Influence of Various Building Materials on Seismic Wave Amplification: A case study of Tapovan, Rishikesh

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Abstract

This study examines the impact of various coarse aggregate compositions—gneiss, schist, gravel, and granite—on the seismic performance of G+24 RC frame structures in Tapovan, Rishikesh. Using ETABS, modal, linear static and response spectrum analyses were conducted to evaluate natural period, base shear, fundamental natural period, and peak displacement. Results show that while granite and gravel enhance seismic resistance, high schist content increases flexibility, reducing base shear and increasing drift. The optimized mix (25% schist+40% gneiss +35% granite) offers an ideal balance of rigidity and energy dissipation, minimizing deformation while remaining cost-effective. These findings support improved material selection for seismic-resistant construction in high-risk regions.

Keywords: Wave amplification, High-performance concrete, Aggregate mix optimization, Earthquake-resistant, Sustainability, Seismic microzonation.

1. Introduction

1.1 Background of Tapovan and its Seismic Context

The Tapovan area, located in the north of Rishikesh, Uttarakhand, India, lies within one of the most seismically active zones in the world. This region, part of the Himalayan foothills, is situated at the convergence of the Indian and Eurasian tectonic plates, where the ongoing tectonic activity has created an inherently unstable geological environment. The seismic activity in this region is a result of the collision between these two massive plates, and this tectonic interaction continuously causes earthquakes, some of which have had devastating effects on both human life and infrastructure. In such an environment, understanding how seismic waves propagate and how different building materials respond to these forces is crucial for ensuring the safety and resilience of the structures built in these areas.

Historically, the Tapovan region and its surrounding areas have been subject to frequent seismic events, ranging from moderate tremors to more powerful earthquakes that have left deep scars on the local infrastructure. Given that the region continues to be seismically active, it is vital to focus on improving the earthquake resilience of infrastructure to reduce the loss of life and property during seismic events. One of the most significant factors influencing how a structure responds to seismic waves is the local geology and the materials used in construction. Tapovan, being situated in a complex geological setting, is particularly vulnerable to the amplification of seismic waves, which can lead to devastating damage if not properly accounted for in building practices.

The geology of Tapovan is marked by its diverse rock formations, which include metamorphic rocks such as gneiss and schist, alongside fractured layers and fault zones that are present in the area. This complex geological structure means that seismic waves behave differently in

Tapovan compared to other regions, especially considering that seismic waves can be amplified as they travel through these diverse rock formations. Moreover, the region also contains natural springs, such as the Tapovan Springs, which add another layer of complexity to the seismic hazard analysis. These springs, resulting from groundwater movement through fractured rocks, alter local soil and rock properties, influencing the seismic waves that travel through the ground.

1.2 Importance of Material Selection in Seismic Resilience

The response of seismic waves is further influenced by the materials used in construction. In Tapovan, like much of Rishikesh, the traditional construction materials, particularly stones like gneiss and schist, have been used for centuries due to their abundance in the region. These materials, which have been locally sourced, offer significant advantages in terms of cost, sustainability, and structural integrity when compared to commonly used coarse aggregate like gravel and granite. Gneiss and schist, when crushed and processed, can serve as high-quality coarse aggregates in concrete mixes. As coarse aggregates, these materials contribute to the durability, strength, and resilience of concrete, making them suitable for seismic-resistant construction.

Despite their proven utility in construction, the potential of gneiss and schist as coarse aggregates in mitigating seismic wave amplification remains underexplored. These indigenous rocks possess high compressive strength and energy dissipation capabilities, which is a preferrable quality in regions like Tapovan which has complex geology to enhance the seismic resilience of buildings. Incorporating gneiss and schist as coarse aggregates in modern construction could provide a sustainable, cost-effective solution while ensuring that infrastructure is more capable of withstanding the seismic forces typical in this seismically active region.

1.3 Objective of the Study

Objectives:

1. To analyse influence of various building materials on seismic wave amplification in Tapovan, Rishikesh
2. To analyse the dynamic behaviour of G+24 RC frame structures with different aggregate compositions under seismic loads
3. To identify the optimal aggregate mix w.r.t seismic resistance and structural performance
4. To develop site-specific recommendations for earthquake-resistant construction in the Tapovan region.

2 Material Selection: Gneiss and Schist as Coarse Aggregates

The study investigates the impact of replacing conventional coarse aggregates with varying proportions of gneiss and schist in the concrete mix. These metamorphic rocks possess distinct geological properties, influencing seismic wave behaviour and structural response.

