INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
(Int Peer Reviewed Journal)
Vol. 04, Issue 10, October 2024, pp : 1293-1307
www.ijprems.com
editor@ijprems.com
e-ISSN : 2583-1062
Impact Factor : 7.001

LATERAL LOAD ANALYSIS ON KAOLIN-ACRYLONITRILE BUTADIENE STYRENE CONCRETE STRUCTURES IN ETABS

Harshit Shukla[1], Abhishek Mishra[2], Sachin Kumar Singh[3]

[1]M. Tech Student, Institute of Engineering and Technology, Lucknow, Uttar Pradesh, India.

[2,3]Assistant Professor, Institute of Engineering and Technology, Lucknow, Uttar Pradesh, India.

DOI: https://www.doi.org/10.58257/IJPREMS36480

ABSTRACT

This study explores the structural behavior of high-rise buildings using an innovative concrete mix modified with 1% kaolin and 10% Acrylonitrile Butadiene Styrene (ABS), referred to as K2 concrete. Laboratory tests were conducted to measure its compressive and tensile strengths, along with density. The primary goal of this research is to assess the seismic resilience of K2 concrete under both wind and seismic loads using ETABS software through static and response spectrum analyses. Structural responses such as story shear, displacement, drift, stiffness, and overturning moments were thoroughly evaluated. Additionally, a pushover analysis was performed to examine the nonlinear behavior, focusing on base shear, displacement, and energy dissipation. The enhanced characteristics of K2 concrete, such as improved ductility, stiffness, and energy absorption, are crucial for seismic resilience. Findings show that, concrete boosts structural performance by enhancing stability, energy dissipation, and deformation capacity, making it a viable material for buildings in earthquake-prone regions.

Keywords: Kaolin, Acrylonitrile Butadiene Styrene, High-rise Structure, Seismic resilience, Pushover Analysis.

1. INTRODUCTION

Concrete is a foundational material in construction, continuously evolving to meet growing demands for improved performance, durability, and sustainability. Enhancing concrete's properties can be achieved through the addition of advanced materials such as mineral and polymeric additives. This study investigates the combined effects of kaolin and Acrylonitrile Butadiene Styrene (ABS) granules on the mechanical and microstructural properties of concrete. ABS, a polymeric additive, improves concrete's resilience by enhancing its flexibility and resistance to cracking. By distributing stress across the concrete matrix, ABS granules help mitigate microcrack formation, increasing durability under tensile stress and making the material more adaptable to dynamic loads. The inclusion of ABS also enhances workability and reduces concrete density, which can be beneficial for certain structural applications. Kaolin, as a mineral additive, improves concrete's strength by enhancing hydration, forming more calcium silicate hydrates (C-S-H), and reducing permeability. This enhances resistance to environmental stressors like freeze-thaw cycles and chemical attacks, making kaolin an effective additive for strengthening concrete and extending its lifespan in harsh conditions. Furthermore, ABS granules increase the material's ductility, lowering the likelihood of cracking under tension and absorbing energy under impact, which is particularly advantageous for applications that require resistance to both static and dynamic stresses. When used together, kaolin and ABS granules substantially enhance concrete's toughness and energy absorption, making it more resilient under diverse forces. This study explores how the combined effects of kaolin and ABS impact workability, compressive strength, tensile strength, and durability. By understanding these interactions, this research aims to contribute insights toward the development of advanced concrete formulations tailored to contemporary construction demands. Prior research demonstrates kaolin's ability to improve concrete's early strength, especially in M30 and M40 grade concrete. Studies reveal that low percentages of kaolin enhance both compressive strength and resistance to environmental factors, while ABS granules improve ductility.

2. MATERIALS AND METHODS

2.1 Cement- The properties of OPC43 grade cement that has been used in this work is shown in table 1.

Table 1. Physical Properties of Cement

SN.	Properties	Result
1	Specific Gravity	3.15
2	Consistency	29.5%
3	Initial Setting	35 minutes
4	Final Setting	370 minutes

2.2 Kaolin- Kaolin is a fine, white clay mineral used in concrete to improve strength, durability, and resistance to environmental damage, making it valuable for high-performance construction materials. Physical properties of kaolin are present in table 2.

Table 2. Physical Properties of Kaolin

SN.	Properties	Result
1	Size	90nm
2	Particle Shape	Sphere
3	Density	2.65 g/cm^3
4	Color	Yellowish

2.3 Acrylonitrile Butadiene Styrene- Acrylonitrile Butadiene Styrene (ABS) is a durable, lightweight thermoplastic known for its toughness, impact resistance, and flexibility. Used in various applications, ABS enhances concrete by improving its ductility, energy absorption, and resistance to cracking, making it an effective additive for structures needing resilience under dynamic loads.

Table 3. Properties of Acrylonitrile Butadiene Styrene

SN.	Properties	Result
1	Formula	$(C_8H_8)x.(C_4H_6)y.(C_3H_3N)z$
2	Density	940 kg/m^3
3	Size	1 mm

2.4 Fine Aggregate- Fine aggregate consists of materials with particles smaller than 4.75 mm, such as natural sand or finely crushed stone. It is essential in concrete and mortar mixtures, where it fills gaps between larger aggregates, thereby improving workability and overall structural performance. Typically, fine aggregate particles range from 0.075 mm to 4.75 mm in size, and factors such as gradation and quality directly affect the strength and durability of the final concrete product. Table 4 presents the results of these tests.

Table 4. Properties of Fine Aggregates

SN.	Properties	Result
1	Specific Gravity	2.71
2	Water Absorption	1.40%
3	Fineness Modulus	2.96
4	Zone graded	II

2.5 Coarse Aggregate- Coarse aggregate is made up of larger particles, generally ranging from 4.75 mm to 20 mm or more, and typically includes crushed stone, gravel, or recycled concrete.

These aggregates form the main structural component in concrete, adding bulk and strength to the mix. Test results for these aggregates are shown in Table 5.

