

Behavioral Study of RC Deep Beams Using Experimental Tests and Software Analysis

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Abstract

This study uses nonlinear finite-element analysis in ANSYS and coordinated experimental testing to assess the structural response of M25-grade Conventional RC deep beams and Hybrid Fiber Reinforced Concrete (HFRC) deep beams. To determine load-deflection behavior, ultimate capacity, energy dissipation, simply supported deep beams were evaluated under two point loading. To simulate cracking and post-peak reaction, a calibrated concrete model with and without tri hybrid fibers in concrete mix was used. It was found that ANSYS prediction correlates reasonably well, validating the model. The value of energy dissipation in HFRC deep beam is about 50% higher than the conventional RC deep Beam specimen. Thus HFRC deep beam significantly improves energy absorption compared to conventional behavior. In comparison to control beams (conventional beam), HFRC deep beam specimens showed improved ductility, delayed diagonal cracking, energy dissipation and thus greater shear capacity.

Keywords: *RC Deep Beam, Hybrid Fiber Reinforced Concrete Deep Beam (HFRC Deep Beam), Load- Deflection, ANSYS Model, Energy Dissipation.*

Introduction

A beam is to be said as a deep beam (simply supported) if the effective span is less than or equals to twice the depth of the beam. The beams had a small shear span-to-depth ratio to emphasize shear behavior (1, 18,20). The deep fails in shear. The load–deflection curves typically exhibited an initial linear response up to first cracking, followed by nonlinear behavior until peak load, after which failure was dominated by diagonal shear mechanisms, reflecting deep beam action (1,7). In order to improve shear capacity, HPC mortars with mesh can be used, significantly improve energy absorption capacity, mitigate detrimental effects of openings, in deep beams. This energy absorption enhancements up to 127% relative to control specimens (2). It was found that crumb rubber + steel fibers enhance energy dissipation capacity of RC deep beams (3). Also, a tri-hybrid fiber mix (crimped steel + polypropylene + glass fibers) in RC deep beams more than 40% shear strength improvement over control beams which helps to improve stiffness and energy absorption (4). The effect of two types of steel fibers in HFRC deep beam on the shear capacity, cracking pattern, load deflection behavior of HFRC deep beams compared to RC deep beams. Hybrid fibres improve damage tolerance and deformation capacity (5.6.8). As the shear span-to-effective depth ratio increased, the rate of increase in the shear capacity decreased (9). According to the experimental results, the improvement in the shear strength of strengthened UHPFRC deep beams was moderate i.e. 16% (10). Strain gauges are used to measure load–strain relationships along main tension reinforcement, showing changes in strain after initial cracking and through subsequent loading stages, reflecting shear and tension behavior under load (11). It helps to improve ductility and energy dissipation coefficients of RC deep beams under cyclic (seismic-type) loading. (12). Hybrid CFRP reinforcement substantially increases ductility energy index and energy absorption, indicating beneficial effects on energy dissipation for RC deep beams under load (13,16). The main shear transfer mechanisms of reinforced concrete (RC) deep beams ($a/d < 2.0–2.5$) differ from those of slender beams (14). RC deep beam enhanced damage tolerance, increased ultimate load capacity and deformation capacity, reduced crack widths and delayed cracking due to fiber bridging action (15). Due to use of hybrid fibers' shear ductility enhanced, flatter post-peak load

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deflection curves (higher energy dissipation), and changed failure modes (17). Shear strength enhancement, it additionally highlights fiber roles in crack control and ductile response (19).

