The behavior of rehabilitee beam-column joint under repeated load

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Abstract: This study aims to examine three kinds of rehabilitation techniques which are Carbon Fiber Reinforced Polymer "CFRP" Internal sheets, CFRP jacketing, and Slurry infiltrated Fiber Concrete "SIFCON" jacketing. The experimental program involved casting six specimens of R.C beam-column joints. These specimens are rehabilitated by the proposed techniques and retested. Three of these specimens are rehabilitated by SIFCON jacketing with different levels of jacket thickness and steel fibers. All the specimens (before and after rehabilitation) were tested under the repeated load of three cycles every 400 kN till failure. The specimens consisted of beam and column of 600mm and the joint area is 400mm by 400mm. The results showed that all the techniques were efficient in the recovery of the original structural properties of R.C joints. The CFRP internal sheets recover 144.49 % of maximum strength and 141.57% for yielding load while CFRP jacketing recovers 142.86% and 189.87%. While the SIFCON jacketing recovers about 170.71% to 188.14% of maximum strength and about 214.15% to 249.71% to 226.58% of yielding load respectively for all the proposed steel fibers content and jacket thickness. The recovery of original levels of maximum and yielding deflection about 32% and 50% respectively, also recovery in the stiffness factor.

Keywords: Beam Column Joints, Rehabilitation Techniques, CFRP

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1. Introduction

During the whole life of the reinforced concrete building system, the beam – column joints may face earthquake loads. This means that it may exhibit to vary high levels of shear and moment loads. In addition to this idea, the most prominent mark of damage is manifested by such kind of structural members. In this way, there are many justifications for looking for new rehabilitation techniques that can recover the inherent resisting characteristics of reinforced concrete joints.

Reinforced concrete beams and columns are the most important elements of moment-resisting frame systems. Beam-column joints are exposed to a mixture of strong moments and shear forces during extreme earthquakes. The failure due to these enforced actions can result in serious harm. This can in turn adversely affect the integrity of the entire system.

Although buildings designed and constructed in accordance with the known seismic standards are capable to withstand the applied seismic forces, this fact does not exist for old exhausted buildings. Exploration reports of recent earthquakes are always revealing the vulnerability of older existing RC buildings [1]. However, when beam-column joints were severely damaged, in many cases observed or reported building failures may be happening as shown in Figure 1.

Figure 1: Severe damage (semi collapse) in beam-column connections after the 1999 Izmit, Turkey earthquake [2]

In addition, earthquakes reveal how exterior joints are highly vulnerable to seismic activity while interior joints are not. That is due to the existing abrupt adjustment in geometric circumstances of exterior reinforced concrete. This causes lower and unbalanced applied moments (both torsion and flexural) as well as increasing internment and weaker bond demand for the fastened beam bars [3, 4].

More precisely, the observed failure in exterior beam-column joints is ascribed to response damage in older buildings. In general, such joints experienced a significant lack of shear, stability; poor beam bar anchorage, and/or due to lap splices [5]. Inside historic buildings, breakdown usually occurs gradually or suddenly, from the weakest joint to the weakest in a form of chain of structural elements. [6]. However, studies were done on how to enhance the seismic performance of such structural members within moment resisting frames. On the other hand, such studies have not concentrated on testing of older buildings with poorly designed beam-column joints (although such buildings represent the vast majority between the current stocks of buildings).

It is obvious that the earthquake engineering community is rather concerned on the risks that many of these old and poorly constructed buildings represent when a catastrophic earthquake occurs. In addition to the lack of financial resources, it is difficult to retrofit such buildings because of the low level of public awareness in such countries. The only method presently possible is to spread public awareness in addition to develop powerful appraisal advance that able to precisely estimating strength of existing buildings with minimal cost. Consequently, the rehabilitation need for exterior beam column dictates the search for any new effective technique to manage the deficient joints in the old buildings experienced a seismic beam column joint failure. Because the behavior of concrete joints is not understood before and after exposure to deformation under various types of loads according to its location and dimensions in the building and it is not possible. Therefore, studies take into account the harmonization of techniques according to structural and chemical suitability and are studied laboratory and modeling. So, this study tries to understand the behavior of beam column joints rehabilitated by some innovative proposed techniques,

2. Review of the History of Beam-Column Joints

The first laboratory concerned with the behavior of joints American Portland cement society [7]. There are many reasons behind retrofitting and rehabilitation of concrete RC structures. These could be strengthening, increase capacity of loads, the faults of construction and design, and modifying the structural system, strength, shear and flexure capacity in joints etc. [8]. In the last few decades, there has been an increase in interest in using fibers to strengthen and rehabilitate concrete joints of buildings, due to the incomplete and clear picture of the behavior of the elements of the structural joint and noticed the failure and damage in the connection area of the column with the beam under the influence of earthquakes because it is not taken into consideration in the design of the joints. The beam-column joints should have great concern because it had a complex behavior under non seismic loads, which is obvious by a combination of the diagonal tension, shear forces, bond stresses, which lead the cracking to brittle mode of failure [Uma 2005, Engindeniz 2008]. In the previous literature there are several techniques for strengthening the joint area as adding jacket for deficient beam-column joint. It was used extensively in the 1980s and 1990s. [9]. There have been problems with field application of steel jackets due to their heavy weight. So it was replaced by the CFRP sheets or sheets or CFRP Figure for strengthening purposes, , the sheet can take a form of diagonal X or L or jacket according to the joint condition,[10],but it faced the problem of the economic and practical side [Campione et al. 2013,]The CFR Sheets are CFRP are different in applications, texture, shape, and dimensions It is used for strengthening according to the state of the building member and the direction of the influencing stresses Modeling with Finite elements program has become an effective computational method for nonlinear analyses of RC connections in order to predict the behavior crack patterns and load deflection under the applied different types of loading. The simulation results must be verified by real experimental test [Alsayed et al. 2010]. In this paper, the research focuses on the sprayed FRP joint strengthening and other techniques, mode of failure, mechanism and theories like truss mechanism. The joint, it turns out, is not safe to cut. In such instances, one of the three options listed below can be tried. mode of failure, mechanism and theories According To ACI 352-02 .

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(1) Expanding the column portion

This choice not only expands joint space, but it also reduces the primary longitudinal needs.

Due to the benefits of increasing the dimensions of the joint and it’s the size of its steel bars on the stiffness and sheer resistance of connections:

(2) Increase the beam section's size.

If this option is used, it is suggested that the depth has to be increased the resistance of shear forces in critical zones to rehabilitate the joint in the old building. This reduces the amount of steel required in the beam and, as a result, the joint cut. If the difference in shear strength between the joint and the common sternum is minimal, an increase in beam width can be considered.

(3) Raise the concrete quality. This choice will boost the joint's shear strength while also lowering the amount of steel required in the columns [11].

3. Methods for Strengthen and Retrofit

There are several ways to rehabilitate and strengthen concrete joints, such as:

A. Injection inside cracks

Crack injection is one of the most cost-effective rehab options in booster therapy RC building. For this process, according to the shape, length, and size of the crack, cement grout and epoxy are used commonly for adhesive. Epoxy is suitable for a range to a crack width of 5-6 mm, while cement is used plaster of up to 20 mm crack width. Incisions injection is a basic method in which the damage to the connection should be reduced and the incisions must be ongoing; if not, challenges may arise while the repair procedure. In the beginning, bulk materials are removed. Then, the damaged concrete should be removed. It is commonly filled by a paste of cement under a proper pressure ranging from 2-5 bar depending on the shape and cracks width [12] In epoxy injection, first, nozzles are primed on the surface of the joint for epoxy Injection. The distance between the holes depends on the size of the crack and the viscosity of the epoxy resin. After that, the epoxy resin is used to fill the path of the crack [13].

