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# COMPARATIVE STUDY ON THE PERFORMANCE OF GEOPOLYMER RETROFITTING IN RCC BEAM-COLUMN JOINTS

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## ABSTRACT
*This paper presents a comprehensive analysis of the effectiveness of geopolymer retrofitting in enhancing the performance of reinforced concrete (RCC) beam-column joints. The study employs finite element (FE) analysis to compare the response of beam-column joints retrofitted with geopolymer materials against non-retrofitted specimens under various loading conditions. The investigation focuses on key parameters such as crack development, deflection, stress, and strain to evaluate the structural behavior and effectiveness of geopolymer retrofitting. The findings highlight the significant improvements in load-carrying capacity and strength achieved through geopolymer retrofitting, along with reduced deflection and enhanced crack resistance. Moreover, the paper discusses different configurations of geopolymer application and their impact on structural performance, emphasizing the superiority of complete wrapping around the beam-column connection. Overall, this research contributes valuable insights into the efficacy of geopolymer retrofitting as a sustainable and cost-effective solution for enhancing the seismic resilience of RCC structures.*

*Keywords: Retrofitting, Structural engineering, Geopolymer , Beam-column joints, Seismic resilience, Concrete reinforcement*

## 1 INTRODUCTION

### 1.1 Background and Motivation
In the realm of structural engineering, ensuring the safety and longevity of infrastructure is paramount. Over time, structures are subjected to various environmental and loading conditions, leading to degradation and potential failure. One critical aspect of maintaining structural integrity is retrofitting, which involves the modification or strengthening of existing structures to enhance their performance against seismic events, corrosion, or other forms of deterioration. As urbanization continues to grow, particularly in regions prone to seismic activity, the need for effective retrofitting strategies becomes increasingly evident. This paper focuses on exploring the efficacy of geopolymer retrofitting technology in addressing these challenges.

### 1.2 Importance of Retrofitting in Structural Engineering
Retrofitting plays a crucial role in extending the service life of infrastructure and ensuring its resilience in the face of evolving threats. Aging structures, inadequate design standards, and changing environmental conditions contribute to the vulnerability of buildings and bridges. Retrofitting interventions not only mitigate existing vulnerabilities but also enable structures to meet modern safety standards and performance requirements. By strengthening key components such as beam-column joints, retrofitting efforts contribute to overall structural stability, reducing the risk of catastrophic failure during seismic events or other extreme conditions.

### 1.3 Overview of Geopolymer Retrofitting Technology
Geopolymer retrofitting technology has emerged as a promising solution for enhancing the structural performance of concrete elements. Geopolymers, formed through the activation of aluminosilicate materials with alkaline solutions, offer several advantages over traditional retrofitting materials. These include high strength, durability,

and chemical resistance, making them well-suited for applications in harsh environmental conditions. In the context of retrofitting, geopolymers can be used to reinforce concrete members, improve crack resistance, and increase load-carrying capacity. This paper seeks to provide a comprehensive overview of geopolymer retrofitting technology, exploring its mechanisms, applications, and effectiveness in enhancing the seismic resilience of structures.

## 2 LITERATURE REVIEW

### Previous Studies on Beam-Column Joint Retrofitting Techniques

Beam-column joints are critical components in reinforced concrete structures, vulnerable to failure under seismic loading. Numerous studies have investigated retrofitting techniques to enhance the seismic performance of these joints. Traditional approaches include steel jacketing, external bonding of fiber-reinforced polymers (FRP), and concrete jacketing. Steel jacketing provides increased confinement and ductility, while FRP applications offer lightweight and corrosion-resistant solutions. Concrete jacketing improves the overall stiffness and strength of the joint. Comparative studies have evaluated the effectiveness of these techniques in terms of load-carrying capacity, ductility, and energy dissipation.

