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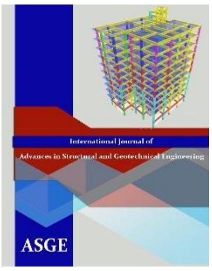

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STRENGTHENING OF CONTINUOUS LOW STRENGTH RC U-SHAPED BEAMS USING DIFFERENT TECHNIQUES

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ABSTRACT
In this paper, different strengthening techniques have been implemented in order to enhance both flexural and shear strengths at the intermediate support of continuous RC beams made of low strength concrete. Four two-equal span continuous RC beams made of concrete strength of target cube strength of about 18 MPa have been prepared and cast of u-shaped cross-sections. One beam was control un-strengthened beam, while the remaining beams were strengthened using three different techniques; namely, Externally Bonded Carbon Fiber Reinforced Polymer (EB-CFRP) sheets, external thin layer of Engineered Cementitious Composites (ECC) material and externally bonded steel plates. All strengthening materials were applied at the intermediate support and extended between the mid-span points at both sides. All beams have the same concrete dimensions and internal reinforcement detailing. The overall cross-sectional dimensions were 600mm width by 330mm total depth and 2100mm center-to-center span. For the mid-span sections and away from the supporting points, the cross section was u-shaped of 80mm flange thickness and 100mm web thickness. The experimental test results showed that all strengthened beams showed increased sustain loads by about 94%, 103% and 123% respectively, for strengthened beams by EB-CFRP sheets, ECC material and steel plates compared to that of the un-strengthened beam. Thus, the strengthening technique based on steel plates exhibited the outermost ultimate capacity. On the other hand, the strengthening technique based on ECC material enabled the strengthened beam to show about 96% of the ductility index for un-strengthened beam.

Keywords: Low strength concrete, Continuous beams, U-shaped cross-section, Strengthening, Carbon Fiber Reinforced Polymer (CFRP), Engineered Cementitious Composites (ECC), Steel plate.

INTRODUCTION
Reinforced concrete structures could be produced with low strength concrete owing to different reasons such as poor quality control and design error in the mix proportions. Besides, using poor material such as improper aggregate and poor quality cement are considered as the most significant reasons for reducing the hardened strength of concrete. Therefore, the constructed structures will have lower resisting strength compared to the design strength. However, most of these structures do not fail due to the considered safety factors in the design. On the other hand, catastrophic collapse could be produced due to unconsidered case of loading. Different post-earthquake reconnaissance reports from different countries revealed the irresponsible use of poor materials, bad design and inappropriate construction practices are the reasons of collapsed structures [1, 2]. Accordingly, those structures constructed by low strength concrete are in urgent need of strengthening in order to increase their resistance as well as to save lives.

Currently, various strengthening techniques have been developed and widely used in order to strengthen reinforced concrete structures. The most common techniques include section enlargement using either added jacket or cementitious composite material such as Engineered Cementitious Composties (ECC) or Ultra-High- Performance Strain-Hardening Cementitious Composite (UHP-SHCC) material [3-18], external plate bonding using either steel plates or fiber reinforced polymers (FRP) sheets or laminates [19-28], and external posttensioning techniques. Nevertheless, proper bonding agent and/or shear dowels should be used to achieve a full composite action between the existing substrate structure and the new overlay.

Obviously, each one of strengthening techniques comes up with some benefits and shortcomings. For example, section enlargement technique provides significant additional permanent load to the structure. The external steel plate bonding technique is susceptible to corrosion damage that may impair the strengthened structure, thus lead to complete failure of the structure. Inspite the higher tensile strength and the non-corrosive characteristics of the externally bonded CFRP laminates, it is expensive and needs more precautions to anchorage their ends as well as they cannot sustain high temperature.

The main objective of the current study is to verify the adequacy of different strengthening techniques including ECC overlay, externally bonded CFRP sheets and external steel plates aiming to identify the most efficient one in increasing the ultimate capacity of at the negative moment zone of continuous U-shaped RC beams made of low strength concrete.

EXPERIMENTAL WORK PROGRAM

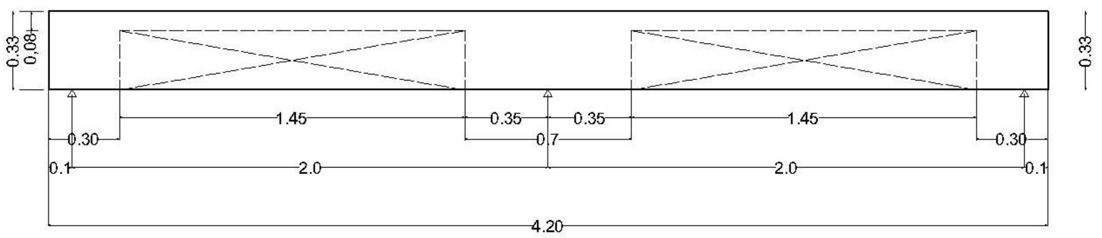
Test Specimens

The experimental program consisted of four continuous beams divided into two groups. The first group contained only one control un-strengthened beam, while the second group consisted of three strengthened continuous beam using three different techniques as summarized in Table 1.

Table 1 Description of test specimens

Group No.	Specimen	Description
1	BC	Control beam (un-strengthened)
2	B–CFRP	Strengthened beam using CFRP sheets
	B–ECC	Strengthened beam using ECC layer
	B–ST	Strengthened beam using steel plate

The overall concrete dimensions and internal steel reinforcement were the same for all un-strengthened and strengthened beams. The total length of all beams was 4,200 mm divided into two equal spans, while the center-to-center span was 2,000 mm and the overall depth was 330 mm including 80 mm flange thickness. The flange width of the beam was 600 mm, while the web thickness was 100 mm. Figures 1 and 2 shows the concrete dimensions as well as the reinforcement detailing of both group.



