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Rehabilitation of Damaged Reinforced Concrete Beams

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Abstract: *The concrete structures are often exposed to damaged as a result of several factors including, environment, design, and other factors, and because of the high cost and long time needed for reconstruction of the damaged buildings, it become necessary to consider techniques for rehabilitation of the damaged structural members in the building.*
12 reinforced concrete beams (2200x200x150 mm) were cast and tested under point load at mid-span to limit the failure. Several techniques for repairing the damaged beams are carried out in the present work. Ferrocement composite, steel plate, fiber carbon reinforced polymer (FCRP), nano cement composite, and the injection of the developed nano cement mortar are considered.
Keywords: *Rehabilitation; Nano; Micro; failure load.*

I. Introduction

Exposed concrete structures to damage, as a result of some natural disasters such as earthquakes or hurricanes, or as a result of exposure to abnormal loads, or something wrong in the design, or a bug in the implementation or a decrease in the area of reinforcement as a result of rust and corrosion with the passage of time, or a change in function and increased loads of service to its members, which did not intervene during the initial design and thus carries origin stresses more than afford it.

In 2010 Bhikshma and et.al(1), presented an investigation to determine the suitability of epoxy resin material type to be used in reinforced concrete beams for repairing and restoring good strength. In their work six beams (150x230x1500mm) for M50 grade of concrete were distressed in flexure due to the application of two point loads by taking 90% of the ultimate load. The distressed beams were then repaired and retested up to ultimate failure load. Three types of epoxy resin materials were considered for repairing. The results of these experiments show that the beams repaired using epoxy resin material (EXPACRETE SNE1) gave higher increase in the ultimate load than other epoxy resin materials. Sivagurunathan and Vidivelli in 2012(2) proposed the application of ferrocement layer for strengthening the predamaged reinforced concrete beams. Eight beams of size 125x250x3200mm were cast and tested for flexure. Six of these beams were loaded to a predetermined damaged level, and strengthened by fastening ferrocement laminates using epoxy resin adhesive and then tested again by conducting flexural test for ultimate load carrying capacity. They concluded that ferrocement can be used as strengthening materials for reinforced concrete beams damaged due to overloading.

The present work associated with the behaviour of rehabilitation the damaged reinforced concrete beams by using several techniques. 12 reinforced concrete beams of size 120 mm width, 200 mm depth and 2200 mm overall length were cast and tested for flexure. The damaged beams were loaded to a failure and then repaired by several teckniques. The repaired beams were again tested for ultimate load carrying capacity by conducting the same flexural test. A comparative study was made between the failure behaviour before and after repairing.

II. Experimental Program

Testing procedure

1. 12 reinforced concrete 150x200x2200 mm beams were constructed. Beams were design to avoid shear failure, in which the beams were reinforced by four bars (12 mm diam.), 2-bars at the top and 2-bars at the bottom of the cross section with 10 mm. diam. at 250 mm c/c stirrups.
2. The beams were loaded until failure and first crack and ultimate loads were recorded.
3. Rehabilitate the damaged beams with several method of repairing.

Materials used in the present work

Cement: Ordinary Portland cement were used throughout the present investigation for casting the reinforced concrete. The chemical composition and physical properties are tabulated in Tables (1) and (2).

Table (1): Chemical composition of the Ordinary Portland cement used during the present investigation.

Compound composition	*Chemical compositio*	*Weight (%)*
Lime	**CaO**	**62.28**
Silica	**SiO2**	**20.82**
Alumina	**Al2O3**	**4.34**
Iron oxide	**Fe2O3**	**4.20**
Magnesia	**MgO**	**3.15**
Sulfate	**SO3**	**2.45**
Loss on ignition	**L.O.I**	**2.33**
Insoluble residue	**I.R**	**1.26**
Lime saturation factor	**L.S.F**	**0.89**

Table (2): Physical properties of the Ordinary Portland cement used during the present investigation.

Physical Properties	*Test Results*	
Fineness (m^2/kg)	**265**	**230 (m^2/kg) lower limit**
Initial (min.)	**110**	**Not less than 45**
Final (min.)	**225**	**Not more than 600**
3 days age (N/mm^2)	**21.5**	**Not less than 15**
7 days age (N/mm^2)	**31.2**	**Not less than 23**

Micro cement: Micro cement were used throughout the present investigation for repairing the damaged beams. The chemical composition and physical properties are tabulated in Tables (3) and (4).

