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FLEXURAL PERFORMANCE OF RCC BEAM USING TEXTILE FABRIC

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Abstract — *Infrastructure development is proliferating. Many reinforced concrete and masonry buildings are constructed annually around the world. With this, there are large numbers of them which deteriorate or become unsafe to use because of changes in use, changes in loading, change in design configuration, inferior building procedure. Thus repairing and retrofitting these structures for safe usage of these structures has a great market. There are several situations in which a civil structure would require strengthening or rehabilitation due to lack of strength and durability. Beams may be strengthened in flexure through the use of textile fabric bonded to their tension zone using epoxy adhesive. Due to increasing use of textile industrial materials in construction industry, the use of textile fabrics is becoming popular. The paper makes an experimental study of the RCC beam performance in flexure after application of textile fabric at tension surface of RC beam. An experiment study is carried out to study the load carrying capacity and deflection until failure of RCC beams to enhance the flexural capacity of the beams along with the existing practice of doing the repair work.*

I. INTRODUCTION

There is a considerable number of existing concrete structures in India that do not meet current design standards because of inadequate design and construction or need structural upgrade to meet new seismic design requirements because of new design standards, excessive loading conditions, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes. Inadequate performance of this type of structures is a major concern for civil engineering standpoint. Strengthening or upgrading becomes necessary when these structural elements cease to provide satisfactory strength and serviceability. Industrial Textile materials can be effectively used as an external reinforcement for upgrading such structurally deficient RCC beams.

The majority of structural strengthening process involves improving the ability of the structural elements to safely resist the internal forces caused by loading: flexure, shear, axial, and torsion. Additional strength may be needed to allow for higher loads to be placed on the structure. The main advantages of textile materials are related to their light weight, ease of application, and resistance to corrosion. Industrial textile fabrics have proven to give excellent performances both in terms of application and durability, cost efficiency, fire resistance, low water permeability. External bonded reinforcement is one of the method of repair or strengthening and rehabilitation of RCC beam; it can be done using non-woven fabrics or woven fabrics or steel plates.

Retrofitting by steel is more popular for repair work of such structures but is time consuming and may be difficult to retain the aesthetic view of these structures. So our aim was to find an alternative to retrofitting by steel without damaging the aesthetic view of important buildings such as using technical textile fabrics of woven and non-woven type bonded externally on the beam. In this paper the increase in load carrying capacity of RCC beams strengthened with high tensile strength Textile fabric is studied experimentally. The analytical results are compared with experimental data.

II. EXPERIMENTAL INEVESTIGATION

Reinforced concrete beams were designed as Under- reinforced section using M20 grade concrete and Fe 500 grade steel. The beams in the calculation were considered as single – reinforced beams. Stirrups were made with 6mm diameter steel bars. The dimensions of the beam were 700mm x 150mm x 150mm. The reinforcement details are given in fig. 1. The beams were cured in a water tank for 28 days. After curing, two beams were tested as reference beams to confirm and remaining beams were strengthened with single, double and triple layer of both the fabrics with two for each kind for accurate measurement.

Additionally, Experiment was carried out using woven fabric polypropylene and non-woven fabric polyester, both of 180 GSM(gram per sq.m) available at around ₹110/kg and ₹130/kg respectively. So, retrofitting of around 5 m^2 can be done using a one kg raw material. The Fabric testing was carried out at **MANTRA Laboratory** and results were obtained for elongation, load, extension, modulus of elasticity as well along with the tensile strength of fabric. The strength of 180GSM polypropylene was 211.2 N and that of polyester was 2790 N.

