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ANALYTICAL STUDY OF BEAM-COLUMN JOINT USING ANSYS WORKBENCH

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ABSTRACT:

Beam-column joints are critical to the structural integrity of reinforced concrete (RC) buildings, particularly under seismic loads. This study investigates the performance of conventional concrete and geopolymer concrete in beam-column joints utilizing finite element analysis (FEA) in ANSYS software. The research focuses on analyzing shear strength, deformation, and Stress distributions under various loading conditions: axial load with uniformly distributed load (UDL), uniaxial load with UDL, and biaxial load with UDL.

A detailed 3D model of the beam-column joints were developed for both conventional and geopolymer concrete. The conventional concrete exhibited slightly higher total deformation and directional deformation compared to geopolymer concrete under all loading conditions. However, geopolymer concrete demonstrated superior shear strength, with a significant increase in shear stress values, indicating its enhanced capacity to resist shear forces. The total deformation was reduced by up to 10.57% under biaxial loading, and shear stress increased by up to 161.99% in geopolymer concrete relative to conventional concrete.

The findings suggest that geopolymer concrete offers improved performance in terms of stiffness and shear strength, making it a viable alternative to conventional concrete for structural applications. Its enhanced capacity for shear resistance and reduced deformation under complex loading scenarios underscores its potential for increasing the durability and reliability of structural joints in reinforced concrete buildings.

KEYWORDS: Beam-Column joint, Geoploymer concrete, Finite Element Analysis (FEA), Ansys Workbench.

INTRODUCTION:

Beam-column joints are among the most critical components in reinforced concrete structures. Their primary function is to ensure the effective transfer of loads between connected members, maintaining the continuity of the structural system. In such structures, the area of the column that overlaps with the depth of the beam at their intersection is known as the beam-column joint.

During seismic or ground movement events, beam-column joints are subjected to the significant forces, particularly lateral forces. As the behavior of these joints is crucial to the overall reinforced concrete structure's response. Lateral forces generate high shear stresses at the beam-column joint, and if the joint fails to resist these forces, it could lead to structural failure. In reinforced concrete moment-resisting frames, beam-column joints are often the weakest elements. Their stability is essential, as failure at these joints can initiate a progressive collapse of the entire structure. The beam-column joint acts as a vital connection, transferring loads between the beams and columns. Many structural failures originate at these joints, often due to inadequate detailing of shear reinforcement.

Types of Joints:

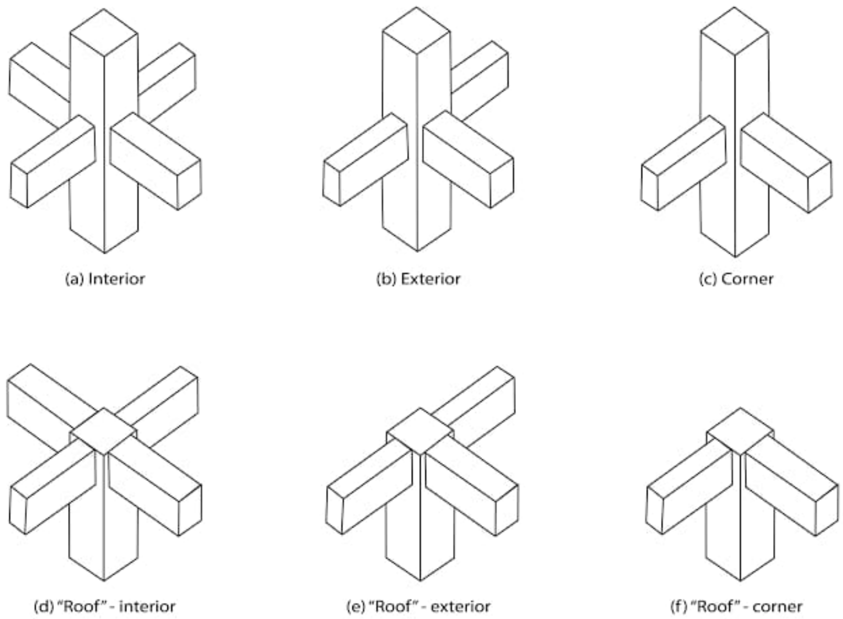


Fig. 1. Types of Beam & Column Joints

There are mainly seven types of beam-column joints:

1. **Interior Joint:** A joint where four beams connect to a central column within a building's interior.
2. **Exterior Joint:** Characterized by one beam connecting to a column, with two additional beams joining perpendicularly, typically found on a building's exterior.
3. **Corner Joint:** Occurs where two beams intersect with two adjacent sides of a column, usually at the corner of a building.
4. **Roof Interior Joint:** Occurs where four beams intersect with a column, typically within a building's roof structure.
5. **Roof Exterior Joint:** Involves a column and two beams that intersect at perpendicular angles at the roof level.
6. **Roof Corner Joint:** Formed where two beams meet the two side faces of a column at a corner of the structure.
7. **Planner Joint:** Formed when one beam connects to a single side of the column, aligning with a specific plane.

