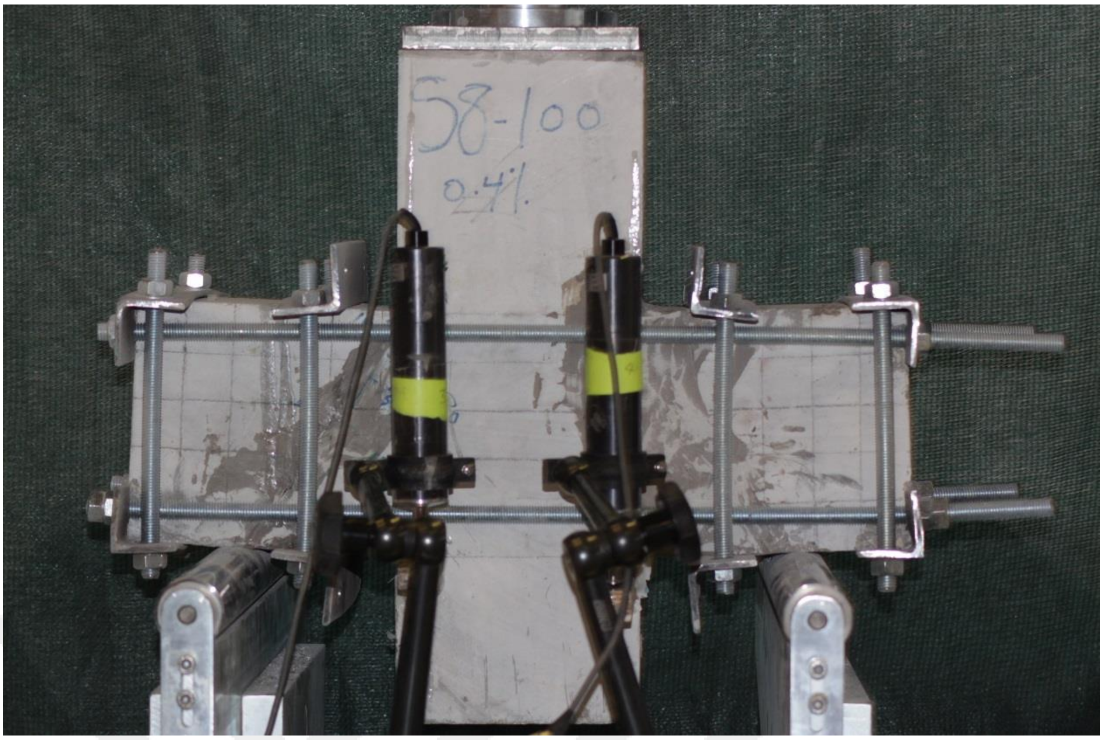


Figure 4.37 (Specimen S8 - 100 - 0.4%) in the test machine

Figure 4.38 Unconfined (Specimen S8 - 100 - 0.4%) after testing

4.5.5 Response of Specimen (S8-A80)

Specimen (S8-A80) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.39 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 100.6 kN at the right side –previously damaged side-. At 260 kN, another crack started to appear at the left side –not damaged side-. At 318 kN (Maximum Load), a sudden big crack occurred at the right side. Later, the specimen failed strongly at the righ side. The deflection at the failure was 5.96 mm. The failure mode was diagonally shear failure.

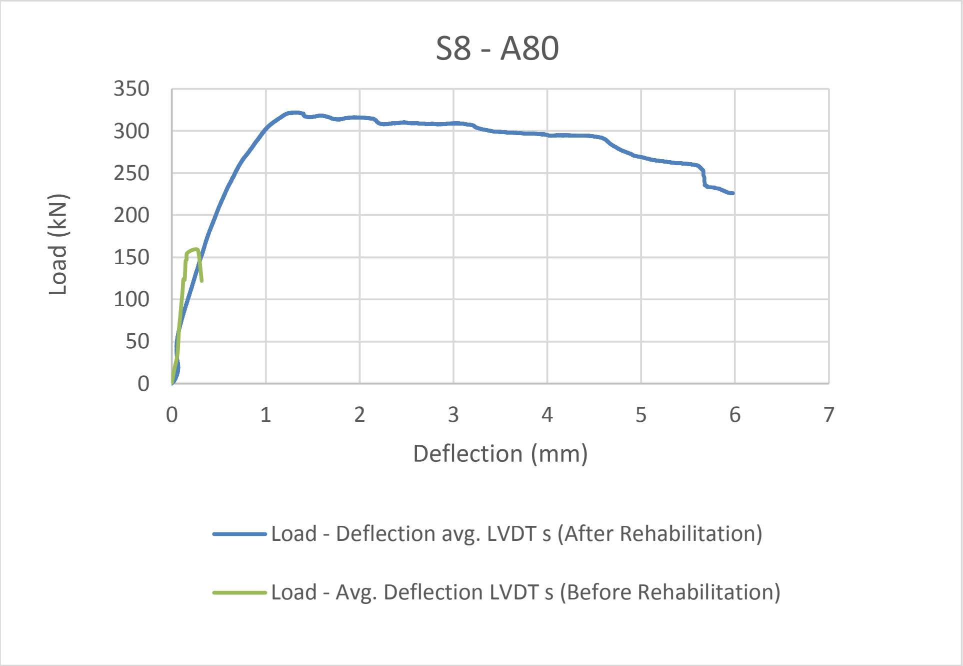


Figure 4.39 Effect of rehabilitation, style-4 (Specimen S8 – A80)

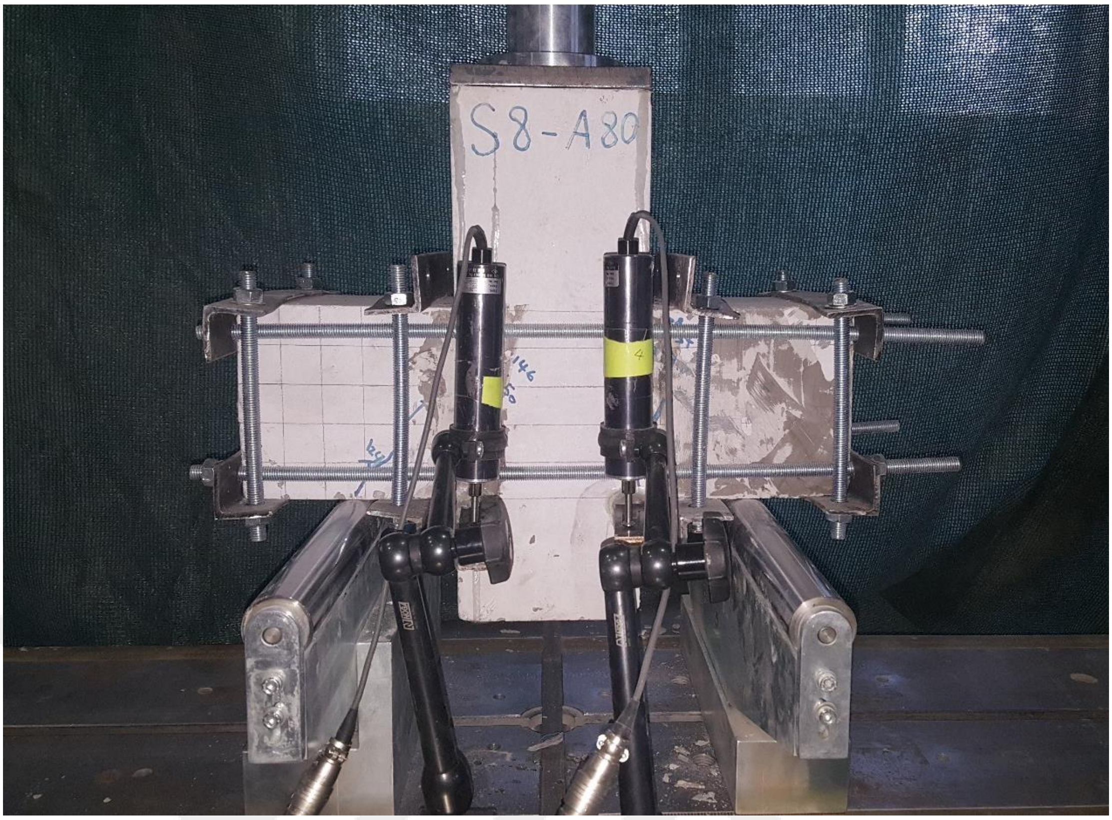


Figure 4.40 (Specimen S8 - A80) in the test machine

Figure 4.41 Unconfined (Specimen S8 – A80) after testing

4.5.6 Response of Specimen (S8-A80-0.2%)

Specimen (S8-A80-0.2%) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.42 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 80 kN at the right side –previously damaged side-. At 291 kN, another crack started to appear at the left side –not damaged side-. At 313 kN (Maximum Load), a sudden big crack occurred at the right side. Later, the specimen failed strongly at the righ side. The deflection at the failure was 7.23 mm. The failure mode was diagonally shear failure.

