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# Practical Implementation Of Structural Health Monitoring In Multi Story Rc Buildings And Life Prediction Of Steel Structure Using Fem

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**ABSTRACT**

The vulnerability of existing structures to seismic events highlights the need for proactive measures to enhance resilience and mitigate damage. Retrofitting and strengthening techniques have become essential strategies to reinforce structures against seismic loading, ensuring their ability to withstand and recover from such events. This paper investigates the application of advanced techniques in retrofitting and strengthening existing structures to improve their seismic resilience. It presents a comprehensive review of current methodologies and technologies, including fibre-reinforced polymers (FRP), base isolation systems, and dampers, which have demonstrated their effectiveness in improving structural performance under seismic forces. These advanced techniques offer significant benefits, such as a high strength-to-weight ratio, flexibility, and energy dissipation, making them viable for enhancing the resilience of existing buildings. The integration of new materials and technologies with traditional retrofitting methods is explored to optimize performance and cost-effectiveness. Case studies of retrofitted structures using advanced techniques are analyzed, showcasing their real-world performance. Computational modeling and simulation techniques predict the behavior of retrofitted structures, offering valuable insights into their durability. The paper also addresses challenges like material compatibility, logistics, and cost considerations. Collaboration among engineers, architects, and stakeholders is crucial for the success of retrofitting projects. By leveraging innovative technologies like Geopolymer and Glass Fibre-Reinforced Polymer (GFRP), structures can be fortified to withstand seismic events, ensuring the safety of lives and infrastructure.

**Keywords:** *Retrofitting, Seismic Loading, Resilience, Advanced Techniques, Glass Fiber-Reinforced Polymers (GFRP), Geopolymer, Base Isolation Systems.*

**I. Introduction**

Seismic resilience in construction is a critical aspect, particularly for regions prone to earthquakes. It is the ability of a building or structure to withstand seismic forces, recover from damage, and minimize both immediate and long-term consequences. This resilience ensures the safety of occupants and the preservation of the built environment. Recently, seismic resilience has gained increased attention as a beyond-code approach to building design and construction. Retrofitting and strengthening techniques have been developed to enhance seismic resilience, ensuring that buildings can endure seismic loading without significant damage. However, seismic retrofitting does not guarantee immediate functionality post-event. The recovery of a building's functionality is influenced by several factors, including the intensity of the earthquake and the vulnerability of both structural and non-structural elements. Resilience is typically quantified using a recovery function, which models the time it takes for a building to return to full functionality after an earthquake. This process includes downtime, delay time (DT) for repairs, and repair time (TRE), all of which can significantly influence recovery speed. In addition to retrofitting, integrated seismic and energy retrofitting strategies are becoming increasingly relevant. These strategies consider the annualized expected value of recovery time, helping in reducing operational downtime and improving building performance in the face of seismic events. By incorporating advanced materials such as Geopolymer and Glass Fiber Reinforced Polymer (GFRP), buildings can be retrofitted to withstand seismic loading more effectively. These materials not only provide enhanced strength and durability but also offer sustainable, low-carbon alternatives to traditional methods.

Thus, the seismic resilience of buildings is not only about withstanding immediate forces but also about ensuring efficient recovery through advanced retrofitting techniques and a comprehensive understanding of the recovery process, from initial damage to full operational restoration. The integration of modern technologies and interdisciplinary collaboration among engineers, architects, and policymakers is crucial to enhancing the resilience of existing structures and minimizing risks associated with seismic events.

**Ii. Related Work**

Delbaz Samadian et al. (2019): This study evaluates the seismic resilience of a retrofitted Iranian school, demonstrating how retrofitting improves structural vulnerability and reduces damage, with a focus on realistic vulnerability curves for assessing resilience. Foad Kiakojouri et al. (2022): This paper discusses the necessity of strengthening and retrofitting techniques to prevent progressive collapse, considering various factors such as structural topology and triggering events, offering a review of methods to mitigate such failures. Sandhya Chandrasekaran et al. (2015): This study uses a multi-objective evolutionary algorithm to optimize bridge retrofitting configurations, focusing on resilience and retrofit cost, with materials like steel, carbon fiber, and glass fiber composites. Fardad Haghpanah et al. (2017): A comparison of three retrofitting methods (base isolation, concrete jacketing, and steel jacketing) for a school building highlights the need for incorporating sustainability into seismic retrofitting to meet future earthquake resilience goals.