Each of these joints plays a unique role in a building's structural integrity, with their performance directly impacting the stability and safety of the entire structure. Proper design and detailing, especially regarding shear reinforcement, are crucial to prevent failures at these joints.

Proper detailing of beam-column joints is vital for ensuring the durability and resilience of reinforced concrete structures. This emphasizes how important these joints are even more under extreme loading conditions, such as during earthquakes, where the demand for ductility and energy dissipation is high. Inadequate joint design can lead to brittle failures, where the structure may not exhibit sufficient warning before collapse. Therefore, engineers must carefully consider the reinforcement layout, the grade of materials, and the construction practices employed at these joints.

One of the key aspects of joint design is the provision of adequate shear reinforcement. This reinforcement helps to resist the high shear forces that develop at the joint during lateral loading. Typically, stirrups or ties are used to confine the concrete and prevent it from cracking or crushing under stress. The amount and spacing of this reinforcement must be carefully calculated based on the expected loads and the seismic zone of the structure.

Moreover, the geometry of the joint such as, size of the beams and columns, and the angle at which they intersect also influences its behavior. Larger cross-sectional areas provide more space for reinforcement and allow for better load distribution. However, increasing the size of the joint should be balanced with the need for architectural considerations and space constraints.

In conclusion, beam-column joints are integral to overall structural performance of reinforced concrete buildings. Their design requires an holistic approach, taking in account the interaction between materials, reinforcement, and loads. Ensuring the integrity of these joints through meticulous design and detailing is essential to prevent catastrophic failures and to ensure the safety and longevity of the structure.

LITERATURE REVIEW

Jagadeesan Saravanan, Ganapathy Kumaran (2011) study evaluates the shear strength of exterior concrete beam-column joints internally reinforced with the Glass Fibre Reinforced Polymer (GFRP) under monotonically increasing loads on the beams while maintaining a constant load on the columns. A total of eighteen specimens were cast and they tested under varying conditions, including different beam longitudinal reinforcement ratios, concrete strengths, column reinforcement ratios, joint aspect ratios, and effects of joint stirrups. Finite element analysis was also conducted to simulate the behavior of these joints across the various parameters. Based on experimental findings and a review of existing design equations, a modified design equation is proposed to better assess the shear strength of GFRP-reinforced beam-column joints.

B. Venkatesan, R. Ilangovan, P. Jayabalan, N. Mahendran, N. Sakthieswaran (2016) this paper examines the seismic performance of exterior beam-column joints have been strengthened using unconventional reinforcement detailing. The specimens were subjected to the reverse cyclic loading applied at the beam end. The samples were categorized into the two groups based on their joint reinforcement detailing: Group A consisted of three non-ductile specimens following the Indian construction code IS456-2000, while Group B included three ductile specimens with reinforcement detailed according to IS13920-1993, with similar axial load conditions as Group A. The experimental results were validated through finite element analysis using ANSYS. The finding indicates that, the hysteresis simulation is effective for both unstrengthened and ferrocement-strengthened specimens. Notably, ferrocement-strengthened beam-column joints showed superior structural performance compared to unstrengthened specimens, with improvements of approximately 31.56% and 38.98% for DD-T1 and DD-T2, respectively. The analytical predictions of the shear strength were consistent with the test results reported in the literature, thereby confirming accuracy of the proposed models.

Mohammad S. Alhaddad, Nadeem A. Siddiqui, Aref A. Abadel, Saleh H. Alsayed, and Yousef A. Al-Salloum (2016) paper outlines a comprehensive procedure for conducting nonlinear finite-element analysis of exterior beam-column joints in a reinforced concrete (RC) structures that have been upgraded with the fiber reinforced polymer (FRP) and the textile reinforced mortar (TRM). The analysis aims to predict the seismic performance under simulated earthquake conditions. The finite-element (FEM) utilizes a smeared cracking approach for concrete and three-dimensional layered elements for FRP and TRM composites. The results from the FEM analysis were compared with the experimental data from tests conducted on the four as-built exterior beam-column joint specimens subjected to the simulated seismic loads. Among these, one specimen served as a control, while other three were strengthened with TRM, carbon FRP, and glass FRP sheets, respectively. The comparison between FE results and experimental observations focused on load-displacement behavior, ultimate loads, and crack patterns. The results demonstrated that the proposed nonlinear FE model accurately predicts the behavior and response of tested RC beam-column joints.

Mohamed I. S. Elmasry, Ahmed M. Abdelkader & Essam A. Elkordy (2017) introduces a finite element (FEM) designed to simulate the behavior of exterior beam & column joints in older RC frame structures originally built for gravity loads. The study examines several specimens: one representing the unstrengthened condition and others representing various strengthening methods. These methods include use of CFRP sheets for banded joints, proposed as a new technique, and steel jackets, which are based on previous research. Each scenario is modeled and analyzed under incremental loading until failure. The resulting stress and deformation are assessed and compared across different cases. Numerical results indicate that beam & column joints strengthened with CFRP sheets exhibit improved structural stiffness, strength, and the energy dissipation compared to other methods, and this proposed technique also offers practical advantages.