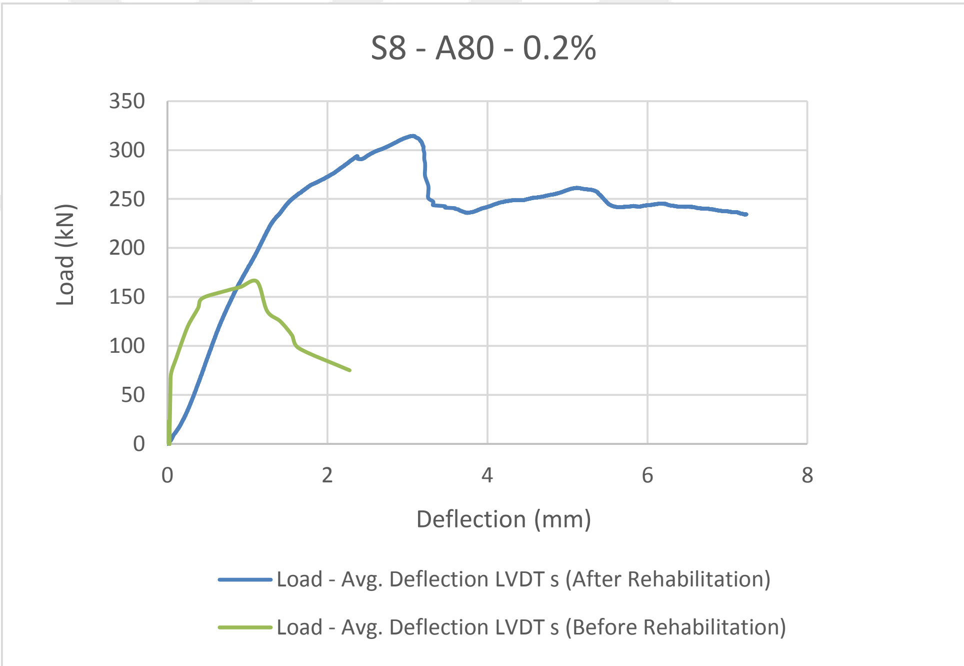


Figure 4.42 Effect of rehabilitation, style-4 (Specimen S8 – A80 – 0.2%)

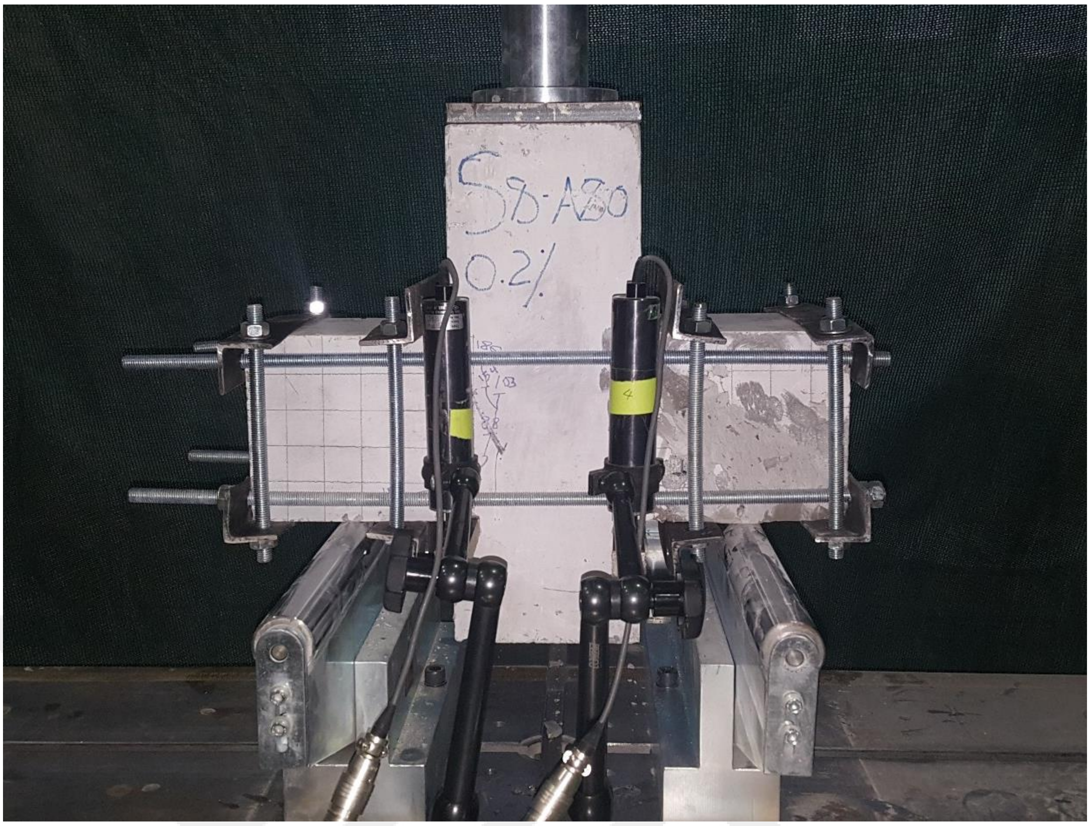


Figure 4.43 (Specimen S8 - A80 – 0.2%) in the test machine

Figure 4.44 Unconfined (Specimen S8 – A80 – 0.2%) after testing

4.5.7 Response of Specimen (S8-A80-0.4%)

Specimen (S8-A80-0.4%) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.45 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 196 kN at the right side (previously damaged side). At 273 kN, another crack started to appear at the left side –not damaged side-. At 314 kN (Maximum Load), a sudden big crack occurred at the right side. Later, the specimen failed strongly at the righ side. The deflection at the failure was 7.34 mm. The failure mode was diagonally shear failure.

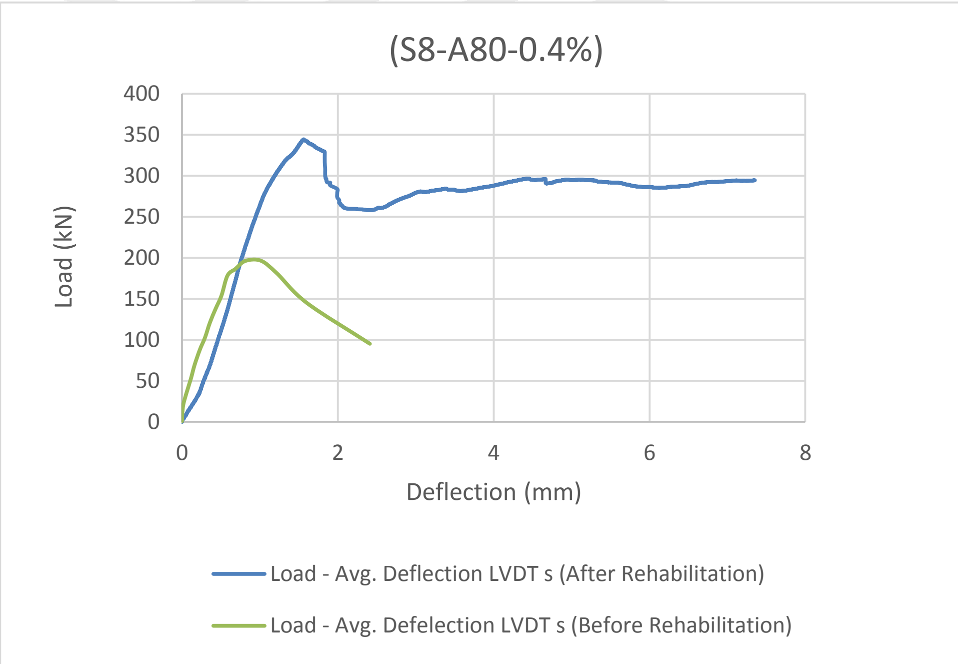


Figure 4.45 Effect of rehabilitation, style-4 (Specimen S8 – A80 – 0.4%)