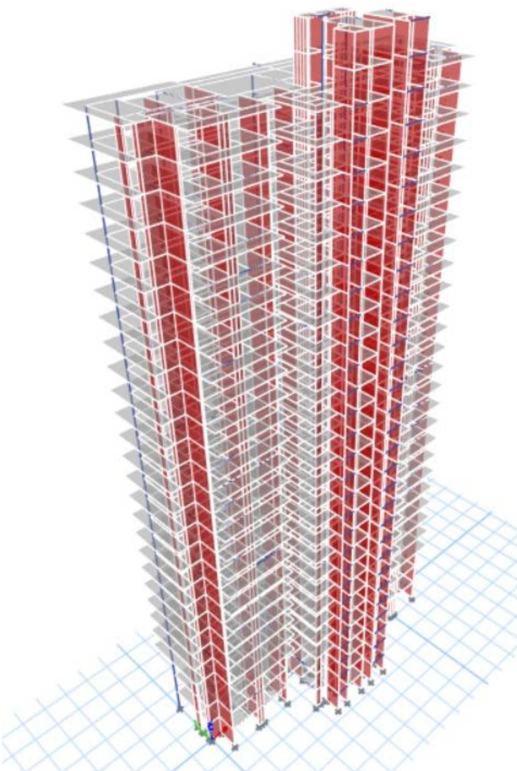
Table 1: Geological Properties of Schist and Gneiss

Property	Schist	Gneiss
Mineral Composition	Mica, Quartz, Feldspar	Feldspar, Quartz, Biotite
Density (kg/m³)	2700	2850
Uniaxial Compressive Strength (MPa)	50-70	100-120
Elastic Modulus (GPa)	18	30
Poisson's Ratio	0.28	0.26
Water Absorption (%)	1.2	0.8
Porosity (%)	5.5	3.2
Specific Gravity	2.65	2.70
Bulk Density (kg/m³)	2600	2550
Compressive Strength (MPa)	160	140
Flexural Strength (MPa)	8-10	7-9

2.1 Comparative analysis of local aggregates and conventional aggregates

2.1.1 Structural Model Development

This section details the comprehensive methodology adopted for the development, modelling, and seismic analysis of G+24 residential reinforced concrete (RC) frame structures to assess the influence of gneiss and schist as coarse aggregates on seismic wave amplification. The study utilizes ETABS software for model development and analysis, in compliance with the provisions outlined in relevant Indian Standard (IS) codes for seismic design.



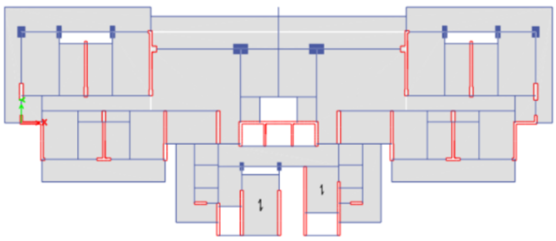


Figure 1: Plan of B+G+25 residential building

Figure 2: Elevation of B+G+25 residential building

2.1.2 Selection of Building Types and Design Parameters

The primary structural typology selected for this study is a G+24 residential RC frame structure. The key design considerations and structural parameters are summarized as follows:

Parameter	Specification
Building Type	Residential, G+24
Structural System	Reinforced Concrete Frame
Foundation Type	Isolated Footings
Storey Height	3.0 m per floor
Seismic Zone	Zone V (High Seismicity)
Importance Factor (I)	1.0
Response Reduction Factor (R)	5 for RC moment-resisting frames
Damping Ratio	5%

The structural model incorporates typical architectural and load considerations, including live loads, dead loads, and imposed loads as per IS 875 (Part 1 & 2) standards.

2.1.3 Comprehensive Seismic Response Evaluation

To comprehensively evaluate the seismic performance of the G+24 reinforced concrete frame structure incorporating varying compositions of schist and gneiss aggregates, a multi-step analysis framework was implemented using ETABS. The seismic analyses conducted included modal analysis and response spectrum analysis.

Modal Analysis

Modal analysis was performed to compute the natural frequencies and mode shapes of the structure. The material properties of schist and gneiss, such as density, modulus of elasticity, flexural strength, compressive strength and Poisson's ratio was taken as an input. Fixed boundary conditions were applied, and the first ten modes of vibration were extracted.