Pranali Wasnik, Prof. Sanket Sanghai & Dr. P.Y. Pawade (2021) study focuses on finite element (FE) analysis of beam-column joints reinforced with stirrup bars at varying spacings under cyclic loading, aiming to enhance joint strength. The development of these joints is crucial in a seismic zones where cyclic loading is common. Six samples with the different characteristics were selected and designed according to ductile detailing standards (IS 13920-2016) and non-ductile detailing standards (IS 456-2000), and analyzed using ANSYS software. The results indicates that the addition of lateral reinforcement significantly increases shear strength. Among all samples, the highest shear strength were observed with stirrups placed at L/3 and L/4 scaled distances.

Gopi raju D, Dr. P. Parthiban(2022) In this study, a beam-column joint was manually designed and cast according to IS 456-2000. After a 28-day curing period, the joint was tested in the laboratory. The same design specifications were then modeled in ANSYS software using finite element method to obtain analytical results. These analytical results were compared with the experimental findings to assess their accuracy and consistency.

Kranti Uttam More, Anand Bankad(2023) The primary goal is to analyze the reinforced concrete beams using ANSYS software and compare the behavior of the reinforced versus unreinforced beams under load. The analysis is performed using the static structural method. The beam under consideration has dimensions of 750x150x150 mm, with main reinforcement bars of 12 mm diameter and stirrups of 8 mm diameter. Typically, predicting the behavior of a reinforced concrete elements until failure involves experimental testing, which is often limited to critical locations due to the high costs of testing equipment and materials. To circumvent destructive testing and reduce material and labor costs, numerical methods are frequently employed for behavior prediction. This project includes a stress-strain analysis of beam model, evaluates load capacity, and compares the experimental results with those obtained from ANSYS software. The analysis covers both reinforced and unreinforced rectangular concrete beams. The aim is to provide practical insights into beam behavior and to compare experimental findings with software results.

OBJECTIVES

- To study the different loads and resulting forces acting on beam-column joint.
- Analyse the beam - column joint in Ansys software and find out the shear force, bending moment and deflections.
- Compare the results of beam - column joint of both Conventional and Geopolymer concrete.

METHODOLOGY

In this project work, both strengthened and unstrengthened exterior beam-column connections are examined. The study suggests enhancing the shear capacity of these connections by applying Geopolymer concrete. The beam-column connection is modeled and subjected to loading to assess its strength against overturning moments and evaluate the effectiveness of the different strengthening methods compared to the unstrengthened connection. The results are analyzed and compared, including the load-deflection response for each beam-column joint and the unstrengthened joint.

A finite element model is created using ANSYS software to analyze beam-column connection problems. ANSYS is a versatile Finite Element (FE) modeling and analysis tool. The characteristics of various elements utilized in the model are detailed below.

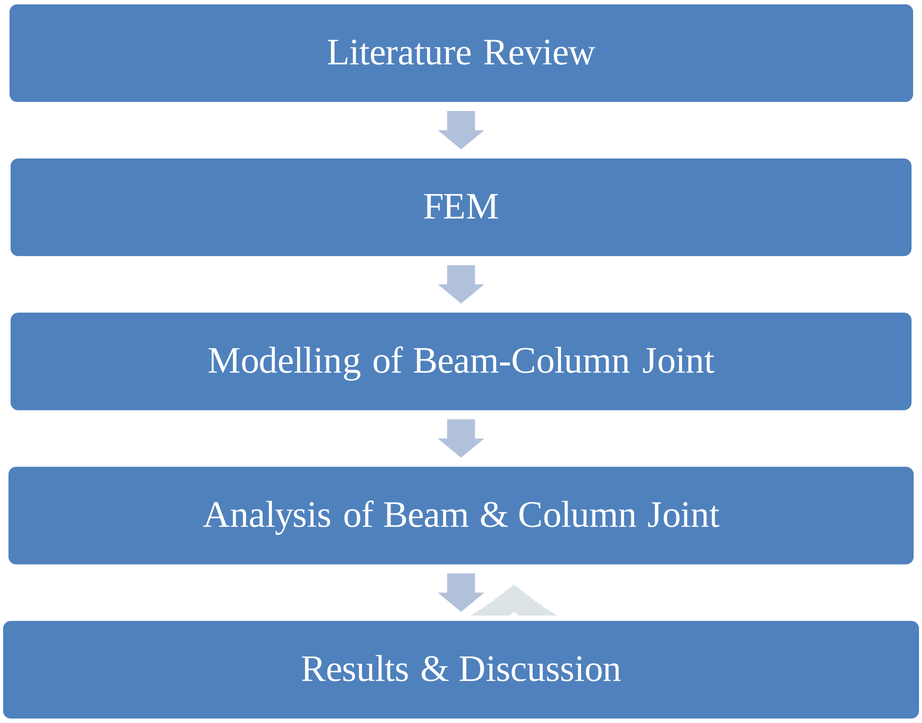


Fig. 2. Flow Chart of the methodology

FINITE ELEMENT METHOD

The Finite Element Method is a numerical technique used to approximate the behavior of structures under various loading conditions. In this context, FEM is employed to simulate the beam-column joint's response, providing insights into stress distribution, deformation, and failure modes.

