UDK 625.843:666.193 ISSN 1580-2949
Original scientific article/Izvirni znanstveni članek Mater. Tehnol.

STRUCTURAL PERFORMANCE EVALUATION OF BASALT FIBER-REINFORCED CONCRETE BEAMS AND BEAM-COLUMN JOINTS: AN EXPERMENTAL INVESTIGATION

EKSPERIMENTALNO RAZISKOVANJE STRUKTURNIH LASTNOSTI BAZALTNIH VLAKEN V ARMIRANO BETONSKIH NOSILCIH IN NJIHOVIH SPOJIH

Gnanasundar Valarmathy Moorthy[1], Palanisamy Thangaraj[2], Thirugnanam Shanmugham[3]

[1]Bannari Amman Institute of Technology, Sathy, Erode-638401, TamilNadu, India
[2]National Institute of Technology,Surathkal-575025, Karnataka, India
[3]Builders Engineering College,Erode-638108, TamilNadu, India

Prejem rokopisa – received: 2025-04-04; sprejem za objavo – accepted for publication: 2025-07-02

doi:10.17222/mit.2025.1430

This study presents an experimental investigation into the structural behavior of basalt fiber-reinforced concrete (BFRC) beams and beam-column joints under cyclic loading conditions. The research aims to explore the mechanical enhancements provided by basalt fibers, particularly in improving tensile strength, ductility, crack resistance, and overall load-bearing capacity. Basalt fibers with a diameter of 30 µm and a length of 25 mm were incorporated at optimal volume fractions of 0.250 % within the concrete matrix. The study examines the effect of the fiber content, fiber orientation, and mix properties on the mechanical properties of BFRC. The results indicate a significant improvement in the flexural and impact resistance, suggesting its suitability for structural applications. The investigations further extend to beam-column joints, demonstrating enhanced seismic resilience, stiffness, and energy dissipation. The findings highlight the potential of BFRC as a sustainable and durable material for modern construction, particularly in seismic-prone regions.

Keywords: basalt fiber, beam, beam-column joint, structural performance, seismic resistance

V članku avtorji predstavljajo eksperimentalno raziskavo strukturnega obnašanja nosilcev in spojev nosilcev iz z bazaltnimi vlakni ojačanega armiranega betona (BFRC; angl.: basalt fiber-reinforced concrete) med statičnimi in dinamičnimi (cikličnimi) obremenitvami. Namen raziskave je bil izboljšati statično in trajno dinamično trdnost betona z dodatno ojačitvijo iz bazaltnih vlaken. Avtorji so ugotavljali zlasti, kakšno je izboljšanje natezne trdnosti, duktilnosti, odpornosti na razpoke in celotne nosilnosti izbranih betonskih nosilcev ter njihovih spojev. V betonsko matrico so avtorji vgradili predhodno določeno optimalno vsebnost (0,25 mas. %) bazaltnih vlaken premera 30 µm in dolžine 25 mm. V študiji so preučevali vpliv vsebnosti in orientacije vlaken ter lastnosti mešanice na mehanske lastnosti BFRC. Eksperimentalni rezultati so pokazali, da je prišlo do znatnega izboljšanja upogibne trdnosti armiranega betona in njegove odpornosti proti udarcem, kar kaže na njihovo primernost za uporabo v gradbeništvu. Raziskave so nadalje razširili na dejanske gradbene nosilce in spoje in izkazalo se je, da imajo le-ti povečano odpornost proti potresom, togost in disipacijo energije. Avtorji zato v zaključkih poudarjajo velik potencial BFRC kot trajnostnega in vzdržljivega materiala za sodobno gradnjo, zlasti v potresno ogroženih območjih.