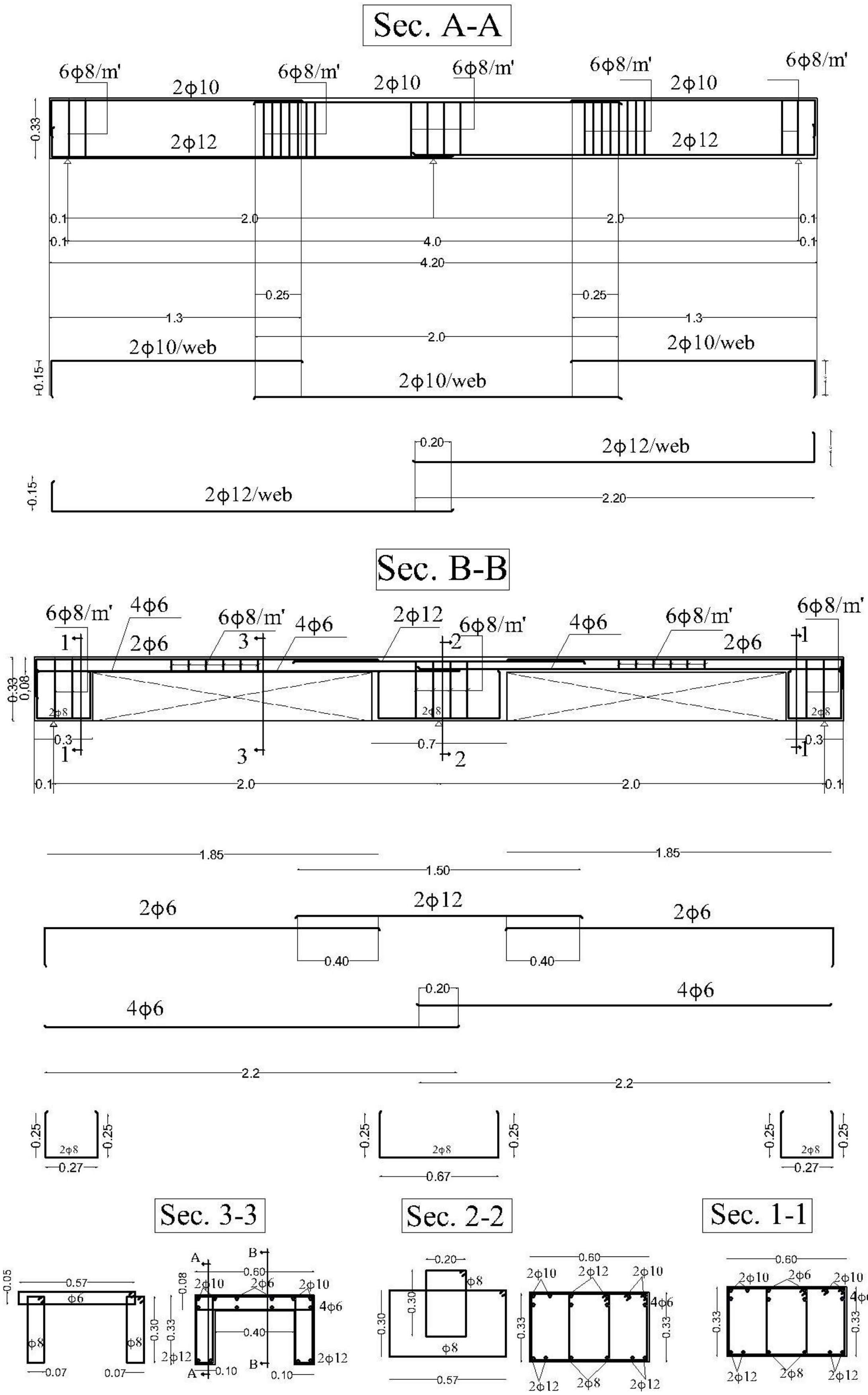
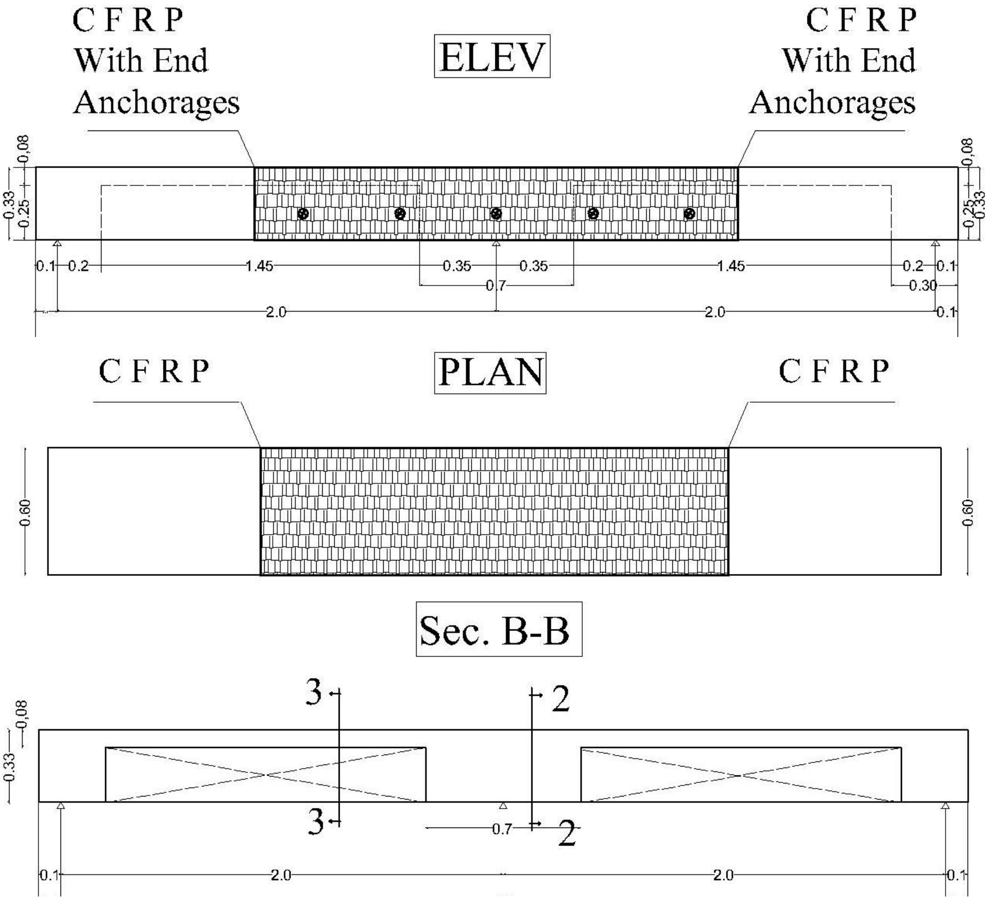