B. Enlargement of the beam-column zone

As in the previous literature, increasing the dimensions of the joint section as a result, increment for shear resistance and the transformation of the shear behavior into a bending behavior, increased stiffness and energy absorption in the joint area.

C. Add fibers to concrete like steel, glass, carbon and others.

D. Patching, coating, spray concrete, electric chemical and others.

4. The Mechanism of Joints

The failure in joints depends on trust mechanism, which is a theory based on the triangle of the three diagonal, vertical and horizontal forces of the section. The behavior of the joint is difficult to understand because it includes various Mechanisms like shear, gravity, flexural effects [14, 15]; see Figure 2.

5. The geometry of Beam Column Joint

There are several forms of column and beam connection such as “T, L. Knee joint...etc.” that ought to be designed within the weak-column strong-column design principle. Laboratory results must provide how the forms of concrete joints behave. This is to know the general behavior of the joint in terms of the type of loading condition and to know the effects of deflection, taking into consideration the eccentricity effect in each member of connections [16].

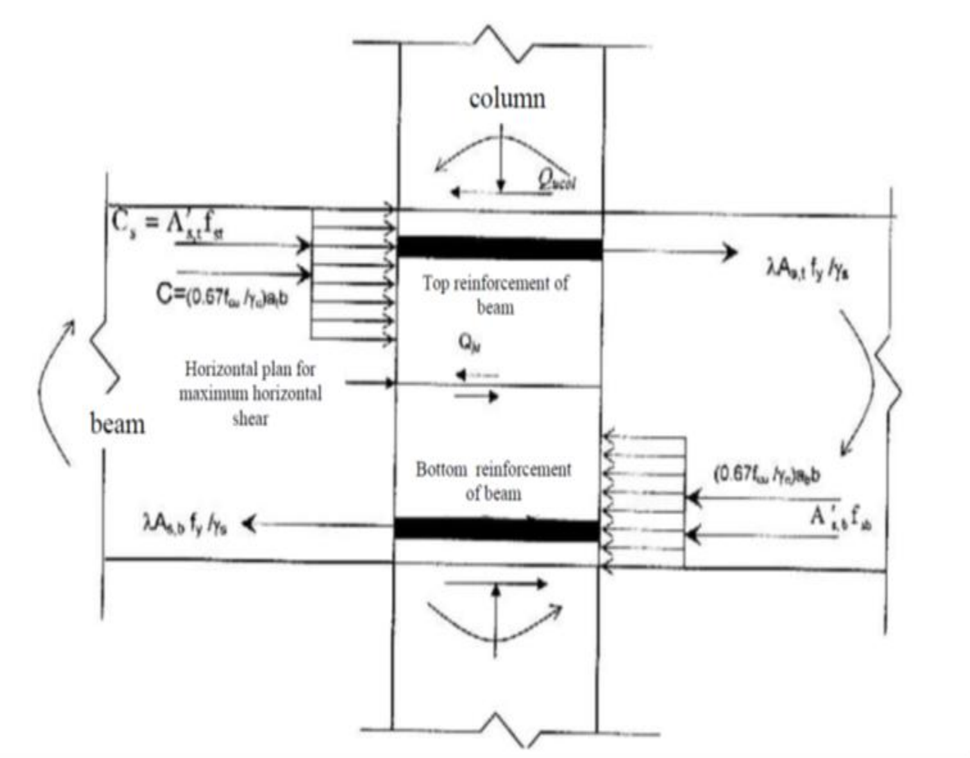

Figure 2: The acting forces on the joint [ECP (2007) [15]

6. Objectives and Scope

The basic goal of this study is to investigate the structural behavior beam – column joint rehabilitated by some proposed techniques when subjected to repeated load. Throughout this study, the following objectives are set to get the former aim:

1. A set of preliminary tests were conducted using the proposed mix to magnify the properties of hardened concrete.
2. The suitable materials and instrumentations were brought and prepared to investigate the effects of some key elements of CFRP beam-column joint rehabilitation technique.
3. The suitable materials and instrumentations were brought and prepared to investigate the effects of some key elements of SIFCON blocks beam-column joint rehabilitation technique.

4. The suitable materials and instrumentations were brought and prepared to investigate the effects of some key elements of (diagonal bars) beam-column joint rehabilitation technique.

7. Experimental Program Specimens Designation

The basic idea behind the current experimental program is to propose and examine two rehabilitation techniques to beam column joint specimens that loaded repetitively and faced a reasonable representative degree of damage in its critical zone “which is the intended joint and the surrounding beam / column nearby zones”. To reach such idea, six beam column joints were loaded initially “as discussed later” until that defined degree of damage.

The first specimen is the “Reference” to obtain a base point for comparison. The second and the third specimen are proposed to examine the Carbon Fiber Reinforced Polymer (CFRP) sheets rehabilitation technique while the other three specimens are directed to examine the Slurry Infiltrated Fiber Concrete (SIFCON).

Within the specimen designation, the “R” is the unique character that refers to the “Reference” specimens. For the other specimens, the first character is either “C” which refers to CFRP rehabilitation or “S” which refers to SIFCON rehabilitation. The second character is either “I” which refers to “Internal sheets” or “J” which refers to “Jacketing”. The third character is a number that may refer to the extension of CRFP sheets (in CFRP specimens) or may be the percent of steel fiber with SIFCON specimens. The last digit is a number which refers to the thickness of the SIFCON jacket and does not appear in CRFP rehabilitation specimens. Table 1 below shows the beam designation of the current study.

The beam column domain consists of 1m total length for both beam and column “including 400mm joint as an interface between them”. Both sections are rectangular of 400mm x 400mm. On the other hand, the main reinforcement of the column section consists of 4 bars 16mm whereas the secondary reinforcement is 12mm @ 250 mm c/c.

Furthermore, the beam was reinforced by 4 bars 16mm as “main reinforcement”; two of them are in the top and the others are in the bottom in addition to 12mm @ 82 mm c/c “secondary reinforcement”. Column sections, beam section as well as a transversal section are shown in Figure 3.

