Compressive Behavior of Fiber Reinforced Concrete Columns Rehabilitated with CFRP Warps

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ABSTRACT

Over the last few years, there has been a worldwide increase in the use of composite materials for rehabilitation of deficient reinforced concrete structures. One important application of this technology is the use of Carbon Fiber Reinforced Polymer (CFRP) jacket to provide external confinement of reinforced concrete columns. Square concrete column specimens 100×100×1000 mm with concrete compressive strength of about 30 and 50 MPa, steel fiber volume fraction 0%, 0.5%, 0.75%, and percentage of longitudinal reinforcement 2.01%, 3.14% and 4.52% were tested until failure in previous research. In this research seven tested columns were repaired and rehabilitated using one layer of CFRP flexible wraps and tested to determine their ultimate load carrying capacity. A comparison between the behavior of column specimens before rehabilitation and after rehabilitation was carried out. The result show that high strength concrete (HSC) columns show reduction in the maximum load carrying capacity of about 2% - 21%, while the deflection at maximum load significantly increases relative to concrete columns before rehabilitation.

KEYWORDS: **Carbon Fiber Reinforced Polymer (CFRP), rehabilitated columns, high strength concrete.**

سلوك الانضغاط للأعمدة الخرسانيةالمعززة بالألياف والمؤهلة باستخدام لفائف الياف تسليح الكاربون البوليمرية

استاذ مساعد د. وسن إسماعيل خليل

الخلاصة

لقد ازداد استخدام المواد المركبة في تأهيل المنشأت الخرسانية المتضررة خلال السنوات القليلة الماضية. إن أحد أهم التطبيقات لهذه التقنية هو إستخدام التغليف بألياف تسليح الكاربون البوليمرية لتوفير تطويق خارجي للأعمدة الخرسانية المسلحة. في بحث سابق تم فحص نماذج لأعمدة خرسانية مربعة المقطع بأبعاد 100×100×1000 مم لحين الفشل، حيث كانت مقاومة الانضغاط للخرسانة 30 ، 50 نيوتن/مم^2 ، النسبة الحجمية للألياف الفولاذية 0%، 0.5% ،0.75% ونسبة التسليح الطولي 2.01%، 3.14%،4.52 %. تضمن هذا البحث اصلاح وتأهيل سبعة نماذج للاعمدة المفحوصة باستخدام لفائف لدنة من الياف تسليح الكاربون البوليمرية ومن ثم إعادة فحص هذه الاعمدة لايجاد مقاومة تحملها القصوى. تم اجراء مقارنة بين سلوك نماذج الاعمدة قبل وبعد التأهيل. أظهرت النتائج بأن أعمدة الخرسانة عالية المقاومة المؤهلة تبدي إنخفاضا في سعة التحمل القصوى بحدود 2%-21% في حين إزداد الانحراف عند الاجهاد الاقصى بشكل واضح بالمقارنة مع الاعمدة الخرسانية قبل التأهيل.

الكلمات الرئيسية: ألياف تسليح الكاربون البوليمرية، الاعمدة المؤهلة، الخرسانة عالية المقاومة.

1. INTRODUCTION

The use of High Strength Concrete (HSC) members has proved to be most promising in terms strength, stiffness, durability and economy. As the strength of concrete increases, it becomes more brittle. The lack of ductility of HSC columns can result in sudden failure without warning. Previous studies have shown that the strength and ductility can be improved by the use of spiral confinement rectangular and circular lateral ties (Saravanan et al. 2010). In the case of a seismic event, energy dissipation allowed by well confined concrete core can often save lives. On the contrary, a poorly confined concrete column behaves in a brittle manner leading to sudden and catastrophic failures (Sadeghian et al. 2009). Over the last few years, there has been a worldwide increase in the use of composite materials for the rehabilitation of deficient reinforced concrete structures. One important application of this composite retrofitting technology is the use of fiber reinforced polymer (FRP) jacket or sheets to provide external confinement to reinforced concrete columns when the existing internal transverse reinforcement is inadequate (Benzaid et al. 2009). The concept of strengthening reinforced concrete columns by FRP composites is that when concrete is uniaxially compressed due to load, Poisson's effect induces transverse strain that result in radial expansion of the concrete. By confining the concrete using continuous FRP jacket, the fibers resist the transverse expansion of the concrete and provide passive confinement which increases both strength and ductility (Rai). Carbon fiber wrap provided a better solution for repair and strengthening concrete columns due to their well known advantages including, a high strength to weight ratio than traditional reinforcing material such as steel, excellent corrosion resistance and the ability to change the orientation of the fibers which allows the user to strengthen a structure in preferential directions to meet performance requirements, and can result in less labour- intensive work (Wang et al. 2008, Sheikh 2002 and Li et al. 2003).

