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Strengthening of R.C. Beams Using Different Techniques

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Abstract: *Experimental program consisting of five reinforced concrete beams with dimensions 2200 mm length, 150 mm width, 200 mm depth and reinforced by* 2ϕ 16 bottom RFT, 2ϕ12 upper RFT and 5ϕ8/m stirrups, *were carried out to investigate the flexure behavior of strengthened R.C. beams using four different techniques. A four strengthening techniques were proposed, the first technique is using 5 cm Ferrocement U-Wrapped from three sides, the second technique using 5cm polypropylene fibers U-Wrapped from three sides, the third technique using one layer U-Wrapped of glass fiber reinforced polymers fixed with bolts, while fourth technique using four layer U-Wrapped of glass fiber reinforced polymers fixed with bolts. Experimental results used to compare between the different strengthening techniques in terms of enhancement of load capacity, first crack load, maximum deflection, Gain in Ductility, Energy Absorption and cost per 1% increase in load capacity. The results indicate that the strengthening of R.C. beam using four layers of glass fiber reinforced polymers fixed with bolts is the best technique to enhancement the flexure behavior with lowest cost, the strengthening of R.C. beam using 5 cm Ferrocement and using polypropylene fibers gives good behavior against flexure with medium cost and the strengthening of R.C. beam using one layers of glass fiber reinforced polymers fixed with bolts the worst technique of strengthening R.C. beams as there is no improvement in the beam behavior.*
Keywords: *strengthening of R.C. beams, Ferrocement, glass fiber reinforced polymers sheets, polypropylene fiber.*

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I. Introduction

The strengthening of structures has been accepted as a good method to improve the load carrying capacity of structures. Strengthening may be needed due to change the function of the structure, change of codes Requirements and/or error during design or construction etc. The selection of strengthening technique depends on one or more of the following criteria: availability of materials used, equipment, construction, qualified contractors, life cycle costs, increase of dimensions, percentage of strength increase, etc.

1.1 Problem description

There are different techniques that can be used for strengthening flexural behavior of R.C. beams, and there are one or more factors affecting the choices of the suitable technique this factors include coast of strengthening, increase of dimensions, availability of materials used and percentage of enhancement of load capacity. The paper investigates four techniques used to strengthening R.C. Beams and concludes the best technique which enhancement the load capacity, deflection, ductility, toughness and which have a suitable coast according to the percentage of strengthening.

1.1.1 Strengthening using Ferrocement technique

Ferrocement is one of the recently developing strengthening materials for concrete structures. ACI Committee [13] in a state of the art report on Ferrocement define ferrocement as “Ferrocement is a type of thin wall reinforced concrete (RC) commonly constructed by hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh” . Ferrocement as a strengthening material can be pretty useful because it can be applied quickly to the surface of the element without the requirement of any special bonding material and also it requires less skilled labor, as compared to other strengthening solutions presently existing. The Ferrocement construction has an edge over the conventional reinforced concrete material because of its lighter weight, ease of construction, low self weight, thinner section as compared to RC & a high tensile strength which makes it a favorable material for prefabrication also. In the present practical research RC beam is initially strengthened using Ferrocement to increase the strength of beams in both shear and flexure. Korany et al [12] used ferrocement laminates technique for repairing reinforced concrete beams. Twenty seven reinforced concrete beams were tested over simply supported one meter span. It was concluded that better cracking for all test specimens could be achieved compared to their original behavior. Also, increase of load capacity for strengthened beams. The ductility ratio and energy absorption properties were also improved by the proposed technique of repair.

1.1.2 Strengthening using polypropylene fibers

Polypropylene fiber has been improved in used as short discontinuous fibrillated material for production of fiber reinforced concrete. The application of the Polypropylene fibers in construction increased largely because addition of fibers in concrete improves the flexural strength, tensile strength, toughness and failure mode of concrete. The first used of Polypropylene fibers was in 1956 as an admixture in concrete for construction of basalt resistant buildings in USA. Polypropylene fiber has many advantages like fire resistance, chemical attack resistance. N.Vimal and N.S.Madhu [1] investigate conducted on the use of polypropylene fibre of length 12mm having an aspect ratio of around 500.It was employed in equal percentages of 0.5 percentages by weight of cast concrete. From the results it concluded that addition of polypropylene fibers increase the flexural strength of concrete and controlled the cracks.