Response Spectrum Analysis

The response spectrum analysis was conducted based on site-specific seismic data per IS 1893:2016, with a 5% damping ratio. Modal responses were combined using the Complete Quadratic Combination (CQC) method.

3. Results and Discussion

The results of seismic analyse conducted on the G+24 RC frame structure include modal analysis, linear static analysis and response spectrum analysis. These results provide insight into the seismic performance and material characteristics of different local aggregate like gneiss and schist.

3.1 Structural Model Analysis

3.1.1 Modal Analysis Results

The modal analysis results for the G+24 reinforced concrete (RC) frame structure using different material compositions are presented in Table 2.

Table 2.: The fundamental natural periods, modal participation factors, and frequencies for different material compositions

Material Used	Fundamental Natural Period (s)	Modal Participation Factor (%)	Frequency (Hz)
Standard Gravel Aggregate	2.0	77	0.50
Standard Granite Aggregate	1.9	78	0.53
25% Schist + 40% Gneiss + 35% Granite	2.0	76	0.49
25% Schist + 50% Gneiss + 25% Gravel	2.1	74	0.46
25% Schist + 75% Gneiss	2.3	72	0.43
50% Schist + 50% Gneiss	2.6	68	0.38
75% Schist + 25% Gneiss	2.9	65	0.34
100% Schist	3.1	62	0.30

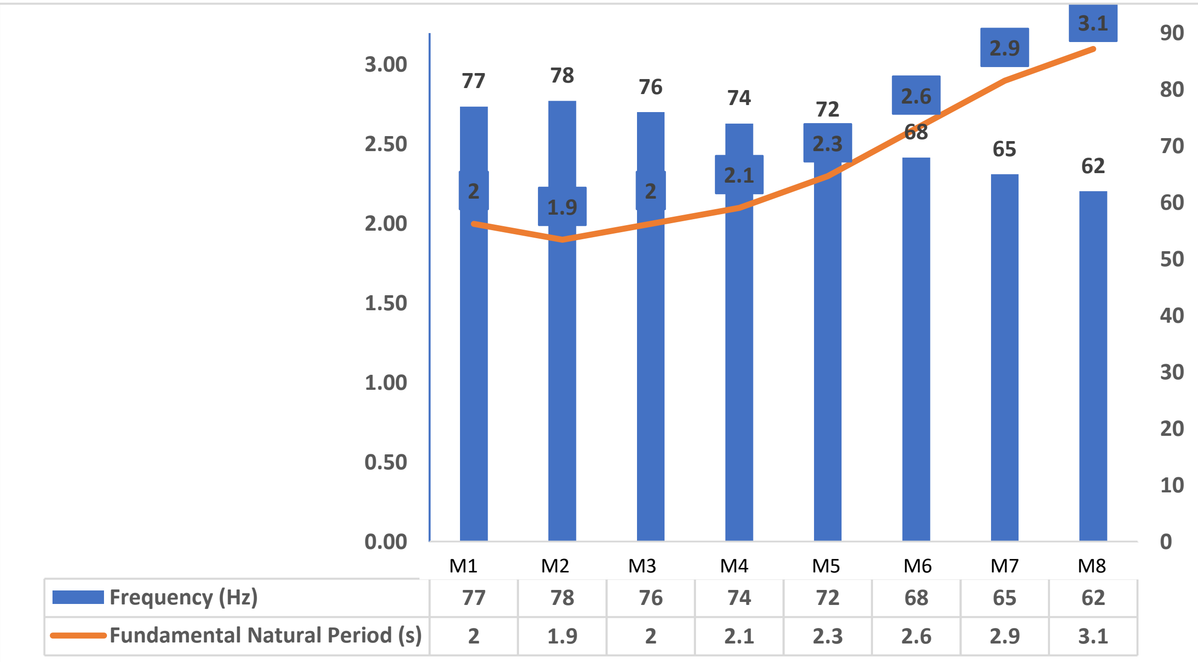


Figure 3: Fundamental Natural period (Seconds) and Frequency (Hertz) for different aggregate mix

