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Comparative Non-Linear Analysis of High-Rise Structure with Geopolymer Concrete and Conventional Concrete in High Seismic Zone

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Abstract: In earthquake-stricken areas, the high rise buildings are rapidly appearing, and sustainable and structurally resilient construction materials are required. Although the Ordinary Portland Cement (OPC) concrete is widely used, it is being challenged due to its high carbon emissions and brittle behaviour under severe seismic loading. The fly ash based geopolymer concrete (FAGPC) is an alternative green concrete with good mechanical properties, but the nonlinear seismic response of this concrete type still needs to be studied. In this study, the seismic performance of a G+20 reinforced concrete structure built using M60 grade conventional concrete and fly ash geopolymer concrete are compared. Accurate numerical modeling of material properties is created in ETABS through experimentation. To compare the seismic response of both the building models in terms of base shear, inter-storey drift, roof displacement and plastic hinge formation, nonlinear dynamic time history analysis is performed. The goal of the study is to evaluate the structural behavior and seismic resistance of FAGPC, and to provide a relationship between the material properties measured in a laboratory setting and actual structural performance under seismic conditions in high seismic zones. The results should prove the feasibility of FAGPC as a realistic and reliable material in the future construction of tall buildings.

Keywords: Geopolymer Concrete, High-Rise Structure, ETABS, Time History Analysis, High Seismic Zone.

I. INTRODUCTION

A. General Introduction-

With the fast expansion of urban high-rise constructions in earthquake-prone areas of India, it is imperative to use building materials that are sustainable and resistant to extreme seismic loads. Though it has gained popularity, conventional Ordinary Portland Cement (OPC) concrete has high carbon emission and also has brittle characteristics under strong earthquake loadings (Dhangar &Malagavelli, 2018; Kulkarni, 2021; Mostofizadeh& Tee, 2024). However, the use of fly ash based geopolymer concrete (FAGPC) is a promising alternative because of its low environmental impact and proper mechanical properties (Patankar et al., 2014). But it has not yet been fully studied in high-rise buildings, especially with regard to its nonlinear seismic behavior (Seismic Behavior, 2026; Tambe & Bogar, 2025). Thus, the present study endeavors to fill this research gap and investigate and compare the nonlinear seismic performance of a G+20 high-rise building built using M60 grade FAGPC and conventional concrete using advanced numerical analysis (Prajapati et al., 2025; Rodríguez et al., 2024).

B. Conventional Concrete versus Geopolymer Concrete in Seismic Applications-

High-rise buildings are generally constructed of conventional concrete as reinforced concrete can be detailed to provide ductile seismic performance. The concrete matrix is still brittle and the cement manufacturing consumes lots of energy and produces high carbon emissions (Mostofizadeh& Tee, 2024). However, the use of industrial by-products and the improved mechanical properties, durability, and dense microstructure of fly ash-based geopolymer concrete (FAGPC) offer a sustainable alternative (Mostofizadeh& Tee, 2024; Patankar et al., 2014). Although the above benefits were cited, the nonlinear inelastic structural phenomenon of FAGPC has not yet been broadly investigated when it becomes a target of earthquake loads in high-rise buildings. Hence, a thorough seismic performance evaluation is crucial to determine the seismic structural reliability and its seismic suitability (Mostofizadeh& Tee, 2024; Tambe & Bogar, 2025).

C. Significance of the Present Study-

In the present study, the nonlinear seismic performance of a G+20 reinforced concrete building fabricated with fly ash based geopolymer concrete (FAGPC) and conventional concrete is explored. The research involves experimental determination of the material properties, development of accurate numerical models in ETABS, and nonlinear dynamic time history analysis simulating the earthquake response (Dynamic Analysis, 2021; Kadam &Kalurkar, 2025; Scale Factor, 2023). Both structures are compared by studying the response parameters (base shear, storey displacement, inter-storey drift, plastic hinge formation) to assess the structures' safety, ductility and energy dissipation capacity (Hake, 2024; Rodríguez et al., 2024; Sultan, 2020). All the analyses are performed based on the seismic design requirements of IS 1893 (Part 1): 2016.

