USING HIGH PERFORMANCE CEMENTITIOUS FOR REPAIR COLUMNS

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Abstract— To restore the structural capacity of the distressed elements, retrofitting and/or strengthening are needed Laboratory investigation was undertaken to develop high-performance cement-based grouts cementitious composites that makes them ideally suited for structural repair. An experimental program was conducted where nine circular reinforced concrete columns were tested with varying material types and repair location (cover only – cover extended to core) – one as control, four contained various material types throughout the cross-section and four contained repair material only in the outer concrete. All nine columns were tested by the application of a concentric, axial compression force. Another nine columns with the same repair techniques were tested subjected to eccentric loads. It was found that ductility of the columns with a silica fume or fibers contain in repair material proved to be more ductile. Placing the repair material at cover through the steel reinforcement into core increased the load capacity compared with cover only. Using Silica fume or fibers in the repair material at cover through the steel reinforcement into core to increases load capacity by 30 %. The use of fibers or silica fume in repair material is an efficient means providing ultimate load of repair columns enhancement in eccentric case
Keywords— Repair, Column, Strengthening, eccentricity, Grout, fibers, Cementitious, silicafume, concentric.

1. INTRODUCTION

In practice, situations arise where existing concrete structures or some of their components may, for a variety of reasons, be found to be inadequate and in need of repair and/or strengthening. The inadequacy may be due to mechanical damage, functional changes, overstress due to temperature changes, or corrosion of reinforcement. A common feature of a number of different causes of deterioration is that there is a reduction of the alkalinity of the concrete, which allows oxidation of the reinforcing steel to take place. This oxidation process leads to cracking of the concrete and possible spalling of the cover to the reinforcement [1-3].

One of the disadvantages of using repair paste in concrete columns is that the repair materials are not always effectively acting throughout the column. As repair takes place, the successful repair depending on the properties of repair material and the location of repair (cover or extended to core) [4, 5].

The weak repair material in the core concrete would lower the density, reducing the compressive strength of the column and the lack of repair material in the cover concrete would mean that cover spalling would not be prevented.

In order to overcome the uncertainties outlined above, it was necessary to trial a repair materials. This cross-section involved the use of concrete only where it was required The proposed column cross-section, developed during the course of this study, was constructed using plain concrete in the core concrete and repair material in the cover concrete only. A secondary trial cross-section was also proposed which involved the cover concrete containing repair material which extended through the conventional steel reinforcement into the core. The reason for the secondary cross-section was to ensure the cover concrete was tied into the core concrete as it was thought the cross-section which was proposed initially may promote cover spalling due to the method of construction. These two cross-sections effectively reduced uncertainty about the location of the repair material and increased confidence that repair material were present within the cover and were not present in the core [6-10].

2. Objective And Scope

·This paper presents a study on the effects of different repair techniques on the structural response of reinforced concrete column. The techniques include:
(a) Cement paste;
(b) Cement paste with silica fume
(c) Cement grout, i.e., Masterflow;
(d) Fiber reinforced polymers, i.e., Emaco;
(e) Repair location
These techniques had been selected for their potential to either increase the structural capacity of members or to restore the original capacity of the sections. Furthermore, this study focuses on the serviceability, strength and ductility performance for each of the repair techniques to ascertain their potential application in cracked reinforced concrete columns.
Two sets of tests in terms of eccentric loading and concentric loading are conducted. Then, the effectiveness of the material types as a repair material under different loading conditions is investigated.