Fig. 1 Concrete dimensions and reinforcement detailing of both groups.

Fig. 2 Image showing steel cages just before casting of the test beams.

Strengthening techniques

For the current study, three different strengthening techniques were applied. The first technique used EB-CFRP sheets extended between the mid-span points of the two spans. The CFRP sheets were applied on the transverse direction as shown in Figs, 3 and 4. The second technique was the application of 20 mm thick layer of ECC material properly connected to the substrate beams using installed steel dowels of 6 mm diameter connected to the internally welded wire mesh install inside the ECC layer for enhancing its tensile characteristics (Figs. 5 and 6). The third technique used externally bonded u-shaped external steel plate of 2 mm thickness as depicted in Figs. 7 and 8.



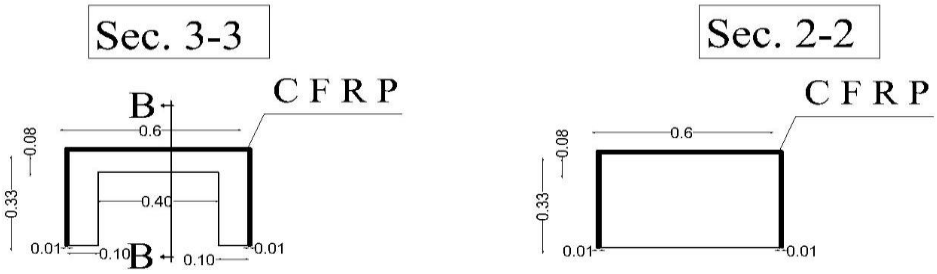


Fig. 3 Strengthening technique for beam B–CFRP.

Fig. 4 Images showing CFRP sheets after application on beam B-CFRP.