Objectives of the Study

- To study behavior of HFRC deep Beam, and RC Deep beam both by experiment and using ANSYS simulation software considering load vs. deflection.
- To study the behavior of conventional R.C. Deep Beam and HFRC Deep beam in concern with energy dissipation both by experiment and using ANSYS simulation software

Experimental Program

Materials and Fibers

Concrete mixes were designed for grade M25 using OPC cement, crushed sand, and 20 mm metal. The mix ratio (cement: sand: aggregate) was found to be 1:1.965:2.998 and water to cement ratio was found to be 0.485. The three fibers (crimped steel, polypropylene, glass) used in concrete mix



Figure 1: Glass Fiber

Figure 2: Crimped Steel Fiber

Figure 3: Polypropylene fiber

Fibers Mix

Optimum proportions of 1.25% of crimped steel fiber, 0.2% of polypropylene fiber and 0.2% of glass fiber in a concrete mix, is considered while casting HFRC Deep Beam specimens.

R.C Deep beam Details

The dimensions of Deep beam are: Length - 0.70 m, depth 0.4 m, and width 0.15m. R.C. Deep is designed using I.S 456-2000 (Reaffirmed: 2021).

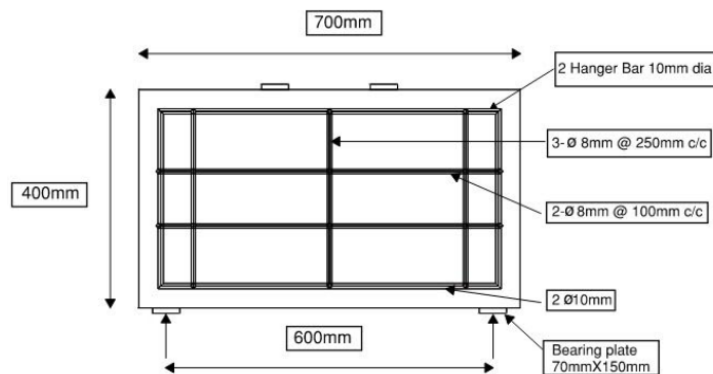


Figure 4: Reinforcement detail of R.C. deep beam

R.C. deep beams are designed for two-point loads of 50 kN each. As seen in Fig. 4, R.C. deep beams with main and side face reinforcement were designed in compliance with I.S. 456-2000. In the present study, HFRC deep beams are cast by completely replacing conventional shear reinforcement with optimum mix of fiber combination.

Casting of Deep beam:-

The steel cage is shown figure 5 and figure 6 for both conventional and HFRC deep beam.



Figure 5: Conventional Steel Cage

Figure 6: Steel Cage without Shear reinforcement.

The mix of M25 grade of concrete is designed as per IS 10262:2019. Three beams are casted with conventional steel and mix design of M25 grade concrete and cured for 28 days in curing tank. The three beams are casted with optimum mix of 1.25% of crimped steel fiber, 0.2% of polypropylene fiber and 0.2% of glass fibers are added w.r.t volumetric proportions of concrete mix of grade M25. The horizontal steel and vertical steel of R.C. deep beam is replaced with optimum proportion of tri hybrid fiber mix, and cured for 28 days.

Test set up:-

The arrangement for test set up for both type of beam is made as follows.

End condition is simply supported with centre to centre distance is 0.6 m a shear span to depth ratio is kept as 0.5.

The specimen is tested with arrangement of two point loading and simply supported condition, using a self-restraining loading frame with a capacity of 1000 kN. (Refer fig.7)