### Advantages and Limitations of Geopolymer Retrofitting

Geopolymer retrofitting technology offers several advantages over conventional techniques. Geopolymers exhibit high early strength development, excellent chemical resistance, and low shrinkage characteristics. They can be easily tailored to match the specific requirements of a retrofitting project, providing versatility and adaptability. Moreover, geopolymers are eco-friendly alternatives to Portland cement-based materials, contributing to sustainable construction practices. However, challenges such as long-term durability, bond strength to existing concrete, and material compatibility need to be addressed. Further research is required to optimize geopolymer formulations and enhance their performance as retrofitting materials.

### Relevant Research on the Performance of Geopolymer-Retrofitted Structures

Several studies have investigated the performance of structures retrofitted with geopolymers in various applications. Experimental investigations have evaluated the mechanical properties, bond behavior, and durability of geopolymer retrofit systems. Structural tests, including cyclic loading and seismic simulation, have demonstrated the effectiveness of geopolymer retrofitting in enhancing the seismic resilience of buildings and bridges. Field studies have assessed the long-term performance of geopolymer-retrofitted structures under real-world conditions. Additionally, numerical modeling and finite element analysis have provided insights into the behavior of geopolymer-retrofitted elements, aiding in the design and optimization of retrofitting strategies.

**Table No. 1** Comparison of deflection, stress and strain value for T Shape with geopolymer specimen 3 load vs Deflection for T Shape with Geo polymer C3

| Load | Deflection | Stress | Strain |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 5000 | 3.8184 | 68.617 | 0.00205 |
| 10000 | 4.6266 | 99.863 | 0.00244 |
| 15000 | 5.4348 | 131.5 | 0.00283 |
| 20000 | 6.243 | 163.137 | 0.00322 |
| 25000 | 7.0512 | 194.774 | 0.00361 |
| 30000 | 7.8594 | 226.411 | 0.00399 |
| 35000 | 8.6676 | 258.048 | 0.00438 |
| 40000 | 9.4758 | 289.685 | 0.00477 |

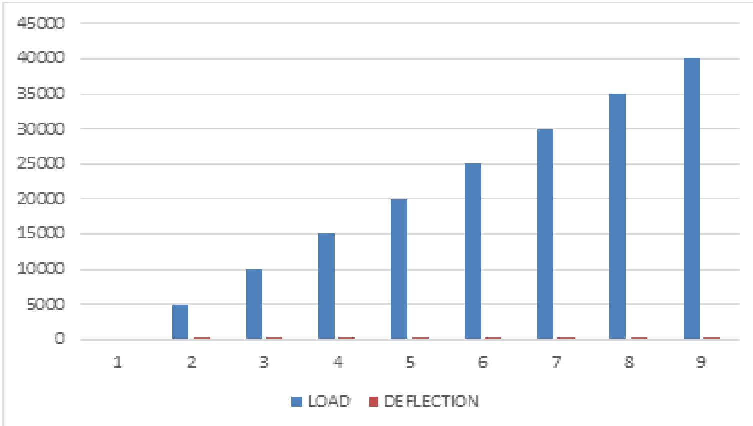


**Fig 1:** load vs Deflection for T Shape with Geo polymer C3

As we can see in the graph, deflection is increasing as per loads are increasing. Also stress and strain and increasing when loads are increasing.

- Comparison of Non Geo polymer and Geo Polymer Beam-column Joints Results
- For T Shape: - Load v/s Deflection Results

**Table No. 2** Deflection

| | Deflection in mm | | | |
|---|---|---|---|---|
| **LOAD** | **NG** | **GS1** | **GS2** | **GS3** |
| 0 | 0 | 0 | 0 | 0 |
| 5000 | 4.3912 | 1.2002 | 2.036 | 3.8184 |
| 10000 | 5.3206 | 1.1786 | 2.8847 | 4.6266 |
| 15000 | 6.25 | 2.1618 | 3.0353 | 5.4348 |
| 20000 | 7.1795 | 3.1504 | 4.4478 | 6.243 |
| 25000 | 8.1089 | 4.139 | 6.2269 | 7.0512 |
| 30000 | 9.0383 | 5.1276 | 7.2729 | 7.8594 |
| 35000 | 9.9677 | 6.1162 | 7.5735 | 8.6676 |
| 40000 | 10.897 | 7.1048 | 9.1865 | 9.4758 |