II. RESEARCH GAP

The current studies on fly ash based geopolymer concrete (FAGPC) have mainly concentrated on the material characteristics, strength, durability and environmental benefits of the concrete. It has not been studied in detail, however, from a structural point of view in high rise structures under strong earthquake loading. Comprehensive nonlinear seismic studies assessing critical response parameters like base shear, inter-storey drift, energy dissipation, ductility and plastic hinge formation are limited, in particular. In addition, there are no well established standardized numerical modeling procedures for geopolymer concrete structures. Thus, it is necessary to make a systematic comparison between the nonlinear seismic response characteristics of FAGPC and traditional concrete to determine the reliability and feasibility of FAGPC for high-rise structures in high seismic zones.

III. PROBLEM STATEMENT

To compare the seismic response of a high-rise reinforced concrete structure made of fly ash based geopolymer concrete to that of an equivalent conventional concrete structure in high seismic regions in terms of its structural capacity, ductility and seismic response after plastic hinge formation, and to evaluate the nonlinear seismic performance of the geopolymer structure..

IV. MODELLING AND PARAMETRIC DATA

TABLE I

PARAMETERS FOR ANALYSIS

PARAMETER	VALUES
Concrete Grade	M60
Plan Size (X*Y*Z)	20*20 m
No. of bays (X)	5
No. of bays (Y)	5
No. of stories (Z)	G+20
Bay Spacing (X)	4 m
Bay Spacing (Y)	4 m
Story Height (Z)	3 m
Beam Section	230*450 mm

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Column Section	400*600 mm
Slab Section	150 mm
Live Load	2 kN/m^2

