ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

FLEXURAL STRENGTH AND DURABILITY OF REINFORCED CONCRETE BEAMS STRENGTHENED BY BASALT FIBRE REINFORCED POLYMER COMPOSITE

AKSHAY. K. UDAY[1], Dr T. FELIXKALA [2]

Research Scholar, Department of Civil Engineering,[1]

Joint Registrar-Student Affairs and Professor, Department of Civil Engineering,[2]

Dr M.G.R Educational and Research Institute, Maduravoyal, Chennai, India[1,2]

Email is: akshay.kandaswamy@gmail.com[1] , kalastrut@yahoo.co.in[2]

ABSTRACT

Owing to its ecologically friendly manufacturing technique and good mechanical qualities, basalt fiber has lately gained favor in concrete applications. Basalt fibers are significantly less expensive, and a few researchers have lately studied novel fibers for concrete. Fiber concrete is one of the most extensively utilized methods for enhancing concrete's flexural and compressive strength. Steel, polypropylene, carbon, glass, and polyester are some of the common fibers used in concrete. This study presents results of Fibre Reinforced Polymer (FRP) materials based on Basalt Fibre Reinforced Polymer (BFRP) materials with natural fibers are less expensive, have superior durability, and are subjected to a much greater fracture strain. The goal of this research is to see if employing BFRP textiles to reinforce RC components in situ is feasible. Externally reinforcing RC structural members with BFRP textiles is an encouraging substitute to conventional RC structural strengthening and repair procedures. The test matrix includes concrete for the composite columns, an epoxy resin matrix, and further specimens having an accumulative number of BFRP layers externally strengthened. In increasing layers, two and three layers of BFRP fabric are used. As associated to control beam, this strengthening procedure resulted in substantial strength improvements in all of the beams. The application of BFRP materials as an exterior strengthening component resulted in significant strength improvements while preserving beam ductility over the control specimen. Moreover, graphs are also plotted against equivalent column examples, and their relevance is discussed. The total deformation and Von-Mises stress criteria are thought to be the most accurate ways for design engineers to forecast a material's strength. This unique way of preserving and strengthening existing RC structures in situ saves money and protects the environment for countries striving to repair and maintain aging infrastructure.

Keywords: Flexural Strength, Concrete Beams, Basalt Fibre Reinforced Polymer (BFRP), Reinforced Concrete (RC), Durability, Ductile

1. INTRODUCTION

The finite element approach is a broad methodology for obtaining approximate solutions to boundary-value issues. The approach entails partitioning the domain of interest into a finite number of simple sub-domains, known as finite elements, then constructing an approximation of the solution across the finite element collection using variation principles. The computation of structural reactions matching to a particular load on a certain structure is known as structural analysis. It suggests that structural analysis has three essential components: the structure, the loading, and the reaction. The quantities defining the first two are presumed to be known in structural analysis, whereas the quantities defining the third are sought. Different programs present a variety of empirical and semi-empirical deflection computation methods. ACI is the most well-known and widely used technique for determining deflection. However, some column behavior and material features are overlooked by this technique. It ignores the variability of concrete, for example, and idealizes concrete as a homogeneous and isotropic substance. The powerful finite element approach can overcome these restrictions. Proper Finite Element (FE) modeling may tolerate material non-homogeneity and difficult boundary conditions. Previous work on seismic ground motion simulation using finite-element approaches has been restricted. Because there is little information available for eccentrically loaded circumstances with restricted ends, all analytical studies of the problem is focused on determining column capacity. It is necessary to monitor the detailed behavior of a column that impacts the strengths, as well as its behavior as the load increases.

The majority of RC column analysis methods are centered on compatibility and equilibrium. To observe genuine behavior, the section's materials attributes are integrated. The transform area idea, in which steel under compression and tension is substituted by comparable concrete areas, may be used to perform elastic analysis on an RC beam. In various regions of the world, computer programs for RC structure analysis are being developed. The goal of this project is to create a computer program using ANSYS to analyze the deflection of a column under lateral load, investigate the effect of flexural reinforcement strength and ratio on the column's carrying capacity, and broaden the scope of the program so that analysis and design can be repeated to account for changes in the column's capacity due to material changes.

