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ANALYSIS OF THE SEISMIC PERFORMANCE AND SUSTAINABILITY DESIGN STRATEGIES OF REINFORCED CONCRETE BUILDINGS

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ABSTRACT

This research examines the seismic performance of reinforced concrete structures, using a six-story RC dormitory building as an example. It focuses on different soil properties, support and foundation conditions, and site seismicity scenarios that reflect the seismicity of india. The goal of the study is to evaluate the possible consequences of surpassing expected site seismic intensities, which might result in safer infrastructure and communities in the event of future earthquakes. Structural Analysis of Robots For structural study and design, professional software is used, taking into account site seismicity and soil-structure interactions. Additionally, this research looks at the environmental effects of RC structures, which are a representation of india's future building inventory. Through a life cycle analysis, it looks at the different material consumption needed to develop structures that adhere to Eurocode requirements. The approach used in this study is consistent with the fundamental ideas of practical design that include environmental and economic sustainability. The main conclusions of the research show that although increasing member size may improve performance at lower intensities, shear barriers may be required in high seismic zones at higher intensities, making this a potentially insufficient method. A balance between material consumption, performance, and environmental effect is required for sustainable design.

KEYWORDS: *Seismic Performance,Reinforced Concrete Structures,Seismic Zones,Life Cycle Cost Analysis*

1. INTRODUCTION

The unpredictable nature of earthquakes necessitates exceeding current seismic design standards. Eurocode regulations are a good start, but inherent earthquake uncertainty requires structures resistant to stronger shaking. Incorporating additional safety margins and advanced seismic technologies protects the infrastructure from unforeseen seismic activity. During earthquakes, soil composition significantly impacts ground motion. Key soil characteristics influence earthquake effects such as soil type (soft, saturated soils like loose sand amplify ground motion, while stiffer soils like rock dampen shaking intensity), density (denser soils transmit seismic waves more efficiently leading to stronger ground motions, while loose soils can absorb some wave energy reducing intensity), water content (saturated soils are more susceptible to liquefaction, where soil loses strength and behaves like a liquid, causing severe damage to foundations), and topography (hillsides and slopes with loose soils are more prone to earthquake-triggered landslides). These soil characteristics directly influence how earthquake-induced ground motions behave, including amplification (soft, saturated soils can amplify seismic waves, significantly increasing ground motion intensity at the surface), attenuation denser soils attenuate seismic waves, meaning the wave energy is absorbed or scattered, reducing ground motion reaching the surface and site response the combined effect of soil properties on a specific location is known as site response which significantly affects the amount of ground shaking experienced during an earthquake). Seismicity, the frequency and intensity of earthquakes in a region, presents challenges and opportunities for sustainable development. Earthquakes can devastate infrastructure, disrupting daily life, hindering economic activity, and limiting access to essential services. Rebuilding requires significant resources, potentially exceeding 40 % of the initial cost, diverting funds from other sustainability initiatives.

This study investigates the seismic performance of RC buildings in India, a moderately seismically active country, focusing on structures connected by fixed supports. It aims to understand how this configuration affects stability and failure modes compared to isolated buildings. The research will use a specific soil type to isolate the effect of building configuration on seismic response. It will consider multiple earthquake intensities exceeding Eurocode standards to evaluate the safety margins in current design approaches. This comprehensive analysis will identify potential vulnerabilities in existing structures for enhancing future design and retrofit strategies. Ultimately, it aims to create safer and more resilient communities in earthquake-prone regions. This analysis using AutoCAD (architectural drawing) and Autodesk Robot Structural Analysis (structural analysis) will provide a comprehensive understanding of the structural behaviour under diverse seismic loading conditions by considering Peak Ground Acceleration (PGA) and soil interactions utilising soil type C (clay), leading to an optimised design for safety, efficiency, and resilience.

2. ANALYSIS METHODOLOGY

Figure 1show the seismic performance of RC buildings india, this research utilises a six-story RC dormitory building as a case study. Inspired by a similar building at India, the model features a total height of 21 m and a footprint of 14.5 m x 43 m (rectangular).

This CAD model avoids vertical irregularities but has a plan irregularity due to the significant difference between its short and long sides.

