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EXPERIMENTAL AND NUMERICAL STUDY OF RC BEAMS USING TEXTILE REINFORCED CONCRETE

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Abstract- *In this paper, the efficacy of Textile Reinforced Concrete (TRC), as a method for increasing the flexural capacity and shear capacity of Reinforced Concrete (RC) beams, is experimentally and numerically examined. A new type of Alkali Resistant (AR) glass textile fabric was utilized as strengthening material and the Polymer modified cementitious mortar was utilized as bonding material for the AR-glass textile fabric instead of Epoxy resin, in view of their advantages related to fire safety, low cost and furthermore it apply at wet surface. The studied parameters in this research work included the number of textile layers as well as the configuration of the textile material. In total, Eighteen Reinforced Concrete (RC) beams were casted and tested as simply supported under three-point loading test till failure. On the basis of the experimental study of reinforced concrete beams strengthened in flexure and shear, it is concluded that the textile composite provides sustainable gain in flexural and shear capacity, this increases as the number of fabriclayers increases. Beside the experimental study, a Numerical investigation utilized non-linear finite element (FE) analysis was also carried out using ABAQUS 6.13 Software. Good agreement was achieved between the experimental and numerical results particularly for the load carrying capacity.*

Keywords- *AR-glass textile fabric,Numerical modelling,Polymer modified mortar, strengthening,Textile Reinforced Concrete*

I. INTRODUCTION

Structural retrofitting of Existing Reinforced Concrete (RC) structures is a continually developing need because of their deterioration like ageing, deficient concrete production, environmental induced degradation, lack of maintenance and need more strict design requirements . As complete replacement or reconstruction of the structure cost very high compared to strengthening or retrofitting, so generally it is preferred to retrofit or strengthened the structure. The most widely retrofitting techniques for RC elements include the utilization of Fiber reinforced polymer (FRP) composites because of their favourable properties like speed of application, high strength to width ratio and corrosion resistance. Despite of all these desire, the FRP strengthening process has a certain drawback mainly associated with the use of epoxy resins because of their High cost, Poor performance at high temperatures, Inability to apply on wet surfaces, De-bonding of FRP etc.

One conceivable key for the above issues would be the replacement of organic binder (typically epoxy resin) with inorganic binder (cementitious mortar). Hence the researchers introduced a new composite material, namely Textile Reinforced Concrete (TRC), which combines textile fabric (with open-mesh configuration) with cementitious matrix. The use of textile fabric mainly made of AR-glass, Carbon, basalt and aramid, which gives high effectiveness because of they are placed in the main stress direction of the composite. In this experimental work, TRC composites comprising of Alkali Resistant (AR) glass textile fabric were used for the strengthening of RC beams. The main objectives of this research work is to develop and validate a numerical model of reinforced concrete beams that are strengthened by TRC laminate.

II. EXPERIMENTAL STUDY

A. Methodology

This study consists of testing total 18 simply supported Reinforced Concrete beams (150 mm × 250 mm × 1500 mm) in three-point bending when externally strengthened by TRC Laminate. The criterion for selection of the beam dimensions was on the basis of available resources in the laboratory. The beams were reinforced with 2-12mmØ longitudinal bar on top and bottom face, a cover of 25 mm.The shear reinforcement consists of 2-legged 8 mm Ø stirrups at a spacing of 100 mm. The main goal is to study the effectiveness of TRC in enhancing the flexural and shear capacity of the beams. The details of the specimens is shown in Table 1. The studied parameters included the Number of strengthening layers (1, 3 and 5) and Textile configuration (Bottom and U-shape). The details of specimens is shown in Table 1.