For the past three decades, composite materials, plastics, and ceramics have been the talk of the town. With their extensive range of applications, they have dominated the market, spanning virtually all fields and divisions. Composite materials have dominated the current engineered material industry since they are used in most everyday items and alcove applications. Unlike cement, steel, and other materials, composite materials may be altered by changing their structural features. Material as well as structural design is required for each composite component. The designer may adjust the stiffness, thermal expansions, and other characteristics of composites. While composing a composite product, a lot of research and analysis goes into it, such as the careful selection of reinforcement types that assist meet particular technical criteria. The most frequent matrix materials are polymeric composites. There are two main causes behind this. The reason for this is that the mechanical characteristics are insufficient for structural purposes. In comparison to ceramics or even metals, the stiffness and strength are poor. By strengthening the polymer with additional components, this can be avoided.

Fibers are thread-like components that take the form of extended hair-like filaments. They are used as a component in composite materials. Natural fiber composites have a lower specific weight as equated to glass fiber composites, ensuing in higher stiffness and specific strength. It is a renewable energy source that produces oxygen from carbon dioxide and may be produced with little input and at a cheap cost. The major source of strength is fibre, while the matrix binds them all together in form and stress-handling positions. Loads are transported in a longitudinal direction. FRP is often wrapped around the circumference of columns, either closed or completely wrapped. This not only improves shear resistance, but it also improves compressive strength under axial stress, which is critical for column design. Concrete or steel-plate jackets are more expensive than reinforcements and FRP jackets. They may be utilized to significantly improve ductility and strength while reducing stiffness. Certain materials are employed to accomplish the modeling according to their particular regulations and standards, as described in this study. The composite columns are made of concrete, and the fresh composite is made of an epoxy resin matrix and hemp composite. The newly produced composite contains Basalt Fiber, which bonds the fibers together and gives the composite excellent tensile strength. When composite columns are subjected to UDL – uniformly distributed axial load, their behavior is determined. It is carried out by creating a preliminary design of two various types of column constructions made of two different materials, and the study involves the supplied columns in two different dimensions, 150 mm, 150 mm and 150 mm. For each column's prototype, an efficient 3-D finite element model is created, and then various characteristics such as equivalent von-mises stress criterion, total deformation, as well as shear stresses are equated.

The organization of the paper is described as follows: Section 2 illustrates an associated survey based on concrete beams strengthened with Basalt fiber, Section 3 defines the proposed methodology based on Strengthening using FRP, Flexural Strengthening using FRP, Modeling of concrete Column and load beam calculation, Sections 4 and 5 explain the results and discussion, respectively, and Section 5 concludes.

2. LITERATURE REVIEW

Jayasuriya et.al [1] and Bastani et.al [2] are utilized for repairing structural steel members. A rusted steel beam is restored using externally connected BFRP fabrics in these investigations. Duic et.al [3] investigated effects of rehabilitate deep RC beams. Bond and durability properties of BFRP and Polyethylene Naphthalate (PEN) fiber/PEN FRP is examined by Choi et al (2020). Bond test findings showed that BFRP with a high elastic modulus (EBF = 68.4 GPa) develops high bond stress over a short distance, whereas PEN FRP with a low elastic modulus (EPEN = 17.4 GPa) develops comparatively low bond stress over a longer length. After 4 months of exposure to wet and alkaline environments, PEN FRP showed extremely good behavior in the beam bond test, whereas BFRP showed intermediate behavior. All of the durability tests undertaken in this study found that PEN fiber/FRP performed satisfactorily.

Hughes et al. [4] investigate the feasibility of employing BFRP textiles to reinforce RC components in place. The maximum number of layers of BFRP fabric that can be utilized to reinforce these RC beams is discovered in this experiment prior to the failure mode changes. FE modeling and analysis of RC beams reinforced with BFRP fabrics are presented by Stephen et al. [5]. The FE models were shown to have a substantial link with the test findings, and they could predict the RC beams' plastic and elastic behavior. Basalt fiber fabric appears as a good material for the purpose of strengthening and rehabilitating RC beams, according to the findings of the FE study.