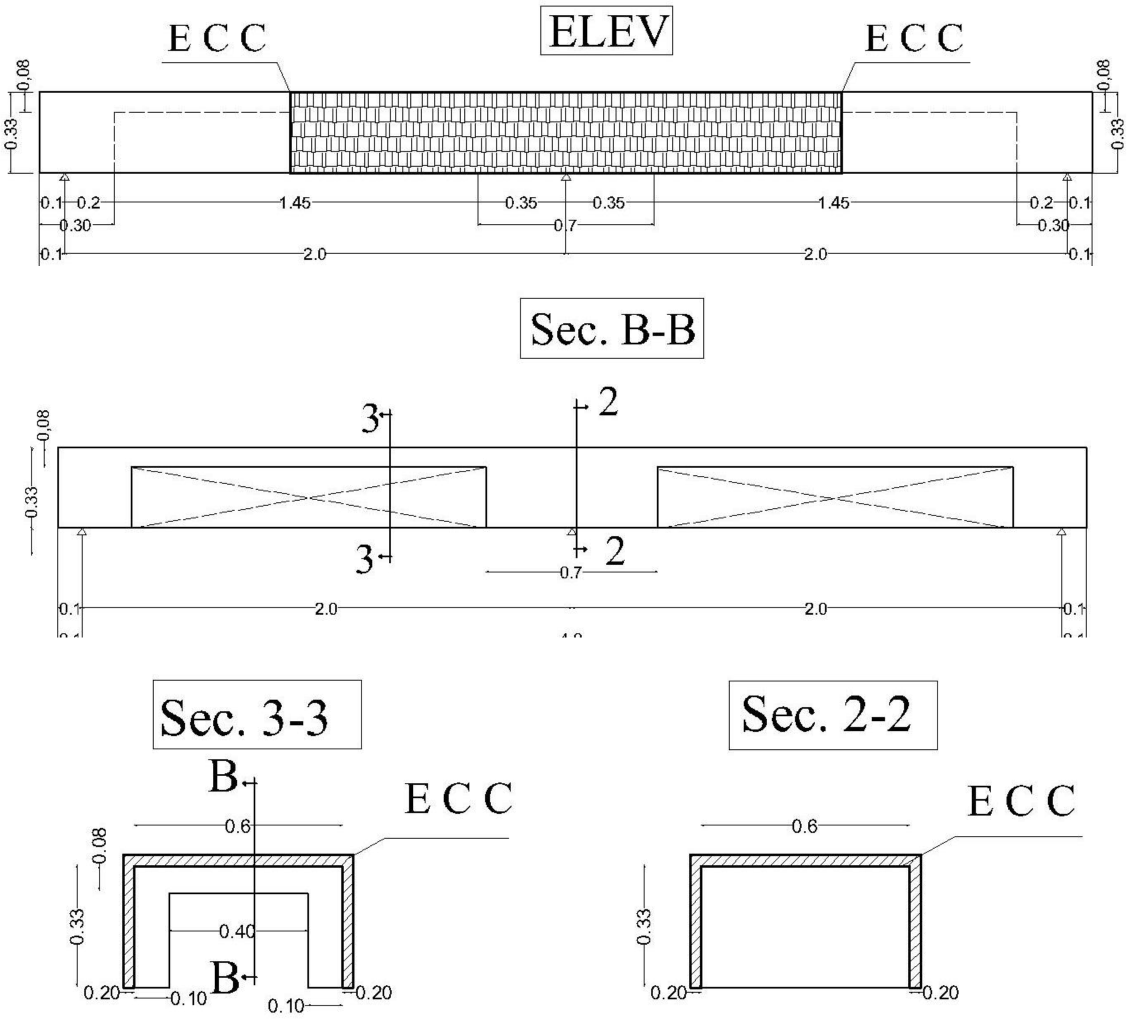


Fig. 5 Strengthening technique for beam B-ECC.

Fig.6 Image showing the ECC pouring for beam B-ECC.

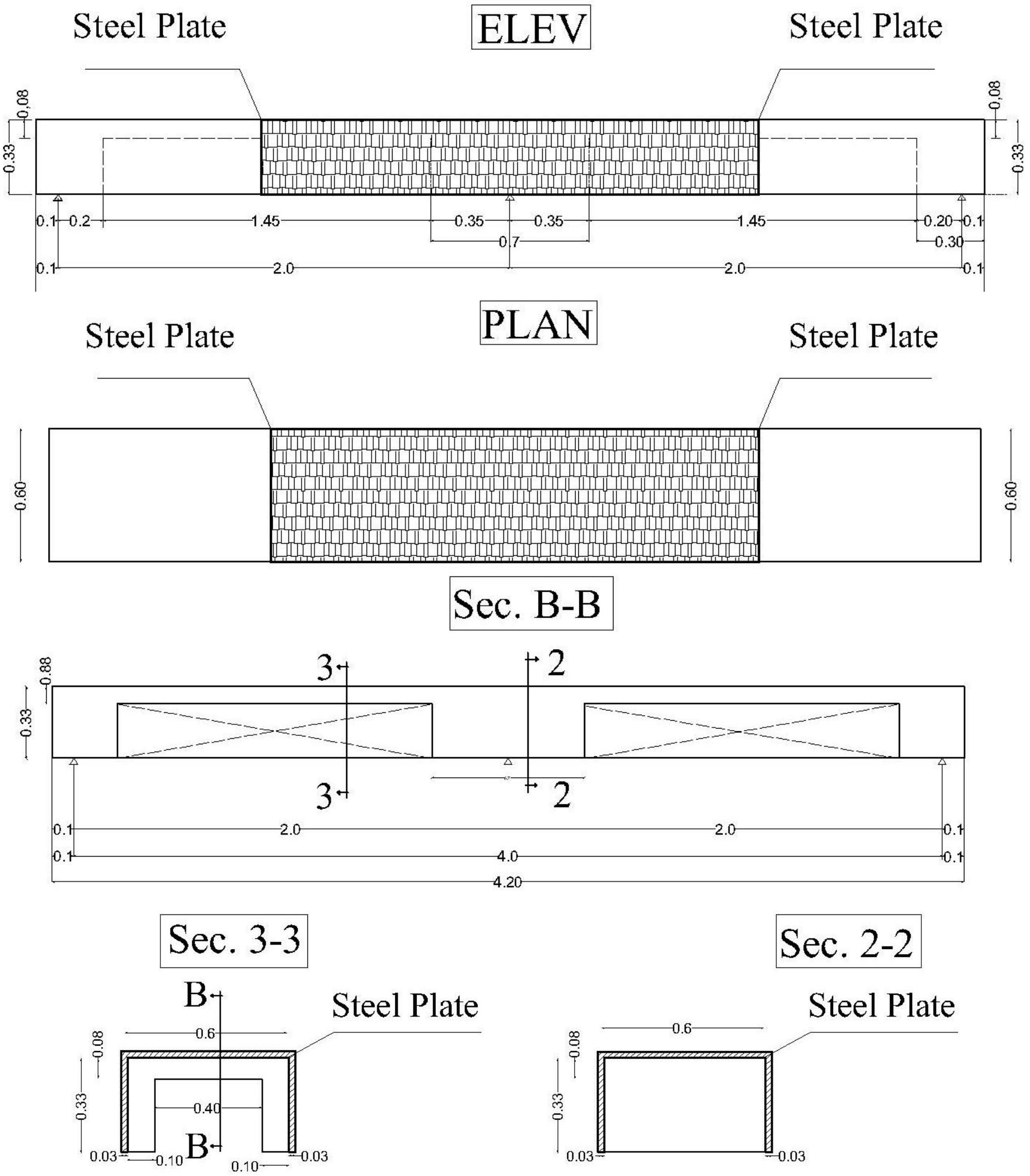


Fig. 7 Strengthening technique for beam B-ST.

Fig. 8 Image showing the external steel plate after its application on beam B-ST.

Material Properties

The used concrete was low strength concrete having 18 MPa concrete compressive strength, based on standard cube of 150 mm side length. The concrete mix proportions for low strength concretes are summarized in Table 2. The actual compressive strength of the test beam was about 19.7 MPa, which was the calculated as the average strength of 6 standard cubes collected from different locations during casting the beams.