Table 1: The specimen designation

Item	Designation	Description
1	R	Reference specimen
2	CI30	Rehabilitation by CFRP Internal sheets with arms of 30cmm
3	CJ50	Rehabilitation by CFRP Jacket extensions of 50cmm
4	SJ10%2.5	Rehabilitation by SIFCON 2.5 cm Jacket thickness and have 10% steel fiber
5	SJ12%2.5	Rehabilitation by SIFCON 2.5 cm Jacket thickness and have 12% steel fiber
6	SJ10%2	Rehabilitation by SIFCON 2 cm Jacket thickness and have 10% steel fiber

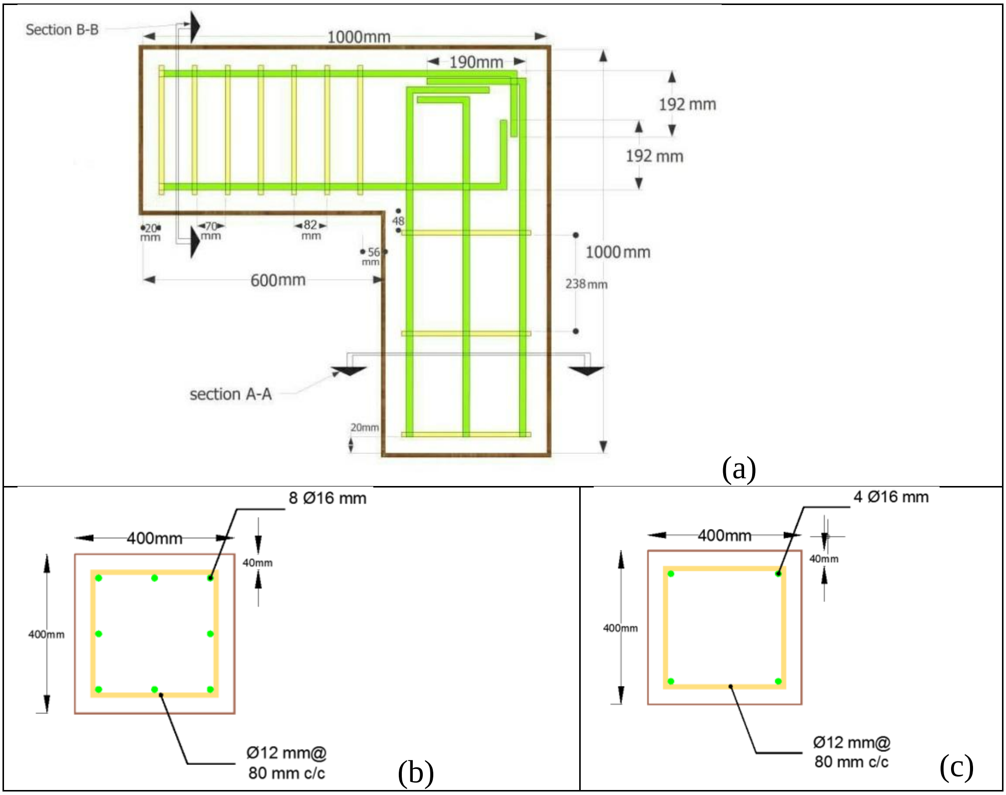

Figure 3: Details of specimens: (a) Transversal section (b) Section A-A (column) (c) Section B-B

8. The Proposed Rehabilitation Techniques

Figure 4 and Figure 5 show such technique. Before applying any procedure for rehabilitation, the rehabilitated specimen's cracks were diagonal in the joint zone formed by axial load and then the repairing process began, cleaning by an air compressor and then filled with Epoxy for all proposed techniques. The Internal CFRP Sheets have 30 cm L shape sheets of CFRP after adding two layers of Epoxy at the intended surface and left for 7 days to gain reasonable strength.

The CFRP jackets which have been proposed in this research program are covering the joint zone as well as an extended 10 cm within beam and column as shown in Figure 6 and Figure 7. As in the previous technique, two layers of Epoxy were added to the intended surface and left for 7 days to gain reasonable strength.

The 50 cm SIFCON jacket was casted to cover all the joint area and extended to 10 cm with beam and column of each specimen. The time of casting SIFCON jackets was calibrated to get 28 day until testing. Furthermore, twelve 5 mm in diameter was bolted through the joint zone of the rehabilitated specimens as shown in Figure 8 and Figure 9. Three specimens were rehabilitated by this technique to calculate two thickness values as well as two amounts of steel fibers, as illustrated previously.

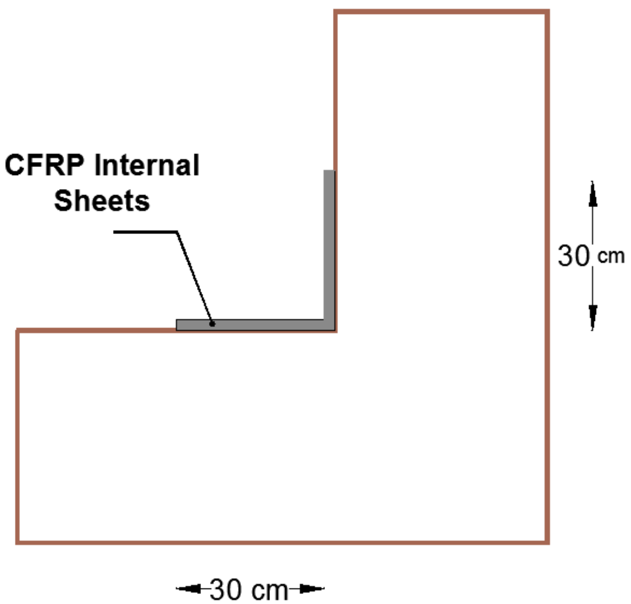

Figure 4: Internal CFRP Sheets

Figure 5: Internal CFRP sheet specimen

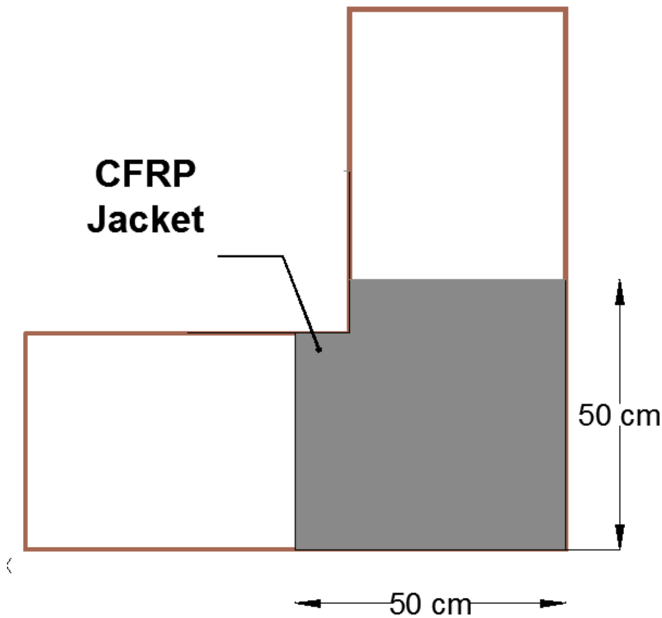

Figure 6: The CFRP jacket

Figure 7: The CFRP jacket specimen

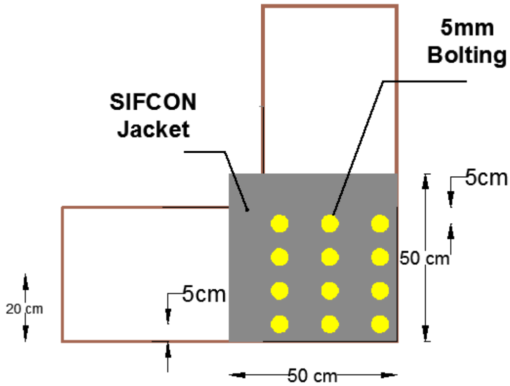

Figure 8: The SIFCON jacket

Figure 9: The SIFCON jacket specimen

9. Results

9.1 CFRP Jacketing

The following sections discuss the feasibility of using CFRP jacketing technique for successful rehabilitation of beam column-joint.