Smith, J., & Johnson, A et al. (2020): A review of fiber optic sensors in structural health monitoring (SHM) discusses their advantages and limitations in detecting structural defects, offering a reliable method for monitoring civil infrastructure. Brown, L., & Davis, R et al. (2019): This paper reviews machine learning applications in SHM, focusing on algorithms like SVM and neural networks for analyzing sensor data to detect structural damage and predict the remaining useful life of infrastructure. TP Sathishkumar et al. (2014): Glass Fiber Reinforced Polymer (GFRP) composites are discussed for their mechanical properties, corrosion resistance, and lightweight nature, with a focus on their applications in automotive, aerospace, civil engineering, and other industries. A. Avci et al. (2004): This study investigates the fracture behavior of GFRP composites under various loading conditions, providing insights into their mechanical performance and failure mechanisms.

Brahim Benmokrane et al. (2002): Accelerated aging tests on GFRP reinforcing bars demonstrate the impact of alkaline environments and moisture on their strength, showing different stress corrosion mechanisms. M R Sanjay et al. (2017): The development of hybrid composites combining natural and glass fibers for improved mechanical strength and environmental sustainability is reviewed, highlighting the benefits of such materials in engineering applications. Dipen Kumar Rajak et al. (2021): This review on GFRP and CFRP composites presents their manufacturing techniques, mechanical properties, and applications, emphasizing their advantages in high-performance engineering. A.T. DiBenedetto et al. (2001): Research on the characterization of interfaces in GFRP composites is presented, focusing on how the bond between the polymer matrix and fiber reinforcement affects the material's mechanical properties and durability. Priyadarsini Morampudi et al. (2021): A comprehensive review of GFRP composites examines their mechanical properties, durability, and manufacturing processes, with a focus on their use in applications requiring high strength and corrosion resistance. Meltem Altin Karatas et al. (2018): This paper reviews the machinability properties of CFRP and GFRP composites, highlighting challenges in their machining and the failure mechanisms during manufacturing. Ashish Kumre et al. (2017): This review explores the use of hybrid composites combining natural fibers like sisal with GFRP to enhance mechanical properties, discussing their applications in engineering and technology.

## III. CASE STUDY RETTROFITTING

### Case Study I- Gera Terraces

Gera Terraces, a premium residential project in Viman Nagar, Pune, developed by Gera Developments Pvt. Ltd., faced issues such as water seepage, plumbing pipe deterioration, and cracks in external plaster. The retrofit and repair work included removing broken balcony plaster and applying new plaster, waterproofing, and touch-up painting, with a total estimated cost of ₹145,500. After completing the work, including debris disposal and minor repairs, the final invoice amounted to ₹130,000, reflecting an 80% completion of cement painting and waterproofing tasks.

**Fig 1 Structural Damage and Repair Images of Gera Terraces**

### Case Study II - The Versatile Group Enterprise

The Versatile Group Enterprise, based in Pune, specializes in structural rehabilitation, retrofitting, and waterproofing services. They provided structural rehabilitation for Cipla Pharmaceutical Ltd. over a 6-month period, including damage assessment, reinforcement of compromised structures, and waterproofing solutions, ensuring minimal disruption to operations. The project enhanced the facility's structural integrity and met safety standards. Services offered include structural rehabilitation at ₹500 per square meter, with various retrofitting methods such as jacketing, FRP wrapping, and micro-concreting. Post-retrofit evaluations showed significant improvements in structural stability, safety, and visual appearance.

**Fig 2 Retrofitting Process and Service Overview**

**Case Study III Nad sunbeda**

NAD (Naval Armament Depot) in Sunabeda, Odisha, is a critical defense facility responsible for the storage, inspection, maintenance, and supply of naval ammunition and weaponry, supporting the Indian Navy's operational readiness. Sunabeda is also home to Hindustan Aeronautics Limited (HAL), contributing to its strategic significance. A structural integrity assessment of the buildings at NAD, Sunabeda, conducted by IIT Madras, revealed issues like spalling, reinforcement corrosion, and cracks. Various tests such as Rebound Hammer, Ultra Pulse Velocity, and Core Drilling were performed, highlighting the need for repairs to ensure safety and structural longevity.