As for the engineered cementituous composite (ECC) material, polypropylene (PP) micro-fibers of 0.01 mm diameter and 12 mm length were used by a volumetric ratio of 1 %. The maximum tensile strength of the PP fibers was about 620 MPa as provided by the supplier (X-Calibur [29]). The average compression strength of six pre-prepared standard cubes of 150 mm side length was about 51 MPa. The component of the ECC material are listed in Table 3.

High strength carbon fiber sheets CFRP X-Wrap C230 along with its compatible X-Wrap resin were used in the current study. Table 4 shows the mechanical properties for the CFRP sheets along with their epoxy resin as provided by the manufacturer (X-Calibur [29]).

As for the reinforcing steel bars, tensile tests were performed on three typical specimens for each bar size and type in order to determine their mechanical properties as summarized in Table 5. The used steel plates had 270 MPa, 396 MPa and 202 GPa for tensile yield strength, ultimate strength and Young's modulus, respectively.

Table 2 Mix proportions of low strength concrete for all specimens

Material	Cement kg/m3	Fine aggregate (Sand) Kg/m3	Coarse aggregate Gravel Kg/m3	Water kg/m3	Cubic strength after 28 days(MPa)
Weight /m3	250	940	1100	150	18

Table 3 Mix proportions of the ECC used as a strengthening material

Concrete Mix	W /B	Cement (kg/ m3)	Sand (kg/m3)	Water (kg/m3)	Silica fume (kg/m3)	Super plasticizer (kg / m3)	PP fiber (kg/ m3)
ECC	0.27	1090	654	327	109	24	12

* W/B is the water / binder ratio, B = Cement + silica fume; Silica fums = 10% by weight of cement.

* super – plasticizer = 2% by weight of binder ratio ; PP fiber = 1% by weight of binder ratio

Table 4 Mechanical properties of the used CFRP sheets along with their epoxy resin

Criteria	CFRP sheets	Adhesive
Tensile strength, MPa	4000	45*
Modulus of elasticity GPa	240	1.67*
Failure strain, %	2	--
Thickness, mm	0.125	---
Glass transition temperature	---	65C

*these values were obtained after 7d/20^{o}C

Table 5 Mechanical properties of the steel bars

Bar diameter, mm	Type	Average yield strength, MPa	Average tensile strength, MPa	Average modulus of elasticity, GPa
12	Deformed	451	575	203
10	Deformed	432	578	204
8	Smooth	284	410	202
6	Smooth	271	396	204

Test Setup and Instrumentation

The steel frame of the reinforced concrete laboratory of the Faculty of Engineering, Tanta University was equipped used to carry out the testing. Four 100 mm gauge length LVDTs were used to measure the mid-span deflection for both webs of the two spans. In addition, the developed normal strains on main tensile steel at both negative and positive moments as well as the developed strains on the CFRP sheets and steel plates were measured by 6 mm length strain gauges. Each span was loaded incrementally at its mid-span point up to complete collapse of the beam under incremental loading. The jacking load (twice the span load) as well was measured by load cells of 600 kN capacity as depicted in Fig. 9. After each loading step, the vertical mid-span deflections, the developed normal strains in the longitudinal steel bars as well as the reading of both load cells were recorded and stored by an automatic data logger unit (TDS-150).

(a) control specimen (b) strengthened specimen

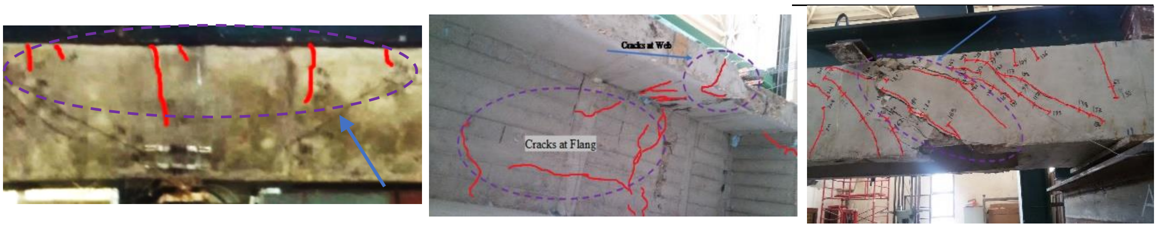
Fig.9 Test Setup.

Results and Discussion

In order to identify the most significant strengthening technique, different failure criteria were considered and compared for for un-strengthened beam BC and all strengthened beams, B-ST, B-ECC and B-CFRP. The considered comparison criteria are failure pattern, both flexural and shear cracking loads, ultimate failure load, load-deflection response and the developed ductility.

Failure Patterns

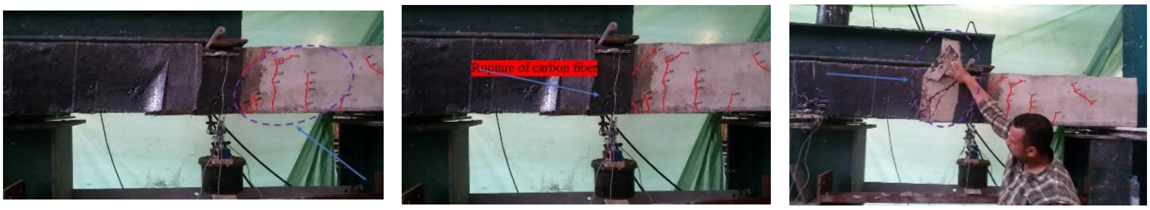
For BC beam, positive flexural cracks started to appear at a vertical a span load of about 35.5 KN. With further loading, this crack propagated around the mid span section till a span load of about 56 KN, then shear cracks stated to be shown near the interior support. Proceeding with loading resulted in development of flexural cracks at the intermediate support at a vertical load of about 63 kN. With nonstop loading, cracks propagated at the outer perimeter as well as at the inner faces of the U-shaped sections along the entire section as depicted in Fig. 10. Complete failure of beam BC was occurred at a span load of about 106.5 kN.



