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Study the Behavior of High Performance Concrete Circular Short Columns Confined by CFRP

Abstract-*This paper presents the results of experimental study on reinforced concrete columns rehabilitation with carbon fiber reinforced polymer (CFRP) under concentrated load. Twelve short circular reinforced concrete columns (150 mm diameter and 600 mm height) were tested. Three specimens were unstrengthening and tested until failure as control specimens. Nine specimens were rehabilitation by carbon fiber reinforced polymer after loading about 75% from ultimate axial load capacity of control specimens. The test parameters were the type of concrete are normal strength concrete (NSC), high performance concrete (HPC) and high performance concrete containing engine oil (HPCEO) in additional to effective the ratio CFRP confining (fall wrap (100%strengthening), 50mm strips wrap 50mm spacing (50%strengthening)and 40mm strips wrap-60mm spacing(40%strengthening)). Test results showed that Adding used engine oil to concrete have significantly effect on workability of concrete where work as plasticizer. HPCEO mix showed lower strength (compressive, splitting tensile and flexural) and ultimate axial load of column than those HPC mix but greater than NSC mix. Where the compressive strength of concrete was (27.3 MPa, 45.8 MPa and 69.7 MPa) for NSC, HPCEO and HPC respectively. The ultimate axial load capacity of unconfined reinforced concrete columns was (52 ton, 78 ton and 117 ton) for NSC, HPCEO and HPC respectively. Reducing efficiency of rehabilitation by CFRP with increasing in compressive strength of concrete. The ratios of increasing in ultimate axial load capacity of rehabilitation RC columns with 100% and 50% wrapping in comparison with 40%wrapping are 20% and 4% respectively for NSC, while these ratios become 15% and 5% respectively for HPCEO and for HPC , these ratios are 10%and 3% respectively.*

Keywords- *RC columns; carbon fiber reinforced polymeric composites (CFRP); strengthening systems; Type of material.*

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1. Introduction

Rehabilitation of existing reinforced concrete columns may be required for a number of reasons. Many older buildings require rehabilitation and structural strengthening to allow for continued service if a change in the use or removal of some adjacent load bearing structural members or when the column is sought to be used in a different manner from previously planned or because it is damaged by external factors during its service. Industrial wastes either solid or liquid based chemical are available in large quantities. Environmental agencies have laws and regulations regarding safe handling of the waste. Hamad et al **[1-4]** investigated the effects of used engine oil on properties of fresh and hardened concrete. The main variables included the type and dosage of an air-entraining agent, mixing time, and the water cement ratio of the concrete. The dosage measured as percentage by weight of cement: 0.075, 0.15 or 0.30%. Results showed that used engine oil increased the percentage of entrained air and slump of the fresh concrete mix, without affect the strength properties of hardened concrete.

In 2014 Kabashi [5] determined the effect of CFRP wrapped on columns, he used the samples with different shape cross sections: three circular and six rectangular columns, in addition to three circular and three rectangular columns as control specimens. The rectangular column specimens were wrapped in two different ways: partially and fully wrapped (in spacing similar with stirrups and width 5-6 cm). The circular specimens were strengthening (wrapped) fully wrapped. The

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partially wrapped and fully wrapped is not big different [6-10].

2. Objectives of Research

The objective of this study is to investigate of rehabilitation short concrete columns by CFRP and effect used UEO (used engine oil) in columns as chemical admixture. The main objectives of this research work are:

1-Effect of compressive strength of concrete for columns on rehabilitation.

2-Behavior of rehabilitation of concrete columns when concrete containing used engine oil.

3-Effective the ratio of CFRP confining (fall confined and partial confined).

3. Experimental Work

The experimental program in the current research work includes testing of A series of reinforced concrete columns normal strength concrete (NSC), high performance concrete (HPC)and high performance concrete containing engine oil (HPCEO) specimens are carried out to illustrate the effect of rehabilitation with carbon fiber reinforced polymer for columns subjected to axial load.

I. Description of Specimens

A total of twelve short column specimens having an overall height of 600 mm with circular cross-section of 150 mm diameter as shown in Figure 1. The experimental parameters were the type of concrete and effective the ratio of CFRP confining [fall wrap (CFRP ratio =100%), 50mm strips wrap 50mm spacing (CFRP ratio=50%), 40mm strips wrap-60mm spacing (CFRP ratio=40% covered), and without CFRP (CFRP ratio=0%)].

