ASEAN Engineering
Journal

Full Paper

SEISMIC SAFETY EVALUATION AND SVD BASED REMEDY RECOMMENDATION OF EXISTING R.C.C RESIDENTIAL BUILDINGS IN SOUTH INDIA

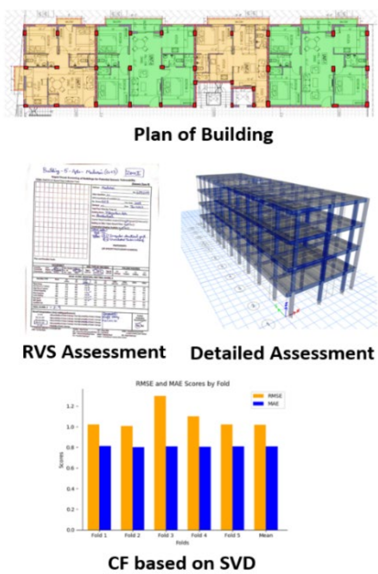
Shrinath B[a], Helen Santhi M[a*], Abinaya S[b], Avi Aaryan Jeet[b]

[a]School of Civil Engineering, Vellore Institute of Technology, Chennai,600127, Tamil Nadu, India
[b]School of Computer Science and Engineering, Vellore Institute of Technology, Chennai,600 127, Tamil Nadu, India

Article history
Received
15 February 2024
Received in revised form
24 July 2024
Accepted
31 August 2024
Published online
28 February 2025

*Corresponding author
helensanthi.m@vit.ac.in

Graphical abstract



Abstract

The project aims to enhance seismic safety in high-risk areas of Tamil Nadu, India, by conducting evaluations of 10 existing reinforced concrete buildings. The evaluation process starts with rapid visual screening, which is used to identify the buildings which require further evaluations. Buildings selected for further assessment are modelled in structural analysis software, ETABS to carry out seismic analysis using linear analysis methods such as equivalent static and response spectrum methods. The next step is to perform a non-linear time-history analysis to evaluate the behavior of buildings under low to moderate ground motions. Finally, deficiencies in the buildings are identified, and retrofitting techniques are suggested. A key innovation lies in the use of machine learning, specifically Singular Valued Decomposition (SVD) based Collaborative Filtering (CF) recommendation approach, to provide tailored retrofitting suggestions, enhancing the effectiveness of seismic safety interventions, which may include strengthening existing structural components, adding damping systems, or improving connections between different elements. The study results can guide similar buildings in the region, and retrofitting techniques can minimize property damage and save lives during future earthquakes. This project combines rapid visual screening, linear and non-linear analysis, machine learning and retrofitting suggestions to improve the seismic safety of buildings in high-risk areas in Tamil Nadu, India.

Keywords: Rapid Visual Screening (RVS), Linear and Nonlinear analysis, Retrofitting, Singular Valued Decomposition, Collaborative Filtering Recommendation.

1.0 INTRODUCTION

The seismic safety evaluation discussed in this project focuses on assessing the seismic vulnerability of existing Reinforced Cement Concrete (R.C.C) residential structures. Given the potential for earthquakes to cause substantial damage, evaluating existing buildings is crucial for occupant safety [1]. This evaluation entails analyzing structural components, assessing their ability to withstand seismic forces, identifying weaknesses, and recommending retrofitting or strengthening measures as necessary. Through this comprehensive assessment, we can enhance the seismic resilience of buildings, mitigate risks, and safeguard lives and properties during seismic events [13].

1.1 Earthquake

Earthquakes, primarily caused by the movement of tectonic plates, are natural phenomena that occur worldwide. They are most commonly found in three regions: the Alpide belt, the Circum-Pacific belt, and the Mid-Atlantic ridge [12]. These areas experience a high frequency of earthquakes due to ongoing tectonic activity beneath the Earth's surface. The interaction of massive plates, shifting and exerting pressure on one another, leads to the fracturing of the Earth's crust. This sudden release of accumulated energy results in the powerful shaking and vibrations associated with earthquakes. While volcanic eruptions, human activities, and fluid withdrawal can also trigger earthquakes, most occurrences can be attributed to plate tectonics [12].

In South India, earthquakes have had a significant impact on communities and infrastructure, demonstrating the devastating consequences of seismic events. While the region is not as frequently affected as other global seismic hotspots, it remains vulnerable to significant earthquakes. Southern India, previously considered part of a stable continental region, has experienced numerous minor earthquakes and 11 earthquakes with magnitudes greater than 6, challenging the perception of its aseismicity [16]. For instance, the 2001 Bhuj earthquake (magnitude 7.7) in Gujarat caused widespread destruction locally and sent shockwaves across South India, damaging buildings and infrastructure in Tamil Nadu and Karnataka. Historical records also highlight events such as the 1905 Kangra earthquake (magnitude 7.8), which resulted in extensive damage and loss of life across South India. The 2011 Sikkim earthquake (magnitude 6.9), though centered in Sikkim, was felt throughout India, causing damage in Tamil Nadu, Kerala, and Karnataka. These events underscore the urgent need for proactive measures to enhance seismic resilience, emphasizing rigorous seismic safety evaluations and retrofitting initiatives to mitigate future earthquake impacts.