The goal of Chiadighikaobi et al. [6] is to provide a framework for evaluating the durability of lightweight expanded clay basalt fiber polymer reinforced concrete when exposed to NaCl. Karaburc et al. [7] used nano Ground Calcium Carbonate (GCC) to evaluate the mechanical and durability features of Basalt fiber reinforced Pumice Lightweight Concrete (BPLC). In the study, GCC is used as a substitute material for standard Portland cement at percentages of 5%, 10%, 15%, 20%, and 25%, while BF with a 6 mm length is added in two contents of 0.5 percent and 1% by volume. Galishnikova et al. [8] conduct an experimental investigation into the mechanical properties of structural expanded clay basalt fiber concrete. The primary goal of this research is to examine how chopped basalt fiber influences the strength of expanded clay concrete. According to the findings of the testing, expanded clay concrete with a high amount of basalt fiber has a better strength.

The goal of this work by Chiadighikaobi et al [9] is to investigate and verify the influence of saltwater on the strength of expanded clay concrete, as well as a best technique to enhance the mix by utilizing basalt fiber. After being exposed to saline water, the compressive strength of the specimens decreases somewhat, the number of young modules increases, and the mass of the specimen's increases. The research's novel contribution is that adding 1.2 percent basalt fiber to the mix reduces or eliminates the influence of saltwater on concrete properties. In this work, Biradar et al. [10] investigate the performance of concrete blended with basalt fibers and their effect on the mechanical characteristics of concrete. Basalt fibers are added to M40-grade concrete BFRC in several percentages (0, 0.1, 0.3, and 0.5 percent), and compressive, tensile, and bending strength are all assessed. According to the data, the concrete containing 0.3 percent fibers had the highest strength. Sim et al[11] investigated thin RC beams that have been externally reinforced using BFRP textiles and discovered that this approach boosted both ultimate and yield loads increase by up to 30%. Serbescu et al.[12] found that using BFRP textiles to reinforce RC beams is promising, however there is limited data on full-size specimen testing. The goal of this study is to address a knowledge gap by looking at the effects of employing BFRP textiles to reinforce full-sized RC beams.

3. MATERIALS AND METHODS

FRP composites are a mixture of two or more materials that, when properly combined, yield a new material with qualities not found in the original materials. Fiber reinforced composite materials are made up of high-tensile-strength fibers and an adhesive that holds the fibers together. In civil engineering business, aramid, basalt, carbon, and glass are often utilized fibers. Epoxy is typical glue that protects the fibers, provides durability, and dispenses the load to fibers under loading conditions. An increased demand for FRP is due to its effective application in several domains like as aerospace, sports, recreation, and the car industry. The qualities of FRP composites, as well as their adaptability, have resulted in considerable improvements in rehabilitation efficiency, dependability, and cost effectiveness.

3.1 Strengthening using FRP

As they are designed to carry both horizontal and vertical pressures, concrete beams are the most significant component in structural engineering, such as seismic or wind loads. They, like all other concrete elements, are vulnerable to circumstances when structural loads increase. Flexure failure and diagonal tension (shear) failure are the two most common methods for RC beams to fail. Because shear failure is ductile while flexural failure is brittle, shear failure is preferred. Stress redistribution is possible due to ductile breakdown and offers occupants advance warning, whereas a brittle collapse occurs suddenly and is hence devastating. External FRP reinforcement may be divided into two categories: shear and flexural strengthening.

3.2 Flexural Strengthening using FRP

FRP laminates are applied to the stress zone of Reinforced Cement Concrete (RCC) members with epoxy for flexural strengthening, acting as external tension reinforcements to strengthen the flexural strength of RCC members. FRP composites glued to the stress zone of structural elements such as beams, plates, and columns can be used to reinforce them in flexure. Epoxy is a typical adhesive for this objective. Fibers are oriented in the same direction as strong tensile strains. FRP strips and sheets, both prefabricated, are employed.

To complete the modeling, certain materials are employed in accordance with their individual codes and standards. The composite columns are made of concrete, and the fresh composite is made of an epoxy resin matrix and hemp composite. The newly produced composite contains a Basalt Fiber layer that bonds the fibers together and gives the composite extraordinary tensile strength.