Concrete is modeled using the Solid 65 element, a 3-D structural solid element designed for reinforced concrete. It can simulate cracking under tension & crushing under compression. This element is defined by the eight nodes, containing with three translational degrees of freedom. A key feature of this element is its handling of nonlinear material properties, as shown in Fig.3.

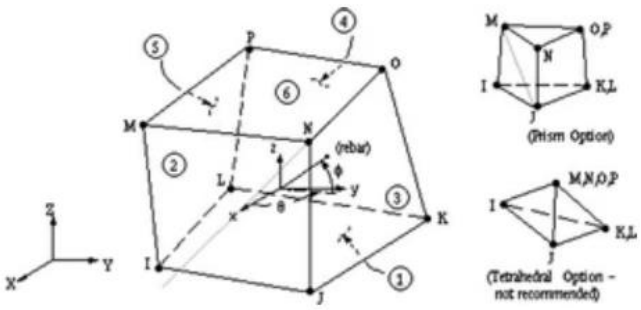


Fig. 3. Solid-65 Elements

Finite Element Analysis (FEA): Experimental studies often involve testing individual components, such as concrete quality under various loads, to understand structural behavior. While this method provides the valuable insights, it is time-consuming and costly. Finite Element Analysis (FEA) offers an efficient alternative by predicting how components will respond to different structural loads. FEA is much faster and more cost-effective compared to experimental methods, making it the preferred approach for analyzing concrete behavior. Advances in numerical tools, such as the Finite Element Method (FEM), now enable detailed modeling of reinforced concrete beams' complex performance.

MODELLING OF BEAM-COLUMN JOINT

This step involves creating a detailed 3D model of the beam-column joint in ANSYS Workbench. The model includes all necessary geometrical features, such as dimensions and connections, to accurately represent the joint for analysis.

An exterior beam column joint is modelled and analysed using ANSYS. The structural dimensions of the studied beam-column joint, as shown in Fig. 4.2, are summarized in having a vertical column with a cross section of 200 mm × 200 mm intersecting a horizontal beam with a 200 mm × 200 mm cross section. The height of the specimen is 1150 mm and the beams extend by 450 mm before and after the connection. The longitudinal reinforcement of the column is 4-T12 rebar as shown in Fig. 4.2, and the shear reinforcement is 8 mm diameter stirrups with a spacing of 150 mm. The beam steel reinforcement is 4-T12 rebar as shown in Fig. 4.2, and the shear reinforcement is 8 mm diameter stirrups with a spacing of 150 mm. The reason for having excessive shear reinforcement in the beam and the column is to enforce the shear cracks to be initiated within the beam-column joint zone rather than in the beam or the column. The cubic strength of concrete is 30 MPa.

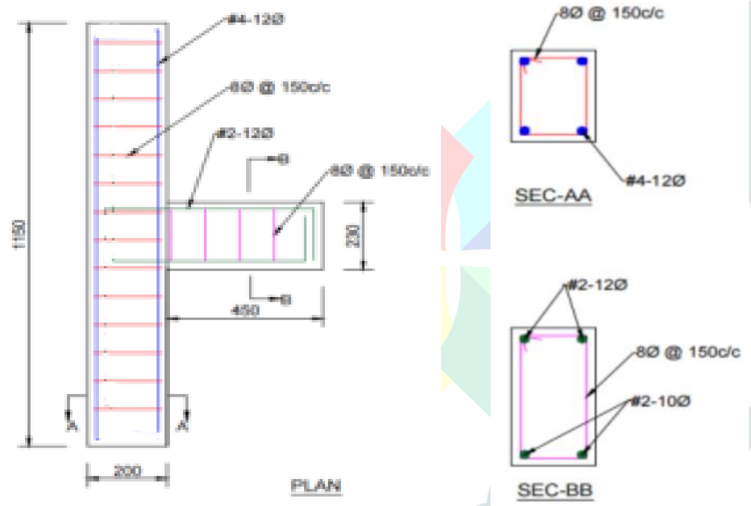


Fig. 4. Plan & Section of beam-column joint

Defining the Material Used:

The material properties, such as Young's modulus, Poisson's ratio, and yield strength, are defined in the software. These properties are crucial as they influence the joint's response to loads and are based on the actual materials used in construction.