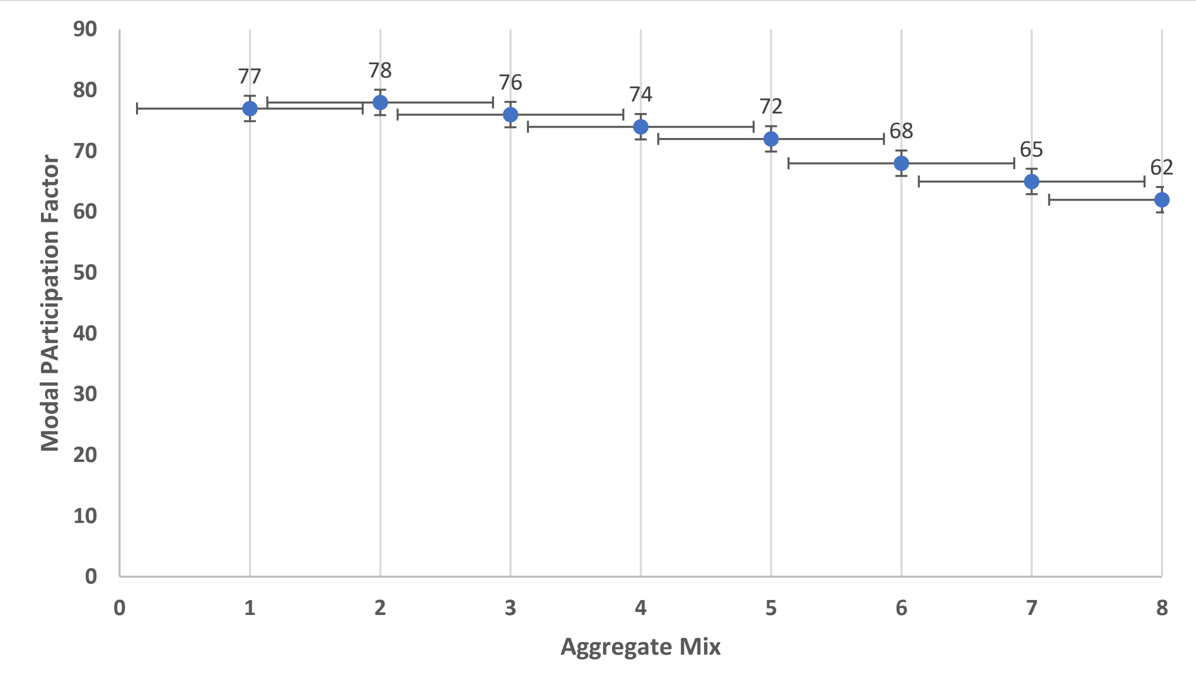


Figure 4: Modal participation factor (%) for different aggregate mix

Structures with standard gravel and granite aggregates demonstrated the shortest natural periods, with 2.0 seconds and 1.9 seconds, respectively. These results are indicative of higher structural stiffness and greater resistance to deformation under seismic excitation. The corresponding modal participation factors for gravel and granite were 77% and 78%, respectively, reflecting efficient dynamic energy absorption and dissipation. Additionally, these materials exhibited the highest frequencies of 0.50 Hz and 0.53 Hz, further corroborating their structural rigidity.

By using alternative coarse aggregates in the concrete mix led to observable changes in the dynamic characteristics. The mix comprising 25% schist, 40% gneiss, and 35% granite yielded a natural period of 2.0 seconds, similar to the standard gravel composition. This mix achieved a modal participation factor of 76% and a frequency of 0.49 Hz. This near-optimal combination suggests that the inclusion of schist and gneiss, in moderate proportions, does not significantly compromise structural stiffness while potentially improving material resilience and resource sustainability.

As the proportion of gneiss and schist increased, notable changes in structural behaviour were observed. The mix with 25% schist and 50% gneiss exhibited a natural period of 2.1 seconds, with a modal participation factor of 74% and a frequency of 0.46 Hz. The composition of 25% schist and 75% gneiss further increased the natural period to 2.3 seconds, while the modal participation factor declined to 72%, and the frequency reduced to 0.43 Hz. This trend clearly indicates a reduction in structural rigidity as the gneiss content increases.

A significant deviation was observed when the mix contained equal proportions of schist and gneiss (50% each), resulting in a natural period of 2.6 seconds and a modal participation factor of 68%. The frequency decreased to 0.38 Hz. Increasing the schist content to 75% further amplified these effects, with a natural period of 2.9 seconds and a modal participation factor of 65%. The corresponding frequency was observed to be 0.34 Hz.