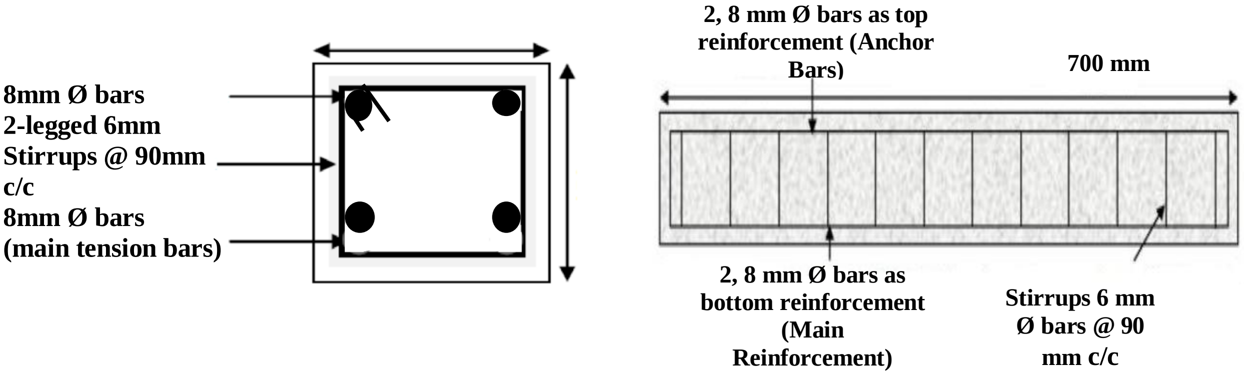


Figure 1: Reinforcement details of beam

1. BONDING PROCEDURE:

The beam after curing for 28 days were applied with fabric using epoxy based adhesive after cleaning the surface of beam of all dirt. Epoxy Resin which comes in two parts Part 1: Epoxy and Part 2: Hardener was mixed in 40:60 proportions. The mixing of the resin was done using two spatula and care was taken to ensure uniform mixing. The adhesive was carefully and uniformly applied on the concrete surface and then fabric was applied over it at bottom surface for single layer. For double and triple layer of fabric, another layer of adhesive was spread on which subsequent layers were prepared. These beams were cured for a week at room temperature to allow the adhesive to get its maximum bonding strength.

1.1 EXPERIMENT SETUP

The Universal Testing Machine (UTM) having a capacity of 600 kN was used for testing all the specimens. A view of the experimental set-up and the arrangement of the deflection measurement devices are shown in fig. 2. Two-point loading system was used. The load is applied at the equal distance of 200 mm from the centre of beam. The span length of the beam is 600mm, same for all specimens.

Table 1 Beam Designation

Beam type	Beam Designation	Number of beams
Reference Beam	O1 and O2	2
Polypropylene Strengthened beam (Single layer)	S1-B-L1 and S1-B-L1	2
Polypropylene Strengthened beam (Double layer)	S1-B-L2 and S1-B-L2	2
Polypropylene Strengthened beam (Triple layer)	S1-B-L3 and S1-B-L3	2
Polyester Strengthened beam (Single layer)	S2-B-L1 and S2-B-L1	2
Polyester Strengthened beam (Double layer)	S2-B-L2 and S2-B-L2	2
Polyester Strengthened beam (Triple layer)	S2-B-L3 and S2-B-L3	2

BEAM TESTING RESULTS:

The beams were tested to the ultimate failure. First of all, two reference control beam were tested and then the remaining twelve beams, two of each kind were tested and the ultimate load as well as the maximum deflection and mode of failure was noted.

The reference beam failed in flexure near the point of application of load with the ultimate load being 76 kN and the deflection was 7.82 mm.

Figure 3: Flexural failure of reference beam

Figure 4: Crushing of concrete in compression and debonding of polypropylene fabric of triple layer

The polypropylene strengthened beam showed an increase in load carrying capacity and a decrease in deflection when compared with the deflection at the ultimate load carrying capacity of reference beam. The failure in case of single and double layer of both the fabrics involved flexural failure with no fabric rupture. However, there was no debonding of fabric-fabric interface or fabric-concrete interface. In case of beam with triple layer of fabric, possibly due to increase in stiffness, the failure of beam in addition to the above failure involved debonding of fabric resulting in reduced load carrying capacity compared to double layer and almost similar to the beam with single layer of fabric and the deflection was more or less same to the double layer of fabric strengthened beam.

Figure 5: Flexural failure of beam strengthened with single layer of Polypropylene fabric

Figure 6: Crushing and debonding of triple layer layer of polyester fabric from concrete

The crushing of beam with triple layer of polypropylene as well as polyester fabric is shown in figure. The crushing of concrete due to breaking of bond between fabric and concrete at upper surface resulted in reduction in load carrying capacity. The table showing the load carrying capacity of the beams and the load vs deflection curve for both the type of fabric strengthened beam is as shown below.