Table 5. Properties of Coarse Aggregates

SN.	Properties	Result
1	Specific Gravity	2.70
2	Water Absorption	0.49%
3	Fineness Modulus	6.90

2.6 Design Mix- Design mix proportion of both the specimens, control (K1) and modified (K2), which having 1% kaolin and 10% Acrylonitrile Butadiene Styrene in partial replacement of cement and fine aggregate, are shown in table 6.

Table 6: Mix Design

Mix	Cement	Sand	Coarse Agg.	Kaolin	Acrylonitrile Butadiene Styrene	w/c ratio
K1	434.11 (kg/m^3)	658.01 (kg/m^3)	1151.34(kg/m^3)	0	0	0.35
K2	429.76 (kg/m^3)	592.21 (kg/m^3)	1151.34(kg/m^3)	4.35 (kg/m^3)	65.8 (kg/m^3)	0.35

3. EXPERIMENTAL TEST RESULTS

3.1 Compressive Strength Test

Table 7. Compressive Strength Results

SN.	Mix	28 days Compressive Strength (MPa)
1	K1	52.33
2	K2	50.02

3.2 Density Test

Table 8. Density Test

SN.	Mix	Density (kg/m^3)
1	K1	2494.21
2	K2	2468.11

3.3 Modulus of Rupture Test

Table 9. Flexural Strength Results

SN.	Mix	28 days Flexural Strength (MPa)
1	K1	6.33
2	K2	5.3

4. MODELING AND ANALYSIS

4.1 Structure Modeling- The multi-story structure was modeled in ETABS software, ideal for analyzing complex building designs under a variety of loading conditions. This model consists of 12 stories, including a ground floor, with a total height of 33.5 meters—featuring a 3.5-meter-high ground floor and 3-meter-high upper floors. The floor plan dimensions measure 30 meters by 20 meters, with a grid layout of 7 grids in the X direction and 5 grids in the Y direction, spaced at 5 meters intervals. The beams across the structure have a cross-sectional size of 300 mm x 450 mm, providing the necessary strength to handle vertical loads and resist lateral forces. These beams are designed with the M2 material, which enhances structural performance by improving strength and energy dissipation under lateral loading. Columns were designed with variable sizes to manage load distribution across different floors: 600 mm x 600 mm for the lower floors (Ground floor, 1st to 3rd floors), 500 mm x 500 mm for the middle floors (4th to 6th floors), and 450 mm x 450 mm for the upper floors (7th to 11th floors). The columns were also assigned M2 concrete, benefiting from the addition of kaolin, which enhances compressive strength and stiffness, while Acrylonitrile Butadiene Styrene (ABS) improves ductility, offering resilience against seismic forces. The 1st to 11th floors feature a uniform 150 mm thick slab, designed for effective load transfer and structural integrity. These slabs use the M2 material to capitalize on the modified concrete's increased strength and energy dissipation properties, which provide better performance under seismic loading. Each floor slab (except the ground floor) was assigned a rigid diaphragm to distribute lateral forces, such as wind and seismic loads, uniformly across the structure. This diaphragm constraint treats the slab as infinitely rigid in its own plane, enhancing lateral force distribution to the vertical elements. Applied from the 1st to the 11th floors, the rigid diaphragm ensures that lateral loads are effectively transferred, resulting in a unified structural response under seismic and wind conditions.

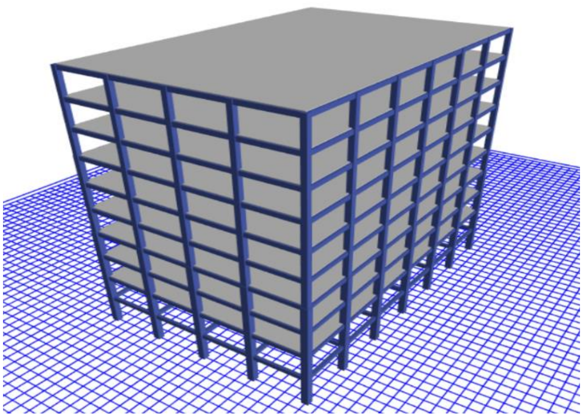

Figure 1: G+11 Building Model

4.2 Material Data in ETABS- The concrete material used in this study is a modified mix referred to as K1, which consists of 1% kaolin replacing cement by weight and 10% Acrylonitrile Butadiene Styrene (ABS) granules replacing fine aggregate by weight. The experimentally determined material properties are presented in Tables 10, 11, and 12.

Table 10. Physical Properties of K2 in ETABS

SN.	Property	Values in ETABS
1	Density	2460 kg/m^3
2	Compressive Strength	52.84 MPa
3	Modulus of Elasticity	36345.56 MPa
4	Poisson’s Ratio	0.2
5	Coefficient of Thermal Expansion	0.000013 1/C
6	Shear Modulus	15143.98 MPa
7	Modulus of Rupture	5.08 MPa

Table 11. Nonlinear Material Properties of K2 Mix in ETABS

SN.	Property	Tension	Compression
1	Immediate Occupancy (IO)	0.000079 mm/mm	-0.000705mm/mm
2	Life Safety (LS)	0.000159 mm/mm	-0.00141 mm/mm
3	Collapse Prevention (CP)	0.000397 mm/mm	-0.003525 mm/mm
4	Hysteresis Type	Concrete	
5	Friction Angle	30 degrees	
6	Dilatational Angle	10 degrees	

Table 12. Strain-Stress Points of K2 in ETABS

Points	Strain	Stress
1	-0.000355	-36.02
2	-0.002958	-39.82
3	-0.00141	-49.78
4	-0.001033	-46.22
5	-0.000656	-35.55
6	-0.000279	-9.96
7	0	0
8	0.000122	4.33
9	0.001337	0

4.3 Gravity and Seismic Load- In this study, ETABS was used to automatically calculate and assign dead loads based on the self-weight of structural components, including beams, columns, slabs, and other permanent features. This dead load represents the constant weight of the building’s structure. Additional superimposed dead loads (SIDL) were manually assigned to account for non-structural elements such as floor finishes, partitions, and fixed equipment. For perimeter beams, the SIDL is set at 12.73 kN/m from the ground floor to the 10th floor and at 4.7 kN/m on the 11th-floor perimeter beams. Slab loads were set at 1.3 kN/m² from floors 1 to 10, with an increase to 3 kN/m² on the 11th floor. Live loads, representing movable loads like furniture, equipment, and occupants, were applied uniformly at 2 kN/m² for floors 1 through 10, with a reduced load of 1.5 kN/m² on the 11th floor, designated as the terrace. Earthquake loads were applied in the X and Y directions with positive and negative eccentricity, shown in table 13.

