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External strengthening of shear deficient beams using AFRP and GFRP Fibers

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***Abstract*— The present study is focused on the nonlinear finite element analysis of Aramid Fiber reinforced polymer (AFRP) strengthened Shear deficient beams. In this study, the stirrup spacing of 750 mm is taken into account for shear deficient beams. The overall length of the chosen beam is 1800 mm and the cross section is 150 mm × 200 mm. Under two-point loading, the behavior of control, shear deficient and AFRP-strengthened beams is investigated. The validated numerical models are then used for studying the efficiency and effectiveness of various strengthening schemes using epoxy impregnated AFRP fabric. The parameters considered include load deformation behavior and percentage increase in maximum load carrying capacity of epoxy impregnated AFRP and GFRP specimens.**

Keywords— Shear deficient beams, Non-linear finite element analysis, Two-point loading, AFRP fabric, GFRP.

I. INTRODUCTION

A reinforced concrete (RC) structure in a severe environment is vulnerable to increasing corrosion-induced deterioration, which reduces the cross-sectional area of the rebars and shortens the structure's lifespan. A structural member's deterioration is influenced by a number of factors. In addition to aging-related structural deterioration, mistakes made during the design and construction phases as well as increased load all contribute to the unsatisfactory performance of structures. In terms of strengthening and repairing of reinforced concrete (RC) structural elements, FRP materials are thought to be the most efficient options right now due to their high strength to-weight ratio and anti-corrosion qualities. Carbon (CFRP), glass (GFRP), basalt (BFRP), and aramid (AFRP) were the most popular FRPs utilized for strengthening.

Nawal Kishor Banjara.et.al. focused on the experimental investigation and nonlinear finite element simulations of shear deficient and Glass Fiber Reinforced Plastic (GFRP) strengthened reinforced concrete beams. In this study, three levels of shear deficiencies—SD1 (20%), SD2 (40%) and SD3 (60%) are taken into account, with stirrups spaced at 375 mm, 500 mm, and 750 mm, respectively. The beam's cross section is 150 mm by 200 mm, and its overall length is chosen to be 1800 mm. The beam's maximum net span is 1500 mm. Under monotonic loading, the shear strengthened beams are tested, and it is discovered that the strengthened shear deficient (SSD-3) beams fail in the flexural mode. The control beam's average load carrying capacity is determined to be 100 kN. It takes two layers of GFRP fabric to fully wrap a SD3 beam in order to bring its load capability. The 45^0 orientation in single ply, 45^0-90^0 orientation in double ply, and 90^0-45^0-90^0 orientation in triple ply strengthening schemes achieve the largest gain in strength for all three classes of deficient beams [1].

Xiangqing Kong. et.al. aimed to assess the retrofitting performance of the Aramid Fiber Reinforced Plastic (AFRP) sheet on the blast response of a reinforced concrete (RC) slab. Only a slight decrease in deflection was noticed once the strengthening layer reached layer 3. As the number of AFRP layers increased, there was no proportional decrease in deflection. The simulation results of a standard RC slab (i.e., a slab that has not been fortified) subjected to blast loads are first compared with the experimental data to verify the numerical models. This comparison reveals very good agreement, with a difference of only 2.6% between the two cases. Additionally, the structural behavior of RC slabs strengthened with AFRP and slabs strengthened with other FRP materials is compared. It is discovered that the AFRP strengthened slab's strengthening effectiveness is slightly lower than that of the CFRP by around 12.9 percent, but higher by about 20 percent than that of the GFRP [2].

Farid Bouziadi. et.al. examined the creep response of reinforced concrete (RC) beams that have been externally reinforced using carbon fiber-reinforced polymer (CFRP) and glass fiber-reinforced polymer (GFRP) laminates. A CFRP retrofitted RC beam has less creep strain than a GFRP-retrofitted beam. For compressive and tensile creep, CFRP laminates reduce creep strain by 20% and 30%, respectively, compared to an un-strengthened beam, whereas GFRP laminates reduce creep strain by 14% and 22%, respectively, compared to the control beam. The reduction in compressive and tensile creep strains at early age is found to be equal to 13 percent and 15 percent, respectively, as compared to strains when the fiber is oriented at 0° for RC beams strengthened with a single layer oriented at 45° [3].