The highest natural period was recorded with 100% schist, reaching 3.1 seconds. The modal participation factor dropped to 62%, and the frequency was at its lowest at 0.30 Hz. These findings suggest a significant loss of structural stiffness and an increased propensity for resonance under seismic excitation, highlighting the limitations of using schist as the sole coarse aggregate in high-rise RC structures.

The incorporation of schist and gneiss as alternative aggregates offers potential sustainability benefits but must be carefully optimized. The 25% schist + 40% gneiss + 35% granite mix can be a sound combination, balancing structural stiffness and natural period effectively. However, compositions with higher schist and gneiss content demonstrated diminished structural integrity and increased susceptibility to dynamic resonance.

3.1.2 Linear Static Analysis Results

Base shear and maximum story drift values obtained from linear static analysis are presented in Table 3.

Table 3: Base shear and Story drift for different material compositions

Material Used	Base Shear (kN)	Maximum Story Drift (mm)
Standard Gravel Aggregate	4500	15
Standard Granite Aggregate	4700	13
25% Schist + 40% Gneiss + 35% Granite	4450	14
25% Schist + 50% Gneiss + 25% Gravel	4200	18
25% Schist + 75% Gneiss	4000	22
50% Schist + 50% Gneiss	3800	26
75% Schist + 25% Gneiss	3600	30
100% Schist	3400	35

Figure 5: Base shear (kN) for different aggregate mix

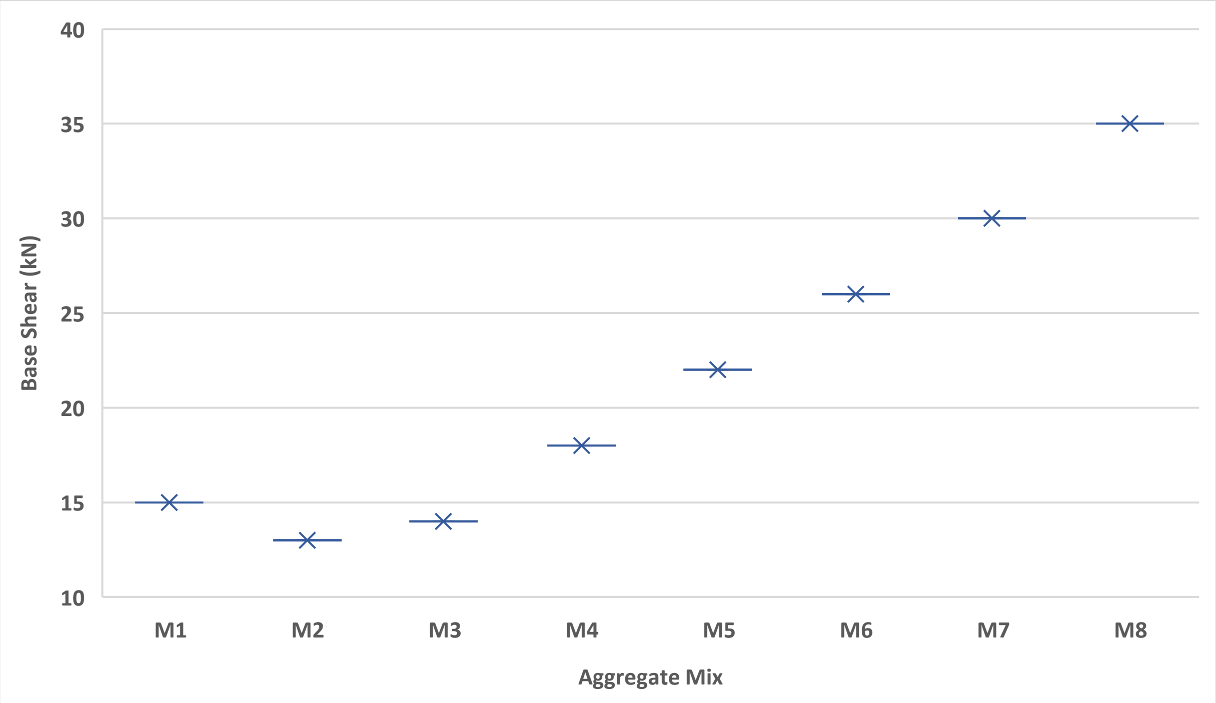


Figure 6: Base shear (kN) for different aggregate mix

The results derived from the linear static analysis, as presented in Table 3, provide a comprehensive understanding of the seismic response of structures based on different aggregate compositions. The analysis indicates that the mix of 25% schist + 40% gneiss + 35% granite provides an optimal solution for enhancing the seismic performance of structures while mitigating the risk of excessive deformation under seismic loading.