Table 1 Load, deflection and mode of failure of beams

Beam type	Load(kN)	Deflection (mm)	Mode of failure
Reference Beam	76	7.82	Flexural Failure
Polypropylene Strengthened beam (Single layer)	80.75	8.23	Flexural Failure without debonding or fabric rupture
Polypropylene Strengthened beam (Double layer)	87.50	7.56	Flexural Failure without debonding or fabric rupture
Polypropylene Strengthened beam (Triple layer)	75.75	8.4	Flexural failure with debonding of fabric from concrete and crushing of concrete
Polyester Strengthened beam (Single layer)	92.0	8.65	Flexural Failure without debonding or fabric rupture
Polyester Strengthened beam (Double layer)	95.7	8.95	Flexural Failure without debonding or fabric rupture
Polyester Strengthened beam (Triple layer)	79.12	5.70	Flexural failure with debonding of fabric from concrete and crushing of concrete

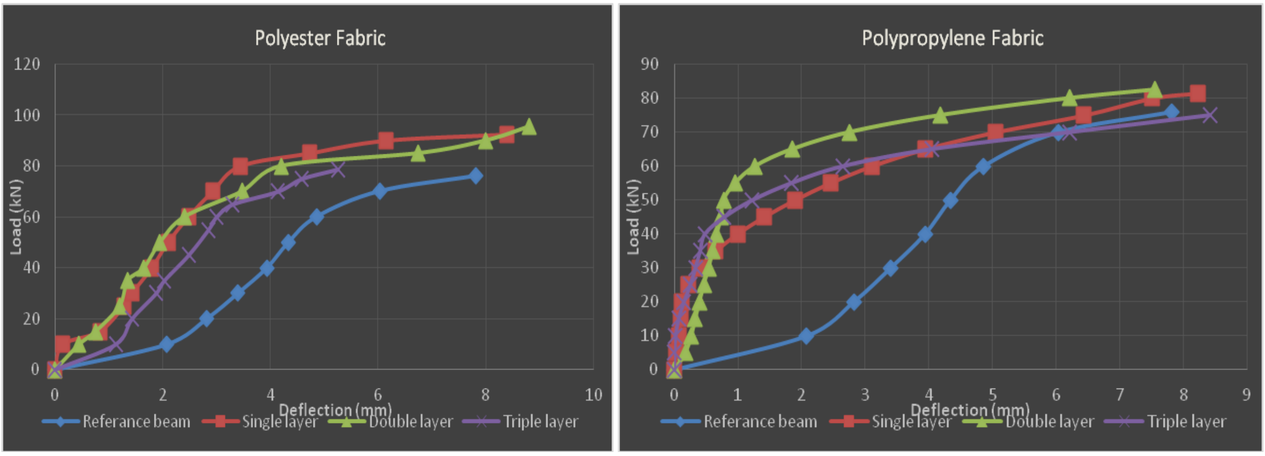


Figure 7: Load v/s Deflection graph of Polyester Fabric applied RC beam and Polypropylene Fabric applied RC beam In Tension zone (at bottom surface)

The reference beam failed at 76 kN showing a maximum deflection of 7.82 mm. The single layer of polypropylene fabric strengthened beam showed a maximum deflection of 8.23 mm at 80.75 kN, however the deflection at ultimate load was about 6.55 mm which is 16% less than reference beam deflection. The beam strengthened with double layer of polypropylene showed a deflection of about 3 mm at 76 kN which is 38.3% less than reference beam. The beam strengthened with triple layer of polypropylene showed a deflection of 0.78 mm at 76 kN which is 9% more than reference beam. However, it is more than beam with single and double layer of fabric possibly due to debonding of fabric.

The single layer of polyester fabric strengthened beam showed a maximum deflection of 8.65mm mm at 92 kN, however the deflection at ultimate load = 76 kN was about 0.83mm which is 10.61% more than reference beam deflection. The beam strengthened with double layer of polyester showed a deflection of about 1.12 mm at 76 kN which is 14.32% more than reference beam. The beam strengthened with triple layer of polypropylene showed a deflection of 2.12 mm at 76 kN which is 27.1% less than reference beam.