New Composite formed with layer of 2 mm thickness

Model I: Concrete + Basalt + Basalt Fiber

Model II: Concrete + Basalt + Basalt + Basalt Fiber

3.3 Modeling of concrete Column

Figure 1 shows a 230x230x1500 cuboid size column that is investigated and modeled in CREO in this study. The design did not include any tie reinforcement. Each column is given a height of 150 mm in accordance with IS 456(2000) and is only exposed to axial stress at the top.

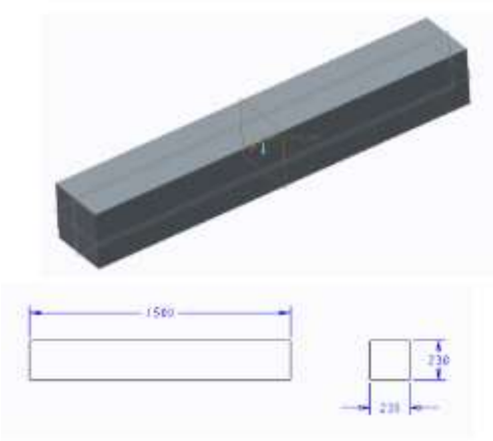


Figure.1 CREO model of concrete column with dimensions

3.4 Material Properties

Tables 1 and 2 detail the material characteristics. The American Society for Testing and Materials (ASTM) provides an appropriate guideline for determining all material attributes. The concrete material parameters in Table.1 is found utilizing ASTM C39/39M (2016), while the BFRP material properties in Table 2 is determined using ASTM D3039 (2014).

Table 1: Concrete Material Properties

S. No	Material Parameter	Concrete
1.	Density (kg cm-3)	2400
2.	Young's Modulus (MPa)	30000
3.	Poisson's Ratio	0.18

Table 2: BFRP Mechanical Properties

S. No	Material Parameter	BFRP
1.	Density (kg cm-3)	2670
2.	Young's Modulus (MPa)	46000
3.	Poisson's Ratio	0.27

3.5 Load Calculation on beam

The models provided in Segment 3.2 forecast the ultimate load within the context of a non-linear analysis, accounting for the real bending moment M25 that each section of the RC beam achieves at the ultimate, This may differ from the greatest bending moment M_{max} that each element might achieve if operating independently at the ultimate (maximum moment). The following is a description of the method utilized to find the ultimate load pertaining to RC beam having a particular geometry.

Grade of Concrete = M25

M25 concrete is used fck = 25 N/mm2

Ec = 5000 Root of fck , Ec = 25000 N/mm2

The concrete's Poisson's ratio (μ) value is 0.2, and concrete has a self-weight of approximately 2400 kg/m3, or 24.54 kn/m3. Note: 1 Kilonewton Is Equal to 101.9716 Kilograms).

Let's say the cross-section dimensions of the beam are 230 mm x 230 mm without the slab.

1. Beam length Size - 1500 mm, breadth = 230mm, Width = 230mm
2. Concrete Volume = 0.23 x 0.23 x 1.5 =0.07935 m³
3. Concrete Column Weight = 0.07935 x 2400 = 190.44 kg = 1.86 KN

Then, using IS code 456 2000, compute the load bearing capacity of a square beam with dimensions of 230 mm x 1500 mm. Beam formula load bearing capability is explained below.

Pu = 0.4fck.Ac

Where Pu denotes the column's ultimate axial load bearing capability, fck denotes the concrete's comprehensive strength properties, and Ac denotes the area of concrete in the column to be determined.

Hence we need to find the following value

1) Ac = Area of concrete

The surface area of concrete Beam Asc = 2(lb + bw + lw)

= 2(1500x230 + 230x230 +1500x230)

= 864800 mm2

Area of concrete Beam = 0.864 m2

Including all of the values in the calculation for Beam's ultimate load bearing capability

