JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

"Study of Lateral Load Resisting Systems of Variable Heights in All Soil Types of High Seismic Zone Using E-TABS"

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Abstract: The present study focuses on the structural performance of G+6 storey reinforced concrete building model with the beam dimensions of 200×600 mm, column dimensions of 300×600 mm, M45 grade concrete, Fe500 reinforcement, and a 150 mm thick M25 slab, when subjected to seismic loading under different soil conditions. Three soil profiles—soft, medium, and hard—were considered using equivalent static nonlinear analysis in ETABS to analyses the variation in lateral response and structural safety. The analysis revealed that structural model passed under soft and medium soil conditions, satisfying both strength and drift criteria, but exhibited critical failure in the hard soil case, where three concrete beam frames at story levels 2, 3, and 4 failed due to increased shear and moment demands. To enhance performance in the hard soil scenario, retrofitting measures such as fluid viscous dampers (250 kN, 44 kg) and X-bracing using ISMB200 were modelled; however, both systems were not able to prevent failure, indicating that isolated strengthening techniques did not provide the required global stiffness. In contrast, the introduction of a 9-inch thick M25 reinforced concrete shear wall provided significant improvement, redistributing lateral forces, controlling storey drifts, and enabling the model to pass all safety checks. This outcome demonstrates that structures founded on hard soil require thorough examination of dynamic response characteristics, as the stiff soil profile shortens the fundamental time period and amplifies seismic shear forces. It also emphasizes that while dampers and bracings may offer partial benefits, the provision of reinforced shear walls remains a highly effective solution for ensuring the safety and stability of mid-rise reinforced concrete frames on hard soil sites.

1. INTRODUCTION

1.1 GENERAL

The seismic safety of multi-storey RC buildings is vital in India's earthquake-prone regions. This study examines a G+6 RC building's behavior on soft, medium, and hard soils, showing that soil stiffness greatly influences performance.

While the structure met seismic requirements on soft and medium soils, beam failures occurred on hard soil due to higher acceleration demands, proving that material strength alone is insufficient. Among retrofitting options—dampers, bracing, and shear walls—only a 9-inch RC shear wall effectively enhanced lateral stiffness and reduced drifts. The findings highlight that identical structures can perform differently across soil types, emphasizing the need for soil–structure interaction analysis and shear wall inclusion to ensure seismic safety in mid-rise RC buildings.

1.2 RESPONSE SPECTRUM

Earthquake-resistant design is crucial in India's seismic zones, especially for mid-rise RC buildings like G+6 structures that dominate urban development. Such buildings must resist both gravity and lateral seismic loads, whose effects depend on material properties, member configuration, and soil conditions. To ensure safety, Indian codes such as IS 1893 (Part 1):2002 recommend advanced analytical methods like the Response Spectrum Method (RSM), which evaluates structural behavior more accurately than static approaches. This study applies RSM to assess the seismic performance of a G+6 RC building on varying soil types, emphasizing soil–structure interaction and the importance of lateral load-resisting systems for overall stability.

- Response Spectrum Method (RSM)
- Soil–Structure Interaction

- Seismic Analysis
- Shear Wall

G+6 Reinforced Concrete Building etc.

2. OBJECTIVES

The main objective of this study is to analyses the seismic performance of a G+6 RC building using the Response Spectrum Method (RSM) as per IS 1893 (Part 1):2002, focusing on how soil type influences structural response. Mid-rise RC buildings are common in India, and their safety largely depends on soil–structure interaction and lateral load-resisting systems, Specific objectives include:
Modelling and analysing a G+6 RC building under soft, medium, and hard soil conditions using RSM.
Comparing seismic responses such as storey shear, displacement, drift, and member forces across soil types.
Identifying critical failure zones and assessing the effect of soil stiffness on seismic demand.
Evaluating retrofitting methods—viscous dampers, X-bracing, and shear walls—for improving performance on hard soils.
Evaluating retrofitting methods—viscous dampers, X-bracing, and shear walls—for improving performance on hard soils.
Recommending safe and economical design strategies, emphasizing shear walls for enhanced seismic resistance.