Emine Aydın. et.al. examined various Fiber Reinforced Plastic (FRP) bars and the flexural behavior of hybrid beams made by putting concretes made with various fibers in glass reinforced plastic (GFRP) box profiles. By mixing polypropylene, steel, and glass fiber concrete in a GFRP box profile, hybrid beams were created. Additionally, flexural tests on each type of beam were conducted using carbon, aramid, glass, basalt, and steel bars in the tension zone. In terms of bar types, carbon fiber reinforced plastic (CFRP) bar contributes 70% more to hybrid beam behavior than other types of bar, and steel fiber concrete contributes 53% more than other forms of fiber concrete to hybrid beam behavior [4].

A. Glass Fiber Reinforced Polymer

GFRP or glass fiber reinforced polymer is a variant of FRP. Glass fiber reinforced plastic, commonly referred to as Glass Fiber Reinforced Polymer, is a composite material made by weaving polyester and E-glass fibers together. It is only one-fourth the weight of steel but has tensile strengths that can range from 44 to 2358 MPa and compressive strengths that can reach 140 to 350 MPa. High-quality vinyl ester resin that is resistant to corrosion and extends the life of a concrete structure is one of the components of GFRP. In new construction projects, GFRP in a range of shapes, designs, and textures can be used for both interior and outdoor fixtures.

B. Aramid Fiber Reinforced Polymer

Aramid fibers are strong synthetic fibers that can withstand heat. It is composed of strong synthetic fibers that give it a high elastic modulus, heat resistance, and a density that is 40% lower than GFRP. It can be produced in lengths, bends, and shapes that are customizable.

II. MODELING AND VALIDATION OF SHEAR DEFICIENT BEAM AND CONTROL BEAM

Modeling of shear deficient beam (SD) and control beam is done using element type SOLID 186 and reinforcement using REINF 264 respectively. ANSYS Version 2022 R1 is used for modeling the beams.

A. Validation of Control beam

The overall length of the beam is chosen as 1800 mm, net span is 1500mm and the cross section is 150 mm × 200 mm. The stirrups are placed at a distance of 160mm. The material properties of Concrete and Reinforcement details given by Nawal Kishor Banjara and K. Ramanjaneyulu [1] are adopted in this study. The material properties of Concrete and Reinforcement are given in the table 1 and table 2 respectively.

TABLE 1. PROPERTIES OF CONCRETE

Properties	***Value***
Grade of Concrete	40 MPa
28 days Compressive strength	44.7 N/mm^2
Modulus of Elasticity	31500 N/mm^2
Poisson’s ratio	0.2
Uniaxial Tensile Strength	3.2 N/mm^2

TABLE 2. PROPERTIES OF REINFORCING STEEL

Properties	***Value***
Modulus of Elasticity	200,000 N/mm^2
Poisson’s ratio	0.3
Yiels Stress	500 N/mm^2

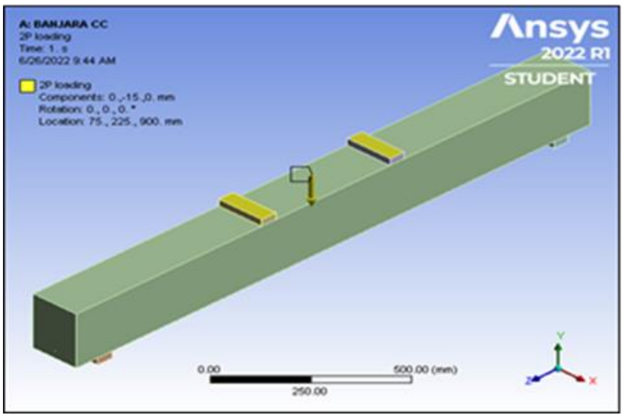

Fig. 1. Support condition of Control beam.

After having modeled the model, the meshing is done as hexahedron mesh. Adaptive mesh controlled size is used for meshing. The load is applied as 70 mm displacement according to displacement Convergence criteria. The support condition is simply supported and is given in figure 1.