Pu = 0.4fck.Ac

Where, fck = 25 N/mm2, Ac = 864800 mm2

Pu = ultimate load carrying capacity of beam

Pu = (0.4× 25×864800) N, Pu = 8648000 N, Pu = 8648 KN

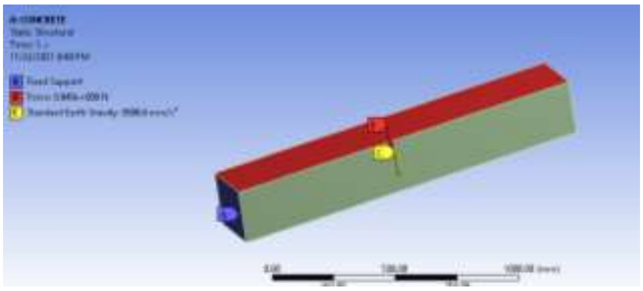
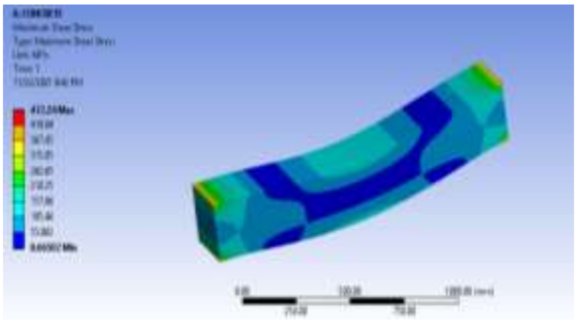


Figure.2 Loading and boundary condition

As a result, the static structural analysis determines a uniformly



distributed axial load with fixed support, with a total load operating on the beam of 8648 KN, as shown in Figure. 2. For the preceding calculation, the ultimate load bearing capacity of the Beam is approximately 8648 KN, and the standard earth gravity is -9806.6 mm/s^2.

4. RESULTS AND DISCUSSION

The goal of this project is to create a computer program using ANSYS to analyze the deflection of a column under lateral load, investigate the effect of flexural reinforcement strength and ratio on the column's carrying capacity, and broaden the scope of the program so that analysis and design can be reiterated to account for changes in the column's capacity due to material changes.

The goal of this study is to see how axial compressive load affected concrete and composite columns. A study of the notion of the finite element technique is carried out with all relevant parameters and data is collected. This information is then evaluated to learn more about the behavior of enclosed composite columns under uniformly distributed impact loads. Von-misses stress calculation, various types of stresses and strains (shear and normal), and deformations are among the factors investigated. Figures 3, 4 and 5 demonstrate an efficient 3-D finite element model for a concrete column prototype, followed by a comparison of different parameters such as total deformation, equivalent von-misses stress criterion, and shear stresses. Table 3 shows the concrete column constructions used in this study as depicted by deformed structural models, together with their respective maximum and minimum values.

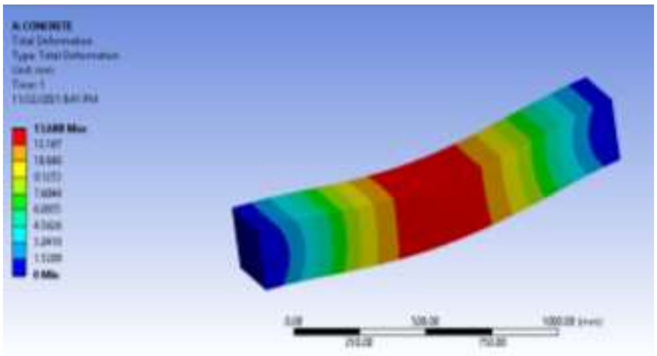


Figure.3 Total deformation

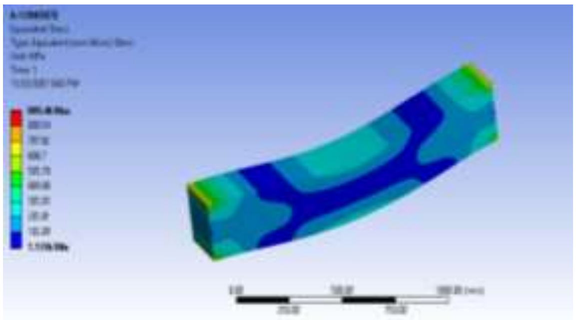


Figure.4 Equivalent (Von-Misses) Stress

Figure.5 Maximum Shear Stress

Table.3 Concrete models for maximum and minimum values

Type	Total Deformation	Equivalent (von-Mises) Stress	Maximum Shear Stress
Minimum	0. mm	1.1706 MPa	0.66502 MPa
Maximum	13.688 mm	909.46 MPa	472.24 MPa

Figures 6, 7 and 8 show the results of a 3-D finite element model for concrete with Basalt Fiber + Basalt Fiber Composites, followed by a comparison of several parameters such as total deformation, equivalent von-misses stress criterion, and shear stresses. Table 4 shows the concrete with Basalt Fiber + Basalt Fiber composites column structures utilized in this work as depicted by deformed structural models, together with their corresponding maximum and minimum values.