1.1.3 Strengthening using Glass fiber reinforced polymer sheets

Glass fiber reinforced polymer sheets (GFRP) is a composite material or fiber-reinforced plastic made of a plastic reinforced by fine glass fibers like graphite-reinforced plastic, the composite material is commonly referred to as fiberglass , glass can be in the form of a chopped strand mat (CSM) or a woven fabric. Many researches proposed an enhanced retrofitting technique using anchors to avoid the slipping between glass and RC beam and also show the effect of increasing the number of layers of GFRP. The advantage of glass fiber reinforced polymer sheets (GFRP) easily to mold into any shape has mechanical strength that is so strong and stiff for its weight that it can out-perform most of the other materials, low maintenance, and anti-magnetic, fire resistant, good electrical insulator and weatherproof. Many experimental works concluded three layers of GFRP equivalent to one layer of CFRP and the minimum layers of GFRP to use in strengthening R.C. beams in flexure not less than two or three layers. Rohit Vasudeva, Mandeep Kaur [2] checks flexure and shear behavior of Reinforced concrete beams strengthened with glass fiber reinforced polymer. The experimental investigation concluded that there was increase in load at initial crack and ultimate failure for strengthened beams as compare to control beams. Failure in case of set a retrofitted beams was flexural shear failure. Strengthening in shear zones was observed most effective in case of ultimate, flexural failure and shear failure. Yeol Choi, Ik Hyun Park, Sang Goo Kang and Chang-Geun Cho [4] use four different strengthening configurations of GFRP composite beam to Strengthening of RC Slabs with Symmetric Openings. The first slab without GFRP strengthening served as the control slab. The other three slabs were strengthened with GFRP composite beams in diagonal, parallel and surround at the near openings respectively. From the experimental results it can be concluded that the investigated strengthening types can be used for strengthening or upgrades of structural capacity of existing RC slabs with openings, since all strengthened slabs seem to raise the load-carrying capacity approximately by an average of 20%. Also, diagonally-strengthened slab showed to be one of the most effective ways for load-carrying capacity, stiffness and crack patterns. It was also observed that the slab strengthened with GFRP composite beams failed by flexure due to the intermediate cracks and debonding of GFRP composite beam with a wide-open crack.

II. Strengthening Solutions

The paper presents three strengthening solutions. One beam strengthened by 5cm from three sides U-Wrapped using ferrocement this beam named (FE-C-B), second beam strengthened by 5cm from three sides U-Wrapped using polypropylene fibers this beam named (P-B), third beam strengthened by one layer U-Wrapped of glass fiber reinforced polymers fixed with bolts (G1-B) while fourth beam strengthened by four layer U-Wrapped of glass fiber reinforced polymers fixed with bolts and named (G2-B).

2.1 The beam (FE-C-B)

In this case, the strengthening method include roughing R.C. Beam surface, implanting shear connectors in the R.C. Beam using epoxy grout (Kemapoxy 165) then fabric the expanded galvanized metal steel mesh of thickness = 2.5 mm, spacing 15mm *40mm and angle of inclination =30°. Ultimate tensile force (Fu) of mesh =6048kg/cm2 and yield tensile force (Fy) of mesh =2363kg/cm2 and fixing using tie wire in the shear connectors in three sides of the R.C. Beam and finally casting the 5 cm strengthening concrete, this procedure illustrated in "Fig.1" .

2.2 The beam (P-B)

In this case, the strengthening method include roughing R.C. Beam surface, implanting shear connectors in the R.C. Beam using epoxy grout (Kemapoxy 165) then casting the 5 cm strengthening new concrete mix of polypropylene fiber, this procedure illustrated in "Fig.2".

2.3 The beam (G1-B and G2-B)

In this case, the strengthening method include roughing R.C. Beam surface, Fabric one or four layers of glass fiber polymers sheets using POLYPLEX 4202 P polyester resin to connect glass fiber sheets with R.C. Beam then use Akmon Anchor to fixing glass fiber polymers layers sheets to R.C. Beam, this procedure illustrated in Figure "Fig.3".