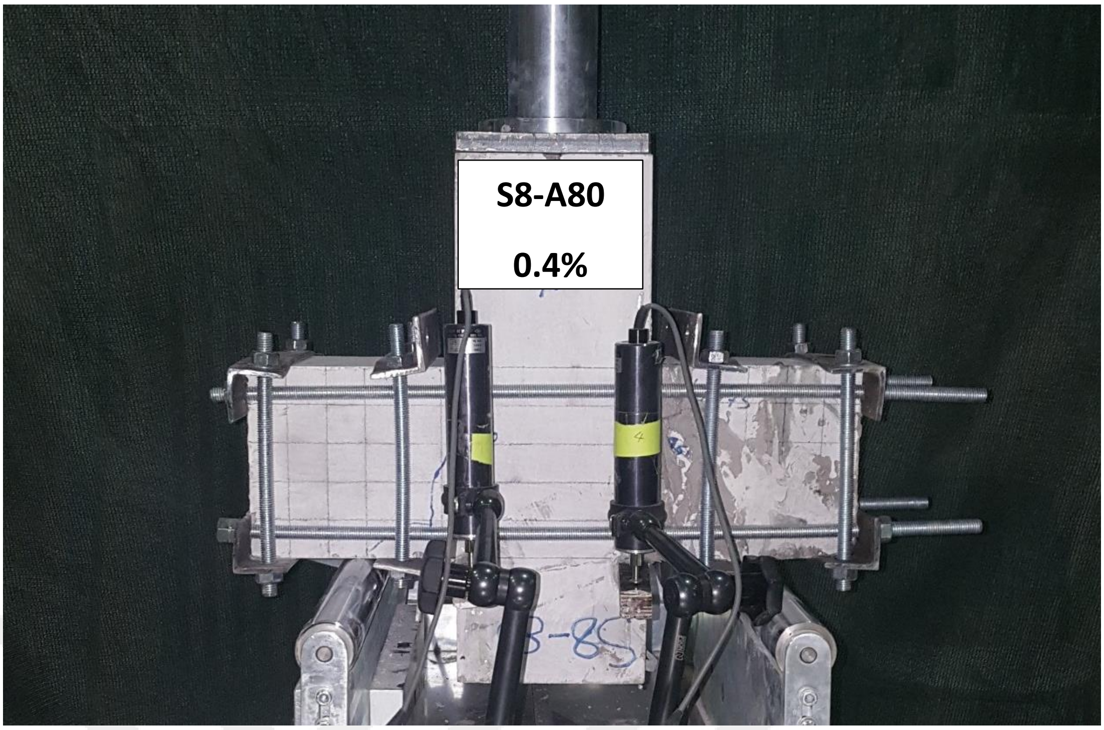


Figure 4.46 (Specimen S8 - A80 – 0.4%) in the test machine

Figure 4.47 Unconfined (Specimen S8 – A80 – 0.4%) after testing

4.5.8 Response of Specimen (S8-80)

Specimen (S8-80) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.48 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 122 kN at the left side –previously damaged side-. At 247.2 kN, another crack started to appear at the right side –not damaged side-. At 319 kN a sudden big crack occurred at the left side. Later, the specimen failed strongly at the righ side. The deflection at the failure was 5.77 mm and the maximum load was (347.3 kN). The failure mode was diagonally shear failure.

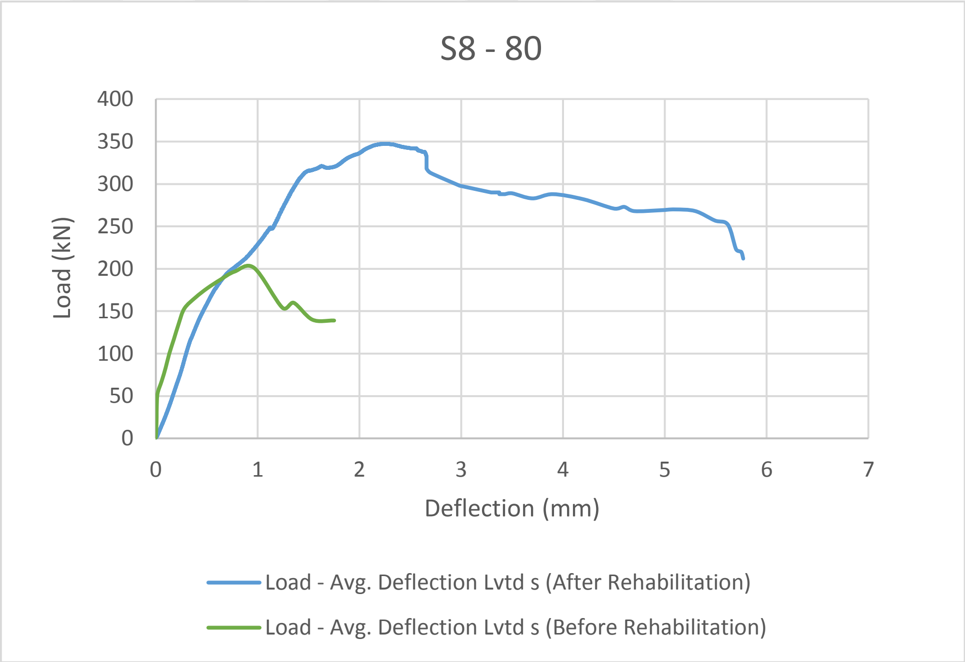


Figure 4.48 Effect of rehabilitation, style-4 (Specimen S8 - 80)

Figure 4.49 (Specimen S8 - 80) in the test machine

Figure 4.50 Unconfined (Specimen S8 - 80) after testing

4.5.9 Response of Specimen (S8-80-0.4%)

Specimen (S8-80-0.4%) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.51 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 113.4 kN at the right side –previously damaged side-. At 242 kN, another crack started to appear at the left side –not damaged side-. At 318 kN (Maximum Load), the crack at the right side began to grow seriously. Later, the specimen failed strongly at the right side. The deflection at the failure was 6.4 mm. The failure mode was diagonally shear failure.

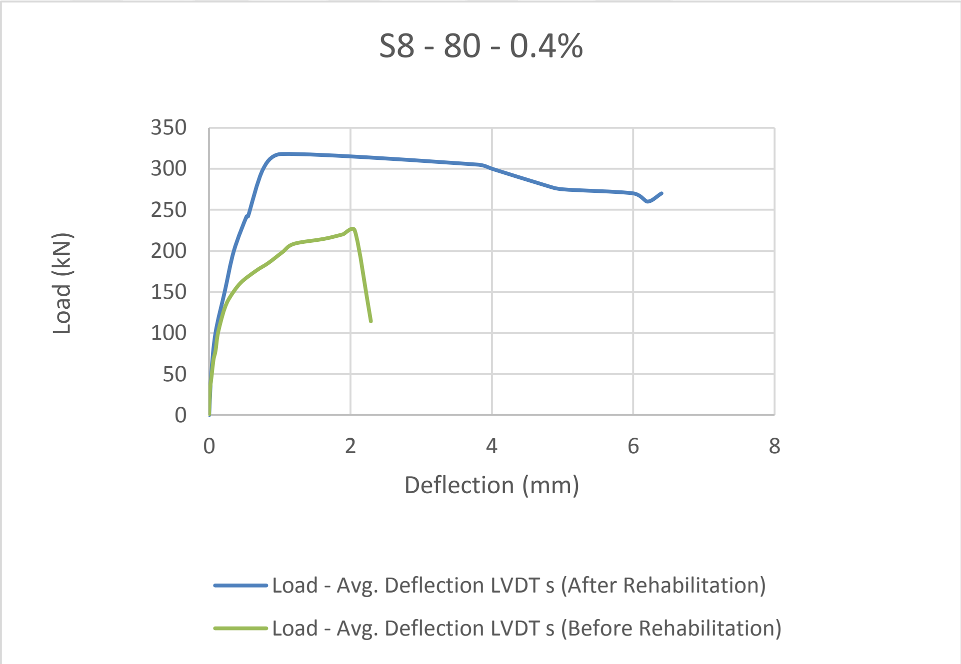


Figure 4.51 Effect of rehabilitation, style-4 (Specimen S8 - 80 - 0.4%)