Beam Designation	No. of specimens	Shape of strengthening Layer	No. of strengthening layers
CB	-	-	3
F1LB	1	Bottom	3
F3LB	3	Bottom	3
F5LB	5	Bottom	3
S1UL	1	U-Shape	2
S3UL	3	U-Shape	2
S5UL	5	U-Shape	2
Total Number of Specimens			18

Table 1: Details of Specimens

Three beams were used as control specimens, which were designed to be under reinforced. So as to reveal the effectiveness of TRC composites in enhancing the flexural and shear capacity. While the remaining beams were strengthened with one, three and five layers of textile fabric bonded with ready mix Polymer-modified mortar. In which, Nine beams were externally strengthened by AR-glass textile laminate at bottom (F1LB, F3LB and F5LB) for enhancing their flexural capacity; and other six beam were strengthened by U-shape wrapping (S1UL, S3UL and S5UL) for enhancing shear capacity. Details of test beam are displayed in Figure 1.

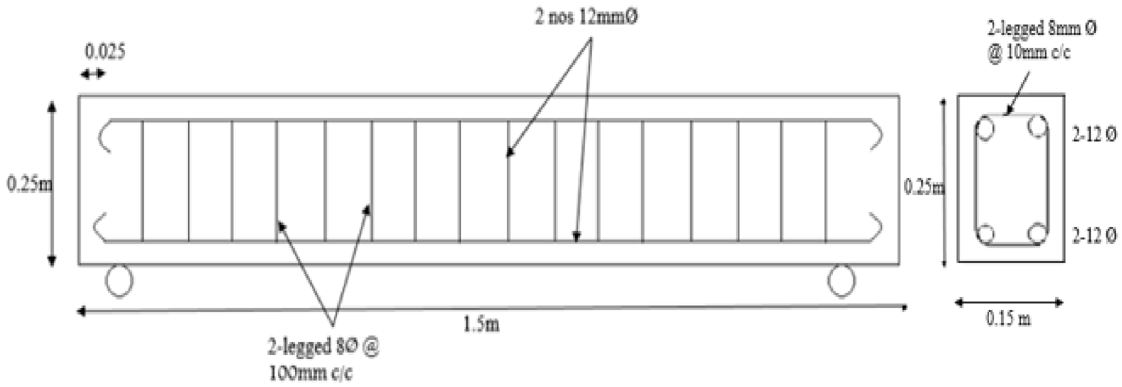

Figure 1: Details of Specimens

B. **Material Properties**

Concrete and Steel reinforcement

Concrete Mix design with a compressive strength of 25 MPa was used to cast the RC beam specimens. Total, 18 standard cubes (150 mm × 150 mm x 150 mm) for concrete were also cast which were tested under compression at 28 days. The average compressive strength of concrete at 28 days was 28.97 N/mm^2.To determine the actual characteristics of steel reinforcement, three samples of steel bars for 12 mm diameter were tested under uniaxial tension. The steel used is Rudra TMT500 grade. The average values for yield and tensile strength of the bars were 496.74 N/mm^2 and 627.87 N/mm^2. After the curing period for RC beams at 28 days, the specimens, which were to be strengthened were thoroughly sandblasted to remove dirt and any loose material. This was done to ensure optimum bond quality in between the concrete substrate and the TRC layers.

Polymer Modified Cementitious mortar (PMC)

The Ready mix Polymer-modified mortar used as Textile Reinforced Mortar (TRM) systems was BS 5F-U, manufactured by THERMAX Limited. BS 5F-U is a one component thixotropic corrosion resistance fiber reinforced polymer modified repair mortar. In order to determine the compressive strength of mortar, Total 6 cubes (100 mm x 100 mm x 100mm) were prepared and then tested under compression at 28 days. The average compressive strength of concrete at 28 days was obtained 22.38 N/mm^2.

Alkali Resistant (AR) Glass Fabric

AR-glass based textile fabric, increase the Structural performance of RC beams after strengthening is shown in Figure 2, and was used in this study. The AR-glass textile fabric used for strengthening the Reinforced Concrete beams had a grid size of 5 mm x 5 mm. The details of AR-glass textile mesh used are given in Table 2.