**Fig 3 Structural Integrity and Maintenance Tasks**

**Fig 4 Structural Damage and Deterioration at NAD Sunabeda**

## IV. RESEARCH METHODOLOGY

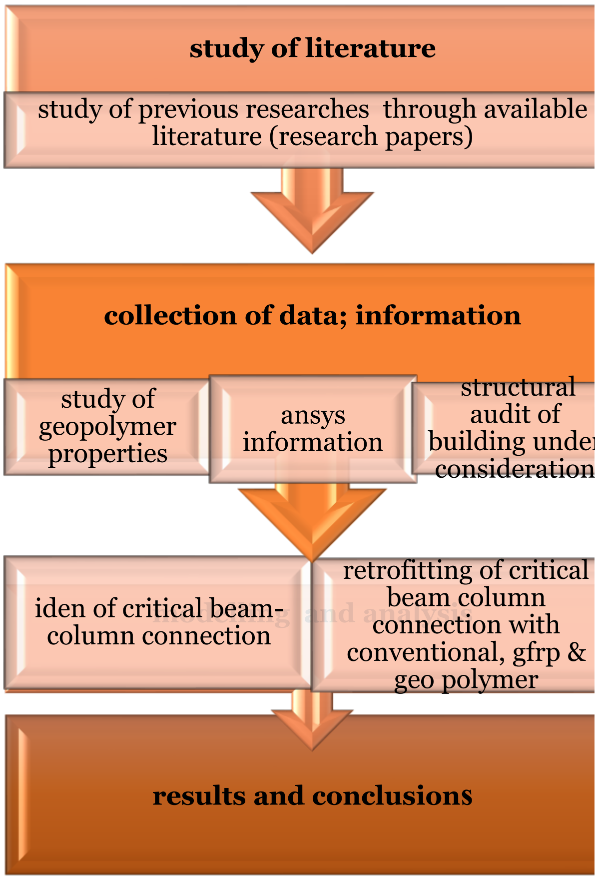



**Fig 5 Flowchart**

**Material properties**

**Table 1 Key Material Properties**

| **Property** | **GFRP** | **Geopolymer** |
|---|---|---|
| Modulus of elasticity in KN/m$^2$ | 2.1*10$^5$ | 3.0*10$^5$ |
| Poisson's ratio | 0.26 | 0.3 |
| Shear modulus in KN/m$^2$ | 1520 | 1500 |
| Density in KN/m$^3$ | 17.3 | 26.5 |

**Seismic analysis of the building**

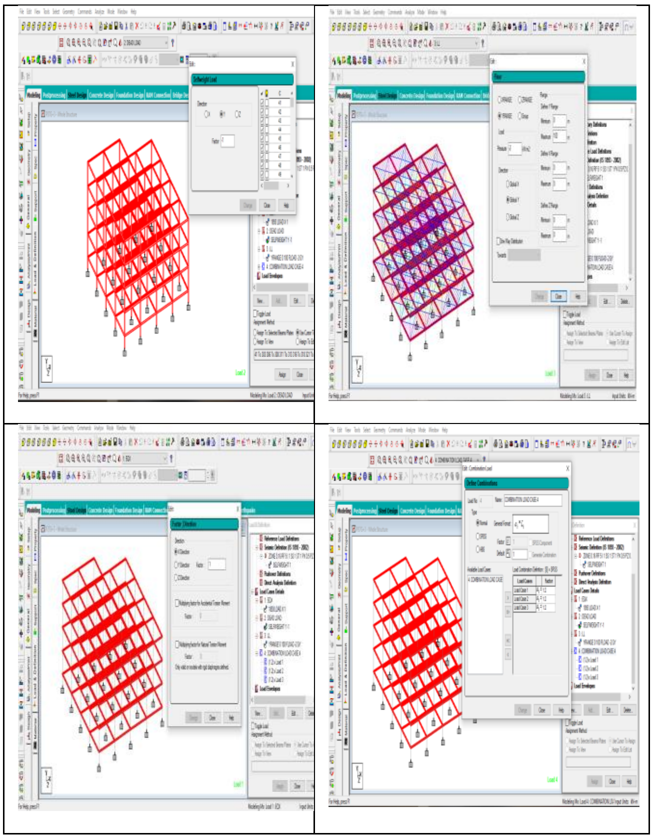


**Fig 6 Seismic Load Analysis and Load Combinations**

The fig 6 represent different load components analyzed in seismic studies for building design. **Dead load** accounts for the permanent, static weight of the building's structure and components, which remains constant. **Live load** refers to the variable forces, such as occupants, furniture, and equipment, that change over time. **Earthquake load** the dynamic forces generated during seismic events, which can significantly affect the building's stability. **Load combination** integrates these loads to assess the building's overall response to various forces, ensuring structural safety and performance under all conditions.

**Retrofitting of the Structure**

Seismic events pose a significant threat to structures, necessitating robust retrofitting strategies to enhance seismic resilience and overall structural performance. The following comparative analysis critically evaluates the three mentioned retrofitting techniques by examining key technical parameters and performance indicators. These observations will subsequently be attempted to correlate in the upcoming sections of the paper using analytical results. A few examples of retrofitting using various techniques under consideration are as under:

Conventional

With GFRP bars

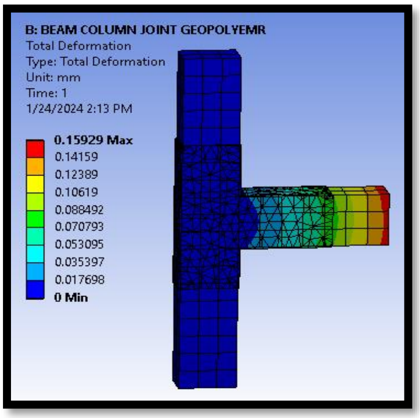
With Geopolymer

**V. RESULT AND DISCUSSION**

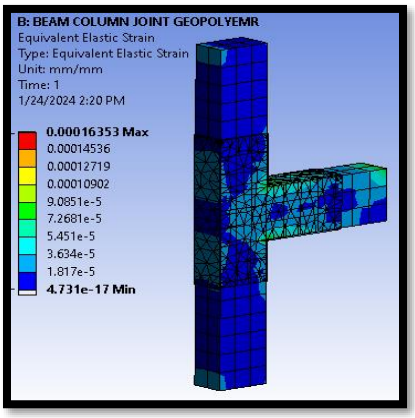
**Key Structural Properties for Comparative Analysis of Retrofitting Techniques**

In evaluating retrofitting technologies, several structural properties are crucial, such as **total deformation**, **equivalent elastic stress**, and **strain**. **Total deformation** helps assess displacement under external loads, critical for structural stability. **Equivalent elastic stress** and **strain** measure stress distribution and material deformation, guiding the selection of effective retrofitting materials. **Normal stress** and **shear stress** analysis helps understand force distribution in building components, while **elastic strain** evaluates a material's ability to resist stress without permanent damage. The comparative analysis of Geopolymer, GFRP, and conventional retrofitting technologies assesses these properties, ensuring optimal structural performance and resilience.