Table 1. Material Properties of Conventional Concrete

SL. NO.	Property	Value
1.	Density	2400 kg/m^3
2.	Young's Modulus	300000 Mpa
3.	Poisson's Ratio	0.2
4.	Bulk Modulus	16667 Mpa
5.	Shear Modulus	12500 Mpa
6.	Compressive Strength	30 Mpa

Table 2. Material Properties of Geopolymer Concrete

SL. NO.	Property	Value
1.	Density	2400 kg/m^3
2.	Young's Modulus	300000 Mpa
3.	Poisson's Ratio	0.2
4.	Bulk Modulus	19000 Mpa
5.	Shear Modulus	12500 Mpa
6.	Compressive Strength	45 Mpa

Table 3. Material Properties of Structural Steel (HYSD 500)

SL. NO.	Property	Value
1.	Density	7850 kg/m^3
2.	Young's Modulus	200000 Mpa
3.	Poisson's Ratio	0.3
4.	Bulk Modulus	16667 Mpa
5.	Shear Modulus	76293 Mpa
6.	Tensile Strength	500 Mpa

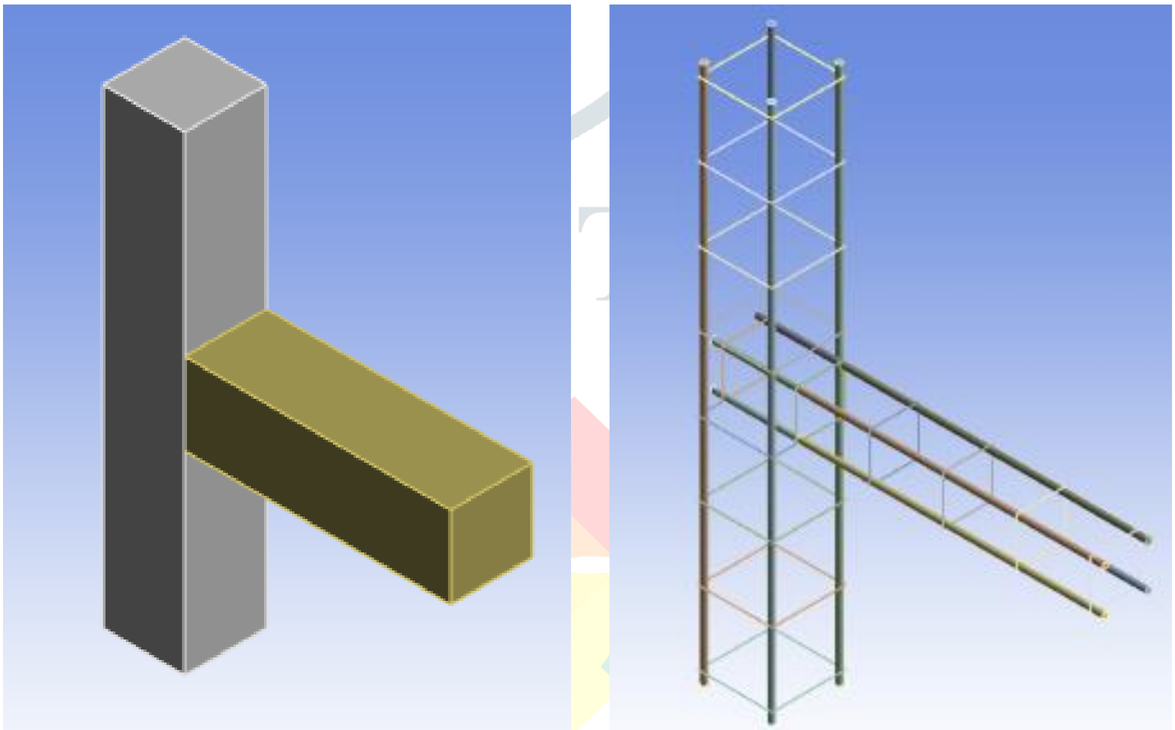


Fig. 5. 3D View & Reinforcement Details

Generating Mesh:

In this stage, the continuous model is discredited into small elements or "mesh." The quality of the mesh significantly affects the accuracy of the FEM results, so careful attention is paid to element size and type, especially near critical regions like the joint.

ANALYSIS OF BEAM & COLUMN JOINT

The analysis phase is crucial in evaluating the structural performance of the beam-column joint under various loading conditions. Using ANSYS Workbench, this step involves performing detailed finite element analysis (FEA) to predict how the joint will behave when subjected to different forces such as axial loads, shear forces, and bending moments. The analysis considers material properties, boundary conditions, and load applications to simulate real-world scenarios. The results from the analysis, including stress distribution, deformation, and potential failure points, are used to assess whether the joint can withstand the applied loads without compromising structural integrity. This information is vital for determining the joint's safety and reliability in the overall structural system.

Load Application & Support Conditions:

When analyzing a beam-column joint, it's essential to consider various loading combinations to ensure the joint can withstand different real-world scenarios.

Load Combinations: In this analysis, the column is subjected to three types of loads: axial load, uniaxial bending load, and biaxial bending load. These loads represent common forces that a column may experience in a structural system. Meanwhile, the beam is consistently subjected to a uniform distributed load (UDL), representing typical loads such as floor loads or other applied forces.

1. Axial Load with UDL: In this scenario, the column is subjected to an axial load, which acts along length of the column, while the beam experiences a constant UDL. The combination of axial load and UDL helps in understanding how the joint handles pure compression along with bending induced by the UDL on the beam.