The specimens are divided into three groups (NSC, HPC and HPCEO). Each group involves four columns; one-reference columns (control specimen) have not strengthened and three columns strengthened after loaded 75% from ultimate load of control specimen (100% wrapping, 50% wrapping and 40% wrapping). The test program and specimen properties are summarized in Table 1.

II. Materials

1. Cement

The Portland cement used in this research, manufactured in Iraq. The cement test conforms to the Iraqi Standard No.5/1984 [11].

2. Fine Aggregate

AL-Ukhaider natural sand of maximum size 4.75 mm was used throughout this investigation. The gradation results of fine aggregate within the requirements of the Iraqi specification No. 45/1984 [12].

3. Coarse Aggregate

Natural crushed aggregate of maximum size 12.5 mm was used in this investigation. It was brought from AL–Badrah region the grading, which conforms to Iraqi specification No.45/1984 [12].

4. Mineral Admixture (Silica Fume) Silica fume that used in this investigation is commercially known as MEYCO MS 610 from the chemical company BASF as partial replacement of cement weight. This silica fume conforms to the requirements of ASTM C1240-06 [13].

5. High Range Water Reducing Admixture

A high range water-reducing admixture (superplasticizer) with a trade name GLENIUM 54 was used. This type of admixture complies with ASTM C 494 Type F [14].

6. Used Engine Oil

The used engine oil used in this research were PERFO XC. It is a monograde engine oil suitable for use in all turbo-charged or normally aspirated diesel engines. It is recommended for use in engines of trucks, fishing boats, construction machinery and stationary diesel engines. PERFO XC used engine oil was collected from Service Station in Baghdad.

7. Water

The tap water was used for mixing and curing of concrete.

8. Reinforcing Steel Bars

Deformed steel bars with nominal diameter 8 mm were used as longitudinal reinforcement. Deformed steel bars with 6 mm diameter were also used as ties. Steel bars, manufactured by Turkish company. The steel reinforcement meet the ASTM A996M- 05 [15].

9. Carbon Fiber Reinforced Polymers (CFRP**)**

SikaWrap®-230 C Woven carbon fiber fabrics for structural strengthening was used, as shown in Figure 2. This type is classified as mid strength carbon fiber as reported by the manufacturer. Table 2 shows the technical description of Carbon fiber reinforced polymers (CFRP) from SikaWrap®- 230 C.

10. Bonding Materials

Sikadur®-330 is recommended by CFRP manufacturer to bond CFRP to the concrete. The product data is listed in Table 3.

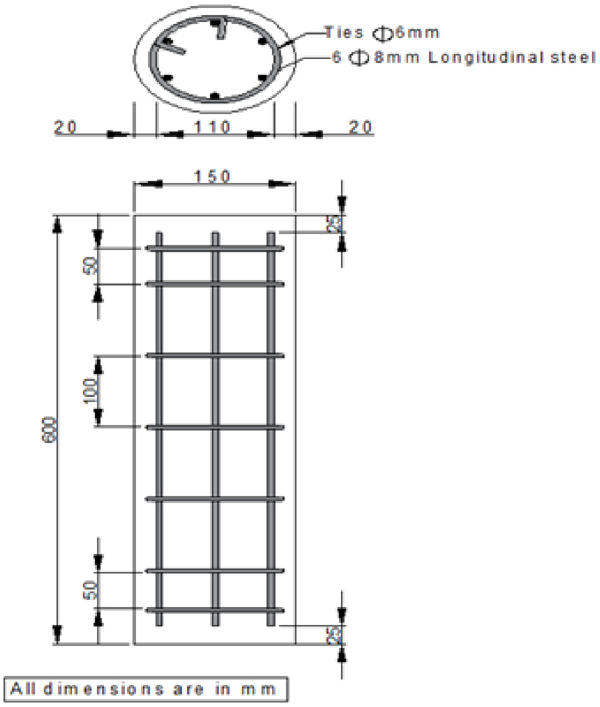

Figure 1: Specimen's details

Table 1: Specimen design details

Specimen	Strengthening	Type of concrete	Form of confined	Ratio of confined
UN	Unstrengthened	NSC	---	0%
SNF	Strengthened	NSC	fall wrap	100%
SN(50-50)	Strengthened	NSC	50mm strips wrap and 50mm spacing	50%
SN(40-60)	Strengthened	NSC	40mm strips wrap and 60mm spacing	40%
UH	Unstrengthened	HPC	---	0%
SHF	Strengthened	HPC	fall wrap	100%
SH(50-50)	Strengthened	HPC	50mm strips wrap and 50mm spacing	50%
SH(40-60)	Strengthened	HPC	40mm strips wrap and 60mm spacing	40%
UHEO	Unstrengthened	HPC with Engine oil	---	0%
SHEOF	Strengthened	HPC with Engine oil	fall wrap	100%
SHEO(50-50)	Strengthened	HPC with Engine oil	50mm strips wrap and 50mm spacing	50%
SHEO(40-60)	Strengthened	HPC with Engine oil	40mm strips wrap and 60mm spacing	40%

