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Rehabilitation of normal and self-compacted steel fiber reinforced concrete corbels via basalt fiber

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Abstract. This paper investigates the behavior of normal and self-compacted steel fiber reinforced concrete (SCC-SFRC) corbels rehabilitated by Basalt Fiber Mesh (BFM) and Basalt Fiber Fabric (BFF) for the first time in literature. The research objective is to study the effectiveness of BFM and BFF in the rehabilitation of damaged reinforced concrete corbels with and without epoxy injection. The experimental program includes two types of concrete: normal concrete, and self-compacted concrete. For normal concrete, 12 corbels were rehabilitated by BFM without injection epoxy in cracks, with two values of compressive strength, three ratios of steel fiber (SF), and two values of shear span. For self-compacted concrete, 48 corbels were rehabilitated with different parameters where 12 corbels were rehabilitated by BFM with and without epoxy injection, 18 heated corbels with three different high-temperature level were rehabilitated by repairing cracks only by epoxy injection, and 18 heated corbels with three different high-temperature level were rehabilitated by repairing cracks by epoxy and wrapping by BFF. All 48 corbels have two values of compressive strength, three values volumetric ratios of SF, and two values of the shear span. Test results indicate that RC corbels rehabilitated by BFM only without injection did not show any increase in the ultimate load capacity. Moreover, For RC corbels that were repaired by epoxy without basalt wrapping, the ultimate load capacities showed an increase depending on the mode of failure of corbels before the rehabilitation. However, the rehabilitation with only crack repairing by epoxy injection is more effective on medium strength corbels as compared to high strength ones. Finally, it can be concluded that use of BFF is an effective and powerful technique for the strengthening of damaged RC corbels.

Keywords: corbels; Self-Compacted Concrete (SCC); Steel Fiber(SF); rehabilitation; Basalt Fiber Mesh (BFM); Basalt Fiber Fabric (BFF)

1. Introduction

Corbels or brackets are reinforced concrete structural members with short cantilevers, with

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shear span-to-depth ratios not greater than one, which are tended to act as simple trusses or deep beams. The failure modes may occur by:

• Shearing along the interface between the column and corbel.
• Yielding of tension tie.
• Crushing or splitting of the compression strut.
• Localized bearing or shearing failure under the loading plate (ACI 318 2011).

Corbels or brackets can be used to support pre-cast structural systems like pre-cast beam and pre-stressed beam. Corbels or brackets became a standard feature in building construction and is typically cast with the column or wall members. The main function for the corbels is transferring the coming load from the beams the supporting columns or walls (Yong and Balaguru 1994, Foster *et al.* 1996, Hwang *et al*. 2000, Foster and Malik 2002, Hwang and Lee 2002, Russo *et al*. 2006, He *et al.* 2012). Structural cracks may occur in RC corbels like other structural members for several reasons. Cracks in the corbels should be strengthened or repaired before the collapse affected the members. In general, repairing is a part of the civil engineering field, to set right the deteriorated, damaged, corroded and aged RC structures, masonry structures, and steel structures. The repairing, retrofitting, rehabilitating and strengthening processes are based on the damage conditions of the structures (Kumar *et al.* 2015). Modern technology has developed new composite materials to increase and enhance the load carrying capacity and mechanical behavior of reinforced concrete members by increasing the flexural and shear strength and decreasing the cracks and deformations that may occur (Ivanova and Assih 2015b).

The differentiation between strengthening and repair isn't perpetually obvious. Reinforced concrete members may be damaged as a result of an overload or as a result of deficient initial capacity. In either case, cracking or other distress is obvious. Whether this is a repair or a strengthening activity depends on the source of the damage. Repairing of cracks are generally achieved by injection epoxy o fiber-reinforced mortar which is a new technique in the literature (Benyahia *et al.* 2017). If the reinforced concrete member is undamaged and the structure's live load is to be increased, then the appliance is merely for strengthening functions (Corry and Dolan 2001).

Unfortunately, there is no data currently available for repair of reinforced concrete corbels by the Basalt fiber. A much fewer number of researchers (Corry and Dolan 2001, Assih *et al.* 2015, Ivanova *et al.* 2016), dealt with CFRP for repairing damaged reinforced concrete corbels, while a significant number of researchers (Ahmad *et al.* 2013, Elgwady *et al.* 2005, Erfan *et al.* 2010, Ivanova *et al.* 2014, 2015, Ivanova and Assih 2015, Ivanova and Assih 2015, 2016, Shadhan and Kadhim 2015, Yassin *et al.* 2016) used CFRP for the strengthening of reinforced concrete corbels. Researchers found CFRP to be an effective and significant technology for strengthening and repairing reinforced concrete corbels.

Till date, very less research has been carried out on the strengthening of heated reinforced concrete elements (Haddad *et al*. 2007, 2008, 2011, Toumi *et al*. 2009, Yaqub *et al*. 2013, Leonardi *et al*. 2011, Yaqub and Bailey 2011a, 2011b, Yaqub *et al.* 2011, Roy *et al.* 2014, 2015). Rehabilitation of reinforced concrete corbels is necessary after a possible heat damage. Moreover, if corbels are both exposed to high temperature and failed about load carrying capacity, repairing of them will become more critical (Abdulhaleem *et al.* 2018).

It is worth mentioning that the ductility is a basic requirement in the design approach for conventional materials such as steel and reinforced concrete, and is considered a structure safety characteristic by civil engineers. Ductility indicates structure failure by means of large deformations (deformability), assures energy dissipation during impact, reverse loading cycles and seismic loading and allows internal force redistribution (De Castro 2005).

The main aim of this study is to investigate the mechanical behavior of heated and non-heated damaged reinforced concrete corbels (with and without steel fiber) after being rehabilitated with new uses of Basalt Fiber Mesh (BFM) and Basalt Fiber Fabric (BFF). In addition to the behavior of corbels which are rehabilitated cracks only by injection material without wrapping by any FRP. Moreover, to investigate the ultimate load capacities and the failure modes before and after the rehabilitation.

2. Experimental work

2.1 Experimental work description

In this study, two groups of corbels consisting of 60 specimens were prepared and cast, for first group having 24 corbels which are rehabilitated by BFM with two parts, for each part having 12 corbels with different parameters (normal concrete for the first part, and self-compacted concrete for the second part, two values of compressive strength, steel reinforcement ratio which was one value for the first part and two values for the second part, three volumetric values of steel fiber ratio and two values of shear span distance), which will be described in detail as follow below.

For the second group, having 36 corbels with two parts, for each part having 18 corbels. the first part was repaired with epoxy resin injection only without wrapping by any FRP and the second part was strengthened with BFF beside the injection material in cracks. The corbels of group two had been constructed and heated up to three different temperature levels of 250℃, 500℃, and 750℃ before the first failure and tested under vertical loading until failure. The concrete was self-compacting concrete (SCC) with two values of compressive strength, two values of steel reinforcement ratio, three volumetric values of steel fiber ratio and two values of shear span distance, which will be described in detail as follow:

2.2 Corbel details

All corbels have the same geometry and the steel reinforcement arrangement which is shown in Fig. 1. The cross-sections of the column and corbels (150 mm×150 mm), 4-φ10 mm steel bars for longitudinal bar reinforcement of the column, and of 4-φ8mm for stirrups. For the main reinforcement of corbel, two sizes of bars were used: 2-φ10 mm and 2-φ14 mm.

2.3 Materials properties

The properties of materials that are used in this experimental work are as follows:

• Ordinary Portland cement was used in all mixes, which corresponded to ASTM type II cement, with specific gravity and fineness, 3.12 and 295 m^2/kg respectively.

• Coarse aggregate used in the first group was crushed gravel with a maximum size of 10mm, and for the second group, was crushed limestone with a maximum size of 11mm.

• The specific gravity for all coarse and fine aggregates was 2.65.

• Average yield strengths for reinforcement of the first part of group one were found to be 491 MPa, and 560 MPa, and average ultimate strength values were found to be 614 MPa, and 678

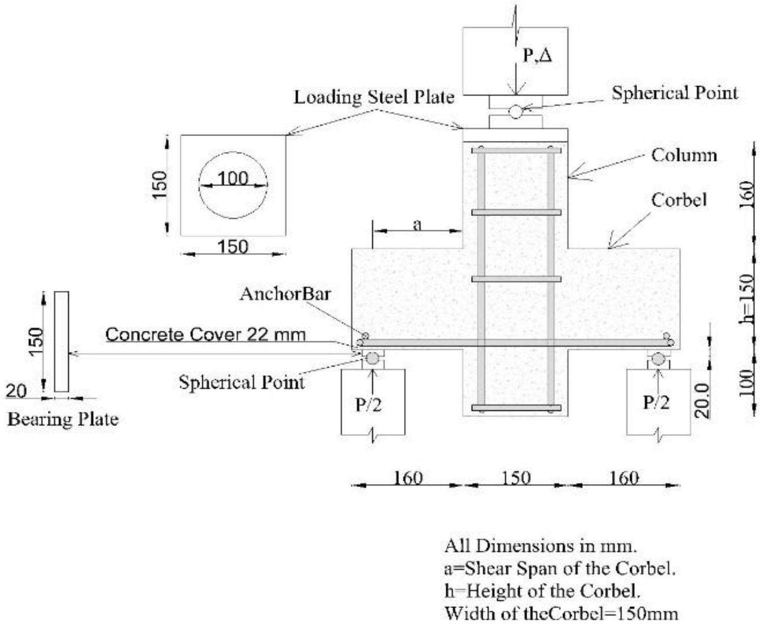

Fig. 1 Corbels details

Fig. 2 Steel and polypropylene fibers

MPa, for 8 mm and 10 mm steel bars, respectively.

In the second group and second part of group one, average yield strengths for reinforcement were found to be 550 MPa, 455 MPa, and 480 MPa, and average ultimate strength values were found to be 640 MPa, 588 MPa, and 595 MPa, for 8 mm, 10 mm and 14 mm steel bars, respectively.

• For the first part of group one, the steel fibers (SF) used were of hooked end, 30 mm length, 0.55 mm diameter, and 54.5 aspect ratio; with 3 different percentages (0%, 1%, and 1.5% steel fiber).

• For the second group and second part of group one, the steel fibers used were hooked end of 30 mm length, of 0.75 mm diameter, and 40 aspect ratio; with 3 different percentages (0%, 0.5%, and 1.0% steel fiber). Polypropylene fibers (PP) of 12 mm length, 0.2 mm diameter, 0.91 g/cm^3 density, and 450 N/mm^2 tensile strength with a percentage of 0.1% of concrete volume were added in the second group. Fig. 2 shows the steel and polypropylene fibers used in this study.

• For normal concrete which was used with two values of compressive strengths (30 MPa and 50 MPa). The amount of ingredients for 1 m^3 of normal concrete was illustrated in Table 1 for both values of compressive strength.

Table 1 Ingredient amount for 1 m^3 of normal concrete

Value of f_{cu}	Cement (kg)	coarse Agg. (kg)	Fine Agg. (kg)	Water (kg)	W/C ratio
f_{cu}= 30MPa	400	1110	600	220	0.55
f_{cu} =50MPa	400	1110	600	190	0.48

Table 2 Ingredient amount for 1 m^3 of SCC

Value of f_{cu}	Cement (kg)	Fine Agg. (kg)	Coarse Agg. (kg)	Fly ash (kg)	Silica fume (kg)	Water (kg)	W/C ratio	Superplasticizer (% binder volume)
MS-SCC 53 MPa	250	1000	667	215	35	170	0.55	1.0
HS-SCC 82MPa	450	1000	667	50	35	160	0.36	1.2

Table 3 Properties of epoxy TEKNOBOND 200 (Tekno Constr Chemicals 2016)

Color	Gray
Density	1.5 gr/cm^3
Consumption	1.5 kg/m^2 for 1 mm thickness
Bonding strength concrete	4.0 N/mm^2 (7 days) (TS EN 1542)
Pot life	30 minutes (at 20℃)
Loading capability	1 day
Full strength	7 days
Application Ground Temperature	(+5℃)-(+30℃)

Table 4 Properties of epoxy TEKNOBOND 300 (Tekno Constr Chemicals 2016)

Color	Component A Light Brown/Component B Transparent
Density	1.15 gr/cm^3 (Component A)- 1.05 gr/cm^3 (Component B)
Consumption	2.0 kg/m^2 for 1 mm thickness
Bonding strength concrete	5.3 N/mm^2
Pot life	45 minutes (at 20^{o}C)
Loading capability	1 day
Full strength	7 days
Application Ground Temperature	(+5℃) - (+30℃)

• For Self-compacted concrete (SCC) which was used with two values of compressive strength medium and high strength (MS-SCC and HS-SCC) around 53 MPa and 82 MPa respectively. The amount of ingredients for 1 m^3 of SCC concrete for both values of compressive strength was illustrated in Table 2.
• TEKNOBOND 200 is the epoxy used for bonding the Basalt Fiber Mesh (BFM) on concrete. Table 3 shows the properties of the epoxy used.
• TEKNOBOND 300 is the epoxy used for bonding the Basalt Fiber Fabric (BFF) on concrete. Table 4 shows the properties of the epoxy used.
• Sikadur 52 is the epoxy used for repair damaged specimens by injection in cracks. Table 5 shows the properties of the epoxy used.

Table 5 Properties of epoxy Sikadur 52 (Sika Company 2014)

Density	Part A: 1.1 kg/l (at +20℃) Part B: 1.0 kg/l (at +20℃) Part A+B mixed (2 : 1):1.1 kg/l (at +20℃)	
Viscosity	Temperature	Type Normal part A+B mixed (2: 1)
	+10℃	~ 1200 MPa_s
	+20℃	~ 430 MPa_s
	+30℃	~ 220 MPa_s
	+40℃	-
Thermal Expansion Coefficient	89×10-6 per ℃ (from -20℃ to +40℃) (According to EN ISO 1770)	
Compressive Strength	52 N/mm^2 (after 7 days at +23℃) (According to ASTM D695-96)	
Flexural Strength	61 N/mm^2 (after 7 days at +23℃) (According to DIN 53452)	
Tensile Strength	37 N/mm^2 (after 7 days at +23℃) (According to ISO 527)	
Bond Strength	To concrete: (According to DafStb-Richtlinie, part 3) > 4 N/mm^2 (failure in concrete) (after 7 days at +23℃)	
E-Modulus	Flexural Strength: 1800 N/mm^2 (after 7 days at +23℃) (According to DIN 53 452)	

Table 6 Mechanical specifications of BFM

Modulus of elasticity (GPa)	Mesh size (mm×mm)	Tensile Strength (MPa)	Rupture Strain	Design thickness (mm)
32	10 x 10	1600	0.05	0.035

Table 7 Properties of BFF

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

• Basalt Fiber Mesh (BFM) was used in this study and had a 10×10 mm spaced mesh geometry. The mechanical specifications of the basalt fiber mesh are given in Table 6.
• Unidirectional Basalt Fiber Fabric (BFF) was used for strengthening of some of the corbels. The mechanical properties of the fabric are specified in Table 7.

2.4 Description of rehabilitation

2.4.1 Corbels with BFM

The surface preparation was of primary importance and called for care. Preparation of concrete should be meted out to get rid of any loose or weak material, oil, grease, etc.…Therefore a grinder machine was used. The four corners of the corbels were rounded with minimum 13 mm radius to cut back a decrease in the strength and to forestall tearing of the FRP as recommended by ACI 440.2R-08 (ACI 440 2008). Step 1 in Fig. 3 shows the corbel after being surface prepared.