Ključne besede: bazaltna vlakna, betonski nosilci, betonski spoji, strukturne lastnosti, nosilnost, seizmična (protipotresna) odpornost

1 INTRODUCTION

Introducing basalt fiber-reinforced concrete as an innovative technique to enhance concrete structural behavior, this study involves the integration of basalt fibers into conventional concrete. The investigation focuses on the structural performance of a single-bay, two-story concrete frame. Fundamental parameters such as load-carrying capacity, hardness, flexibility, and energy dissipation limit are analyzed. A three-straight reinforced concrete frame, both with and without a shear wall in the center, is subjected to static cyclic horizontal loads. The Assessment covers the entire range of loading limits, from the basic flexible period to the ultimate load. The load-carrying capacity is found to be 1.67 times greater than the exposed mold and twice that of the shear wall frame. This enhanced capacity is attributed to the contribution of the shear wall, absent in the exposed covering, and the second redistribution of column section elements, lacking in the shear wall frame. The total energy dissipation limit of the double covering is 0.374 times that of the exposed covering and 0.3 times that of the shear wall frame, despite being subjected to a higher lateral load. The specimens undergo horizontal reversed cyclic loading until reaching equitant load-carrying capacity or 80 % of the failure load.[1] Steel fibers are employed to assess pre and post-fatigue flexural properties[2], while Spanish broom (natural fiber), flax, hemp-shaped broom

*Corresponding author's e-mail:
gnanasundar@bitsathy.ac.in (GnanasundarValarmathy Moorthy)

fiber,[3] glass fibers,[4] and sisal fibers (natural fiber)[6] are used to determine various cement composite and concrete mechanical parameters. In the second stage, the retrofitted examples, exposed to a similar loading arrangement, exhibit superior behavior.[7] Researchers also investigate the correlation between ductility and global displacement flexibility significantly during seismic earthquakes. Mathematical models for five-story and ten-story RC frames are developed, and pushover analysis and earthquake nonlinear dynamic time-history analysis determine maximum global flexibility demands and ductility requests.[8,9] Seismic assessment and risk analysis are performed on typical supported structures, separating them with limit design concepts considering shear, flexural capacity, and floor support resistance to total dissipation capacity for frames.[10] Economic risks aligned with both experimental and analytical works.[11] In contrast, the majority of Seismic cyclic load studies focus on RC frames, promoting this examination to explore the primary behavior of supported structures with BFRC frames.[12]

This study investigates the influence of basalt fiber reinforcement on the structural behaviour of concrete beams and beam-column joints. The primary focus is on improving mechanical characteristics such as flexural strength, ductility, energy absorption, and crack resistance. Experimental studies have shown that fiber-reinforced concrete exhibits superior seismic resistance, making it an ideal candidate for structures in earthquake-prone areas.

2 OBJECTIVES

The principal aim of the this investigation is to enhance the resilience of concrete in seismic regions. The utilization of manufactured basalt fibers is employed to fortify the concrete and elevate its performance both pre- and post-cracking. The incorporation of basalt fibers is specifically geared towards enhancing the tensile strength, flexible strength, and ductility of the concrete. However, a meticulous assessment of concrete workability is essential, for an excessive content mix. Additionally, economic considerations for applications in structural elements are taken into account.

3 EXPERIMENTAL METHODOLOGY

3.1 Materials and Mix Proportions

The experimental program utilized various materials to ensure the mechanical performance and durability of BFRC. The details of the materials used are elaborated below.

3.1.1 Cement

The cement used in this study was 43-grade ordinary Portland cement (OPC) conforming to IS:12269-2013. This cement was chosen due to its well-balanced properties of strength development, workability, and durability. The cement had a specific gravity of 3.16, with an initial setting of 36 min and a final setting time of 5 h and 10 min. These properties ensured that the cement provided sufficient binding characteristics and allowed for a proper hydration of the mix.

The properties of the cement used in this study were evaluated based ion standard tests, and the results were compared with the specifications provided in IS8112-1989.The standard consistency of the cement was found to be 32 %. The initial setting time was recorded as 36 min, which satisfies the requirement of not being less than 30 min as per IS8112-1989.The final setting time observed to be 5 h and 10 min, well within the permissible limit of 10 h, Additionally, the specific gravity of the cement was determined to be 3.16, which is in close agreement with the standard value of 3.15 specified in IS8112-1989.These results indicate that the cement used in this study conforms to the standard requirements, ensuring its suitability for construction applications.