2.1 PROBLEM STATEMENT

Earthquakes pose a major threat to urban RC buildings, especially mid-rise (G+6) structures common in India. Their seismic performance varies with soil type, as soil–structure interaction greatly influences stability. While buildings may perform safely on soft and medium soils, those on hard soils experience higher accelerations and shear forces, leading to failures even with identical designs. In this study, a G+6 RC building (200×600 mm beams, 300×600 mm columns in M45 concrete, and 150 mm M25 slab) passed checks on soft and medium soils but failed under hard soil when analyzed using the Response Spectrum Method. Failures occurred in beams on storey 2–4 due to increased acceleration demands. Traditional retrofitting methods like dampers and X-bracing were ineffective. **Problem Statement:** A G+6 RC building that satisfies seismic criteria on soft and medium soils becomes vulnerable under hard soil conditions due to amplified accelerations. Conventional retrofitting methods are inadequate, emphasizing the need for more effective solutions such as reinforced concrete shear walls

2.2 PROBLEM SOLUTION

The problem identified in this study necessitates a solution that addresses both the root cause of failure and the overall seismic safety of the structure. The key issue lies in the amplification of seismic shear forces on hard soil, which concentrates stresses in certain beams and causes member failures. To counter this, the solution must provide enhanced lateral stiffness, improved force redistribution, and greater control of story drift. The Response Spectrum Method serves as the analytical tool to evaluate the effectiveness of potential solutions, as it accounts for multiple vibration modes, modal mass participation, and soil-specific design spectra as per IS 1893: 2002.Several strengthening techniques were modelled and tested. Fluid viscous dampers, though effective in absorbing seismic energy in tall or irregular buildings, did not proves. Similarly, X-bracing using ISMB200 sections failed to provide the required continuity and stiffness across the critical stories. The most effective solution was found in the addition of a 9-inch thick M25 reinforced concrete shear wall. The adequate relief in this mid-rise model due to insufficient engagement with the dominant mode shear wall acted as a continuous vertical element, significantly increasing the lateral stiffness of the structure, reducing storey drifts, and redistributing shear forces uniformly. This enabled the model to pass all seismic checks under hard soil conditions. Thus, the proposed solution is the incorporation of shear walls in G+6 RC buildings constructed on stiff soils, either as part of the initial design or as a retrofitting measure.

2.3 EXISTING SYSTEM

The existing system of seismic design for mid-rise RC buildings typically relies on RC frames consisting of beams, columns, and slabs without the addition of specialized lateral load-resisting elements such as shear walls or bracing systems. Under IS 1893:2002, many buildings are designed using the equivalent static method or simplified dynamic methods that do not fully account for soil–structure interaction. While this system is generally adequate for soft and medium soil conditions, it becomes insufficient when buildings are constructed on hard soils.

In the specific case of the present study, the G+6 RC frame designed with M45 concrete beams and columns and a 150 mm M25 slab demonstrated satisfactory performance for soft and medium soils but failed under hard soil conditions in response spectrum analysis. Conventional retrofitting systems like dampers and X-bracing, which form part of the existing toolkit of structural strengthening, proved ineffective in addressing these failures. Therefore, the existing system is limited in its ability to ensure seismic safety for structures on stiff soils.

2.4 PROPOSED SOIL

The proposed system involves the integration of reinforced concrete shear walls into the RC building frame to enhance seismic performance, particularly on hard soils. Unlike dampers or bracings, shear walls provide a continuous, stiff, and strong lateral load-resisting system that works effectively with the frame to redistribute seismic forces and reduce storey drifts. In the recent study, the addition of a 9-inch thick M25 shear wall was found to eliminate beam failures under hard soil conditions, ensuring compliance with seismic safety requirements in response spectrum analysis.