3. EXPERIMENTAL PROGRAM

2.1 Materials

Cement :The type of cement used in this research was CEM I N 42.5, ordinary Portland cement, Amrya company production. Test result performed on the cement specimens according to ECP, 203/2007 [11] and E.S.S, 4756-1/2005 [12].
Fine Aggregate: The fine aggregate used in this research was natural siliceous sand. The sand used was clean, free from impurities, silt, loam and clay. The main physical and mechanical properties of the used sand were measured according to ECP, 203-2007 [13] and E.S.S, 1109-2002 [14].
Steel Reinforcement :The used steel in this research was 3.4 mm diameter mild steel grade 240/350 for all columns. Test results performed on the steel specimens according to Egyptian Code for Concrete Structure (ECP, 203-2007) [12] and Egyptian Standard Specifications (E.S.S, 203-2001) [14]. The steel yield strength was 265 MPa.
High range water reducer:- (Superplastizer SP) complies with ASTM C494 type F was used.
EMACO S88 CT:- It is a pre-bagged ready-to-use structural repair mortar in powder form. When mixed with the correct amount of water, it produces a thixotropic, high strength repair mortar, reinforced with acrylic polymer fiber. It possess excellent bond characteristics to steel reinforcement and to concrete. EMACO S88 CT mortar is shrinkage compensated [5]. It has low permeability and is extremely durable. EMACO S88 CT contains no metallic aggregate and is chloride-free. It is formulated for sprayed or trowelled applications – in thicknesses up to 50 mm in one layer by hand application. It has the following advantages:-

- Shrinkage compensation – reduces the risk of cracking due to shrinkage and ensures full contact with host concrete and load transfer in structural repair situations
- • Can be spray applied – rapid application of large quantities
- • Low rebound – when spray applied rebound is minimal, with subsequent saving in material cost
- • Extremely low permeability – gives excellent resistance to attack by aggressive elements

MASTERFLOW 980M:- It is a ready-to-use product in powder form, which requires only the on-site addition of water to produce a shrinkage compensated micro concrete of predictable performance. The larger size aggregate of MASTERFLOW 980M permits precision grouting of thickness more than 80 mm. It has the following advantages:-

- Shrinkage compensated.
- Formulated for deep section grouting.
- Excellent workability retention even at high ambient temperatures.
- High bond strength to steel and concrete.
- Early strength development even at fluid.
- Consistency.
- Micro silica content enhances strength and durability.

Primer:- We used epoxy (**Concresive 1414**) as a primer. It is a two component, solvent-free, low viscosity liquid, based on high strength epoxy resins. It complies with ASTM C 881-78 Type I, Grade 1 Class B + C [16]. It is a permanent epoxy adhesive for internal or external bonding of renderings, granolithic toppings, and concrete to concrete. It tolerates a degree of moisture before and during curing and is insoluble when cured. The ultimate bond strength is greater than the tensile strength of concrete. CONCRESIVE 1414 does not shrink and provides an even and stress free bond. It has the following advantages:-

- • High strength
- • Non shrink
- • Moisture tolerant
- • Durable
- • Resistant to chemical attack

2.2 Design of experiments

Considering that a slender column might cause buckling and secondary bending moments, which are not part of the present study, all columns were designed as short columns. Eighteen short cylindrical (900 mm high with 190 mm diameter) concrete columns were designed for testing. The concrete was designed to be poor concrete. All columns were reinforced longitudinally with 5 $\varphi16$ steel bars. Helices were provided with 8 mm plain bars at 80 mm pitches as shown in Fig. (1, 2). The clear cover to helices was 20 mm. There are two groups of columns one group was tested concentrically and the second group was tested with 50 mm eccentric load.

Fig. 1. Columns casting procedure

Fig. 2 column form with reinforcement

Fig. 3 Columns prepared to applay repairing

Fig. 4 Primer coated column surface

2.3 Mix proportions for repair material

The laboratory program investigated the formulation and preparation of the mixes along with some of their important properties such as flowability, compressive strength. The objective was to produce high- to very high strength flowable repair material. The program conducted in this investigation focused on four basic mixes as a repair material. The details of two mixes are given in Table 1. The remaining mixes used in this programme were pre-bagged ready-to-use structural repair mortar in powder form, namely Masterflow as a grout mix and Emaco as a fiber mix.