Most of the available studies on the behavior of FRP confined concrete columns have concentrated on the strengthening of circular shaped columns, while relatively few studies have addressed rectangular columns. This partly because the rectangular section is not uniformly confined and the compressive pressure is unevently distributed. The higher stress is usually found at the corners (Toutanji et al. 2007, Benzaid et al. 2008). No detail study has been available on the repair and rehabilitation of high strength fiber reinforced concrete rectangular columns after subjected to failure using carbon fiber reinforced polymer (CFRP) wraps.

The effect of corner radius on the performance of CFRP confined square columns were investigated by Wang and Wu 2008. They reported a series of tests on 108 CFRP confined short concrete columns. The primary variables were the corner radius, transverse jacket stiffness, and concrete grade. The test results demonstrated that the corner radius ratio is in direct proportion to the increase in confined concrete strength. Furthermore, it is revealed and explained that confinement provided by a jacket with sharp corners is insignificant in increasing the strength of columns but significant in increasing the ductility of columns.

The main objective of the present investigation is to:

- Rehabilitation failed normal and high strength concrete columns by CFRP flexible wraps.
- To determine the ultimate load carrying capacity of the rehabilitated columns under axial compression.
- To make a comparison between the behavior of conventional concrete columns (before rehabilitation) and the columns after rehabilitation using CFRP flexible wraps.

2. EXPERIMENTAL WORK

2.1 Materials and Concrete Mixes

In previous research (Khalil et al. 2012) concrete column specimens were manufactured using the following material, ordinary Portland local cement with physical and chemical test results conform to the provisions of Iraqi specification No.5/1984 as shown in Table (1) and (2) respectively. Natural sand of maximum size 4.75 mm and gradation lies in zone (2) was used. The gradation and sulfate content results were within the requirements of the Iraqi specification No. 45/1980, as shown in Table (3). Normal weight crushed aggregate of maximum size 10 mm was also used. Its grading and sulfate content conform to the requirements of Iraqi specification

No. 45/1980, as shown in Table (4). High range water reducing admixture (HRWRA) commercially known as TopFlow SP 703 was used to produce the HPC mix. Its properties are shown in Table (5). The dosage recommended by the manufacturer was (0.75-2) liters/100 kg of cementations material. This type of admixture conforms to the requirement of ASTM C494-04. Silica fume with pozzolanic activity index and the chemical oxide compositions conform to the requirements of ASTM C1240-05 specifications was also used, as shown in Table (6) and (7) respectively. Hooked end steel fiber was used. It is commercially known as Dramix-Type ZC, with 50 mm long and 0.5 mm diameter (aspect ratio, l/d = 100), the density of the steel fiber is 7850 kg/m^3, and the ultimate tensile strength for individual fiber is 1117 MPa. Deformed steel bars with nominal diameters 8mm, 10mm and 12 mm were used as longitudinal reinforcement. Three specimens for each bar diameter were tested in tension according to ASTM A996M-05 to determine their properties; the results were summarized in Table (8) and Fig. (1).

Reference concrete mix for normal strength concrete (NSC) was designed in accordance with ACI (ACI 211. 1991) to have compressive strength about 35 MPa at 28 days without using any admixtures. The mix proportions are 1: 1.19: 1.8 by weight of cement with cement content 525 kg/m^3 and w/c ratio of 0.43 to obtain a slump of 100±5 mm. Several trail mixes were carried out to determine the optimum content of silica fume and the optimum dosage of HRWRA to have the same workability (slump 100 ±5) in order to achieve a high strength concrete mix with compressive strength of about 50 MPa. The results indicated that maximum compressive strength obtained was for mixes with 5% silica fume as addition by weight of cement and a dosage of HRWRA 2 liter/100kg of cement. Finally, discrete steel fibers with different volume fractions (0.5% and 0.75%) were added to the concrete mixes. Table (9) indicates the details of concrete mixes used. The column specimens were tested under uniaxial compression till failure.

In this research some tested columns from previous research were repaired using bonding slurry Sika Monotop-610 which was applied to the prepared substrate, then a polymer modified repair mortar Sika Monotop-612 was applied wet by wet to the bonding slurry. After curing period, the repaired concrete columns were wrapped with a unidirectional carbon fiber fabric SikaWrap-300C/60. The manufacturers guaranteed tensile strength for this carbon fiber fabric is 3900 MPa, with a tensile modulus of 230 GPa, maximum tensile strain 0.006, an ultimate elongation of 1.5% and a fiber thickness of 0.166mm. Two part epoxy resin Sikadur-330 was used to bond the carbon fabrics over the column specimens.