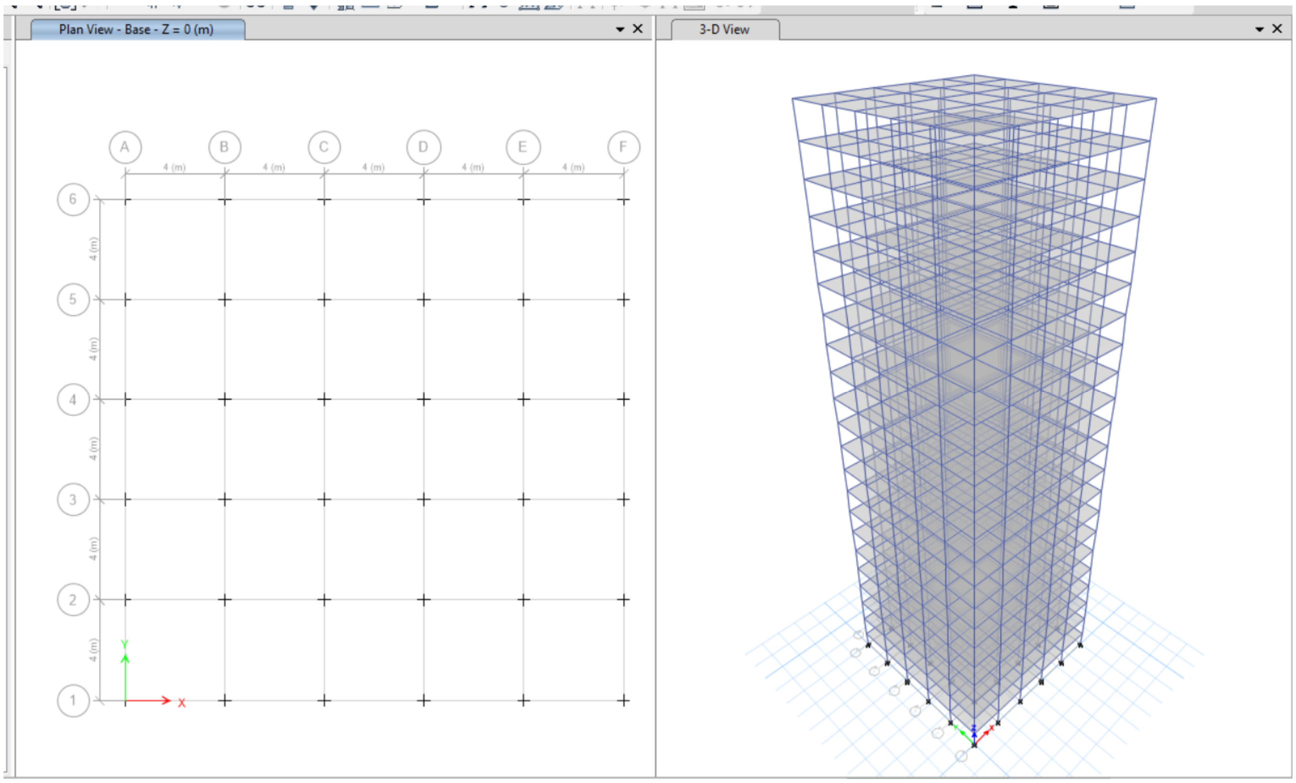

Fig. 1 G+20 Building Model

V. PROPOSED METHODOLOGY

A. Detailed Workflow-

1) Produce M60 grade 100% fly ash based geopolymer concrete and test its mechanical properties. The tests cover compressive strength, split tensile strength, flexural strength, modulus of elasticity, Poisson's ratio and density.
2) Experimentally determine the material properties of the V.A.1 work.V.A.2 Design material models for conventional concrete and fly ash based geopolymer concrete in ETABS. The properties of the reinforcement steel are maintained the same in both structural models.
3) Create a three dimensional model of G+20 reinforced concrete building using ETABS. To guarantee a fair comparison the geometry, member dimensions, structural layout and boundary conditions are the same for both models of conventional concrete and geopolymer concrete.
4) Assign dead, live and seismic load as per IS 875 and IS 1893 (Part 1): 2016..
5) Assign automatic FEMA 356/ASCE 41 plastic hinges to beams and columns, and ensure that these are assigned to represent the nonlinear behavior, stiffness degradation and yielding of members subjected to earthquake forces.
6) Select the Bhuj earthquake ground motion record and scale the seismic input acceleration time-history to match with the structural model.
7) Evaluate the dynamic response of both the building models by conducting nonlinear direct integration time history analysis with the selected earthquake excitation.

8) Extract and evaluate important seismic response parameters such as base shear, roof displacement, inter-storey drift, storey shear, and sequence and distribution of formation of plastic hinges.
9) Analyze the nonlinear seismic response of the conventional concrete and fly ash based geopolymer concrete buildings using the response parameters obtained and evaluate the structural capacity, ductility and overall seismic response of the buildings.