3.1.2 Fine Aggregate

Locally available manufactured sand (M-sand) was used as the fine aggregate. M-sand was preferred due to its superior particle shape, controlled grading, and reduced impurities. The fine aggregate had a specific gravity of 2.7, water absorption of 1 %, and conformed to Zone III as per IS:383-2016. Proper selection and grading of the fine aggregate contributed to improved workability and packing density of the concrete mix.

The properties of the fine and coarse aggregates used in this study were determined through standard testing procedures. The fine aggregate exhibited a specific gravity of 2.7 and a water absorption capacity of 1 %. It was classified as Zone III, conforming to the standard grading requirements.

3.1.3 Coarse Aggregate

Crushed granite with a maximum particle size of 20 mm was used as the coarse aggregate. This material was selected based on its availability and high strength properties. The specific gravity of the coarse aggregate was 2.72, and its water absorption rate 1.37 %. The aggregate was free from deleterious, materials such as clay, silt, and organic impurities, ensuring consistent quality and performance in the concrete mix.

Similarly, the coarse aggregate had a fineness modulus of 8.27, indicating a well-graded distribution of particle sizes, its specific gravity was found 2.72 and the water absorption capacity of 1.37 %. This values confirm the suitability of the selected aggregates for concrete application, ensuring adequate and durability in the prepared mix.

3.1.4 Water

Portable water available on the campus was used for both mixing and curing of concrete. The water quality conformed to IS:3025-1987 (reaffirmed 2019), ensuring

Figure 1: Basalt Fibre

that it was free from harmful impurities that could affect the hydration process and long-term durability of concrete.

3.1.5 Basalt Fiber

Basalt fibers were incorporated into the concrete matrix to enhance the mechanical performance. The fibers were sourced from a commercial supplier in Gujarat, India and were derived from molten basalt rock through a high-temperature extrusion process. The fibers had a diameter of 30 µm, a length of 25 mm, and an aspect ratio of 1250. Basalt fibers were chosen due to their superior tensile strength, resistance to chemical degradation, and environment-friendly nature. The volume fraction of basalt fibers ranged from 0.250 % to 0.50 % of the total concrete volume, with BFRCO representing the control mix (0 % fiber), BFRC1 containing 0.250 %, and BFRC2 containing 0.50 % fiber content.

3.1.6 Reinforcement Steel

Thermo-Mechanically Treated (TMT) steel bars of different diameters were used as reinforcement. The reinforcement bars conformed to IS:1786-2008, ensuring high yield strength and ductility. The reinforcement configuration included:

- 12 mm diameter bars for primary flexural reinforcement in beams.
- 8 mm diameter stirrups for shear reinforcement in beams and beam-column joints.
- 10 mm diameter bars for main longitudinal reinforcement in columns.
- 6 mm diameter ties for lateral confinement of concrete in beam-column joints.

The TMT bars had an ultimate tensile strength of 544 N/mm^2, a yield stress of 500 N/mm^2, and a modulus of elasticity of 199 GPa, ensuring adequate load resistance and ductility.

3.1.7 Concrete Mix Design

The concrete mix was designed in accordance with IS:10262-2019 for M25-grade concrete. A water-to-cement (w/c) ratio of 0.50 was used to achieve a balance between workability and strength. The mix proportions per cubic meter of concrete were as follows.

Table 1: Materials required per m^3

S.No.	Mix ID	Materials (kg/m^3)				
		Cement	CA	FA	Water	Fiber
1.	BFRC0	383	1229	565	191.6	0
2.	BFRC1	383	1229	565	191.6	2.96
3.	BFRC2	383	1229	565	191.6	5.92
4.	BFRC3	383	1229	565	191.6	8.88
5.	BFRC4	383	1229	565	191.6	11.84

The mix proportions ensured a dense and well-graded concrete matrix, providing superior mechanical performance in both beam and beam-column joint specimens.