Table 1 Mix proportion by weight (by weight of cement)

Mix	Cement	Sand	Silica fume	Water	Superplastizer
M1	1	0.6	-	0.5	-
M2	1	0.6	0.15	0.33	0.02

The mixes were prepared following a modified ASTM C 305 procedure [17] using a laboratory mixer and extended mixing time to break as much as possible silica fume clumps that tend to occur in the dry material and to obtain a fluid mix. The sequence of mixing was to add 75% of mixing water, 50% of superplasticizer, cement, silica fume, and the remaining amount of superplasticizer and water. The mixes were poured and compacted in 50-mm cubes in accordance with a modified ASTM C 109 procedure [17]. The results of 28 days compressive strength are shown in Table 2.

Table 2 Compressive strength for repair material.

Repair material	Compressive Strength f_{c28} (MPa)
M1	25
M2	45
MASTERFLOW 980M	60
EMACO S88 CT	65

2.4 Preparing test specimens

The first stage of specimen construction was to prepare the circular PVC tubes. Eighteen formworks were used in the experiment. In order to maintain a perfect environment for concrete columns, high pressure air was first used to clean the wooden platform. Then, the PVC tubes were fixed straight up on the wooden platform and were tested to make sure the tubes were level.

Reinforcement cage was tied for each column and then put into the formwork, and then steel cages were used at the bottom of the reinforcement to ensure a 20 mm clearance. Next, the reinforcement cage was placed into the formwork (as shown in Fig. 1) and oil was brush inside of formwork in order to easily remove it from the concrete. The 28-day cube compressive strength, f_{cu} of the concrete was 25 N/mm^2. A slump test gave a reading of 120 mm. In the curing period, the concrete columns were covered by moist Hessian in order to give a suitable humidity. Seven days was required for the concrete to cure before removing the formwork. The specimens covered by moist Hessian to obtain further curing. After twenty eight days curing, the concrete columns were ready for start the programme. Eight columns were removed the cover (outer 20 mm) and another eight were removed cover and extending into core (outer 40 mm). These columns will repair with different repair material and tested (concentric, eccentric). The areas of the concrete surfaces of the columns to be repair with mortar were well scraped and carefully cleaned by removing dust and fine materials with compressed air using electric blower as shown in Fig. 3. Then epoxy primer were coated with brush over the required repair areas of columns (Fig .4). Columns were putting into PVC pipe and repair material was placed around columns. The repair material was pushed with 6 mm bars and the sides of formwork were tapped with a mallet to ensure the repair material dropped to the bottom of the column. The column was filled in this way until the top surface was finished with wet trowel. Two columns were providing a reference point to which results could be compared and compared with control columns. Repair material types and location for each column are shown in Table 3. All repair columns are shown in Fig. 6

Table 3 Column number by repair material type, location and loading pattern.

Col	Type of repair material	location	Loading pattern
C01	N/A	N/A	Concentric
C11	N/A	N/A	Eccentric
C02	Mix1	Cover only (20 mm)	Concentric
C12	Mix1	Cover only (20 mm)	Eccentric
C03	Mix1	Cover + extending into core (40 mm)	Concentric
C13	Mix1	Cover + extending into core (40 mm)	Eccentric
C04	Mix2	Cover only (20 mm)	Concentric
C14	Mix2	Cover only (20 mm)	Eccentric
C05	Mix2	Cover + extending into core (40 mm)	Concentric
C15	Mix2	Cover + extending into core (40 mm)	Eccentric
C06	MASTERFLOW	Cover only (20 mm)	Concentric
C16	MASTERFLOW	Cover only (20 mm)	Eccentric
C07	MASTERFLOW	Cover + extending into core (40 mm)	Concentric
C17	MASTERFLOW	Cover + extending into core (40 mm)	Eccentric
C08	EMACO	Cover only (20 mm)	Concentric
C18	EMACO	Cover only (20 mm)	Eccentric
C09	EMACO	Cover + extending into core (40 mm)	Concentric
C19	EMACO	Cover + extending into core (40 mm)	Eccentric

2.5 Loading setup

Steel loading frame with hydraulic jack was used to apply vertical load on columns .Fig. 6 shows test setup for axially loaded columns and Fig. (2) shows test setup for loaded columns. The capacity of the hydraulic jack applying the vertical load was 3000kN. The value of applied load was appeared automatically on special monitor connected to the hydraulic jack.