2.2 Preparation and Test Procedure of Specimens

In previous research (Khalil et al. 2012) reinforced concrete columns 100×100×1000 mm were prepared as indicated in Table (10). To comply with existing reinforced concrete members in any structure, the corners for all prismatic specimens were kept sharp for CFRP application. Four longitudinal reinforcing deformed steel bars one at each corner of column specimen cross section with different diameter (8, 10 and 12) were used. Lateral ties with 8mm diameter were used for all columns specimens as shown in Fig. (2). Concrete cover of 12.5 mm was provided in all columns and a cover of 20 mm was provided between the ends of longitudinal bars at the top and bottom surfaces of the specimens to prevent direct loading on the bars. The columns were continuously cured with water and after that, they were kept in the laboratory to be normally dried until the time of testing.

Universal testing machine with maximum capacity of 2500 kN was used for testing the reinforced concrete columns (conventional columns).The column specimens were externally confined by 5 mm thick and 100 mm height steel collars at both ends of the specimen to avoid premature failure at the end regions of the columns throughout the test. The columns gross deflection was measured by a dial gauge of (0.01mm/div) sensitivity, fixed with the two collars by a steel frame.

2.3 Procedure for Repairing and Rehabilitation of Tested Column Specimens

In this research the column specimens tested in previous research were repaired and then wrapped with carbon fiber fabric (rehabilitated columns) using the following procedure:

- The unsound concrete was removed and the surface of the concrete was well cleaned from dust by a steel brush.

- The bonding slurry was mixed with water/powder ratio 0.17-0.18 according to manufacturers. Then it was applied by brush to the prepared (pre-wetted) concrete surface.
- Polymer modified repair mortar was mixed with water/powder ratio 0.11- 0.13 by weight according to manufacturers. The mortar is applied wet on wet to the bonding layer in several layers with thickness not greater than 30mm.
- The repaired part of the column specimens was cured by covering it with burlap and spraying water on it every day, then covering it with polyethylene sheets. The repaired part was cured for 28 days after that the specimens were kept in the laboratory for seven days to be normally dried.
- Two part epoxy impregnation resin was mixed by hand (part A: part B=4:1 by weight according to the manufacturers) and applied to the prepared concrete column surfaces using a brush.
- A unidirectional woven carbon fiber fabric wrapped around the column. A roller used parallel to the fabric direction until the resin is squeezed out between and through the fiber strands and distributed evenly over the whole fabric surface. Carbon fiber layer was wrapped around the column with an overlap of ¼ of the perimeter to avoid sliding or debonding of fibers during test. The wrapped specimens were left at room temperature for seven days before testing. Fig. (3-A) shows one of concrete column specimens before repair and rehabilitation, while Fig. (3-B) shows the same column after repair and rehabilitation with CFRP.

The same testing procedure was followed for wrapped column specimen.

3. TEST RESULTS AND DISCUSSION

3.1 Properties of Bonding Slurry and Repair Mortar

The compressive strength and direct tensile strength specimens for the bonding slurry and polymer modified repair mortar used to repair the column specimens was casted cured and tested according to ASTM C-109 and AASHTO T132 respectively.

Table (11) and (12) show the results of the compressive strength and direct tensile strength at different ages for bonding slurry and polymer modified repair mortar respectively used in this research. The results show that both the compressive strength and direct tensile strength increase with age.

3.2 Maximum Load Carrying Capacity and Deflection

The comparison of maximum load carrying capacity and deflection between conventional (tested columns until failure) and rehabilitated columns are shown in Table (13). Generally it can be observed that high strength concrete columns after rehabilitation with CFRP wraps show a reduction in the maximum load carrying capacity of about 2%-21% in comparison with conventional high strength concrete columns. This is because FRP not increases the compressive strength of the square columns with sharp corners, since the confining action is mostly limited at the corners, producing therefore a confining pressure not sufficient to overcome the effect of concrete degradation (Chikh et al. 2012). The deflection at maximum load significantly increases (except for column 0.75SF100-10H100) in comparison with conventional high strength concrete columns. So the application of CFRP wrap improves the ductility of the rehabilitated column specimens. This attributed to the fact that when FRP confined concrete subjected to axial compression, the FRP jackets are loaded mainly in hoop tension while the concrete is subjected to triaxial compression, so that both materials are used to their best advantages. As a result of the confinement, both the strength and the ultimate strain of concrete can be enhanced and instead of the brittle behavior exhibited by both materials, FRP confined concrete possesses an enhanced ductility (Nicolae et al. 2008). The results also show that the percentage decrease in maximum load carrying capacity for rehabilitated fibrous HSC columns relative to the conventional column specimens is higher than that for nonfibrous concrete specimens. The maximum load of rehabilitated normal strength concrete columns (NF-8N100) considerably increases relative to conventional normal strength columns. The percentage increase is about 65%. It can be concluded that rehabilitation of normal strength concrete columns with CFRP wraps produce higher results in terms of strength than for similar high strength concrete columns.