(a) Negative flexural cracks | (b) propagating of crack at web and flange at bottom of the Specimen | (c) Shear Failure Pattern

Fig. 10 Cracks mapping and failure pattern of beam BC.

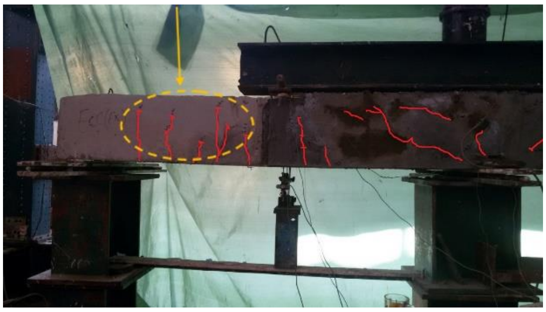
For beam B–CFRP, positive flexural cracks started to appear at a vertical a span load of about 60 KN near the mid span section at the un–strengthened part. With further loading, this crack propagated near the mid span section till a span load of about 164.5 KN. And then, shear crack started at the end support side at a span load of about 164.5 kN. Proceeding with loading, the epoxy resin started to be fractured, then the CFRP sheet showed some debonding at a span load of about 200 KN. Increasing the acting load further resulted in the complete failure of the beam at span load of about 206 KN. It is worth mentioning that during loading the developed cracks at the support region were hidden under the CFRP sheets .Thus, after complete failure, the CFRP sheets were removed to reveal the surface cracks on the negative moment zone as depicted in Fig. 11.



(a) flexural cracks | (b) Rupture of carbon fiber sheet | (c) Shear Failure Pattern

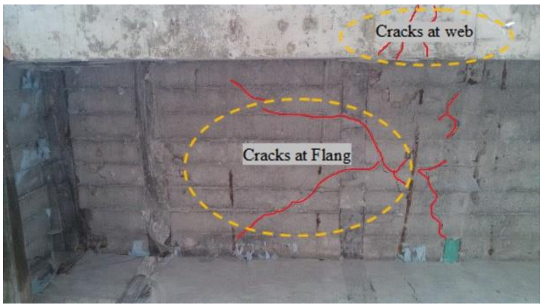
Fig. 11 Cracks mapping and failure pattern of beam B–CFRP.

For beam B–ECC, positive flexural cracks started to appear at a vertical span load of about 65 kN near the mid span section at the un–strengthened part which was higher than that exhibited by beam B-CFRP. With further loading, this crack propagated near the mid span section till a span load of about 150 kN. In the sequel, negative flexural crack started at a vertical span load of about 160 kN at the strengthened part. Soon later, shear crack started to appear at the strengthened part (inner support) at a span load of about 170 kN. Increasing the acting load further resulted in the complete failure of the beam at span load of about 216 kN. Fig. 12 shows cracks mapping and failure pattern of beam B-ECC.



(a) flexural cracks at the un – strengthened part

(b) flexural cracks at the strengthened part



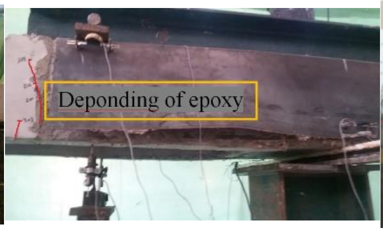
(c) The cracks at web and flange at bottom of the Specimen

(d) Shear Failure Pattern

Fig. 12 Cracks mapping and failure pattern of beam B–ECC.

For beam B–S T, positive flexural cracks started at appear at a vertical span load of about 65 kN near the mid span section at the un–strengthened part . With further loading, this crack propagated near the mid span section till a span load of about 175 kN. Then, shear crack started at inner web in a mid-substrate at a span load of about 175 kN. Proceeding with loading, the epoxy resin started to be fractured, then the steel plate showed some debonding at a span load of about 225 KN. Increasing the acting load further resulted in the complete failure of the beam at span load of about 238 KN . Fig. 13 shows cracks and failure pattern.

(a) flexural cracks



(b) Debonding of steel plate from epoxy

(c) Shear Failure Pattern

Fig. 13 Cracks mapping and failure pattern of beam B–ST.

Cracking and ultimate loads

Table 6 summarizes the results of the cracking and ultimate loads for all beams. It can be noticed that all strengthening techniques enabled the strengthened beams to hinder the appearance of flexural cracks at the positive moment zone significantly. The percentages of increases in the cracking loads are 69% for beam B-CFRP and 83% for both beams B-ECC and

B-ST. For the negative moment zone, the CFRP sheets and steel plates prevent tracing the developed cracks at that region. As for the first shear cracking loads, it was observed that the shear resistance of the strengthened beams enhanced effectively since the shear cracks loads were about 2.94, 3.06 and 3.13 times that of the un-strengthened beams for beams B-CFRP, B-ECC and B-ST, respectively. Regarding the ultimate capacity, the strengthened beam using steel plates showed the outermost increase, while the strengthened beams using CFRP sheets exhibited the lowest ultimate capacity. The percentages of increases in the ultimate load are about 93,4%, 102,8% and 123,5%, respectively, for beams B–CFRP, B–ECC and B–ST compared to that of beam BC.