The proposed system can be implemented in two ways:

1. **As a preventive measure in new constructions** on hard soils, where shear walls are included in the initial design to provide adequate stiffness and safety.
2. **As a retrofitting measure** for existing RC frames where failures are anticipated or observed, by strategically adding shear walls to critical regions such as stair cores or elevator shafts.

This system ensures that the building not only complies with IS 1893:2002 provisions but also achieves a higher level of resilience against seismic forces.

Motivation of Project

The motivation behind this project arises from the urgent need to improve seismic safety in India's rapidly urbanizing regions. G+6 storey RC buildings are increasingly common due to population pressures, and their failure during earthquakes can lead to catastrophic loss of life and property. While many structures are adequately designed for soft and medium soils, the failures observed in hard soil conditions highlight a significant gap in conventional design practices.

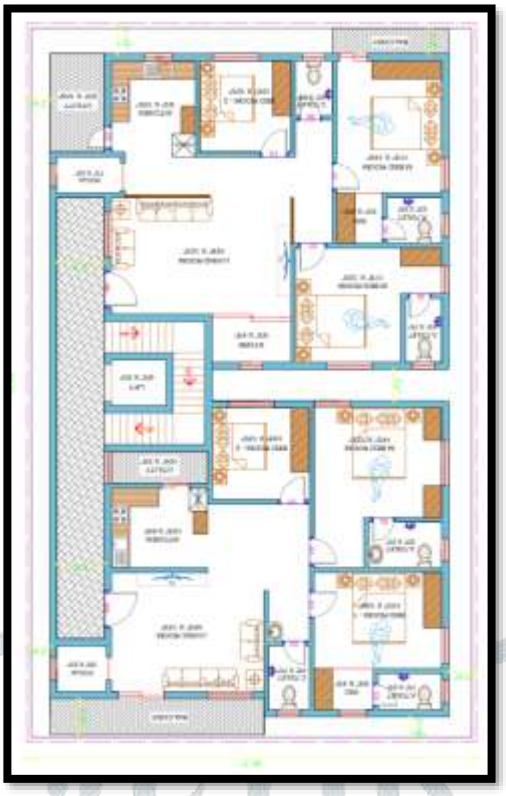
The project is motivated by the following factors:

- The **destructive potential of earthquakes** in India's seismic zones, requiring advanced analysis methods like RSM.
- The **sensitivity of building performance to soil conditions**, which is often underestimated in design.
- The **limitations of conventional systems** like dampers and bracings in providing adequate safety for RC frames.
- The **proven efficiency of shear walls** as a robust solution to seismic challenges.
- The need to **provide practical design recommendations** for engineers, ensuring that future G+6 constructions on hard soils are both safe and economical.

This motivation establishes the relevance and practical importance of this project, seeking to close the gap between theoretical design provisions and real-world structural performance across different soil conditions.

3. METHODOLOGY

Here's a concise and reduced version of your methodology paragraph, keeping all key technical details and logical flow intact: The study adopts a systematic methodology to analyze the seismic response of a G+6 reinforced concrete (RC) frame under soft, medium, and hard soil conditions. The process includes defining structural geometry, materials, and loading conditions, modelling in ETABS, performing response spectrum analysis, and interpreting results for design recommendations. The structure consists of six stories with 3 m floor heights, 200×600 mm beams, 300×600 mm columns, and a 150 mm slab. M45 concrete and Fe500 steel are used for beams and columns, while M25 concrete is used for slabs. Loads are applied as per IS 1893 and IS 456, assuming rigid diaphragms and appropriate base conditions for each soil type. ETABS 2023 Ultimate is used for 3D modelling and nonlinear analysis; Excel and Python for data processing and visualization; and AutoCAD for layout preparation. The model passes for soft and medium soils but fails in the hard soil case due to excessive shear and moment in stories 2–4. To improve performance, retrofitting options—ISMB200 X-bracing, 250 kN fluid viscous dampers, and a 9-inch M25 shear wall—are modelled. Only the shear wall effectively redistributes lateral forces and ensures compliance with safety criteria. Comparative analysis in Excel and Python evaluates base reactions, story displacements, shear forces, and drifts across soil types.