3.3 Stress – Strain Response

The stress-strain relationships for both conventional and rehabilitated column specimens are shown in Figures (4) to (10). All CFRP wrapped specimens showed almost linear stress-strain relationship at the first stage governed by the stiffness of the unconfined tested concrete, no confinement is activated in the CFRP wraps when the lateral strains in the concrete are very small. Then the increase of load produces large lateral expansion in columns, and consequently the CFRP wrap reacts accordingly and a confining action is created on the concrete core. In the cases of square section columns, the confining action is mostly limited at the corners, producing therefore a confining pressure not sufficient to overcome the effect of concrete degradation, thus the ultimate load for rehabilitated high strength columns is lower than that of conventional columns. Also high strength concrete is more brittle than normal strength concrete. Moreover the high slenderness ratio of column specimen tested in this investigation leads on overall to a decrease in load carrying capacity of CFRP wrapped columns (Chikh et al. 2012).

3.4 Mode of Failure of Rehabilitated Column Specimens

The summary of mode of failure for rehabilitated column specimens is tabulated in Table (14), also Fig. (11) shows the failure mode of some rehabilitated specimens. Even though the CFRP and reinforced concrete columns combination is a composite action, the most of the load is carried by the CFRP alone. Clicking sounds were heard during various stages of loading which were attributed to the microcracking of the concrete. It was noticed that after the failure of CFRP the ultimate load of column is reached and failure occurred as tensile rupture or snatching of fiber wraps. It was observed that the failure of fiber wraps was mostly concentrated in column specimen end regions (at the head or the base of specimen). This is due to the high slender ratio of column specimens (L/h=10) which leads to small rupture area for CFRP wraps (Chikh et al. 2012). For all confined specimens delamination was not observed at the overlap location of the jacket, which confirmed the adequate stress transfer over the splice.

4. CONCLUSIONS

From the experimental results presented in this investigation, the following conclusions can be drawn:

1- High strength concrete columns after rehabilitation with CFRP wraps shows a reduction in the maximum load carrying capacity of about 2%-21% relative to HSC columns before rehabilitation.
2- The deflection of the rehabilitated HSC columns is significantly increases in comparison with HSC columns before rehabilitation.
3- The maximum load of the rehabilitated normal strength concrete columns increases by about 65% relative to concrete column before rehabilitation, so the rehabilitation of normal strength concrete columns produce higher results in terms of strength than for similar HSC columns.
4- The failure of the rehabilitated columns occurred as a tensile rupture or snatching of fiber wraps mostly concentrated in column end region.

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Table 1 Physical properties of cement*

Physical properties	Test results	Limits of Iraqi Specification No.5/1984
Specific surface area (Blaine method), m^2/kg	372	≥ 230
Soundness (Autoclave), %	0.01	≤ 0.8
Setting time (Vicat's apparatus) Initial setting time, hrs: min. Final setting time, hrs: min.	 3:58 4:50	 $\geq$ 45 min $\leq$ 10 hrs
Compressive strength 3days, N/mm^2 7days, N/mm^2	 29.80 34.84	 ≥ 15 ≥ 23

* Physical tests were carried out by the National Center for Construction Laboratories and Researches (NCCLR).

Table 2 Chemical composition and main compounds of the cement used throughout this investigation*

Oxide composition	Abbreviation	Content (percent)	Limit of Iraqi Specification No.5/1984
Lime	CaO	62.44	---
Silica Dioxide	SiO_2	20.25	---
Alumina Trioxide	Al_2O_3	4.73	---
Iron Oxide	Fe_2O_3	4.32	---
Magnesia oxide	MgO	1.5	$\leq 5.0\%$
Sulphate	SO_3	1.88	$\leq 2.8\%$ If $C_3A > 5\%$
Loss on Ignition	L. O. I.	3	$\leq 4.0\%$
Insoluble residue	I. R.	0.8	$\leq 1.5\%$
Lime saturation factor	L. S. F.	0.93	0.66- 1.02
Main compounds (Bogue's equations)			
Tricalcium Silicate	C_3S	56.90	---
Dicalcium Silicate	C_2S	15.21	---
Tricalcium Aluminate	C_3A	5.23	---
Tetracalcium alumino-Ferrite	C_4AF	13.13	---

*Chemical tests were carried out by the National Center for Construction Laboratories and Researches (NCCLR).