Table (3): Chemical composition of the micro cement used during the present investigation.

Compound composition	*Chemical composition*	*Weight (%)*
Magnesia	**MgO**	**2.1**
Sulfate	**SO3**	**2.35**
Loss on ignition	**L.O.I**	**2.25**
Insoluble residue	**I.R**	**0.8**

Table (4): Physical properties of the micro cement used during the present investigation.

Physical Properties	*Test Results*	
Fineness	**425**	
Initial (min.)	**116**	**Not less than 45**
Final (min.)	**130**	**Not more than 600**
3 days age (N/mm²)	**25.4**	**Not less than 15**
7 days age (N/mm²)	**37**	**Not less than 23**

Fine aggregates (sand): Fine aggregate complies with ASTM C33-01 is used in the present work for casting the reinforced concrete beams. Sieve analysis is given in Table (5).

Table (5): Sieve analysis of the fine aggregate used in the present work.

Sieve size	*Cumulative passing %*	*Limit of ASTM C33-01*
(3⁄8-in.) 9.5-mm	**100**	**100**
(No. 4) 4.75-mm	**92.96**	**95 to 100**
(No. 8) 2.36-mm	**84.33**	**80 to 100**
(No. 16) 1.18-mm	**77.89**	**50 to 85**
(No. 30) 600-µm	**59**	**25 to 60**
(No. 50) 300-µm	**19.83**	**5 to 30**
(No. 100) 150-µm	**4.25**	**0 to 10**

Micro fine aggregates: Micro sand (300-75) µm, complies with ASTM C33 is used for nano materials used for repairing the damaged beams.

Coarse aggregates (gravel): Coarse aggregate complies with ASTM C33-01 is used in the present work for constructing the reinforced concrete beams. Sieve analysis is given in Table (6).

Table (6): Sieve analysis of coarse aggregate used in the present work.

Limit of ASTM c33-01	**Cumulative passing %**	**Sieve size**
(1 in.) 25.0 mm	**100**	**95 to 100**
(1⁄2 in.) 12.5 mm	**73.4**	**50 to 85**
(No. 4) 4.75 mm	**3.3**	**0 to 10**
(No. 8) 2.36 mm	**0**	**0 to 5**

Steel bars: 12 mm and 10 mm dia. bars for flexural and stirrup reinforcement of the beams. The mechanical properties of the bars used are given in Table (7).

Table (7): Mechanical properties of steel bars used in the present work.

Dim. (mm)	*Yield strength (MPa)*	*Ultimate strength (MPa)*
Φ 6 mm	490	582
Φ 10 mm	543	712
Φ 12 mm	547	730

Steel plates: 2 mm steel plates used in the present work and the yield strength and ultimate strength are 528 and 588 MPa respectively.
Wire mesh: Two types of galvanized welded square wire mesh were used in the present work. The mechanical properties of the wire mesh are given in Table (8).

Table (8): Mechanical properties of wire mesh used in the present work

Type of reinforcement	Opening mm	Diameter mm	Yield strength Mpa	Ultimate strength Mpa
Wire mesh (1)	12.7	1	440.7	488.9
Wire mesh (2)	2.5	0.4	320.5	350

Silica fume: Nano particles (500-40 µm) is used Nano silica (500-100) µm, the chemical and mechanical properties of nano silica fume used in the present investigation are given in Tables (9) and (10).

Table (9): Chemical composition of nano silica fume.

Pozzolanic activity	*Limit of ASTM C1240-03*	*Chemical decomposition*		*Limit of ASTM C1240-03*
		Oxides	**Result%**	
121.5%	105%	L.O.I	3.89	6% Max
		SiO_2	91.03	85% Min
		Al_2O_3	4.02	-
		Fe_2O_3	0.32	-
		SO_3	0.73	-

Table (10) mechanical properties of nano silica fume.

Particle size	< 1 Micro meter
Specific gravity	2.2
Surface area	13-30 m^2/gm

Nano metakaoline: By burning pure kaolin with 750 °C for a period of 4 hours. The mechanical and chemical properties of the developed nano metakaoline in the present work are tabulated in Tables (11) and (12).