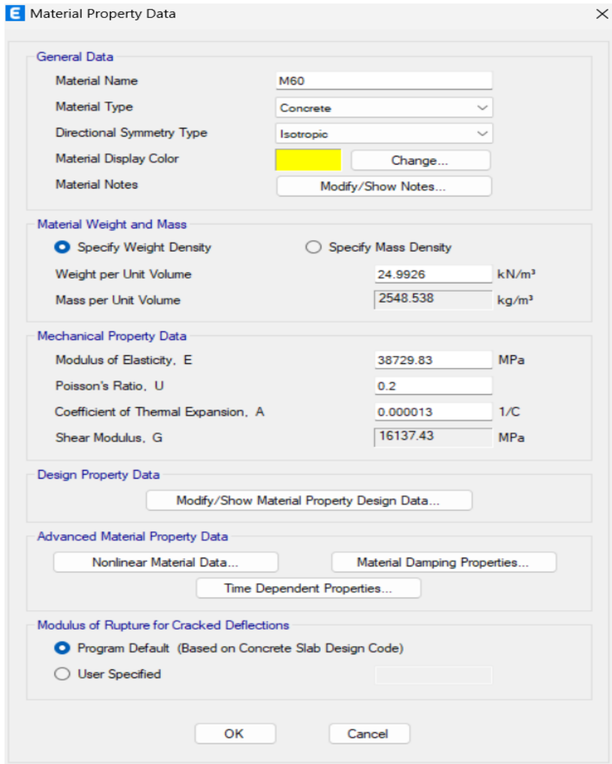

Fig. 2 Conventional Concrete Property

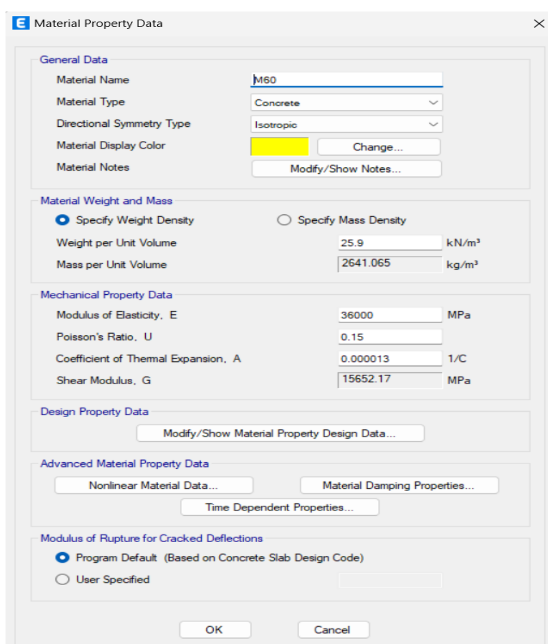

Figure 3: Geopolymer Concrete Property

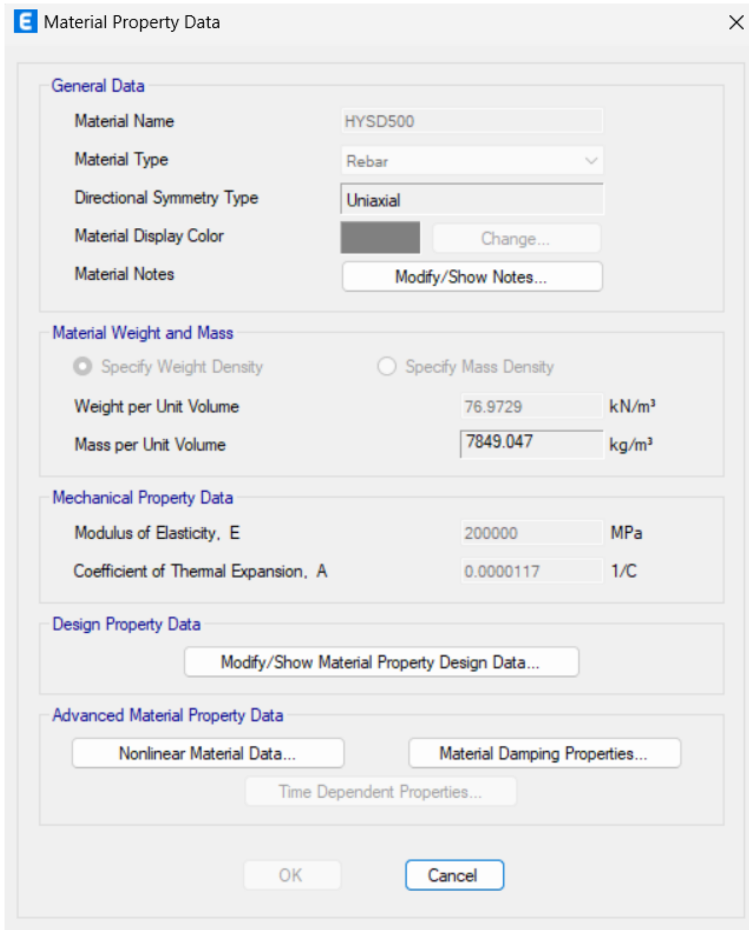

Figure 4: Steel Reinforcement Property

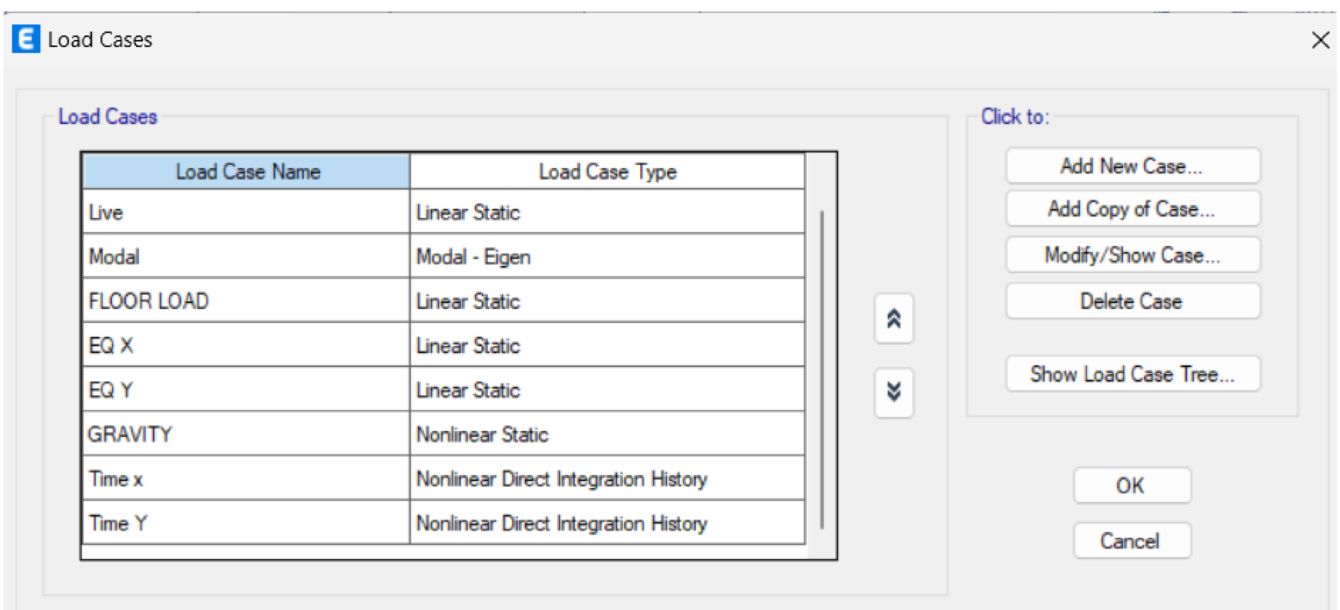

Fig. 5Load Case Definitions

Fig. 6Time History Function Definition

VI. MECHANICAL PROPERTIES

TABLE II

COMPRESSIVE STRENGTH

Sr. No	Typeof Concrete	Type of Curing	Age of curing (day)	Compressivestrength (N/mm^2)
1	Conventional concrete	Water curing	7	44.89
			14	60.55
			28	69.18

2	Geopolymer concrete (80^0C) 48 hrs	Oven curing	7	43.47
			14	58.49
			28	67.85

TABLE IIII
SPLIT TENSILE STRENGTH

Sr. No	Type of Concrete	Type of Curing	Age of curing (day)	Split Tensile strength (N/mm^2)
1.	Conventional concrete	Water curing	7	3.87
			14	4.60
			28	5.08
2.	Geopolymerconcrete (80^0C) 48 hrs	Oven curing	7	3.65
			14	4.3
			28	4.83

TABLE IIIV
FLEXURAL STRENGTH

Sr. No	Type of Concrete	Type of Curing	Age of curing (day)	Flexural strength (N/mm^2)
1	Conventional concrete	Water curing	28	7.0
2	Geopolymer concrete (80^0C) 48 hrs	Oven curing	28	6.9

TABLE V
SHEAR STRENGTH

Sr. No	Typeof Concrete	TypeofCuring	Age of curing (day)	Shearstrength (N/mm^2)
1	Conventional concrete	Water curing	28	7.6
2	Geopolymer concrete (80^0C) 48 hrs	Oven curing	28	7.5

VII. RESULTS

TABLE VI
RESULT COMPARISON FOR CC AND GPC MODELS

Parameters	Conventional Concrete	Geopolymer Concrete
Base Shear (kN)	9593	9593
Roof Displacement (mm)	183.19	197.70
Inter-storey Drift (mm)	0.004878	0.005271
Yield Hinges	586	585

1) Base Shear-The nonlinear time-history analysis results indicated that the maximum base shear for both the conventional concrete (CC) and geopolymer concrete (GPC) structures are around 9593 kN.