Table 2 shows the maximum strength, yielding strength. Figures 10 to 13 highlight the load deflection curves. Where: deflection in column right direction (denoted as DCR), deflection in beam right direction (denoted as DBR), and deflection in column left direction (Denoted as DCL) and deflection in column downward direction (denoted as DCD).

Table 2: The maximum strength, yielding strength

Specimen	Maximum load (kN)	% increase in P_u %	Yielding load P_y in kN	*% increase in P_y %
Reference	1400	/	653.75	/
CFRP Internal Sheets	2000	142.86	1241.25	189.87

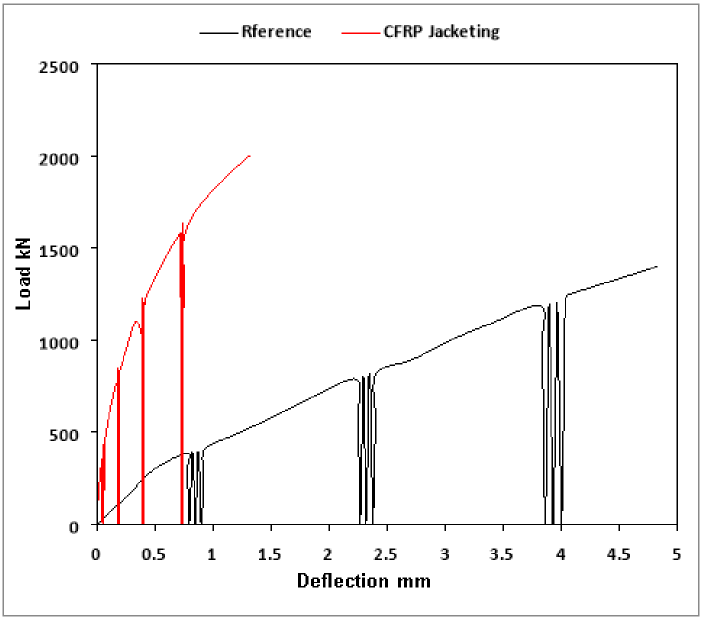

Figure 10: Load deflection curves of CFRP jacketing DCR

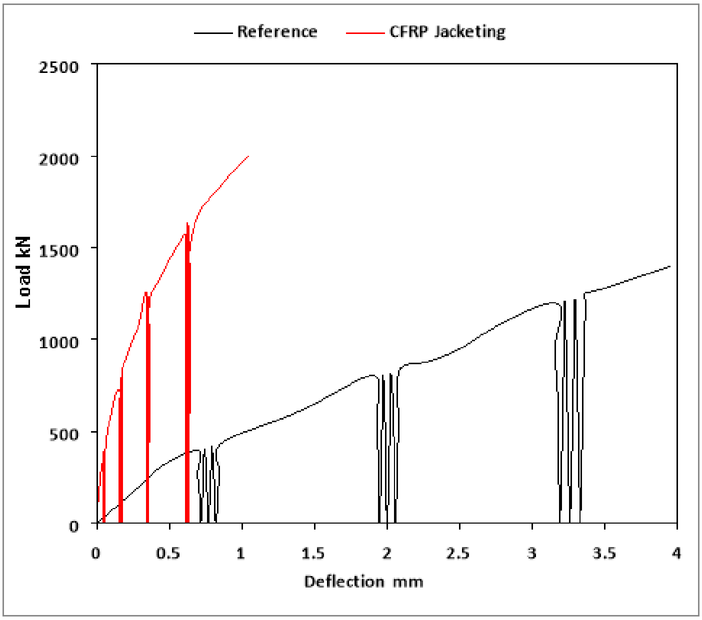

Figure 11: Load deflection curves of CFRP jacketing DBR

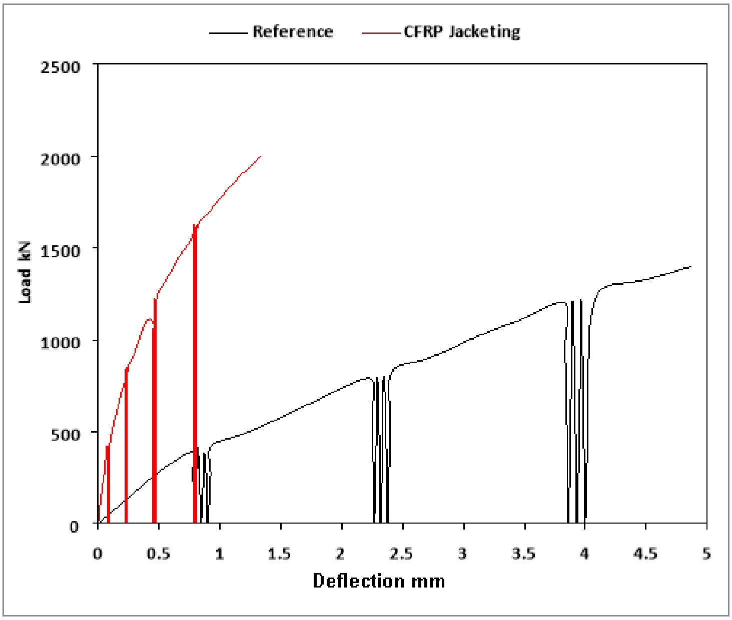

Figure 12: Load deflection curves of CFRP jacketing DCL

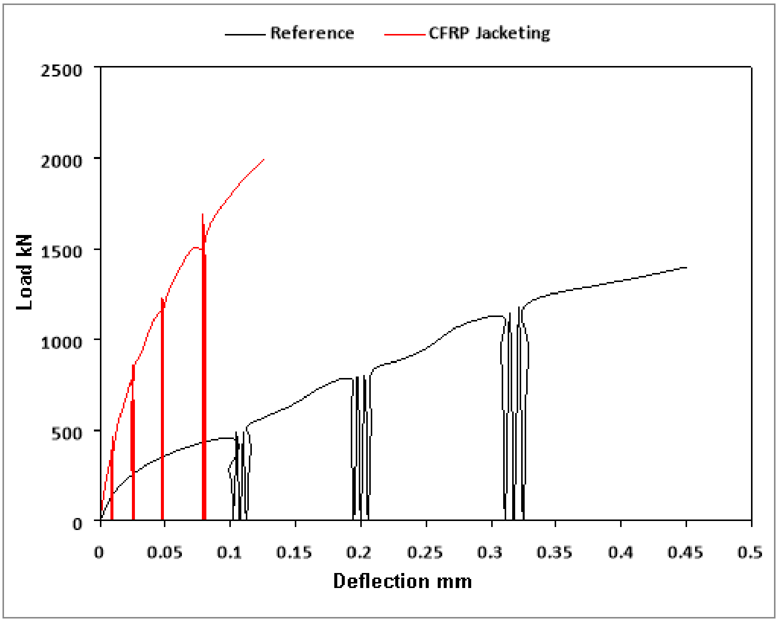

Figure 13: Load deflection curves of CFRP jacketing DCD

On average, the results presented in Table (2) show that the recovery is 142.86 % and 189.87 % for maximum load and yielding load respectively. Together these degrees of recovery with CFRP internal sheets, CFRP jacketing proved more level of performance. These results can be explained by the fact that the jacketing play the role of enhancement in two possible ways, the first is the resisting components of CFRP and epoxy along the surface of failure (as in CFRP internal sheets technique) and the second is the confinement action of CFRP.