Table (11): Mechanical properties of the developed nano metakaoline.

Particle size	**< 1 Micro meter**
Specific gravity	**2.2**
Surface area	**13-30 m^2/gm**

Table (12): Chemical composition of the developed nano clay

Chemical composition	Contents %
Silicon dioxide, SiO_2	49.87
Aluminum oxide, $Al2O_3$	32.11
Ferric oxide, Fe_2O_3	8.78
Calcium oxide, CaO	0.34
Titania	١,٤٥
MgO	0.28
K_2O	0.81
Na_2O	0.77
Loss on Ignition	0.66

Steel bolts: Steel bolts number 4.8 with size 17 are used in fixing sections for repairing the damaged part of the beams. The ultimate shear strength was found to be 17.3 kN.
Carbon fiber reinforced polymer (CFRP): Carbon fiber type (Sika Warp Hex-230c) was used in the present work for strengthening the reinforced concrete beams. Table (13) gives the physical properties of the carbon fibers[5].

Table (13): Physical properties of the carbon fibers Sika Warp Hex-230c.

1	Fiber type	High strength carbon fibers
2	Fiber orientation	0^0 (unidirectional)
3	Construction	Warp: Carbon fibers(99% of total a real weight) Weft: Thermoplastic heat-set fiber(1% of total a real weight
4	A real weight	225 gm/cm^2
5	Fiber density	1780 kg/m^3
6	Fiber design thickness	0.13 mm (Based on total area of carbon fiber)
7	Tensile strength	3500 N/mm^2
8	Tensile -E-modulus	230,000 N/mm^2
9	Elongation at break	1.5%
10	Fabric length / roll	≥ 45.7 m
11	Fabric width	305/610 mm
12	Shelf life	Unlimited
13	Package	1 roll in card board box

The mechanical properties of the carbon fibers used in the present study are tabulated in Table (14).

Table (14): Mechanical properties of carbon fiber used in the present study.

Notes	*Yield strength (MPa)*	*Ultimate strength (MPa)*
Without epoxy	**806**	**849**
With epoxy	**969**	**1095**

Binder materials: Epoxy binder type (SikaDure-330) was used. The Epoxy is a medium viscosity and consists of two parts; A resin and it is white in color and B as hardner and it is grey in color. Mixing ratio considered in the present investigation was (1:4). The physical properties of the binder are tabulated in Table (15).

Table (15): Physical properties of the epoxy binder used in the present work.

Density	1.31 Kg/L mixed (Comp. A+B)
Mixing ratio (A:B) by weight	1:4
Pot life	+15°C :90 min. +35°C :35 min.
Open time	+35°C :30 min.
Viscosity	Pasty, not flow able.
Application temperature	Substrate and ambient temperature: +15°C to +35°C
Adhesive tensile strength on concrete	Concrete fracture after 1 day (>15°C), on sandblasted substrate
Tensile strength	(Curing 7 day, +23°C)= 30 N/mm^2
Flexural-E-Modulus	(Curing 7 day, +23°C) = 3800 N/mm^2

Fumed silica: The properties of nano fumed silica are given in Table (16).

Table (16) Properties of fumed silica used during the injection of the cracks.

Parameter	*Specification*
Specific surface , m2/gr	200, (160-240)
Ph-value	3.7-4.7
Loss on drying, %	3

Super plasticizers: The super plasticizer used is Sikament®FFN and complies with ASTM C494. The specifications are given in Table (17).

Table (17): Specifications of the super plasticizer used in the present work.

Main Action	*Concrete Super plasticizer*
Form	Viscous Liquid
Color	Brown homogenous liquid
Relative Density	1.20 – 1.24 kg/l, at 20°C
pH value	6.42
Freezing point	-5°C
Total Chloride Ion Content	Max. 0.1%, Chloride-free
Equivalent Sodium Oxide as % Na2O	Max. % 7

Water: Tap water was used in mixing and curing all concrete and cement mortar mixture considered in this study.