3.2 Reinforcement Fabrication

3.2.1 Beam Reinforcement

The reinforced concrete beams were designed in accordance with IS: 456:2000 and IS:13920-2016 to ensure adequate flexural and shear resistance. Each beam specimen was reinforced with two 12-mm diameter bars as tensile reinforcement at the bottom and two 8-mm-diameter bars as compression reinforcement at the top. Shear reinforcement was provided using 8-mm-diameter stirrups at 100-mm center-to–center along the beam length. The reinforcement layout ensured the required ductility and crack control under cyclic loading conditions.

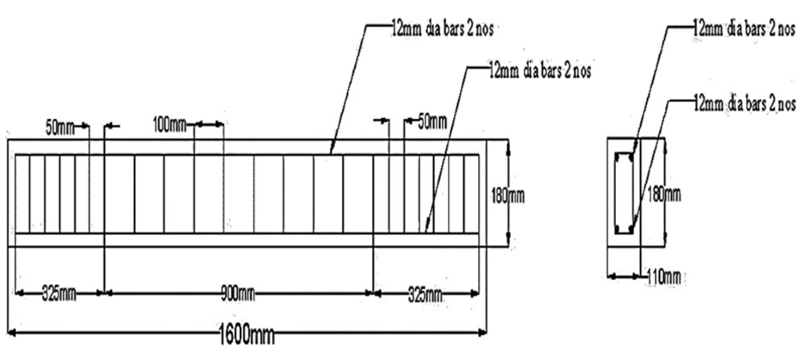

Figure 2: Beams reinforcement

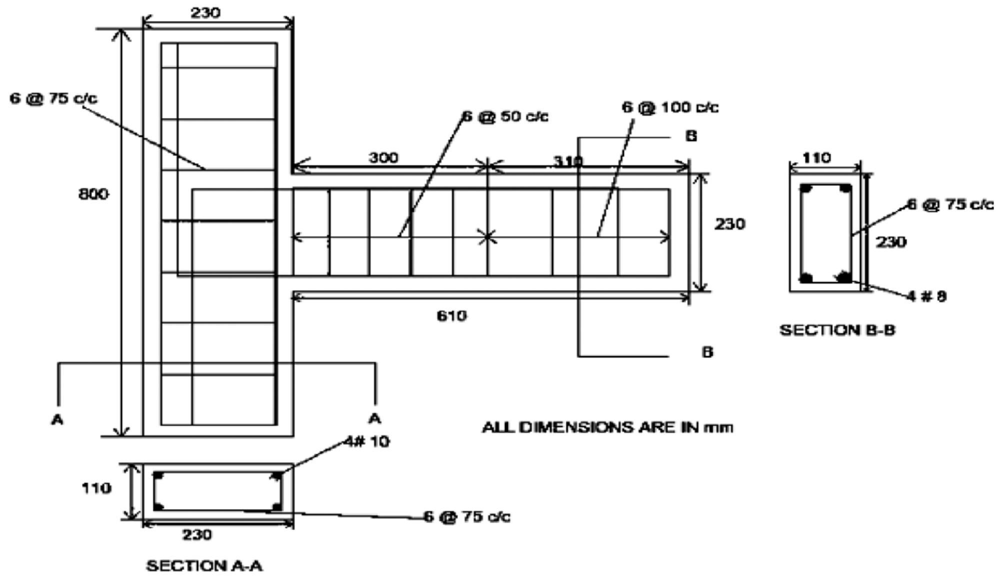

Figure 3: Beam-Column Joint Reinforcement

3.2.2 Beam-Column Joint Reinforcement

The beam-column joint specimens were reinforced following seismic detailing provisions in IS:13920-2016.The columns were reinforced with four 10-mm diameter bars as longitudinal reinforcement, complemented by 6-mm-diameter lateral ties at a 50-mm spacing. The beam reinforcement followed a similar configuration to that of the stand-alone beam specimens, ensuring uniformity in the experimental conditions. The reinforcement detailing aimed to improve the joint integrity, enhance energy dissipations, and mitigate premature shear failure.