A. EXPERIMENTAL FLEXURAL STRENGTH CALCULATION:

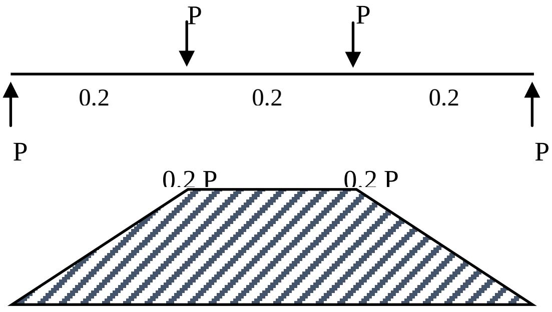


Figure 8: Diagrammatic view of test set-up

The above figure gives a diagrammatic view of the test set-up. The span length of 600 mm = 0.6 m is divided into 3 spans each of 0.2 m with the moment diagram given below it.
For reference beam, Total load obtained by test is 76 kN. Since it is a two point loading system, the load at each point P = 76/2 = 38 kN. Hence M_u = Px0.2 = 38x0.2 = 7.6 kN.m.
The similar moment values are obtained for the beams wrapped in fabric, the values of which are tabulated below.

Table 2 Experimental flexural strength

Beam type	M_u (kN.m)
Reference Beam	7.6
Polypropylene Strengthened beam (Single layer)	8.1
Polypropylene Strengthened beam (Double layer)	8.75
Polypropylene Strengthened beam (Triple layer)	7.58
Polyester Strengthened beam (Single layer)	9.20
Polyester Strengthened beam (Double layer)	9.57
Polyester Strengthened beam (Triple layer)	7.91

B. ANALYTICAL FLEXURAL STRENGTH CALCULATION:

The flexural strength of beam is obtained from the following data:
f_y = tensile strength of steel = 500 N/mm^2
f_{ck} = grade of concrete = 20 N/mm^2
f_f = tensile strength of fabric = 211.2 N/mm^2
A_{st} = area of steel = 100.53 mm^2
b = width of beam = 150 mm
d = effective depth of beam = 150 – 24 = 126 mm
f_{fp} = tensile strength of polypropylene = 8.45 N/mm^2
f_{fe} = tensile strength of polyester = 111.6 N/mm^2
LA_s, LA_{f1}, LA_{f2} = lever arm of steel in tension, fabric in bottom and fabric on sides of beam respectively

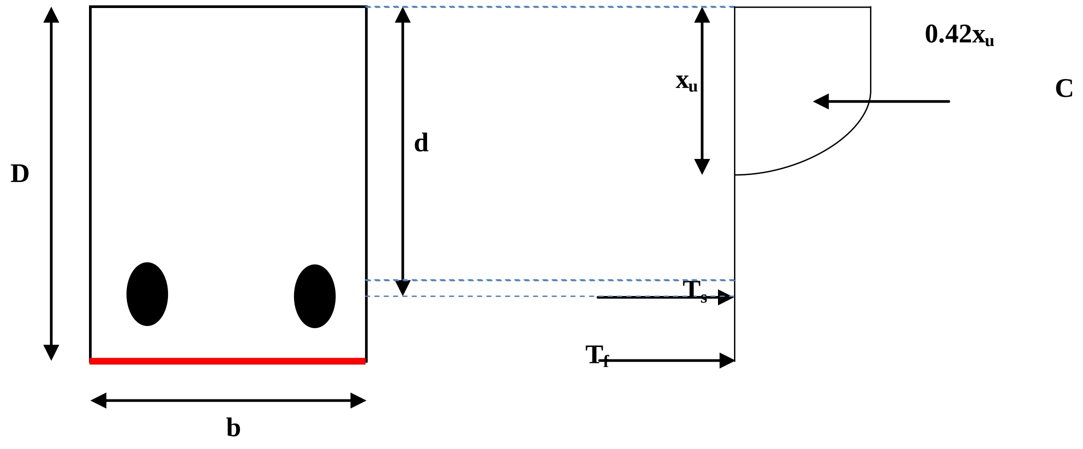
For reference beam;
As per IS:456-2000, for limit state method,

$$Mu = 0.87 \text{ X fy X Ast X d } \left(1 - \frac{fy \; . \; Ast}{d \; . \; fck \; . \; b}\right)$$

$$= 0.87x500x100.53x126 \left(1 - \frac{100.53 \text{ X } 500}{126 \text{ X } 20 \text{ X } 150}\right)$$

= **4.78 kN.m**

- **Beam with single layer of polypropylene fabric in Bottom**



Stress diagram of beam with a layer of fabric in bottom

Cross-Sectional area = 50 X 0.5 mm^2= 25 mm^2.