Table 13. EQ in X and Y direction

Direction	X	Y
Eccentricity	±0.05	±0.05
Zone Factor, Z	0.16, Zone III	0.16, Zone III

Soil Type	II (Medium Soil)	II (Medium Soil)
Importance Factor, I	1	1
Response Reduction Factor	5	5
Time Period	1.814	1.814
Range	Top Story	Bottom Story
	11th Floor	Base

4.4 Response Spectrum- The response spectrum was configured in ETABS using the specified parameters shown in table 14. The software generated the response spectrum based on code-specified spectral acceleration factors for both X and Y directions, ensuring accurate representation of seismic forces. This setup incorporates the structure's dynamic properties through a scale factor and suitable modal combinations, reflecting seismic behavior in both directions effectively.

Table 14. RS in X and Y direction

Direction	X	Y
Load type	Acceleration	Acceleration
Load Name	U1	U2
Scale Factor	11992.4	11992.4
Modal Load Case	Modal	Modal
Modal Combination Method	CQC	CQC
Directional Combination Type	SRSS	SRSS
Modal Damping	0.05	0.05
Diaphragm Eccentricity	0	0

4.5 Pushover Analysis- In ETABS, pushover analysis, a nonlinear static approach, was employed to evaluate the seismic behavior of the M2 concrete structure along both the X and Y axes. Initially, a "Gravity" load case was applied, incorporating dead loads (1.0) and live loads (0.25) to represent baseline conditions. Subsequently, pushover analysis load cases "PA-X" and "PA-Y" were introduced, applying lateral forces in the UX and UY directions, respectively, with displacement control set to reach 1000 mm at a joint on the 9th floor. No cracked section analysis was included. Plastic hinges were assigned to beams and columns at relative positions of 0.1 and 0.9 to capture inelastic behavior. The defined load cases in ETABS are detailed in Table 15.

Table 15. Load Cases

Load Name	**Load Case**
Dead Load	Linear Static
Live Load	Linear Static
Super Dead Load	Linear Static
Earthquake in X	Linear Static
Earthquake in Y	Linear Static
Response Spectrum in X	Response Spectrum
Response Spectrum in Y	Response Spectrum
Gravity	Nonlinear Static
Pushover in X	Nonlinear Static
Pushover in Y	Nonlinear Static

5. RESULTS AND DISCUSSION

5.1 Story Shear Result of K2 concrete Structure

In this analysis, the modified concrete mix, referred to as K2, was used to model a multi-story structure. This mix involves a 1% replacement of cement weight with kaolin and a 10% substitution of fine aggregate weight with

Acrylonitrile Butadiene Styrene (ABS). The presence of kaolin and ABS in the concrete mix provides enhanced strength and flexibility, particularly beneficial for structural performance under seismic loading conditions. These modifications in the K2 mix contribute to improved durability and ductility, allowing the structure to better absorb and dissipate energy during seismic events. The results for base shear due to both equivalent static and response spectrum analysis are summarized in Table 16. The equivalent static analysis estimates the lateral forces based on the seismic weight and fundamental mode of the structure in both X and Y directions. For the 9th floor, static analysis due to earthquake loads (EQ) in the X direction shows a base shear value of 211.4821 kN, while the Y direction has no load assigned. The dynamic analysis using the response spectrum (RS) in the X direction yields a slightly lower base shear of 206.2352 kN for the same floor level, with a similar trend in the Y direction. Moving down to the ground floor, the static analysis for EQ-X reaches a base shear of 841.8358 kN, while the response spectrum analysis for RS-X records 841.9248 kN, indicating consistency and minimal deviation between static and dynamic base shear values. Each floor from the 9th down to the ground floor shows a similar pattern, where the base shear values from dynamic analysis are marginally lower than those from static analysis, reflecting how the K2 mix helps in moderating force distributions across the height of the structure. The results indicate that the K2-modified concrete, with kaolin and ABS, contributes to effective seismic force resistance in both static and dynamic load conditions, with kaolin enhancing compressive strength and ABS contributing to ductility, which is essential for the structure's energy dissipation capacity. This balance between strength and flexibility enables the building to achieve efficient seismic performance across varying heights, promoting overall structural resilience.

Table 5.1 . Base Shear for K2 structure, due to Equivalent Static and Response Spectrum.

Story	Elevation	Static Analysis due to EQ in X		Static Analysis due to EQ in Y		Dynamic Analysis due to RS in X		Dynamic Analysis due to RS in Y	
		X (in kN)	Y	X	Y (in kN)	X (in kN)	Y	X	Y (in kN)
9th Floor	27	211.4821	0	0	206.7167	206.2352	0	0	204.0198
8th Floor	24	386.3383	0	0	377.6327	356.9877	0	0	351.2758
7th Floor	21	525.1249	0	0	513.2919	460.2348	0	0	451.2103
6th Floor	18	632.9407	0	0	618.6782	533.8934	0	0	522.2544
5th Floor	15	713.5901	0	0	697.5103	592.8934	0	0	578.5616
4th Floor	12	770.2038	0	0	752.8483	648.8887	0	0	633.2237
3rd Floor	09	807.7752	0	0	789.5730	708.7446	0	0	691.5081
2nd Floor	06	829.9787	0	0	811.2763	772.6065	0	0	754.1242
1st Floor	03	840.3732	0	0	821.4365	828.7365	0	0	809.5678
G.F	00	841.8358	0	0	822.8661	841.9248	0	0	822.6099

5.2 Story Displacement Result of K2 concrete Structure

Table 17 illustrates the story displacements for the K2 concrete mix structure, which replaces 1% of cement weight with kaolin and 10% of fine aggregate weight with Acrylonitrile Butadiene Styrene (ABS). These substitutions enhance the structural performance by providing better flexibility and energy absorption during seismic events, key qualities for mitigating displacement and drift in multi-story buildings.