3.5 Casting of specimens

The casting was carried out in a controlled environment to ensure uniformity in material properties. Standard steel moulds were used for beam and beam-column joint specimens, ensuring dimensional accuracy and surface finish. The concrete mix was prepared using a mechanical mixer, and basalt fibers were added gradually to ensure uniform dispersion within the matrix.

Once mixed the concrete was poured into the moulds in three layers, each compacted using a vibrating table to remove air voids and enhance density. The specimens were demoulded after 24 h and cured in water for 28 d to achieve full hydration and optimal mechanical properties. **Figure 4**.

4 TESTING PROCEDURE

The mechanical behaviour of basalt fiber reinforced concrete was assessed following IS 516:1959. Each specimen underwent cyclic loading in the laboratory setup, where the specimens were securely held by the foundation bed block. The loading famed featured a hydraulic jack, laterally mounted and a hand-opened hydraulic jack with a 100 kN was employed for testing the specimens. This the basalt fiber-reinforced concrete under cyclic loading conditions.

Figure 4: Beam Casting

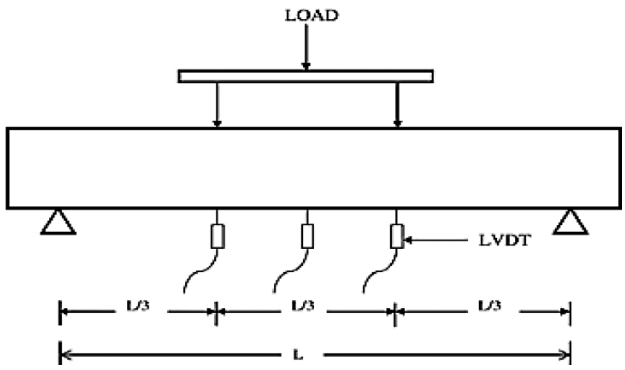

Figure 5: Experimental Setup for Beam – Column Joint

4.1 Beam Testing

A three-point bending test was conducted using a 750-kN capacity loading frame to evaluate the flexural strength of BFRC beams. The beams were simply supported at both ends, and load was applied at the mid-span to induce bending stress. Load-deflection behaviour, energy absorption capacity, ductility factor, and stiffness were recorded for each specimen **Figure 5**.

4.2 Beam-column joint testing

Beam-column joint specimens were subjected to reverse cyclic loading to simulate seismic forces, A500 kN hydraulic jack was used for forward loading, while a 100 kN hand-operated jack was employed for reverse loading. Dial gauges measured displacements at critical locations to evaluate stiffness degradation, crack propagation, and energy dissipation capacity **Figure 6**.

5 RESULTS AND DISCUSSION

5.1 Structural Performance of Beams

5.1.1 Load – carrying capacity

BFRC beams exhibited a significant improvement in loading-bearing capacity due to the reinforcement effect of basalt fiber. The BFRC2 specimen demonstrated a 34.30 % increase in ultimate load compared to conventional concrete beams. The enhanced load resistance is attributed to fiber bridging, which mitigated the crack propagation and improved the stress distribution (**Figure 7**).

Figure 6: Experimental Setup for Beam – Column Joint

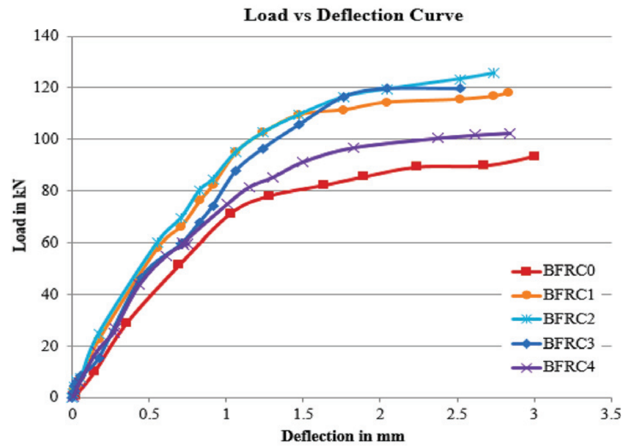

Figure 7: Load deflection behaviour of beams

5.1.2 Energy Absorption

The incorporation of basalt fibers resulted in a notable increase in the energy-absorption capacity BFRC2 specimens absorbed 93.35 % more energy than the control specimen, indicating superior toughness and impact resistance. These findings confirm that basalt fibers ef-