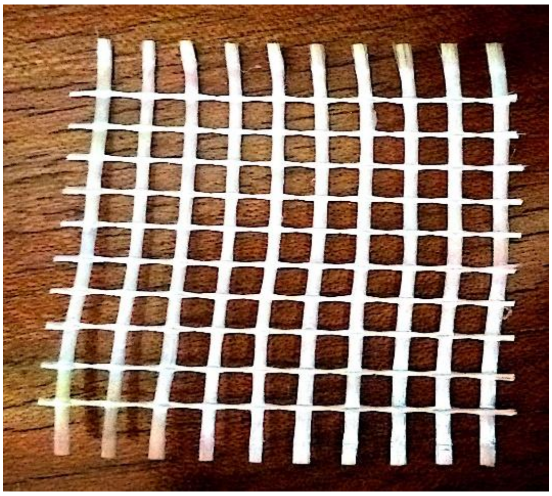

Figure 2: AR-glass textile fabric

Woven Structure	Elastic Modulus (MPa)	Tensile Strength (MPa)	GSM	Density (g/cm^3)	Thickness (mm)
Leno	72000	36.54	145	10	0.49

Table 2: Mechanical properties of fabric

Instrumentation and loading setup

Total 18 beams were tested in a three-point loading system till failure with a clear span of 1.5m and an effective span of 1.2 m. The test setup is as shown in Figure 3. The load was applied using Hydraulic jack. Two Dial gauges were used to measure the displacement of the specimen near the load point. The testing of beams were carried out in Loading frame of 1000 kN load capacity. The tests were carried out using Load control, and the applied loads were monitored through a high accuracy load. The reading was taken at regular intervals of load. During loading, the specimen was visually inspected and cracks were marked. The test region was coated with white paint in order to clearly observe the evolution and propagation of cracks appeared. The Pictures were taken at regular intervals to properly capture the crack pattern during testing.

Figure 3: Test Setup

III. RESULTS & DISCUSSION

Table 3 shows a summary of the flexural and shear behaviour of all test beams in terms of loading capacity, failure mode and displacement. The average load carrying capacity of control beam was 86.43kN. The maximum load carrying capacity of one, three and five layers of strengthened beams were 120kN, 126.46kN and 131.7kN observed for flexural failure, which are increased with the increasing numbers of strengthening layers as shown in Figure 4. Debonding of textile laminate occurs at the bottom of the beam but the failure of beams strengthened by one and three layers of fabric in bottom face due to the rupture of the textile fabric and the final failure of beam is by crushing of concrete at the compression face in both RC strengthened beams. In addition, other six beams with U-shape strengthening for shear enhancement, they should not be failed in shear. The ultimate load carrying capacity of one, three and five layers of strengthened beams was 123.1kN, 137.33kN and 141.3kN, respectively, the corresponding increase in their shear capacity with increasing the number of strengthening layers as shown in Figure 5. As a result, the effectiveness of TRC layers were enhancing the both flexural and shear capacity of the test beams as shown in Table 3.

Beam Designation	Failure mode	Ultimate Load (kN)	Displacement (mm)
CB	CC	86.43	6.81
F1LB	TR, end debond	120	12.25
F3LB	TR, end debond	126.46	8.35
F5LB	TR, end debond	131.7	7.69
S1UL	CC	123.1	11.76
S3UL	CC	137.33	10.83
S5UL	CC	141.3	9.89