The table presents the displacements at each story level under both equivalent static and dynamic response spectrum (RS) analyses in the X and Y directions. At the 9th floor, for example, the displacement due to static analysis in the X direction is recorded at 21.913 mm, while the response spectrum analysis shows a reduced displacement of 16.688 mm in the same direction. This reduction reflects the K2 mix's contribution to seismic resistance, where kaolin enhances compressive strength and stiffness, while ABS improves ductility and flexibility, allowing the structure to manage displacement effectively under dynamic loading conditions.

As the elevation decreases from the 9th floor down to the ground floor, the displacements generally follow a decreasing trend, consistent with the distribution of seismic forces in high-rise structures. By the ground floor, displacements are significantly minimized, with static analysis showing only 1.490 mm in the X direction and 1.365 mm in the Y direction. These reduced values indicate effective load distribution and resistance throughout the structure, underscoring how the modified K2 concrete mix supports reduced displacement and increases structural stability across floors. This balance helps the building manage lateral loads better, which is essential for its safety and performance during seismic activities.

Table 5.2 . Story Displacement for K2, due to Equivalent Static and Response Spectrum.

Story	Elevation	Static Analysis due to EQ in X		Static Analysis due to EQ in Y		Dynamic Analysis due to RS in X		Dynamic Analysis due to RS in Y	
		X	Y	X	Y	X	Y	X	Y
9th Floor	27	21.913	2074	2.028	24.096	16.688	2.156E-09	4.384E-09	17.069
8th Floor	24	20.955	1.982	1.938	23.023	16.073	3.872E-09	1.031E-08	16.423
7th Floor	21	19.383	1.831	1.790	21.283	15.056	7.609E-08	1.223E-08	15.372
6th Floor	18	17.249	1.626	1.590	18.928	13.652	1.083E-08	7.410E-09	13.928
5th Floor	15	14.855	1.397	1.365	16.284	12.030	1.118E-08	6.337E-09	12.261
4th Floor	12	12.179	1.141	1.115	13.336	10.137	5.794E-08	1.265E-08	10.321
3rd Floor	09	9.309	0.868	0.848	10.180	7.971	1.074E-08	1.173E-08	8.107
2nd Floor	06	6.574	0.610	0.597	7.173	5.767	1.636E-08	8.232E-09	5.852
1st Floor	03	3.897	0.360	0.352	4.238	3.493	6.817E-09	4.611E-09	3.534
G.F	00	1.490	0.137	0.134	1.610	1.365	0.001	0.001	1.373

5.3 Story Drift Result due to K2 concrete Structure

Table 18 shows the story drift values for each floor level of the K2 structure, which incorporates 1% kaolin replacing cement weight and 10% Acrylonitrile Butadiene Styrene (ABS) replacing fine aggregate weight. Story drift is an essential parameter in structural engineering, representing the relative lateral displacement between two consecutive floors, critical for assessing a building's ability to withstand seismic forces.

For the K2 structure, the values reflect the story drift in both X and Y directions, calculated using Equivalent Static (EQ) and Response Spectrum (RS) methods. At the 9th floor, for instance, the drift due to static analysis in the X direction is 0.000319, and the RS analysis reveals a slightly reduced drift of 0.000275. This pattern is consistent throughout the building height, showing slightly lower RS values compared to static analysis, a result of the improved flexibility and ductility provided by the ABS component. Additionally, the kaolin substitution enhances the compressive properties, thus increasing the stiffness and stability of the concrete.

Drifts decrease progressively down the structure, aligning with expected structural response to seismic loads, where upper floors exhibit slightly higher drift. By the ground floor, drift values are minimized, demonstrating effective lateral force management throughout the structure. The K2 mix's modified concrete composition allows for controlled drift, maintaining safe levels under both static and dynamic loading conditions, thus contributing to the overall resilience of the structure.

Table 5.3 . Story Drift for K2 structure, due to Equivalent Static and Response Spectrum.

Story	Elevation	Static Analysis due to EQ in X		Static Analysis due to EQ in Y		Dynamic Analysis due to RS in X		Dynamic Analysis due to RS in Y	
		X	Y	X	Y	X	Y	X	Y
9th Floor	27	0.000319	0.000031	0.00003	0.000358	0.000275	0	0	0.000288

8th Floor	24	0.000524	0.000050	0.000049	0.000580	0.000435	0	0	0.000450
7th Floor	21	0.000711	0.000068	0.000067	0.000785	0.000566	0	0	0.000583
6th Floor	18	0.000798	0.000077	0.000075	0.000881	0.000617	0	0	0.000635
5th Floor	15	0.000892	0.000085	0.000083	0.000983	0.000685	0	0	0.000702
4th Floor	12	0.000957	0.000091	0.000089	0.001052	0.000750	0	0	0.000767
3rd Floor	09	0.000912	0.000086	0.000084	0.001003	0.000745	0	0	0.000762
2nd Floor	06	0.000892	0.000084	0.000082	0.000978	0.000761	0	0	0.000776
1st Floor	03	0.000805	0.000075	0.000073	0.000878	0.000715	0	0	0.000726
G.F	00	0.000426	0.000039	0.000038	0.00046	0.000390	0	0	0.000392

5.4 Story Stiffness Result of K2 concrete Structure

Table 19 presents the story stiffness values for the K2 structure, where 1% of cement weight has been replaced with kaolin and 10% of fine aggregate weight with Acrylonitrile Butadiene Styrene (ABS). Story stiffness is a key factor in determining how resistant each story is to lateral displacement under seismic or wind loads. Higher stiffness values indicate greater resistance to lateral motion.

The values are calculated using both Equivalent Static (EQ) and Response Spectrum (RS) analyses in the X and Y directions. For example, at the ground floor, the stiffness under static analysis in the X direction is recorded at 603701.474 kN/m, while the RS analysis shows 620532.742 kN/m in the X direction. The consistency between static and dynamic stiffness values throughout the floors reflects the impact of the kaolin and ABS modifications, which contribute to improved stiffness without compromising ductility. Moving up the structure, stiffness decreases, which is typical as higher floors experience less accumulated structural load and thus exhibit lower resistance to lateral forces.