Table 6 results of the cracking and ultimate loads

Group No.	Specimen	Cracking load, kN			Ultimate load, kN
		$P_{cr(+ve)}$	$P_{cr(-ve)}$	$P_{cr(shrear)}$	
1	BC	35.5	63	56	106.5
2	B –CFRP	60	----	164.5	206
	B – ECC	65	----	170	216
	B – ST	65	----	175	238

Load - deflection behavior

Figure 14 shows the relationships between the span load and the mid-span deflection for all beams. It can be observed that the un-strengthened control beam BC represents the lower bound among all beams. That means it has the lowest stiffness. On the other hand, beam B-CFRP represents the highest stiffness, while beam B-ST showed the lowest stiffness approaching the ultimate load. Then, near the failure load, beam B-ST exhibited the outermost load-deflection plateau.

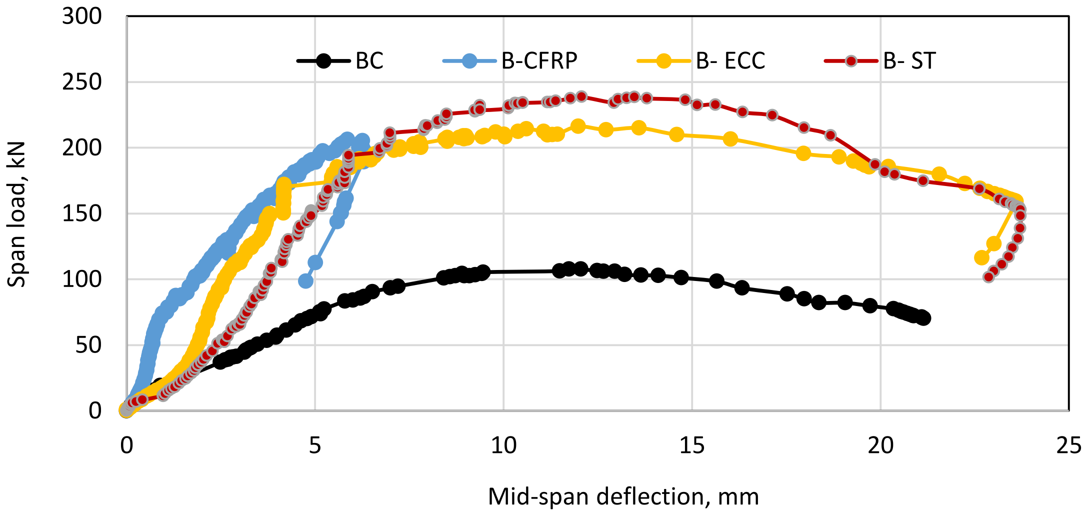


Fig. 14 Span-load versus mid-span deflection for all specimens.

Displacement-ductility index of all beams

Reinforced concrete ductile member that develops inelastic deformation while resisting more loads further than the initial yielding point is more preferable than reinforced concrete member that fails in sudden brittle manner. Commonly, the ductility of reinforced concrete member is measured by a ratio called the ductility index. This index is the ratio between the curvature, displacement, or absorbed energy at failure and the corresponding property at yielding point. For the current study, the displacement-based index was adopted in order to calculate the ductility of all un-strengthened as well as strengthened beams. The displacement-based ductility index is the ratio between the maximum deflection divided by the deflection corresponding to the yielding point. Park [30] described the method for estimating the yielding deflection as well as the maximum deflection where this method was adopted in the current study. The calculated ductility index for the control beams BC was 2.5, while the ductility indices for strengthened beams B-CFRP, B-ECC and B-ST were 1.09, 2.4 and 1.8, respectively. That means the beam B-ECC is the best one from the ductility viewpoint. It showed about 96% of the corresponding ductility for control beam BC. On the other hand, the strengthened beam B-CFRP showed the lowest ductility index where its index was about 44% of that for control beam BC.

CONCLUSION

This paper discusses the results of experimental tests conducted on 4 reinforced concrete two-equal spans beams; one un-strengthened beam and 3 beams strengthened with CFRP, ECC and steel plates The following conclusions can be drawn:

1. The ultimate loads for all strengthened beams increased by about 93.4%, 102.8% and 123.5% respectively, for beans B-CFRP, B-ECC and B-ST compared to that of BC beam
2. The mode of failure of strengthened beam B-CFRP was brittle shear failure; however the strengthened beams B-ECC and B-ST exhibited more ductile shear failure.
3. The strengthened beam using steel plates showed the highest ultimate capacity, however, the strengthened beam using ECC layer showed the highest ductility. Therefore, it is a matter of compromise to choose the required criteria in order to identify the most proper strengthening technique.
4. The strengthened beams B-CFRP showed the lowest ultimate capacity and ductility among the considered strengthening techniques. That means it is not suitable for the current application from the ductility viewpoint, however it showed significant enhancement in the ultimate capacity but lower than that retained by other techniques.