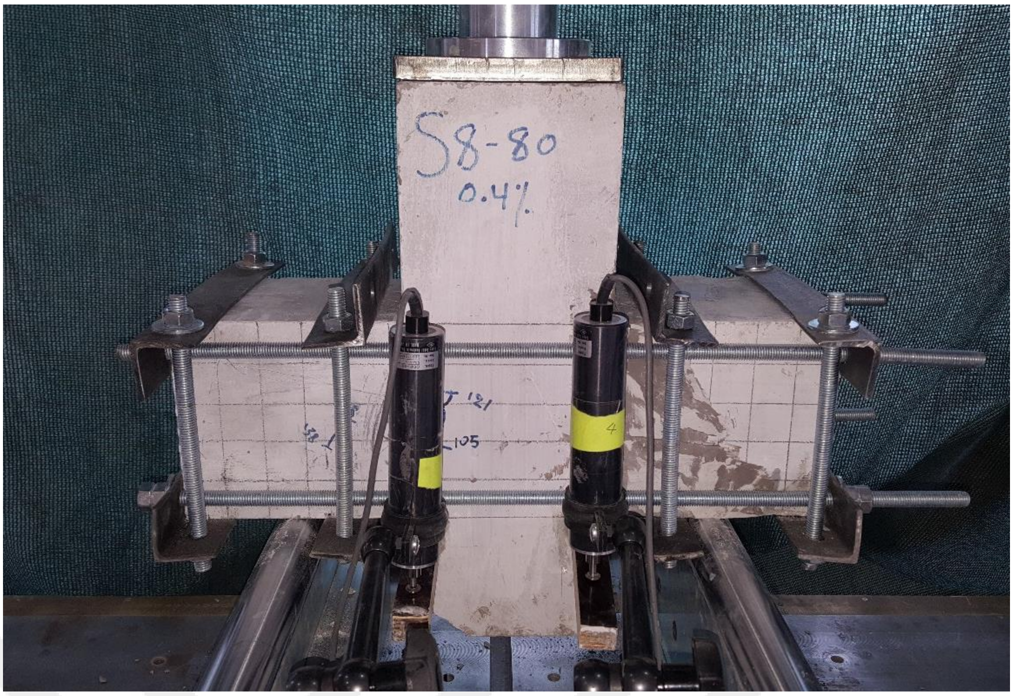


Figure 4.52 (Specimen S8 - 80 - 0.4%) in the test machine

Figure 4.53 Unconfined (Specimen S8 - 80 - 0.4%) after testing

4.5.10 Response of Specimen (S10-A120)

Specimen (S10-A120) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.54 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 99.4 kN at the left side –previously damaged side-. At 162 kN, another crack started to appear at the right side –not damaged side-. At 210 kN a sudden crack happened at the left side. At 249.7 kN (Maximum Load), the crack at the left side began to grow seriously. Later, the specimen failed strongly at the left side. The deflection at the failure was 8.84 mm. The failure mode was diagonally shear failure.

Figure 4.54 Effect of rehabilitation, style-4 (Specimen S10 - A120)

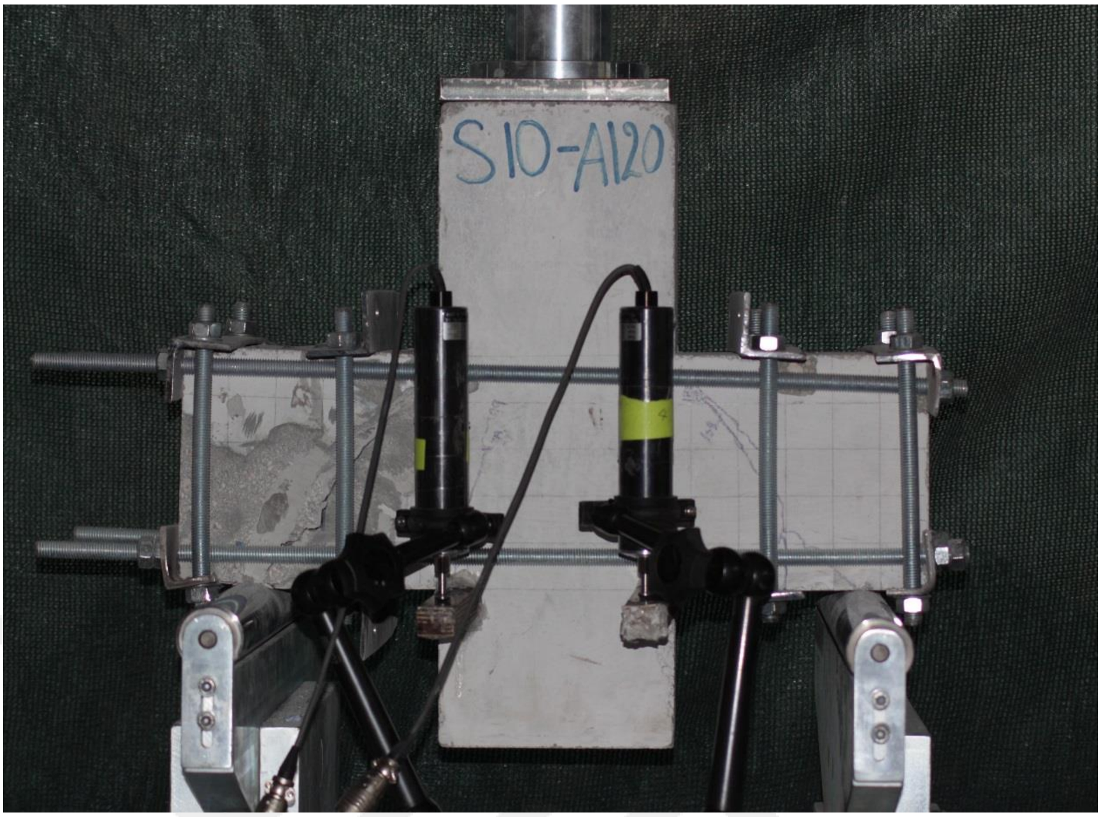


Figure 4.55 (Specimen S10 - A120) in the test machine

Figure 4.56 Unconfined (Specimen S10 - A120) after testing

4.5.11 Response of Specimen (S10-A80)

Specimen (S10-A120) is a rehabilitated -previously shear failed- RC corbel. The used style of rehabilitation was Style-4. This style consists of repairing the cracks with epoxies, then, confining the corbel using 8 L-Sections. Figure 4.57 shows the Load-Deflection behavior of the specimen before and after rehabilitation. The first crack propagation have been recorded at 116 kN at the right side –previously damaged side- and the crack began to grow. At 377.6 kN (Maximum Load), the crack at the right side began to grow seriously. Then, a sudden crack happened at the right side at (337.6 kN). Later, the specimen failed strongly at the same side. The deflection at the failure was 9.55 mm. The failure mode was diagonally shear failure.