The K2 concrete modification enhances the rigidity of the structure, evident in higher stiffness values for each floor. The inclusion of ABS also brings in ductility, balancing the overall structural response under seismic actions. This balance in stiffness and flexibility is beneficial in achieving a stable seismic performance, effectively absorbing and distributing forces while minimizing excessive lateral movements across the height of the building.

Table 5.3 . Story Stiffness for K2, due to Equivalent Static and Response Spectrum in X and Y directions.

Story	Elevation	Static Analysis due to EQ in X		Static Analysis due to EQ in Y		Dynamic Analysis due to RS in X		Dynamic Analysis due to RS in Y	
		X	Y	X	Y	X	Y	X	Y
9th Floor	27	235941.589	0	0	220404.962	250336.918	0	0	236172.526
8th Floor	24	262604.748	0	0	248584.832	273538.203	0	0	260215.174
7th Floor	21	262875.437	0	0	249877.634	270858.009	0	0	258185.153
6th Floor	18	282447.745	0	0	268223.967	288243.317	0	0	274211.319
5th Floor	15	284851.859	0	0	271037.168	288308.864	0	0	274624.478
4th Floor	12	286482.057	0	0	273195.62	288425.46	0	0	275308.958
3rd Floor	09	315103.175	0	0	300229.55	317170.778	0	0	302516.838
2nd Floor	06	330678.622	0	0	316052.637	338427.961	0	0	323999.795

1st Floor	03	371385.397	0	0	356497.077	387845.244	0	0	373162.553
G.F	00	603701.474	0	0	584666.423	620532.742	0	0	602382.23

5.5 Overturning Moment Result of K2 concrete Structure

Table 20 illustrates the overturning moments for the K2 structure, which is modified with 1% kaolin and 10% Acrylonitrile Butadiene Styrene (ABS) in the concrete mix, providing insights into the lateral stability of the building under seismic loads. The data reflects moments due to both Equivalent Static (EQ) and Response Spectrum (RS) analyses in the X and Y directions.

Overturning moment values increase toward the base of the building as cumulative forces build downward, with the highest moments observed at the base. In static analysis for the Y direction, the base shows an overturning moment of -20099.8465 kN-m, whereas the corresponding RS analysis in the Y direction gives 16158.0394 kN-m. This trend highlights the impact of the modified material properties, as K2's enhanced stiffness and ductility contribute to the structure's resistance against overturning, especially under dynamic conditions represented by RS analysis.

ABS in the K2 mix likely plays a role in distributing these forces, helping to absorb and reduce the total overturning effect under dynamic conditions, which is essential for seismic resilience. The presence of small values or zeros in the upper stories, especially in the X direction, indicates minimal overturning influence at higher elevations. These results imply that the K2 structure modification not only improves stiffness but also contributes to the building’s overall stability, reducing the risk of excessive overturning under lateral loads.

Table 5.4 . Overturning Moment for K2, due to Equivalent Static and Response Spectrum in X and Y directions.

Story	Elevation	Static Analysis due to EQ in X		Static Analysis due to EQ in Y		Dynamic Analysis due to RS in X		Dynamic Analysis due to RS in Y	
		X	Y	X	Y	X	Y	X	Y
9th Floor	27	0	0	0	0	0	0	0	0
8th Floor	24	0	-634.4464	620.15	0	1.957E-05	618.7057	612.0593	4.187E-05
7th Floor	21	0	-1793.4613	1753.048	0	2.62E-05	1681.307	1657.2492	3.081E-05
6th Floor	18	0	-3368.8361	3292.9238	0	4.741E-05	3023.4419	2971.2453	3.689E-05
5th Floor	15	0	-5267.6581	5148.9583	0	4.824E-05	4544.5258	4455.8197	4.07E-05
4th Floor	12	0	-7408.4284	7241.4891	0	2.811E-05	6189.0481	6057.185	0.0001
3rd Floor	09	0	-9719.0398	9500.0339	0	0.0001	7935.641	7755.4262	0.0001
2nd Floor	06	0	-12142.3652	11868.7529	0	0.0001	9794.2369	9561.5535	0.0001
1st Floor	03	0	-14632.3015	14302.5817	0	4.399E-05	11788.5002	11499.993	3.967E-05
G.F	00	0	-17153.4212	16766.8912	0	3.964E-05	13932.2748	13585.8475	4.125E-05
Base	-3	0	-20099.8465	19646.9227	0	4.472E-05	16572.3622	16158.0394	2.716E-05

5.6 Pushover Analysis on K2 Concrete Structure

Base Shear and Displacement in the X-Direction

In Table 23, the pushover analysis results highlight the progressive behavior of the structure made with the K2 mix under lateral loads in the X-direction. The K2 concrete mix, incorporating kaolin as a nano alumina source and acrylonitrile butadiene styrene (ABS) particles, plays a significant role in defining the structure's response to increased displacement and base shear.

The K2 mix is designed to enhance ductility and energy absorption capacity due to the synergistic effects of kaolin and ABS particles. Kaolin, acting as a nano alumina source, contributes to strength and microstructural refinement, which improves the concrete's resistance to initial cracking. Meanwhile, ABS particles provide additional toughness by enhancing post-crack bridging capabilities. This combination is particularly advantageous in the pushover analysis, as observed in the delayed transition of hinges from the elastic stage (< IO) to more severe damage states (IO-LS, LS-CP, and > CP).

At the early steps, all 3,720 hinges remain within the elastic (< IO) range, indicating that the K2 mix helps the structure withstand initial load applications without significant damage. As the displacement and base force increase, the structure begins to experience a gradual shift in hinge states. The increase of hinges in the IO-LS range from steps 9 to 15 demonstrates how the K2 mix allows for a controlled progression in structural response, likely due to improved material flexibility and ductility introduced by ABS particles. This controlled transition is essential for seismic resistance, as it helps dissipate energy and reduce the likelihood of brittle failure.