a) Surface Roughing process

b) Positioning of the shear connector and drilling



c) Using air compressor to remove dust and fines

d) Mixing of the epoxy grout used in implanting shear connector

e) (FE-C-B) After implanting shear connectors


f) fabric the expanded steel mesh and fixing using tie wire

g) (FE-C- B) Beam ready for casting the 5 cm strengthening concrete

Figure (1) Illustrate Strengthening of R.C. Beam using ferrocement procedure (FE-C-B)

a) Surface Roughing process

b) Drilling shear connector

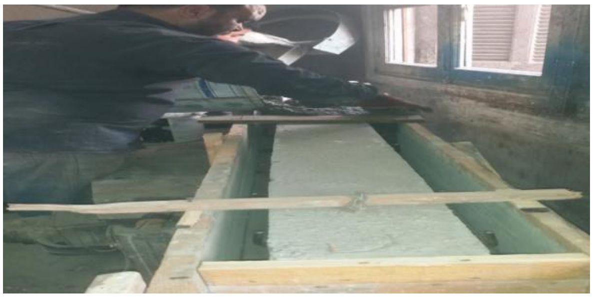
c) Using air compressor to remove dust and fines

d) Mixing of the epoxy grout and implanting shear connector

e) (P-B) After implanting shear connectors

f) Polypropylene fibers used in strengthening mix.

g) Mixing new concrete mix of polypropylene fiber



h) Casting new concrete mix of polypropylene fiber

Figure (2) Illustrate Strengthening of R.C. Beam using polypropylene fibers procedure (P-B)

a) Surface Roughing process

b) Glass fiber polymers sheets used in Strengthening

c) Akmon anchor used for fixing glass fiber sheets to R.C. Beam

d) Fabric glass fiber polymers sheets

e) POLYPLEX 4202 P polyester resin used to connect glass fiber sheets with R.C. Beam

f) Strengthening with one layer of glass fiber polymers sheets

g) Strengthening with four layer of glass fiber polymers sheets

h) Akmon Anchor fixing glass fiber polymers sheets to R.C. Beam

Figure (3) Illustrate Strengthening of R.C. Beam using one or four layer of glass fiber polymers sheets (G1-B and G2-B)

III. Experimental work

3.1 Introduction

Effect of strengthening 2200*150*200 mm beam R.C beam using the 5 cm Ferrocement U- Wrapping, 5 cm polypropylene fibers, one layer of glass fiber polymers sheets and four layers of glass fiber polymers sheets were discussed in form of comparisons between different parameters such as crack pattern, ultimate deflection, ultimate failure load, ductility, toughness (Energy absorption) and coast per 1% of load capacity enhancement. The two point loading pattern is used to achieve the pure bending. The external bonding for strengthened beams made for the full length of the beam and it covers three faces of it (U wrapping).

3.2 Experimental work schedule

The schedule was planned to allow enough time for curing and be sure that the concrete will gain 100% of its designed strength. 7 continuous days of curing were made using water and burlap.

Age of the Control beam (C-B) , strengthened beam with Ferrocement (FE-C-B), strengthened beam with polypropylene fibers (P-B), strengthened beam with one layer of glass fiber polymers sheets and strengthened beam with four layer of glass fiber polymers sheets at the test are 28 days. Table (1) summarized experimental work schedule.

3.3 Test Setup and procedure:

The beam specimen is setup as shown in the Fig. (4). Loading jack is kept in position and its loading end is connected with the beam using the frame. The instruments are then mounted. The initial readings in the dial gauges are noted. The beam is then loaded to check the effectiveness of test setup. Dial gauge readings are recorded for each stage. The process is repeated till the initial and final readings in the dial gauges are identical. The beam is then subjected to loading through the predetermined loading stages. Dial gauge readings are taken for all stages. Crakes formed on all the faces of the beams are marked and identified.