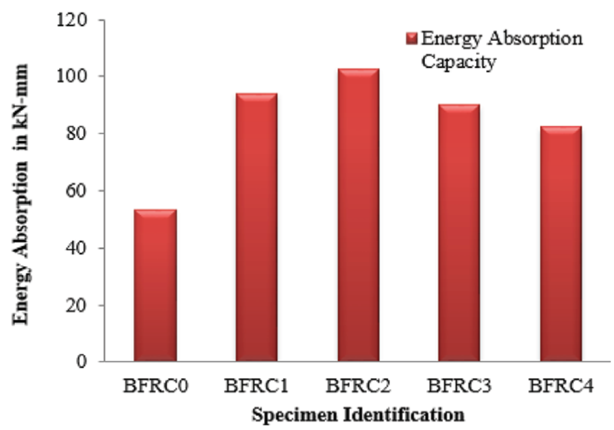

Figure 8: Energy Absorption capacity of beams

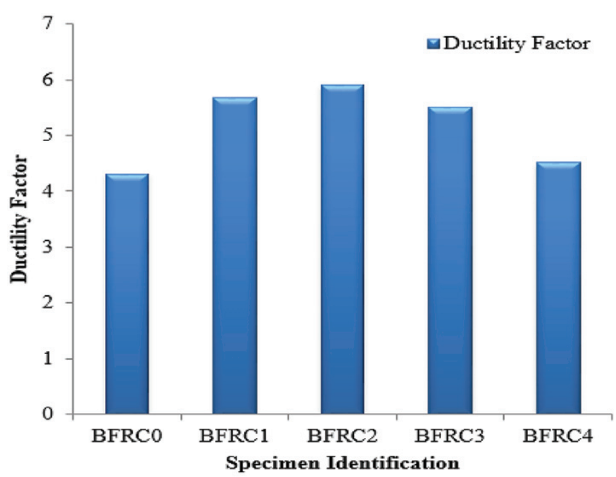

Figure 9: Ductility Factor of beams

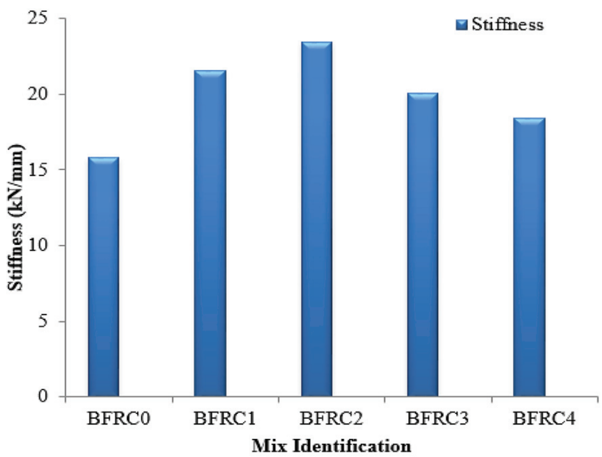

Figure 10: Stiffness behaviour of beams

fectively enhance the post-crack behaviour of concrete structures (**Figure 8**).

5.1.3 Ductility Factor and Stiffness

Ductility was improved by 37 %, while stiffness increased by 48 % in BFRC2 Specimens. The higher ductility index suggests an ability to undergo deformation before failure, which is crucial for structures subjected to seismic forces. The improved stiffness further contributed to better load resistance and reduced deflections under applied loads (**Figure 9** and **10**).

5.2 Structural Performance of Beam-Column Joints

3.2.1 Load-Deflection Behaviour

BFRC beam-column joints demonstrated superior resistance to cyclic loading. The BFRC2 specimen exhibited a 1.84 times higher load-carrying capacity than the control specimen. The enhanced joint performance was attributed to fiber-induced crack control and improved stress transfer mechanisms within the joint region.