In future investigations, it might be possible to study the effect of the number of CFRP sheets layers that add on the connection as a jacketing that are used in the joint area, in its resistance and stiffness.

The stiffness and ductility factor calculations of the CFRP jacketing specimen are listed in Table 3.

Table 3: Stiffness Factor for CFRP jacketing specimen

Specimen	Response	Yielding Deflection mm	Yielding load (kN)	Stiffness Factor (kN/mm)	Recovery in stiffness factor (%)
Reference	DCR	1.1	625	568.18	/
	DBR	0.88	620	704.55	/
	DCL	1.05	690	657.14	/
	DCD	0.05	680	13600	/
CFRP jacketing	DCR	0.14	1250	8928.57	1571.43
	DBR	0.13	1255	9653.85	1370.21
	DCL	0.22	1260	5727.27	871.54
	DCD	0.024	1200	50000	367.65
	Average		1241.25	Average	1045.13

*Recovery of $k = k_{specimen} / k_{reference}$

Within Table 3, the observed recovery has been reached to huge extent (1045.13 % as an average), because the damaged concrete and CFRP work as a combined material and the incensement in the stiffness. when it is compared with CFRP internal sheets. It seems possible that this jump is dictated by the high strength gain. However, future work should be undertaken to propose empirical relations between CFRP material stiffness and the RC rehabilitated specimens with respect to stiffness.

9.2 SIFCON Jacketing SJ10%3

The following sections are devoted to discuss the feasibility of using SIFCON jacketing technique (That includes 10% Steel fibers and 3 cm thicknesses) for rehabilitation of beam column-joint.

With respect to maximum Strength, Yielding Strength, Maximum Deflection and Yielding Deflection, Table 4 shows the maximum strength, yielding strength, maximum deflection. Figure 14, 15, 16, and 17 show the load deflection curves.

Table 4: Maximum and yielding strength for SJ10%3

Specimen	Maximum load (kN)	Recovery in P_u %	Yielding load in kN	Recovery (%)
Reference	1400	/	653.75	/
SJ10%3	2515	179.64	1481.25	226.58