In terms of base shear, the 25% schist + 40% gneiss + 35% granite mixture yields a value of 4450 kN, which is slightly lower than the base shear observed for the standard granite aggregate (4700 kN) and standard gravel aggregate (4500 kN). However, this reduction is minimal, and the resulting base shear is still significantly higher than the compositions with a greater proportion of schist. For instance, the mix of 25% schist + 50% gneiss results in a base shear of 3800 kN, while the 75% schist + 25% gneiss composition exhibits a further decrease to 3600 kN. The lowest base shear value, 3400 kN, is observed for the 100% schist composition, which highlights the significant loss of lateral stiffness associated with schist due to its lower shear strength compared to gneiss and granite. This demonstrates that the addition of gneiss and granite in the 25% schist + 40% gneiss + 35% granite mix plays a crucial role in maintaining a high level of lateral stiffness, preserving seismic resistance despite the inclusion of schist, a material that inherently has lower stiffness.

Along with base shear, the maximum story drift provides further insights into the structural behaviour under seismic loading. The standard gravel aggregate composition experiences a maximum story drift of 15 mm, while the standard granite aggregate exhibits slightly better performance with a drift of 13 mm, indicating the higher lateral stiffness of granite. The optimized mix of 25% schist + 40% gneiss + 35% granite results in a maximum drift of 14 mm, which is a increase compared to the standard aggregates but remains well within acceptable limits for seismic performance. This indicates that while the inclusion of schist leads to a slight increase in deformation, the structural response is still acceptable, and the drift remains relatively low. In contrast, as the schist content increases in the mix, the drift values rise considerably, reflecting a reduction in lateral stiffness and a corresponding increase in deformation under seismic loading. The mix of 25% schist + 50% gneiss results in a drift of 18 mm, and the 25% schist + 75% gneiss composition experiences a drift of 22 mm. The drift continues to increase with higher proportions of schist, reaching 26 mm for the 50% schist + 50% gneiss mix, 30 mm for the 75% schist + 25% gneiss mix, and 35 mm for the 100% schist composition. This increase in drift highlights the detrimental effects of increasing schist content, leading to higher structural displacements and a loss of lateral stiffness under seismic forces.

The analysis thus reveals a clear trend, as the schist content in the aggregate mix increases, both the base shear and lateral stiffness decrease, leading to higher story drift and greater structural deformation during seismic events. Specifically, the 100% schist composition exhibits the lowest base shear (3400 kN) and the highest drift (35 mm), indicating a significant reduction in the structure's ability to resist seismic forces and increased vulnerability to excessive deformation. On the other hand, the optimized 25% schist + 40% gneiss + 35% granite mix maintains a reasonable level of seismic resistance (4450 kN base shear) and only a moderate increase in drift (14 mm), which represents a balanced response to seismic forces. This composition thus ensures that the structure retains adequate seismic resistance while minimizing deformation, which is essential for maintaining structural integrity and safety under seismic loading.

Thus, 25% schist + 40% gneiss + 35% granite mix is identified as the most effective material composition for achieving an optimal balance between seismic resistance and structural deformation. While this mix results in a slight reduction in base shear compared to the standard granite and gravel aggregates, it offers a more favourable seismic response than mixes with higher proportions of schist. The slight decrease in base shear (4450 kN) and the marginal increase in drift (14 mm) suggest that this combination provides an effective alternative, offering adequate seismic resistance without inducing excessive deformation. In contrast, as the proportion of schist increases, both the base shear and lateral stiffness decline, leading to higher story drift values and reduced structural integrity. Therefore, incorporating a balanced mix of strong aggregates like gneiss and granite with controlled amounts of schist enhances seismic performance while mitigating the risk of excessive lateral drift, ensuring the stability and safety of structures subjected to seismic forces.

3.1.3 Response Spectrum Analysis

The peak roof displacement and acceleration values from the response spectrum analysis are presented in Table 4.