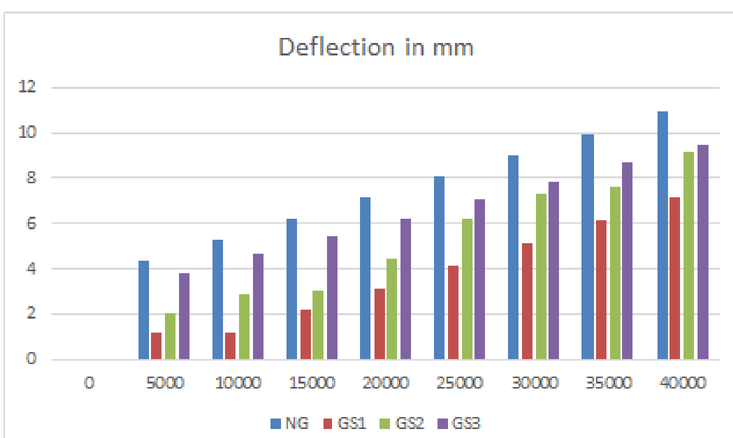


**Fig 2:** Deflection

As we can see that RCC model has higher deflection than the other geo polymer models.

**T SHAPE GEOPOLYMER SPECIMEN**

**Table 3:** Total Deformation

| Total Deformation in mm | | | |
|---|---|---|---|
| **Load case** | **GS 1** | **GS 2** | **GS3** |
| 0 | 0 | 0 | 0 |
| 1 | 1.2002 | 2.036 | 3.8184 |
| 2 | 1.1786 | 2.88465 | 4.6266 |
| 3 | 2.1618 | 3.03525 | 5.4348 |
| 4 | 3.1504 | 4.4478 | 6.243 |
| 5 | 4.139 | 6.22692 | 7.0512 |
| 6 | 5.1276 | 7.2729 | 7.8594 |
| 7 | 6.1162 | 7.5735 | 8.6676 |
| 8 | 7.1048 | 9.18645 | 9.4758 |
| 9 | 8.0934 | 9.53715 | 10.284 |
| 10 | 9.082 | 9.88785 | 11.0922 |
| 11 | 10.0706 | 11.3004 | 11.9004 |
| 12 | 11.0592 | 11.7012 | 12.7086 |
| 13 | 12.0478 | 13.6148 | 13.5168 |
| 14 | 13.0364 | 14.0657 | 14.325 |
| 15 | 14.025 | 14.5166 | 15.1332 |
| 16 | 15.0136 | 15.6327 | 15.9414 |
| 17 | 16.0022 | 16.4462 | 16.7496 |
| 18 | 16.9908 | 17.2799 | 17.5578 |
| 19 | 17.9794 | 18.1335 | 18.366 |
| 20 | 18.968 | 19.0431 | 19.1742 |
| 21 | 17.9794 | 18.502 | 18.366 |
| 22 | 16.0022 | 16.4462 | 17.5578 |