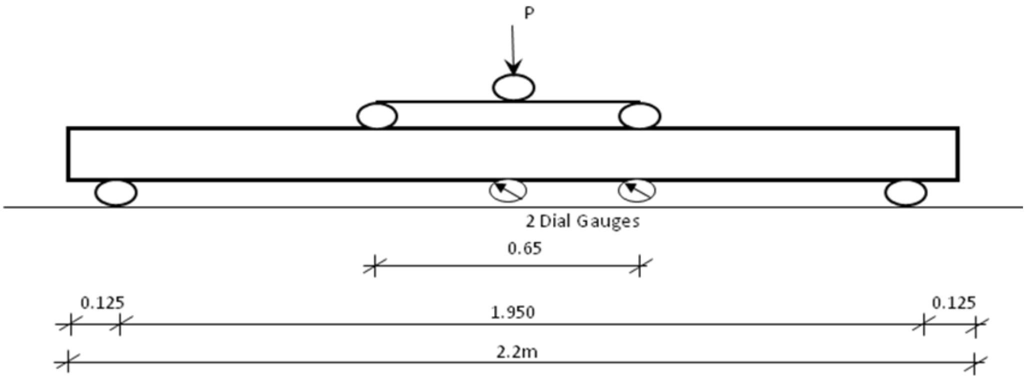


Figure 4 Test Setup

Table 1 Experimental work schedule

Item No.	Item Description	Duration (days)	Date
1	Casting control beam and four strengthened beams.	1	
2	removal of formwork for all five beams	1	
3	Curing process	7	
4	Surface preparation and implanting shear connectors for (FE-C-B) and (P-B)	1	
5	fabric the expanded steel mesh and fixing using tie wire for (FE-C-B)	1	
6	Casting the 5 cm concrete for (FE-C-B) and polypropylene fiber concrete mix for (P-B)	*1*	
7	Curing process for (FE-C-B) and (P-B)	7	
8	Fabric one layer of glass fiber polymers sheets for (G1-B) and four layer for (G2-B) and fixing the layers to the R.C. beam using POLYPLEX 4202 P polyester resin and Akmon Anchors	1	
9	Testing control beam after 28 day from casting	1	
10	Testing (FE-C-B) after 28 day from Strengthening	1	
11	Testing both (G1-B) and (G2-B) after 28 day from Strengthening	1	

IV. Results and Discussion

The results of experimental work for testing the five beams are recorded and summarized in table 2 and figures from 5 to 18 as shown. A cost-per 1 % enhancement of load capacity study was done to investigate the cost of all the techniques used in this study and the results of the investigation summarized in Table 3 and Figure 19. The experimental results indicated that the strengthening using ferrocement increase load capacity by 23 %, enhancement crack pattern, increase first crack load by 50 %, increase gain in ductility by 19.7 % increase in energy absorption by 64 %, the failure occur due to pure flexure tensile failure and the cost of increasing load capacity by 1% equal 47.43 units. The strengthening using polypropylene fibers increase load capacity by 11.5 %, enhancement crack pattern, increase first crack load by 90 %, increase gain in ductility by 36.48 %, increase in energy absorption by 77.5 %, the failure occur due to pure flexure tensile failure and the cost of increasing load capacity by 1% equal 102.7 units. The strengthening using one layers of glass fiber reinforced polymers fixed with bolts did not made any change of R.C beam behavior while the strengthening using four layers increase load capacity by 38.4 %, enhancement crack pattern, increase gain in ductility by 96.6 % increase in energy absorption by 227 %, the failure occur due to debonding of GFRP layers and the cost of increasing load capacity by 1% equal 44.27 units.

Table 2 Results Summary

Beam	First Crack		Ultimate		Gain in Ductility	Energy Absorption (kN-mm)
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)		
C-B	20	1.99	52	8.66	Control	251.5
FE-C-b	30	3.28	64	10.367	19.7%	412
PB	38	5.27	58	11.82	36.48 %	446
G1-B	21	Initial rupture of GFRP	52	8.7	0.46 %	256.4
G2-B	50		72	17.03	96.6%	824

Table 3 Cost Comparison of different strengthening techniques

ITEM #	Manpower Cost	Material Cost	Equipment Cost	Total Cost	Enhancement of Load Capacity
FE-C- B	600	329.9	161.55	1091.45	23 %
P-B	600	420	161.55	1181.55	11.5 %
G1-B	600	150	50	800	0%
G2-B	1050	600	50	1700	38.4 %