Table 3 Fine aggregate properties*

Sieve size (mm)	Cumulative passing %	Limits of Iraqi specification No.45/1980, zone 2
4.75	100	90-100
2.36	90.15	75-100
1.18	74.22	55-90
0.60	51.37	35-59
0.30	19.3	8-30
0.15	3.79	0-10
Fineness modulus = 2.61		
Specific gravity =2.65		
Sulfate content =0.08% (Iraqi specification requirement ≤ 0.5%)		
Absorption = 0.75%		

* Properties of fine aggregate were performed by the National Center for Geological Survey and Mines

Table 4 Coarse aggregate properties*

Sieve size (mm)	Cumulative passing %	Limits of Iraqi specification No. 45/1980
14	100	100
10	100	85-100
5	15.3	0-25
2.36	0.53	0-5
Specific gravity = 2.66		
Sulfate content = 0.08% (Iraqi specification requirement ≤ 0.1%)		
Absorption = 0.52%		

* Properties of coarse aggregate were performed by (NCCLR)

Table 5 Technical data of the superplasticizer used in this investigation*

Technical description	Properties
Appearance	Dark Brown/Black liquid
Specific gravity	1.235 at 25±2˚C
Chloride content	Nil.
Storage life	Up to 1 year in unopened containers.

*According to manufacturer.

Table 6 Physical requirements and pozzolanic activity index for condensed silica fume(SF)*

Physical properties	SF	ASTM C1240-05 limits
Specific surface area, min, (m^2/g)	20	≥ 15
Strenght activity Index with Portland cement at 7days, min. percent of control.	122	≥ 105
Percent retained on 45μm (No.325), max, %	9	≤ 10

*Tests were carried out by Building Research Center

Table 7 Chemical composition for silica fume *

Oxides	content(%)	ASTM C1240-05 limitations
SiO_2	90.51	≥ 85
Al_2O_3	0.60	–
Fe_2O_3	2.32	–
Na_2O	0.15	–
CaO	0.58	–
MgO	0.3	–
TiO_2	0.01	–
K_2O	1.26	–
P_2O_5	0.10	–
SO_3	0.35	≤ 4
L.O.I	3.82	≤ 6

*Test was carried out at by the National Center for Geological Survey and Mines

Table 8 Properties of steel reinforcing bars

Nominal bar diameter (mm)	Bar area (mm^2)	Modulus of elasticity (GPa)	Yield stress (MPa)	Strain at yield stress (mm/mm)	Ultimate stress (MPa)	Strain at ultimate stress (MPa)	Elongation (%)
8	50.27	202	545	0.0027	660	0.18	15.5
10	78.54	202	514	0.00255	625	0.16	14.5
12	113.1	200	503	0.00252	615	0.13	14.5

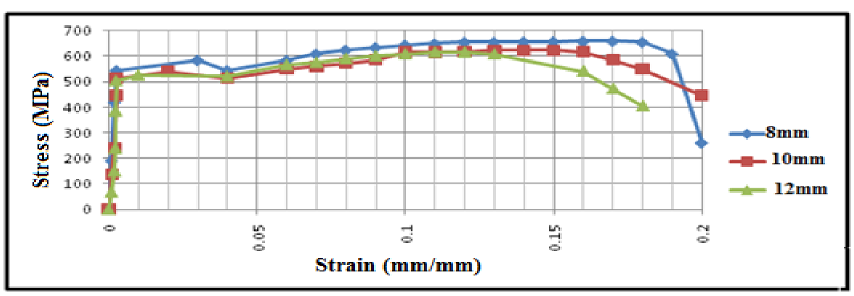


Fig. 1 Stress-strain curves for steel reinforcement

Table 9 Details of trail mixes for various volume fractions of steel fiber

Mix proportions by weight	Concrete type	HRWRA (liter/100kg of cement)	Silica fume (% as addition by weight of cement)	w/c ratio	Type of fiber	aspect ratio	Fiber volume fraction	Slump (mm)	Compressive strength at 28days $f'c^*$ *(MPa)*
1: 1.19: 1.8	HSC	2	5	0.295	-	-	-	105	48.15
					Steel	100	0.5	75	52.73
					steel	100	0.75	65	56.02
	NSC	-	-	0.43	-	-	-	105	29.38

***** Cylinder compressive strength (150×300)

Table 10 Details of the column specimens

Column symbols	Volume fraction of Fibers V_f (%)	Aspect ratio of fibers L/d	Type of concrete	Diameter of long. reinf. (mm) (Percent of long. Reinf.) (ρl %)	Spacing of lateral reinf.(mm) (Percent of lateral reinf.) (ρ_s %)
NF-8H100	0	--	HSC	8 (2.01)	100 (2.79)
NF-10H100	0	--	HSC	10 (3.14)	100 (2.79)
0.5SF100-10H100	0.5	100			
0.75SF100-10H100	0.75	100			
NF-12H100	0	--	HSC	12 (4.52)	100 (2.79)
0.75SF100-12H100	0.75	100			
NF-8N100	0	--	NSC	8 (2.01)	100 (2.79)