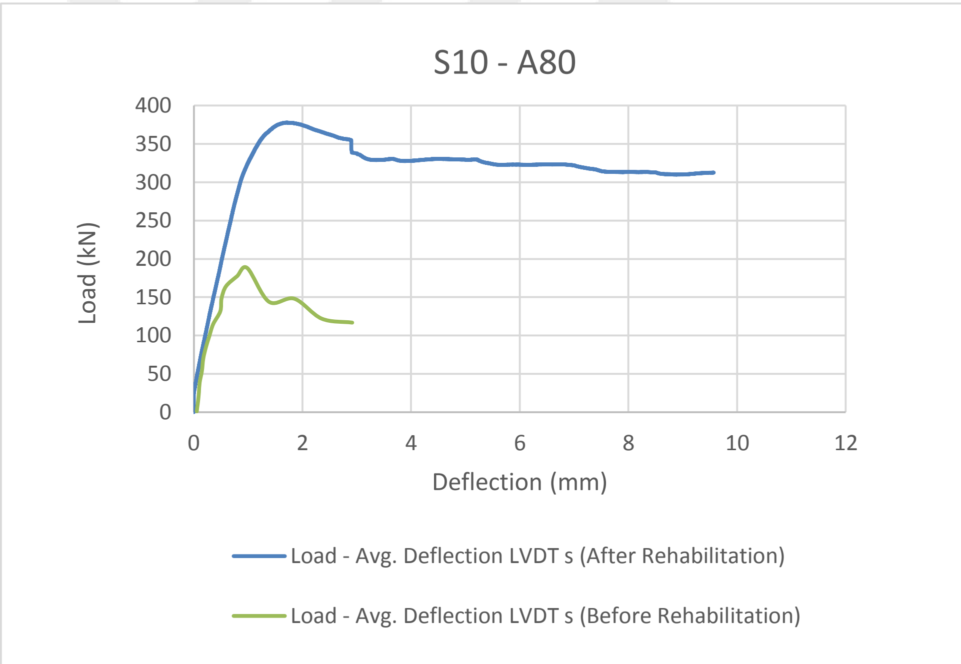


Figure 4.57 Effect of rehabilitation, style-4 (Specimen S10 – A80)

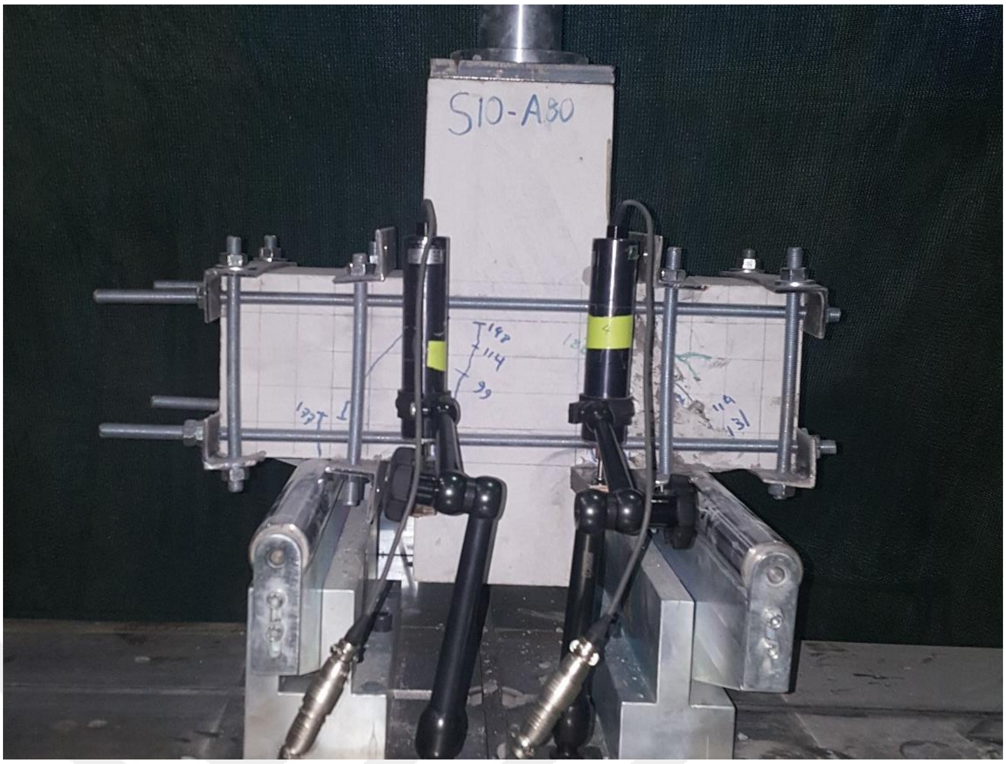


Figure 4.58 (Specimen S10 – A80) in the test machine

Figure 4.59 Unconfined (Specimen S10 – A80) after testing

4.6 Results Comparison

There were several factors determined the efficiency of each style used for rehabilitation. The steel confinement affected as a double factor, a factor of load capacity, and a factor of ductility of the specimens. While, the injection materials (Epoxies) were factors of bonding the sides of the cracks and provide the members extra strength. The previous remarks were general, and the details will be shown with the graphs and tables below. Average values are given in Table 4.1.

Table. 4.1 Average values of recovery

Style of Rehabilitation	Average of Load Capacity Recovery %	Average of Energy absorption Recovery %
Style-1 (Control Style)	100	332
Style-2	152	286
Style-3	192	790
Style-4	184	782

Results show that the used technique is very effective, and could recover the original performance easily. However, the improvement rates vary due to different factors that will be discussed next at this section.

By examining the results, it was observed that shear span affects the rehabilitation efficiency, figure (4.60). Specimens with larger shear span were recovered better than those with smaller shear spans. This remark was obvious especially in styles-(2, and 3). This may be because of two reasons: first reason, the activity of the steel system starts at earlier time, since the epoxies have no serious effect in large spans and fail early. The second reason, the old performances were different, while, the new performances are more similar because the rehabilitation system forms a new composite material instead of the concrete. The figure (4.61) gives a further explanation about this point.

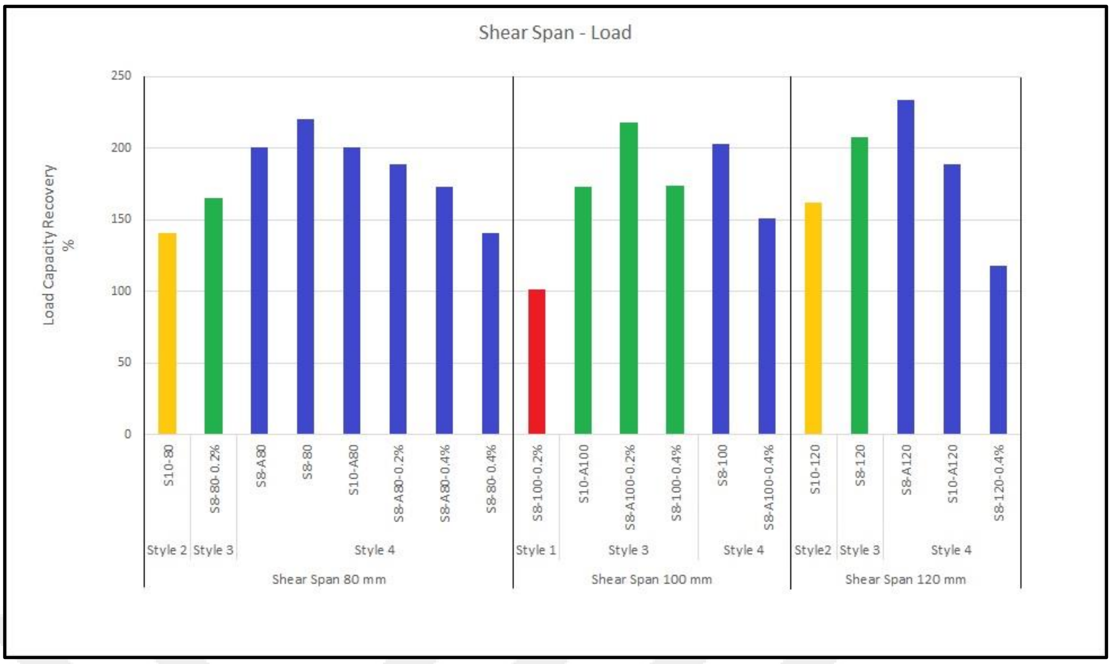
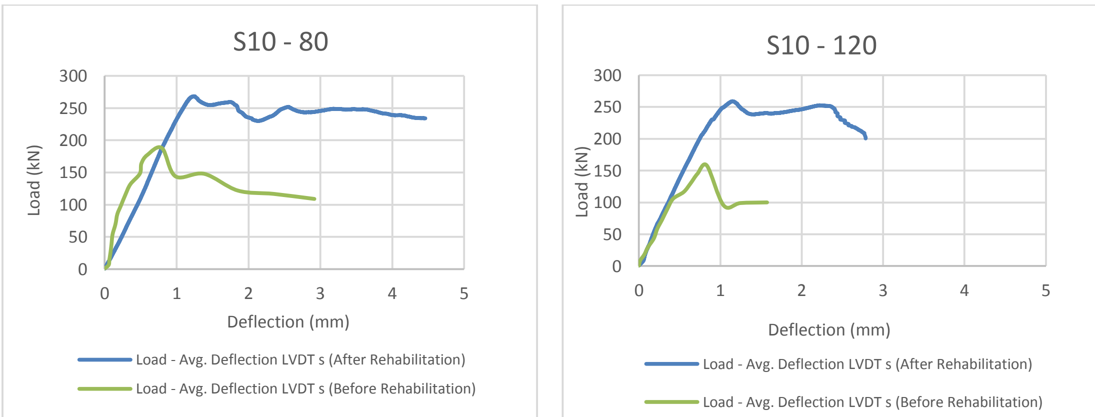