Earthquakes are highly destructive, causing loss of life, injuries, and extensive damage to buildings and infrastructure. The built environment's vulnerability to seismic hazards necessitates proactive measures to ensure safety and resilience. Seismic retrofitting enhances the structural integrity of existing buildings, making them more resistant to seismic forces and preventing catastrophic collapses. Implementing rigorous seismic safety evaluations and upgrading building codes further reduces societal vulnerabilities. Proactive measures not only mitigate immediate impacts but also contribute to long-term community resilience, ensuring infrastructure remains functional and secure during and after seismic events. Swift aid provision is challenging due to the catastrophic impact, thus emphasizing preparedness and mitigation. In earthquake-prone areas, protective measures include designing flexible structures, educating the public on safety, conducting drills for officials, and enforcing stringent building codes. Risk mapping helps identify vulnerable areas and structures, facilitating retrofitting and repairs to enhance resilience. Seismic safety assessments evaluate potential risks, damage, and economic losses based on seismic hazards, aiding in prioritizing areas and structures needing attention [13,15]. By adopting these strategies, communities can reduce the impact of earthquakes and enhance their ability to withstand seismic events.

This project aims to contribute significantly by:

- Enhancing Seismic Resilience: By conducting detailed seismic analyses and suggesting retrofitting methods, the project directly contributes to improving the seismic performance of R.C.C residential buildings.
- Innovative Strengthening Techniques Recommendation: The recommendation approach using Singular Valued Decomposition offers innovative and tailored strengthening techniques, showcasing a novel contribution to seismic retrofitting strategies.

1.2 Seismic Safety Assessment

Seismic safety assessment is crucial for proactive risk mitigation and emergency preparedness. It identifies vulnerabilities in buildings and infrastructure, guiding retrofitting and strengthening efforts to enhance resilience. By evaluating potential risks and damages, these assessments help prioritize critical areas for intervention, ensuring safety and reducing economic losses. Implementing such measures prepares communities to better withstand and respond to earthquakes, minimizing impacts on lives and properties.

Seismic safety assessments have informed building codes, land-use planning, and infrastructure development in various real-world applications. In California, the Uniform Building Code incorporates stringent seismic design criteria based on detailed seismic assessments. In Japan, seismic zoning maps derived from safety assessments guide land-use planning, restricting development in high-risk areas. New Zealand's Christchurch rebuild after the 2011 earthquake relied on seismic assessments to enhance the resilience of new infrastructure. In India, the Bureau of Indian Standards (BIS) uses seismic assessments to update the Indian Seismic Code (IS 1893), ensuring buildings are designed to withstand earthquakes. Additionally, cities like Mumbai and Delhi have integrated seismic risk assessments into their urban planning to mitigate potential damage.

The combination of seismic hazard, exposure, and vulnerability assessments allows for estimating potential economic and human losses. By analyzing seismic activity, population density, and structural weaknesses, these assessments provide a comprehensive risk profile. Integrating these components helps prioritize mitigation efforts, ensuring resources are allocated effectively to reduce the impact of earthquakes, enhance preparedness, and protect lives and properties. The seismic safety assessment has been extensively employed by regulators, engineers, etc. [7,8], for:

- Mitigating earthquake damages.
- Detailing building codes and design levels for structures with seismic aspect.
- Evaluating and assessing the existing facilities for seismic activity.
- Planning and preparing for financial and societal emergencies.
- Prioritizing seismic risk mitigation measures.
- Insurance related assessment.

1.2.1 Simplified Assessment

Simplified seismic assessment methods involve preliminary evaluations of a building's seismic performance using color-based or score-based approaches. These methods provide initial insights into the building's vulnerability but have their strengths and limitations.

The color-based assessment is an initial seismic evaluation that includes visual inspections of the building's exterior, interior, and construction plans [2]. Buildings are assigned a color code—green, yellow, or red—to indicate their level of seismic safety. For example, a school building in a seismically active region might be inspected, with green indicating good condition, yellow suggesting moderate risk, and red highlighting significant vulnerability. This method is efficient and straightforward, allowing for quick identification of at-risk structures. However, it may lack the precision needed for a comprehensive assessment of seismic performance.

The score-based assessment, similar to the color-based method, involves visual inspections and a review of construction plans. Instead of a color code, a numerical score is assigned based on predetermined criteria to evaluate the building's seismic performance [8]. For instance, a hospital might receive a score reflecting its structural integrity, construction materials, and design features. This approach provides a more detailed assessment than the color-based method, but it requires additional time and resources. An example is the seismic evaluation of residential buildings in Istanbul, where detailed scoring helped prioritize retrofitting efforts.

1.2.2 Detailed Assessment

Detailed seismic assessment methods offer a more in-depth analysis using manual calculations and software-based tools. These methods consider dynamic behavior, load distribution, and material properties [1,7]. It provides a comprehensive understanding of the building's seismic behavior.

The manual calculation-based approach involves analyzing the building using simplified analytical methods like Linear Static or Dynamic Analysis (LSA or LDA) [2,11]. This approach might include testing or modeling to evaluate seismic performance under various earthquake scenarios [7]. For example, a historic building in San Francisco might undergo detailed manual calculations to determine its vulnerability and necessary retrofitting measures. While this method offers more accuracy than simplified assessments, it may not fully capture the building's complex behavior under seismic loading.