Figure 5 Control beam (C-B) Flexure failure

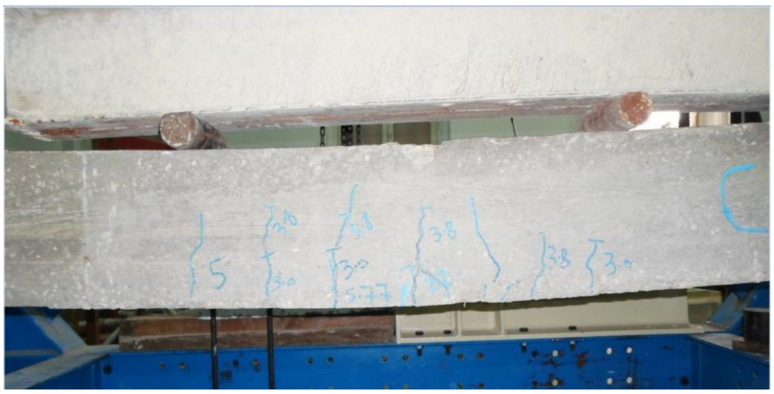


Figure 6 Control beam (C-B) cracks Pattern

Figure 7 Strengthened beam (FE-C) Flexure failure

Figure 8 Strengthened beam (FE-C-B) cracks Pattern

Figure 9 Strengthened beam (P-B)Flexure failure

Figure 10 Strengthened beam (P-B) Cracks Pattern

Figure 11 Strengthened beam (G-B)Flexure failure

Figure 12 Rupture of GFRP sheet

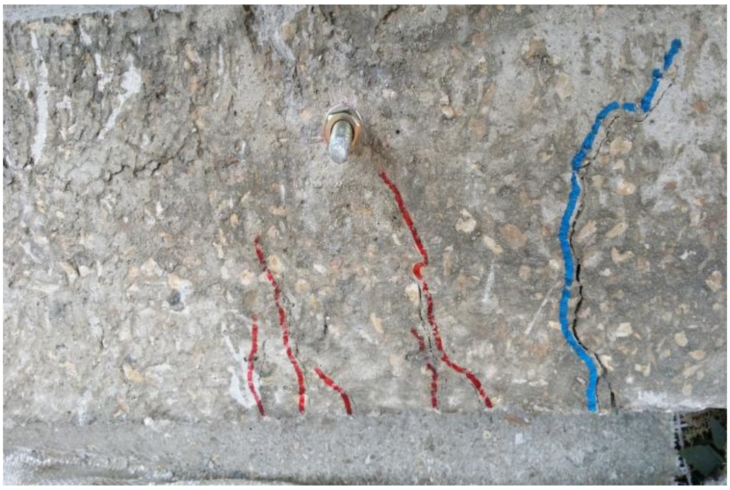


Figure 13 Cracks pattern for strengthened beams after removal of GFRP sheets G1-B

Figure 14 Cracks pattern for strengthened beams after removal of GFRP sheets G2-B

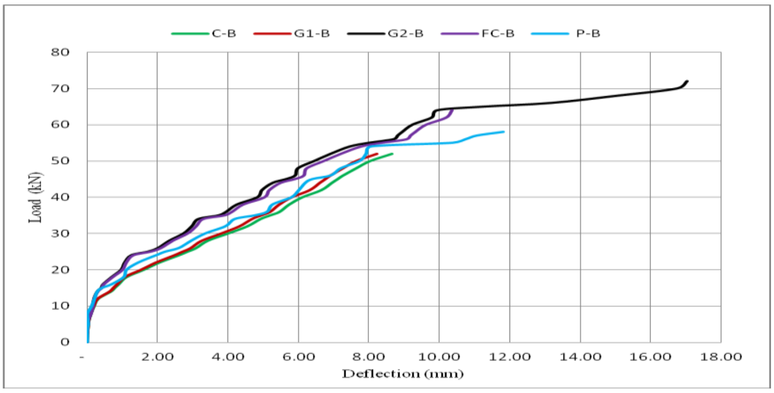


Figure 15 Enhancement of Load Deflection with different strengthening Method of RC beam

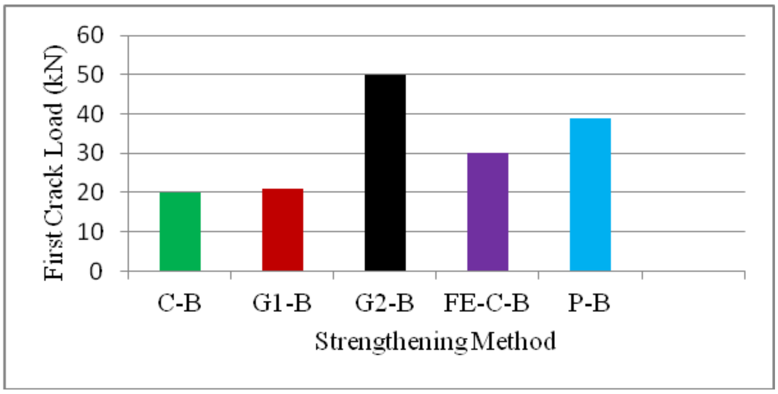


Figure 16 Enhancement of Initial Crack Load with different strengthened methods of RC beam