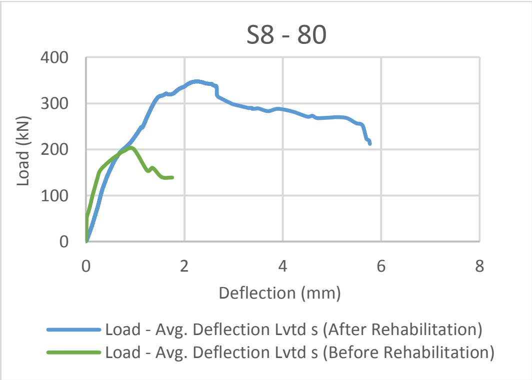
Figure 4.60 Relation between load capacity recovery and shear span according to rehabilitation styles



(a) Style-2, shear span of 80 mm (b) Style-2, shear span of 120 mm

Figure 4.61 Effect of the glass fibers on the improvement ratio after rehabilitation:

(a) Style-2, shear span of 80 mm. (b) Style-2, shear span of 120 mm.



(c) Style-4, shear span (80 mm)

(d) Style-4, shear span (100 mm)

Figure 4.61 Effect of the glass fibers on the improvement ratio after rehabilitation: (c) Style-4, shear span of 80 mm. (d) Style-4, shear span of 100 mm.

In style-4, the epoxy system fails later than style-2 because of the perpendicular pieces of threaded rods. These pieces let the repaired concrete work. So, steel system don't work directly till the epoxy system fails. Therefore, the high rates of energy absorption starts after the epoxy fails. It was noticed once the epoxy fails, it causes a sudden loading on the steel system, and this load affects the performance of the steel slightly. However, the performance stills very active.

For specimens that were sudden failed previously, values of energy absorption recovery have been neglected because their old energy absorptions were too small (neglected). However, the new energy absorptions have been calculated, and good results have been obtained because of the effect of steel confinement, Table 4.2. For more details, Table 4.3 is giving full details about the improvement of all the specimens.

Table 4.2 energy absorption values of previously sudden failed specimens

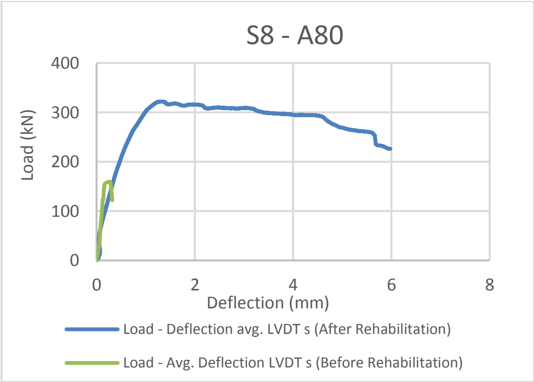
Specimen	Energy absorption after rehabilitation (J)
S8-A80	1648
S8-80	1530

Table 4.3 Details of Improvements

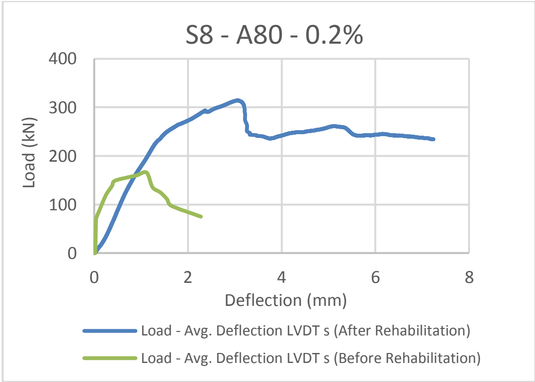
Style	Sample	Old Load Capacity	New Load Capacity	Δ Load Capacity	Load Capacity Recovery	Old Energy Absorption	New Energy Absorption	Energy Absorption Recovery
Style 1	S8-100-0.2%	173	174	1	101	255	847	332
Style]2	S10-80	188	265	77	141	371	952	257
	S10-120	158	256	98	162	148	571	286
Style 3	S8-80-0.2%	217	359	142	165	353	750	212
	S10-A100	201	347	146	173	175	1306	746
	S8-A100-0.2%	144	314	170	218	180	778	432
	S8-100-0.4%	155	270	115	174	593	1811	305
	S8-120	124	258	134	208	83	1392	1677
Style 4	*S8-A80	158	318	160	201	29	1648	5683
	*S8-80	158	347	189	220	34	1530	4500
	S10-A80	188	378	190	201	382	3023	791
	S8-A80-0.2%	166	313	147	189	256	1672	653
	S8-A80-0.4%	197	341	144	173	324	1946	601
	S8-80-0.4%	225	318	93	141	397	3216	810
	S8-100	143	291	148	203	144	1266	879
	S8-A100-0.4%	195	295	100	151	158	924	585
	S8-A120	104	243	139	234	100	1502	1502
	S10-A120	132	250	118	189	273	1970	722
	S8-120-0.4%	174	205	31	118	304	1534	505

It was observed that improvement of samples contain less glass fibers were higher than those with more glass fibers. In figure 4.62, we can see results of specimens (S8-A80), (S8-A80-0.2%), and (S8-A80-0.4%), which have been rehabilitated by style-4. Their load capacities have been increased to 201%, 189% and 173% respectively. The high load capacity is due to the confinement mainly. The strong confinement provides a high friction between the sides of the crack. While the epoxy provides an extra strength by bonding the sides of the crack.

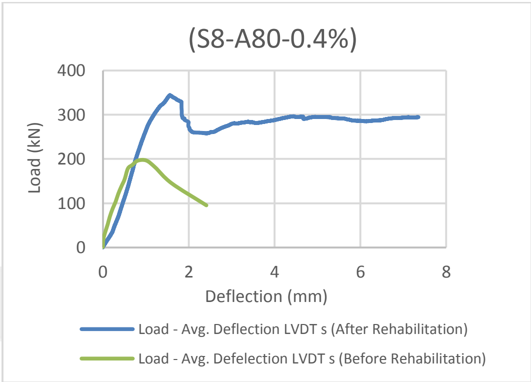
The absorbed energy for specimens (S8-A80-0.2%), and (S8-A80-0.4%) were increased to 653%, and 601% respectively, figure 4.63. While, the recovery of (S8-80) was not measured because it was previously sudden failed, and the new energy absorption was (1530 J), see Table 4.3.