The software-based assessment is the most comprehensive and accurate method for evaluating a building's seismic performance. It involves modeling the building in structural analysis software such as ETABS, STAAD Pro, etc and using advanced analytical methods like Nonlinear Static or Dynamic Analysis (NSA/NDA) [5]. An example is the seismic evaluation of high-rise buildings in Tokyo, where software-based assessments provided detailed insights into the buildings' seismic behavior and informed retrofitting strategies. This method provides a thorough understanding of the building's response to seismic loading and offers specific recommendations for strengthening or upgrading the structure. However, it requires significant expertise and resources.

1.3 Objectives And Scope Of The Project

The specific outlining of the project's objectives and scope to conduct a comprehensive seismic safety evaluation to enhance the resilience of existing buildings, reduce the potential for loss of life and property damage during seismic events, and contribute to long-term disaster risk reduction efforts are mentioned below.

Objectives:

a. Assess structural integrity: Conduct preliminary evaluation (RVS) to find the vulnerable buildings and evaluate the ability of those buildings to withstand seismic forces by analysing the structural components, to identify potential weaknesses.

b. Recommend tailored retrofitting measures: Provide customized recommendations for retrofitting based on the specific vulnerabilities identified during the evaluation process, ensuring that each building receives appropriate and effective interventions.

c. Integrate innovative techniques for optimization: Incorporate advanced methodologies, including machine learning algorithms and Singular Valued Decomposition, to recommend the best technique based on user inputs and rating which enhances the overall effectiveness of seismic safety interventions.

Scope:

a. Visual screening and structural analysis: Conduct rapid visual screening followed by detailed structural analysis including linear and non-linear analysis using software tools to assess the seismic performance of buildings under various loading conditions.

b. Retrofitting recommendation and implementation guidance: Provide guidance on the implementation of recommended retrofitting measures, including best practices, while also disseminating findings and recommendations to relevant stakeholders to facilitate informed decision-making and promote resilience-building efforts.

1.4 Novel Approach Of Svd:

Novelty includes :

Data-Driven Insights: Is more likely to present the situation and, more specifically, seismic vulnerabilities based on the available data and using higher math tools.

Efficiency and Precision: Improves the efficacy of retrofitting recommendations by limiting consideration mostly on critical parts and their interconnections within the building's structural framework.

Scalability: It is an efficient solution as it can apply the changes on a large number of buildings at once to fit the urban planning scale or disasters management needs.

Integration with Modern Technologies: It can also be synchronized with other sophisticated technologies, for instance, machine learning algorithms and structural health monitoring systems which makes the overall risk of seismic activities to be reduced even further.

1.5 Research Gap And Need

The primary research gap in this project is the lack of comprehensive understanding and implementation of seismic resilience measures in regional construction practices. Despite existing guidelines and standards, many buildings, particularly in regions with moderate seismic activity like Tamil Nadu, may not fully adhere to these requirements. This gap is further worsened by insufficient data on the actual performance of different building types and designs under seismic loads. There is also a need for more robust and detailed methodologies for rapid and cost-effective seismic vulnerability assessments, as current practices may not be uniformly applied or thoroughly validated across various building categories.

To address the identified research gaps, there is a crucial need for more detailed and comprehensive seismic vulnerability assessments that can be widely adopted. This includes enhancing and validating rapid visual screening (RVS) methods, and employing advanced analytical tools such as ETABS for more precise evaluations. Innovative retrofitting strategies, like those utilizing Singular Value Decomposition (SVD), must be developed and implemented to improve the seismic resilience of existing buildings. Additionally, creating regional-specific guidelines tailored to local building practices, materials, and seismic hazards is essential. Comprehensive data collection and analysis of past seismic events and building performance in the region will inform future guidelines and construction practices. Furthermore, increasing awareness and training among engineers, builders, and stakeholders on the importance of seismic resilience and the adoption of best practices in construction and retrofitting is vital. These measures will significantly enhance the seismic safety and resilience of buildings, safeguarding lives and properties against future seismic events.

2.0 METHODOLOGY

The seismic analysis design project follows a systematic methodology, starting with literature collection and RVS methods for quick assessment of seismic vulnerability. Buildings are selected based on criteria, and detailed data collection is performed. Simplified and detailed assessments are conducted using various approaches. The overall methodology is explained further.

2.1 Overall Methodology

The seismic analysis design project follows a systematic methodology to ensure the accurate assessment of buildings' responses to seismic forces. Each step is crucial for achieving the project objectives. The first step involves collecting relevant literature, research papers, and technical resources to establish a solid foundation of knowledge, which is crucial for informed decision-making and identifying best practices in seismic safety assessment. This ensures the project is grounded in current research and technical standards as per the Indian Standard IS 1893:2016. The next step involves identifying methods for Rapid Visual Screening (RVS) of buildings. RVS is a visual inspection technique used to quickly evaluate the seismic vulnerability of structures, providing an efficient way to identify at-risk buildings without extensive resources. These methods typically involve visual observations of building components, such as structural elements, non-structural elements, and overall building performance, to assess their potential vulnerability to seismic hazards [2,10].

Following RVS, buildings are selected for analysis based on predetermined criteria such as building type, construction materials, height, and location. This selection ensures that the study focuses on a representative and relevant sample, essential for generalizing findings and making applicable recommendations. Detailed data collection is then carried out, encompassing architectural plans, structural drawings, and material specifications for the selected buildings. Gathering comprehensive data is vital for accurate modeling and analysis, ensuring the assessments are based on precise and detailed information.