Mixing design and procedure

All tested beams were cast with mixing ratio of cement/ fine aggregate/ coarse aggregate 1:1.5:3 respectively by weight with water/ cement ratio of 0.4. It was designed to achieve a concrete cube compressive strength of 32 N/ mm^2 at 28 curing days according to B.S. 116:1989. The mixing of concrete was carried out in a rotary pan type mixer of 0.1 m^3 capacity. In all mixes of concrete, the aggregate and cement were first mixed dry for about 60 seconds and for further 120 seconds after the addition of water. Steel moulds with inner dimensions 150x200x2200 mm as shown in photo (1) were prepared for casting all the beams.

After the steel moulds were cleaned and lightly oiled, the previously prepared steel reinforcement was placed inside the mould and justifies the concrete cover by multi spacers. Then the concrete was poured and vibrated, the top surface was then smoothed and covered with polythene sheets. After 24 hours the mould and control specimens were demolded and cured for 28 days. With each beam three 150 mm cubes for compressive strength (*fcu*) were cast to determine the compressive strength of the hardened concrete.

Photo (1) Steel moulds for casting the all reinforced concrete beams.

Testing program

The beams were tested up to failure load in a Universal Testing Machine under point loading at mid-span. As it was mentioned earlier, all beams were design for flexural failure, in which 4-12 mm diam. bars (2-bars at the top and 2-bars at the bottom) as the reinforcement with 10mm bar dia. At 250mm c/c as stirrups were considered as shown in the Figure (2) and Photo (2).

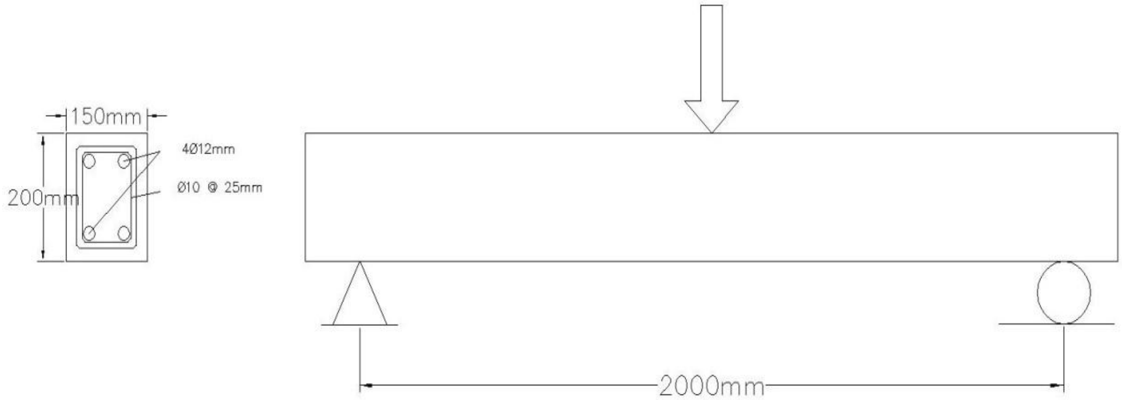

Figure (2) Dimensions and detailing reinforcement of the beams considered in the present investigation.

Photo (2) Beam under the test.

Techniques used for repairing:

The collapsed beams removed from the testing machine and loose debris were first removed. Then water was sprinkled on the crushed part of the beams to remove the loss particles. Then cement mortar with ratio of 1:1 as cement/ sand passing sieve 2.36 mm is used with water/ cement ratio = 0.4 for plastering the crushed parts of the tested beams as shown in photo (3).

Photo (3) View of the crushed part of the beam after flexural testing.

The 12 preloaded the damaged reinforced concrete beams were rehabilited as follows:

(a) Rehabilitation of the damaged part of the tested beam using ferrocement composite technique. Three U ferrocement cross section as shown in Fig. (4) were cast with length of 700 mm and mixing ratio of the cement mortar (cement: sand = 1:1) and water :cement ratio = 0.4 prior to fixing the sections to the damaged part of the beams. Fig. (5) and photo (4) show the methods of fixing the elements.