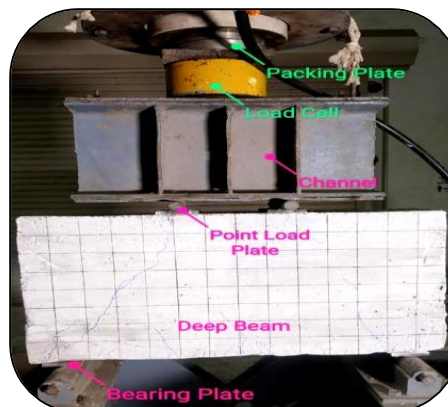


Figure 7: Testing specimen with two point loading

A self-restraining loading frame of 1000 kN capacity was used for testing the beam specimen. The Immetrum Video Gauge Measurement System (VGMS) with 1.0 micron least count measured deflection and strain. M.S. bearing plates (150 mm x 70 mm x 5 mm) were provided at supports and loading points to limit bearing stress. Markings were made on the deep beams for strain, deflection, and crack detection. The load cell was connected to VGMS for synchronized load, strain, and deflection data. Virtual gauges were created in the VGMS interface between selected points on the specimen. A hydraulic jack was operated to apply load gradually to the beam specimens. The loading rate was kept constant as per IS 516 (2021) recommendations. Initial crack load, ultimate load, and corresponding deformations were accurately recorded. Strains, central deflections, and crack pattern were monitored until beam failure.

Data Collection

The load is applied gradually with interval of 5 kN and reading of central deflection and shear strain is recorded in Video Gauge Immetrum. VGMS provides precise readings of loads, strains, and deflections at various points on a structure.

Finite Element Analysis

To validate the result obtained by experiment, simulation software ANSYS is used. A concrete beam's dimensions and characteristics were modeled as part of the calibration research for finite element analysis. In order, for the finite element model to function correctly, a number of tasks must be finished during the creation process in ANSYS. SOLID WORK is used to prepare the model, which is then exported to ANSYS

Modeling The model measured 0.7 m in length and 0.15 m width and depth is 0.4 m in cross section. Each support has two loading points positioned symmetrically 0.6 m apart. SOLID WORKS was also used to sketch the reinforcement details, such as stirrups and longitudinal bars. The finished SOLIDWORKS model was imported into ANSYS Space Claim for meshing and simulation, after being saved as an ACIS file. Two models have been constructed , one for conventional beam and another for HFRC Deep beam.(Refer figure 4,5)

Material Property:- Material property is assigned for reinforcement, concrete etc with proper poissons ratio, density and modulus of elasticity. Equivalent property of hybrid fibers in concrete mix is provided in HFRC Deep Beam model.

Meshing To obtain results from mesh tetrahedral element was recommended.

Meshing was done in ANSYS Mechanical after importing model from SOLIDWORKS.

Mesh details: Tetrahedral meshing is used with Global element size: 50 mm. (Refer figure 9)

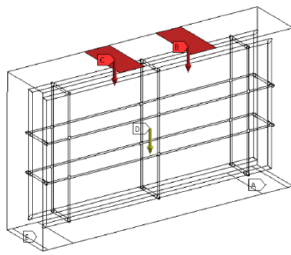


Figure 8: Conventional RC Deep Beam model

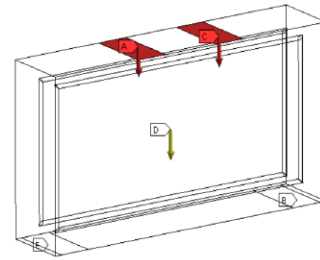


Figure 9: HFRC RC Deep Beam model

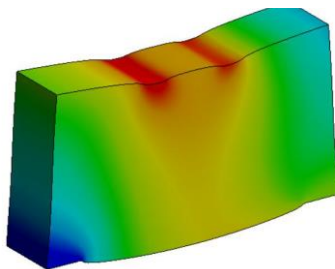


Figure 10: Beam model showing deformation

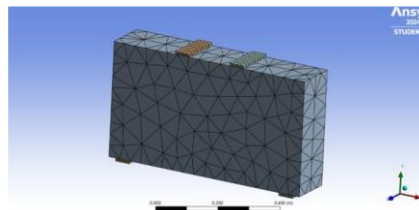


Figure 11: Beam model with meshing

Results

- 1) The Load Vs Deflection graph (Refer Figure 10) shows that ANSYS prediction correlates reasonably well, validating the model.

HFRC Deep Beam improves: post-cracking load-carrying capacity. continues to sustain additional load even after larger deflections.