Preparation of the surface should be meted out before the bonding operation to forestall any contamination. To avoid contamination, the glue was applied to the concrete and BFM with a

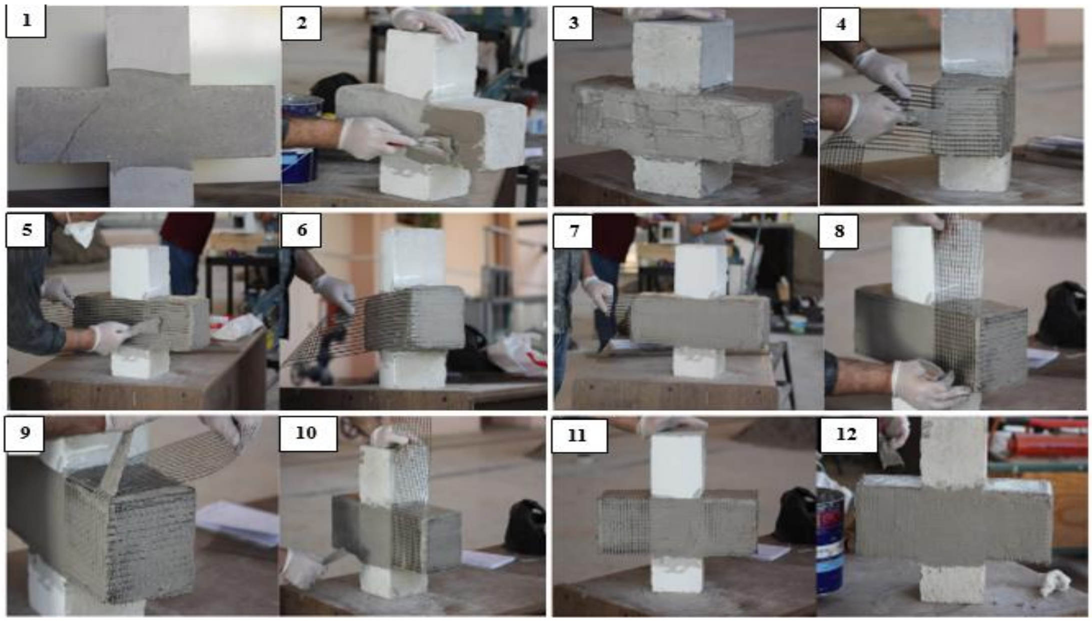

Fig. 3 Configuration steps of the bonding surface and applying the Basalt Fiber Mesh with epoxy to the damaged corbel from 1 to 12 steps

brush or trowel, pressure was applied to squeeze out excess glue and hold the BFM in place until the glue had hardened. Resin and hardened glue are simply mixed before the gluing operation, epoxy is applied on concrete with a brush or trowel, and then BFM is placed on the epoxy. Steps 2 and 3 show how the glue was placed on the surface of the corbel (Ivanova and Assih 2015b).

Four *U* strips of the BFM were placed on the four positions of the corbel for all specimens to rehabilitate the damaged corbels. The 1st *U* strip was placed on the front face of corbel as illustrated in steps 4 and 5 in Fig. 3. The 2nd *U* strip was placed on the back face of corbel as the 1st *U* strip was placed on the front face of corbel as illustrated in steps 4 and 5. The 2nd *U* strip was placed on the back face of corbel as illustrated in step 6 and 7 in Fig. 3, The positions of the 3rd and 4th U strips of BFM were placed on the bottom face of the corbel as illustrated in step 8, 9, 10 and 11 in Fig. 3.

For every strip of BFM after being placed on the first coat of epoxy; a second coat of epoxy was rolled over the BFM. Step 12 in Fig. 3 illustrates the final shape of rehabilitation by BFM for all samples of corbels.

2.4.2 Corbels with injection material

First of all, surfaces of corbels were cleaned with the same details in the part 2.4.1. The high viscosity epoxy was used as a replacing material for loosing parts of the concrete, and this epoxy was also used in order to prevent the leaking of crack repairing epoxy whose viscosity is very low. The crack repairing epoxy was injected into the cracks by injection syringe. Injection of the epoxy was implemented until ensuring the filling of all cracks. The steps of repairing with epoxy injection are shown in Fig. 4. All of the corbels strengthened with BFF were also subjected to these methods before gluing the BFF. After injection process, the corbels were left for 7 days for curing of the epoxy in order to obtain the target strength of the epoxy. Eventually, grinder machine

Fig. 4 Configuration steps of the preparation surface and injection of crack repairing epoxy

Fig. 5 Configuration steps of bonding surface and applying the BFF with epoxy

was used to level the bottom surface of the all corbel beams as shown in step 7 in Fig. 4, in order to provide the appropriate setup on the supports of the testing machine.

2.4.3 Corbels with BFF

The second part of group two of corbels was strengthened with BFF in addition to repairing of cracks. The wet lay-up method was followed to replace the strips of BFF which is recommended by ACI 440.2R-08 (ACI 440 2008). Three strips of the BFF were prepared in specific dimensions that are compatible with the corbel dimensions. The components of crack repairing epoxy (epoxy hardener and resin) were mixed by an electric drill machine according to datasheet of the repairing epoxy. Then the BFF was saturated with the low viscosity epoxy for gluing process. The saturated BFF were glued bi-directionally onto the corbels to achieve better resistance to the combination of vertical and horizontal stresses. Therefore, one layer of the fabric was placed parallel to the corbel axis, and the other layer was wrapped transversally to the corbel surface. Afterward, a trowel was used to eliminate air voids and to achieve perfect adhesion between the fabric and corbel surface. At last, grinder machine was used again for leveling bottom surface of corbels to provide successful simultaneous load transfer mechanism up to both of the supports. The steps of strengthening with BFF are illustrated in Fig. 5.

2.5 Test setup

The values of compressive strength were determined as average of three cylindrical sample

Fig. 6 Corbel setup on the test machine

(150×300) mm according to ASTM C39 specification. All corbels before and after the rehabilitation were tested under a three-point load (Fig. 1). The maximum load capacity of the machine used was 500 kN. The loading rate displacement controlled (0.2 mm/min), the datasets were recorded every 0.2 s. Two LVDTs were used to record the deflections of corbels as shown in Fig. 6.

3. Experimental results and discussions:

3.1 Experimental results of first group:

3.1.1 Experimental results of part one:

The test results of part one of first group normal concrete corbels which are rehabilitated by BFM are shown in Table 8.

The first and second columns contain the designation of part one of first group with all related values. The first term of specimen index represents the name of the sample (Corbel No. # #), the second term represents the cubic compressive strength of the sample, the third term represents the steel fiber ratio, the fourth term represents the diameter of the main reinforcement, and the last term represents the shear span that will be applied to test the corbels. For all corbels of part one, no injection material was used to repair the cracks in the corbels to investigate the performance of the BFM to rehabilitate the corbels without internal epoxy injection. The third column of Table 8 contains all relevant cylindrical compressive strength of corbels. The four column of Table 8 represents the ultimate load capacity of the corbels before the rehabilitation. It can be concluded from the test results that when the shear span increases, the value of ultimate load capacity decreases for all corbels. Indeed, the increase of compressive strength from 30 MPa to 50 MPa also increases the ultimate load for all corbels as expected. The addition of steel fibers (SF) on the concrete mix enhances the ultimate load and the ductility of each corbel (Fattuhi 1990). The fifth column of Table 8 presents the ultimate load capacity of corbels after rehabilitation, and these

Table 8 Part one of first group normal concrete corbels rehabilitated by BFM

Type of Concrete and Rehabilitation	Specimen Index	Comp. Strength (f_c) (MPa)	Ultimate Load Capacity before Reh. (kN)	Ultimate Load Capacity After Reh. (kN)	% Recovered of Ultimate Load Capacity after Reh.	Deflection Before Reh. δ_{max} (mm)	Deflection After Reh. δ_{max} (mm)	Mode of Failure Before Reh.	Mode of Failure After Reh.
Normal Concrete / Rehabilitation By BFM	C1-50-0.0-10-100	39	151.44	124.4	82.145	1.46	5.35	Shear failure	BFM rupture
	C2-50-0.0-10-130	39	114.013	87.077	76.375	0.863	1.634	Diagonal splitting	BFM rupture
	C3-50-1.0-10-100	40	242.095	188.03	77.668	2.918	6.161	Flexural failure	BFM rupture
	C4-50-1.0-10-130	40	176.77	128.034	72.430	2.489	3.552	Flexural /shear failure	BFM rupture
	C5-50-1.5-10-100	42.5	253.43	188.04	74.198	4.588	8.453	Flexural failure	BFM rupture
	C6-50-1.5-10-130	42.5	171.209	132.332	77.293	1.55	5.378	Shear failure	BFM rupture
	C7-30-0.0-10-100	24	125.7	102.8	81.782	1.134	5.674	Diagonal splitting	BFM rupture
	C8-30-0.0-10-130	24	98.3	78.14	79.491	0.812	3.48	Shear failure	BFM rupture
	C9-30-1.0-10-100	22.3	145.6	120.034	82.441	2.312	5.096	Shear failure	BFM rupture
	C10-30-1.0-10-130	22.3	111.108	86.323	77.693	2.12	5.92	Diagonal splitting	BFM rupture
	C11-30-1.5-10-100	25.5	158.25	119.98	75.817	2.821	6.96	Diagonal splitting	BFM rupture
	C12-30-1.5-10-130	25.5	115.18	96.25	83.565	1.873	5.715	Diagonal splitting	BFM rupture

values are less than the original values. The percentage recovered of load capacity after rehabilitating can be observed in the sixth column of Table 8.

It can be summarized from Table 8 that the percentage recovered of ultimate load capacity after being rehabilitated for all corbels were found to be variable from 72.430% of C4 until 83.565% of C12 from the original load capacity before rehabilitation, Fig. 7 shows all values of ultimate load capacity before and after the rehabilitation for all corbels. It can be concluded from the results that the value of rehabilitation depends on the damage degree of corbel before the rehabilitation, which affects results of rehabilitation.

It can be concluded after rehabilitation by BFM led to a significant increase in the maximum deflection which is led to significant increase in the ductility. The values of δmax for all corbels of part one of first group can be seen in the curves of Load-Deflection behavior as shown in Appendix part Table A1. Obviously, it can be seen from the relation of Load-Deflection that the slope of the curves decreased after rehabilitated by BFM, which means the stiffness of corbels decreased after being rehabilitated by BFM.

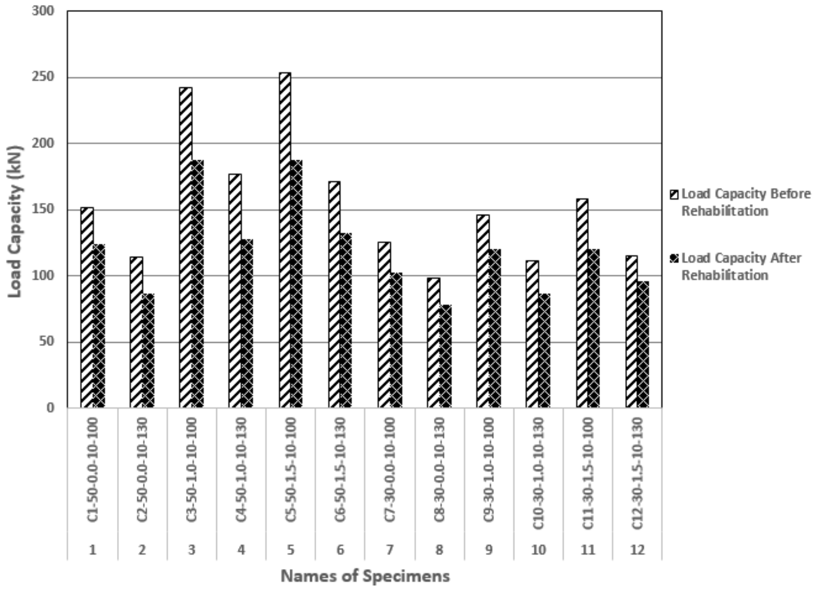

Fig. 7 Ultimate load capacity of all corbels before and after the rehabilitation by BFM

Fig. 8 The mode of failure in the Basalt Fiber Mesh (Rupture in the Fibers)

The failure modes of the corbels before and after rehabilitation are summarized in Table 8. The modes of failure for the corbels before the rehabilitation; flexural failure, shear failure, flexural/shear failure and diagonal splitting failure (Fattuhi 1990). Obviously, the mode of failure after rehabilitation was simply ruptured in the BFM for all corbels and no other type of a failure like a de-bonding failure was observed in the BFM. This type of failure (rupture in the BFM) was a most significant and interesting outcome of this study. Fig. 8 shows the failure in BFM after being tested for four selected corbels, which is occurred in all samples of part one of first group. Moreover, summary of all results of the corresponding corbels were given in Appendix part (Table A1).

3.1.2 Experimental results of part two:

The test results with all details of self-compacted concrete (SCC) corbels belonging to part two of first group which are rehabilitated by BFM are shown in Table 9. Varying parameters of corbels in part two were shear span (120 mm and 90 mm), steel fiber ratio (0.0%, 0.5%, and 1.0%) and compressive strength (53 MPa and 82 MPa). Low viscosity epoxy was injected into some corbels to show the effect of internal epoxy injection in rehabilitation. The third column of Table 9 contains all relevant cylindrical compressive strength of corbels.

Table 9 Part two of first group SCC corbels rehabilitated by BFM

Type of Concrete and Rehabilitation	Specimen Index	Comp. Strength (f_c) (MPa)	Ultimate Load Capacity before Reh. (kN)	Ultimate Load Capacity After Reh. (kN)	% Recovered of Ultimate Load Capacity after Reh.	Injection Status	Deflection Before Reh. δ_{max} (mm)	Deflection After Reh. δ_{max} (mm)	Mode of Failure Before Reh.	Mode of Failure After Reh.
Self-Compacted Concrete/ Rehabilitation By BFM	C13-53-0.0-10-90	52.9	202.1	164.25	81.272	Without injection	0.75	2.607	Shear failure	BFM rupture
	C19-53-0.0-10-120	52.9	90.6	52.033	57.432	Without injection	0.88	3.399	Diagonal splitting	BFM rupture
	C14-53-0.5-10-90	51.1	217.3	170.635	78.525	Without injection	2.546	8.682	Shear failure	BFM rupture
	C20-53-0.5-10-120	51.1	140.2	87.3	62.268	Without injection	2.2	2.85	Diagonal splitting	BFM rupture
	C15-53-1.0-10-90	50.8	230.5	245.3	106.421	injected	0.592	3.944	Diagonal splitting	BFM rupture
	C21-53-1.0-10-120	50.8	156.2	213.1	136.428	injected	1.347	6.504	flexural failure	BFM rupture
	C16-82-0.0-10-90	83.3	235.2	186.55	79.315	Without injection	0.935	4.953	Shear failure	BFM rupture
	C17-82-0.5-10-90	79.5	281.3	186.5	66.299	Without injection	2.339	6.26	Flexural/ shear failure	BFM rupture
	C18-82-1.0-10-90	79.8	327.1	180.5	55.182	Without injection	2.504	7.07	Flexural/ shear failure	BFM rupture
	C22-82-0.0-14-90	83.3	264.82	265.3	100.181	injected	1.72	4.66	Diagonal splitting	BFM rupture
	C23-82-0.5-14-90	79.5	285.6	130.12	45.560	Without injection	0.46	3.1	Diagonal splitting	BFM rupture
	C24-82-1.0-14-90	79.8	334.402	136.3	40.759	Without injection	4.596	4.71	Diagonal splitting	BFM rupture

It can be observed the detail values of corbels (C13, C19, C14, and C20), 53 MPa cubic compressive strength, 0.0% and 0.5% steel fiber ratio, no injection material was used in these corbels. The percentage recovered of ultimate load capacity after being rehabilitated by BFM was found to be started from 57.432% of C19 until 81.272% of C13 from the origin load capacity before rehabilitation. The ductility was increased after rehabilitation, by comparing the maximum deflection before and after the rehabilitation. However, the stiffness of these corbels decreased, and it is obvious to see that by comparing the slope of load-deflection curves in Appendix part (Table A2) before and after using the BFM. The mode of failure after rehabilitation was ruptured in the fiber for all corbels of self-compacted concrete corbels.

C15 and C21 were injected by low viscosity epoxy to repair the internal cracks. The percentage recovered of ultimate load capacity was found to be a 106.421% and 136.428% for C15 and C21 respectively from the original load capacity before the rehabilitation.