**Model with Geopolymer**

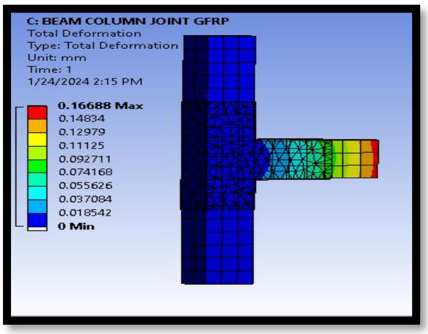



Total Deformation

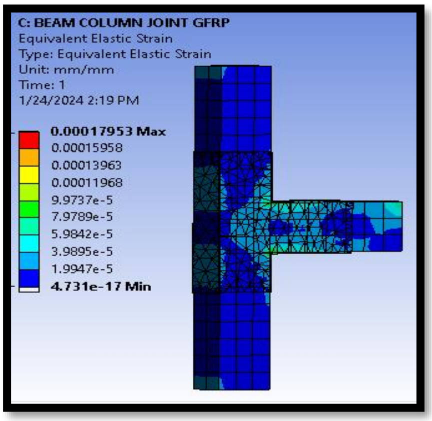



Equivalent Elastic Strain

**Model with GFRP**

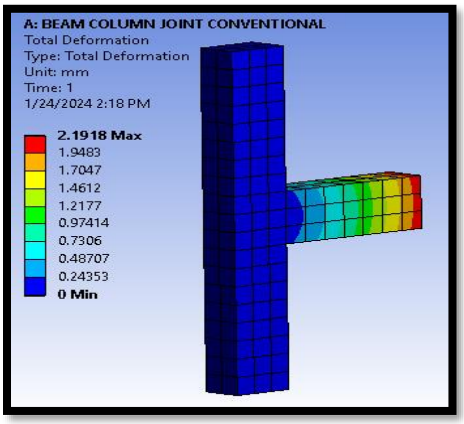



Total Deformation

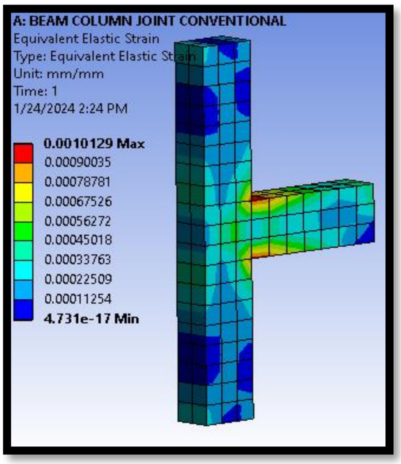



Equivalent Elastic Strain

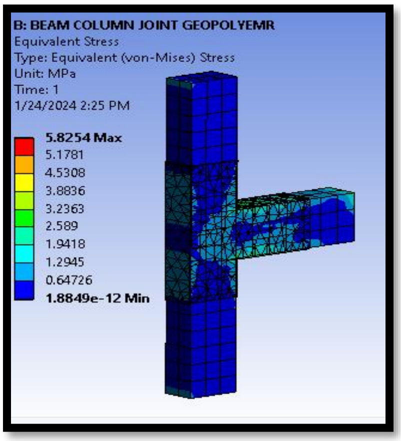
**Conventional Model**



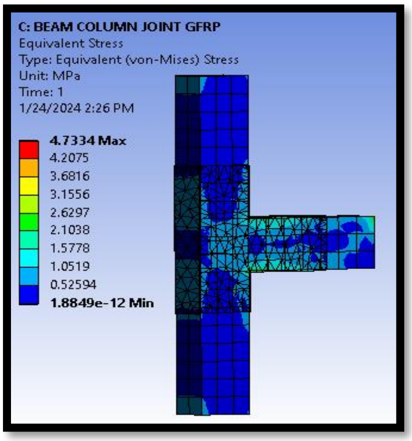

Total Deformation



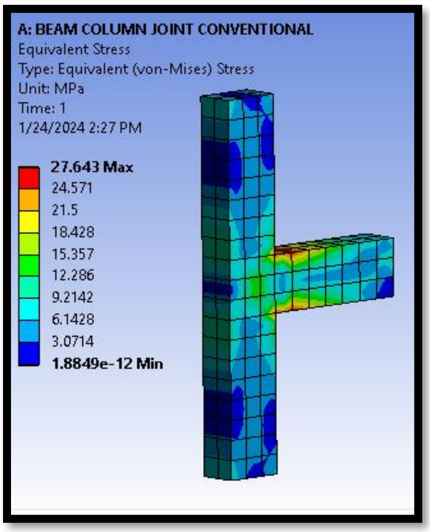

Equivalent Elastic Strain




Equivalent Stress




Equivalent Stress




Equivalent Stress

**Comparative Analysis of Key Structural Properties in Retrofitting Techniques**

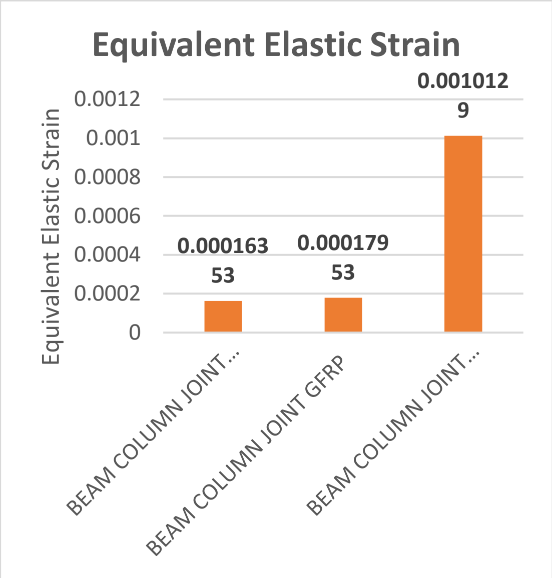



**Fig 7 Comparison of Equivalent Elastic Strain in Beam-Column Joints**

This fig 7 presents the equivalent elastic strain in beam-column joints made from different materials: Geopolymer, GFRP, and Conventional concrete. The strain values indicate the deformation under applied stress. The conventional beam-column joint shows significantly higher strain (0.0010129) compared to the geopolymer (0.00016353) and GFRP (0.00017953) joints, implying that the conventional material has a lower resistance to deformation. This suggests that Geopolymer and GFRP offer better structural performance and can potentially be used in the design of more resilient multi-story RC buildings for extended life prediction and improved safety.

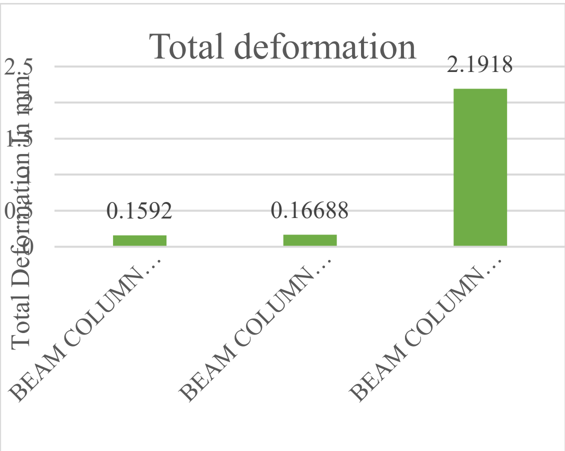



**Fig 8 Total Deformation Comparison for Different Beam-Column Joints**

The fig 8 illustrates the total deformation (in mm) for three types of beam-column joints: Geopolymer, GFRP, and Conventional. The total deformation for the conventional beam-column joint is significantly higher (2.1918 mm) compared to the Geopolymer (0.1592 mm) and GFRP (0.16688 mm) joints. This highlights the better performance of Geopolymer and GFRP materials in minimizing structural deformation. The findings emphasize the potential of these materials for enhancing the durability and load-bearing capacity of multi-story reinforced concrete (RC) buildings, aligning with the goal of implementing structural health monitoring and life prediction using FEM for steel structures.