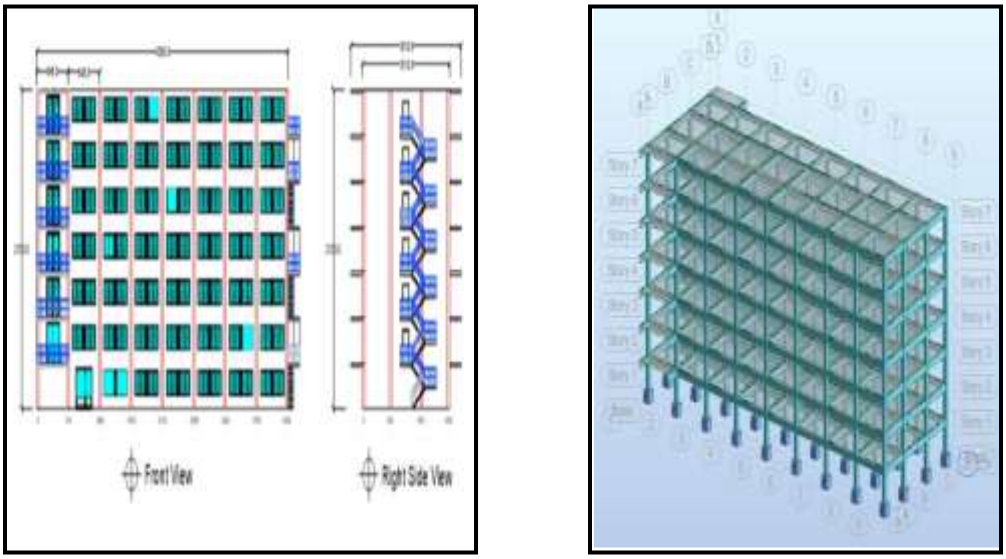

Figure 1: Front and right side view of RC building structure

A scientific investigation on the performance of buildings under different stress levels is summarized in Table 1. The five levels of building functionality are as follows: "Operational Performance" means that the building is still fully functional; "Immediate Occupancy" means that minor to moderate damage has been repaired and the building is safe for immediate occupancy; "Damage Control" means that structural damage can be repaired; "Life Safety" means that there is significant or severe damage and evacuation may be necessary; and "Collapse Prevention" means that the building is about to collapse. Every floor has a corresponding inter-story drift ratio, which shows how much the floors move in relation to one another. Engineers use this information to design buildings that can survive urban stressors and emergency responders use it to evaluate the safety of buildings.

Table 1: Performance level of Built Structures

Performance Level	**Abbreviation**	**EMS damage states**	**Inter-story Drift Ratio (%)**
Operational Performance	OP	No / Slight	0.5
Immediate Occupancy	IO	Slight / Moderate	1
Damage Control	DC	Moderate / Heavy	1.5
Life Safety	LS	Heavy / Very Heavy	2
Collapse Prevention	CP	Destruction	2.5

A technique for evaluating the environmental effect of a product or service at every stage of its life cycle, from material extraction to disposal, is life cycle assessment, or LCA. It aids in finding opportunities to enhance sustainability. For sustainable construction projects, Life Cycle Cost Analysis (LCCA) is essential, especially when concrete, a popular building material, is included. Throughout the concrete lifespan, LCCA takes into account the expenses of material procurement, processing, and disposal. In order to survive earthquakes of varying magnitudes, this research uses IdematLightLCA to conduct a life cycle assessment and determine the environmental effect of the materials used in each building design that is constructed around certain PGA values. In relation to the unit, the LCCA will evaluate the carbon footprint, which quantifies the greenhouse gas emissions during material manufacturing, and the unit eco-costs, which reflect the environmental harm connected to the material.

3. RESULTS AND DISCUSSION

A structural analysis was performed for a 7-story building with a fixed support system. The analysis considered seismic performance (deflection) and material usage for sustainability. The building model had 252 columns (3 m tall), 413 Beams (5 m), 28 cantilevers (2 m), column spacing of 5 m, and floor slab thickness of 15 cm. The seismic analysis input includes ground response acceleration of 0.12g to 0.72g considering PGA, importance factor, and unit conversion), soil type C, spectrum type using design spectrum, analysis direction of horizontal, and behaviour factor of 1.5 (constant). The analysis explored how member dimensions and PGA values affect a building's seismic performance. Performance is measured by inter-story drift ratio, indicating deflection under load. Lower PGA values (0.1g and 0.2g) had all member configurations achieved good performance (OP to IO) with minimal to moderate damage expected. Moderate PGA values (0.3g) had initial configurations that fell under damage control (DC), and increasing member sizes improved performance in terms of immediate occupancy (IO). As for higher PGA (0.4 g to 0.6 g), even with member size adjustments, performance remained between immediate occupancy and damage control. This suggests the limitations of relying solely on member size at higher seismic intensities. The study recommends investigating the use of shear walls in future analyses, as they can significantly improve seismic performance.