Where eccentric loading differs from concentric loading is that it involves concentrating the load a certain distance form the neutral axis of the cross section. As shown in Fig. 5, two plates were designed and manufactured in order to apply eccentric loading on the columns. These plates were used on either end of the columns during loading.

All the columns were eccentrically loaded until failure with an eccentricity of 50 mm. The testing matrix is summarised in Table 3.

Fig. 5 The eccentric loading mechanism

Fig. 6 Columns after repairing

2.6 Column test

The testing program consisted of testing the nine concrete columns under concentric loading and testing the nine concrete columns with different repair material under the eccentric load. The hydraulically operated 3000 kN, located in the Strength of material Laboratory at the University of Mansoura was used to test all the columns in this study. All the columns were tested to failure.

The axial deflection of the columns was measured by a deflection gauge placed on a corner of the platform and connected to Strain meter system. The peak loads of the tested columns were measured by monitor connected to the hydraulic jack.

Fig. 7 Typical setup for repair column under load

4. RESULTS

Tables 4, 5 show yield load, corresponding displacement, ultimate load and the maximum displacement of the Nine tested columns. Ductility of each of the tested columns was calculated and are shown in Table 4, 5. These ductilities were calculated as a ratio of the ultimate displacement to the yield displacement The ductility of Column C1 was used as a reference value for the remaining columns.

In order to assess the benefits of repair materials, C01, C04, and C8 were compared. All three columns had repair on cover only (20 mm). Fig. 8 shows that cover spalling in both C04 and C08 occurred at a higher load than C01 indicating better performance due to use Silicafume addition and Emaco as repair material. The fibers present in repair material (Emaco) had an effect as cover spalling for C08 occurred at a higher load than for C01 or C04.

Table 4 Results of testing repairing columns, cover only (20 mm)

Col	Yield Load (kN)	Displ. at yield load (mm)	Ult. Load (kN)	Displ. at ult. load (mm)	Ductility: max. disp./ yield disp.	Ductility relative to C01
C01	707	4.34	785	8.9	2.0	1
C02	700	5.26	773	8.5	1.6	0.8
C04	719	2.69	797	7.26	2.7	1.35
C06	633	3.3	690	6.61	2.0	1
C08	710	3.11	785	7.64	2.5	1.25

Table 5 Results of testing repairing columns, cover-core interface (40 mm)

Col	Yield Load (kN)	Displ. at yield load (mm)	Ult. Load (kN)	Displ. at ult. load (mm)	Ductility: max. disp./ yield disp.	Ductility relative to C01
C01	707	4.34	785	8.9	2	1
C03	727	3.94	814	8.13	2	1
C05	800	2.77	974	8.13	2.9	1.45
C07	739	4.36	879	8.7	1.9	0.95
C09	805	3.28	1044	9.2	2.8	1.4

The effect of repair material on cover spalling can also be shown through the comparison of C01, C02 and C06. The column C02 contained normal mortar but C06 contained grout (Masterflow) in the same location (cover only). Fig. 9 shows C02 and C06 reached a ultimate load lower than control column (C01) indicating that using normal mortar or grout as repair material in cover is not significant to restore the integrity of a repair column at cover.