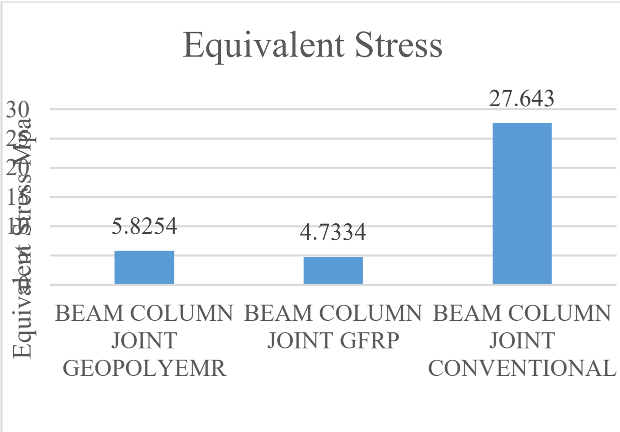



**Fig 9 Equivalent Stress in Beam-Column Joints**

The bar chart presents the equivalent stress values for three different types of beam-column joints: Geopolymer, GFRP, and Conventional. The results highlight that the conventional beam-column joint experiences the highest equivalent stress at 27.643 MPa, indicating a significantly higher stress concentration compared to the Geopolymer and GFRP joints, which have equivalent stresses of 5.8254 MPa and 4.7334 MPa, respectively. This suggests that alternative materials like Geopolymer and GFRP could offer better stress distribution and structural performance, potentially enhancing the durability of multi-story reinforced concrete (RC) buildings. The data supports the need for efficient structural health monitoring and life prediction strategies.

**Response of Beam-Column Joints to Uniform Loading for Retrofitting Techniques**

In our analysis of beam-column joints under uniform loading, three retrofitting methods—GFRP-based, Geopolymer-based, and Conventional—were studied for their effectiveness in reducing stress and enhancing joint resilience. **GFRP-based retrofitting** exhibited significant reduction in equivalent stress, attributed to its high strength-to-weight ratio and corrosion resistance, which allowed for effective load distribution and minimal deformation under stress. This demonstrated GFRP's potential to mitigate failure risks and improve structural durability. **Geopolymer-based retrofitting**, while also reducing stress, showed slightly less effectiveness compared to GFRP. The unique bonding properties of geopolymers helped to enhance the joint's load-bearing capacity and provide increased stability. On the other hand, **conventional retrofitting** involving steel bars and concrete displayed less favorable results, with a higher degree of deformation and limited ability to mitigate stress, indicating that conventional materials may not be as effective under dynamic loading conditions.

**Comparison of Key Retrofitting Properties for Seismic Resilience**

The comparative analysis of GFRP, Geopolymer, and Conventional retrofitting techniques highlights distinct differences in their ability to enhance seismic resilience. **GFRP** offers a high strength-to-weight ratio and excellent corrosion resistance, although it may have limitations in ductility and energy dissipation during seismic events. Despite these challenges, GFRP provides a significant improvement in seismic performance due to its lightness and ability to absorb seismic energy. **Geopolymer-based retrofitting** stands out for its superior compressive strength, chemical resistance, and seismic ductility, making it ideal for high seismic resilience. Its environmental benefits, such as reduced carbon footprint, further enhance its sustainability. In contrast, **Conventional retrofitting**, while proven to provide seismic resistance, often suffers from drawbacks such as increased weight, corrosion over time, and lack of energy dissipation capacity. Overall, GFRP and Geopolymer offer superior long-term benefits for seismic resilience, while conventional techniques may require more maintenance and have reduced effectiveness in dynamic conditions.

## VI. CONCLUSION

In our comprehensive study to identify the critical beam-column joint in the G+3 RC structure, advanced STAAD.Pro software was employed to accurately locate the pivotal junction, facilitating a thorough structural audit. The audit focused on evaluating the building's performance under extreme shear forces and bending moments. Our comparative analysis, enhanced by Finite Element Method (FEM) analysis, revealed that Glass Fiber Reinforced Polymer (GFRP**)** retrofitting resulted in the lowest equivalent stress, followed by Geopolymer-based retrofitting, both of which outperformed conventional retrofitting techniques. In terms of equivalent strain**,** Geopolymer-based retrofitting demonstrated superior results, closely followed by GFRP, while conventional methods showed higher strain values, indicating less favorable performance. Additionally, disparities in total deformation were evident, with Geopolymer-based solutions achieving the best outcomes, followed by GFRP. Both modern retrofitting methods also showed significant improvements in load-carrying capacity compared to conventional techniques. Ultimately, our findings validated that GFRP and Geopolymer retrofitting not only enhanced structural strength and longevity but also bolstered seismic resilience, extending the building's lifespan by approximately 8-10 years, ensuring continued safety and performance.