In general, when the shear span to the depth (*a/h*) ratio is decreased, the ultimate load will be increased when the other variables are kept constant. Actually, it is observed that the value of

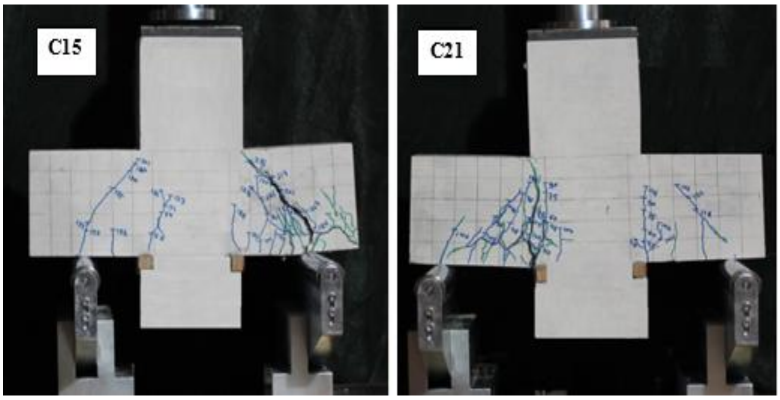

Fig. 9 Mode of failure of C15 was Diagonal splitting failure and C21 was flexural failure

increase load capacity after rehabilitation of C15 equal to 6.24% and for C21 equal to 36.43% of original load capacity were used 90 mm & 120 mm as a shear span respectively. When it is focused on the result of these corbels; the result was opposite of the general concept of shear spans, and to conclude the reason; first of all, must be observed the mode of failure for both corbels. the first corbel (C15) was failed as a diagonal splitting failure and the second corbel (C21) was failed as a flexural failure (Fig. 9). For a diagonal splitting failure; the bond between main bars reinforcement and surrounding concrete covers were damaged, therefore, the reinforcement of the main bars cannot be working correct status. While the failure of C21 was less damaged than the diagonal splitting.

Therefore, the reinforcement of the main bars will work better than the first case of failure. The results show in Table 9 that when the self-compacted concrete corbels had a diagonal splitting failure, the result after rehabilitated by BFM will be less than another type of failure. On another hand, the performance of rehabilitation depends on the damaged degree of the specimen before the rehabilitation, which is controlled in the result of strengthening after rehabilitation.

Unfortunately, the result showed that the self-compacted concrete corbels that had a high compressive strength in Table 9, had low values after rehabilitation by BFM. The percentage recovered of ultimate load capacity for C16, C17, and C18 which were rehabilitated by BFM without injection epoxy in cracks were found to be 79.315%, 66.299%, and 55.182% respectively from the original load capacities before rehabilitation. The increases of ductility of these samples were variable depending on the maximum deflection before and after the rehabilitation., in addition to the decreasing of the stiffness of these corbels which are concluded by comparing the slope of load-deflection curves before and after the rehabilitation as shown in Appendix part (Table A2).

The other samples of high compressive strength C22, C23, & C24 were rehabilitated by BFM, C22 was injected by low viscosity epoxy to repair the cracks, the result showed that the percentage recovered of ultimate load capacity after rehabilitated was 100.181% of original load capacity. The mode of failure was a diagonal splitting failure before the rehabilitation. the samples C23 & C24 were rehabilitated by BFM without injection epoxy, which is no reliability between the BFM and high compressive self-compacted concrete, and the percentage recovered of ultimate load capacity of C23 and C24 were about 45.560% and 40.759% respectively, from original value before the rehabilitation. The increase of ductility can be concluded from the results of maximum deflection

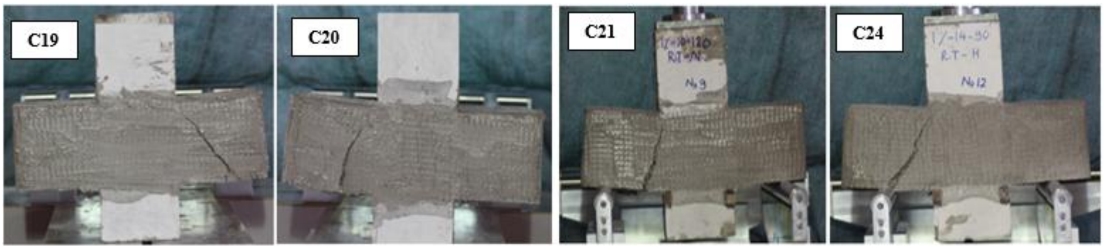

Fig. 10 Failure mode of Basalt Fiber Mesh in several corbels of part two of second group (Ruptured in BFM)

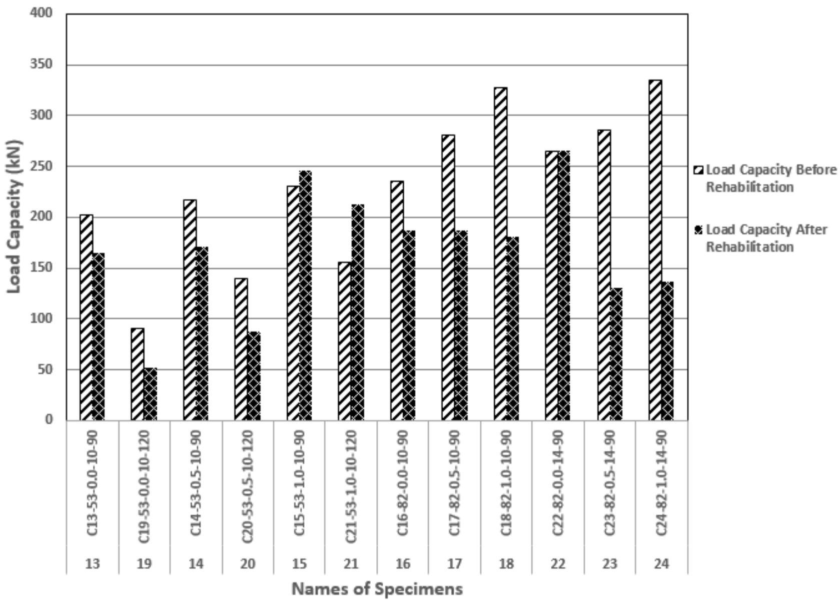

Fig. 11 The behaviour of part two of second group after rehabilitation by BFM with respect to the ultimate load capacity

before and after the rehabilitation and the decrease of stiffness can be seen in the behaviour of load-deflection curves in Table A2.

Fig. 10 shows the mode of failure of several selected corbels after rehabilitation (ruptured in BFM), which is the same mode in all corbels of part two. Fig. 11 shows the ultimate load capacities of part two of second group before and after the rehabilitation which are recorded as values in Table 9. Moreover, summary of all results of the corresponding corbels were given in Appendix part (Table A2).

3.2 Experimental results of second group:

3.2.1 Experimental results of part one:

Eighteen damaged corbels were repaired with only crack repair material in order to investigate the efficiency of epoxy injection for restoring the capacity of the corbels after heated up to three different temperature levels of 250℃, 500℃, and 750℃ before the first failure and tested under

Table 10 Part one of second group SCC heated corbels rehabilitated by injection epoxy

Type of Concrete and Rehabilitation	Specimen Index	Comp. Strength (f_c) (MPa)	Ultimate Load Capacity before Reh. (kN)	Ultimate Load Capacity After Reh. (kN)	% Recovered of Ultimate Load Capacity after Reh.	Deflection Before Reh. δ_{max} (mm)	Deflection After Reh. δ_{max} (mm)	Mode of Failure Before Reh.	Mode of Failure After Reh.
Self-Compacted Concrete/ Rehabilitation By Injection	C25-53-0.0-10-250-120	53.3	130	150	115.385	0.736	2.523	Shear failure	Shear failure
	C26-53-0.0-10-500-120	48.8	80	102	127.500	0.697	1.057	Shear failure	Diagonal splitting
	C27-53-0.0-10-750-120	21.1	51	43	84.314	1.085	1.672	Diagonal splitting	Diagonal splitting
	C28-53-0.5-10-250-120	54.8	201	135	67.164	1.718	1.628	Diagonal splitting	Shear failure
	C29-53-0.5-10-500-120	50.5	117	132	112.821	0.682	0.765	Shear failure	Shear failure
	C30-53-0.5-10-750-120	25.4	88	80	90.909	2.083	2.157	Diagonal splitting	Diagonal splitting
	C31-53-1.0-10-250-120	57.1	212	190	89.623	1.221	1.094	Diagonal splitting	Shear failure
	C32-53-1.0-10-500-120	51.1	136	157	115.441	1.723	2.621	Shear failure	Shear failure
	C33-53-1.0-10-750-120	27.9	99	80	80.808	1.852	2.868	Diagonal splitting	Diagonal splitting
	C34-82-0.0-10-250-90	77.8	227	98	43.172	0.551	1.116	Diagonal splitting	Diagonal splitting
	C35-82-0.0-10-500-90	70.6	195	90	46.154	1.147	1.348	Diagonal splitting	Diagonal splitting
	C36-82-0.0-10-750-90	28.8	107	59	55.140	0.979	0.954	Diagonal splitting	Diagonal splitting
	C37-82-0.5-10-250-90	72.7	280	150	53.571	1.63	3.927	Diagonal splitting	Diagonal splitting
	C38-82-0.5-10-500-90	71.4	235	234	99.574	1.19	3.131	Diagonal splitting	Diagonal splitting
	C39-82-0.5-10-750-90	38.6	267	231	86.517	1.816	2.849	Shear failure	Shear failure
	C40-82-1.0-10-250-90	74.8	317	293	92.429	1.022	3.522	Flexural/ shear failure	Diagonal splitting
	C41-82-1.0-10-500-90	72.2	267	231	86.517	2.432	1.883	Flexural failure	Shear failure
	C42-82-1.0-10-750-90	40.3	171	169	98.830	1.645	3.593	Shear failure	Diagonal splitting

vertical loading until failure. The results of these rehabilitated corbels are listed in Table 10.

Again the designation of corbel is the same as it explained before, except it is added term before the last term which is represented to the degree of heating. The ultimate load capacities

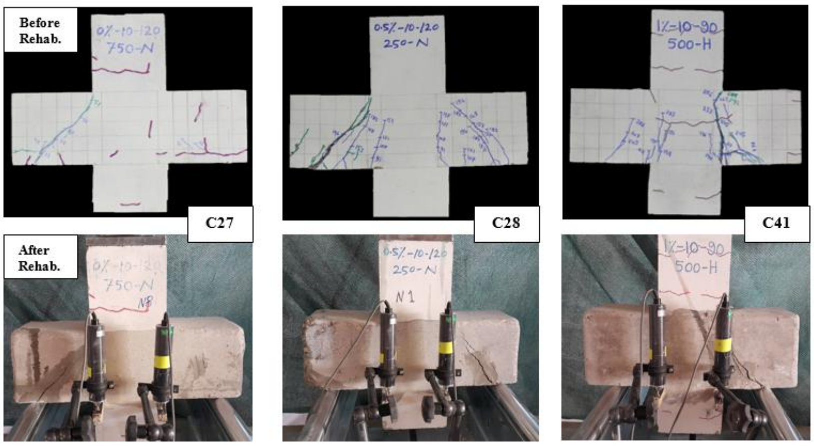

Fig. 12 Mode of failure for several corbels before and after the rehabilitation.

before repairing were affected by various parameters, especially the heating degree and steel fiber ratio. While increasing the temperature adversely affected the capacity. The addition of steel fiber increased ultimate load capacity and ductility as well.

It is observed that the result of percentage recovered of ultimate load capacity after rehabilitation varies from 43.172% to 127.5% depending on the mode of failure before the rehabilitation which determines the damaged degree of the specimen and the existence of cracks and micro-cracks. Micro-cracks width which is less than 0.3 mm cannot be repaired by low-viscosity epoxy which sufficiently influences adversely to the effectiveness of rehabilitation process (ACI 224 2008, ACI 440 2008). Again it can be concluded from the result in Table 10 that when the self-compacted concrete corbels had a diagonal splitting failure, the result after rehabilitated by injection epoxy will be less than another type of failure, especially for the high compressive strength of self-compacted concrete corbels (C34 until C38), the rehabilitation by repairing cracks only cannot be restoring the strength to the original value of load capacity before the rehabilitation, which is restored about 43.172% from C34 until 99.574% from C38. It can be seen in the Fig. 12 the mode of failure of several selected corbels which is recorded in Table 10. Table A3 in Appendix shows the load-deflection behavior of all corbels of part one of second group with all details.

3.2.2 Experimental results of part two:

The part two of second group contains eighteen damaged corbels were rehabilitated with crack repair epoxy and wrapped with BFF after heated up to three different temperature levels of 250℃, 500℃, and 750℃ before the first failure and tested under vertical loading until failure. The main purpose of this part is to investigate the effectiveness of the use of epoxy injection and BFF together on the serviceability of reinforced concrete corbels. Test results with all details are listed in Table 11. It can be noticed from Table 11 that use of BFF to strengthen the corbels leads to a significant increase in the load capacity for all types of corbels. The percentage recovered of load capacity after rehabilitation varied from 102.459% of C60 until 151.208% of C50 from the original value of load capacity before the rehabilitation. This increment of load capacity depends on the type of failure of specimen before the rehabilitation which determines the damage degree of the specimen. Again it can be concluded from Table 11 that the failure diagonal splitting was the

Table 11 Part two of second group SCC heated corbels rehabilitated by injection epoxy beside to BFF

Type of Concrete and Rehabilitation	Specimen Index	Comp. Strength (f_c) (MPa)	Ultimate Load Capacity before Reh. (kN)	Ultimate Load Capacity After Reh. (kN)	% Recovered of Ultimate Load Capacity after Reh..	Deflection Before Reh. δ_{max} (mm)	Deflection After Reh. δ_{max} (mm)	Mode of Failure Before Reh.	Mode of Failure After Reh.
Self-Compacted Concrete/ Rehabilitation By BFF & Injection	C43-53-0.0-10-250-90	53.3	208	256.2	123.173	1.186	4.897	Diagonal splitting	De-bonding
	C44-53-0.0-10-500-90	48.8	175	227	129.714	1.102	3.125	Shear failure	De-bonding
	C45-53-0.0-10-750-90	21.1	82	123.8	150.976	1.102	3.125	Shear failure	De-bonding
	C46-53-0.5-10-250-90	54.8	243	278	114.403	1.936	5.51	Diagonal splitting	De-bonding
	C47-53-0.5-10-500-90	50.5	193	260	134.715	0.913	7.437	Shear failure	De-bonding
	C48-53-0.5-10-750-90	25.4	119	142	119.328	1.591	6.158	Diagonal splitting	De-bonding
	C49-53-1.0-10-250-90	57.1	247	269	108.907	1.71	2.442	Diagonal splitting	De-bonding
	C50-53-1.0-10-500-90	51.1	207	313	151.208	1.884	6.769	Shear failure	De-bonding
	C51-53-1.0-10-750-90	27.9	132	185	140.152	1.74	7.034	Shear failure	De-bonding
	C52-82-0.0-14-250-90	77.8	268	292.5	109.142	0.744	4.443	Diagonal splitting	De-bonding
	C53-82-0.0-14-500-90	70.6	210	246.5	117.381	1.654	3.6	Diagonal splitting	De-bonding
	C54-82-0.0-14-750-90	28.8	113	150	132.743	1.231	7.583	Diagonal splitting	De-bonding
	C55-82-0.5-14-250-90	72.7	370	399.6	108.000	1.6	7.3	Diagonal splitting	De-bonding
	C56-82-0.5-14-500-90	71.4	251	262	104.382	2.309	6.292	Diagonal splitting	De-bonding
	C57-82-0.5-14-750-90	38.6	134	201	150.000	1.654	3.69	Shear failure	De-bonding
	C58-82-1.0-14-250-90	74.8	382	430.3	112.644	2.048	6.125	Diagonal splitting	De-bonding
	C59-82-1.0-14-500-90	72.2	294	306	104.082	2.329	3.805	Diagonal splitting	De-bonding
	C60-82-1.0-14-750-90	40.3	183	187.5	102.459	1.68	6.886	Diagonal splitting	De-bonding

worst type which affects the performance of load capacity after the rehabilitation more than other types of failure before the rehabilitation.