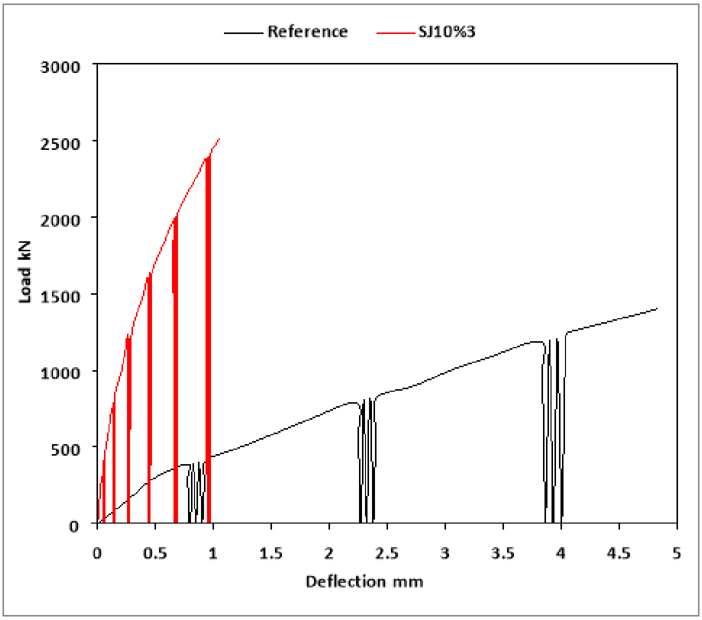

Figure 14: The load deflection curve DCR

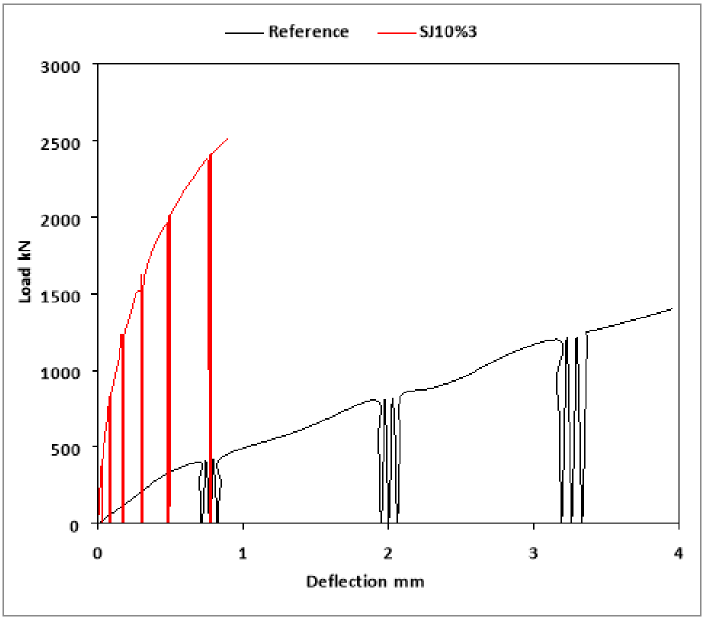

Figure 15: The load deflection curve DBR

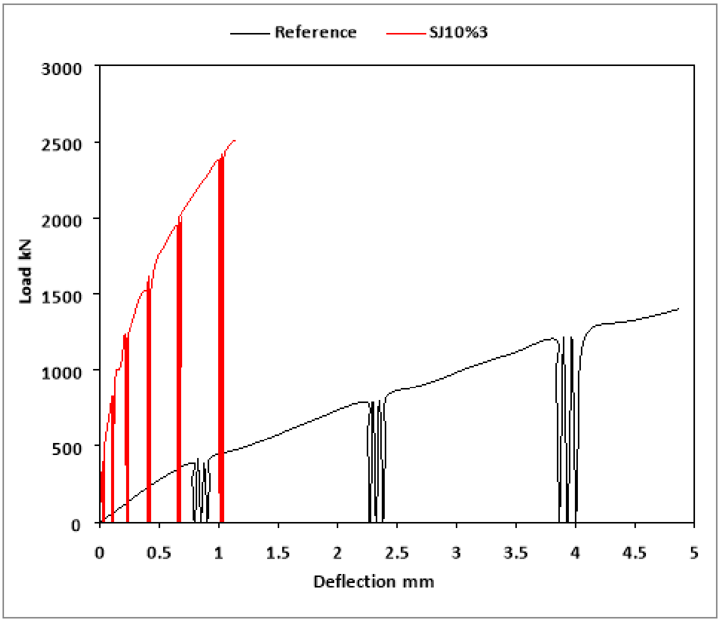

Figure 16: The load deflection curve DCL

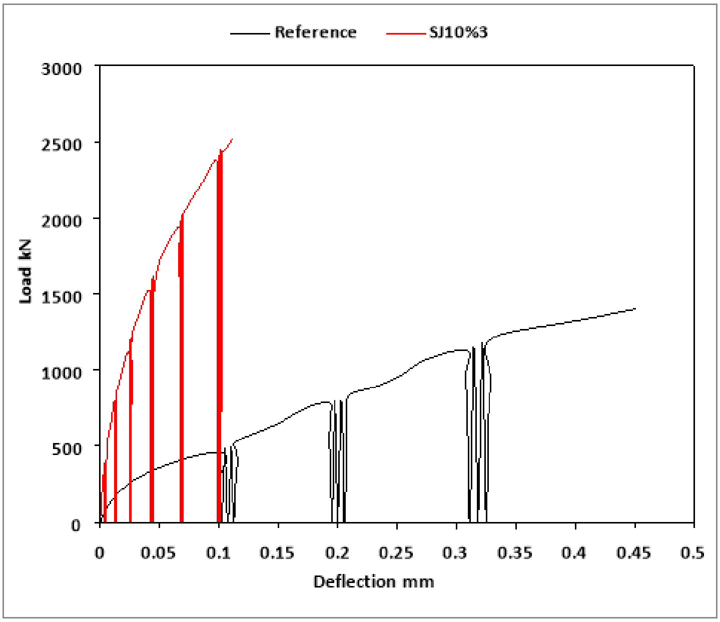

Figure 17: The load deflection curve DCD

As Table 4 shows, there is a significant degree of recovery in load carrying capacity as well as the yielding load when SIFCON jacketing was used with 10% steel fibers and 3cm jackets thickness. The load carrying capacity recovery has reached 179.64% while the yielding load recovery has reached 226.58%. There are, however, possible explanations for these results. This can be presented by the interference between the new cement past and the RC joint where this paste can be infiltrated between the concrete fragments, the high strength of SIFCON (due to the presence of steel fibers) as well as to the enhancement role of steel bolting which can also play a major share in this jump of capacity.

With respect to Stiffness and Ductility Factor, the stiffness and ductility factor calculations of the SJ10%3 specimens are listed in Tables 5 and 6.

Table 5: Stiffness Factor for SJ10%3 specimen

Specimen	Response	Yielding Deflection (mm)	Yielding load (kN)	Stiffness Factor (kN/mm)	Recovery in stiffness factor (%)
Reference	DCR	1.1	625	568.18	/
	DBR	0.88	620	704.55	/
	DCL	1.05	690	657.14	/
	DCD	0.05	680	13600	/
SJ10%3	DCR	0.14	1425	10178.57	1791.43
	DBR	0.09	1500	16666.67	2365.58
	DCL	0.075	1510	20133.33	3063.78
	DCD	0.013	1490	114615.38	842.76
	Average			Average	2015.89

Recovery of $k = k_{\text{specimen}} / k_{\text{reference}}$

Table 6: Ductility Factor for SJ10%3 specimen

Specimen	Response	Yielding Deflection (mm)	Maximum Deflection (mm)	Ductility Factor	Recovery in ductility factor (%)
Reference	DCR	1.1	4.82	4.38	/
	DBR	0.88	3.95	4.49	/
	DCL	1.05	4.86	4.63	/
	DCD	0.05	0.45	9	/
SJ10%3	DCR	0.14	1.05	7.5	171.23
	DBR	0.09	0.89	9.89	220.27
	DCL	0.075	1.14	15.2	328.29
	DCD	0.013	0.11	8.46	94
	Average		0.80	Average	203.45

Recovery of $d = d_{specimen} / d_{reference}$

From Table 5, it is obvious that there is an interesting increase in stiffness factor when SIFCON jacketing is used with 10% steel fibers and 3cm jackets thickness. The stiffness recovery level extended to 2015.89 % which is representing 626.77 % times the recovery in CFRP internal sheets and 192.88 % times the CFRP jacketing. It is clear that this preeminence is due to the high yielding load and the corresponding yielding deflection.

On the other hand, in Table 6, the average ductility factor recovery is 203.45 % for SIFCON jacketing was used with 10% steel fibers and 3cm jackets thickness. This recovery typifies 68.11 % times the recovery of CFRP internal sheets and about 140% times the recovery in CFRP jacketing.

Although the ductility factor recovery in SJ10%3 is more than CFRP jacketing, it is less than the CFRP internal sheets. Therefore, there are no significant context can be drown from the comparison between the three techniques with respect to ductility gain. However, further studies which take these concerns into account will need to be implemented in term of experimental and numerical researches.

9.3 SIFCON Jacketing: SJ10%2.5

The following sections are presented to discuss the feasibility of using SIFCON jacketing technique (That includes 10% Steel fibers and 25mm thickness) for rehabilitation of beam column-joint:

With respect to Maximum Strength, Yielding Strength, Maximum Deflection and Yielding Deflection, Tables 7 and 8 below show the maximum strength, yielding strength, maximum deflection and yielding deflection for the J10%2.5 specimens.

Table 7: Maximum and yielding strength for SJ10%2.5

Specimen	Maximum load P_u in kN	Recovery in P_u %	Yielding load (kN)	Recovery (%)
Reference	1400	/	653.75	/
SJ10%2.5	2390	170.71	1400	214.15

Recovery of $P_u = P_{uspecimen} / P_{ureference}$
Recovery of $P_y = P_{yspecimen} / P_{yreference}$
Average of DCR, DBR, DCL and DCD respectively

Table 8: Maximum and yielding deflection for SJ10%2.5

Specimen	Response	Maximum Deflection (mm)	Recovery (%)	Yielding Deflection (mm)	Recover (%)
Reference	DCR	4.82	/	1.1	/
	DBR	3.95	/	0.88	/
	DCL	4.86	/	1.05	/
	DCD	0.45	/	0.05	/
SJ10%2.5	DCR	1.1	22.82	0.12	10.91
	DBR	0.94	23.80	0.18	20.45
	DCL	1.19	24.49	0.16	15.24
	DCD	0.12	26.67	0.013	26
		Average	24.45	/	18.15

Recovery of $\Delta_u = \Delta_{uspecimen} / \Delta_{ureference}$
Recovery of $\Delta_y = P_{yspecimen} / \Delta_{yreference}$

In Table 8 the recovery extends to 170.71 % for maximum load and 214.15% for yielding load for SJ10%2.5. The maximum load of SJ10%2.5 represents 95.03 % times SJ10%2.5 while the yielding load represents 94.51 %.
The maximum load capacity and yielding load of SJ10%2.5 are still more than those of reference specimen. The reasons that justify this behavior were discussed in SJ10%3 results. But on the other hand, the degree of recovery is less than SJ10%2.5. It is clear that this discrepancy is due to the impact of jacket thickness.
It is believed that comparing two specimens is not enough for understanding the impact of thickness of SIFCON jackets. In this respect, further research should be conducted for investigating this impact by taking reasonable increments.
In Table 8, it is observed that in SJ10%2.5, the recovery in maximum deflection of 24.45% and 18.04% for the yielding deflection. The maximum deflection recovery of SJ10%2.5 is 106.07% times SJ10%3 whereas this recovery is 129.27 % in yielding deflection. This behavior is compatible with maximum and yielding load.
With respect to Stiffness and Ductility Factor, the stiffness and ductility factor calculations of the SJ10%2.5 specimens are listed in Tables 9 and 10.