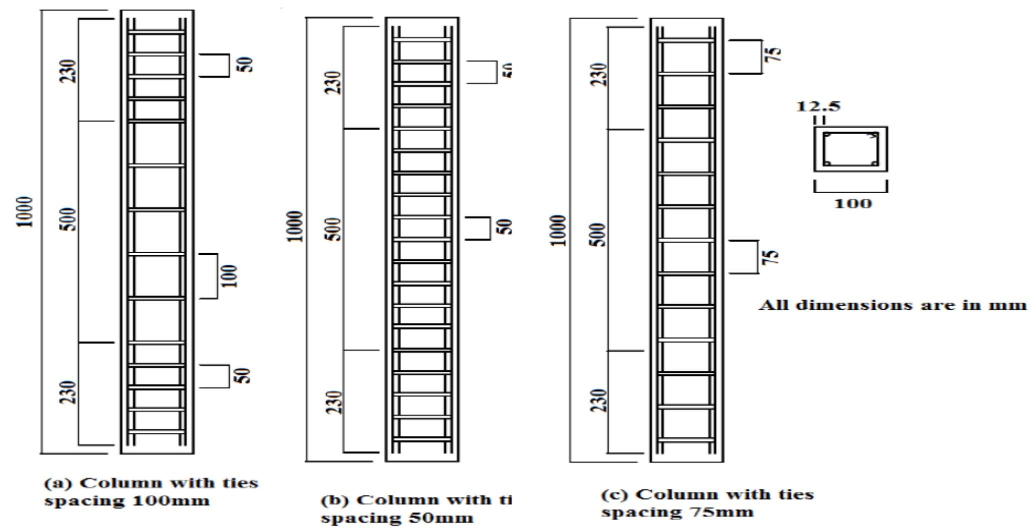


Fig. 2 Details of columns reinforcement

A- Conventional column (0.75SF100-12H100) before rehabilitation (after testing)

B- Column (0.75SF100-12H100) after rehabilitation

Fig. 3 Column specimen before and after rehabilitation

Table 11 Compressive and direct tensile strengths for bonding slurry used in this research

Age (days)	Compressive strength (MPa)	Direct tensile strength (MPa)
1	41.12	1.01
7	48.5	1.37
14	55.59	1.49
28	57.54	1.67

Table 12 Compressive and direct tensile strengths for modified mortar used in this research

Age (days)	Compressive strength (MPa)	Direct tensile strength (MPa)
1	28.3	0.75
7	42.0	1.59
14	48.6	2.72
28	68.2	2.95

Table 13 Comparison between conventional and rehabilitated column results

Specimen	Conventional columns		Rehabilitated columns		Rehab.max.load/Conv. max.load (%)
	Max. load (kN)	Deflection at max. load (mm)	Max. load (kN)	Deflection at max. load (mm)	
NF-8H100	515	1.32	490	3.46	95.2
NF-10H100	481	2.81	470	3.06	97.7
0.5SF100-10H100	560	2.33	440	3.20	78.6
0.75SF100-10H100	575	2.80	520	2.39	90.4
NF-12H100	550	2.35	470	4.74	85.5
0.75SF100-12H100	670	2.03	550	2.72	82.1
NF-8N100	260	0.95	430	1.96	165.4

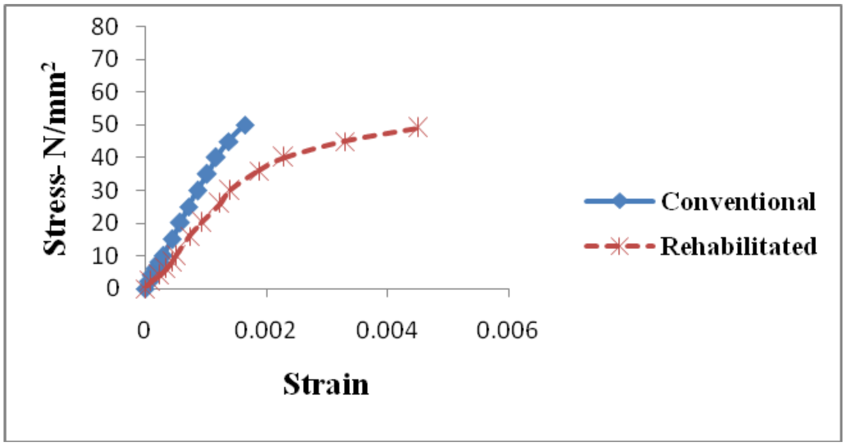


Fig. 4 Comparison of stress vs strain curve for conventional & rehabilitated column specimen NF-8H100