The analysis proceeds with simplified assessment methods, including color-based [2] and score-based approaches [10], providing initial insights into the buildings' seismic performance [4]. These initial assessment methods offer quick, preliminary insights and help prioritize buildings for more detailed analysis, optimizing resource allocation. Subsequently, a more detailed assessment is conducted, employing manual calculations and software-based tools for a comprehensive analysis [5]. Conducting in-depth analyses with manual calculations and advanced software tools offers a thorough understanding of each building's seismic behavior, ensuring that detailed and accurate recommendations can be made for enhancing seismic resilience. This systematic approach, from initial screening to detailed analysis, enables effective identification of vulnerabilities and development of targeted retrofitting strategies, ultimately enhancing seismic resilience and safety. The entire sequence of steps is illustrated and presented in the accompanying flowchart in Figure 1.

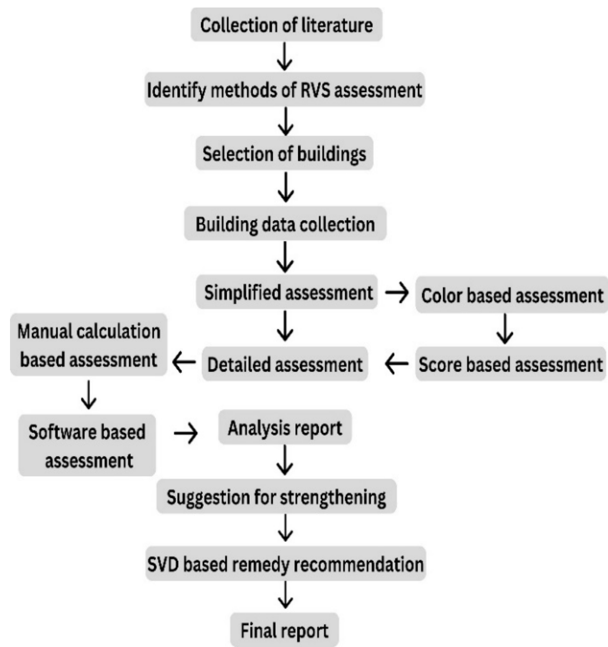


Figure 1 Methodology flowchart

2.2 Building Data Collected

The building data are collected for analysis based on predetermined criteria such as building type, construction materials, height, and location. The rationale behind selecting these specific buildings is to ensure a diverse and representative sample. The buildings are located in different areas of Tamil Nadu, encompassing two seismic zones: Zone III, which is more vulnerable to seismic activity, and Zone II. This geographic diversity allows the study to address varying levels of seismic risk. The buildings also vary in storey levels, generally up to five levels, which is common in residential buildings in the region. The sample includes different building types, such as villas and apartments, with a focus on apartments due to their prevalence in densely populated city areas. Additionally, the selected buildings range in age from 2 to 15 years, providing insights into how construction practices have evolved over time. This diversity ensures the study's findings are applicable to a wide range of structures. The buildings data collected for conducting seismic assessment is shown in Table 1.

Table 1 Building data collected

Building No.	Storey Level	Building Type	Seismic Zone	Location
1	G + 1	Villa	Zone III	Tiruvallur
2	G + 1	Villa	Zone III	Guduvancheri
3	G + 2	Apartment	Zone III	Chennai
4	G + 2	Apartment	Zone II	Madurai
5	G + 3	Apartment	Zone II	Madurai
6	G + 3	Apartment	Zone III	Ambattur
7	G + 3	Apartment	Zone III	Perambur
8	G + 5	Apartment	Zone II	Madurai
9	G + 5	Apartment	Zone III	Chennai
10	G + 5	Apartment	Zone III	Chennai

2.3 Building Details And Plans

The building details of the collected structures are presented below in Table 2 which includes essential information such as the grade of concrete, number of storeys, column and beam sizes, slab thickness, storey heights, and dimension details. The floor plans of the buildings are shown in Table 3.

2.4 Simplified Assessment: Rvs Of Selected Buildings

The assessment of selected buildings according to the procedure adopted in the study of literatures is done and results are noted. The assessment output gives the overall idea of the buildings under study to know their strength and weakness towards their safety against earthquakes.

The seismic assessment process involves several stages. Initially, data on the building's characteristics is reviewed, including occupancy, age, foundation type, and more [3]. Structural systems such as walls, roof, and foundation are visually inspected for distress signs [4]. Non-structural systems like mechanical and electrical systems are evaluated [10,15]. The seismic efficiency is assessed by comparing the building's condition to seismic performance standards. The results are compiled into a report containing the evaluation, retrofitting recommendations, and a summary of vulnerabilities. The results provide suggestions regarding whether further detailed seismic assessment is necessary for the building or not. A typical example of the assessment is shown in Figure 2 [10].