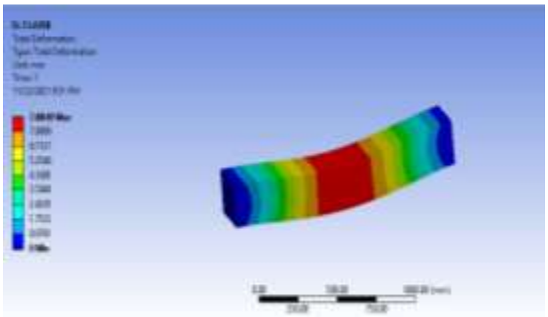


Figure.6 Total deformation

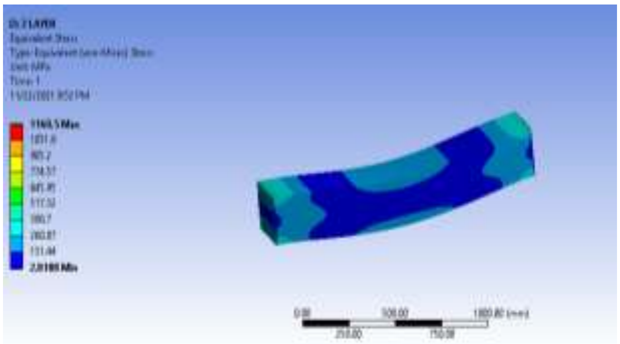


Figure.7 Equivalent (Von-Misses) Stress

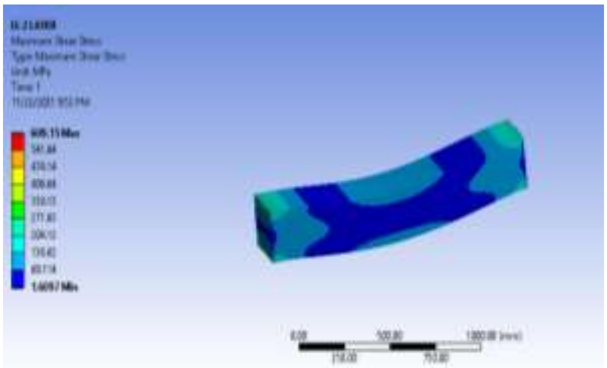


Figure.8 Maximum Shear Stress

Table.4 Concrete with Basalt Fiber + Basalt Fiber composites models for maximum and minimum values

Type	Total Deformation	Equivalent (von-Mises) Stress	Maximum Shear Stress
Results			
Minimum	0. mm	2.8188 MPa	1.6097 MPa
Maximum	7.8849 mm	1160.5 MPa	609.15 MPa

Figures 9, 10 and 11 show the results of a 3-D finite element model for concrete with Basalt Fiber + Basalt Fiber + Basalt Fiber composites, followed by a comparison of several parameters such as total deformation, equivalent von-misses stress criterion, and shear stresses. Table 5 shows the concrete with Basalt Fiber + Basalt Fiber +Basalt Fiber composites column structures utilized in this work, as depicted by deformed structural models with their corresponding maximum and minimum values.