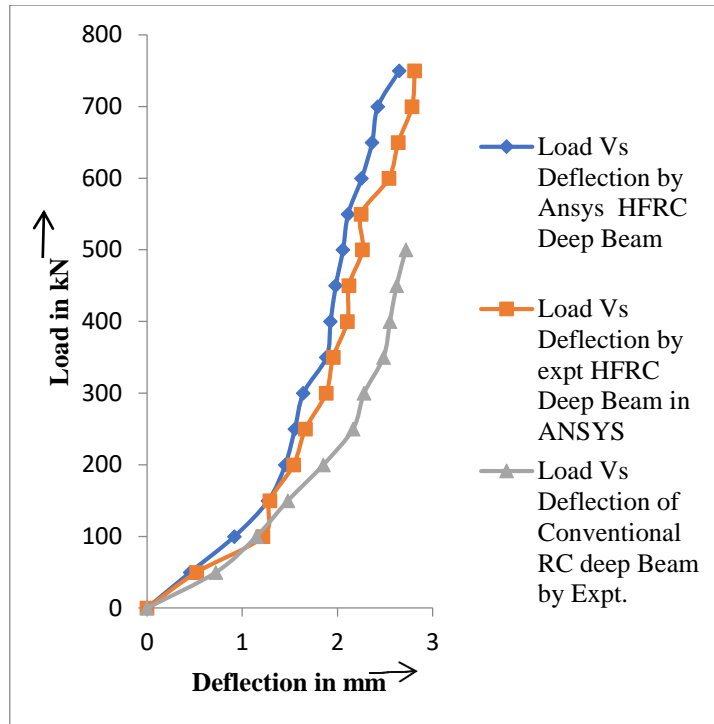


Figure 12: Load vs Deflection of Conventional Deep Beam and HFRC Deep Beam.

Energy Dissipation curve for M25 Conventional RC Deep Beam.

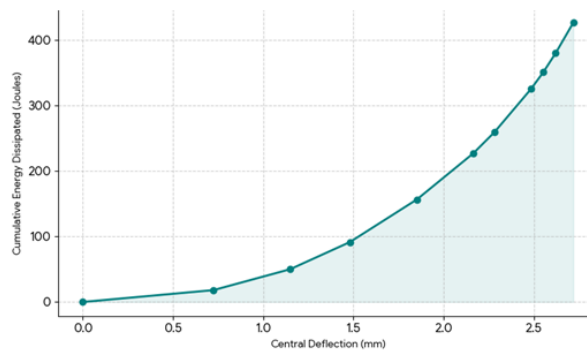


Figure 13 : Energy dissipation curve for conventional RC deep Beam

Total energy dissipation in joule is 472.18 Joule at peak load of 500 kN.

Energy Dissipation curve for M25 HFRC Deep Beam by Experiment.

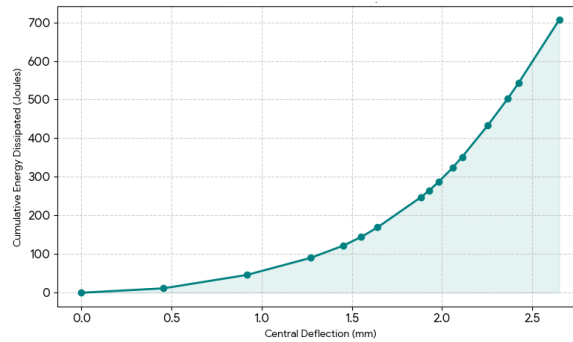


Figure 14. Enrgy dissipation curve for conventional RC deep Beam

Total energy dissipation in joule is 706.72 Joule at a peak load of 750 kN

Energy Dissipation curve for M25 HFRC Deep Beam in Ansys.