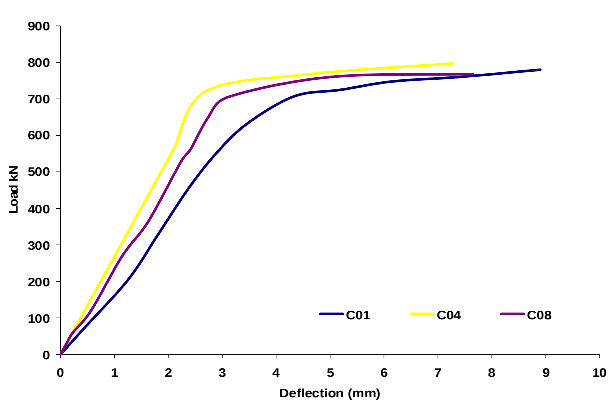

Fig. 8 Load – Deflection for C01, C04 and C08

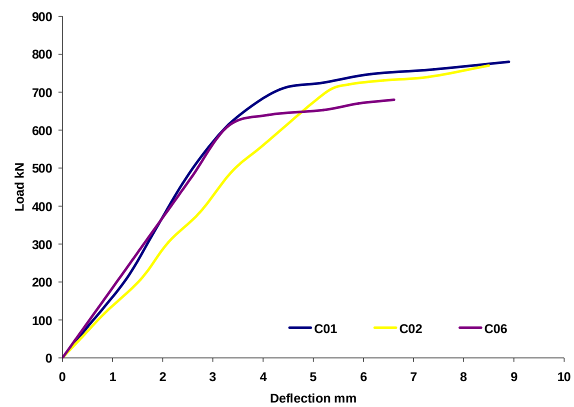

Fig. 9 Load – Deflection for C01, C02 and C06

Column C01, C05 and C09 may also be compared in a similar manner as in identical locations (cover extended into core 40 mm). Fig. 10 show the maximum load for Column C09 was higher than for Column C01 by 33% indicating that using Emaco as material repair performs much better than other repair material using in this study. Also, using silicafume in repair material was higher than for control column (C01) by 24% at in location up to core. It can be concluded, silica fume was significant improvement for load capacity. Moreover, Emaco as a repair material can be used as strengthening at location up to core.

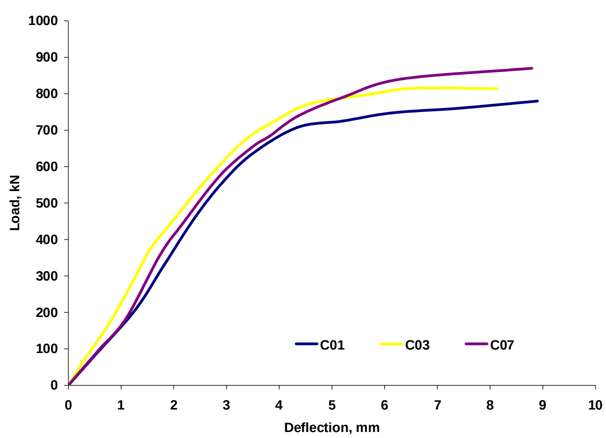

Fig. 10 Load – Deflection for C01, C05 and C09

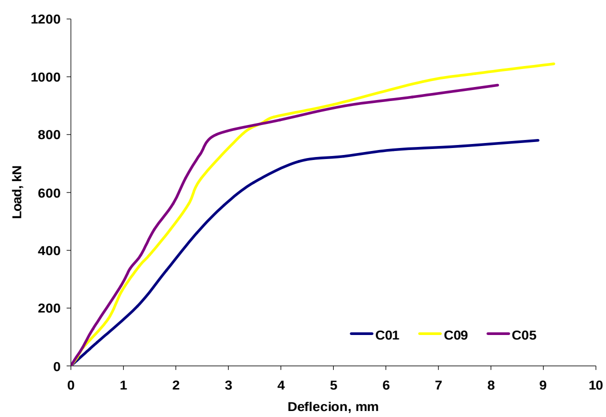

Fig. 11 Load – Deflection for C01, C03 and C07

Column C01, C03 and C07 compared in the same way as the same location (cover extended into core 40 mm) are shown in Fig. 11. It can be shown, using grout (Masterflow) or normal mortar improved load capacity by 12% and 4% respectively. This percentage was lower than the other repair material, using silicafume or fiber as shown above.

In order to assess the benefits of varying the location of the repair material, all columns were compared. As can be seen in Fig. 12, columns repair in cover extending through the region of the steel reinforcement into the core gave a higher load than those repair at cover only. Emaco as a repair material gave a higher load capacity than control column (without repair C01) by 33%. Silicafume added to repair material (C03, C04) gave a higher load capacity by 4, 24% respectively, compared with control column (without repair). Grout (Masterflow) gave a load capacity slightly higher than control column (C01) by 12% at repair case up to core. On the contrary, grout gave a load capacity lower than control column (C01) by 12% at only cover location. It was concluded that grout are not adequate as a repair material, especially at location in cover only. Columns Approximately, C02 and C03 gave a same load capacity compared with control column C01. As shown in Fig. 12, It was concluded that Emaco (mortar with fiber) or mortar with silicafume can be used as strengthening and repairing material, especially at the location in cover extending into the core.