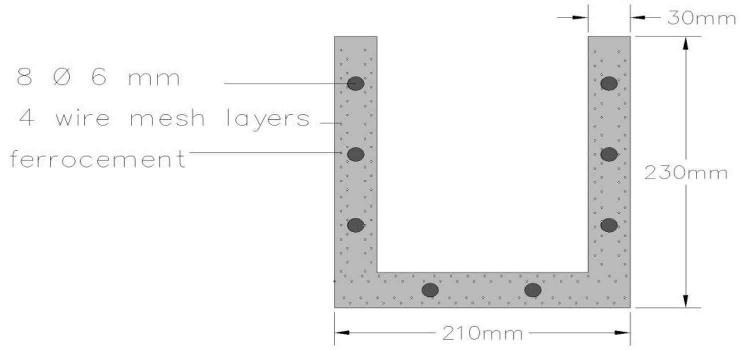

Fig. (4) Details of ferrocement cross section.

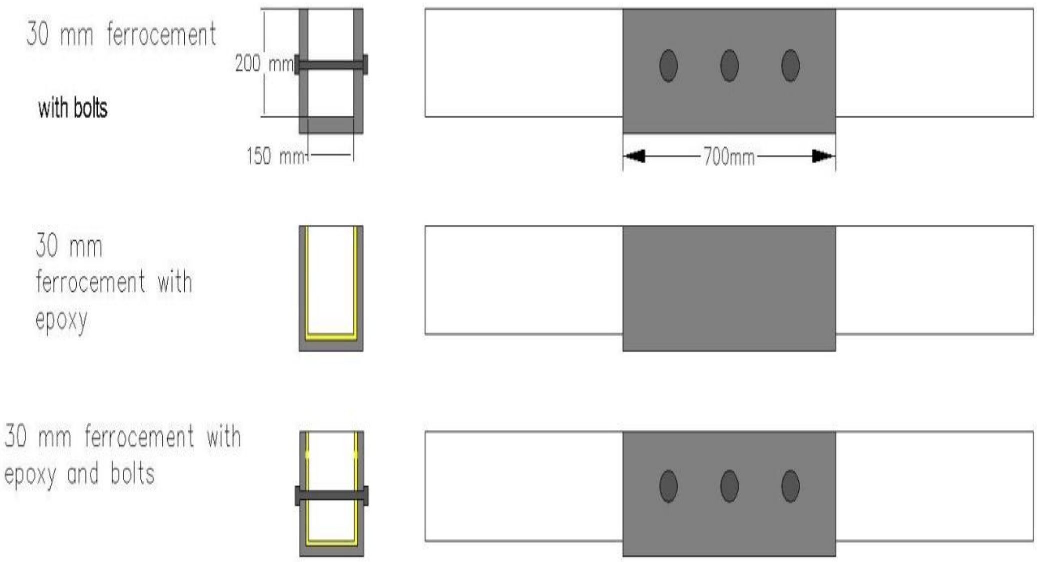

Fig. (5) Methods of fixing U ferrocement element.

Photo (4) Methods of casting and fixing the ferrocement sections.

(b) Rehabilitation of the damaged part of the tested beams using steel section technique. Fig. (6) shows the methods of fixing the elements.