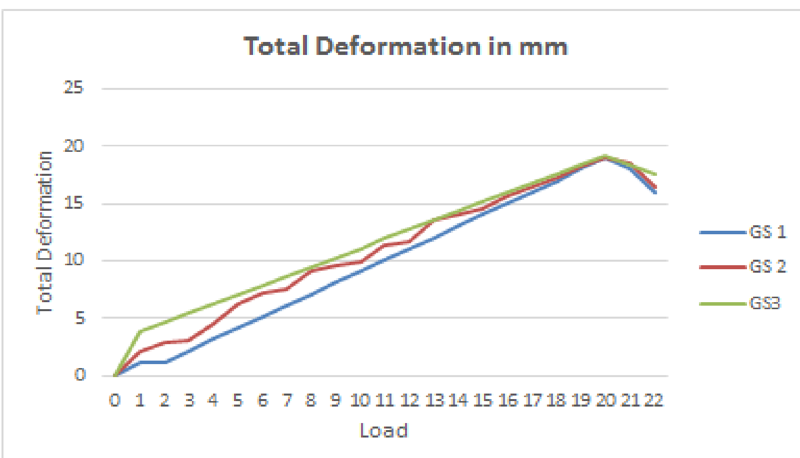


**Fig 3:** Total Deformation

the above graph shows total deformation for the T shape model for 3 different specimens with using geo polymer. as we can see that total wrapping geo polymer model has the lower displacement which is 1.2002mm and top bottom geo polymer wrapping model hasthe highest deformation which is 3.8184mm.

**Table 4:** Equivalent Stress

| Equivalent Stress in mpa | | | |
|---|---|---|---|
| **Load case** | **GS1** | **GS2** | **GS3** |
| 0 | 0 | 0 | 0 |
| 1 | 154.47 | 97.152 | 68.617 |
| 2 | 180.56 | 131.248 | 99.863 |
| 3 | 206.65 | 164.955 | 131.5 |
| 4 | 232.74 | 199.023 | 163.137 |
| 5 | 258.83 | 206.77 | 194.774 |
| 6 | 284.92 | 268.236 | 226.411 |
| 7 | 311.01 | 303.381 | 258.048 |
| 8 | 337.1 | 318.552 | 289.685 |
| 9 | 363.19 | 327.053 | 321.322 |
| 10 | 389.28 | 363.024 | 352.959 |
| 11 | 415.37 | 378.697 | 384.596 |
| 12 | 441.46 | 422.199 | 416.233 |
| 13 | 467.55 | 452.218 | 447.87 |
| 14 | 493.64 | 482.524 | 479.507 |
| 15 | 519.73 | 513.124 | 511.144 |
| 16 | 545.82 | 544.005 | 542.781 |
| 17 | 577.629 | 575.173 | 574.418 |
| 18 | 606.055 | 599.491 | 598 |
| 19 | 637.692 | 631.198 | 624.09 |
| 20 | 669.329 | 655.983 | 650.18 |
| 21 | 637.692 | 631.98 | 624.09 |
| 22 | 574.418 | 569.938 | 568.1 |

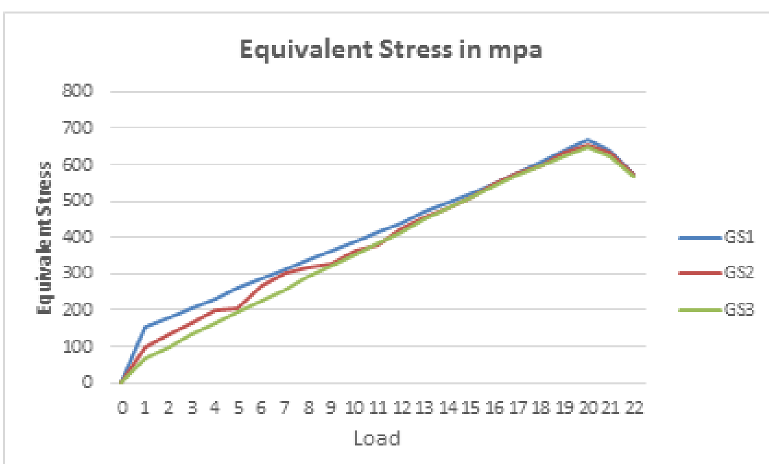


**Fig 4** Equivalent Stress mpa

The above graph shows Equivalent Stress for the T shape model for 3 different specimens with using geo polymer. as we can see that top bottom geo polymer model has the Highest Equivalent Stress which is 154.47 mpa and total wrapping geo polymer wrapping model has the highest Equivalent Stress which is 68.617 mpa.