2. Uniaxial Load with UDL: The column is subjected to a uniaxial load, causing bending in one direction (about either the X or Y axis). This load, combined with the UDL on the beam, simulates conditions where the column may be eccentrically loaded, inducing bending in one plane. This combination is critical for assessing the joint's ability to resist bending stresses along with the UDL on the beam.

3. Biaxial Load with UDL: In this scenario, the column experiences biaxial bending, with loads applied about both X and Y axes, while beam is under the constant UDL. Biaxial loading is common in situations where the column is subjected to loads from different directions simultaneously. This combination tests the joint's performance under the more complex loading, where the interaction between bending in both planes and the UDL on the beam must be carefully analyzed.

Table 4. Details of specimens

Specimens	Load Combinations
Specimen 1	Axial Load + UDL
Specimen 2	Unaxial Load + UDL
Specimen 3	Biaxial Load + UDL

By analyzing these load combinations, engineers can gain a comprehensive understanding of how the beam-column joint will perform under various loading scenarios, ensuring that the joint is designed to maintain structural integrity and safety in all conditions.

Support conditions, representing the Colum is fixed and the beam is allowed to move, are also defined to ensure realistic boundary conditions for analysis.

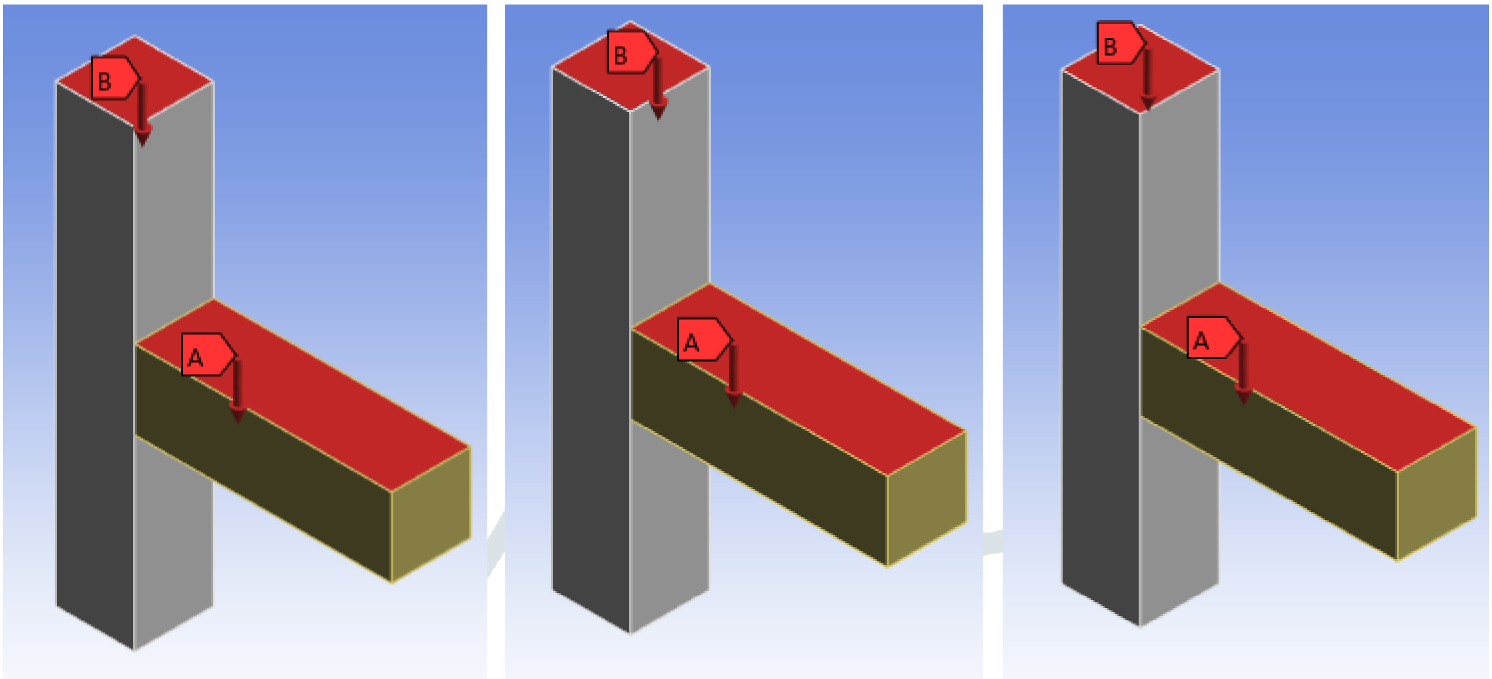
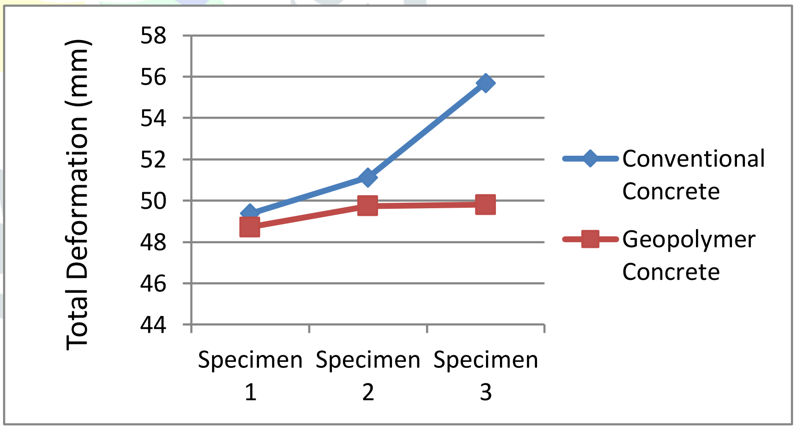