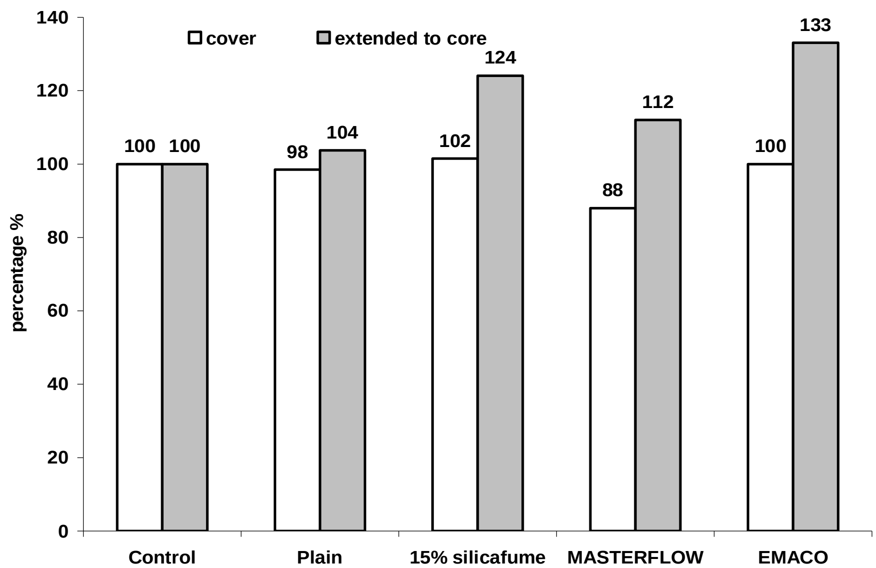

Fig. 12 Effect repair material types on ultimate concentric load, compared with control column

Compared to the repair material type for columns tested under eccentricity load, loads were observed at the tests as shown in Fig. 13. The eccentrically loaded columns were compared, as well as the concentrically-loaded column. The testing results indicated that Emaco as repair material is more effective as a material repair compared to other material repair. This proved because the presence of fibers has a significant influence on the behavior of eccentrically loaded columns. The comparison among the eccentrically columns show that all material excluding plain mix (mix1) achieve a good result to increased ultimate load by 5% - 24%,.compared with control columns. There is no significant effect between the location of repairing (cover only – cover extended to core). NSC as a material repair can not be restore the integrity of a repair column at eccentricity case.