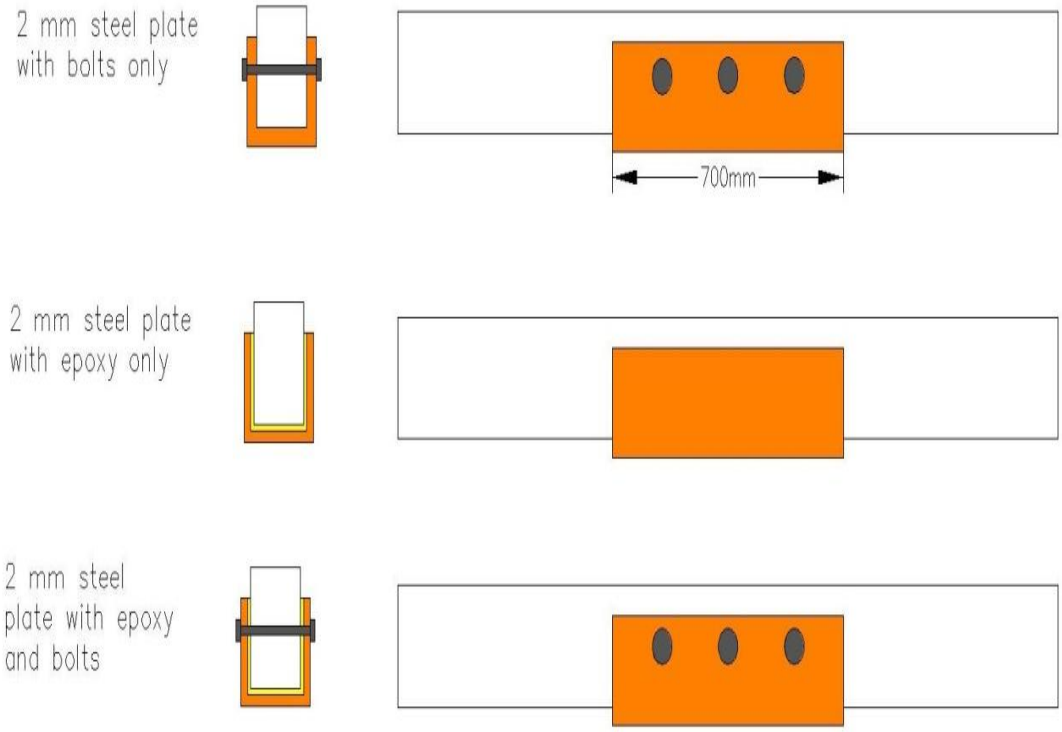

Fig. (6) Methods of fixing steel element.

(c) Rehabilitation of the damaged part of the tested beams using carbon fiber technique. Fig. (7) and photo (5) show the methods of fixing the element.

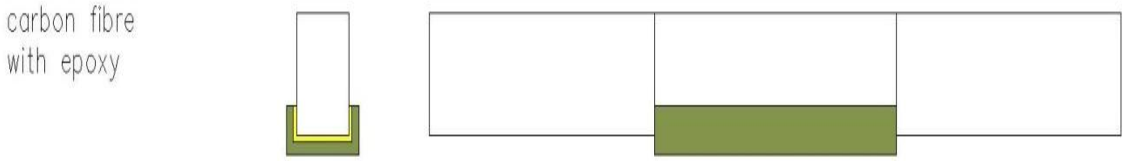

Fig. (7) Method of fixing carbon fiber layers.

Photo (5) Method of rehabilitate the damaged beam using carbon fiber.

(d) Rehabilitation of the damaged part of the tested beam by U section cast by the developed nano ferrocement, see Fig. (8) and photo (6).

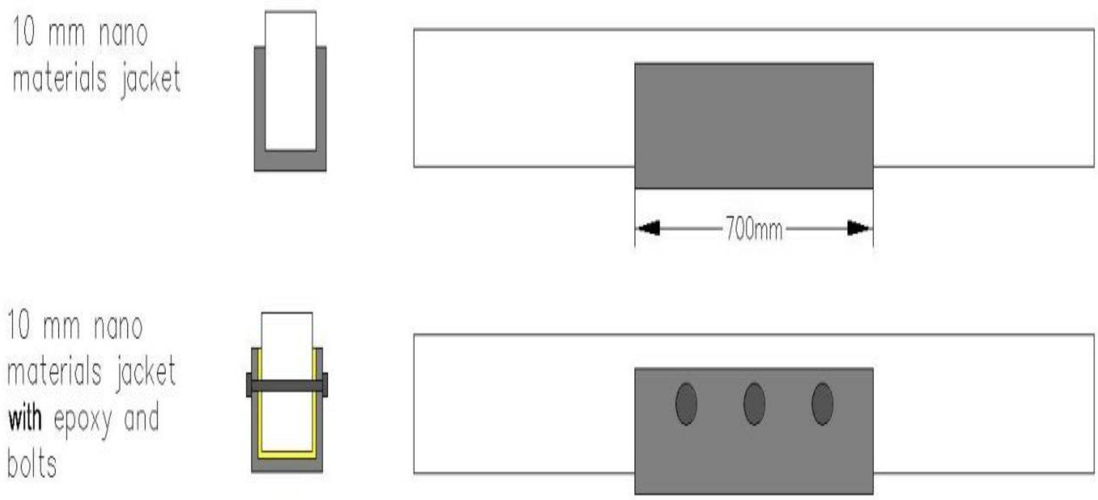

Fig. (8) methods of fixing sections made from the developed nano ferrocement.