3.2.2 Energy Dissipation and Seismic Resistance

Energy dissipation capacity was enhanced by 23.6 % in BFRC joints. The improved energy absorption capacity indicates that basalt fiber reinforcement can significantly improve the seismic resilience of structures by delaying stiffness degradation and reducing residual deformations.

5.2.3 Discussion on Failure Mechanism and Practical Implications

The experimental findings reveal that fibers effectively mitigate crack propagation, enhance ductility, and improve structural resilience under cyclic loading. The fiber-bridging mechanism plays a crucial role in controlling crack widths, thereby improving the long-term durability of concrete structures.

From a practical perspective, the use of BFRC can advantages in earthquake-resistant buildings, bridges, and infrastructure projects where enhanced ductility and energy dissipation are critical. Furthermore, the environmental sustainability of basalt fibers, derived from natural volcanic rock, makes them a viable alternative to synthetic fibers and steel reinforcements.

The study suggests that an optimal fiber content of 0.250 % provides the best balance between workability and mechanical performance. Future research should explore the long-term durability and performance of BFRC under real-would conditions, including exposure to varying environmental factors.

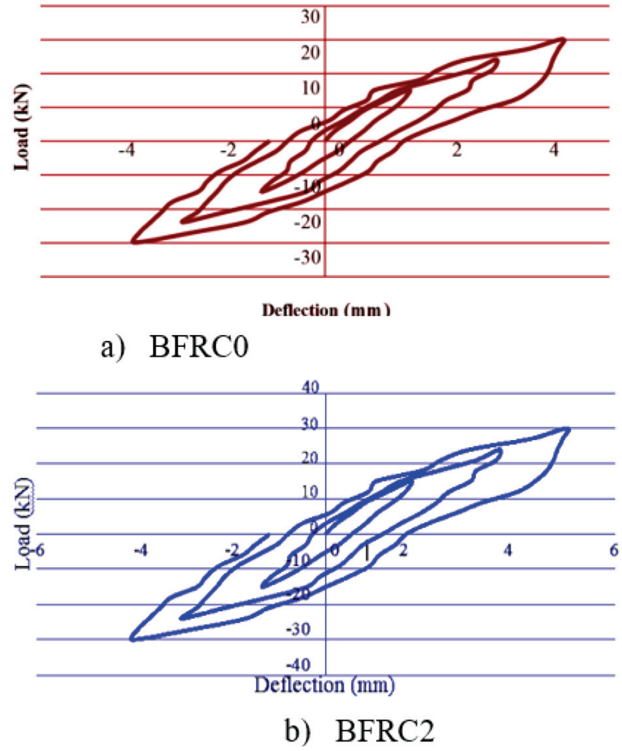

Figure 11: Load vs Deflection Behavior of beam-columnjoint

6 CONCLUSIONS

The experimental findings confirm that basalt fiber reinforcement significantly enhances the mechanical

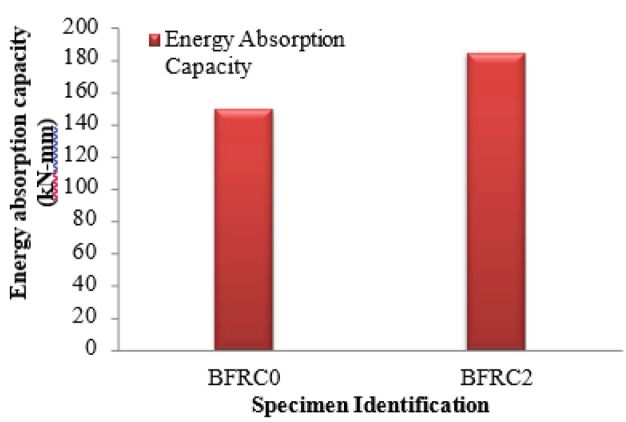

Figure 12: Energy absorption capacity of beam-column joint

properties of concrete. The addition of basalt fibers improved load-carrying capacity, flexural strength, ductility, and crack resistance in BFRC beams and beam-column joints. The optimized fiber dosage (0.250 %) yielded the most effective structural performance.