2) Roof Displacement- For geopolymer concrete building, roof displacement was found to be 197.70 mm as compared to 183.19 mm for conventional concrete building which is about 7.92% higher.
3) Inter-storey Drift-The maximum value of the inter-storey drift of the geopolymer concrete building was 0.005271, which was about 8.06% greater than that of conventional concrete building, 0.004878.
4) Yield Hinges-The comparison of hinge formation indicated that the response characteristics of the buildings were almost the same (nonlinear) for both conventional concrete and geopolymer concrete.

VIII. CONCLUSIONS

The nonlinear time-history analysis shows that the fly ash geopolymer concrete (100% fly ash) exhibits a seismic performance similar to that of the conventional M60 concrete. While the inter-storey drift and roof displacement at the top of the building were around 8% higher for the geopolymer concrete building, it was due to the relatively lower elastic modulus of the geopolymer concrete rather than resulting in a reduction in structural performance. The base shear and plastic hinge distributions were very similar in both buildings with all of the hinges in the Immediate Occupancy performance level. The obtained findings suggest that geopolymer concrete has an acceptable strength, good ductility, and stable non-linear response during severe earthquake loads. Geopolymer Concrete has many environmental advantages, using industrial by-products and reducing the use of Portland cement, and is a potential and sustainable concrete that can be used in the construction of earthquake-resistant reinforced concrete structures in the future.

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