Nonlinear static analysis is carried out to find out the maximum load carrying capacity by using ANSYS software. From ANSYS, the maximum load carrying capacity value of 94.612 kN and corresponding deformation of 7.66mm is obtained for Control beam.

B. Validation of Shear deficient beam

The overall length of the shear deficient beam is chosen as 1800 mm and the cross section is 150 mm × 200 mm. The shear deficient RC beam (SD) is having three stirrups i.e. one at the middle and the other two are at the ends of the reinforcement at spacing 750 mm as shown in figure 2. The material properties are same as that of control beam. From ANSYS, the maximum load carrying capacity value of 60.7 kN and corresponding deformation of 4.39 mm is obtained for Shear deficient beam.

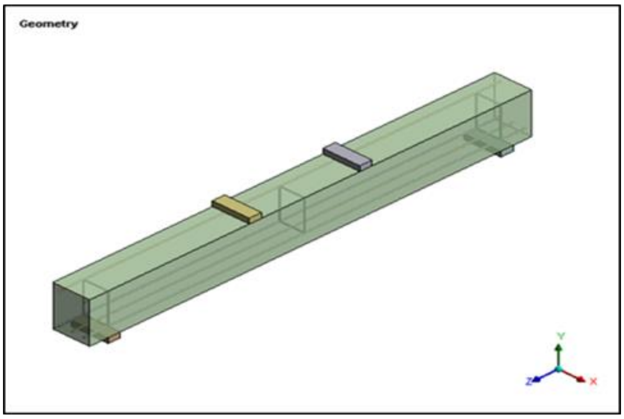

Fig. 2. Model of Shear deficient beam.

III. COMPARISON OF GFRP AND AFRP STRENGTHENED SHEAR DEFICIENT BEAMS

Shear deficient beams externally strengthened with AFRP and GFRP in the shear zone are modeled and analyzed. From the various literatures reviewed the thickness of AFRP is taken as 0.286mm and for the GFRP thickness taken is 0.17 mm. Hence for the present study the thickness of AFRP and GFRP are 0.286mm and 0.17 respectively.

The dimension details and material properties of the beam are same as that for validation of model given in the table 1 and 2. The Material properties of AFRP, GFRP and epoxy [1] are given in table 3.

A. *Modeling*

Shear deficient beams externally strengthened with one layer of AFRP/GFRP in Shear span and two layers of AFRP/GFRP Strip of 50 mm width at the bottom of the beam are modeled and analyzed .The thickness of AFRP is taken as 0.286mm and for the GFRP thickness taken is 0.17 mm.

B. *Analysis*

Analysis is carried out to study the performance of AFRP and GFRP strengthened shear deficient beams as shown in figure 3 and 4 respectively.

TABLE 3. MATERIAL PROPERTIES OF AFRP, GFRP AND EPOXY

Material Properties	***Epoxy***	***AFRP***	***GFRP***
Layer thickness	1	0.286	0.17
Modulus of Elasticity	3800 N/mm2	1310000 N/mm2	71000 N/mm^2
Poisson's ratio	0.21	0.3	0.28
Tensile Strength	45 MPa	47.2 MPa	2000 MPa

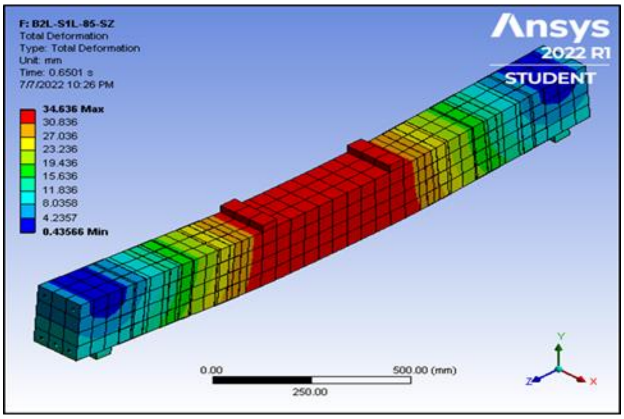

Fig. 3. Deformation model of AFRP Strengthened SD beam.