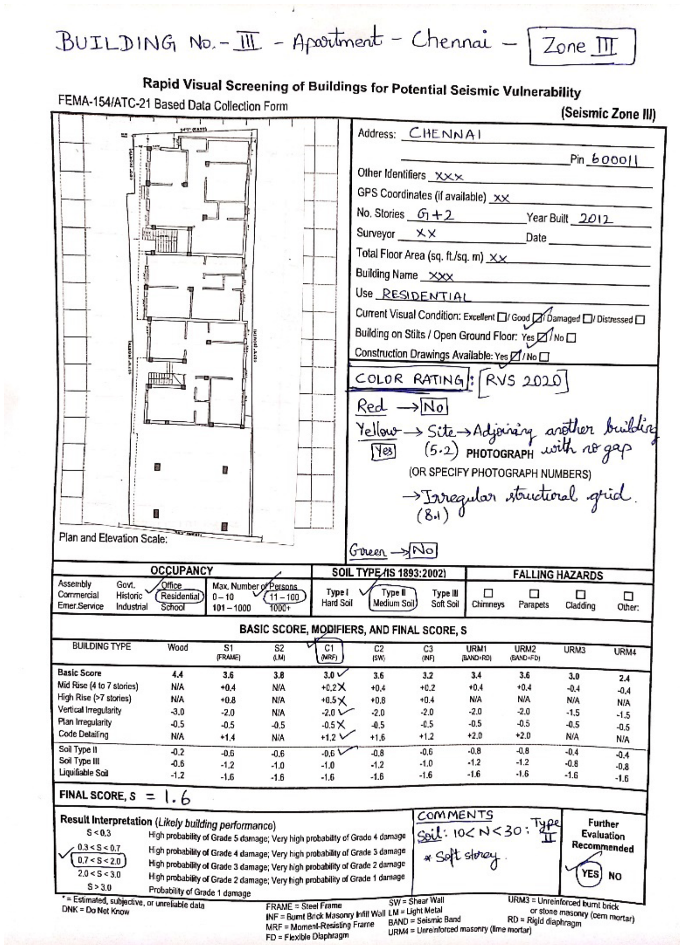
2.5 Modeling Of Building In Etabs Software

The modeling of buildings in ETABS software is an essential aspect of structural engineering and analysis [9]. It is a widely used software tool designed for accurate modeling and simulation of building structures. It enables precise modeling of building structures, facilitating accurate simulation of behavior under various loads and optimizing structural designs for safety and performance [9].

To model a building for seismic analysis in ETABS software, follow these steps: define the building's geometry with floor plans and elevations, assign material properties to structural elements, create an accurate structural model, specify boundary conditions and supports, apply various loads (including seismic), and analyse the model using ETABS' seismic analysis capabilities [5]. The beams and columns are modeled as frame elements and the slab is modeled as shell element. Rigid diaphragm is considered at each floor level and the base is fixed. The soil condition is taken as medium soil which matches with the soil available in all the building sites considered under study. The process evaluates the building's response to seismic forces, considering dynamic behaviour, load distribution, and material properties, ultimately assessing its overall seismic performance [5]. A typical example of modelling a building in ETABS software is shown in Figure 3 and Figure 4 shows a photo of a typical building under study.

Table 2 Building details

Building No.	1	2	3	4	5	6	7	8	9	10
Zone	III	III	III	II	II	III	III	II	III	III
No. of stories	G+1	G+1	G+2	G+2	G+3	G+3	G+3	G+5	G+5	G+5
Concrete grade	M 25	M 25	M 30	M 25	M 25	M 25	M 25	M 30	M 30	M 30
Steel grade	Fe 415	Fe 415	Fe 500	Fe 500	Fe 500	Fe 500	Fe 500	Fe 500	Fe 500	Fe 500
Dimension of beam (mm)	230x300	230x300	250x350	270x270	270x380	230x380	230x460	270x380	270x380	280x350
Dimension of column (mm)	230x300	230x230	250x350	270x270	270x380	230x380 ,230	230x460	270x380	270x380	280x350
Thickness of slab (mm)	115	110	125	127	127	127	127	127	127	127
Height of bottom storey (m)	3	3	3	3	3	3	4	3	3	3
Height of remaining storey (m)	3	3	3	3	3	3	3	3	3	3



BUILDING No.- III - Apartment - Chennai - Zone III

Rapid Visual Screening of Buildings for Potential Seismic Vulnerability

FEMA-154/ATC-21 Based Data Collection Form

(Seismic Zone III)

Plan and Elevation Scale:

Address: CHENNAI

Pin 600011

Other Identifiers xxx

GPS Coordinates (if available) xx

No. Stories G+2 Year Built 2012

Surveyor xx Date

Total Floor Area (sq. ft./sq. m) xx

Building Name xxx

Use RESIDENTIAL

Current Visual Condition: Excellent ☐ / Good ☑ / Damaged ☐ / Distressed ☐

Building on Stilts / Open Ground Floor: Yes ☑ / No ☐

Construction Drawings Available: Yes ☑ / No ☐

COLOR RATING: [RVS 2020]

Red → No

Yellow → Site → Adjoining another building with no gap (5.2)

Yes

PHOTOGRAPH

(OR SPECIFY PHOTOGRAPH NUMBERS)

→ Irregular structural grid (8.1)

Green → No

OCCUPANCY				SOIL TYPE (IS 1893:2002)			FALLING HAZARDS			
Assembly Commercial Emer.Service	Govt. Historic Industrial	Office (Residential) ✓ School	Max. Number of Persons 0 – 10 (11 – 100) ✓ 101 – 1000 1000+	Type I Hard Soil	(Type II Medium Soil) ✓	Type III Soft Soil	☐ Chimneys	☐ Parapets	☐ Cladding	☐ Other:

BASIC SCORE, MODIFIERS, AND FINAL SCORE, S

BUILDING TYPE	Wood	S1 (FRAME)	S2 (LM)	C1 (MRF) ✓	C2 (SW)	C3 (INF)	URM1 (BAND+RD)	URM2 (BAND+FD)	URM3	URM4
Basic Score	4.4	3.6	3.8	3.0 ✓	3.6	3.2	3.4	3.6	3.0	2.4
Mid Rise (4 to 7 stories)	N/A	+0.4	N/A	+0.2 ✗	+0.4	+0.2	+0.4	+0.4	-0.4	-0.4
High Rise (>7 stories)	N/A	+0.8	N/A	+0.5 ✗	+0.8	+0.4	N/A	N/A	N/A	N/A
Vertical Irregularity	-3.0	-2.0	N/A	-2.0 ✓	-2.0	-2.0	-2.0	-2.0	-1.5	-1.5
Plan Irregularity	-0.5	-0.5	-0.5	-0.5 ✗	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Code Detailing	N/A	+1.4	N/A	+1.2 ✓	+1.6	+1.2	+2.0	+2.0	N/A	N/A
Soil Type II	-0.2	-0.6	-0.6	-0.6 ✓	-0.8	-0.6	-0.8	-0.8	-0.4	-0.4
Soil Type III	-0.6	-1.2	-1.0	-1.0	-1.2	-1.0	-1.2	-1.2	-0.8	-0.8
Liquifiable Soil	-1.2	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6

FINAL SCORE, S = 1.6

Result Interpretation (*Likely building performance*)

S < 0.3	High probability of Grade 5 damage; Very high probability of Grade 4 damage
0.3 < S < 0.7	High probability of Grade 4 damage; Very high probability of Grade 3 damage
✓ (0.7 < S < 2.0)	High probability of Grade 3 damage; Very high probability of Grade 2 damage
2.0 < S < 3.0	High probability of Grade 2 damage; Very high probability of Grade 1 damage
S > 3.0	Probability of Grade 1 damage

COMMENTS

Soil: 10< N <30 : Type II

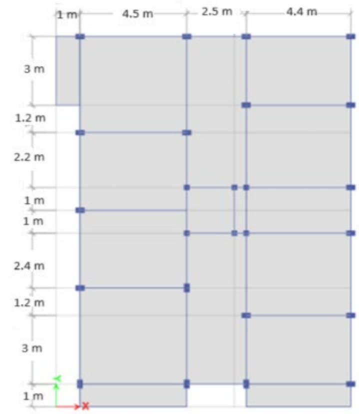
* Soft storey.

Further Evaluation Recommended: (YES) ✓ NO

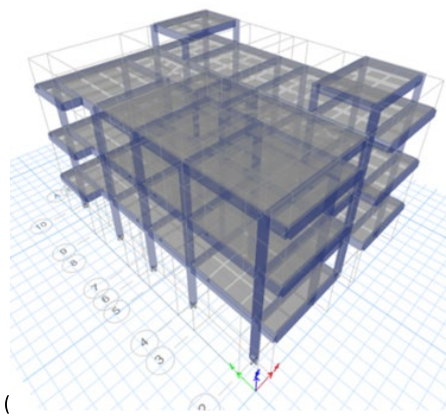
* = Estimated, subjective, or unreliable data
DNK = Do Not Know

FRAME = Steel Frame
INF = Burnt Brick Masonry Infill Wall
MRF = Moment-Resisting Frame
FD = Flexible Diaphragm
SW = Shear Wall
LM = Light Metal
BAND = Seismic Band
URM4 = Unreinforced masonry (lime mortar)
URM3 = Unreinforced burnt brick or stone masonry (cem mortar)
RD = Rigid diaphragm

Figure 2 A typical example of RVS of a building [10]