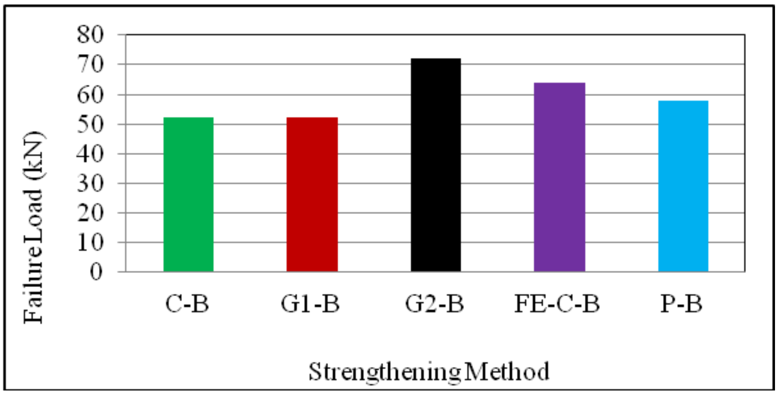


Figure 17 Enhancement of Failure Load with different strengthened methods of RC beam.

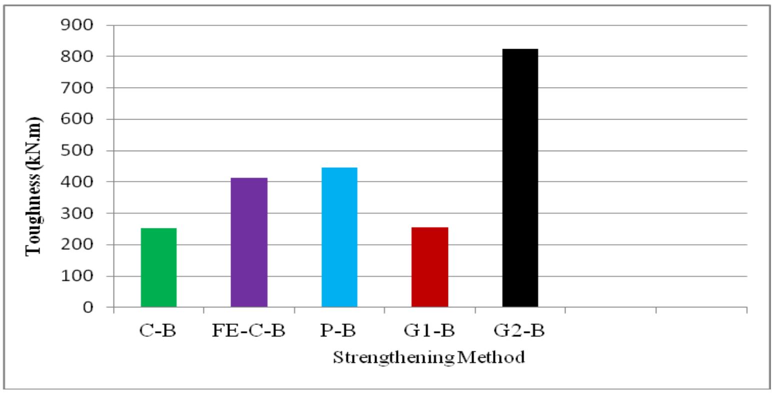


Figure 18 Enhancement of Toughness with different strengthened methods of RC beam.

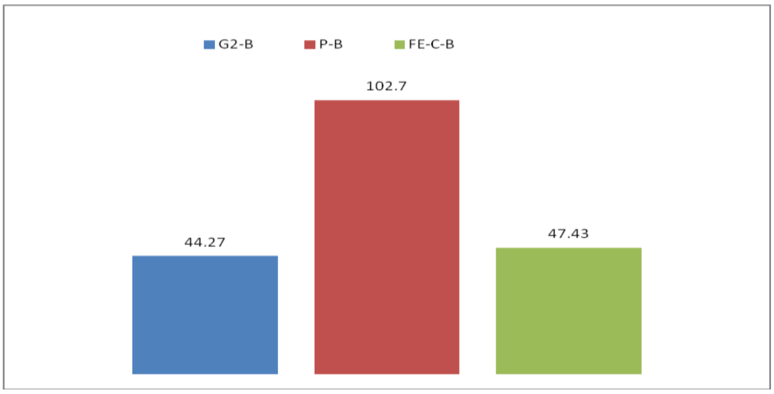


Figure 19 Unit cost for each one % increase in load capacity.

V. Summary and Conclusions

This paper presents five beams with dimensions 2200x150x200 mm, 2ϕ 16 bottom RFT, 2ϕ12 upper RFT and 5ϕ8/m stirrups casted, first beam used as control beam and the other four beams strengthened using different techniques. One beam strengthened using ferrocement technique; one beam strengthened using polypropylene fibers while the other two beams strengthened using one and four layers of glass fiber reinforced polymers fixed with bolts.

Techniques used in this study enhance the flexural behaviour and crack patterns. The most suitable technique according to increase load capacity and cost is the strengthening using four layers of glass fiber reinforced polymers fixed with bolts while the worst one is the strengthening using one layers of glass fiber reinforced polymers fixed with bolts as no change in flexural behavior which confirms the previous r researches.

The Strengthened beam showed a decrease in cracks width, significant change in ductility ratio, decrease in deflection compared with control beam and considerable increase in energy absorption which leads to that techniques used in this study useful for application in components subjected to dynamic loads

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