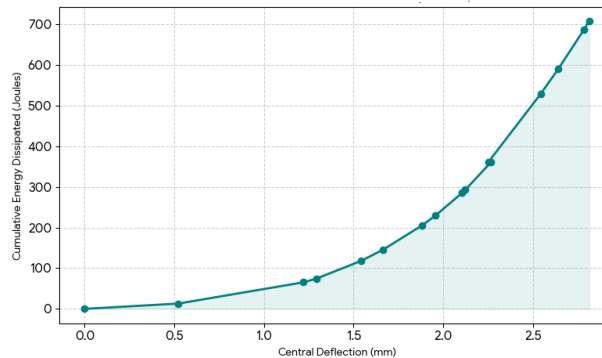


Figure 15. Enrgy dissipation curve for conventional RC deep Beam

- Total energy dissipation in joule is 707.95 Joule at a peak load of 750 kN

Conclusion

The present investigation finds following improvements in behavior of HFRC deep beams both by experiment and using ANSYS in comparison with conventional R.C. deep beams by experiment.

- The load Vs deflection graph shows that experimental HFRC deep beam correlates reasonably well with HFRC Model in ANSYS, thus validating the model. In HFRC Deep Beam marginal difference in deflection when compared with conventional RC Deep Beam. at ultimate load.
- The value of energy dissipation in HFRC deep beam is about 50% higher than the conventional RC deep Beam specimen. Thus HFRC deep beam significantly improves energy absorption compared to conventional behavior.
- The ability to dissipate energy while maintaining lower deformation suggests that the HFRC material provides better structural control and crack resistance.

Acknowledgements

Thankful to Guide Dr. S. S. Patil for encouraging me to publish paper.

Author Contribution

Author 1 conducted the experimental and analytical studies and prepared the manuscript. Author 2 supervised the research and reviewed the manuscript.

Ethical Issues

Not applicable. This experiment does not involve any experiments on humans and animals. Hence, ethical approval was not required.

Funding

There are no pertinent financial or non-financial interests that the writers need to disclose.

Conflict of Interest

The authors declare that, they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data and Materials Availability

Data that support the findings of this study are embedded within the manuscript.