Figure 2: Assembled column moulds

Table 2: SikaWrap®-230C (Carbon Fiber Fabric) Technical Data*

Areal weight	230 g/m^2 ± 15 g/m^2
Fabric design thickness	0.131 mm (based on fibre content).
Tensile strength	4'300 N/mm^2
Tensile E – modulus	234'000 N/mm^2
Elongation at break	1.8 %

* Provided by the manufacturer.

Table 3: Sikadur®-330 product data*

Appearance / Colours	Part A: white Part B: grey Part A+B mixed: light grey
Density Tensile strength Tensile E – modulus Elongation at break Mixing ratio	1.30 kg/l ± 0.1 kg/l (parts A+B mixed) (at +23°C) 30 N/mm2 (7 days at +23°C) Flexural: 3800 N/mm2 (7 days at +23°C) Tensile: 4500 N/mm2 (7 days at +23°C) 0.9% (7 days at +23°C) Part A :part B = 4 : 1 by weight**

***** Provided by the manufacturer.
****** A: Resin part and B: Hardener part.

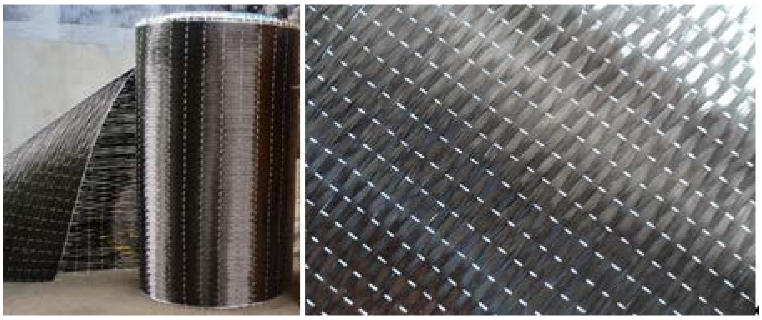

Figure 3: Carbon fiber reinforced polymers (CFRP) used in this research

III. Concrete Mixes

The mix proportions are 1: 1.2: 1.85 by weight with w/c ratio of 0.42 and cement content 500 kg/m3. Several trail mixes were carried out to determine the silica fume content, dosage of super plasticizer and engine oil content. Mixtures details are given in Table 4.

VI. Molds Preparation

Four steel molds are designed for casting all twelve columns in three stages for each type of concrete NSC, HPC and HPCEO. The molds were made of 2 mm thickness steel plate, as shown in Figure 2.

V. Casting and Curing

All column specimens were vertically cast in two layers to simulate the typical construction practice of columns. Each layer was compacted by pendulum concrete vibrator by touch on external surface mold for 1 minute to minimize the air voids and to get well-compacted concrete. The accompanied control specimens of cubs, cylinders and prisms were also cast and vibrated on vibrating table together with the columns specimens. After two days, the specimens were stripped from the molds and cured in a water bath for curing until age of 28 days.

Table 4: Concrete Mixtures details

Mix	% Silica fume (replacement by weight of cement)	w/c ratio	Dosage of HRWRA (liter/100kg of cement)	% used engine oil (by cementitious material)	Slump (mm)
NSC	0	0.42	0	0	100
HPC	10	0.27	1.3	0	103
HPCEO	10	0.27	1	0.075	100

4. Experimental Tests

I. Testing of Concrete Column

Universal testing machine of 2500 kN capacity was used for testing the columns. The columns gross axial shortening is measured using dial gauge of 0.01mm/div. sensitivity, located at the bottom surface of testing machine, which moves upward throughout testing process and also other dial gauge located at mid height of column to measured literal displacement. To measure the surface strains of concrete, we used Demec points along the concrete surfaces. Two demec gauge points are mounted at spacing of 100 mm at the column mid-height along the column vertical axis to measure longitudinal compressive strains at two opposite directions of the column. One column (control specimen) from each group is tested until failure. Then, three columns for each group is loaded 75% from ultimate loaded of control specimen and then three columns for each group is repaired to strengthening by CFRP. After curing for 7 days at laboratory temperature 35o C from strengthening this columns tested until failure.