- BFRC beams exhibited a 34.30 % increase in ultimate load capacity and a 93.35 % improvement in energy absorption.
- Beam-column joints demonstrated superior seismic resilience, with a 1.84 times increase in load resistance, a 1.5 times increase higher load carrying capacity in first crack load, a 23.6 % of energy absorption.
- Optimal fiber content enhances stiffness, ductility, and energy dissipation, making BFRC an ideal material for earthquake-resistant structures.
- The sustainable nature of basalt fibers supports their application in modern, eco-friendly constructions.

7 REFERENCES

[1] V. M. Gnanasundar, T. Palanisamy, G. S. Thirugnanam: Structural behaviour of a single bay two-story basalt fiber reinforced concrete frame, GRADEVINAR,74 (**2022**) 12, 1085–1092, doi:10.14256/JCE.3550.2022

[2] Ramasamy, A. Maria Rajes, M. Madasamy, Performance of bamboo- and glass-fibre –reinforce concrete slab subjected to static and cyclic loads. Mater. Tehnol. 58 (**2024**) 3, 265–270, doi:10.17222/mit.2023.959

[3] T. Ehab, AI-ROUSAN, R. Hammad, Khalied, Muhammad kalimur Rahman, Fresh, mechanical, and durability properties of basalt fiber-reinforced concrete (BFRC): A review, Developments in the Built Environment, 14 (**2023**), 100155, doi:10.1016/j.dibe.2023.100155

[4] B. Ramesh, S. Eswari, Mechanical behaviour of basalt fibre reinforced concrete: An experimental study, Materials Today: Proceedings, 43 (**2021**) 2, 2317–2322, doi:10.1016/j.maptpr.2021.01.071

[5] D. Wang, Y. Ju, H. Shen, [6]L. Xu, Mechanical properties of high performance concrete reinforced with basalt fiber and polypropylene fiber, Construction and Building Materials, 197 (**2019**), 464–473, doi:10.1016/j.conbuildmat.2018.11.181

[6] Dhakal, Alisha, (**2023**), A report on BASALT FIBER REINFORCED CONCRETE Postgraduate coursework on Advanced Materials Engineering for Construction Faculty of Engineering and science, doi:10.33140/RG.2.2.14432.87043

[7] O. Branston, S. Das, S. Y. Kenno, C. Taylor, Mechanical behaviour of basalt fibre reinforced concrete, construction, and Building Materials, 124 (**2016**), 878–886, doi:10.1016/j.conbuildmat.2016.08.009

[8] N. Vatin, M. Hematibahar, T. Gebre, Impact of basalt fiber reinforced concrete in protected building's: a review Frontiers in Built Environment. (**2024**), doi:10.10.3389/fbuil.2024.1407327

[9] C. E., Ventura, W. D. Liam Finn, J. F. Lord, N. Fujita, Dynamic characteristics of a base isolated building from ambient vibration measurements and low level earthquake shaking, Soil Dyn. Earthquake Eng, 23 (**2002**) 4, 313–322, doi:10.1016/S0267-7261(02)002208-7

[10] H. Yoshioka, J. C. Ramallo, B. F. Jr. Spencer, Smart base isolation strategies employing magneto rheological dampers, J.Eng.Mech.,128 (**2002**) 5, 540–551, doi:10.1061/(ASCE)0733-9399(202)128:5(540)

[11] Y. M. Wu, B. Samili, Shake table testing of a base isoloated model, Eng.Struct, 24 (**2002**) 9, 1203–1215, doi:10.1016/S0141-0296(02)00054-8

[12] Stewart, J.P., Conte, J.P., Aiken, I.D., Observed behaviour of seismically isolated buildings, J.Struct. Eng., 125, (1999) 9, 955–964, doi:10.1061/(ASCE)0733-9445(1999)125:9(955)