By step 18, some hinges begin to move into the LS-CP range, where the structure starts to exhibit more significant damage. However, the gradual shift, with only 55 hinges reaching LS-CP at this stage, underscores the effectiveness of the K2 mix in delaying severe damage. The kaolin's enhancement of compressive strength and modulus of elasticity contributes to this resilience, allowing the structure to retain its load-bearing capacity even under considerable displacement.

At step 23, as the base force begins to decline, a few hinges exceed the CP threshold, indicating localized failures. However, even as the structure approaches its ultimate load-bearing limits, the combination of kaolin and ABS particles in the K2 mix helps maintain a substantial portion of hinges in less critical states. This resilience is visible at step 27, where the structure undergoes notable displacement, but a large number of hinges (226) are still within the LS-CP range, and only 34 hinges exceed CP, preventing a sudden collapse.

In summary, the K2 mix's enhanced ductility, strength, and microstructural properties contribute to a gradual and controlled response in the pushover analysis.

Table 5.5. Number of Displaced Hinges Due to Pushover analysis in X-direction

Step	**Monitored Displacement (mm)**	**Base Force (kN)**	**< IO**	**IO-LS**	**LS-CP**	**> CP**	**Total Hinges**
0	0	0	3720	0	0	0	3720
1	-73.083	4737.6425	3720	0	0	0	3720
2	-111.961	6929.4681	3720	0	0	0	3720
3	-211.278	9894.0429	3650	70	0	0	3720
4	-233.987	10165.7219	3530	190	0	0	3720
5	-237.641	10173.9789	3530	190	0	0	3720
6	-244.949	10178.526	3530	190	0	0	3720
7	-252.258	10221.6216	3530	190	0	0	3720
8	-264.188	10245.6378	3530	190	0	0	3720
9	-270.484	10278.2483	3520	200	0	0	3720
10	-276.78	10289.8456	3470	250	0	0	3720
11	-295.58	10357.0021	3460	260	0	0	3720
12	-297.143	10369.3681	3460	260	0	0	3720
13	-300.269	10379.9978	3460	260	0	0	3720
14	-306.521	10382.2522	3460	260	0	0	3720

15	-312.773	10415.2265	3460	260	0	0	3720
16	-349.442	10541.0923	3460	260	0	0	3720
17	-350.011	10538.954	3460	260	0	0	3720
18	-351.15	10517.132	3460	205	55	0	3720
29	-369.538	9898.1462	3460	140	120	0	3720
20	-370.424	9849.5897	3460	140	120	0	3720
21	-373.812	9213.0038	3460	140	120	0	3720
22	-379.6	8594.7782	3460	140	120	0	3720
23	-379.747	8486.335	3460	140	96	24	3720
24	-398.239	7347.7471	3460	70	166	24	3720
25	-398.703	7222.0963	3460	70	166	24	3720
26	-398.854	7133.7087	3460	70	166	24	3720
27	-371.256	2669.021	3460	0	226	34	3720

Base Shear and Displacement in the Y-Direction

In Table 24, the pushover analysis results for the structure under lateral loads in the Y-direction provide valuable insights into the performance and behavior of the K2 mix. This analysis illustrates the structural response as displacement increases and the base shear force changes throughout the different steps of the analysis.

At the initial steps, the structure maintains all 3,720 hinges in the elastic range (< IO), indicating that the K2 mix effectively allows the structure to handle initial lateral loads without sustaining significant damage. The K2 concrete mix, which incorporates kaolin and acrylonitrile butadiene styrene (ABS), is designed to improve both strength and ductility, which is evident in these early stages of loading.

As the monitored displacement increases, a noticeable shift occurs in hinge behavior. By step 3, some hinges transition into the IO-LS range, while the overall number of hinges in the elastic range decreases to 3,650. The increase in hinge state changes highlights the structure's gradual response to increased lateral loads. This transition illustrates the ability of the K2 mix to allow for some flexibility before significant damage occurs.

From steps 4 to 12, the data show a steady increase in the number of hinges in the IO-LS and LS-CP ranges, particularly in steps 7 and 9, where 252 and 112 hinges are classified in these ranges, respectively. This progression reflects the ductile behavior of the K2 mix, as the ABS particles enhance post-crack performance, contributing to energy absorption and reducing the potential for brittle failure.

By step 13, the base force drops significantly to 7,068 kN, while some hinges reach the LS-CP range, indicating a more substantial level of damage. The presence of 182 hinges in this range by step 14 suggests that the K2 mix effectively mitigates the extent of damage, allowing many hinges to remain in less critical states even as the structure undergoes considerable displacement.

Overall, the results from Table 24 indicate that the K2 mix demonstrates a well-controlled response to lateral loads in the Y-direction. The combination of kaolin and ABS enhances the concrete's ductility and toughness, providing a gradual transition from elastic behavior to the onset of damage. This behavior is crucial for ensuring structural integrity and safety during seismic events, as it allows the structure to dissipate energy effectively while minimizing the risk of sudden collapse. The ability to maintain a significant number of hinges in the less severe damage states (< IO and IO-LS) demonstrates the K2 mix's effectiveness in enhancing the structural resilience of the building.

Table 5.6 : Number of Displaced Hinges at Various Safety Levels Due to Pushover Analysis in Y-Direction

Step	Monitored Displacement (mm)	Base Force (kN)	< IO	IO-LS	LS-CP	>CP	Total Hinges
0	0	0	3720	0	0	0	3720
1	-74.012	4585.674	3720	0	0	0	3720
2	-120.798	7056.7979	3720	0	0	0	3720
3	-220.919	9915.1472	3650	70	0	0	3720
4	-249.073	10321.7104	3538	182	0	0	3720

5	-254.1	10331.4443	3538	182	0	0	3720
6	-260.383	10363.1238	3538	182	0	0	3720
7	-358.995	10679.6637	3468	252	0	0	3720
8	-359.927	10669.7336	3468	237	15	0	3720
9	-378.691	10008.2388	3468	140	112	0	3720
10	-379.682	9951.5554	3468	140	112	0	3720
11	-381.887	9531.3603	3468	140	112	0	3720
12	-382.676	9313.8253	3468	140	112	0	3720
13	-404.499	7068.0996	3468	70	182	0	3720
14	-404.515	7033.4161	3468	70	182	0	3720
15	-404.524	7033.9549	3468	70	182	0	3720
16	-404.525	7033.9416	3468	70	182	0	3720
17	-404.527	7032.1557	3468	70	182	0	3720

Energy Dissipation of K2 Concrete

In Table 25, the energy dissipation characteristics of the K2 concrete structure during pushover analysis are summarized, illustrating how different energy components behave under lateral loads in both the X and Y directions. This analysis is crucial for understanding the structure's performance, particularly in seismic design.