II. Preparing Columns for CFRP Application

After loading each group of columns 75% from ultimate load. The surface of the columns must be grounded by using electric hand grinder to remove any loose and weak materials and then washed with water to obtain a clean surface. That clean surface ensures a good bond between the concrete surface and CFRP.

III. Application of CFRP

After the preparing of the surfaces and making sure that, they are clean and dry; type A and type B epoxy impregnation resin had been mixed to the recommended ratio (4:1) as directed by the manufacturer until the color be homogenous. Resin mixing was in quantities sufficiently small to ensure that all mixed resin can be used within the resin's pot life. Applying epoxy on column with thickness about 1mm. After that, setting CFRPsheet on column surface on the coated region by epoxy. The CFRP was then coated with another layer of epoxy resin. Figure 4 shows application of CFRP. Finally, the column be ready to test after curing for 7 days at laboratory temperature 35oC.

5. Results and Discussions

I. Slump Test

In this study, all mixes exhibited the desired workability (slump of 100 ± 5 mm) for all types of concrete (NSC, HPC, and HPCEO). The w/c ratio for high performance concrete mix was adjusted to have the same workability of normal strength concrete where reduced from 0.42 to 0.27. The significance of the study was to check the hypo thesis that adding used engine oil to the fresh concrete mix could be similar to adding chemical admixture, thus enhancing some properties of fresh and hardened concrete while serving as technique of disposing the Iraqi oil waste. Results of high performance concrete with used engine oil showed that performance of used engine oil acted as a chemical plasticizer by improving the fluidity and the slump of the concrete mix.

II. Compressive Strength Test

The compressive strength test results for all types of concrete mixes are presented in Table 5. It can be observed that the compressive strength results of the high performance concrete containing superplasticizer only (HPC) is significantly increased relative to normal strength concrete (NSC). The increase in strength was due to adding 10% of silica fume (by weight of cement) and reducing w/c ratio from 0.42 to 0.27 due to adding superplasticizer. The compressive strength of the concrete containing superplasticizer and used engine oil (HPCEO) is increased relative to (NSC) but less than the compressive strength of (HPC). The decreasing in compressive strength of (HPCEO) in comparison with the (HPC) is due to reduce the dosage of superplasticizer from 1.3 to 1 (liter/100kg of cement) and used engine oil is acted as a chemical plasticizer only. In additional to used engine, oil could slightly decrease in compressive strength (16). Based on results of this experimental work can considered concrete containing used engine oil with another chemical and mineral admixture (HPCEO) as high performance concrete.

Figure 4: Application of CFRP

Table 5: Compressive strength, Splitting tensile strength, Flexural strength of alltype of concrete

Type of concrete	Compressive strength $f_ć$ (MPa)	Measured Splitting tensile strength (MPa)	Measured Modulus of Rupture (MPa)
NSC	27.3	3.1	3.3
HPC	69.7	5.3	5.6
HPCEO	45.8	4.5	5.3

III. Splitting tensile strength test

Adding used engine oil to high performance concrete has significant effect. The results show that the splitting tensile strength of the concrete containing superplasticizer and used engine oil (HPCEO) is higher than normal strength concrete (NSC) and less than (HPC) with superplasticizer only. Table (5) gives the results of test.

IV. Flexural tensile strength test

The flexural strength test results for all type of concrete mixes are presented in Table 5. The results show that the flexural tensile strength of high performance concrete with superplasticizer and used engine oil (HPCEO) is higher than normal strength concrete (NSC) and less than high performance concrete with superplasticizer only (HPC).

V. Experimental axial load capacity of the tested columns

Most application strengthening of CFRP for element structure is applied after a period from constructed the structure. The structure through this time is exhibited to service load or any external factors during structure service. That cause to damages and deformation of structure. Therefore, experimental programs of this investigation work to simulates applied reality where loaded the columns about 75% from ultimate load of reference columns before strengthening. Then three columns for each group was loaded about 75% from ultimate loaded of control specimen. The NSC columns was appearing first cracks in this range of load while HPCEO and HPC was did not appearing any cracks. Table 6 and Figure 5 show results of investigation work. The results of ultimate load for columns shows that compressive strength of concrete has significantly effect on ultimate strength of unconfined concrete columns and behavior of confined concrete columns.