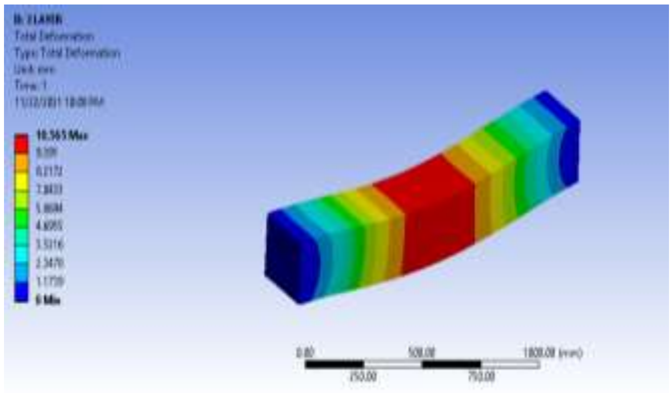


Figure.9 Total deformation

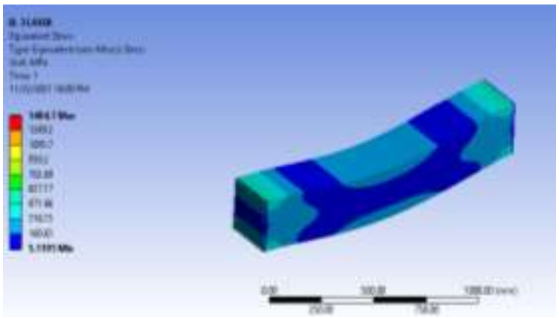


Figure.10 Equivalent (Von-Misses) Stress

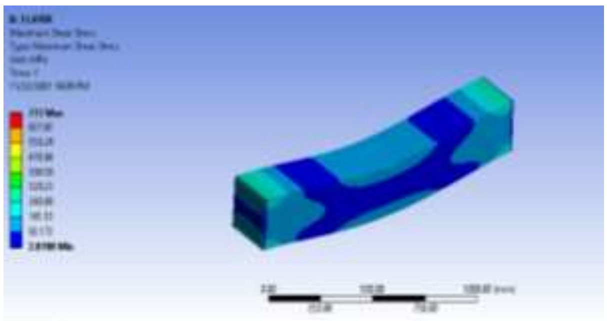


Figure.11 Maximum Shear Stress

Table.5 Concrete with Basalt Fiber + Basalt Fiber+ Basalt Fiber composites models for maximum and minimum values

Type	Total Deformation	Equivalent (von-Mises) Stress	Maximum Shear Stress
Results			
Minimum	0. mm	5.1195 MPa	2.8188 MPa
Maximum	10.565 mm	1404.7 MPa	717. MPa

Plots of reduced data and visuals of column behavior are used to make observations. In addition, graphs are plotted against equivalent column examples, and their relevance is shown in figures 12 and 13. The total deformation & Von-Mises stress criteria is widely regarded as the most accurate approach for design engineers to forecast a material's strength. A structural engineer can use this data to predict if his designs would fail. If the maximal Von-Mises stress value created in the material is larger than the material's strength, it very certainly will. It is based on the distortion energy idea.

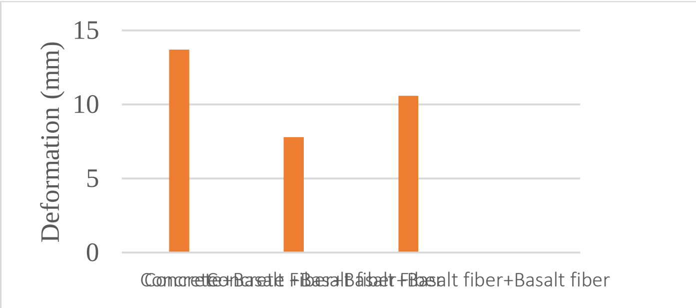


Figure.12 Graphical representation of deformation for concrete with composite column

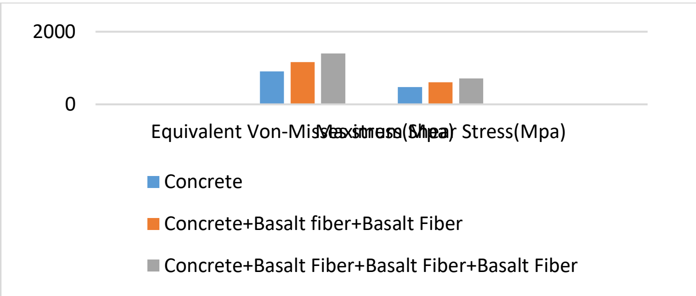


Figure 13 Comparative analysis of concrete with composite columns

5. CONCLUSION

The paper concludes the flexurally strengthening RC beams, which are externally bonded BFRP is a viable alternative to other FRP fabrics. The confinement effect of composite beams increases strength and ductility up to a particular beam length, as evidenced by the results and comparisons. With a rise in composition ratio, the strain produced in the structure increases.