(a) 0% Glass Fibers



(b) 0.2% Glass Fibers



(c) 0.4% Glass Fibers

Figure 4.62 Effect of the glass fibers on the improvement ratio after rehabilitation by style-4: (a) 0% Glass Fibers. (b) 0.2% Glass Fibers. (c) 0.4% Glass Fibers

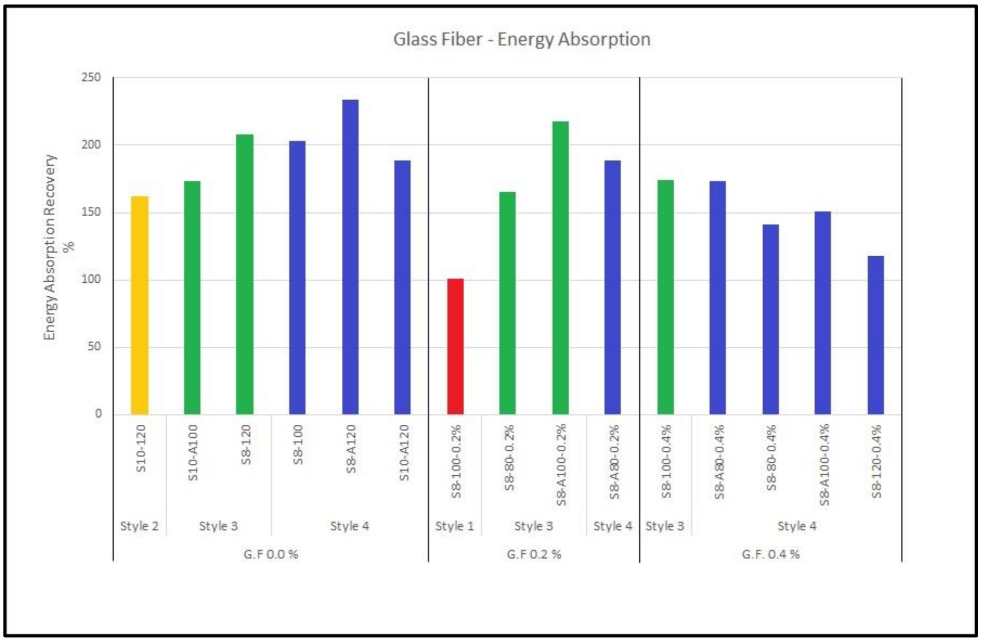
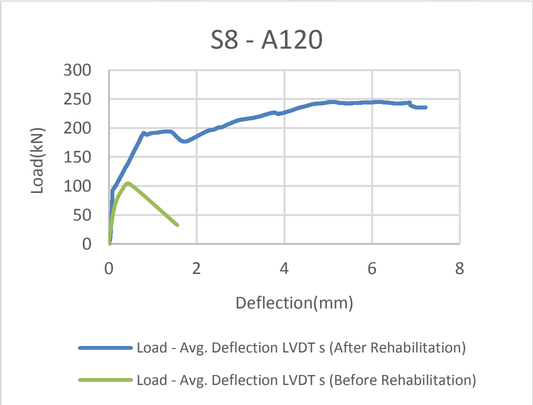


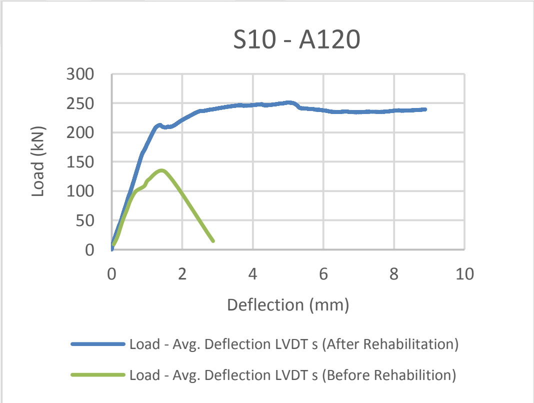
Figure 4.63 Energy absorption recovery according to glass fiber content

The inverse relation between glass fibers and the rehabilitation efficiency is almost because the glass fibers prevent the epoxies to fill the tiny cracks completely.

In figures 4.64 (a) and (b), results of the two specimens (S8-A120) and (S10-A120). They were rehabilitated by style-4 and had different diameters of the reinforcement steel (ϕ). Their responses to the rehabilitation were different. Their load capacities were increased to 234% and 189% respectively.

The absorbed energy values were increased to 1502% and 722% respectively, figure 4.65. These results indicates that the response of the corbels with smaller steel diameter for rehabilitation is higher than those with larger diameters ones. This is mostly because of the response of the pre-deformed steel. The larger diameter means stiffer steel, and stiffer steel means less responding steel to deformation. However, the style-4 is highly effective in the two situations and gives desired results.





(a) ϕ 8 mm

(b) ϕ 10 mm

Figure 4.64 Effect of reinforcement steel diameter (ϕ) on the improvement ratio after rehabilitation: (a) ϕ 8 mm. (b) ϕ 10 mm.

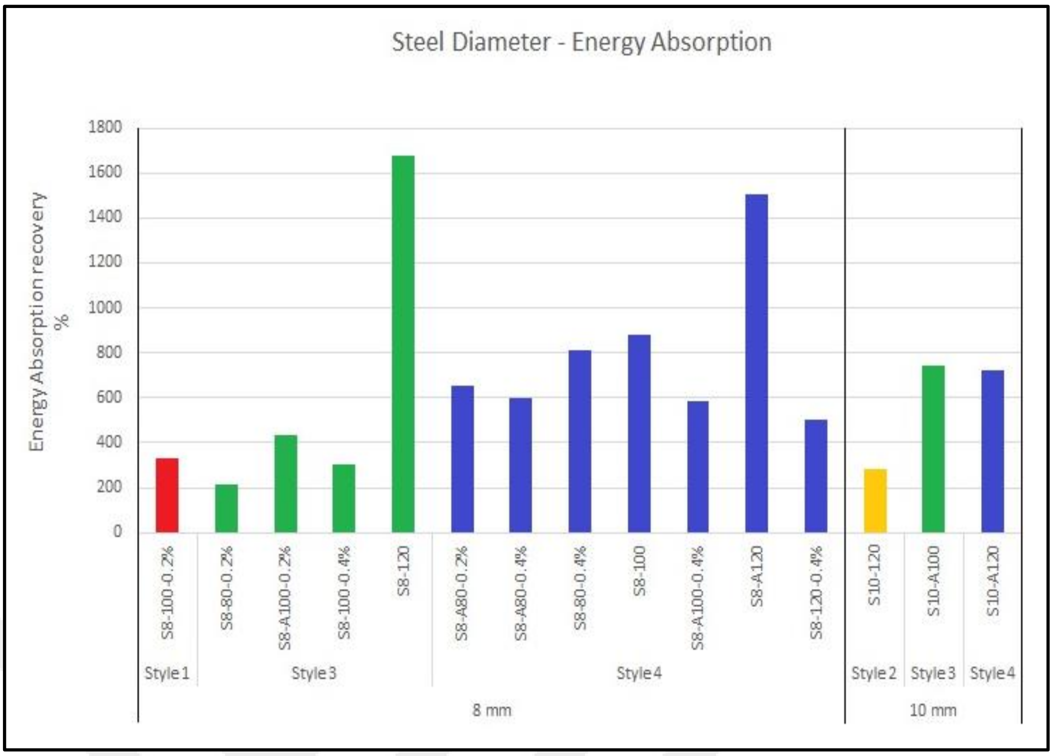
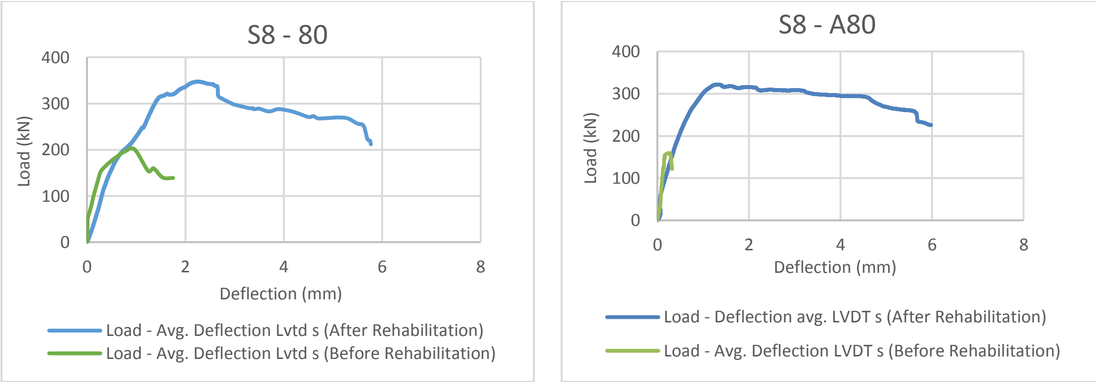


Figure 4.65: Energy absorption recovery according to reinforcement steel diameter

The two specimens (S8-80) and (S8-A80) have been rehabilitated by style-4, and their results are as shown in figure 4.66 (a, and b). They have different compressive strengths. (S8-80) is high strength concrete, while, (S8-A80) was made of normal strength concrete. Their load capacities were increased to 219% and 201% respectively, figure 4.67, and energy absorption values were 1530 J and 1648 J respectively, Table 4.2. The results are close to each other generally, these results tell us that the rehabilitation system is responsible of the load capacity and the energy absorption of the member. While, the compressive strength of the concrete has no obvious effect. The failure modes were diagonally shear failure and cracks appeared from the both sides.