Moreover, strengthening with BFF enhances the ductility of corbels noticeably. Therefore, a preferable seismic performance of reinforced concrete corbels can be achieved with BFF even they

Fig. 13 BFF-strengthened specimen with de-bonding failure

are damaged due to either fire or overloading. All of corbels were covered with unidirectional BFF in two directions, this operation makes the fabric to possess much more strength as compared to adhesive epoxy resin. Therefore, all of the failure modes were a de-bonding failure which occurred between the BFF and concrete surface (see Fig. 13).

The Load-Deflection relationships of BFF-strengthened corbels are shown in Table A4 in Appendix part. The corbels numbered C43 to C51 represent normal strength concrete corbels and remaining ones (C52 to C60) refer to high strength concrete corbels. Moreover, it can be concluded from the results of second group (Tables 10 and 11) that the damaged due to the high level heated degree 750℃ adversely affected the compressive strength of concrete as can be seen in the results of cylindrical compressive strength beside to the capacity of corbels. Summary of all behaviour of the corresponding corbels were given in Appendix part (Table A4).

4. Conclusions

Reinforced concrete corbels play an important role in precast constructions, particularly in industrial buildings. Therefore, the functionality of the corbels is very important for the service life of these types of structures. In this study, a new technique is investigated for the rehabilitation of damaged normal and self-compacted steel fiber reinforced concrete (SCC-SFRC) corbels for the first time in literature via Basalt Fabric and Mesh. The experimental program includes two types of concrete: normal concrete, and self-compacted concrete. For the normal, 12 corbels were rehabilitated by BFM without injection material (epoxy) in cracks, with two values of compressive strength, three ratios of steel fiber (SF), and two values of shear span. For SCC-SFRC, 48 corbels were rehabilitated with different parameters. 12 corbels were rehabilitated by BFM with and without epoxy injection, 18 heated corbels with three different temperatures were rehabilitated by epoxy injection only, and 18 heated corbels with different three temperatures were rehabilitated by epoxy injection and wrapping by BFF. All 48 corbels have two values of compressive strength, three ratios of steel fiber (SF), and two values of shear span.

Following conclusions can be drawn according to results of experimental study;

• For both types of concrete corbels (Normal and Self-Compacting Concrete); BFM cannot improve the ultimate load capacity without epoxy injecting.

• For normal concrete corbels, the percentage recovered of ultimate load capacities after rehabilitation by BFM for all corbels were found to be ranging from from 72.430% until

83.565% from the original load capacity before rehabilitation. However, the mode of failure for normal concrete corbels before the rehabilitation did not affect the result of rehabilitation too much.

• For self-compacted concrete corbels with normal compressive strength and without epoxy injection, the percentage recovered of ultimate Load Capacity after rehabilitation by BFM were found to be ranging from 57.432% until 81.272% from the original load capacity before rehabilitation. On the other hand, for high compressive strength and without epoxy injection, the percentage recovered of ultimate load capacity after rehabilitation by BFM were found to be ranging from 40.759% to 79.315% from the original load capacity before rehabilitation which are depending on mode of failure before the rehabilitation. For normal and high-compressive strength self-compacted concrete corbels which are injected by low viscosity epoxy in the cracks, the ultimate load capacities after rehabilitation by BFM are retained to the original values.

• For both types of concrete (normal and SCC), the mode of failure of BFM was observed to be rupture of Basalt Mesh which is considered to be the most important and significant failure mode for FRP.

• Test results showed that it is not reliable to use BFM alone without injection epoxy in high-compressive strength SCC-SFRC corbels for rehabilitation.

• In general, rehabilitation with only epoxy injection gives better results for medium strength corbels as compared to high strength corbels.

• It can be concluded that use of epoxy and BFF together for the rehabilitation of damaged reinforced or steel fiber reinforced concrete corbels increases the original load capacity and ductility considerably.

• Rehabilitation with only epoxy injection is not sufficient for medium strength corbels that had been damaged due to an elevated temperature (750℃ or higher degrees) and overloading. Therefore, extra measures need to be considered in addition to crack repairing to achieve effective rehabilitation.

• The existence of steel fiber plays an important role in both of the investigated rehabilitation techniques for both medium strength and high strength concrete corbels. It increases the effectiveness of the rehabilitation due to partial restoring of bridging effect of steel fibers. Moreover, the possibility of restoring the original load capacity by repairing with only epoxy injection increases for steel fiber reinforced concrete corbels. This situation leads to an economical alternative for rehabilitation.

• Rehabilitation with BFF can provide the serviceability and functionality of reinforced concrete corbels again even they are damaged due to elevated temperature and overloading.

• The high tensile strength of BFF and bidirectional placement of the fabric on corbel surfaces make it more powerful as compared to the adhesive epoxy leading to de-bonding failure for all of the corbels strengthened with BFF.

• For SCC, the mode of failure before the rehabilitation considerably affects the rehabilitation performance. Moreover, the diagonal splitting failure is observed to be the worst failure type for corbels which is concluded from the results.

• Structure engineers consider ductility to be one of the most important and significant parameters for safety. In this study, it is observed that ductility of rehabilitated corbels depends primarily on the type of concrete, compressive strength, steel fiber ratio, shear span, and type of Fiber Reinforcement.

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Appendix

Table A1 Summary of mechanical behavior of corbels for C1 to C12

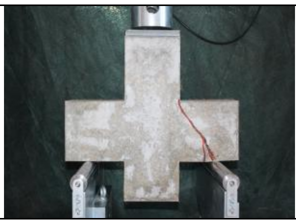
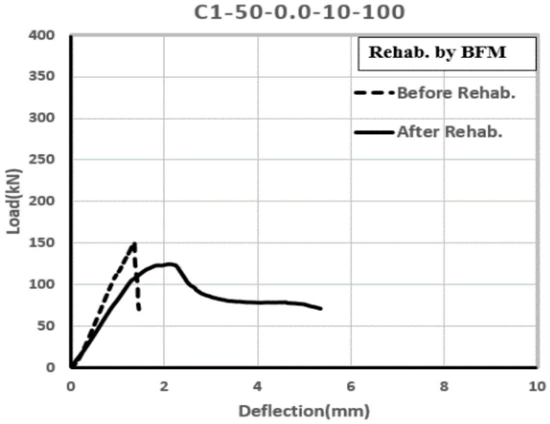
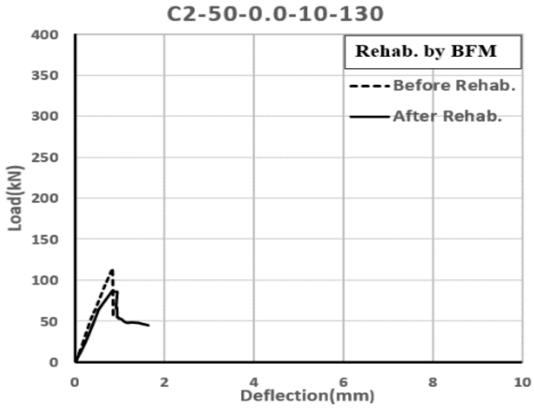
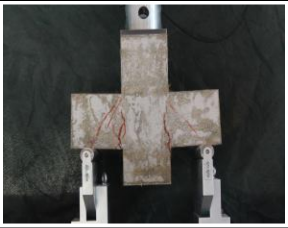
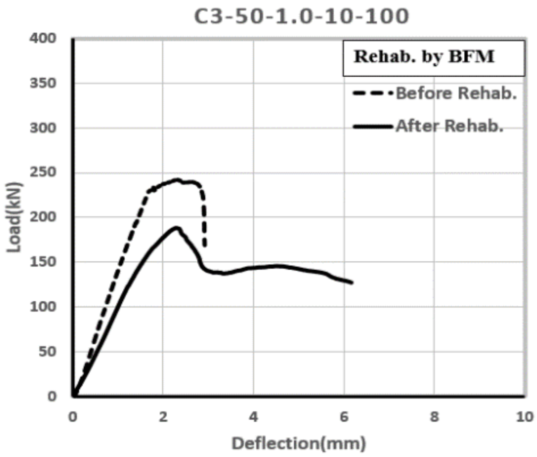
		Mode of failure			Load-Deflection Relationship
Normal Concrete / Rehabilitation By BFM	C1-50-0.0-10-100	Before Reh.		Shear failure	
		After Reh.		BFM rupture	
	C2-50-0.0-10-130	Before Reh.		Diagonal splitting	
		After Reh.		BFM rupture	
	C3-50-1.0-10-100	Before Reh.		Flexural failure	
		After Reh.		BFM rupture	

Table A1 Continued

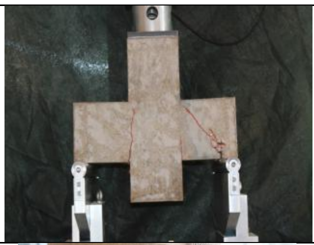
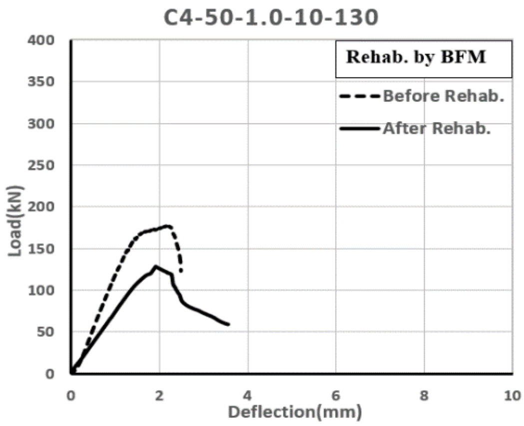
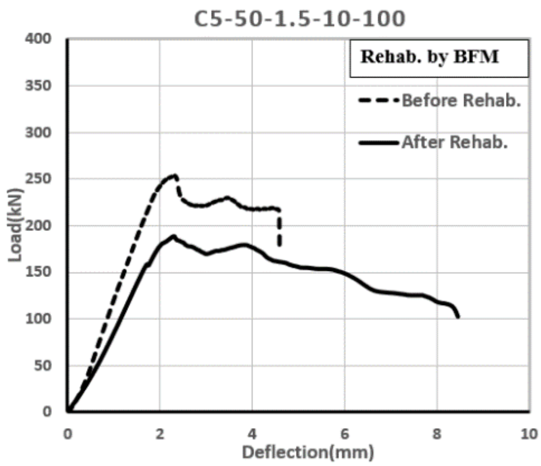
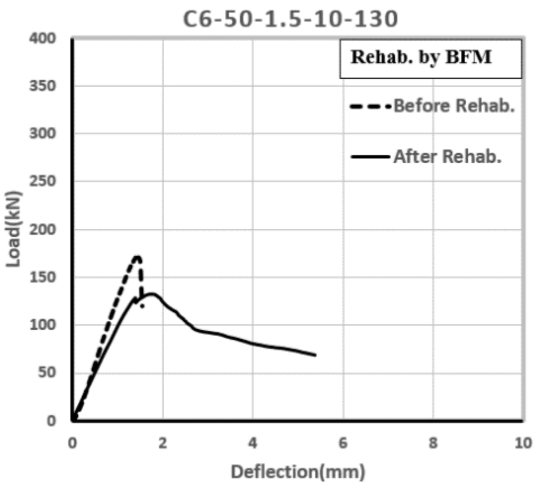
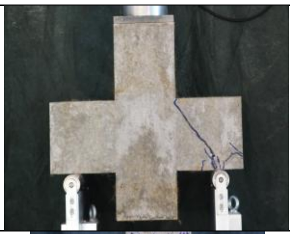
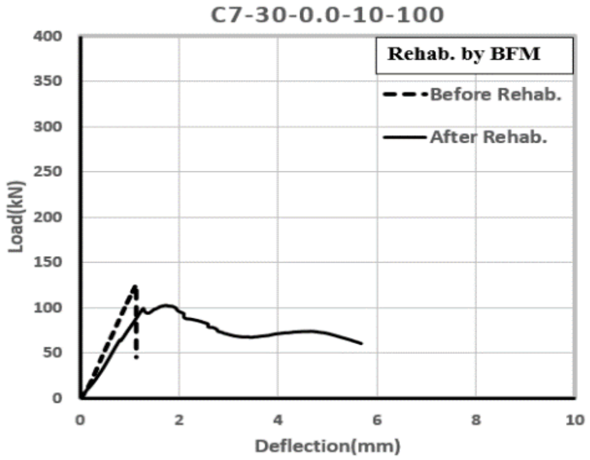
			Mode of failure		Load-Deflection Relationship
Normal Concrete / Rehabilitation By BFM	C4-50-1.0-10-130	Before Reh.		Flexural /shear failure	
		After Reh.		BFM rupture	
	C5-50-1.5-10-100	Before Reh.		Flexural failure	
		After Reh.		BFM rupture	
	C6-50-1.5-10-130	Before Reh.		Shear failure	
		After Reh.		BFM rupture	

Table A1 Continued

<table>
<tr><th></th><th></th><th></th><th colspan="2">Mode of failure</th><th>Load-Deflection Relationship</th></tr>
<tr><td rowspan="6">Normal Concrete / Rehabilitation By BFM</td><td rowspan="2">C7-30-0.0-10-100</td><td>Before Reh.</td><td></td><td>Diagonal splitting</td><td rowspan="2">
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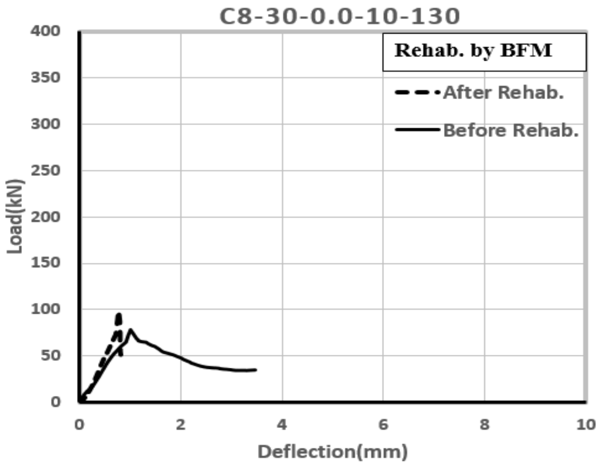
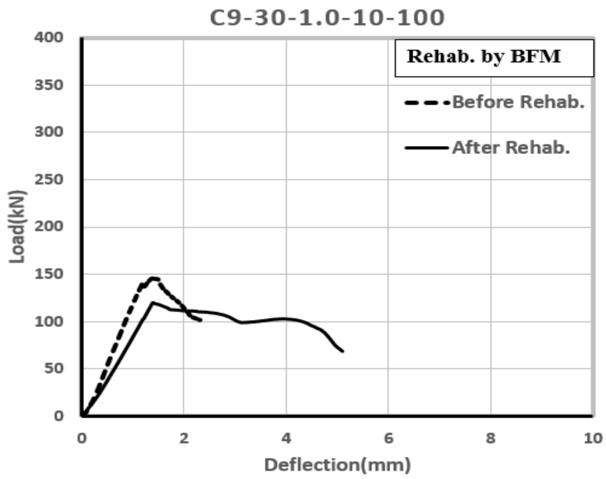
<tr><td>After Reh.</td><td></td><td>BFM rupture</td></tr>
<tr><td rowspan="2">C8-30-0.0-10-130</td><td>Before Reh.</td><td></td><td>Shear failure</td><td rowspan="2">
</td></tr>
<tr><td>After Reh.</td><td></td><td>BFM rupture</td></tr>
<tr><td rowspan="2">C9-30-1.0-10-100</td><td>Before Reh.</td><td></td><td>Shear failure</td><td rowspan="2">
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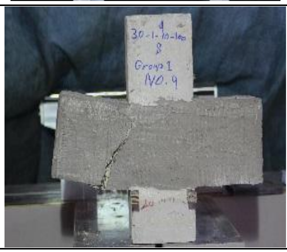
<tr><td>After Reh.</td><td></td><td>BFM rupture</td></tr>
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Table A1 Continued