Table 9: Stiffness Factor for SJ10%2.5 specimen

Specimen	Response	Yielding Deflection (mm)	Yielding Load (kN)	Stiffness Factor (kN/mm)	Recovery in stiffness factor *(k)* %
Reference	DCR	1.1	625	568.18	/
	DBR	0.88	620	704.55	/
	DCL	1.05	690	657.14	/
	DCD	0.05	680	13600	/
SJ10%2.5	DCR	0.12	1380	11500	2024
	DBR	0.18	1410	7833.33	1111.82
	DCL	0.16	1410	8812.5	1341.04
	DCD	0.013	1410	108461	797.51
	Average			Average	1318.59

Recovery of $k = k_{specimen} / k_{reference}$

Table 10: Ductility Factor for SJ10%2.5 specimen z

Specimen	Response	Yielding Deflection mm	Maximum Deflection mm	Ductility Factor	Recovery in ductility factor *(d)* %
Reference	DCR	1.1	4.82	4.38	/
	DBR	0.88	3.95	4.49	/
	DCL	1.05	4.86	4.63	/
	DCD	0.05	0.45	9	/
SJ10%2.5	DCR	0.12	1.1	9.17	209.36
	DBR	0.18	0.94	5.22	116.26
	DCL	0.16	1.19	7.44	160.69
	DCD	0.013	0.12	9.23	102.56
		Average		Average	147.2

Recovery of d = $d_{specimen} / d_{reference}$

As Table 9 shows, the average recovery in stiffness factor for SJ10%2.5 has extended to 1318.59% which is representing 65.41% times that of SJ10%3. Repeatedly, the recovery of SJ10%2.5 is less than SJ10%3 due to the effect of thickness and the corresponding levels of yielding.
Regarding ductility factor, Table 10 shows the recovery level (147.22%) of SJ10%2.5 which is representing 72.36% times the level of SJ10%3. This disparity between SJ10%2.5 and SJ10%3 pointed that decreasing thickness means that consequent loss in ductility may be happening in RC beam column joints.

9.4 SIFCON Jacketing SJ12%2.5

The following sections are presented to examine the feasibility of using SIFCON jacketing technique (That includes 12% Steel fibers and 25 mm thickness) for rehabilitation of beam column -joint:

With respect to Maximum Strength, Yielding Strength, Maximum Deflection and Yielding Deflection, Table (11) presents the maximum strength, yielding strength, maximum deflection and yielding deflection for the J12%2.5 specimens whereas Figures 18 to 21 show the load deflection curves.

Table 11: Maximum and yielding strength for SJ12%2.5

Specimen	Maximum Load (kN)	Recovery (%)	Yielding Load (kN)	Recovery (%)
Reference	1400	/	653.75	/
SJ12%2.5	2634	188.14	1632.5	249.71

Recovery of Pu = $Pu_{specimen} / Pu_{reference}$
Recovery of Py= $Py_{specimen} / Py_{reference}$
Average of DCR, DBR, DCL and DCD respectively