CC: Concrete Crushing, TR: Textile Rupture

Table 3: Test Matrix

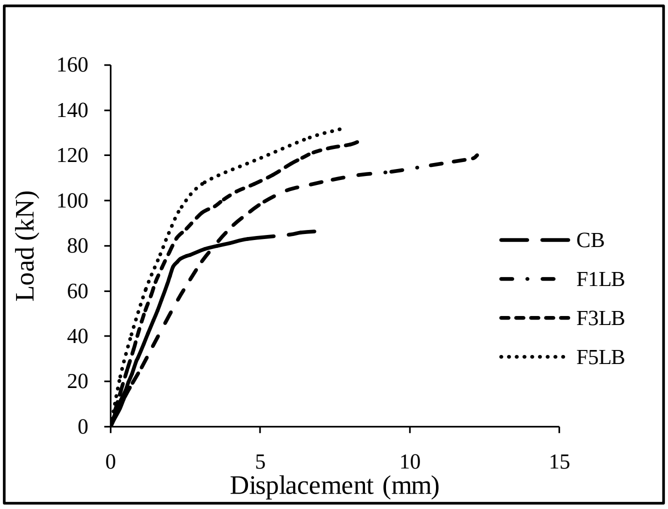

Figure 4: Load-deflection Curve for Bottom wrapping strengthened Beam

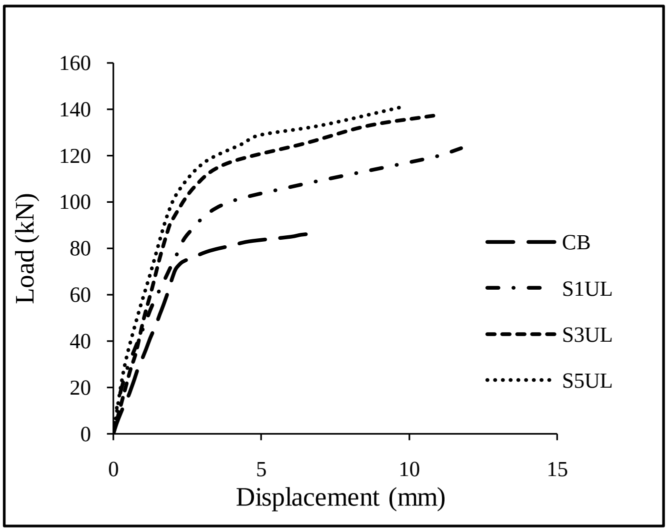

Figure 5: Load-deflection curve of U-shape wrapping Strengthened Beam

IV. NUMERICAL MODELLING

Finite Element (FE) modelling of the TRCstrengthened beams was carried out so as to validate the adopted numerical modelling techniques for TRC along with the material model that can be used for modelling the Textile Reinforced Concrete. ABAQUS, a general purpose finite element modelling, was employed for the numerical simulation of the TRC strengthened beams under three-point bending test.The Finite-element analysis was carried out for all the beam specimens studied in the experimental work were considered in the numerical study. The concrete and laminate were modeled with 3D deformable solid extrusion and shell planar and the reinforcement was modeled as 3D deformable wire planar. The measured material properties were used in the finite element model.

V. FE RESULTS

In case of control beams and strengthened beams, Total 7 Numerical models are developed and analyzed having different numbers of textile layers and textile configuration. A comparison was made between the Experimental result and Numerical results, the load v/s displacement curves are obtained. As seen from the Figures,the experimental load v/s displacement curves showed good agreement especially for the ultimate load carrying capacity, compared with the FE analysis of the control beams as well as TRC strengthen beams. For all the TRC strengthened beams, the ultimate load carrying capacity were only slightly higher for the Numerical results. Table 4 enlist the Comparision details. As seen in Table 4, compared with experimental results, maximum deviation of 0.56 % to 12.62% were found for the Numerical results for ultimate loads respectively. A comparison was made between the load v/s displacement curves obtained from the experimental and the numerical studies for all beam specimens tested as shown in Figure 6-12.

beam Designation	EXP	FEM	(%) Difference
CB	86.43	97.34	12.62
F1LB	120	109..36	9.73
F3LB	126.46	118.63	6.6
F5LB	131.7	130.97	0.56
S1UL	123.1	117.32	4.93
S3UL	137.33	132.4	3.72
S5UL	141.3	139.76	1.1