Table 2: Analysis for Concrete and Steel PGA value

PGA	Configration	Column Dimensions (cm)	Beam Dimensions (cm)	Deflection (cm)	Inter-story Drift Ratio (%)	Combined Carbon Footprint (kg)
	a	50x50	30x60	9.1	0.4333	517,964.4
0.1g	b	45x45	25x40	6.9	0.3285	337,358.2
	c	45x45	25x60	7.7	0.3666	432,292.6
	a	60x60	30x60	11.6	0.5523	668,082.2
0.2g	b	45x45	25x40	18.3	0.8577	386,237.8
	c	50x50	30x50	14.8	0.7047	528,419.4
	a	50x50	35x60	20.7	0.9857	688,367.4
0.3g	b	45x45	30x40	27.1	1.2904	459,963.4
	c	50x50	35x45	23.2	1.1047	579,332.7
	a	50x50	50x70	27.1	1.2904	1,042,574
0.4g	b	45x45	40x60	31	1.4761	774,093.6
	c	50x50	50x50	29	1.3809	823,084.7

Table 2 presents the analysis of the trade-off between material usage and deflection (seismic performance) for PGA values of 0.1g to 0.4g. PGA values of 0.5g and 0.6g were found to have dangerous values of deflection. So, LCA was not conducted, and it is recommended that shear walls be used in this case. Lower deflections under a specific PGA value require more material but lead to better performance (less damage) under seismic loads. Finding a balance between these factors is crucial for sustainable design (minimal material, good performance). For each PGA value, configurations with minimum, maximum, and intermediate deflection were compared. At 0.1g, configuration “a” used the most material but had the least deflection. Configuration “b” used the least material but had the most deflection, and configuration “c” offered a compromise. Similar trends were observed for higher PGA values. The configurations based on performance and sustainability find that 0.1g configuration “a” is the best option due to lower material use with minimal performance compromise. For 0.2g, configuration “c” might be the most reasonable option as it balances material usage and deflection while maintaining good performance. For 0.3g, configuration “c” provides the best performance despite high material use. For 0.4g, all configurations fall within the same performance range; selecting the most sustainable option depends on project priorities (minimising material use vs slightly lower deflection) and configurations “a”, “b”, or “c” could all be potential candidates. The choice depends on project-specific priorities and constraints, such as the relative weight, minimising material usage versus achieving a slightly lower deflection.

The analysis revealed a significant increase in material usage as the PGA increased. For RC structures designed for a PGA of 0.1g to be modified to meet the performance requirements of 0.2g, the quantities increased approximately 28 % for concrete and 61 % for steel. This trend continued at higher seismic intensities. Transitioning from a 0.2g design to a 0.3g design required increases in concrete & steel of 20 % & 31 %. Similarly, from a 0.3g design to a 0.4g design resulted in an additional 32 % & 38 % increase in concrete & steel consumption. In essence, these results suggest that constructing an RC structure designed for a 0.1g PGA in a location with a 0.4g PGA would require approximately 60 % more concrete and 83 % more steel. This highlights the significant impact of seismic intensity on the material requirements for RC structures. Building in earthquake- prone areas (higher PGA) requires stricter designs to ensure safety. This often leads to increased material use, which has a negative environmental impact. The study found that a structure designed for low PGA (0.1g) would need 52 % more eco-cost and 51 % more carbon footprint to meet safety standards in a high PGA (0.4g). While minimising material use is ideal for sustainability at low PGA levels, prioritising performance at higher intensities becomes more important. Lastly, a higher-performing structure is less likely to suffer damage, reducing risk to human life, earthquake waste, and the need for reconstruction.

4. CONCLUSIONS

This study investigated the seismic performance of RC buildings in india. A 6-story building model was analysed under various earthquake intensities (PGA: 0.1g to 0.6g) and soil conditions (dense sand/gravel, stiff clay) using software incorporating soil-structure interaction and site seismicity. LCA considered the environmental impact of material usage. The key findings include member size vs. seismic performance: (increasing member size improved performance at lower PGA of 0.1g & 0.2g but had diminishing returns at higher intensities of 0.3g & 0.4g, where shear walls may be necessary for high seismic zones of 0.5g & 0.6g). Regarding performance levels, lower PGAs of 0.1g & 0.2g achieved operational and immediate occupancy performance, while higher PGAs of 0.3g & 0.4g remained in damage control even with member size adjustments. In terms of material use vs.

deflection, lower deflection (achieved with more material) resulted in less seismic damage, indicating that sustainable design requires a balance between these factors. For material use vs. seismic zone, lower seismic zones of 0.1g & 0.2g allowed prioritising minimal material use configurations, while higher zones of 0.3g may require slightly more material for significantly better performance and lower maintenance costs. The environmental impact analysis showed that stricter building codes in high seismic zones lead to increased material use and higher environmental costs, with eco-cost rising by 52 % and the carbon footprint increasing by 51 % from 0.1g to 0.4g PGA values. Finally, LCA can balance environmental impact with safety, prioritising higher-performance structures in high seismicity zones, which can reduce waste and long-term environmental impact by reducing the need for reconstruction. To further enhance this research, incorporating shear walls into the structural model is recommended. Analysing the influence of shear walls on building performance under different seismic scenarios can provide valuable insights into improving structural efficiency and seismic resistance in RC buildings.

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