Table 6: Maximum strength capacity P_u for tested column specimens

Column designation	Loading of column before strengthening (ton)	% load from ultimate load for reference column	Ultimate load Pu (ton)	% Increase in ultimate load Pu (ton)
UN	52 until failure	Reference column	52	Reference column
SNF	39	75	90	73
SN(50-50)	39	75	78	50
SN(40-60)	39	75	75	44
UH	125 until failure	Reference column	117	Reference column
SHF	88	75	132	12.8
SH(50-50)	88	75	123	5.1
SH(40-60)	88	75	120	2.5
UHEO	78 until failure	Reference column	78	Reference column
SHEOF	60	75	107	37
SHEO(50-50)	60	75	98	26
SHEO(40-60)	60	75	93	19

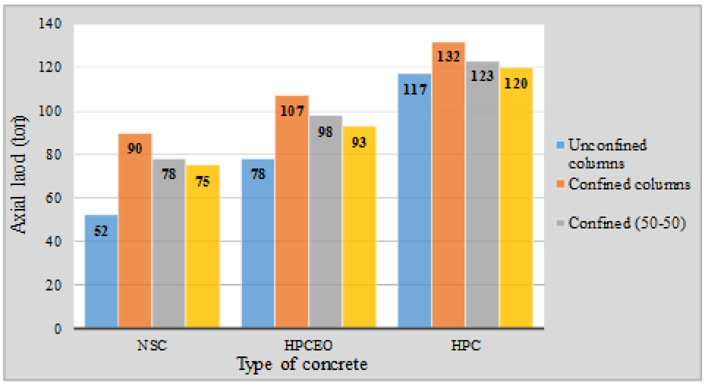

Figure 5: Ultimate experimental load capacities P_u for tested columns

The results indicate that the ultimate strength of unconfined concrete columns increase as the compressive strength of concrete increases. For unconfined columns increase in ultimate load of columns are 140% for HPC and 50% for HPCEO relative to NSC columns. While unconfined columns for HPCEO increased 50% relative to NSC but less about 61% than HPC. This suggests that used engine oil in reinforced concrete columns is reduce from ultimate strength of columns and this may be because drop in the compressive strength of concrete in comparison with HPC columns but heigher than NSC columns. The compressive strength also, significantly effect on behavior of confined concrete columns. The results increasing in compressive strength of concrete is reduced from efficiency confinement of columns by CFRP. The efficiency of confinement columns has little effect when compressive strength of concrete heigher than 70 MPa.

The results indicate confined columns by wrapping ties of CFRP enhancement capacity of ultimate load but less than from fully confined columns. Also, reduce of width wraps ties of CFRP and increasing the spacing between wrapping ties of CFRP reduce from enhancement capacity load. The failure patterns of all columns are shown in Figures 6 to 8.

UN SNF SN (50-50) SN (40-60)

Figure 6: Failure pattern for NSC columns

UHEO SHEOF SHEO (50-50) SHEO (40-60)

Figure 7: Failure pattern for HPCEO columns

UH SHF SH (50-50) SH (40-60)

Figure 8: Failure pattern for HPC column

VI. Load-Displacement Behavior

Figure 9 shows the effect Load-longitudinal displacement behavior of NSC, HPC and HPCEO unconfined columns it can be seen there is little difference between this unconfined columns but improving in ultimate load of columns with increasing in compressive strength of concrete. Figures 10 to 12 show the effect Load-longitudinal displacement behavior on confinement columns with CFRP for each type of columns (NSC, HPC and HPCEO columns) it can be see significantly improving in reducing of longitudinal displacement. In addition a part from this reducing of longitudinal displacement may be because loading before strengthening columns.

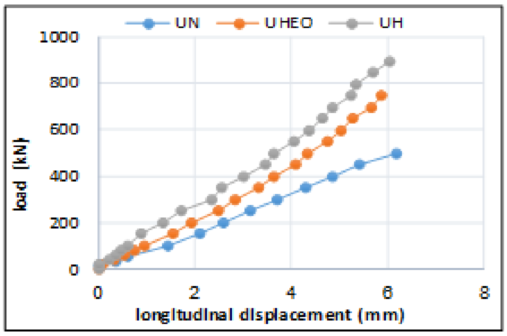

Figure 9: Load-longitudinal displacement behavior of unconfined columns specimens