∴ Tensile strength of fabric = $\frac{8.45}{25}$= 8.45 N/mm^2

As per IS 456:2000, pg. 69, fig. 22

Stress in compression,

σ_c= 0.36 . f_{ck}

∴C = 0.36 . f_{ck}. x_u. b

As per IS 456:2000, pg. 69

Considering FOS (Factor Of Safety) = 1.15 for limit state method.

Stress in tension,

$\sigma_s = \frac{fy}{1.15} = 0.87\ f_y$

∴T_s = 0.87 . f_y . A_s

Tension in Fabric,

T_f= A_f X f_f

Now,

C = T_s+ T_f

∴0.36 . f_{ck}. x_u. b = 0.87 . f_y. A_{st}+ A_f. f_f

∴0.36 X 20 X x_uX 150 = 0.87 (500) (100.53) + (150 X 0.5) (8.45)

∴1080 x_u= 44364.15

∴x_u = 41.08 mm

Now,

$(X_u)_{max}$= 0.46 d = 0.46 x 126 => $(x_u)_{max}$= 57.96 mm (As per IS:456-2000)

Hence, $x_u < (x_u)_{max}$

Therefore, Under Reinforced Section.

Hence,

Moment of resistance,

M_u= T_s (d - 0.42 x_u) + T_f (D – 0.42 x_u)

= 0.87 X 500 X 100.53 [126 – 0.42 (41.08)] + 150 X 0.5 X 8.45 [150 – 0.42 (41.08)]

= 4.93 kN.m

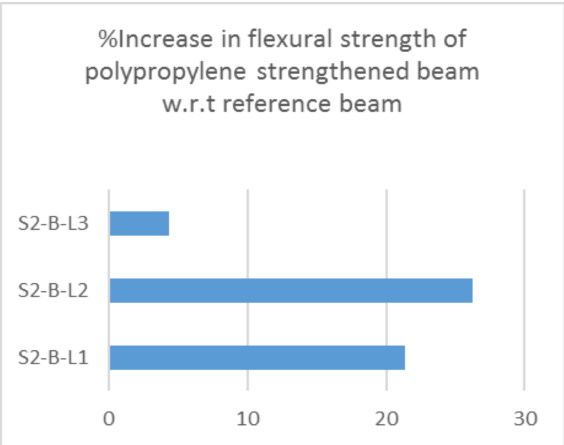
Table 3 Analytical flexural strength

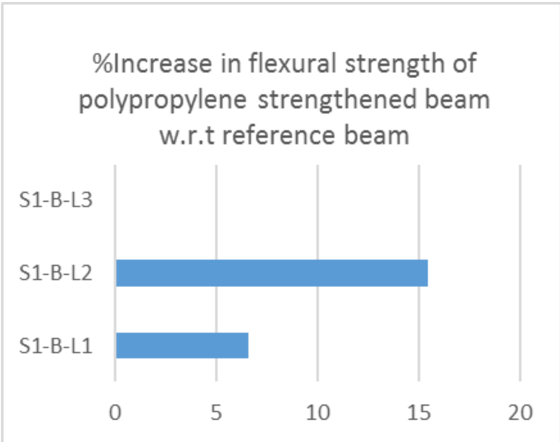
Beam type	M_u (kN.m)
Reference Beam	4.78
Polypropylene Strengthened beam (Single layer)	4.93
Polypropylene Strengthened beam (Double layer)	5.21
Polypropylene Strengthened beam (Triple layer)	5.47
Polyester Strengthened beam (Single layer)	5.71
Polyester Strengthened beam (Double layer)	6.60
Polyester Strengthened beam (Triple layer)	7.45

The experimental values obtained are more than the analytical value. Also, the properties of bond between fabric-fabric as well as fabric-concrete has not been touched which may possibly the reason for high experimental values and lower analytical value.