PLAN

3.1 STRUCTURAL GEOMETRY

Component	Dimensions (mm)	Remarks
Beam	200 × 600	M45 Concrete, Fe500 Steel
Column	300 × 600	M45 Concrete, Fe500 Steel
Slab	150	M25 Concrete
Floor Height	3000 mm	Each story uniform
Number of Stories	G+6	Ground + 6 floors

3.2 MATERIAL PROPERTIES

Material	Grade	Young's Modulus (GPa)	Density (kN/m³)	Poisson's Ratio
Concrete (Beam & Column)	M45	36.0	25	0.2
Concrete (Slab)	M25	25.0	25	0.2
Steel	Fe500	200	78.5	0.3

3.3 SOIL TYPES

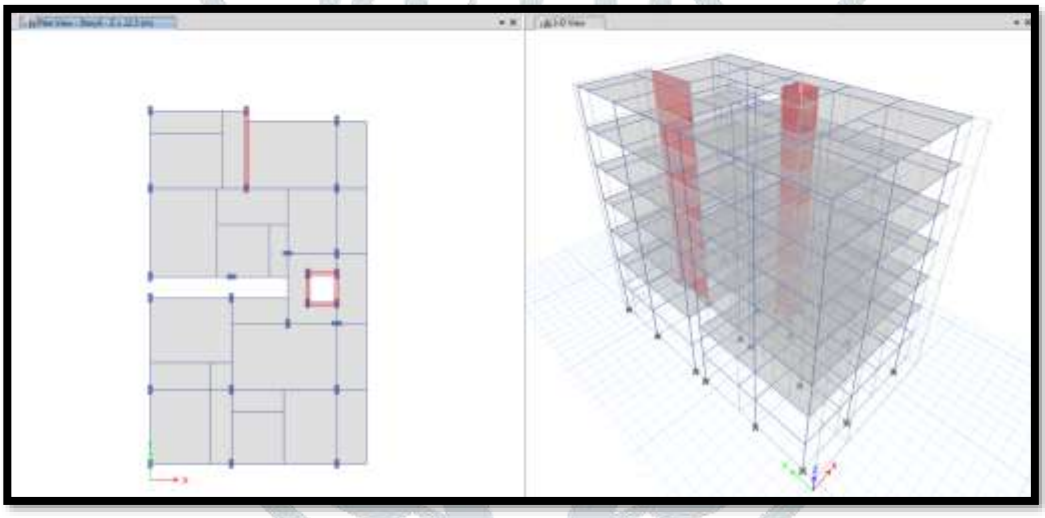
Soil Type	Boundary Condition	Model Status

Soft Soil	Pinned Base	Passed
Medium Soil	Pinned Base	Passed
Hard Soil	Fixed Base	Failed at 3 frames (Stories 2,3,4)

3.4 Retrofitting / Strengthening for Hard Soil

Solution Implemented	Description	Result
Shear Wall	9-inch M25 wall at critical frames	Passed all checks
X-Bracing	ISMB200 at critical frames	Insufficient alone
Fluid Viscous Damper	250 kN, 44 kg	Insufficient alone

4. Response Spectrum Analysis



4.1 Soil Analysis

Parameter	Value
RSMAX (kN)	1131.14
EQX (kN)	1330.77
BS>84% (%)	84.99
SUM UX	0.9375
SUM UY	0.9375
UX %	93.75
UY %	93.75

Soft Soil

Parameter	Value
RSMAX (kN)	1590.09
EQX (kN)	1861.19
BS>84% (%)	85.43
SUM UX	0.9750
SUM UY	0.9372
UX %	97.50
UY %	93.72