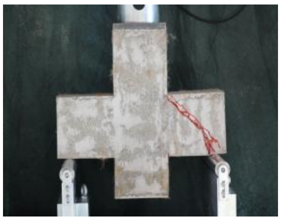
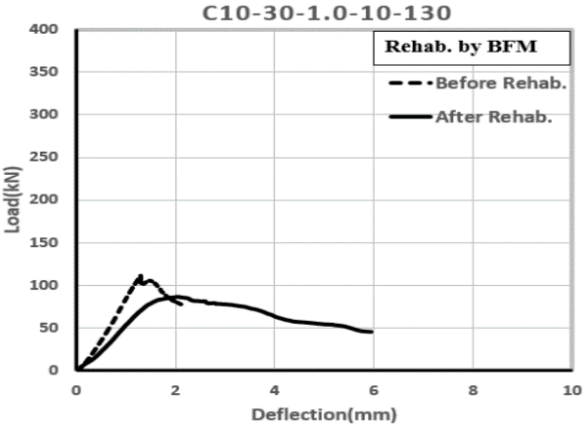
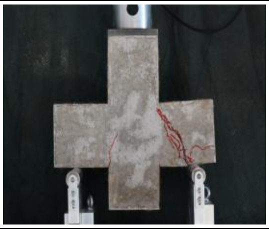
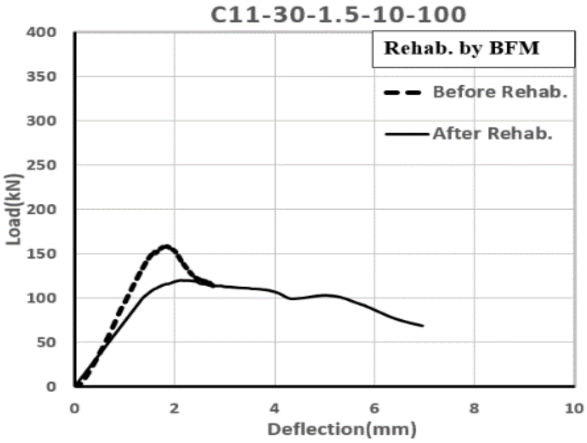
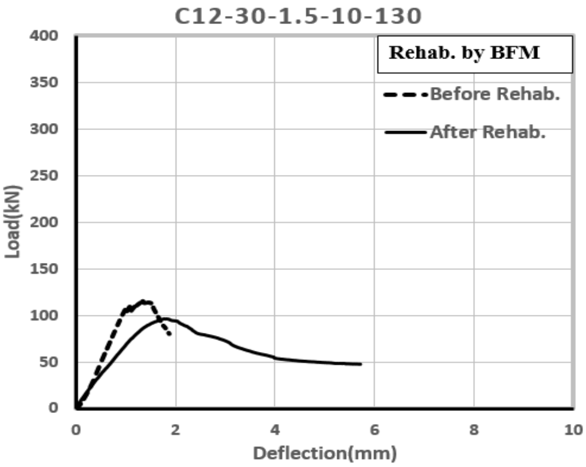
			Mode of failure		Load-Deflection Relationship
Normal Concrete / Rehabilitation By BFM	C10-30-1.0-10-130	Before Reh.		Diagonal splitting	
		After Reh.		BFM rupture	
	C11-30-1.5-10-100	Before Reh.		Diagonal splitting	
		After Reh.		BFM rupture	
	C12-30-1.5-10-130	Before Reh.		Diagonal splitting	
		After Reh.		BFM rupture	

Table A2 Summary of mechanical behavior of corbels for C13 to C24

Self-Compacted Concrete/ Rehabilitation By BFM

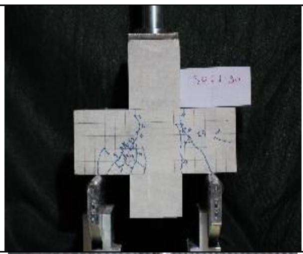
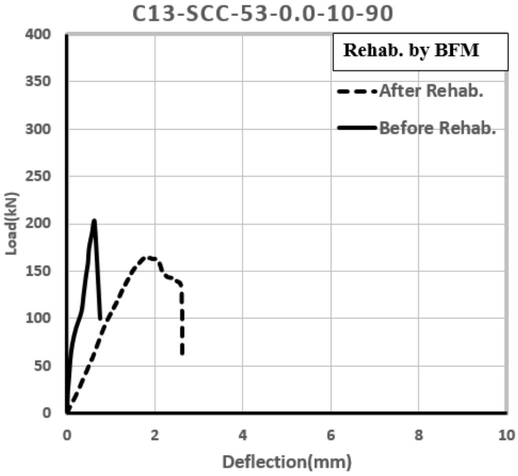
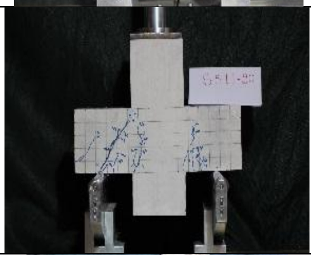
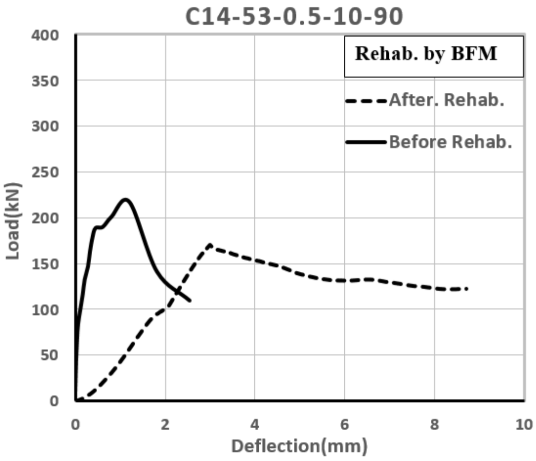
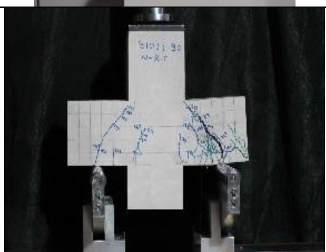
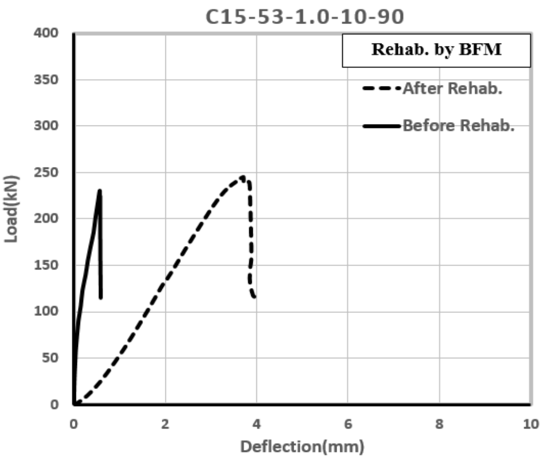
Specimen	Stage	Mode of failure		Load-Deflection Relationship
C13-53-0.0-10-90	Before Reh.		Shear failure	
	After Reh.		BFM rupture	
C14-53-0.5-10-90	Before Reh.		Shear failure	
	After Reh.		BFM rupture	
C15-53-1.0-10-90	Before Reh.		Diagonal splitting	
	After Reh.		BFM rupture	

Table A2 Continued

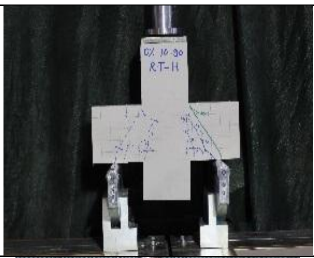
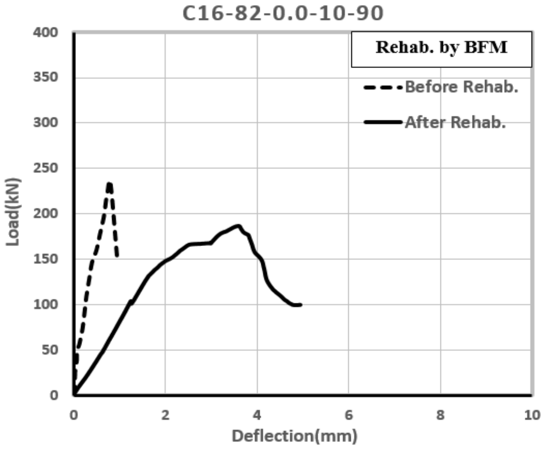
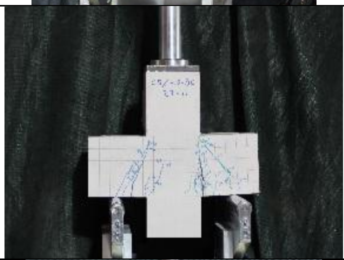
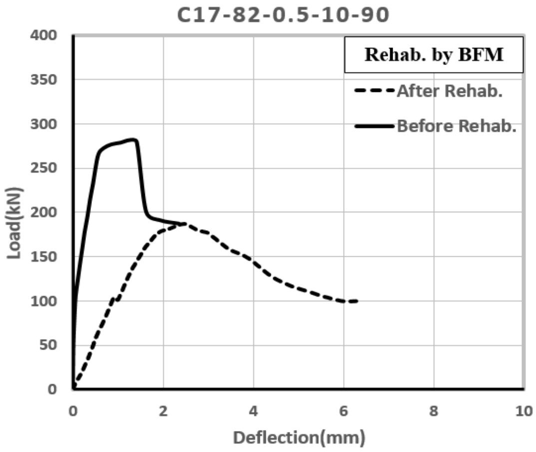
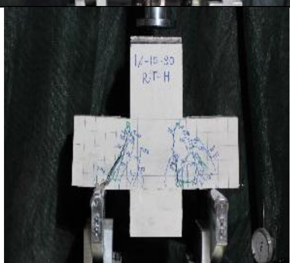
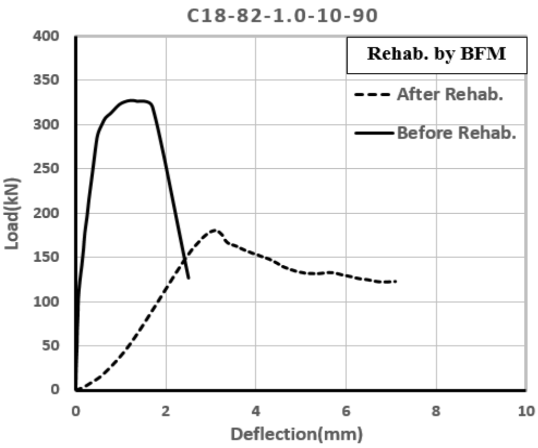
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By BFM	C16-82-0.0-10-90	Before Reh.		Shear failure	
		After Reh.		BFM rupture	
	C17-82-0.5-10-90	Before Reh.		Flexural/ shear failure	
		After Reh.		BFM rupture	
	C18-82-1.0-10-90	Before Reh.		Flexural/ shear failure	
		After Reh.		BFM rupture	

Table A2 Continued

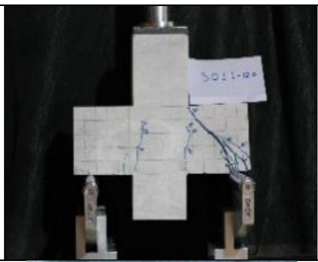
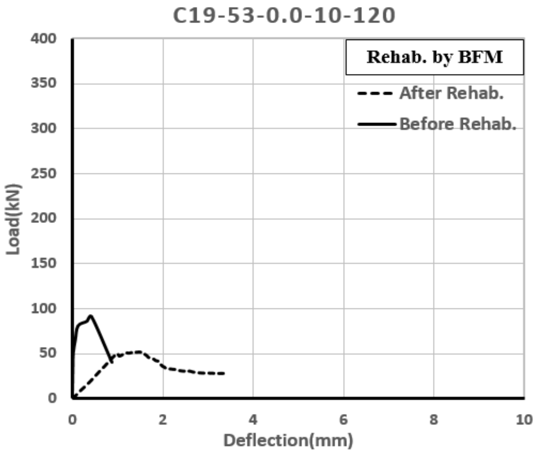
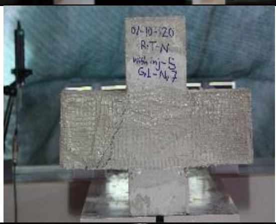
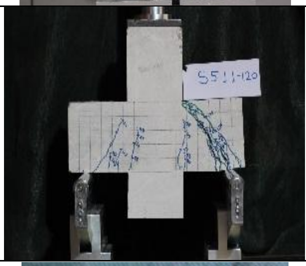
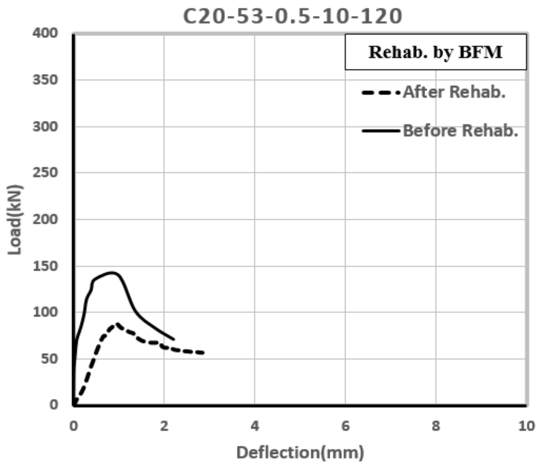
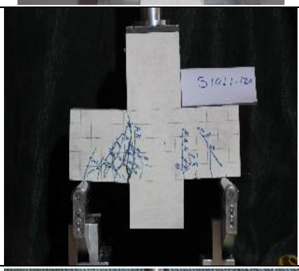
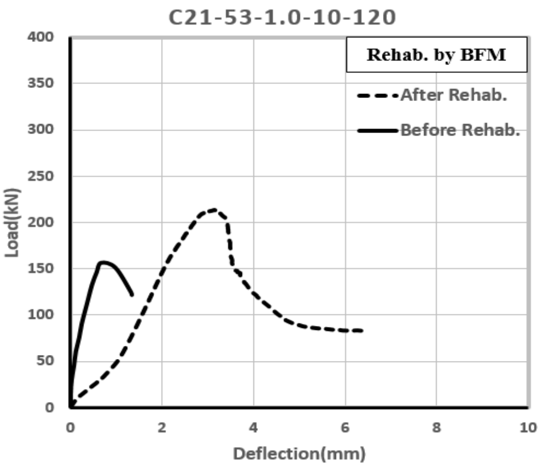
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By BFM	C19-53-0.0-10-120	Before Reh.		Diagonal splitting	
		After Reh.		BFM rupture	
	C20-53-0.5-10-120	Before Reh.		Diagonal splitting	
		After Reh.		BFM rupture	
	C21-53-1.0-10-120	Before Reh.		flexural failure	
		After Reh.		BFM rupture	