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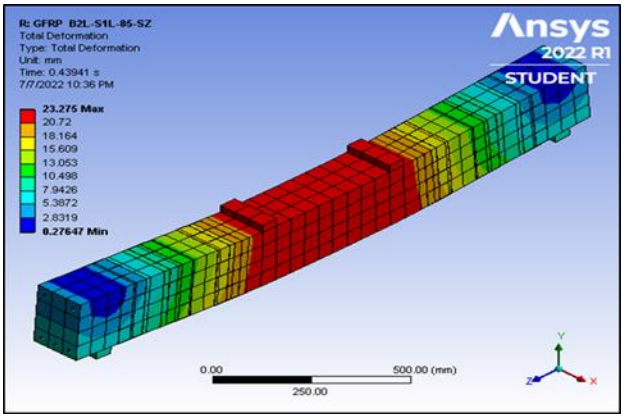

Fig. 4. Deformation model of GFRP Strengthened SD beam

Static analysis of GFRP Strengthened Shear deficient Beam is performed. The load deformation curves are compared as shown in chart 1.

For the GFRP Strengthened beam with one layer thickness the maximum deformation was 23.33 mm at an ultimate load carrying capacity of 81.83 kN. For the AFRP Strengthened beam with one layer thickness the maximum deformation was 34.64 mm at an ultimate load carrying capacity of 112.05 kN.

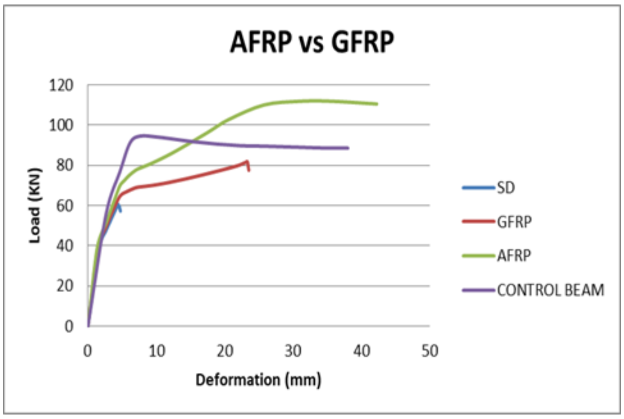

Chart .1. Load deformation comparison of AFRP and GFRP Strengthened SD Beam.

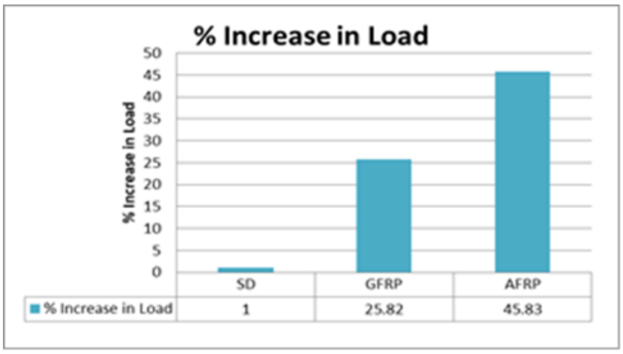

Chart .2. Comparison of percentage increase in load.

Chart 2 shows Percentage increase in load between AFRP and GFRP compared to SD. For the GFRP Strengthened beam the load increased by 25.82% and for the AFRP Strengthened beam the load increased by 45.83% as compared to the shear deficient beam. The load carrying capacity of the control beam is found to be 94.612 kN. This indicates the AFRP is superior to GFRP on improving the load carrying capacity of the Strengthened shear deficient beam and can be used as a substitute in the field of concrete structure reinforcement.

IV. CONCLUSIONS

- For the GFRP Strengthened beam the load increased by 25.82% and for the AFRP Strengthened beam the load increased by 45.83% as compared to the shear deficient beam.
- This indicates the AFRP is superior to GFRP on improving the load carrying capacity of the Strengthened shear deficient beam and can be used as a substitute in the field of concrete structure reinforcement.

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