**Table No.5:** Equivalent Strain

| Equivalent Strain | | | |
|---|---|---|---|
| **Load case** | **GS1** | **GS 2** | **GS3** |
| 0 | 0 | 0 | 0 |
| 1 | 0.00185 | 0.00189 | 0.00205 |
| 2 | 0.00197 | 0.0022 | 0.00244 |
| 3 | 0.00201 | 0.00255 | 0.00283 |
| 4 | 0.00227 | 0.003 | 0.00322 |
| 5 | 0.00276 | 0.00324 | 0.00361 |
| 6 | 0.00325 | 0.00359 | 0.00399 |
| 7 | 0.00373 | 0.00394 | 0.00438 |
| 8 | 0.00422 | 0.00429 | 0.00477 |
| 9 | 0.00452 | 0.00464 | 0.00516 |
| 10 | 0.0052 | 0.00499 | 0.00555 |
| 11 | 0.00532 | 0.00536 | 0.00593 |
| 12 | 0.0055 | 0.00569 | 0.00632 |
| 13 | 0.00583 | 0.00604 | 0.00671 |
| 14 | 0.00601 | 0.00639 | 0.0071 |
| 15 | 0.00632 | 0.00674 | 0.00749 |
| 16 | 0.00647 | 0.00709 | 0.00787 |
| 17 | 0.00701 | 0.00744 | 0.00826 |
| 18 | 0.00724 | 0.00792 | 0.00865 |
| 19 | 0.00768 | 0.00814 | 0.00904 |
| 20 | 0.00804 | 0.0085 | 0.00943 |
| 21 | 0.00814 | 0.00904 | 0.00958 |
| 22 | 0.00775 | 0.00779 | 0.00865 |

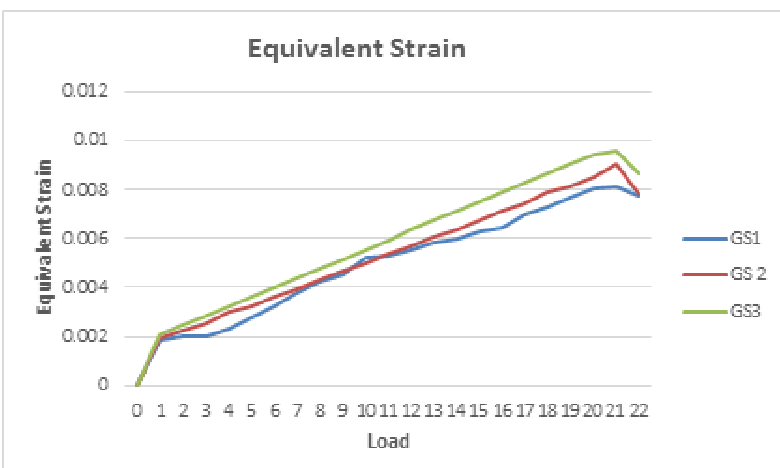


**Fig 5:** Equivalent Strain

the above graph shows Equivalent Strain for the T shape model for 3 different specimens with using geo polymer. as we can see that total wrapping geo polymer model has the lower Equivalent Strain which is 0.00185 and top bottom geo polymer wrapping model has the higher Equivalent Strain which is 0.00205.