Table A2 Continued

<table>
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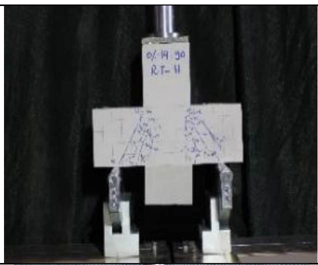
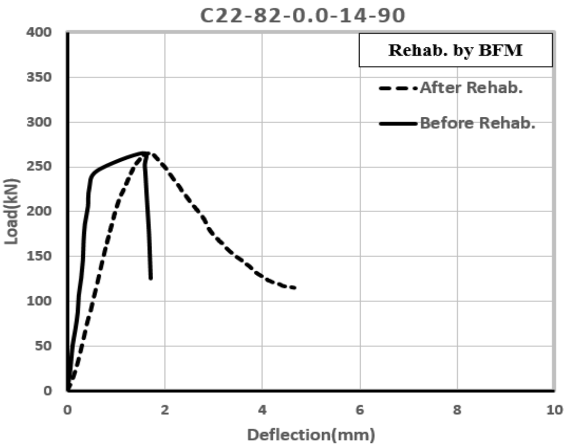
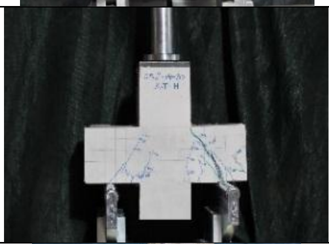
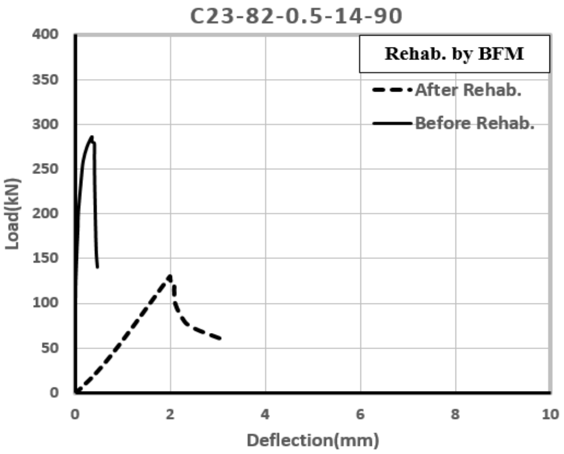
<tr><td rowspan="6">Self-Compacted Concrete/ Rehabilitation By BFM</td><td rowspan="2">C22-82-0.0-14-90</td><td>Before Reh.</td><td></td><td>Diagonal splitting</td><td rowspan="2">
</td></tr>
<tr><td>After Reh.</td><td></td><td>BFM rupture</td></tr>
<tr><td rowspan="2">C23-82-0.5-14-90</td><td>Before Reh.</td><td></td><td>Diagonal splitting</td><td rowspan="2">
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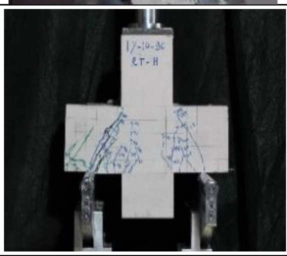
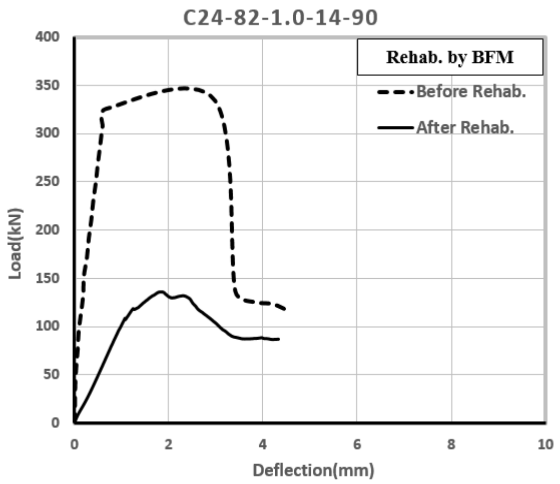
<tr><td>After Reh.</td><td></td><td>BFM rupture</td></tr>
<tr><td rowspan="2">C24-82-1.0-14-90</td><td>Before Reh.</td><td></td><td>Diagonal splitting</td><td rowspan="2">
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<tr><td>After Reh.</td><td></td><td>BFM rupture</td></tr>
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Table A3 Summary of mechanical behavior of corbels C25 to C42

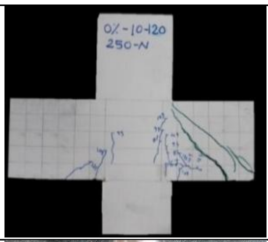
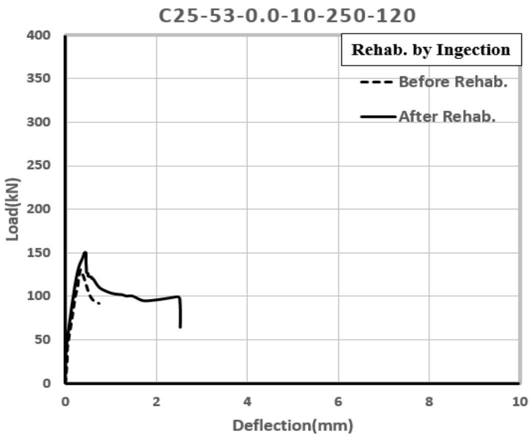
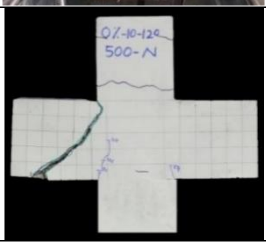
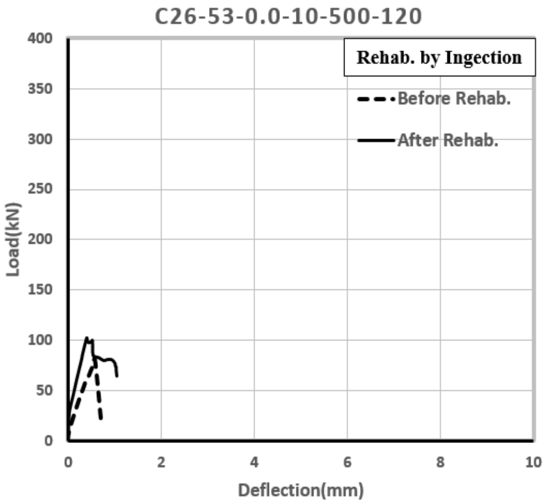
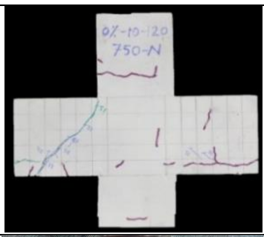
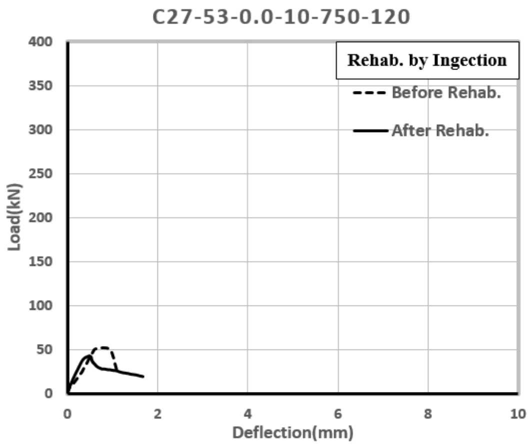
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By Injection	C25-53-0.0-10-250-120	Before Reh.		Shear failure	
		After Reh.		Shear failure	
	C26-53-0.0-10-500-120	Before Reh.		Shear failure	
		After Reh.		Diagonal splitting	
	C27-53-0.0-10-750-120	Before Reh.		Diagonal splitting	
		After Reh.		Diagonal splitting	

Table A3 Continued

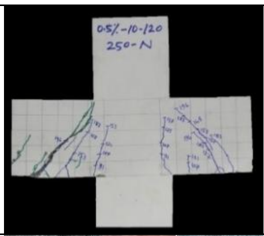
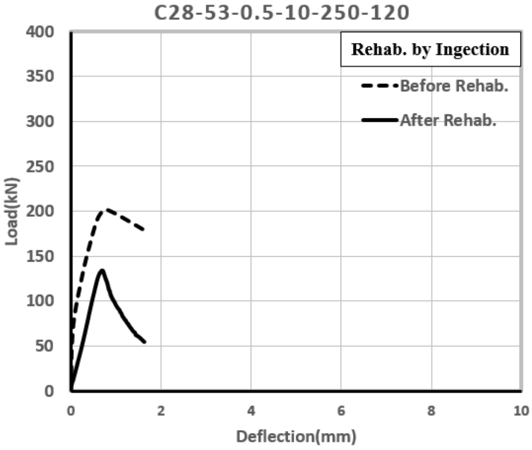
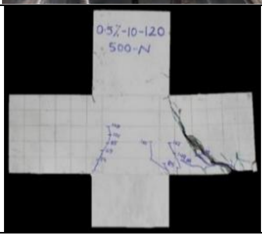
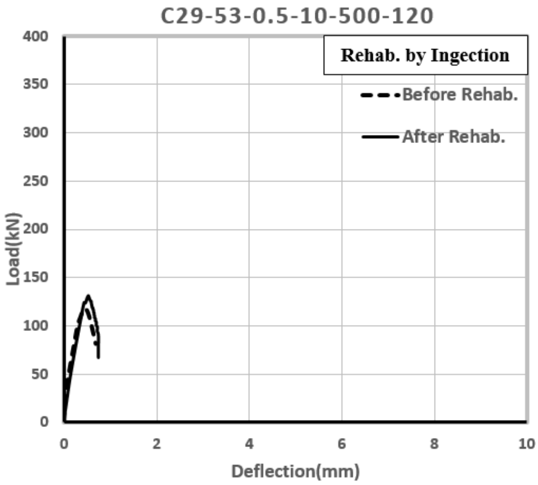
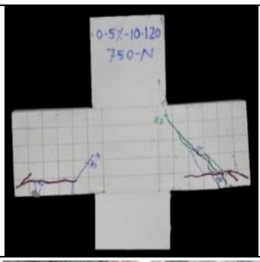
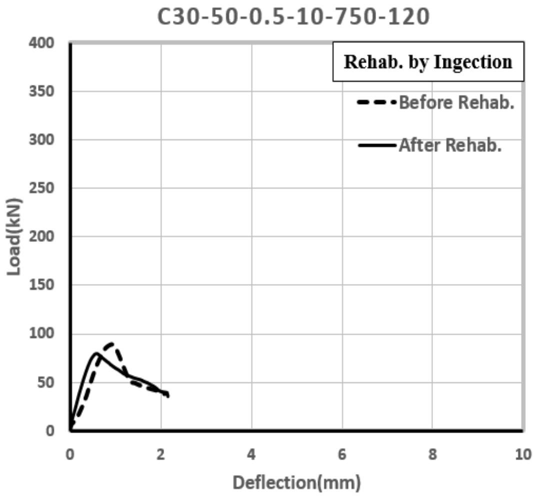
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By Injection	C28-53-0.5-10-250-120	Before Reh.		Diagonal splitting	
		After Reh.		Shear failure	
	C29-53-0.5-10-500-120	Before Reh.		Shear failure	
		After Reh.		Shear failure	
	C30-53-0.5-10-750-120	Before Reh.		Diagonal splitting	
		After Reh.		Diagonal splitting	

Table A3 Continued

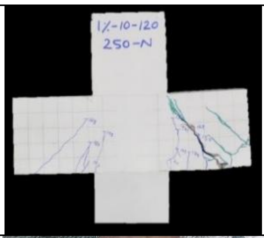
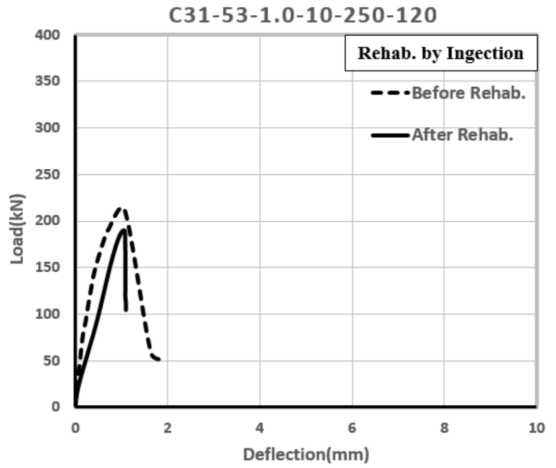
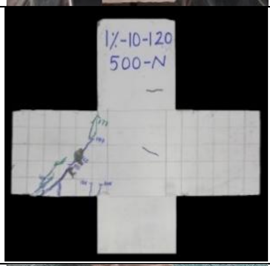
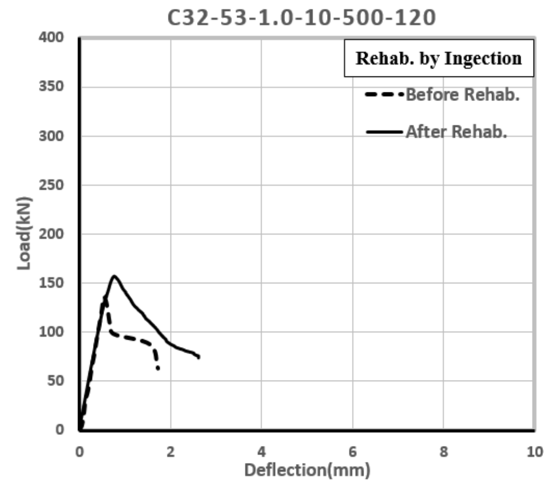
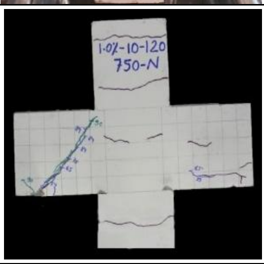
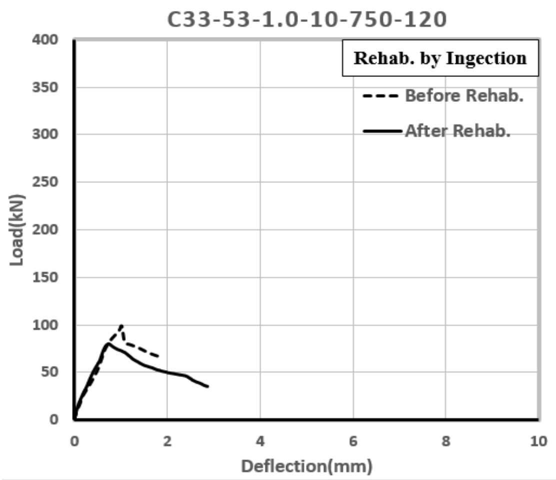
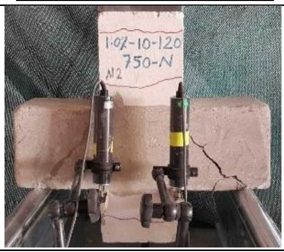
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By Injection	C31-53-1.0-10-250-120	Before Reh.		Diagonal splitting	
		After Reh.		Shear failure	
	C32-53-1.0-10-500-120	Before Reh.		Shear failure	
		After Reh.		Shear failure	
	C33-53-1.0-10-750-120	Before Reh.		Diagonal splitting	
		After Reh.		Diagonal splitting	