Input Energy (I.E) represents the total energy supplied to the structure during the pushover analysis. For the maximum cases in both directions, the K2 structure exhibits significant input energy values: 2,909.4467 kN-m for the X-direction and 2,947.8335 kN-m for the Y-direction. These values indicate that the structure is subjected to considerable external forces during the analysis.

Kinetic Energy (K.E), which quantifies the energy associated with the motion of the structure, is recorded as zero in both cases. This suggests that the structure remains relatively stable during the analysis, with no significant dynamic effects influencing its response, which is a desirable outcome in pushover analysis for static loading conditions.

Potential Energy (P.E) accounts for the energy stored in the structure due to its elevation under lateral loads. The maximum values are 719.1523 kN-m for the X-direction and 772.1667 kN-m for the Y-direction. These figures reflect the structural displacement and associated energy changes as the building responds to the applied lateral forces.

Global Damping Energy (G.D.E) and Link Damper Energy (L.D.E) are both recorded as zero, indicating that no energy is dissipated through global or link damping mechanisms during the analysis. This could imply that the K2 structure primarily relies on material properties for energy dissipation rather than supplemental damping systems, which aligns with the intended design using kaolin and acrylonitrile butadiene styrene.

Link Hysteresis Energy (L.H.E) is the energy dissipated through hysteretic behavior in the structure. For the maximum cases, the values are 2,863.2393 kN-m for the X-direction and 2,492.9257 kN-m for the Y-direction, highlighting the significant energy dissipation capacity of the K2 concrete mix. This dissipation is critical for maintaining structural integrity during seismic events, as it helps mitigate the forces transmitted through the building.

Finally, the Energy Error (E.E) values are minimal, indicating that the energy balance is well-maintained throughout the pushover analysis. The negligible error values of 0.8312 kN-m for the X-direction and 1.0069 kN-m for the Y-direction suggest that the energy calculations align closely with the theoretical expectations, affirming the reliability of the analysis.

Overall, the energy dissipation characteristics of the K2 concrete mix during pushover analysis demonstrate its effectiveness in managing energy through hysteresis, contributing to the overall resilience of the structure under lateral loads. This performance is essential for enhancing safety and ensuring that the structure can withstand seismic forces while maintaining structural stability.

Table 5.7 : Total Energy Component**s** on K2 structure, due to Pushover Analysis

Case	Step Type	I.E	K.E	P.E	G.D.E	L.D.E	L.H.E	E.E
		kN-m	kN-m	kN-m	kN-m	kN-m	kN-m	kN-m
PA -X	Max	2909.4467	0	719.1523	0	0	2863.2393	0.8312

PA -X	Min	36.3403	0	36.3403	0	0	0	-0.0023
PA -Y	Max	2947.8335	0	772.1667	0	0	2492.9257	1.0069
PA -Y	Min	36.3403	0	36.3403	0	0	0	-0.0023

6. CONCLUSION

The research on the K2 concrete mix for high-rise structures offers significant insights into the structural behavior under static and dynamic loading. The results from static analysis, dynamic analysis, and pushover analysis illustrate the effectiveness of this modified concrete in improving building performance.

From the static analysis, it is evident that the base shear distribution in both the X and Y directions under lateral loading conditions demonstrates that the K2 structure efficiently resists seismic loads. The analysis indicates that the load transfer mechanism operates effectively, with shear forces increasing progressively from the upper floors to the foundation.

This ensures a stable distribution of loads throughout the structure. Additionally, the improved stiffness and crack resistance of K2 concrete, attributed to the incorporation of kaolin and acrylonitrile butadiene styrene (ABS), contribute significantly to its enhanced shear resistance and overall stability under lateral forces.

The dynamic analysis further confirms the effectiveness of the K2 structure. Modal analysis results reveal that the natural frequency and mode shapes of the building indicate sufficient stiffness to resist lateral forces while preserving structural integrity. The response spectrum analysis demonstrates that the base shear values for the X and Y directions, 754.31 kN and 737.1182 kN, respectively, show the structure's capability to withstand dynamic seismic forces. Moreover, the story drift and lateral displacement checks confirm that the use of K2 concrete helps maintain drift within acceptable limits.

The pushover analysis provides valuable insights into the nonlinear behavior of the structure. The results show that the building has a high ductility capacity, essential for absorbing and dissipating seismic energy without failure. The displacement at peak load falls within permissible limits, indicating that the structure can tolerate significant lateral displacements during earthquakes without compromising its load-carrying capacity. The pushover curve's performance point further validates that the building possesses the strength needed to resist collapse under large lateral displacements, supporting its suitability for use in earthquake-prone areas.

Considering the results from the static, dynamic, and pushover analyses, it is clear that the K2 concrete mix offers several advantages that make it suitable for use in seismic-prone areas.

The incorporation of kaolin improves the concrete's compressive strength and stiffness, while ABS contributes to its ductility and energy absorption capabilities. These properties are essential for seismic resistance, as they enable the structure to withstand ground vibrations and deformations during an earthquake. Furthermore, the ABS helps reduce microcracking under dynamic loads, enhancing the overall durability of the structure, which is crucial in regions subject to frequent seismic activity.

The ductile behavior observed in the pushover analysis also indicates that the K2 structure can effectively dissipate seismic energy, reducing the risk of sudden failure during an earthquake. This characteristic is particularly important for ensuring the safety and longevity of buildings in earthquake-prone regions.