References

- [1] Kannan, H., Veerappan, S. K., & Sivasubramanian, M. V. R. (2025). Experimental and numerical investigation of shear performance of RC deep beams strengthened with engineered cementitious composites. *Construction Materials*, 5(3), 51.
- [2] Hamoda, A., Emara, M., Ahmed, M., & Abadel, A. A. (2025). Shear Strengthening of High-Strength Reinforced Concrete Deep Beams with Openings Using High-Performance Concrete Mortars. *International Journal of Concrete Structures and Materials*, 19, Article 70. <https://doi.org/10.1186/s40069-025-00765-5>
- [3] Al-Ghamdi, et al. (2025). Sustainable self-compacting steel-fibre rubber concrete: mechanical response and deep beam behaviour. *Journal of King Saud University – Engineering Sciences*. <https://doi.org/10.1007/s44444-025-00041-7>.
- [4] Javheri, S. B., & Patil, S. S. (2025). Performance Assessment of Tri Hybrid Fiber Composites in the Shear Behavior of Concrete Deep Beam. *Architecture Image Studies*, 6(4), 903-911.
- [5] Hamoda, A., Ghalla, M., Yehia, S. A., Ahmed, M., Abadel, A. A., & Shahin, R. I. (2024). Experimental and numerical investigations of the shear performance of RC deep beams strengthened with hybrid SHCC-mesh. *Case Studies in Construction Materials*, 21, e03495. <https://doi.org/10.1016/j.cscm.2024.e03495>.
- [6] Al-Enezi, M. S., Yousef, A. M., & Tahwia, A. M. (2023). Shear capacity of UHPFRC deep beams with web openings. *Case Studies in Construction Materials*, 18, e02105. <https://doi.org/10.1016/j.cscm.2023.e02105>.
- [7] M. Saleh, M. AlHamaydeh & M. Zakaria (2023), Shear capacity prediction for reinforced concrete deep beams with web openings using artificial intelligence methods, *Engineering Structures*, Volume 280, 2023, DOI: 10.1016/j.engstruct.2023.115675.
- [8] Ma, K., Qi, T., Liu, H., & Wang, H. (2018). Shear behavior of hybrid fiber reinforced concrete deep beams. *Materials*, 11(10), 2023.
- [9] Akkaya, Aydemir, Guray Arslan(2022), An experimental research on reinforced concrete deep beams fully wrapped with fiber reinforced polymers against shear, *Case Studies in Construction Materials*, Volume 17, e01198, ISSN 2214-5095, <https://doi.org/10.1016/j.cscm.2022.e01198>
- [10] Abadel, A. A., Abbas, H., Almusallam, T., Alshaikh, I. M. H., Khawaji, M., & Alghamdi, H. (2022). Experimental study of shear behavior of CFRP strengthened ultra-high-performance fiber-reinforced concrete deep beams. *Case Studies in Construction Materials*, 16, e01103. <https://doi.org/10.1016/j.cscm>.
- [11] Rao, A., et al. (2021). Experimental investigation of RC deep beams with web reinforcement and improvement of ACI 318-19 strut coefficient. *Structures*, 32, 914–928. <https://doi.org/10.1016/j.istruc.2021.03.052>
- [12] Li, J., Jiang, L., Zheng, H., Jiang, L., & Zhou, L. (2021). Cyclic tests and numerical analyses on bolt-connected precast reinforced concrete deep beams. *Applied Sciences*, 11(12), 5356. <https://doi.org/10.3390/app11125356>.
- [13] Hason, M. M., Hanoon, A. N., Saleem, S. J., Hejazi, F., & Al Zand, A. W. (2021). Characteristics of experimental ductility energy index of hybrid-CFRP reinforced concrete deep beams. *SN Applied Sciences*, 3, 200. <https://doi.org/10.1007/s42452-021-04202-6>
- [14] Hui Chen, Wei-Jian Yi, Zhongguo John Ma (2019), Shear size effect in simply supported RC deep beams, *Engineering Structures*, Volume 182, 2019, Pages 268-278, ISSN 0141-0296, <https://doi.org/10.1016/j.engstruct.2018.12.062>.
- [15] Ma, K., Qi, T., Liu, H., & Wang, H. (2018), Shear Behavior of Hybrid Fiber Reinforced Concrete Deep Beams, *Shear Behavior of Hybrid Fiber Reinforced Concrete Deep Beams. Materials*, 11(10), 2023. <https://doi.org/10.3390/ma11102023>.
- [16] Liu, S. B., & Xu, L. H. (2013). Ductility and Deformation Performance of Hybrid Fiber Reinforced High Performance Concrete Shear Deep Beams. *Applied Mechanics and Materials*, 357-360, 858–862. <https://doi.org/10.4028/www.scientific.net/AMM.357-360.858>
- [17] Reinforced High Performance Concrete Shear Deep Beams. *Applied Mechanics and Materials*, 357-360, 858–862. <https://doi.org/10.4028/www.scientific.net/AMM.357-360.858>

- [20] Sheng Bing Liu & Li Hua Xu. (2013). Ductility and deformation performance of hybrid fiber reinforced high performance concrete shear deep beams. *Applied Mechanics and Materials*, 357-360, 858-862.
- [21] G. Campione & G. Minafò (2012) Behaviour of concrete deep beams with openings and low shear span-to-depth ratio *Engineering Structures*, Volume 41, Pp 294–306.
- [22] Liu, S. B., & Xu, L. H. (2012), Experimental Study on Shear Behavior of Hybrid Fiber Reinforced High Performance Concrete Deep Beams. *Applied Mechanics and Materials*, 166-169, 664-669. <https://doi.org/10.4028/www.scientific.net/AMM.166-169.664>.
- [23] K.-H. Yang, H.-C. Eun & H.-S. Chung (2006) — The influence of web openings on the structural behavior of reinforced high-strength concrete deep beams, *Engineering Structures*, 28(13), pp. 1825–1834, DOI: 10.1016/j.engstruct.2006.03.021.