***STATEMENTS AND DECLARATIONS***

***Ethical Approval***

"The submitted work is original and not have been published elsewhere in any form or language (partially or in full), unless the new work concerns an expansion of previous work."

***Consent to Participate***

"Informed consent was obtained from all individual participants included in the study."

***Consent to Publish***

"The authors affirm that human research participants provided informed consent for publication of the research study to the journal."

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support were received during the preparation of this manuscript.”

***Competing Interests***

“The authors have no relevant financial or non-financial interests to disclose.”

***Availability of data and materials***

“The authors confirm that the data supporting the findings of this study are available within the article.”

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***Declaration of competing 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.

**REFERENCES**

1. Caverzan, A., Lamperti Tornaghi, M., & Nigro, P. (2016). Proceedings of the SAFESUST Workshop. In SAFESUST Workshop (Issue November 2020). https://doi.org/10.2788/252595
2. Almutairi, A. L., Tayeh, B. A., Adesina, A., Isleem, H. F., & Zeyad, A. M. (2021). Potential applications of geopolymer concrete in construction: A review. Case Studies in Construction Materials, 15(October), e00733. https://doi.org/10.1016/j.cscm.2021.e00733
3. Guades, E. J., & Stang, H. (2019). Structural performance of concrete elements retrofitted by a geopolymer strengthening system: Input in the rehabilitation of historical buildings. WIT Transactions on the Built Environment, 191, 369–380. https://doi.org/10.2495/STR190321
4. Longo, F., Lassandro, P., Moshiri, A., Phatak, T., Aiello, M. A., & Krakowiak, K. J. (2020). Lightweight geopolymer-based mortars for the structural and energy retrofit of buildings. Energy and Buildings, 225, 110352. https://doi.org/10.1016/j.enbuild.2020.110352
5. Samadian, D., Ghafory-Ashtiany, M., Naderpour, H., & Eghbali, M. (2019). Seismic resilience evaluation based on vulnerability curves for existing and retrofitted typical RC school buildings. Soil Dynamics and Earthquake Engineering, 127(May), 105844. https://doi.org/10.1016/j.soildyn.2019.105844
6. P, D. (2021). Geopolymer Concrete Preparation Methodology. International Journal for Research in Applied Science and Engineering Technology, 9(3), 565–568. https://doi.org/10.22214/ijraset.2021.33282
7. Kiakojouri, F., De Biagi, V., Chiaia, B., & Sheidaii, M. R. (2022). Strengthening and retrofitting techniques to mitigate progressive collapse: A critical review and future research agenda. Engineering Structures, 262, 1–45. https://doi.org/10.1016/j.engstruct.2022.114274
8. Kinnane, O., Nanukuttan, S. V, Hyde, R., West, R., Nanukuttan, S., & Davis, G. (2017). Moisture movement in concrete during drying View project High-performance, low-impact geopolymer concrete facade panel View project Manufacture and assembly of a thin, lightweight, low impact, prototype precast geopolymer sandwich panel for the retrofit c. October. https://www.researchgate.net/publication/320183067
9. Souza Junior, F. G. de. (2018). Geopolymer: A Review of Structure, Applications and Properties of Fiber Reinforced Composites. Research & Development in Material Science, 7(4). https://doi.org/10.31031/rdms.2018.07.000666
10. Composite, G., & Samal, S. (2021). An Application Review of Fiber-Reinforced.
11. Abulencia, A. B., Villoria, M. B. D., Libre, R. G. D., Quiatchon, P. R. J., Dollente, I. J. R., Guades, E. J., Promentilla, M. A. B., Garciano, L. E. O., & Ongpeng, J. M. C. (2021). Geopolymers as sustainable material for strengthening and restoring unreinforced masonry structures: A review. Buildings, 11(11). https://doi.org/10.3390/buildings11110532
12. Bagde, A., Jamgade, A., Kalambe, D., Ghaiwat, A., & Sir, V. G. (2022). Geopolymer : The Concrete of The Next Decade. 11(05), 38–40.
13. Rajamane, N. P., Nataraja, M. C., & Lakshmanan, N. (2011). An introduction to geopolymer concrete. Indian Concrete Journal, 85(11), 25–28.
14. Eisa, A. S., Sabol, P., Khamis, K. M., & Attia, A. A. (2022). Experimental Study on the Structural Response of Reinforced Fly Ash-Based Geopolymer Concrete Members. Infrastructures, 7(12).

