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

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**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.

1. **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/cm3 |
| 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 | (C8H8)x.(C4H6)y.(C3H3N)z |
| 2 | Density | 940 kg/m3 |
| 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/m3) | 658.01 (kg/m3) | 1151.34(kg/m3) | 0 | 0 | 0.35 |
| K2 | 429.76 (kg/m3) | 592.21 (kg/m3) | 1151.34(kg/m3) | 4.35 (kg/m3) | 65.8 (kg/m3) | 0.35 |

1. **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/m3)** |
| 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 |

1. **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/m3 |
| 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 |

1. **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 16.** 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 17.** 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 18.** 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 19.** 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 20.** 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 23.** 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 24:** 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 25:** 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 |

1. **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.

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