**Table No.6:** Normal Elastic Strain

| Normal Elastic Strain | | | |
|---|---|---|---|
| **Load case** | **GS1** | **GS2** | **GS3** |
| 0 | 0 | 0 | 0 |
| 1 | 0.00021 | 0.00026 | 0.00044 |
| 2 | 0.00028 | 0.00035 | 0.00053 |
| 3 | 0.00035 | 0.00043 | 0.00061 |
| 4 | 0.00041 | 0.00051 | 0.00069 |
| 5 | 0.00048 | 0.00059 | 0.00078 |
| 6 | 0.00055 | 0.00067 | 0.00086 |
| 7 | 0.00061 | 0.00075 | 0.00094 |
| 8 | 0.00068 | 0.00084 | 0.00103 |
| 9 | 0.00074 | 0.00092 | 0.00111 |
| 10 | 0.00081 | 0.00105 | 0.00119 |
| 11 | 0.00088 | 0.00114 | 0.00128 |
| 12 | 0.00094 | 0.00122 | 0.00136 |
| 13 | 0.00101 | 0.00134 | 0.00144 |
| 14 | 0.00107 | 0.00139 | 0.00153 |
| 15 | 0.00114 | 0.00148 | 0.00161 |
| 16 | 0.00121 | 0.00157 | 0.00169 |
| 17 | 0.00127 | 0.00165 | 0.00177 |
| 18 | 0.00134 | 0.00174 | 0.00186 |
| 19 | 0.0014 | 0.00183 | 0.00194 |
| 20 | 0.00147 | 0.00191 | 0.00202 |
| 21 | 0.00134 | 0.00174 | 0.00194 |
| 22 | 0.00127 | 0.00165 | 0.00186 |

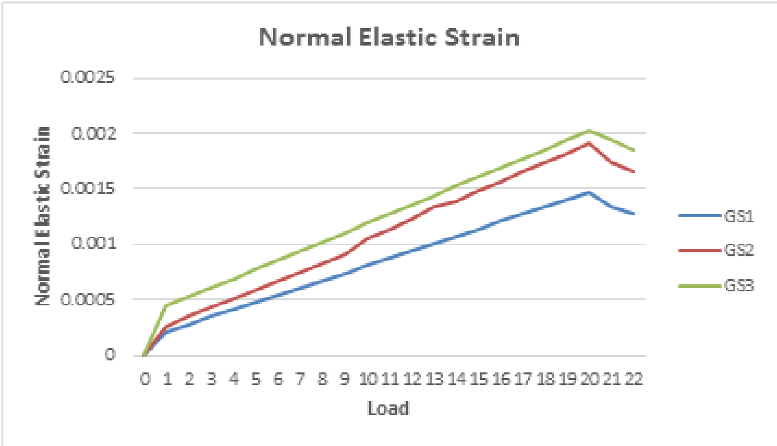


**Fig 6:** Normal Elastic Strain

The above graph shows Normal Elastic Strain for the T shape model for 3 different specimens with using geo polymer. as we can see that total wrapping geo polymer model has the lower Normal Elastic Strain which is 0.00021 and top bottom geo polymer wrapping model has the higher Normal Elastic Strain which is 0.00044.

**Table No7:** Normal Elastic Stress MPa

| Normal Elastic Stress MPa | | | |
|---|---|---|---|
| **Load case** | **GS1** | **GS2** | **GS3** |
| 0 | 0 | 0 | 0 |
| 1 | 28.2579 | 10.4509 | 9.5008 |
| 2 | 37.1943 | 10.4654 | 9.514 |
| 3 | 46.1307 | 21.109 | 19.19 |
| 4 | 55.0671 | 31.7526 | 28.866 |
| 5 | 64.0035 | 42.3962 | 38.542 |
| 6 | 72.9399 | 53.0398 | 48.218 |
| 7 | 81.8763 | 63.6834 | 57.894 |
| 8 | 90.8127 | 74.327 | 67.57 |
| 9 | 99.7491 | 84.9706 | 77.246 |
| 10 | 108.686 | 95.6142 | 86.922 |
| 11 | 117.622 | 104.258 | 96.598 |
| 12 | 126.558 | 116.901 | 106.274 |
| 13 | 135.495 | 127.545 | 115.95 |
| 14 | 144.431 | 128.189 | 125.626 |
| 15 | 153.368 | 145.699 | 135.302 |
| 16 | 162.304 | 154.189 | 144.978 |
| 17 | 171.24 | 162.678 | 154.654 |
| 18 | 180.763 | 171.725 | 153.797 |
| 19 | 191.407 | 181.836 | 171.921 |
| 20 | 202.05 | 191.948 | 180.045 |
| 21 | 220.763 | 211.725 | 191.921 |
| 22 | 240.119 | 221.613 | 211.797 |