https://doi.org/10.3390/infrastructures7120170
15. Matsimbe, J., Dinka, M., Olukanni, D., & Musonda, I. (2022). Geopolymer: A Systematic Review of Methodologies. Materials, 15(19). https://doi.org/10.3390/ma15196852
16. Meskhi, B., Beskopylny, A. N., Stel'makh, S. A., Shcherban', E. M., Mailyan, L. R., Shilov, A. A., El'shaeva, D., Shilova, K., Karalar, M., Aksoylu, C., & Özkılıç, Y. O. (2023). Analytical Review of Geopolymer Concrete: Retrospective and Current Issues. Materials, 16(10). https://doi.org/10.3390/ma16103792
17. Ozturk, M., Sengun, K., & Arslan, G. (2023). CFRP contribution to load-carrying capacity of retrofitted geopolymer concrete beams. Structures, 48(January), 1391–1402. https://doi.org/10.1016/j.istruc.2023.01.028
18. Vona, M., Flora, A., Carlucci, E., & Foscolo, E. (2021). Seismic retrofitting resilience-based for strategic RC buildings. Buildings, 11(3). https://doi.org/10.3390/buildings11030111
19. Ahmad, M., & Butt, F. (2022). NUMERICAL INVESTIGATION OF CFRP RETROFITTED , QUARRY ROCK DUST , FLY ASH , AND SLAG BASED GEO-POLYMER CONCRETE.
20. Di Vece, D., & Pampanin, S. (2019). Combined retrofit solutions for seismic resilience and energy efficiency of reinforced concrete residential buildings with infill walls. XVIII CONVEGNO ANIDIS ASCOLI PI CENO 2019 L' i Ngegner i a Si Smi ca i, 199–209.
21. HAGHPANAH, F., FOROUGHI, H., & BEHROU, R. (2017). Sustainable Seismic Retrofitting of a Rc Building Using Performance Based Design Approach. Engineering Structures and Technologies, 9(3), 133–141. https://doi.org/10.3846/2029882x.2017.1380539
22. Madheswaran, C. K., Prakash vel, J., Sathishkumar, K., & Rao, G. V. R. (2017). Earthquake Response of Reinforced Concrete Building Retrofitted with Geopolymer Concrete and X-shaped Metallic Damper. Journal of The Institution of Engineers (India): Series A, 98(1–2), 41–52. https://doi.org/10.1007/s40030-017-0209-z
23. Chandrasekaran, S., & Banerjee, S. (2016). Retrofit Optimization for Resilience Enhancement of Bridges under Multihazard Scenario. Journal of Structural Engineering, 142(8), 1–12. https://doi.org/10.1061/(asce)st.1943-541x.0001396
24. Cong, P., & Cheng, Y. (2021). Advances in geopolymer materials: A comprehensive review. Journal of Traffic and Transportation Engineering (English Edition), 8(3), 283–314. https://doi.org/10.1016/j.jtte.2021.03.004
25. Kumre, A., Rana, R. S., & Purohit, R. (2017). A Review on mechanical property of sisal glass fiber reinforced polymer composites. Materials Today: Proceedings, 4(2), 3466–3476. https://doi.org/10.1016/j.matpr.2017.02.236
26. Altin Karataş, M., & Gökkaya, H. (2018). A review on machinability of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) composite materials. Defence Technology, 14(4), 318–326. https://doi.org/10.1016/j.dt.2018.02.001
27. Avci, A., Arikan, H., & Akdemir, A. (2004). Fracture behavior of glass fiber reinforced polymer composite. Cement and Concrete Research, 34(3), 429–434. https://doi.org/10.1016/j.cemconres.2003.08.027
28. Sathishkumar, T. P., Satheeshkumar, S., & Naveen, J. (2014). Glass fiber-reinforced polymer composites - A review. Journal of Reinforced Plastics and Composites, 33(13), 1258–1275. https://doi.org/10.1177/0731684414530790
29. Morampudi, P., Namala, K. K., Gajjela, Y. K., Barath, M., & Prudhvi, G. (2020). Review on glass fiber reinforced polymer composites. Materials Today: Proceedings, 43, 314–319. https://doi.org/10.1016/j.matpr.2020.11.669
30. Rajak, D. K., Wagh, P. H., & Linul, E. (2021). Manufacturing technologies of carbon/glass fiber-reinforced polymer composites and their properties: A review. Polymers, 13(21). https://doi.org/10.3390/polym13213721
31. Sanjay, M., & Yogesha, B. (2017). Studies on Natural/Glass Fiber Reinforced Polymer Hybrid Composites: An Evolution. Materials Today: Proceedings, 4(2), 2739–2747. https://doi.org/10.1016/j.matpr.2017.02.151
32. Benmokrane, B., Wang, P., Ton-That, T. M., Rahman, H., & Robert, J.-F. (2002). Durability of Glass Fiber-Reinforced Polymer Reinforcing Bars in Concrete Environment. Journal of Composites for Construction, 6(3), 143–153. https://doi.org/10.1061/(asce)1090-0268(2002)6:3(143)