Medium Soil

Parameter	Value
RSMAX (kN)	1774.05
EQX (kN)	2219.61
BS>84% (%)	79.93
SUM UX	0.9831
SUM UY	0.9295
UX %	98.31
UY %	92.95

Hard Soil

5. Results and comparison

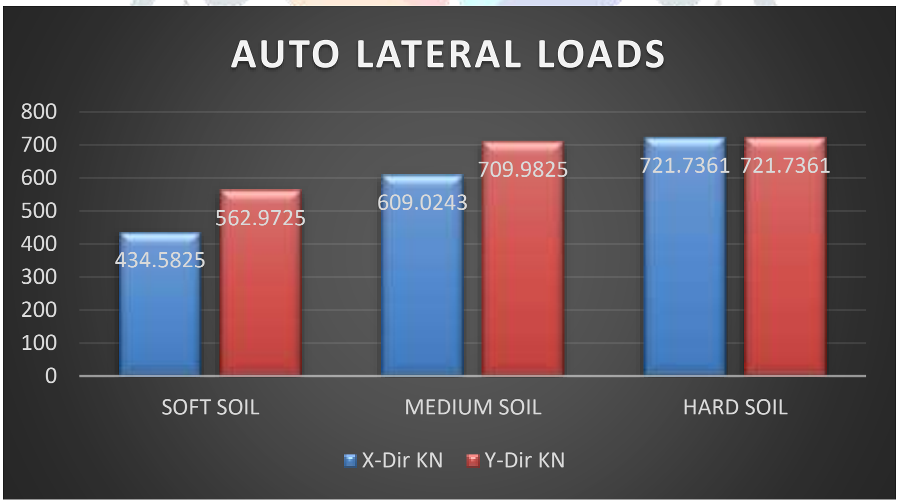
5.1 Base Reaction Analysis

Soil Type	RSMAX (kN)	EQX (kN)	BS >84% (%)
Soft Soil	1131.1353	1330.7689	84.99
Medium Soil	1590.0943	1861.1874	85.43
Hard Soil SW	1774.0512	2219.6046	79.93

Interpretation:

- Softer soils absorb more seismic energy, resulting in smaller displacements and lower response reductions.
- Hard soils have higher base reactions and slightly higher horizontal displacements along X, meaning structures on hard soils experience stronger forces but slightly less damping.

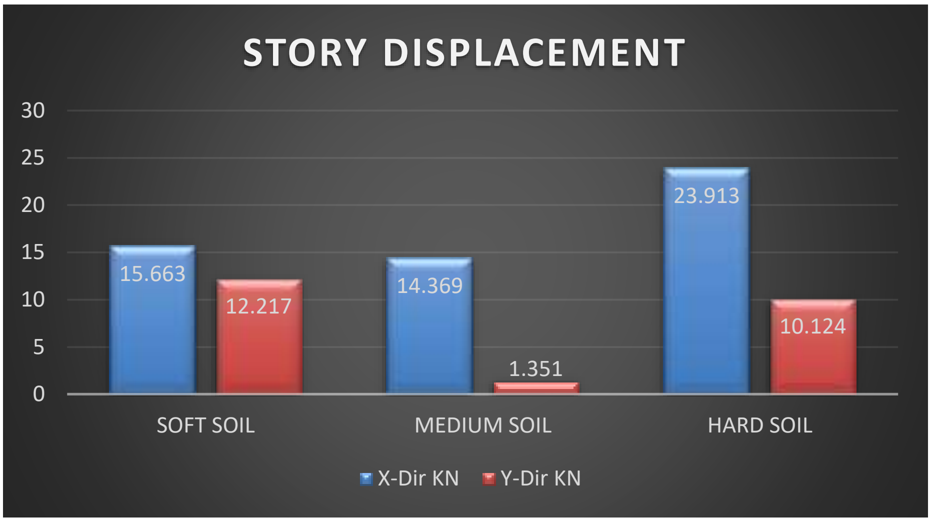
5.2 Auto Lateral Loads



Interpretation:

Hard soils transfer seismic forces more directly to the structure, resulting in the highest lateral forces. Softer soils absorb energy, reducing lateral forces.