(a) Plan

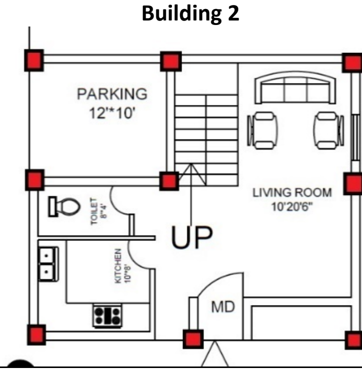
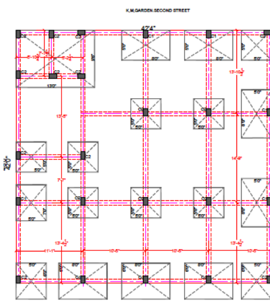
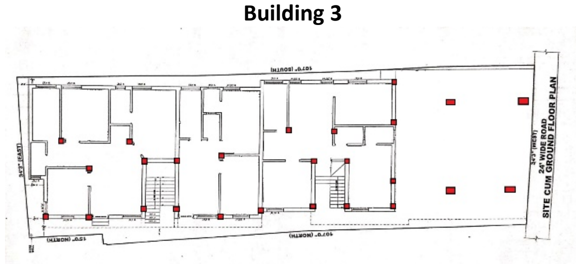
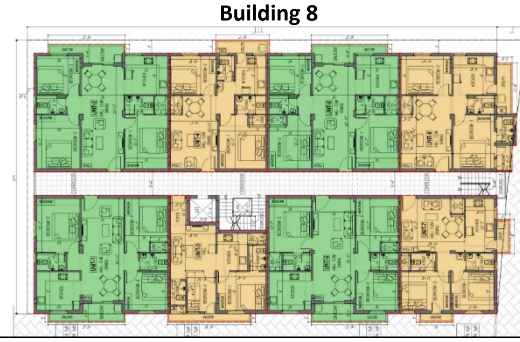
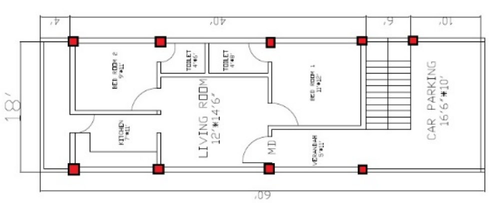
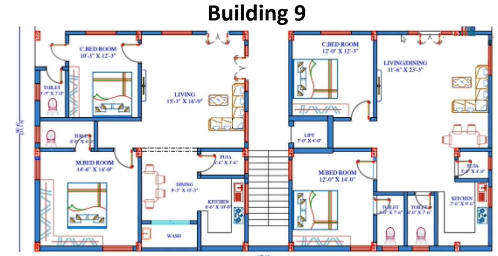
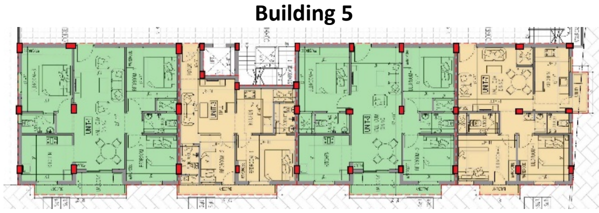
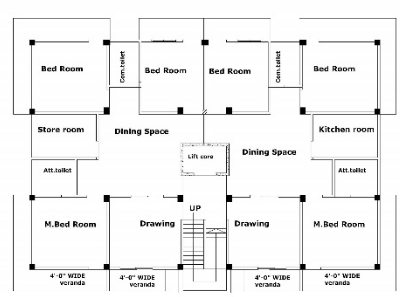


(b) 3 D View

Figure 3 Model of a typical Building in ETABS

Figure 4 Example building under study

Table 3 Building plan details

Building 1	Building 6
	
Building 2	**Building 7**
	
Building 3	**Building 8**
	
Building 4	**Building 9**
	
Building 5	**Building 10**
	

2.6 Detailed Assessment: Seismic Analysis Methods

The detailed assessment using ETABS software employed equivalent static analysis, response spectrum analysis, and time history analysis to evaluate seismic performance. All three methods are run in ETABS software to analyse the building models. Equivalent static analysis simplifies seismic forces into static loads, while response spectrum analysis examines structural response at various frequencies. Time history analysis simulates real earthquake events for detailed dynamic behavior. Modeling assumptions included fixed base conditions, rigid diaphragms, and linear material properties, ensuring realistic simulation of building response to seismic forces. Key input parameters included building geometry, material properties, load combinations, and seismic zone factors. Output results from ETABS analysis comprised modal properties (natural frequencies and mode shapes), structural response quantities (displacements, drifts, and overturning moments). These outputs provided a comprehensive understanding of the buildings' seismic behavior, informing necessary retrofitting measures. Understanding seismic response enhances resilience, reducing the impact of earthquakes on lives and the environment.

2.6.1 Equivalent Static Method

The equivalent static method in ETABS software simplifies seismic analysis by using a static load that simulates the effects of an earthquake [6]. It involves calculating the seismic base shear and distributing it across the height of the building based on its lateral stiffness. This method is computationally efficient and provides a conservative estimate of the structural response. It is suitable for regular and moderately irregular structures with low-to-moderate seismic hazards. It is often applied to low-rise buildings, simplifies calculations by assuming a uniform distribution of seismic forces but may lack accuracy for irregular structures. This method is straightforward, it may not capture complex behaviors.

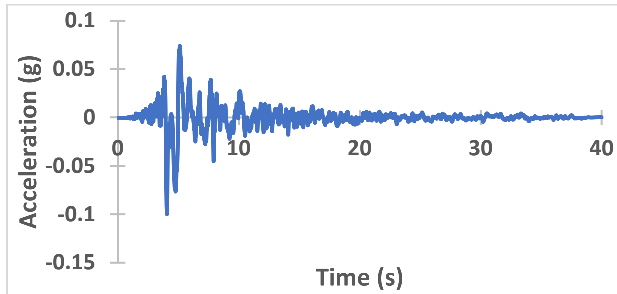
2.6.2 Response Spectrum Method

Response spectrum analysis is a commonly used method in structural engineering, including in ETABS software [9]. It allows engineers to evaluate the dynamic response of structures to seismic forces. By considering ground motion response spectra, which represent the maximum response of a structure to various frequencies of harmonic excitations, critical parameters such as displacements, accelerations, and inter-storey drifts can be determined. The response spectrum method, used in mid-rise buildings, evaluates how structures respond to different frequencies of ground motion, offering a more detailed assessment but requiring extensive data. This analysis method provides valuable insights into structural behavior under seismic loading, aiding in design and optimization for seismic resilience.