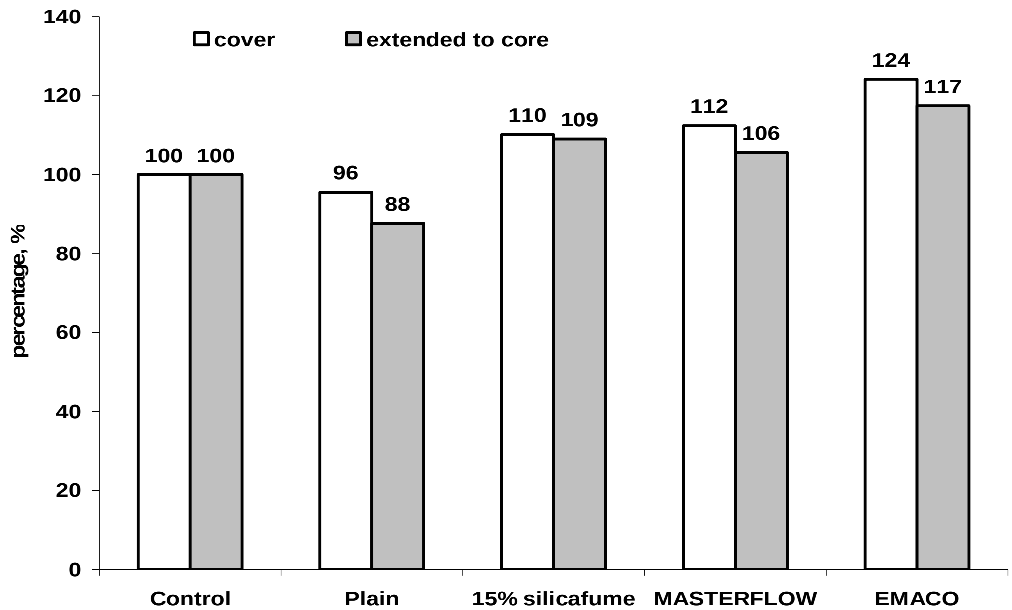

Fig 13 Effect repair material types on ultimate eccentric load, compared with control column

5. Discussion

The experimental program indicated that the load carrying capacity of repair columns was significantly affected through the addition silica fume and fibres in repair material. Column C05 and C09 were showing an improvement in load carrying capacity of 24% and 33% when compared to Column C01.

The ductility of the repairing columns showed the most significant improvement when compared to Column C01. The ductility was improved from repair location at the outer cover (compared to Column C01) as in columns C04 and C08.

From Table 5, it is apparent that to improve the ductility of a column it is more effective to place the repairing in the outer cover as opposed to in the cover–core interface.

Table 6 Relative ductility

Test Variable	Specimens	R*
Type of repair material	C09/C07	1.12
	C09/C05	0.965
	C09/C03	1.4
	C09/C08	1.12
Repair Location	C07/C06	0.95
	C05/C04	1.07
	C03/C02	1.25

*Ratio of ductilities

The observed failure behaviour of the columns indicated that the repair material contain fiber assisted in the reduction of cracking and spalling. Columns C08 and C09 failed with the spiral fracturing and the longitudinal reinforcement bending whereas the other columns did not as shown in Fig. 14. Repair material containing fibre is sufficient to control cracking to prolong the life of a column under loading until the yield strength of the reinforcement is reached.

Fig. 14 Failure of helices

In Table 6, the ductilities of the columns repairing by Emaco as a type of material are compared with the ductilities of the other repairing columns. The location of repair is held constant in each comparison. The ratio is greater than 1.0 for the ductility indicating that the columns (C09 and C08) exhibited a greater ductility at ultimate load than the control columns (C03 and C07). However, for the columns (C09 and C05), the ratio between the ductilities of the columns was less than 1.0 indicating that the column repairing by normal paste with 15%silicafume at the location cover- core interface was more ductile than column using Emaco as repairing material.

Table 6 also compares the ductilities of the columns with a location of repair. The type of material repair was constant in each comparison. From the comparison, it is clear that for the columns at cover-core interface repair, the ductility ratio is higher than 1.0, however it is indicating that a greater ductility can be achieved for the columns with repairing location at cover-core interface.

6. CONCLUSION

This study of repair reinforced concrete columns involved the testing of eighteen concrete columns with varying repair material types and locations. The main aim of this study was to determine whether placing repair material only in the outer cover, would be sufficient to maintain, or enhance, the desirable properties concrete columns. The following is a list of the conclusions drawn from this study:

1- The ductility of the columns with a silica fume or fibers contain in repair material proved to be more ductile.

2- Placing the repair material at cover through the steel reinforcement into core increased the load capacity compared with cover only.

3- Introducing silica fume or fibers to repair material are more significant to restore the integrity of a repair column at cover only.

4- The use of repair material is an efficient means of providing strengthening of concrete. Using Silica fume or fibers in the repair material at cover through the steel reinforcement into core to increases load capacity by 30 %

5- Placing the grout in the cover only in the cover concrete did not affect to increased or restore the integrity of a repair column.

6- The use of fibers or silica fume in repair material is an efficient means providing ultimate load of repair columns enhancement in eccentric case.

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