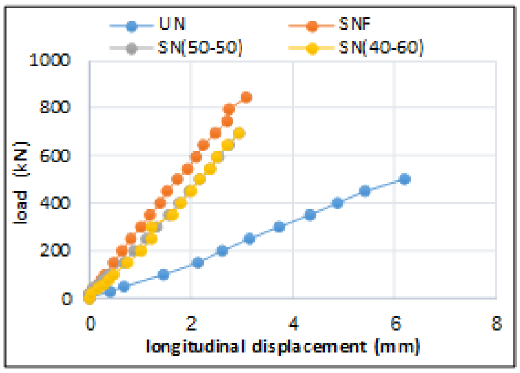

Figure 10: Load-longitudinal displacement behavior of NSC columns specimens

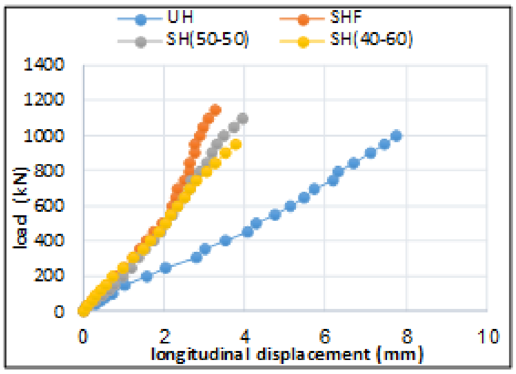

Figure 11: Load-longitudinal displacement behavior of HPC columns specimens

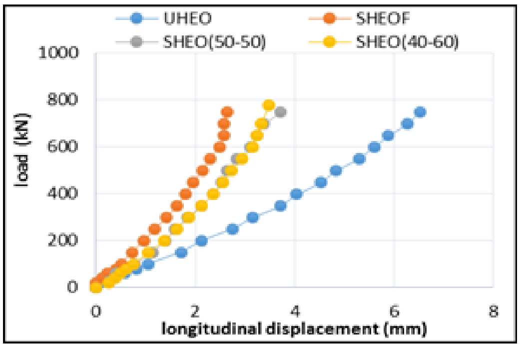

Figure 12: Load-longitudinal displacement behavior of HPCEO columns specimens

Conclusions

1. Adding used engine oil to concrete have significantly effect on workability of concrete where work as plasticizer. When adding used engine oil to high performance concrete can be reducing of superplasticizer with same w/c and slump.

2. High performance concrete mix containing superplasticizer and used engine oil (HPCEO) showed lower strength (compressive, splitting tensile and flexural) and also ultimate axial load of column then those mix containing superplasticizer (HPC) only but greater than normal strength concrete (NSC). The increasing in compressive strength of concrete was 68% and 155% for HPCEO and HPC respectively, in comparison with NSC.

3. The increasing in ultimate axial load capacity of unconfined reinforced concrete columns was 50% and 125% for HPCEO and HPC respectively, in comparison with NSC.

4. Rehabilitation of columns by CFRP is increasing ultimate axial load capacity of columns. Reducing the efficiency of rehabilitation by CFRP with increasing in compressive strength of concrete. Where slightly effect on rehabilitation when compressive strength of concrete equal to 69.7 MPa. The ratio of increasing enhancement in ultimate axial load capacity of rehabilitation NSC is (73%, 50% and 44%) from control specimen for strengthening (100% wrapping, 50% wrapping and 40% wrapping) respectively. For the same strengthening, the ratio of increasing enhancement in ultimate axial load capacity of rehabilitation HPCEO is (37%, 26% and 17%) respectively from control specimen, while for HPC this ratio becomes (12%, 5% and 2%) from control specimen for these strengthening(100%, 50% and 40% wrapping).

5. The ratios of increasing in ultimate axial load capacity of rehabilitation RC columns with 100% and 50% wrapping in comparison with

40%wrapping are 20% and 4% respectively for NSC, while these ratios become 15% and 5% respectively for HPCEO and for HPC , these ratios are 10%and 3% respectively.

6. Significantly reducing in rehabilitation using wrapping ties in comparison with fully confined columns.

7. Slightly different between wrapping ties (50-50) and wrapping ties (40-60). Therefore, prefers using wrapping that width of CFRP is equal to spacing between ties of CFRP.

8. When rehabilitation of columns by wrapping ties of CFRP prefer application-wrapping ties between ties of reinforced columns.

9. Failure of rehabilitation columns by CFRP was mainly by rupture of CFRP.

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