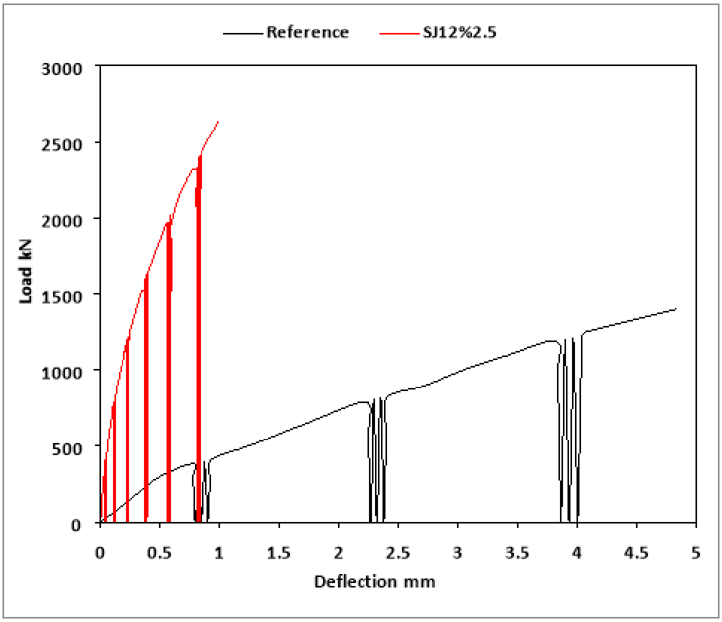

Figure 18: Load deflection curves of SJ12%2.5 DCR

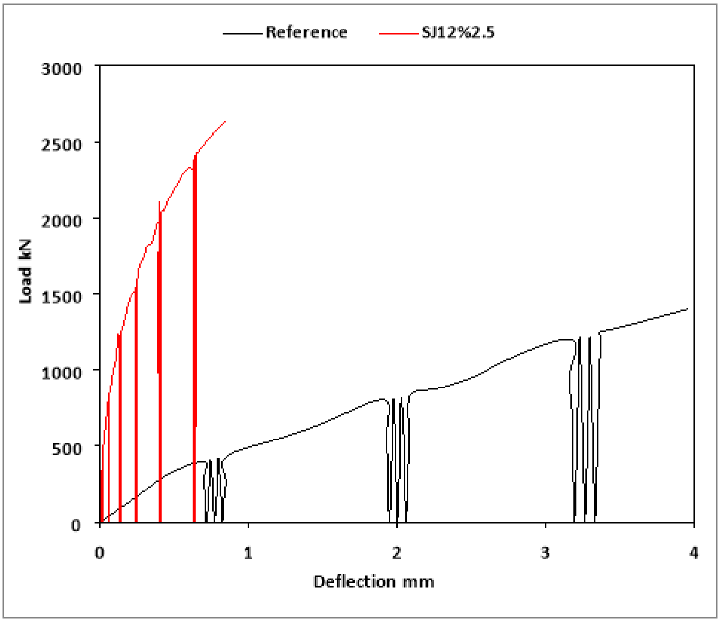

Figure 19: Load deflection curves of SJ12%2.5 9 DBR

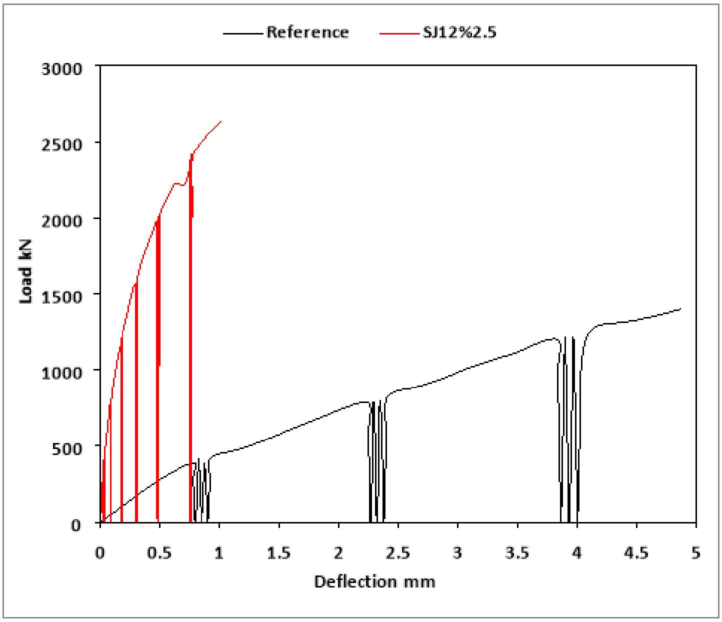

Figure 20: Load deflection curves of SJ12%2.5 DCL

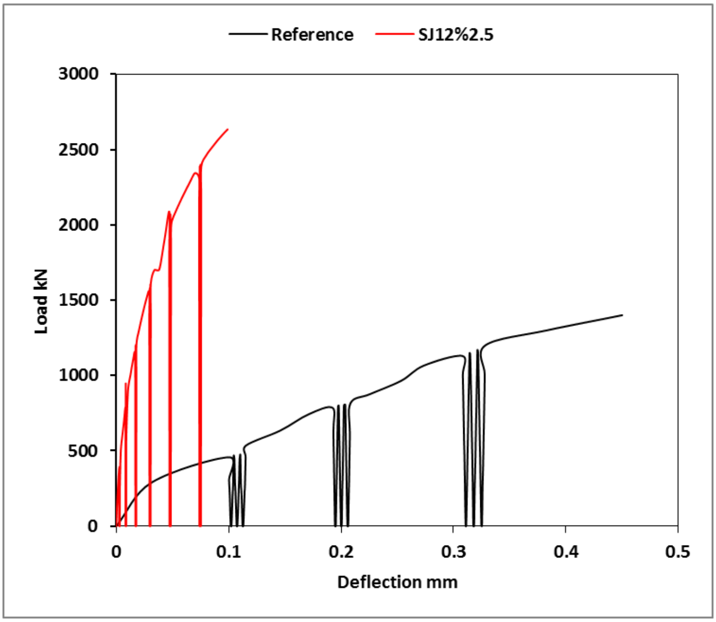

Figure 18: Load deflection curves of SJ12%2.5 DCD

As noted in Table 11, the recovery in maximum load capacity is 188.14 % and 249.71% in yielding load for SJ12%2.5 specimens. In this way, the recovery of this specimen with respect to maximum load represents 110.21% times the SJ10%2.5 whereas in yielding the value represents 116.21%. The supremacy of SJ12%2.5 against the SJ10%2.5 is related to the impact of difference in the content of steel fiber.

Turning to SJ10%3, the recovery in maximum load capacity of the current specimen represent 104.73% and for yielding, and the value of about 110.21%. Together, in all the final levels, it can be stated that the impact of steel fiber and jacket thickness play a major share in the improvement in the rehabilitation of RC joints by SIFCON jacketing. This confirmed the fact that this is an important issue for future research.

In the whole, the last results insured that the SJ12%2.5 can perform better than SJ10%3 and SJ10%2.5. Changing the steel fibers content from 10 % to 12 % gives an enhancement more than changing jacket thickness from 2.5 cm to 3 cm.

The stiffness and ductility factor calculations of the SJ12%2.5 specimen is listed in Table 12.

Table 12: Stiffness Factor for SJ12%2.5 specimen

Specimen	Response	Yielding Deflection mm	Yielding Load in kN	Stiffness Factor (kN/mm)	Recovery in stiffness factor (%)
Reference	DCR	1.1	625	568.18	/
	DBR	0.88	620	704.55	/
	DCL	1.05	690	657.14	/
	DCD	0.05	680	13600	/
SJ12%2.5	DCR	0.15	1600	10666.67	1877.34
	DBR	0.09	1625	18055.56	2562.71
	DCL	0.08	1625	20312.5	3091.05
	DCD	0.012	1655	137916.7	1014.09
	Average		/	Average	2136.30
Recovery of k = $k_{specimen}$ / $k_{reference}$					

Table 12 shows that the recovery may come to 2136.3 % in stiffness factor for SJ12%2.5 which represents152.013% times SJ10%2.5 and 105.97% times SJ10%3. This can be due to the effect of steel fiber volume and the related high yielding strength of the current specimen.

It is conceived by the authors that this behavior can be interpreted as an effect of confinement due to the difference in jacket thickness. However, it is recommended that future research in term of numerical modeling is useful to understand such behavior more and more.

10. Conclusions

The conclusions that may be pointed throughout this study are listed as follows:

1. The rehabilitation by CFRP jacketing and SIFCON jacketing can effectively recover the original structural behavior of RC un-damaged beam – column joint.
2. In all the proposed rehabilitation techniques, the recovery in maximum deflection does not exceed 32% and the yielding deflection does not exceed 50%.
3. In general, SIFCON jacketing gives a good degree of recovery as compared with CFRP jacketing.
4. Increasing the thickness and steel fiber content of SIFCON jackets improves the relevant performance.

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سلوك مفصل العمود-العتبة المُعاد تأهيله تحت الحمل المتكرر

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المستخلص: خلال العمر الكلي لنظام البناء الخرساني المسلح ، قد تواجه منطقة وصلات العمود – العتبة أحمال زلزالية مما يعني أنها من الممكن أن تتعرض الى مستويات عالية من اجهادات القص وأحمال العزم. من خلال نفس السياق ، تتجلى أبرز علامات الضرر في مثل هذا النوع من العناصر الانشائية. بهذه الطريقة ، هناك العديد من المبررات للسعي إلى ايجاد تقنيات إعادة تأهيل جديدة يمكنها استعادة الخصائص الميكانيكية الاصلية في الوصلات الخرسانية المسلحة. تم توجيه الدراسة الحالية لتقديم اختبار ثلاثة أنواع من إعادة التأهيل تجريبيًا وهي الألواح الداخلية المصنوعة من البوليمر المقوى بألياف الكربون والبوليمر المقوى بألياف الكربون ، وتغليف البوليمر المقوى بألياف الكربون وغلاف الخرسانة الليفي المتسرب من "SIFCON". تضمن تنفيذ البرنامج التجريبي صب ست عينات من الوصلات المسلحة. بعد ذلك، تم إعادة تأهيل خمسة من هذه العينات بالتقنيات المقترحة وإعادة اختبارها. تمت إعادة تأهيل ثلاث من هذه العينات الخمس بواسطة غلاف SIFCON بمستويات مختلفة من سماكة الغلاف ومستوى الألياف الفولاذية بينما تم تحديد العينات المتبقية لتقنيات أخرى. تم اختبار جميع العينات (قبل وبعد إعادة التأهيل) تحت الحمل المتكرر لثلاث دورات كل 400 كيلو نيوتن حتى الفشل. تتكون العينات من عتبة وعمود 600 مم ومساحة الوصلة بينهما 400 مم × 400 مم ، بالإضافة إلى أن المقطع العرضي للعينات 400 مم × 400 مم. أظهرت النتائج التجريبية أن جميع التقنيات المقترحة كانت فعالة في استعادة الخواص الإنشائية الأصلية للخرسانة المسلحة وفواصل العمود. استعادت الألواح الداخلية المصنوعة من البلاستيك المقوى بألياف الكربون 144.49٪ من القوة القصوى و 141.57٪ لحمل الخضوع بينما استعادة اغلفة CFRP 142.86٪ و 189.87٪. بالإضافة إلى ذلك ، فإن غلاف SIFCON استعاد ما بين 170.71٪ إلى 188.14٪ من القوة القصوى وما بين 214.15٪ إلى 249.71٪ إلى 226.58٪ من حمل الخضوع على التوالي لجميع محتوى ألياف الصلب المقترح وسماكة الغلاف. علاوة على ذلك ، فإن استعادة المستويات الأصلية للحد الأقصى و لحد الخضوع من الانحراف لا تتجاوز 32٪ و 50٪ على التوالي. بالإضافة إلى ذلك ، تم تسجيل مستويات عالية من الاستعادة لمحددات الصلابة والليونة لجميع العينات المقترحة.

الكلمات المفتاحية: وصلات العمود-العتبة، تقنيات التأهيل، البوليمر المقوى بألياف الكربون

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