Table A3 Continued

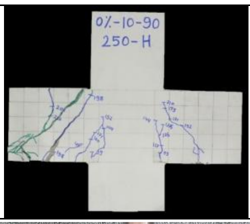
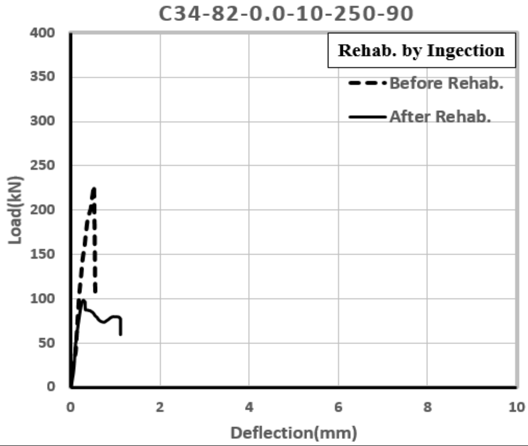
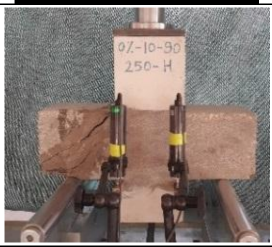
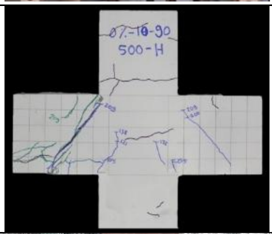
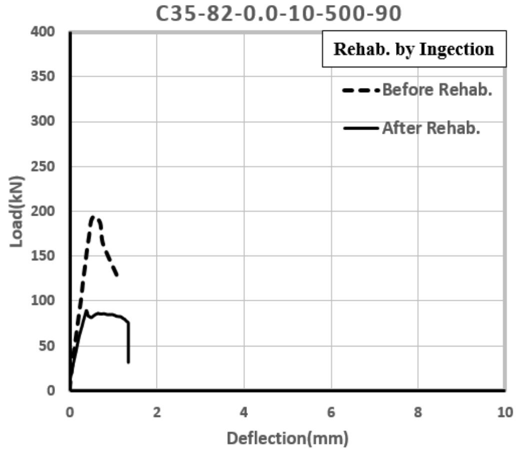
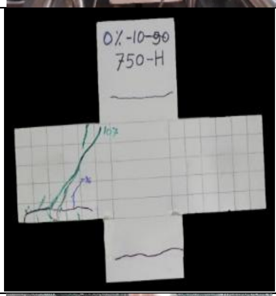
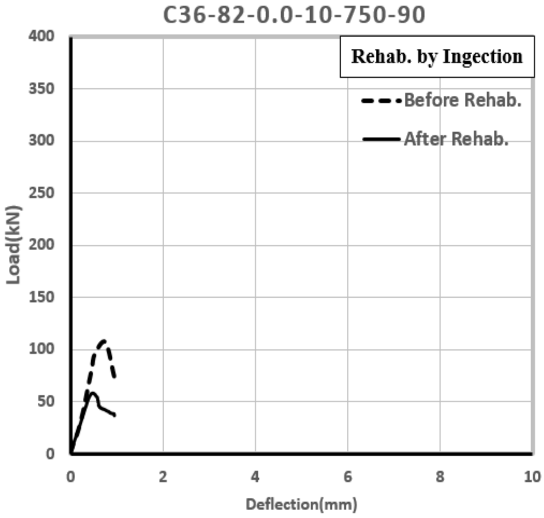
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By Injection	C34-82-0.0-10-250-90	Before Reh.		Diagonal splitting	
		After Reh.		Diagonal splitting	
	C35-82-0.0-10-500-90	Before Reh.		Diagonal splitting	
		After Reh.		Diagonal splitting	
	C36-82-0.0-10-750-90	Before Reh.		Diagonal splitting	
		After Reh.		Diagonal splitting	

Table A3 Continued

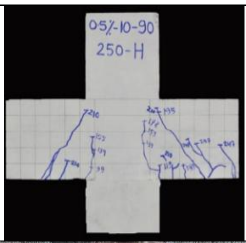
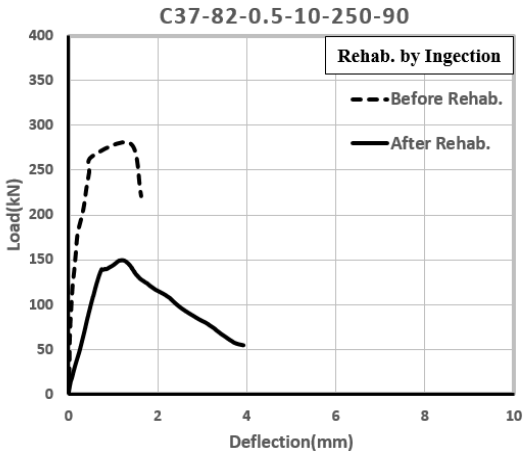
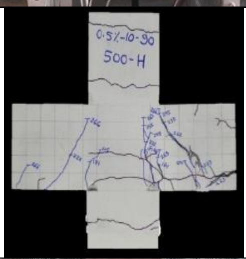
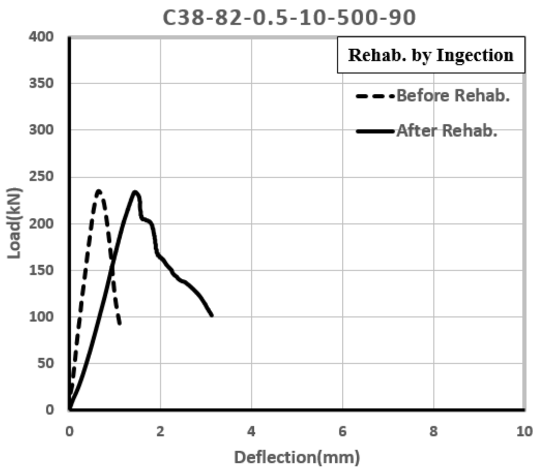
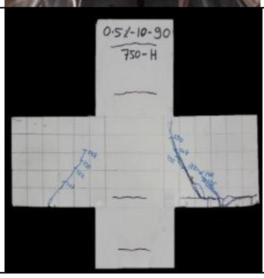
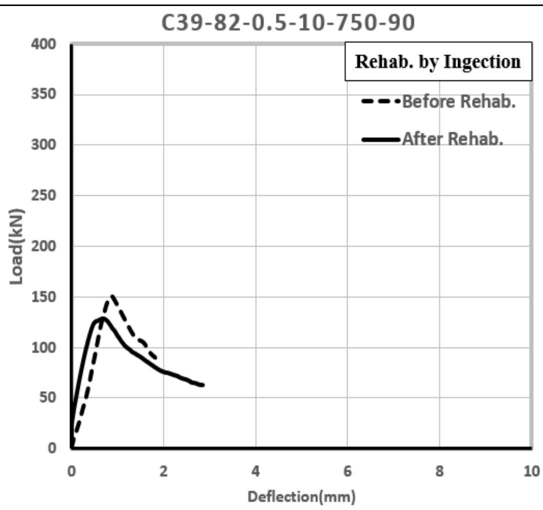
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By Injection	C37-82-0.5-10-250-90	Before Reh.		Diagonal splitting	
		After Reh.		Diagonal splitting	
	C38-82-0.5-10-500-90	Before Reh.		Diagonal splitting	
		After Reh.		Diagonal splitting	
	C39-82-0.5-10-750-90	Before Reh.		Shear failure	
		After Reh.		Shear failure	

Table A3 Continued

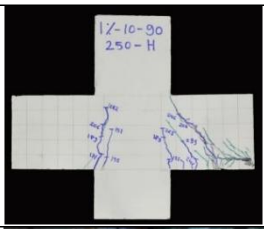
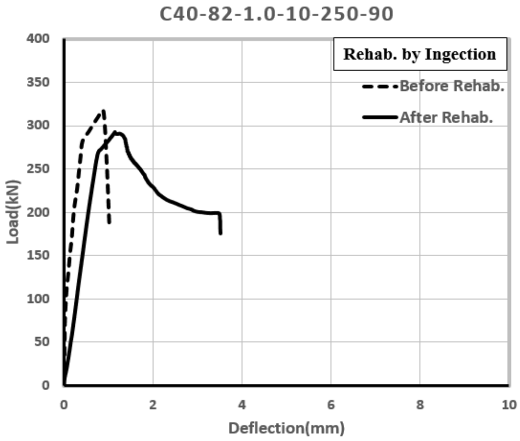
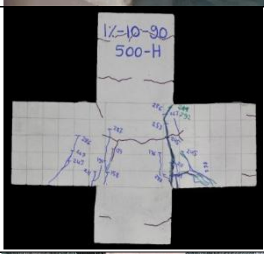
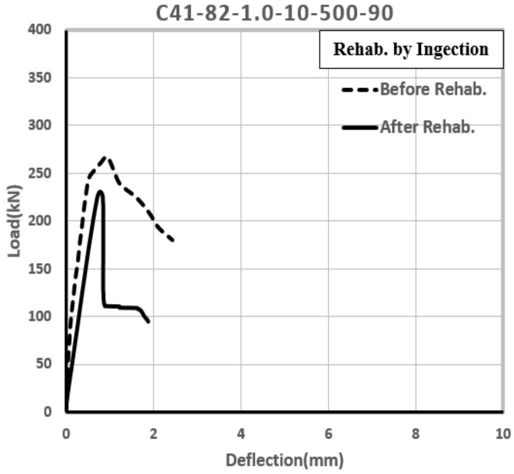
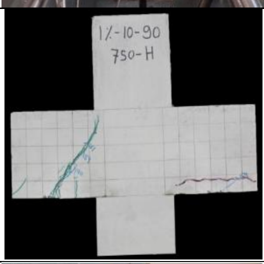
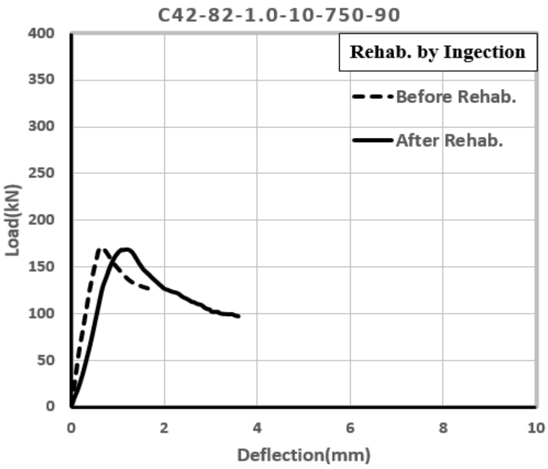
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By Injection	C40-82-1.0-10-250-90	Before Reh.		Flexural/ shear failure	
		After Reh.		Diagonal splitting	
	C41-82-1.0-10-500-90	Before Reh.		Flexural failure	
		After Reh.		Shear failure	
	C42-82-1.0-10-750-90	Before Reh.		Shear failure	
		After Reh.		Diagonal splitting	

Table A4 Summary of mechanical behavior of corbels C43 to C60

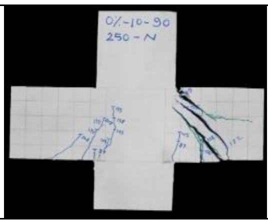
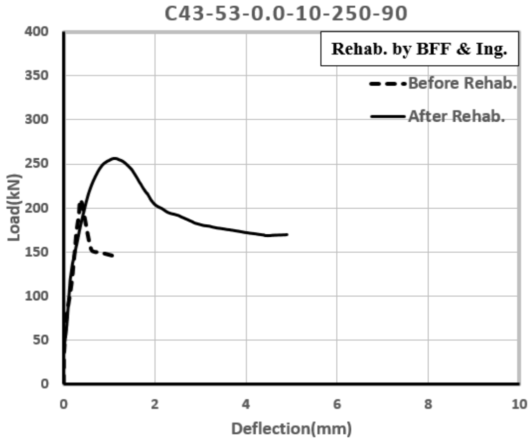
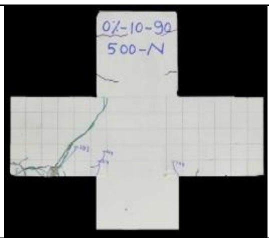
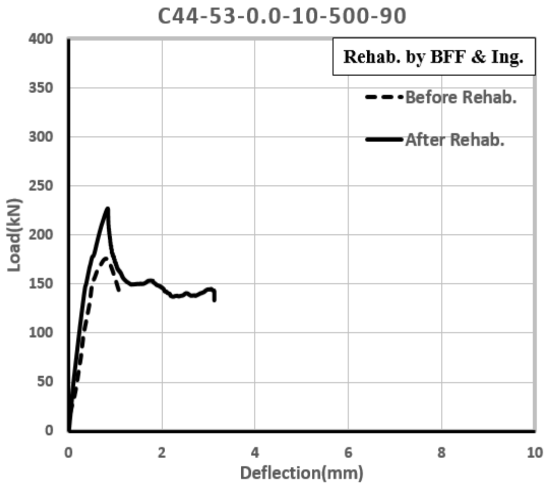
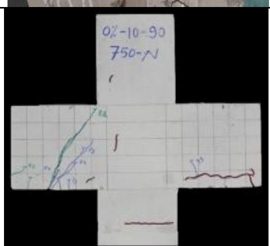
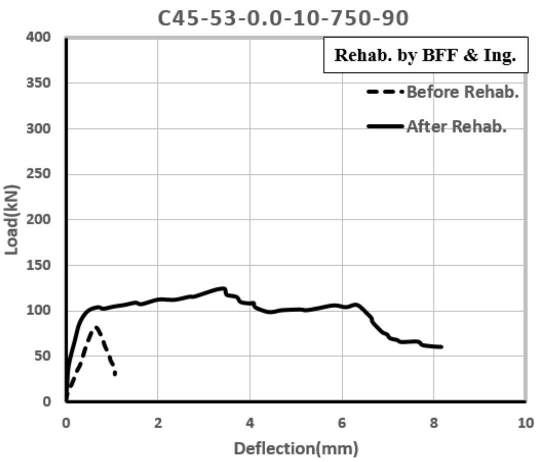
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By BFF & Injection	C43-53-0.0-10-250-90	Before Reh.		Diagonal splitting	
		After Reh.		De-bonding	
	C44-53-0.0-10-500-90	Before Reh.		Shear failure	
		After Reh.		De-bonding	
	C45-53-0.0-10-750-90	Before Reh.		Shear failure	
		After Reh.		De-bonding	

Table A4 Continued

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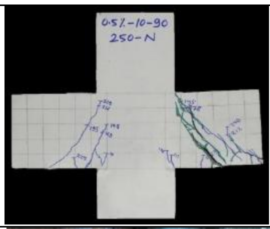
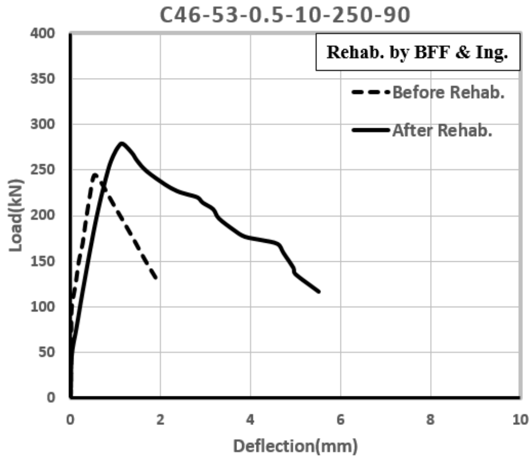
<tr><td rowspan="6">Self-Compacted Concrete/ Rehabilitation By BFF & Injection</td><td rowspan="2">C46-53-0.5-10-250-90</td><td>Before Reh.</td><td>
</td><td>Diagonal splitting</td><td rowspan="2">
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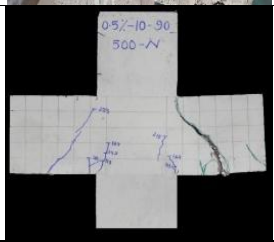
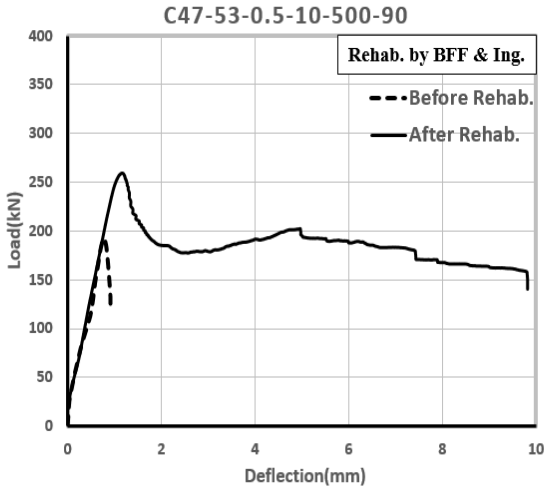
<tr><td>After Reh.</td><td></td><td>De-bonding</td></tr>
<tr><td rowspan="2">C47-53-0.5-10-500-90</td><td>Before Reh.</td><td>
</td><td>Shear failure</td><td rowspan="2">
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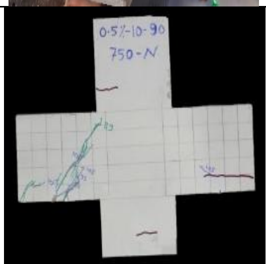
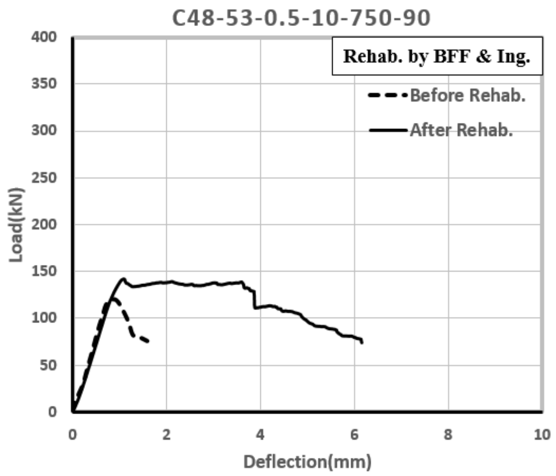
<tr><td>After Reh.</td><td></td><td>De-bonding</td></tr>
<tr><td rowspan="2">C48-53-0.5-10-750-90</td><td>Before Reh.</td><td>
</td><td>Diagonal splitting</td><td rowspan="2">
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<tr><td>After Reh.</td><td></td><td>De-bonding</td></tr>
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Table A4 Continued