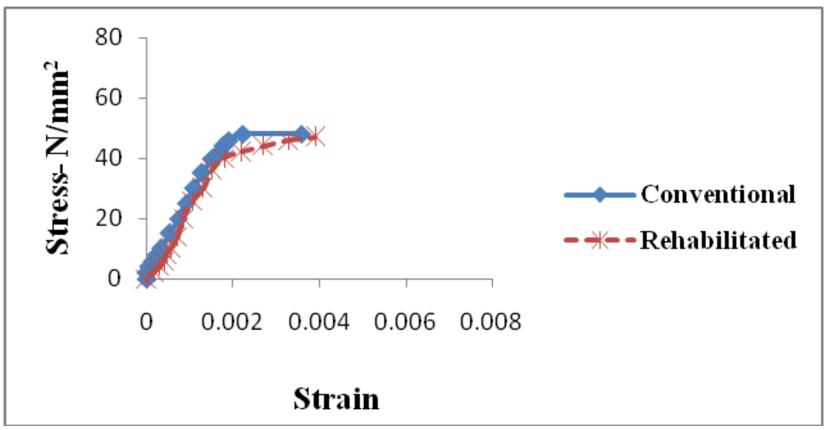


Fig. 5 Comparison of stress vs strain curve for conventional & rehabilitated column specimen NF-10H100

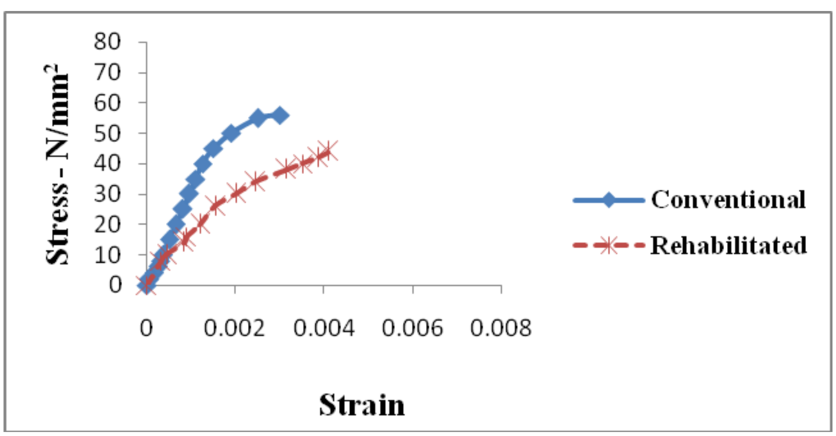


Fig. 6 Comparison of stress vs strain curve for conventional & rehabilitated column specimen 0.5 SF100-10H100

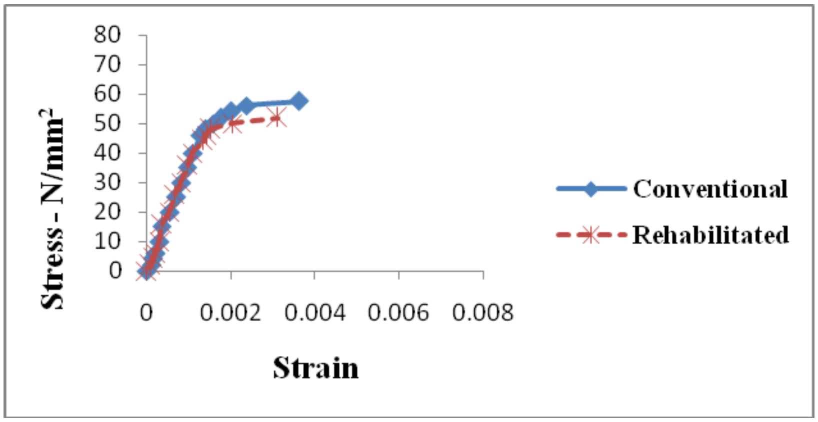


Fig. 7 Comparison of stress vs strain curve for conventional & rehabilitated column specimen 0.75 SF100-10H100

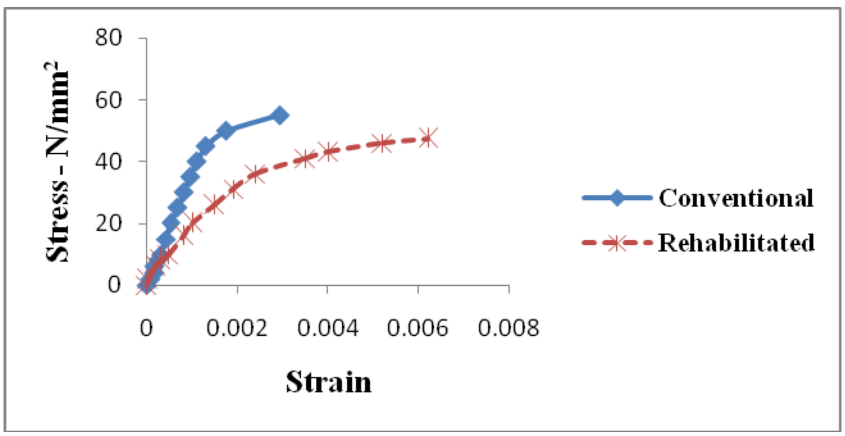


Fig. 8 Comparison of stress vs strain curve for conventional & rehabilitated column specimen NF-12H100