(a) High strength

(b) Normal Strength

Figure 4.66 Effect of concrete strength on the improvement ratio after rehabilitation: (a) High strength. (b) Normal Strength.

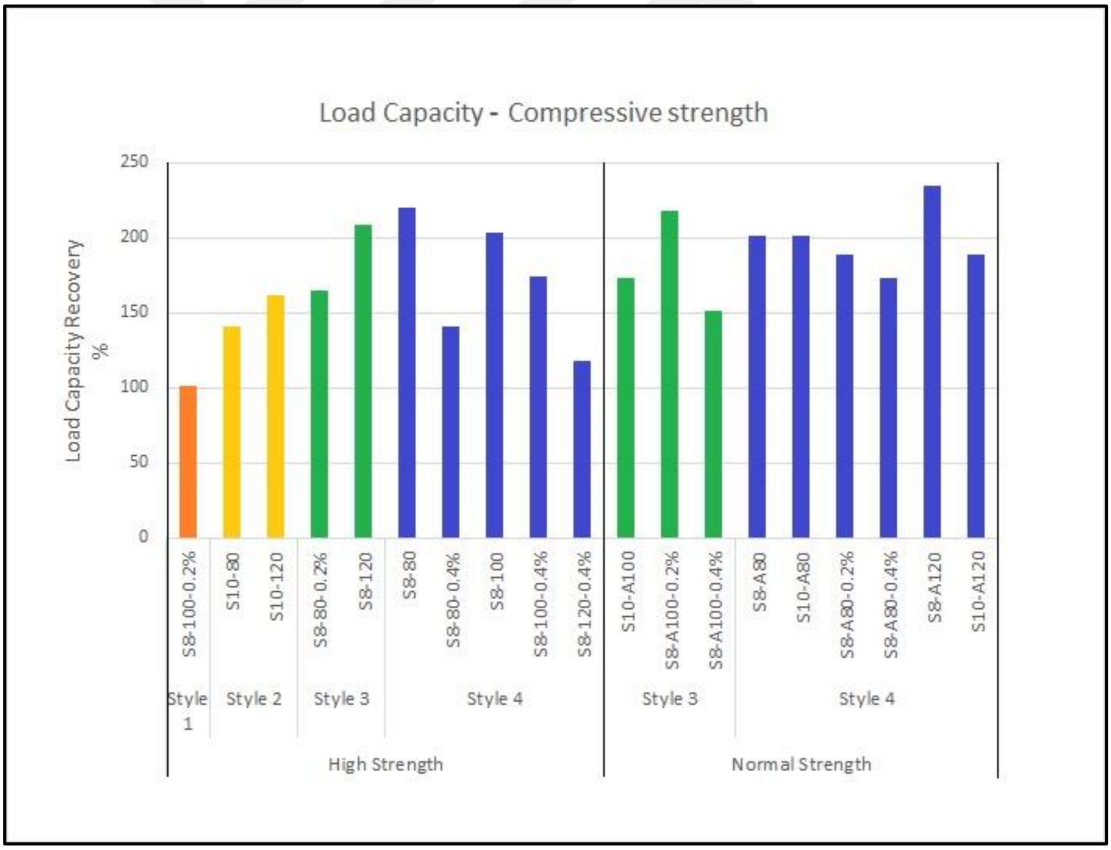


Figure 4.67: Load capacity recovery according to compressive strength

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Corbels are widely used in precast construction, and generally used in the huge buildings, such as, industrial buildings. Therefore, the problem of cracking due to diagonal shear forces is common in these members, and, as the rebuilding is not a preferred option –because of the financial regards-, an available economic rehabilitation will be a desired option. Many researches have been done about corbels and their behavior, however, there are no studies about corbels rehabilitation. This is the first study of rehabilitating RC corbels using steel confining and injecting techniques, and the rehabilitated pre-damaged specimens had the same dimensions but the different characteristics of shear-span, reinforcement steel diameter, glass fiber content, and the strength of the concrete. In the other hand, they got treated with 4 different styles. The following topics are presented in this thesis:

- A literature review about concrete strengthening, injecting, and shear failure.
- An experimental program about RC concrete rehabilitation using steel confining and injecting with epoxies in four different styles.
- Examining the results and discussing the responses of the specimens.

Corbels are members that could be regarded short cantilevers that behave as deep beams, where, it is designed for shear. These members have an important role in supporting precast beams at columns, so, the ductility and the strength of the corbel are the chief structural characteristics. Basing on the results of the experimental investigation, the following conclusions can be obtained:

1. The technique is so effective and can easily recover the original load capacity and the energy absorption of the specimen.

2. Steel confinement compresses the member highly, and this compression provides a high friction between the two sides of cracks. The high load capacity friction resists the diagonal shear force.
3. Members with larger shear span were improved more than those with smaller shear span, and this is mostly because the confinement steel systems start to work earlier.
4. Compressive strength of the concrete has no clear effect on the rehabilitation. The reason is that the concrete was failed previously, and after the rehabilitation we get new composite materials with new properties that depends basically on the properties of epoxies and steel.
5. Members confined with styles containing perpendicular rods (styles 3, and 4) showed a very high load capacity. This is because the confining perpendicular rods work to resist any sliding caused by diagonal shear forces.
6. Members that contain less glass fibers are improved better than those with more glass fiber, and this is mostly because the glass fibers prevent the very low viscosity epoxy from filling cracks properly.
7. Corbels reinforced with smaller diameter steel are more responsive to the rehabilitation, since steel with larger diameter is stiffer and less responsive to reforming.
8. For epoxy treated members, existing of the perpendicular steels make the epoxy more effective because they press the center of the diagonal crack zone and protect it from sliding.
9. This technique could be applied in the field easily for any two-sided corbels.
10. In case of two-sided corbels with a wall separating them, this technique could be applied by drilling four holes to pass the rods of confinement system from these holes.

5.2 Recommendations for Future Research

Rehabilitation of RC concrete by confining and injecting is a new method, therefore, further studies will make a better understanding about the technique, as well as, lead to obtain more effective application methods. Different styles of rehabilitation have been done in this study, steel and epoxies were used. However, further studies could be take place using specimens with different parameters, different styles of rehabilitation, and different characteristics of the used materials.

ST37 Steel have been used in the tests, more investigations using steel sections with different characteristics are needed to understand the effect of the confining sections.

Threaded rods with diameter of ϕ12mm, yield strength of 438 MPa, and ultimate strength of 475 MPa have been used, it was noticed that existing of these rods in the midpoint of the shear span has an important role in increasing the load capacity, so, using rods with different diameters and strengths could lead to different results.

Only L40×40×4 steel sections have been used in the tests, and for additional understanding the effect of the confining sections, L-sections with different dimensions could be used.

Effect of using other sections could be investigated, where, C-sections with large dimensions for the ends and steel plates at the mid points of shear spans could lead to different results and further understanding the effect of steel sections used in confining.

Epoxies used for coating and injecting the specimens, investigating about the use of varied coating and injecting materials make a clearer view about the effect of coating and injecting materials on the rehabilitation of corbels.

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