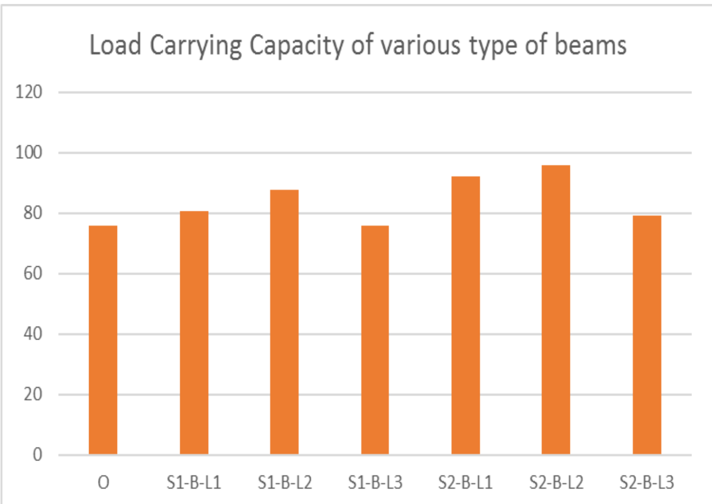
III. RESULT AND DISCUSSION:

The % increase in the moment carrying capacity is shown in bar chart. The beam with triple layer of fabric didn't show the expected rise in flexural strength as calculated analytically. In fact it was less than the single and double layer of fabric. The bottom application of single layer of polypropylene showed an increase of flexural strength by about 6.60%, double layer of polypropylene showed more increase of 15.44% and the triple layer of polypropylene showed no increase with respect to the moment carrying capacity of reference beam.





The beam with single layer of polyester fabric showed an increase of flexural strength by 21.37%, double layer of polyester fabric showed an increase of flexural strength by 26.25% while the beam with triple layer of fabric showed an increase of flexural strength with respect to reference beam.



The ultimate load carrying capacity of these beams as obtained experimentally is given above. The maximum load carrying capacity was obtained with beam strengthened with double layer of polyester. The polyester fabric had in general achieved higher load carrying capacity when compared with polypropylene fabric. The load carrying capacity of single as well as triple layer of polypropylene applied on beam was approximately the same. Hence, the triple layer of fabric is not needed for strengthening. The best option is to use double layer of fabric for the strengthening purpose for either of the fabric.

IV. CONCLUSION

1. The analytical value of moment carrying capacity and load carrying capacity of reference beam was found to be less than the experimental value of moment carrying capacity and load carrying capacity of the beam. Concrete having higher compressive strength than the selected grade of concrete due to the nominal mix design may result in these values.

2. The beam with single layer of fabric showed an increase in load carrying capacity and flexural strength of the beam. The flexural strength of polypropylene and polyester fabric applied beam increased by 6.6 % and 21.37% respectively compared with reference beam. The deflection of a beam with single layer of polypropylene and polyester is about 6.55 mm and 4.1mm at the failure load of reference beam = 76 kN. Thus indicating that the beam deflects less compared to reference beam and is able to resist the deflection initially when tested with single layer of fabric compared to reference beam but gradually the beam with single layer of fabric deflects more without collapse at high loads whereas the reference beam collapses easily at high loads. The beam failed in flexure without the debonding of fabric from concrete.

3. The beam with double layer of fabric the flexural strength of such beam increased by 15.44 % and 26.65% compared with reference beam. The polypropylene and polyester applied beam showed a deflection of 4.65mm and 3.95mm respectively at the failure load of 76 kN in reference beam and showed an increase in load carrying capacity and flexural strength of the beam. The deflection is also less compared to the deflection obtained in single layer of fabric for polypropylene. This is possibly due to increase in stiffness due to increase in layer of fabric.

4. Triple layer of fabric applied in tension area of beam showed no increase for polypropylene fabric applied beam and a very little increase of 4.38% for polyester fabric applied beam in load carrying capacity and the moment carrying capacity of the beam which is lower than analytical calculations. However, the deflection of the beam was about 7.56mm and 8.95mm respectively at maximum load. The beam with triple layer of fabric failed in flexure plus the debonding of fabric from concrete. This may be due the fact that the stiffness of the fabric increases to such an extent that it may not be able to elongate resulting in the debonding and doesn't provide an additional tensile strength.

5. The results of load carrying capacity and moment carrying capacity was higher experimentally compared to the analytical results. The compressive strength of concrete was 25.11 N/mm^2 experimentally instead of 20 N/mm^2 used than that meant to be. But the increase in flexural strength is found to be higher analytically compared to the experimental value. Thus a detailed study is required to analyze the adhesive property of bonding agent and fabric with each other.

6. It can be concluded that deflection at reference beam's ultimate load is less for all fabrics strengthened beam indicating its ability to withstand the onset of initial crack. The beams with single and double layer of both fabrics showed improved performance in flexure suggesting it can also be a suitable alternative to retrofitting by steel for strengthening of beam.

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