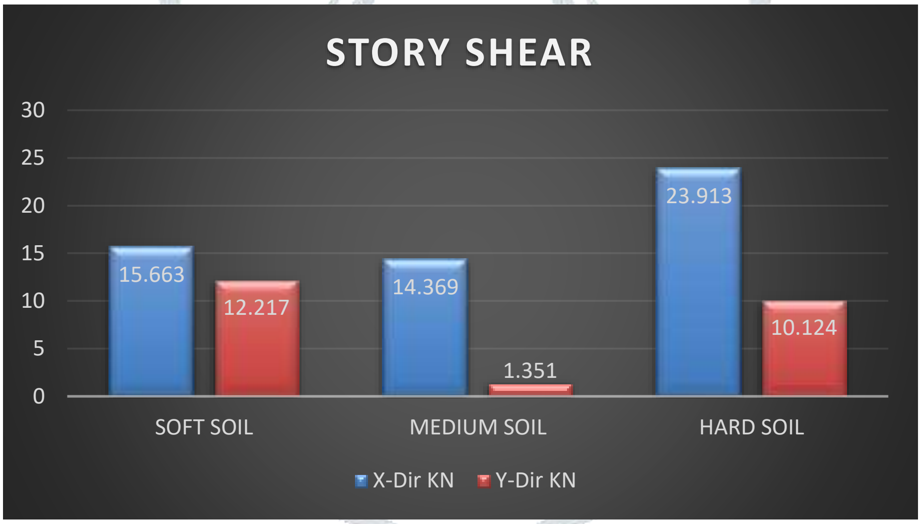
5.3 Story Displacement



Interpretation:

Stiffer soils (Hard Soil) produce higher forces and larger X-direction displacements, while medium soils provide a more stable lateral movement along Y.

5.4 STORY SHEAR



Interpretation:

Story shear distribution reflects soil stiffness effects: stiffer soils concentrate shear forces, while medium soils may redistribute or reduce directional shear.

Summary

1. **Lateral Loads:** Increase with soil stiffness; hard soil produces the highest X/Y forces.
2. **Displacement:** Hard soils show maximum X-displacement; medium soils control Y-displacement effectively.
3. **Story Shear:** Follows displacement trends; highest in hard soil, lowest in medium soil for Y-direction.

6. CONCLUSION

- **Soft Soil:**
  - Lowest base shear and story shear.
  - Moderate displacements.
  - Meets modal requirements but just above 90%.

- Not conservative for design.

- **Medium Soil:**
  - Balanced participation.
  - Reasonable displacements in X but suspiciously low in Y (model check needed).
  - Intermediate forces.

- **Hard Soil + Shear Wall:**
  - Highest base shear and story shear.
  - Higher displacement in X-direction.
  - Slightly lower modal participation in Y, but still >90%.
  - Conservative and safe for design — but requires **careful detailing of shear wall, foundation, and beams**.

The Hard Soil model with Shear Wall should be considered the governing case for design, since it produces the largest forces (base shear, story shear, base reactions) and meets modal mass participation requirements. Although displacements in X are higher, this represents a conservative and safe design scenario.

Conclusion Summary

From the analysis of auto lateral loads, story displacements, story shear, base reactions, and response reduction factors for Soft Soil, Medium Soil, and Hard Soil with a shear wall:

- Soft Soil gives the lowest base shear and story shear, with moderate displacements, but is not conservative for design.

- Medium Soil shows balanced mass participation, but unrealistic very low displacement in Y-direction indicates modelling irregularities.

- Hard Soil with Shear Wall produces the highest base shear, story shear, and base reactions, ensuring a conservative design. Modal participation remains above 90%, making the model acceptable though higher modes contribute more. The shear wall effectively strengthens the system but increases base reactions, requiring careful detailing of wall and foundation.

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