Table 4: Peak acceleration and roof displacement for different material compositions

Material Scenario	Peak Roof Displacement (mm)	Peak Acceleration (g)
Standard Gravel Aggregate	55	0.45
Standard Granite Aggregate	50	0.48
25% Schist + 40% Gneiss + 35% Granite	58	0.44
25% Schist + 50% Gneiss + 25% Gravel	65	0.42
25% Schist + 75% Gneiss	75	0.40
50% Schist + 50% Gneiss	90	0.37
75% Schist + 25% Gneiss	110	0.34
100% Schist	125	0.31

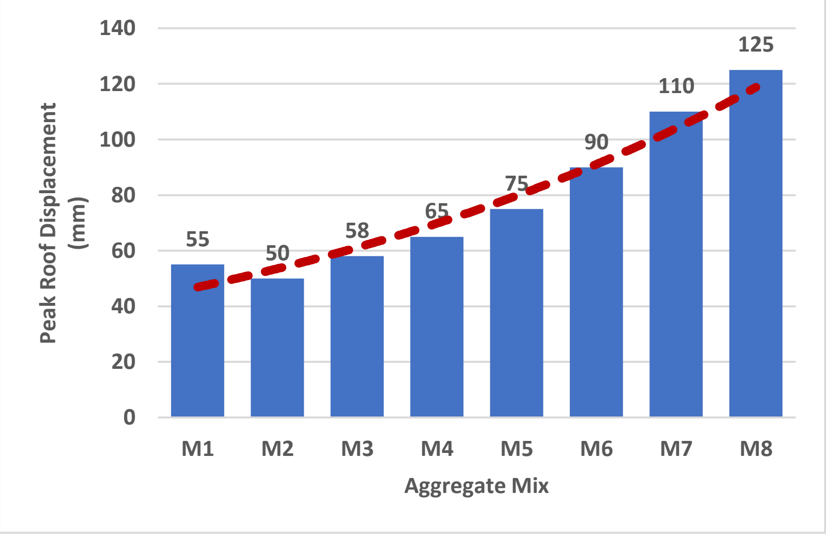


Figure 7: Peak Acceleration (mm) for different aggregate mix

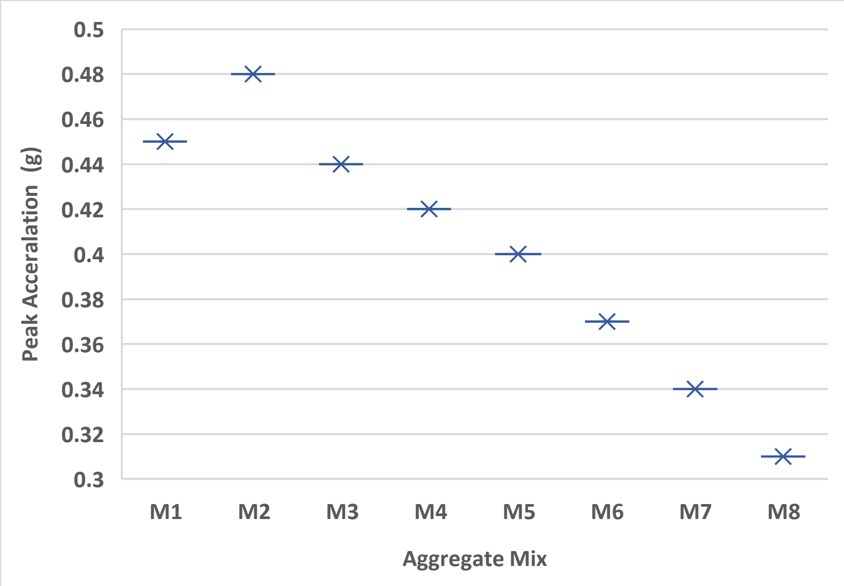


Figure 8: Peak Acceleration (g) for different aggregate mix

The results from the response spectrum analysis, provide insights into the seismic performance of different aggregate compositions, specifically focusing on peak roof displacement and peak acceleration.

The standard gravel aggregate composition yields a peak roof displacement of 55 mm and a peak acceleration of 0.45 g, while the standard granite aggregate performs slightly better, with a displacement of 50 mm and an acceleration of 0.48 g. The higher stiffness of granite allows it to better resist lateral displacement and sustain higher forces compared to gravel, making it an effective material for seismic resistance. However, the 25% schist + 40% gneiss + 35% granite mix exhibits a peak roof displacement of 58 mm and a peak acceleration of 0.44 g. While this mix results in a slightly higher displacement than the standard granite aggregate, it remains within an acceptable range. The slight increase in displacement (58 mm compared to 50 mm for granite) and the moderate decrease in acceleration (0.44 g compared to 0.48 g for granite) suggest that this mix provides a balanced seismic response, combining sufficient seismic resistance with a controlled increase in structural deformation.