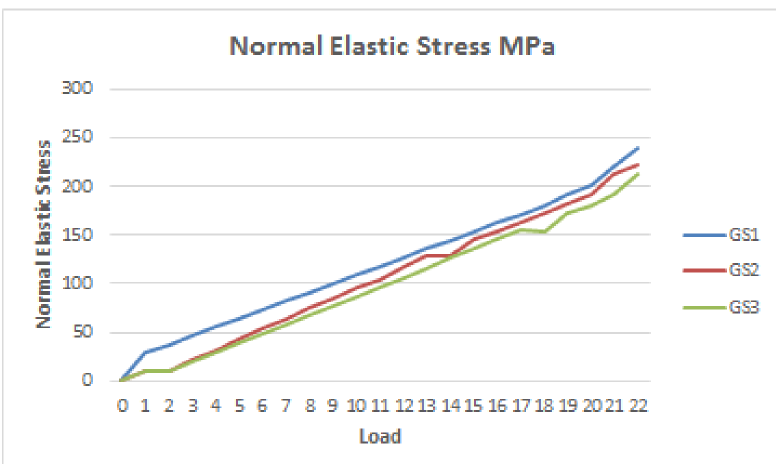


**Fig 7:** Normal Elastic Stress MPa

The above graph shows Normal Elastic Stress for the T shape model for 3 different specimens with using geo polymer. as we can see that total wrapping geo polymer model has the highest Normal Elastic Stress which is 28.2579 mpa and top bottom geo polymer wrapping model has the lower Normal Elastic Stress which is 9.5008 mpa.

## CONCLUSIONS

**Validation of Finite Element Analysis:**
The comparison between finite element (FE) analysis and experimental test results aimed to ensure the accuracy and reliability of the present finite-element model in predicting the response of beam-column joints. This validation process underscores the robustness of our analytical approach.

**Cracking Pattern and Shear Failure:**
Cracks observed at the joint are indicative of shear failure, revealing the typical cracking pattern in beam-column joints. Understanding the nature and distribution of these cracks is essential for assessing the structural performance and integrity of the system.

**Effect of Geopolymer Material on Deflection:**
The absence of geopolymer material results in a notable increase in deflection within the RCC beam-column connection. This highlights the crucial role of geopolymer retrofitting in reducing deflection and enhancing structural stability under load.

**Increasing Stress and Strain with Load:**
Both stress and strain exhibit a consistent increase with the application of load. This behavior underscores the progressive deformation and stress accumulation within the structural elements under varying loading conditions.

**Impact of Geopolymer Wrapping Configuration:**
Comparative analysis reveals significant differences between side wrapping and complete wrapping configurations of geopolymer connections. Specifically, the completely wrapped geopolymer connection exhibits a 63.015% increase in normal elastic stress and a 4.22% reduction in equivalent strain compared to side wrapping, emphasizing the importance of wrapping configuration in retrofitting efficacy.

**Effectiveness of Geopolymer Retrofitting on Stress Distribution:**
Comparison of load-stress results between control and geopolymer specimens demonstrates a substantial increase in stress for geopolymer-retrofitted specimens. The stress reduction observed in GFRP specimens of T shape - GS1, GS2, and GS3, by 63.15%, 17.04%, and 13.04%, respectively, highlights the effectiveness of geopolymer retrofitting in enhancing structural performance.

**Enhanced Load-Carrying Capacity with GFRP:**
As stress decreases, the load-carrying capacity and strength of the structure increase, particularly evident with the use of GFRP in comparison to non-geopolymer specimens. This underscores the role of GFRP as an effective retrofitting material in enhancing structural resilience.

**Optimal Configuration of GFRP Retrofitting:**
Different configurations of GFRP retrofitting, including attachment to the top, bottom, and lateral sides of beams, were evaluated. Results indicate that complete wrapping of geopolymer material around the RCC beam-column connection yields superior outcomes compared to non-geopolymer specimens, emphasizing the importance of optimal retrofitting configuration for maximizing structural performance.

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