When it comes to shear or normal stress, different types of composite beams behave differently. The numerical model used in this study proved to be quite successful in terms of the findings obtained under various material circumstances. As a result, it may be employed in a variety of situations, including materials, beam size, layer thickness of non-elasticity concrete, and beam resistance or ductility. These characteristics are well-defined and shown in order to compare the efficiency and strength of these various sorts of columns. The easiest technique for design engineers to anticipate the strength of a certain material is to use deformed structural models with their associated maximum and minimum values. The material's maximum Von-Mises stress value is larger than the material's strength. The current numerical model has been shown to be effective in the safe design and cost-effective reinforcement of concrete Beams utilizing natural FRP.

Reference

[1] Jayasuriya, S., Bastani, A., Kenno, S., Bolisetti, T., and S. Das, "Rehabilitation of Corroded Steel Beams Using BFRP Fabric," Structures, vol. 15, no. March, pp. 152–161, 2018.

[2] Duic, J., Kenno, S., and Das, S."Flexural Rehabilitation and Strengthening of Concrete Beams with BFRP Composite," J. Compos. Constr., vol. 22, no. 4, pp. 1–11, 2018.

[3] Donguk Choi, Youngho Kim, Batzaya Baasankuu and Gombosuren Chinzorigt, "Bond and durability investigation of basalt fiber and PEN fiber reinforced composites for concrete applications", Journal of Asian Concrete Federation, Vol. 6, No. 1, pp. 37-51, June 2020 ISSN 2465-7964 / eISSN 2465-7972 https://doi.org/10.18702/acf.2020.6.6.37.

[4] Eric Hughes, Adeyemi Adesina, Bruno Paini, Sreekanta Das and Niel Van Engelen, "Strengthening of Concrete Beams with Basalt Fibre Reinforced Polymer", Structures Congress, 2020.

[5] Iyinoluwa Stephen, Eric Hughes and Sreekanta Das, "Reinforced concrete beams strengthened with basalt fibre fabric – A parametric study", Structures, Volume-27, 2020, pp-309-318.

[6] Paschal Chimeremeze Chiadighikaobi, Hayder Abbas Ashour AlAraza , Nmecha Udo Ibeh , Milad Ahmad Niazmand, Muritala A Adegoke, Bewuket Bekele Tefera and Jean Paul Vladimir, "Durability assessment of basalt fiber polymer as reinforcement to expanded clay concrete in harsh environment", Cogent Engineering, 2021, 8: 1918855, https://doi.org/10.1080/23311916.2021.1918855.

[7] S.N. Karaburc, S.A. Yildizel and G.C.Calis, "Evaluation of the basalt fiber reinforced pumice lightweight concrete", Magazine of Civil Engineering, vol-94, issues-2, pp-81–92. https://doi.org/10.18720/MCE.94.7.

[8] V. Galishnikova, M. Kharun, D.D. Koroteev and P.C. Chiadighikaobi, "Basalt fiber reinforced expanded clay concrete for building structures. Magazine of Civil Engineering",2021, Vol- 101, issues-1, pp-1-12. Article No. 10107. https://doi.org/10.34910/MCE.101.7.

[9] P.C. Chiadighikaobi, H.A.A.Alaraza and S. Abdo, "Structural Strength of Expanded Clay Basalt Fiber Concrete Exposed to Salty Environment", International Journal on Emerging Technologies, 2021, Vol-12, issues-2, pp- 98-103.

[10] Sangmesh V Biradar, M Sai Dileep and Dr T Vijaya Gowri, "Studies of Concrete Mechanical Properties with Basalt Fibers", ScTACE, 2020, doi:10.1088/1757-899X/1006/1/012031.

[11] Sim, J., Park, C., and Moon, D. "Characteristics of basalt fiber as a strengthening material for concrete structures," Compos. Part B Eng., vol. 36, no. 6–7, pp. 504–512, 2005.

[12] Serbescu, A., Guadagnini, M., and Pilakoutas, K, "Applicability of Basalt FRP in strengthening of RC beams," in Fourth International Conference on FRP Composites in Civil Engineering, 2008, no. July, pp. 22–24.