K2 concrete results in a combination of high compressive strength, improved stiffness, and enhanced ductility, making it suitable for high-rise buildings subjected to both static and dynamic loads.

The concrete's ability to resist wind loads, seismic forces, and control lateral displacements highlights its superior performance compared to conventional concrete. In seismic areas, the use of K2 concrete proves beneficial when utilized in moderate proportions of its constituents, as it enhances structural resilience through improved energy absorption, crack resistance, and ductility. The concrete's capacity to resist seismic forces while maintaining stability under lateral displacements makes it a promising material for earthquake-resistant designs.

The energy analysis from the pushover results highlights the significant impact of K2 concrete on the structure's response to lateral loads. The input energy, particularly higher in the Y-direction, indicates the need for more energy to achieve similar deformations, reflecting the mix's enhanced ductility and stiffness.

The potential energy suggests higher flexibility and strain energy storage. The kaolin in the K2 mix increases compressive strength, while the ABS contributes to ductility, allowing the structure to absorb more energy before failure. The energy error remains small, confirming the analysis' validity despite slightly higher nonlinear behavior in the Y-direction. Overall, K2 concrete improves the structure's ability to resist and dissipate lateral forces, demonstrating superior performance in both strength and energy absorption.

7. REFERENCES

[1] Gul Samad Khan Lodi, Dr Sachin Kumar Singh & Dr. Abhishek Mishra, "Dynamic and Static Analysis of Nano Alumina-Polypropylene Granules Concrete Structures in ETABS," International Research Journal of Modernization in Engineering Technology and Science, Vol. 06, Issue 10, October 2024, Pg.2597-2617.

[2] Correia, João & Brito, Jorge & Pereira, A.. (2006). Effects on concrete durability of using recycled ceramic aggregates. Materials and Structures / Materiaux et Constructions. 39. 169-177. 10.1617/s11527-005-9014 7.

[3] Shen, Junan & Xie, Zhaoxing & Griggs, David & Shi, Yao. (2012). Effects of Kaolin on Engineering Properties of Portland Cement Concrete. Applied Mechanics and Materials. 174-177. 76-81. 10.4028/www.scientific.net/AMM.174-177.76.

[4] Nasir Shafiq, Muhd. Fadhil Nuruddin, Sadaqat Ullah Khan, Tehmina Ayub, Calcined kaolin as cement replacing material and its use in high strength concrete, Construction and Building Materials, Volume 81, 2015, Pages 313 323, ISSN 0950-0618,

[5] Abdurrahmaan Lotfy, Okan Karahan, Erdogan Ozbay, Khandaker M.A. Hossain, Mohamed Lachemi, Effect of kaolin waste content on the properties of normal-weight concretes, Construction and Building Materials, Volume 83, 2015, Pages 102-107, ISSN 0950-0618

[6] Nikhila, & Jagarapu, Durga Chaitanya Kumar. (2015). PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN IN HIGH STRENGTH CONCRETE. INTERNATIONAL JOURNAL IN ENGINEERING RESEARCH AND SCIENCE & TECHNOLOGY. 4. 336-349.

[7] Baridjavan, Saeed & Sheikhi, Morteza & Pournoori, Pooyan & Rajaee, Arash. (2023). Glass powder and PVC granules as partial replacement of cement and aggregate; An experimental study.

[8] Manvendra Verma et al 2023 Mater. Res. Express 10 095508

[9] Sonu Saji and S Unnikrishnan 2023 IOP Conf. Ser.: Earth Environ. Sci. 1237 012005

[10] Yetunde, Abiodun & Orisaleye, Joseph & Adeosun, S.O. & Unilorin, Njtd. (2023). Effect of Calcination Temperatures of Kaolin on Compressive and Flexural Strengths of Metakaolin-Concrete. Nigerian Journal of Technological Development. 20. 10.4314/njtd.v20i1.1390.

[11] Md. Jahidul Islam, Tasnia Ahmed, Md. Shahjalal, Abdul Mubin Jihad, Zillol Based, Md. Mahmud Hasan, Strength, durability, and impact behavior of recycled aggregate concrete with polypropylene aggregate, Construction and Building Materials, Volume 408, 2023, 133646, ISSN 0950-0618

[12] Amin Al-Fakih, Madyan A. Al-Shugaa, Mohammed A. Al-Osta, Blessen Skariah Thomas, Mechanical, environmental, and economic performance of engineered cementitious composite incorporated limestone calcined clay cement: A review, Journal of Building Engineering, Volume 79, 2023, 107901, ISSN 2352-7102

[13] Lewis A. Parsons, Sunday O. Nwaubani, Mechanical and durability performance of concrete made using acrylonitrile butadiene styrene plastic from waste-EEE as a partial replacement of the coarse aggregate, Journal of Building Engineering, Volume 85, 2024, 108635, ISSN 2352-7102

[14] Gyusoo Kim and Seulgi Lee, "2014 Payment Research", Bank of Korea, Vol. 2015, No. 1, Jan. 2015.

[15] Chengwei Liu, Yixiang Chan, Syed Hasnain Alam Kazmi, Hao Fu, "Financial Fraud Detection Model: Based on Random Forest," International Journal of Economics and Finance, Vol. 7, Issue. 7, pp. 178-188, 2015.

[16] Hitesh D. Bambhava, Prof. Jayeshkumar Pitroda, Prof. Jaydev J. Bhavsar (2013), "A Comparative Study on Bamboo Scaffolding And Metal Scaffolding in Construction Industry Using Statistical Methods", International Journal of Engineering Trends and Technology (IJETT) – Volume 4, Issue 6, June 2013, Pg.2330-2337.

[17] P. Ganesh Prabhu, D. Ambika, "Study on Behaviour of Workers in Construction Industry to Improve Production Efficiency", International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD), Vol. 3, Issue 1, Mar 2013, 59-66

[18] Artemio Palos, Nandika Anne D'Souza, C.Todd Snively, Richard F. Reidy, Modification of cement mortar with recycled ABS, Cement and Concrete Research, Volume 31, Issue 7, 2001, Pages 1003-1007, ISSN 0008-8846