Table 4: Comparison of Finite Element Analysis result with Experimental Results

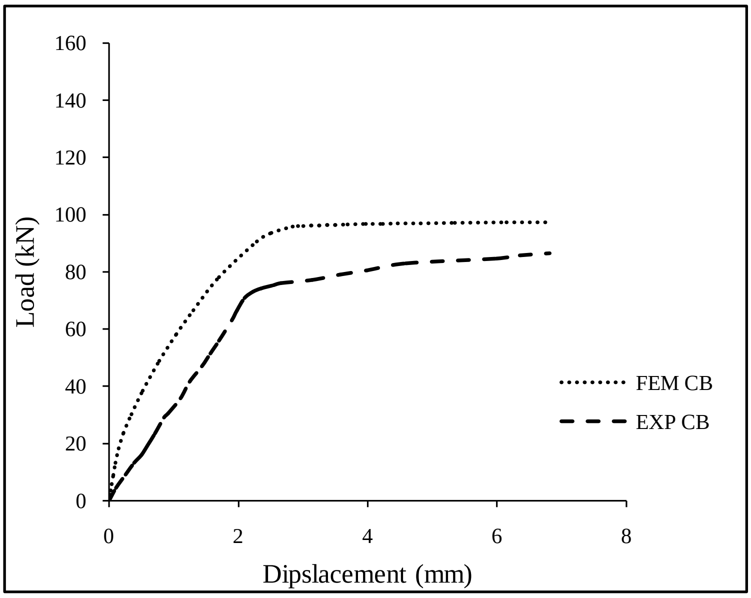

Figure 6: Load-displacement curve for Control beam

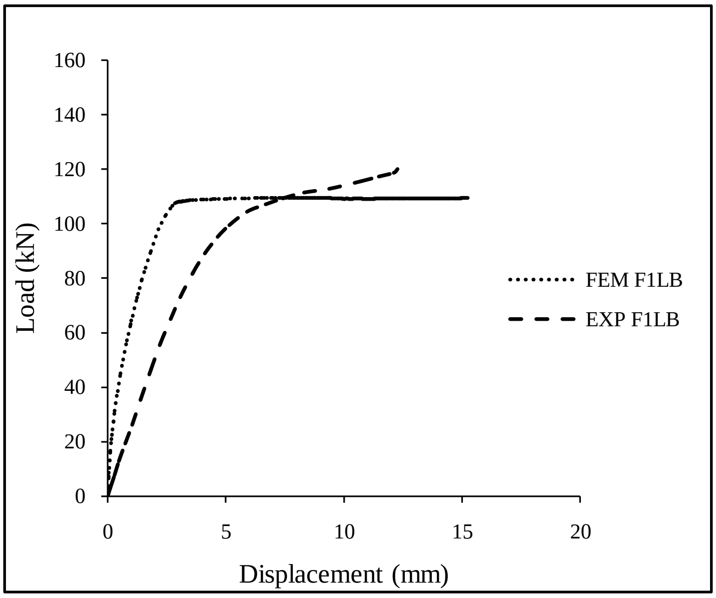

Figure 7: Load-displacement curve for 1 layer Bottom strengthened beam

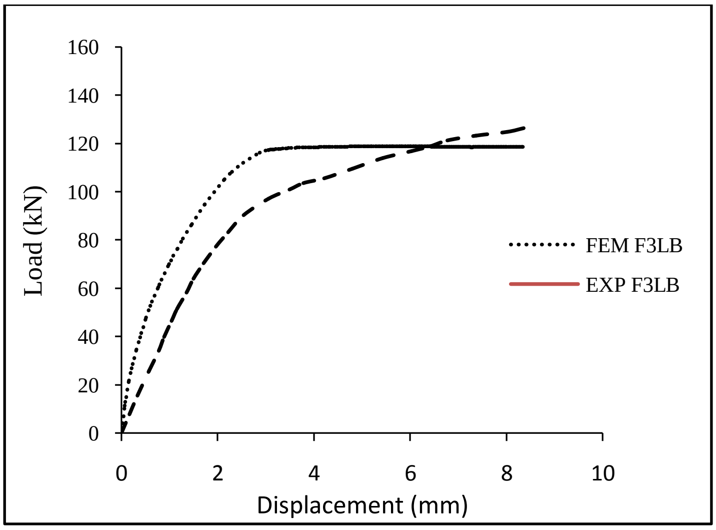

Figure 8: Load-displacement curve for 3 layer Bottom strengthened beam

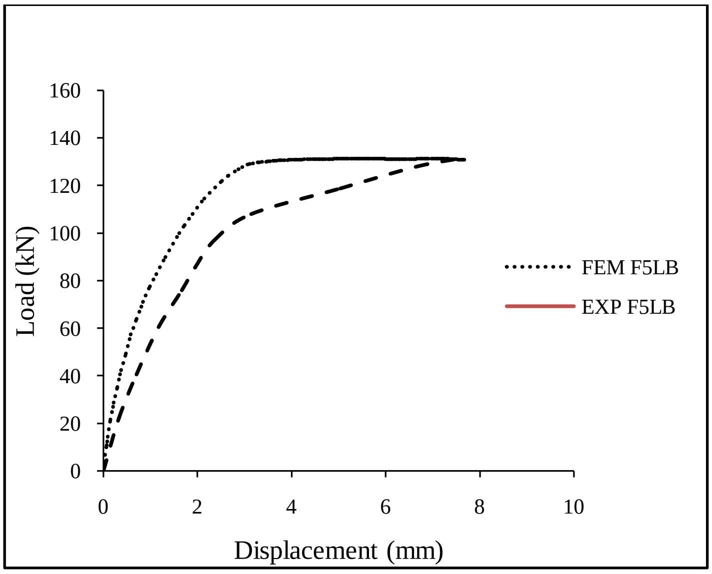

Figure 9: Load-displacement curve for 5 layer Bottom strengthened beam

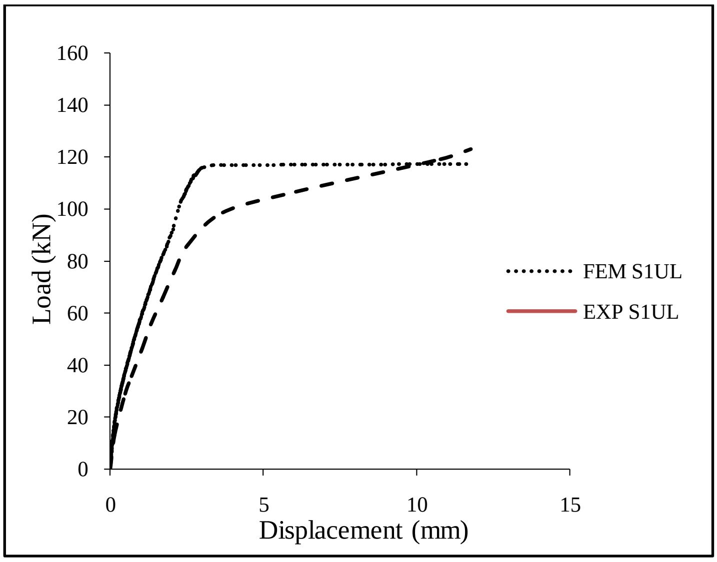

Figure 10: Load-displacement curve for 1 layer U-shape strengthened beam

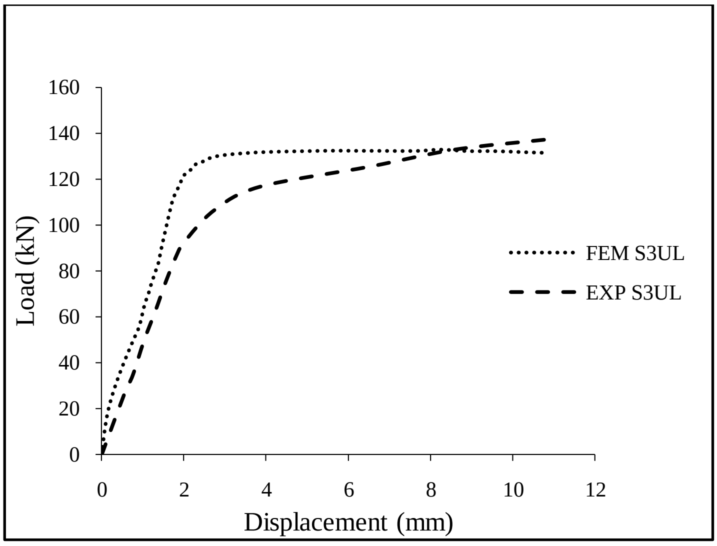

Figure 11: Load-displacement curve for 3 layer U-shape strengthened beam

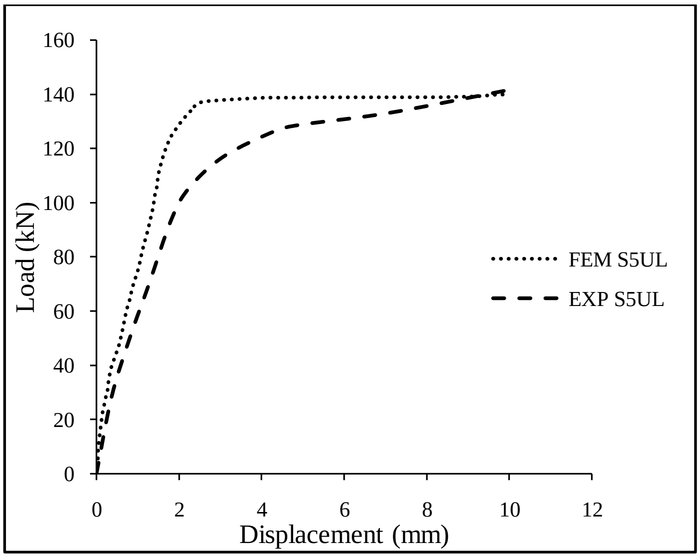

Figure 12: Load-displacement curve for 5 layer U-shape strengthened beam

VI. CONCLUSION

On the basis of experimental and numerical results presented in this paper, the following conclusions can be drawn.