REFERENCES

1. A. Naseer, S.M. Ali, Z. Hussain, Reconnaissance Report on the 8th October, 2005 Earthquake Pakistan, in, Earthquake Engineering Centre, Department of Civil Engineering NWFP UET Peshawar, Pakistan, 2006.
2. I.E. Bal, H. Crowley, R.F. Pinho, F.G. Gulay, Detailed assessment of structural characteristics of Turkish RC building stock for loss assessment models, Soil Dynamics and Earthquake Engineering, 28 (2008) 914–932.
3. Afefy HM and Fawzy TM (2013) Strengthening of RC one-way slabs including cut-out using different techniques. Engineering Structures 57C: 23-36.
4. Afefy HM, Kassem NM, Mahmoud MH and Taher S F (2016a) Efficient strengthening of opened-joint for reinforced concrete broken slabs. Composite Structures 136: 602-615.
5. Afefy HM, Kassem N and Hussein M (2015) Enhancement of flexural behavior of CFRP-strengthened reinforced concrete beams using engineered cementitious composites transition layer. Structure and Infrastructure Engineering 11: 1042-1053.
6. Afefy HM and Mahmoud MH (2014) Structural performance of RC slabs provided by pre-cast ECC strips in tension cover zone. Construction and Building Materials 65: 103-113.
7. Li VC (1993) From micromechanics to structural engineering: the design of cementitious composites for civil engineering applications. JSCE Journal of Structural Mechanics & Earthquake Engineering 10: 37-48.
8. Kunieda M, Denarie E, Bruhwiler E and Nakamura H (2007) Challenges for strain hardening cementitious composites-deformability versus matrix density. Proc. of the 5th International RILEM Workshop on HPFRCC: 31-38.
9. Kunieda M, Hussein M, Ueda N and Nakamura H (2010) Enhancement of crack distribution of UHP-SHCC under axial tension using steel reinforcement. Journal of Advanced Concrete Technology 8: 49-57.
10. Kunieda M, Ueda N, Nakamura H and Tamakoshi T (2009) Development of spraying technique for UHP-SHCC. Proceedings of the Concrete Structure Scenarios 9: 349–354.

11. Li M and Li VC (2011) High-early-strength ECC for rapid durable repair: Material properties. ACI Material Journal 108: 3–12.
12. Li VC (1998) ECC for repair and retrofit of concrete structures. Proceedings of Fracture Mechanics of Concrete Structures, FRAMCOS-3: 1715-1726.
13. Dhawale AW and Joshi VP (2013) Engineered Cementitious Composites for structural applications. International Journal of Application or Innovation in Engineering & Management (IJAIEM) 2: 198-205.
14. Zhang Y, Lv W and Peng H (2018) Shear stress transfer model for evaluating the fracture behaviour of SHCCs for RC shear strengthening. Magazine of Concrete Research 70(10): 512–518.
15. Boughanem . S , Smith , D.A , M lheron , M.J , Eddie.C, Psomans .S , Rimes . M ." Engineered Cement Composites Properties for Civil Engineering Applications ", 18th conference on composite Material
16. Shiram. J , Sreenath .S and Saravana .J (2018) " Strengthening of international reinforced concrete beams using Engineered cementitious composites " ,international Journal of Civil Engineering and Technology , vol.9. No.4.pp. 608 -613
17. Singh, S.B, Sivasubramanian.V.R. (2013)"Flexural response of ECC Strengthened Reinforced Concrete beams", The Indian Concrete Journal.PP.1-11
18. Guan, Yanhua, yuan , H, Ge, z, Huang, Y,Li,S and Sun,R .(2018)"flexural properties of ECC-Concrete composite Beam" . Hindawi Advances in Civil Engineering.PP.1-7
19. Afefy HM, Sennah K and Cofini A (2016b) Retrofitting actual-size precracked precast prestressed concrete double-tee girders using externally bonded CFRP sheets. ASCE Journal of Performance of Constructed Facilities 30(2): 04015020.
20. Jumaat MZ, Rahman MM and Rahman MA (2011) Review on bonding techniques of CFRP in strengthening concrete structures. International Journal of Physical Sciences 6: 3567-3575.
21. Ombres L (2010) Prediction of intermediate crack de-bonding failure in FRP-strengthened reinforced concrete beams. Composite Structures 92: 322-329
22. Morsy ,Alaa , Mahmoud , E.T. (2013) "Bonding techniques for flexural strengthening of R . C . beam using CFRP laminate",Ain shams Engineering Journal No . 4, pp . 369 – 374
23. Khan , Asad , ur.R ,Fareed , Sh . (2014) "Behaviour of reinforced concerete Beams strengthened by CFRP wraps with and without End Anchorages ", ELSEVIER procedia Engineering No .77. pp. 123- 130
24. Rhman , Muhammad , Rhman , Md.W(2013) "Simplified method of strengthening RC continuous T beam in the hogging zone using carbon fiber reinforced polymer laminate " , Journal of Civil Engineering Construction technology , vol . 4n .No.6 . pp. 174-183
25. Desurkar , V.P , Kulkarni , K.S (2015) "performance of reinforced beam strengthened with carbon fiber reinforced polymer sheet at elevated temperature " , International Journal of Civil and Structural Engineering , vol . 6.No.1 .pp. 1-10
26. Norris , Tom , Saadatmanesh , H , and Ehsani , M. R. (1997) "shear and flexural strengthening of RC beams with carbon fiber sheets " , Journal of Structural Engineering , vol . 123 .No .7 .pp . 903 – 911
27. Al-Hassani, H. M , Al-Ta'an, S.A and Mohammed, A.A. (2013) "Behavior of damaged reinforced concrete beams strengthened with externally bonded steel plate ", Tikrit Journal of Engineering Sciences, vol.20.No.2.PP.48-59
28. Suresh, J, Prabhavathy, R.A. (2014) "Behaviour of steel fiber reinforced concrete beams with Duct opening Strengthened by Steel plate ", International Journal of Advanced Information Science and Technology, Vol. 28. No. 28. PP. 86-940.
29. X-Calibur, www.x-calibur.us.
30. Park. R . (1989) "Evaluation of Ductility of Structures and Structural Assemblages From Laboratory Testing", BULLETIN OF THE NEW ZEALAND NATIONAL SOCIETY FOR EARTHQUAKE ENGINEERING, Vol. 22, No. 3, pp. 155-166.