Fig. 6. Load application for Specimens 1, 2 & 3

RESULTS & DISCUSSION

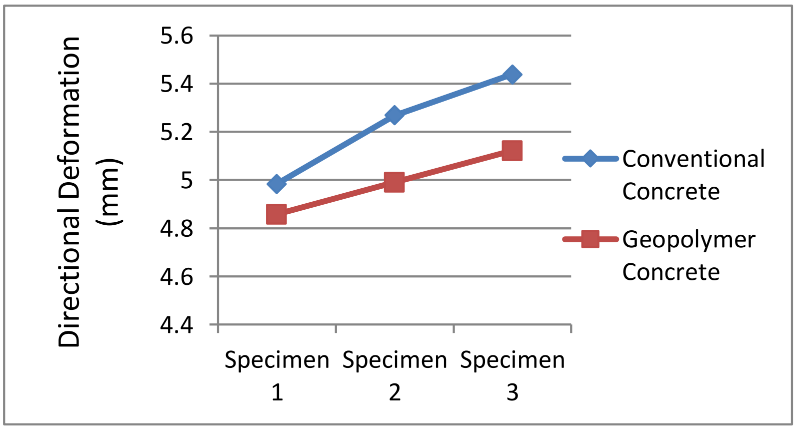
Total Deformation

	Conventional Concrete (mm)	Geopolymer Concrete (mm)
Specimen 1	49.381	48.717
Specimen 2	51.126	49.745
Specimen 3	55.691	49.811



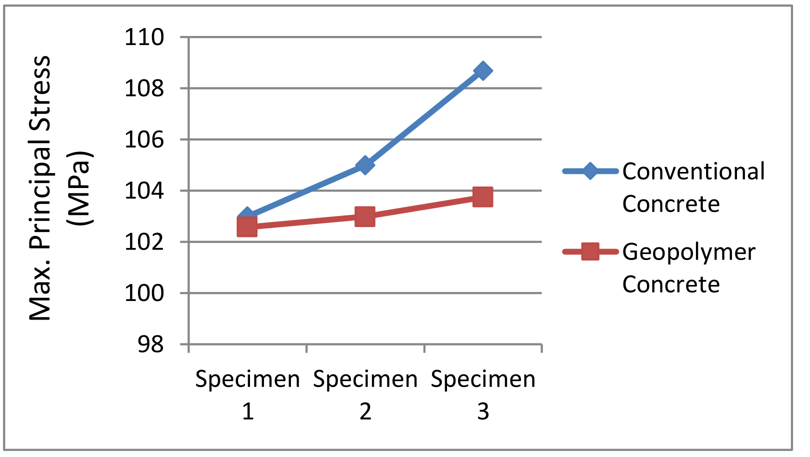
Directional Deformation

	Conventional Concrete (mm)	Geopolymer Concrete (mm)
Specimen 1	4.9836	4.8579
Specimen 2	5.2685	4.9911
Specimen 3	5.4381	5.1214



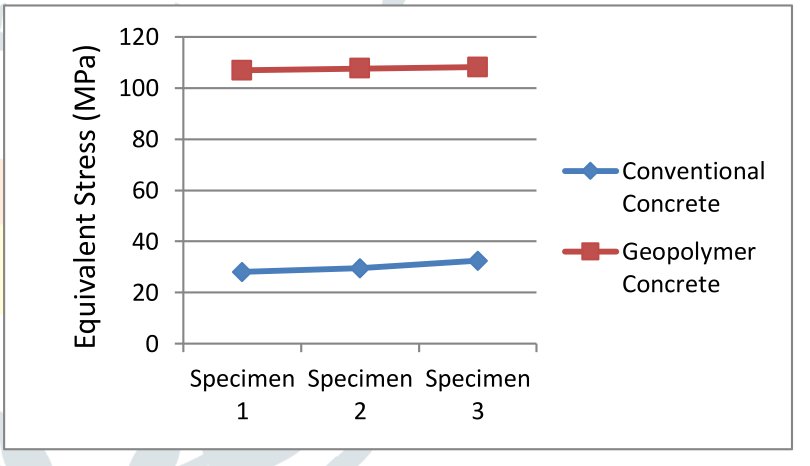
Maximum Principle Stress

	Conventional Concrete (MPa)	Geopolymer Concrete (Mpa)
Specimen 1	1.03 X 10^2	1.0258 X 10^2
Specimen 2	1.05 X 10^2	1.0298 X 10^2
Specimen 3	1.087 X 10^2	1.0375 X 10^2