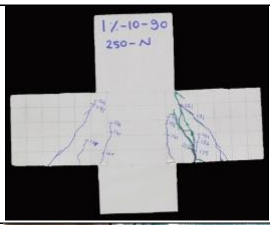
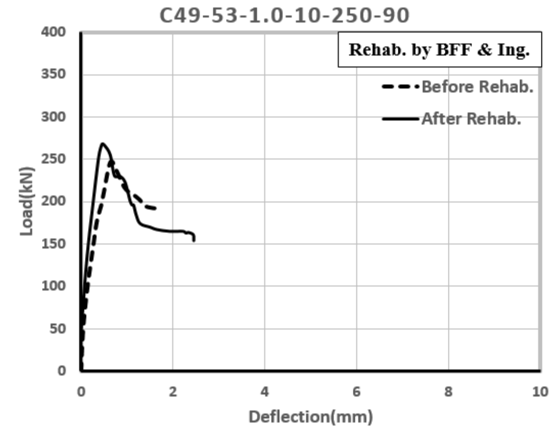
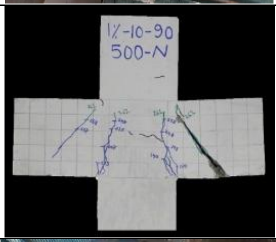
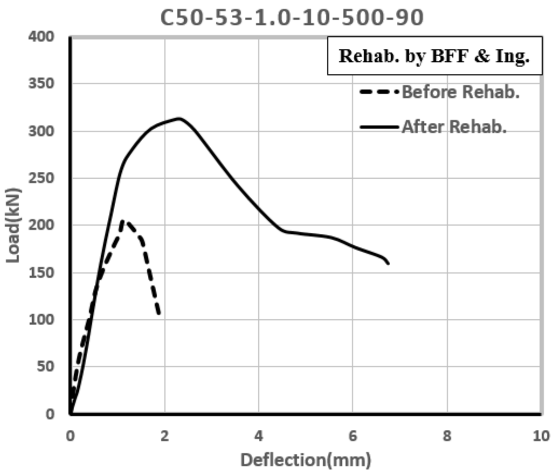
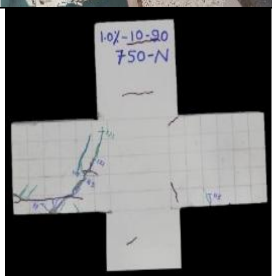
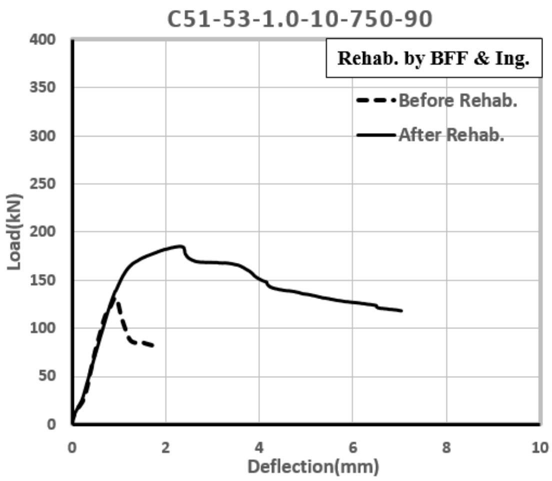
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By BFF & Injection	C49-53-1.0-10-250-90	Before Reh.		Diagonal splitting	
		After Reh.		De-bonding	
	C50-53-1.0-10-500-90	Before Reh.		Shear failure	
		After Reh.		De-bonding	
	C51-53-1.0-10-750-90	Before Reh.		Shear failure	
		After Reh.		De-bonding	

Table A4 Continued

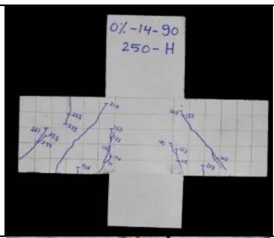
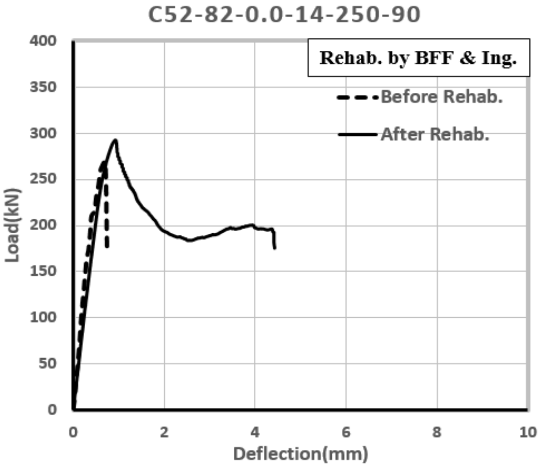
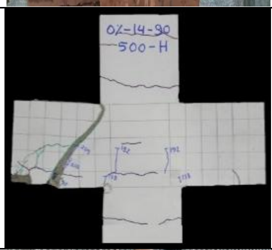
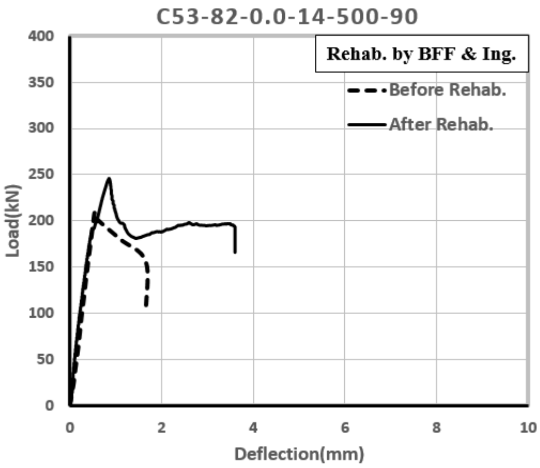
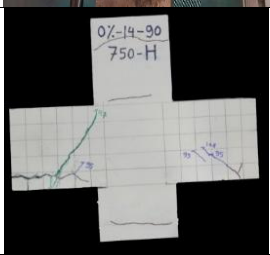
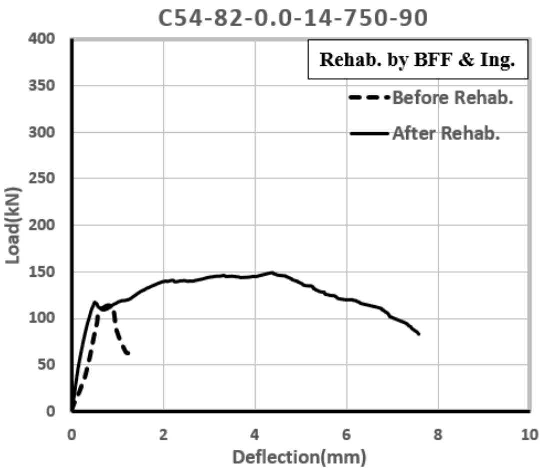
			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By BFF & Injection	C52-82-0.0-14-250-90	Before Reh.		Diagonal splitting	
		After Reh.		De-bonding	
	C53-82-0.0-14-500-90	Before Reh.		Diagonal splitting	
		After Reh.		De-bonding	
	C54-82-0.0-14-750-90	Before Reh.		Diagonal splitting	
		After Reh.		De-bonding	

Table A4 Continued

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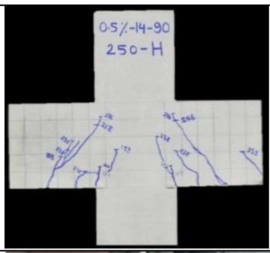
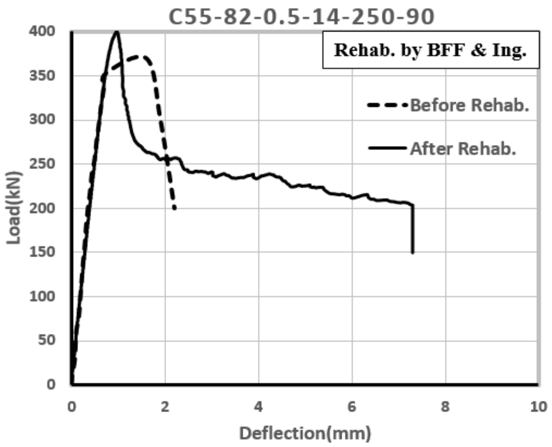
<tr><td rowspan="6">Self-Compacted Concrete/ Rehabilitation By BFF & Injection</td><td rowspan="2">C55-82-0.5-14-250-90</td><td>Before Reh.</td><td>
</td><td>Diagonal splitting</td><td rowspan="2">
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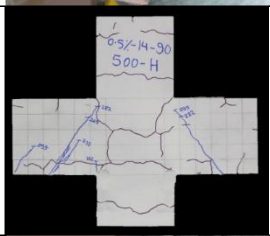
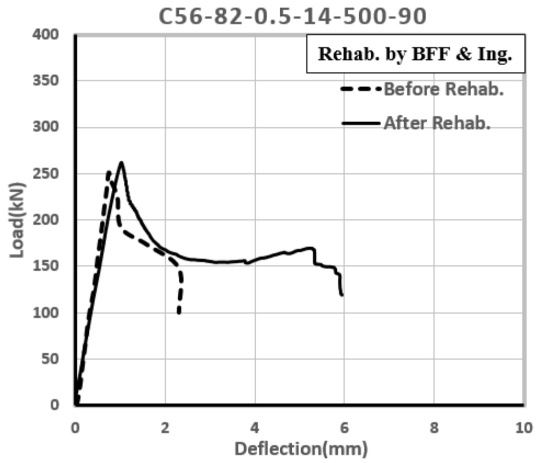
<tr><td>After Reh.</td><td></td><td>De-bonding</td></tr>
<tr><td rowspan="2">C56-82-0.5-14-500-90</td><td>Before Reh.</td><td>
</td><td>Diagonal splitting</td><td rowspan="2">
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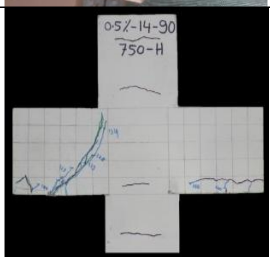
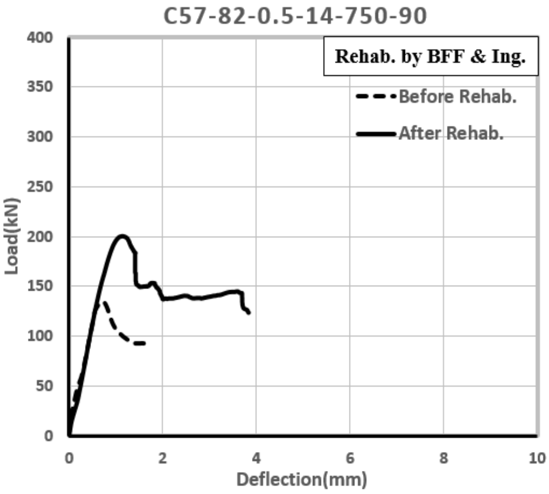
<tr><td>After Reh.</td><td></td><td>De-bonding</td></tr>
<tr><td rowspan="2">C57-82-0.5-14-750-90</td><td>Before Reh.</td><td>
</td><td>Shear failure</td><td rowspan="2">
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<tr><td>After Reh.</td><td></td><td>De-bonding</td></tr>
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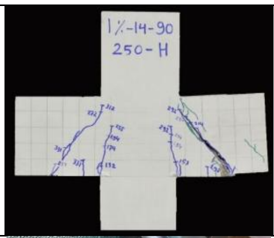
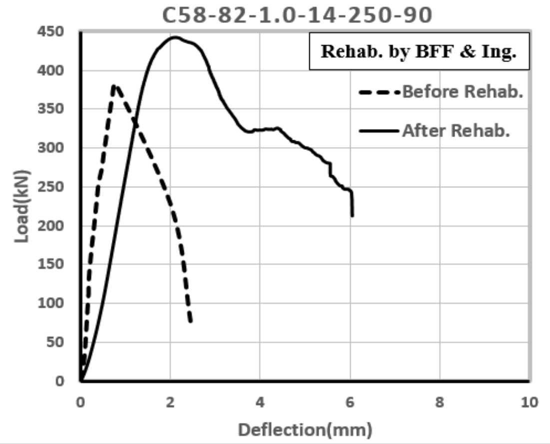
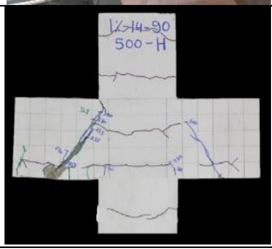
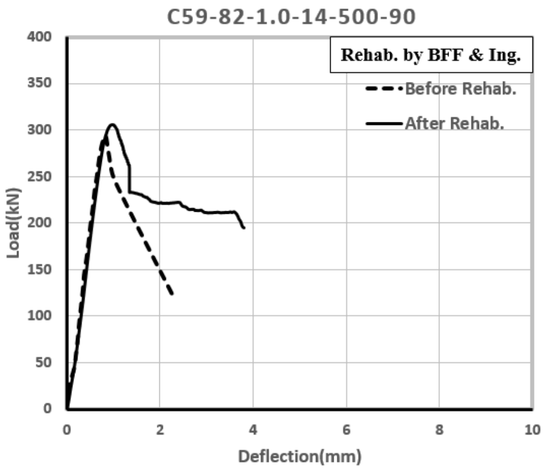
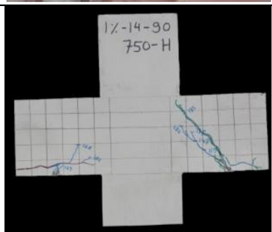
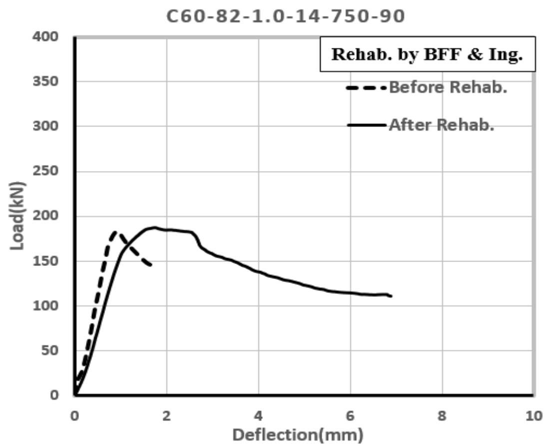
Table A4 Continued

			Mode of failure		Load-Deflection Relationship
Self-Compacted Concrete/ Rehabilitation By BFF & Injection	C58-82-1.0-14-250-90	Before Reh.		Diagonal splitting	
		After Reh.		De-bonding	
	C59-82-1.0-14-500-90	Before Reh.		Diagonal splitting	
		After Reh.		De-bonding	
	C60-82-1.0-14-750-90	Before Reh.		Diagonal splitting	
		After Reh.		De-bonding	