1. It conclude that the performance of existing member strength can be enhanced by strengthening with AR glass textile fabric. The effectiveness depends on both the strengthening configuration and the number of layers.

2. Based on the experimental study conducted in this study, the AR glass textile reinforced concrete provided substantial gain in the flexural capacity of reinforced concrete beams. The ultimate load carrying capacity increased from 38.84%, 5.38% and 4.14% with one, three and five layers of fabric at Bottom. Also the AR glass textile reinforced concrete provided substantial gain in the shear capacity of reinforced concrete. The ultimate load carrying capacity increased from 42.43%, 11.56% and 2.89% with one, three and five layers of fabric at U-shape end anchorage respectively.

3. Based on the experimental and FE analysis performed in this study, it was observed that TRC strengthened beams fails in flexure by either textile rupture or TRC end debonding. Also the results obtained from the investigation opens up possibilities of further investigations to prove the efficiency of AR glass Textile Reinforced Concrete towards structural strengthening.

4. The comparison of the FE analysis results with the experimental results confirmed that the proposed numerical approach is appropriate for estimating the ultimate load-carrying capacity of both the unstrengthened and TRC strengthened concrete beams. This will thereby indicate the validity of the numerical modeling procedures, which may be used for conducting future research in the area of TRC upgraded concrete elements. From this study, it is concluded that the TRM system would be a promising solution for Flexural and shear strengthening of RC beams provided textile material of higher strength is used. The FE analysis showed a good consistency with experimental results, and it can be applied to other problems.

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