Photo (6) Casting and fixing the developed nano ferrocement section.

(e) Rehabilitation of the damaged part of the tested beams using injection technique by nano materials.
Cracks of the damaged beam were injected as shown in photo (7), by the following mixture.

1. 60% of micro cement.
2. 40% of nano fumed silica.
3. Super plasticizers (2% x weight of cement).
4. w/c ratio = 0.4.

Photo (7) Beam during repairing using the injection technique.

Instrumentations:

1. Ultimate loads were measured using Universal Testing Machine with a capacity of 1000 kN.
2. Compressive strength of concrete cubes was tested using compression machine Wekob.
3. Ultra-sonic, type (V-Meter MK IV) to measure the compressive strength of the tested beams.

Test results and discussions:
The test results are summarized in Table (18). It shows the comparative representation of all the twelve beams distressed by ultimate load Pu and rehabilitated.

1. The technique of using bolts in fixing the new elements for rehabilitation of the damaged part of the loaded beams showing excellent results, in which the ratios of ultimate load after rehabilitation/ actual ultimate load of ferrocement and steel jackets are 105% and 100.8% respectively.
2. It may be seen that using epoxy for fixing the ferrocement or steel section for rehabilitation is less efficient than using epoxy for fixing carbon polymer fibers, in which the ratios of original ultimate load/ultimate load after rehabilitation are 87% and 87.4% using epoxy for fixing ferrocement and steel sections respectively. While ratio reach 100% when using epoxy for fixing carbon polymer fibers.
3. But, the ratio reaches 100% of the original beams using ferrocement or steel jacket when using epoxy and bolts together.
4. The ultimate load of beam after rehabilitation is 99% of the original ultimate load when using nano ferrocement jacket for rehabilitation.
5. Using nano materials injection technique tend to reach the ultimate load for beam after rehabilitation to 80% of the original loads. But this technique was tested for tested span of 2 m. Further study need to be conducted for further spans.
6. It may be noted that Ultra-Sonic tests were carried out to measure the value of compression strength of concrete before flexural testing to failure and after repairing using injection technique by the developed nano/ micro materials. It was found that concrete was recovered its compressive strength after repairing by about 61%.

During uploading the pre-damaged rehabilitated beams, it was observed that cracks were occurred and number of cracks were increased by increasing the loads even in the injected cracks and the first flexural cracking strength were recorded as 62.99, 57.27, and 50% of the first cracking strength before rehabilitation respectively. Also, the ultimate flexural strengths were recorded as 85.87, 85.09, and 82.77% in comparison with ultimate flexural strength before rehabilitations respectively.

Table (18): The measured values of first crack and ultimate loads of the tested beams with nano cement mortar injection for rehabilitation.

Method of rehabilitation		Compressive strength of concrete, *fcu., MPa*		First cracking load *(Fcr, kN)*	First cracking load *(Fcr., kN)* after repairing.	Ultimate load *(Fult., kN)*	Ultimate load *(Fult., kN)* after repairing.
		Concrete	Cement mortar/ or nano materials				
a	U-Ferr. sec. with bolts	30	33.87	12.7	13	42.7	45.1
	U-Ferr. sec. with epoxy	33	32.9	14	11.5	45.6	39.7
	U-Ferr. sec. with bolts and epoxy	34	33.9	13	12.5	50	54
b	U-Steel sec. with bolts	35	-	11	10	47.1	47.5
	U-Steel sec. with epoxy	35.6	-	12	9.8	50	43.7
	U-Steel sec. with bolts and epoxy	31.5	-	15.6	16	51	51
c	Carbon fiber	35.4	-	13.7	11	47.6	48
d	U-Nano materials.	36	36.6	13	14.7	50.5	50
	U-Nano materials. with bolts and epoxy	36.2	37.2	11	10	52	53.5
e	Injection by nano materials	-	33.1	12.7	8	44.6	38.3
		-	35	11	6.3	53	45.1
		-	29	13	6.5	56.9	47.1

III. Conclusions

Using different techniques for rehabilitation of the damaged beams in buildings are illustrated in the present investigation.

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