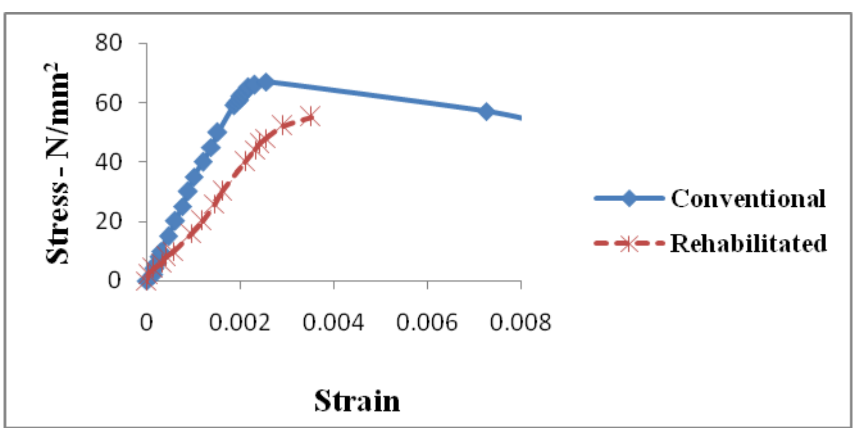


Fig. 9 Comparison of stress vs strain curve for conventional & rehabilitated column specimen 0.75 SF100-12H100

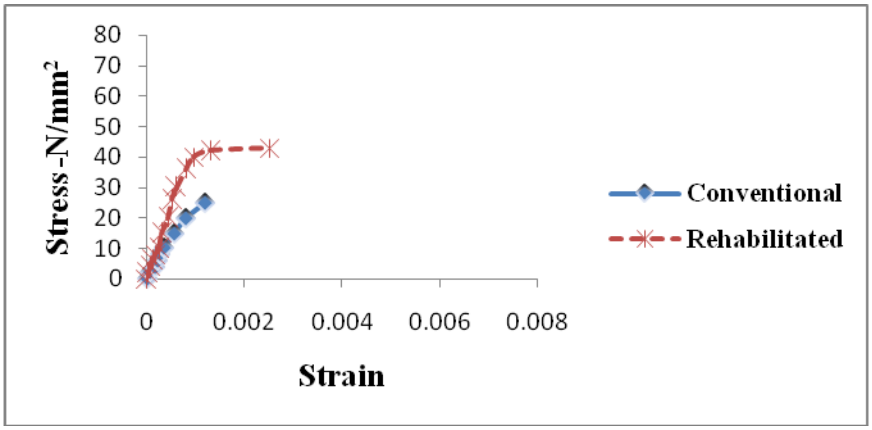


Fig. 10 Comparison of stress vs strain curve for conventional & rehabilitated column specimen NF-8N100

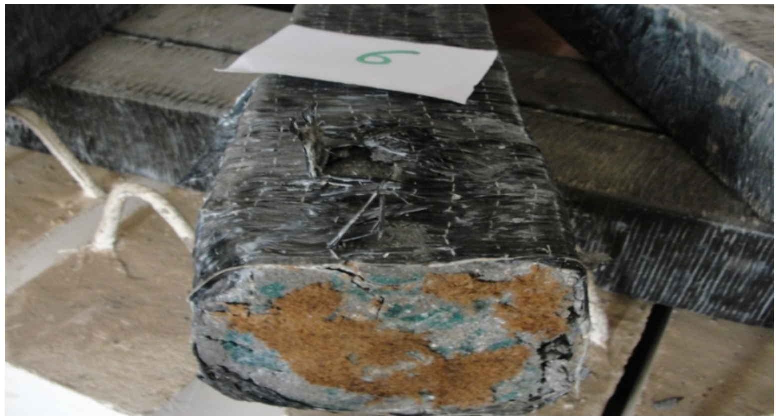
Table 14 Failure mode of rehabilitated concrete columns

Specimen	Failure mode
NF-8H100	Snatching of fiber with considerable crushing of concrete at the column base
NF-10H100	Snatching of fiber near the column base
0.5SF100-10H100	Snatching of fiber with slight crushing of concrete at the column head
0.75SF100-10H100	Tensile rupture of the fiber in the corner at the column base
NF-12H100	Tensile rupture of fiber near the column base
0.75SF100-12H100	Tensile rupture of fiber in the corner at the column base
NF-8N100	No sign of any tensile rupture or snatching of fiber is appears on the column

A- Failure mode for specimen **NF-8H100**

B- Failure mode for specimen **NF-10H100**

C- Failure mode for specimen **0.75 SF100-10H100**



D- Failure mode for specimen **NF-12H100**

E- Failure mode for specimen **0.75 SF100-12H100**

Fig. 11 Failure mode of some rehabilitated concrete column specimens