As the proportion of schist increases in the mix, both peak roof displacement and peak acceleration show a clear upward trend. The 25% schist + 50% gneiss mix results in a peak displacement of 65 mm and a peak acceleration of 0.42 g, while the 25% schist + 75% gneiss mix exhibits a displacement of 75 mm and an acceleration of 0.40 g. These changes indicate that higher schist content reduces the lateral stiffness of the aggregate, leading to greater structural movement and a diminished ability to resist seismic forces. The trend continues with the 50% schist + 50% gneiss mix, where the displacement reaches 90 mm, and the acceleration further drops to 0.37 g. This marked deterioration in seismic performance highlights the adverse effects of increasing schist content.

The 100% schist composition exhibiting a peak roof displacement of 125 mm and a peak acceleration of 0.31 g. This composition shows the highest displacement and the lowest acceleration, indicating that it is highly susceptible to lateral movement and forces during seismic events, making it unsuitable for seismic applications.

In the response spectrum analysis, the 25% schist + 40% gneiss + 35% granite mix results in a slightly higher peak roof displacement (58 mm) and a moderate decrease in acceleration (0.44 g) compared to standard granite, making it a favourable balance between seismic resistance and structural deformation. The analysis reveals that higher proportions of schist lead to undesirable increases in displacement and decreases in acceleration, which significantly reduce seismic performance. Therefore, the 25% schist + 40% gneiss + 35% granite mix proves to be the most optimal solution, providing a robust and cost-effective approach for seismic design while ensuring structural safety and stability under seismic loading.

4 Recommendations

The findings from the response spectrum analysis and linear static analysis emphasize the importance of aggregate composition in determining the seismic performance of structures. Specifically, the 25% schist + 40% gneiss + 35% granite mix emerged as the most optimal aggregate combination, providing a favourable balance between material properties, seismic resistance, and structural performance. This mixture demonstrates a competitive seismic response, achieving a peak roof displacement of 58 mm and a peak acceleration of 0.44 g, which are better than the results observed for standard gravel and granite aggregates. With a slightly higher displacement (58 mm) than the standard granite aggregate (50 mm), the mix maintains an acceptable level of deformation, highlighting its effectiveness in minimizing lateral movement under seismic loads. The relatively stable peak acceleration of 0.44 g suggests that the mixture can withstand seismic forces without excessive structural strain, ensuring the safety of the building.

Material suitability is a key aspect of the findings, as the combination of gneiss, granite, and gravel improved the structural response when compared to more schist-dominated mixes. If the schist content increases, both peak displacement and peak acceleration worsened, demonstrating that schist, due to its lower stiffness and shear strength, is less effective at resisting seismic forces. The 100% schist composition, with a peak roof displacement of 125 mm and a peak acceleration of 0.31 g, is more vulnerable with schist as a primary aggregate material for seismic applications. While 25% schist + 40% gneiss + 35% granite mix reduces these vulnerabilities while maintaining economic feasibility, proving to be a suitable material choice for enhancing seismic resilience.

The recommendation for the optimal mix is reinforced by the superior structural and seismic performance of the 25% schist + 40% gneiss + 35% granite combination. This mix effectively minimized displacement and story drift, which are critical factors in maintaining the integrity of buildings during seismic events. With a base shear resistance of 4450 kN and a maximum story drift of 14 mm from the linear static analysis, this mixture demonstrates robust seismic resistance, while the controlled peak displacement (58 mm) and peak acceleration (0.44 g) from the response spectrum analysis indicate minimal structural deformation under dynamic loading. These factors suggest that the mix offers a balanced solution for both seismic safety and economic considerations in construction as the composition leverages the strengths of gneiss and granite, which offer higher stiffness and resistance to deformation, while reducing the use of schist, which contributes to higher displacement and lower seismic performance when used in excess.

In conclusion, the 25% schist + 40% gneiss + 35% granite mix offers a well-balanced approach to seismic design. By leveraging a mixed composition approach, the proposed mixture can contribute to more resilient and cost-effective structural systems, providing a strong foundation for future earthquake-resistant construction practices.

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