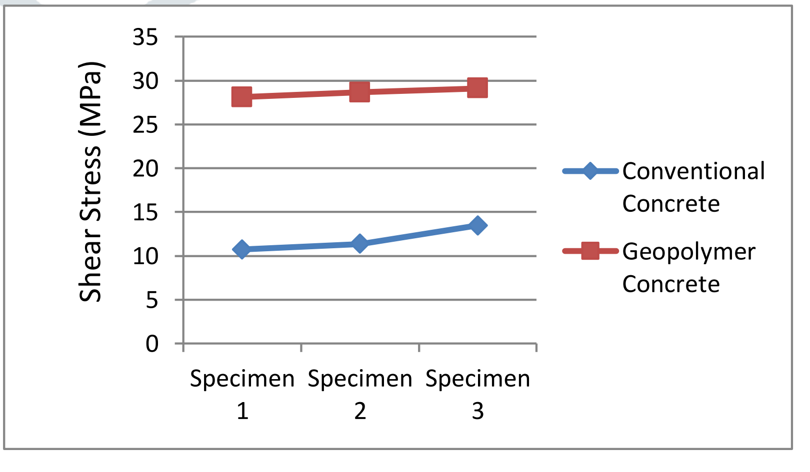
Equivalent Stress

	Conventional Concrete (MPa)	Geopolymer Concrete (Mpa)
Specimen 1	28.1	106.83
Specimen 2	29.5	107.55
Specimen 3	32.4	108.12



Shear Stress

	Conventional Concrete (MPa)	Geopolymer Concrete (Mpa)
Specimen 1	10.73	28.113
Specimen 2	11.35	28.655
Specimen 3	13.47	29.121



The results presented in Tables compares the performance of the conventional concrete and the geopolymer concrete under different loading conditions: axial load with UDL (uniformly distributed load), uniaxial load with UDL, and biaxial load with UDL. The parameters analyzed include total deformation, directional deformation, maximum principal stress, equivalent stress, and shear stress.

- The total deformation is slightly lower in geopolymer concrete compared to conventional concrete under axial and uniaxial loading. However, the difference becomes more pronounced under biaxial loading, indicating a potentially higher stiffness in geopolymer concrete.
- Geopolymer concrete exhibits slightly lower directional deformations across all loading conditions, which could be indicative of its superior performance in maintaining shape integrity under load.
- The principal stresses in both materials are similar, with geopolymer concrete showing a marginally higher resistance under biaxial loading. This suggests comparable performance under direct stresses.
- The equivalent stress is consistently higher in conventional concrete compared to geopolymer concrete, indicating that geopolymer concrete may distribute stresses more effectively, possibly due to its microstructural properties.
- Notably, geopolymer concrete exhibits notably greater shear stress values under all loading conditions compared to conventional concrete. This suggests that geopolymer concrete has much higher shear capacity, making it potentially more suitable for applications where shear strength is critical.

CONCLUSION

Based on the comparative analysis of a conventional concrete and a geopolymer concrete under the different loading conditions the following conclusions can be drawn:

- **Total Deformation:** Geopolymer concrete exhibited a reduction in total deformation by approximately 1.35% under axial loading conditions, 2.70% under uniaxial loading, and 10.57% under biaxial loading compared to conventional concrete. This shows that the geopolymer concrete has a higher stiffness, especially under complex loading conditions.
- **Directional Deformation:** The directional deformation in geopolymer concrete was reduced by approximately 2.52% under axial loading, 6.38% under uniaxial loading, and 5.98% under biaxial loading compared to conventional concrete. This reduction suggests that geopolymer concrete better maintains its shape under load.
- **Maximum Principal Stress:** The maximum principal stress in a geopolymer concrete is comparable to conventional concrete, with a minor reduction of approximately 0.48% under axial loading and 1.53% under biaxial loading. This resemblance indicates that both materials can handle direct stress effectively, with geopolymer concrete having a slight edge under complex loading.
- **Equivalent Stress:** Geopolymer concrete showed a reduction in equivalent stress by approximately 3.53% under axial loading, 6.72% under uniaxial loading, and 10.12% under biaxial loading. This indicates that a geopolymer concrete may distribute and handle stresses more effectively than conventional concrete.
- **Shear Stress:** Remarkably, geopolymer concrete exhibited significantly higher shear stress values, with increases of approximately 161.99% under axial loading, 152.47% under uniaxial loading, and 116.25% under biaxial loading compared to conventional concrete. This suggests that a geopolymer concrete has a

much higher capacity to resist shear forces, making it particularly advantageous in structural applications where shear strength is critical.

Geopolymer concrete demonstrates superior performance compared to conventional concrete, particularly in terms of reduced deformation and enhanced shear strength. The significant improvements in shear stress resistance and reduced deformations under complex loading conditions suggest that geopolymer concrete is a promising alternative for use in structures where stiffness, stress distribution, and shear strength are of paramount importance. The percentage improvements underline its potential to provide enhanced durability and reliability in various structural applications.

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