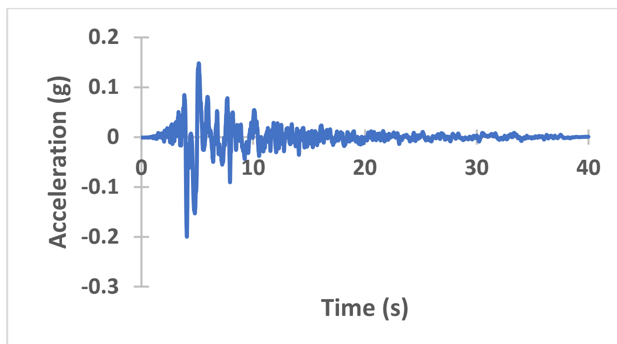
2.6.3 Time History Analysis

Time history analysis is a powerful technique in structural engineering for assessing a structure's dynamic response to actual recorded seismic or dynamic loading. This analysis, ideal for high-rise buildings and complex structures, simulates actual earthquake events to predict detailed structural behavior under dynamic loads, though it is computationally intensive. In ETABS software, it allows engineers to simulate time-varying forces and displacements experienced during earthquakes or other dynamic events. By inputting ground motion data, ETABS calculates structural responses such as displacements, accelerations, and inter-storey drifts. Time history analysis provides a comprehensive understanding of structural behavior under real-world conditions, aiding in design, assessment, and ensuring structural safety and performance.

The input for the time history analysis is the El Centro earthquake, which occurred in 1940. This earthquake data is considered for the project because its data is very similar to Indian earthquake data. El-Centro earthquake data is scaled for zone II and III using Seismosoft software (seismosoft. com) and are shown in Figure 5.



(a) Time History Data for Zone II



(b) Time History Data for Zone III

Figure 5 Earthquake Data for Time History Analysis

2.7 Strengthening Techniques Recommendation Phase

In this phase, the strengthening techniques as remedies to be suggested for different kinds of detected issues are maintained in a database as depicted in Table 4 and the feedback in the form of both rating and review for those corresponding remedial measures has been collected from the users accordingly. Recommendation systems based on SVD [17] are superior to other kinds in many ways. Because they can offer remedial measure to users who have rated relatively few. This is so even in cases where the user hasn't stated their preferences directly, SVD can find latent factors that support their preferences. To begin using SVD-based recommendation systems, one must first build a user_ID-remedy method matrix, in which each row denotes user rating and each column a remedial measure for solving the problem. The ratings that users have given different methods make up the matrix's elements. The user-remedy matrix is then split into its three components using SVD. In this method matrix is divided into three smaller matrices: a diagonal matrix of singular values, a right singular matrix, and a left singular matrix. Before recommending a method for a given issue, recommender systems can use SVD to predict an unknown method rating and then they can suggest best remedy based on the ratings as following the methodology given in Algorithm 1 (Section 2.7.1). Here, the ratings and reviews of the previous users are collected who faced same issue and then were recommended a remedy. Using the feedbacks from the user a recommendation system is created using SVD.

2.7.1 Algorithm for SVD Based Recommendation

Algorithm 1: Strengthening Techniques Recommendation using SVD.

Input: Rating matrix Xij composed of training dataset, where 'i' represents remedies (as rows) and 'j' represents user ID (as columns) and unique value of 'i' and 'j' represents rating given by a particular user and for a given method in the rating matrix.

Output: Recommendation matrix, a final matrix after applying SVD.

Method:

1. Utilizing SVD to decompose the Rating matrix Xij into U, ∑, V

1.1 The singular value decomposition-based recommendation system is represented in mathematical form as in eq. (1).

$$X_{ij} = U\sum VT = U\sum 1/2\ (V\sum 1/2)T \quad (1)$$

Where Σ represents Diagonal matrix, U, V represents orthogonal matrix, subsequently generated a j×k item feature matrix N=Y∑1/2 and i×k user feature matrix M=X∑1/2. k is the feature space dimension. The rows of matrix j and i are the item and user feature vectors correspondingly.

2. To reduce the matrix U, ∑, V, then get Uk, ∑k, Vk.

Where U, V is orthogonal matrix, Σ is Diagonal matrix and k is the dimension of feature space, as in eq. (2) and eq. (3).

$$V = (X_{ij})^* (X_{ij})T \quad (2)$$

$$U = (X_{ij})T * (X_{ij}) \quad (3)$$

3. Computing user feature matrix A=Uk∑1/2k and item feature matrix B=Vk∑1/2k where k is the dimension of feature space.

4. Then we get the Recommendation matrix, from which the system is able to recommend a remedy to the user.

2.7.3 Strengthening Techniques Recommendation

This introduction of the strengthening techniques recommendation phase by us introduces a novel aspect of the methodology, emphasizing the utilization of Singular Value Decomposition (SVD) for personalized retrofitting recommendations. This phase involves several key steps:

Building the User-Remedy Matrix:

- The remedies for different detected issues are maintained in a database.
- User feedback in the form of ratings and reviews for these remedial measures is collected.
- We construct a user_ID remedy method matrix is constructed where each row represents user ratings and each column represents a remedial measure. The matrix elements consist of the ratings given by users for different methods.

Singular Value Decomposition (SVD) Algorithm:

- The user-remedy matrix constructed from the dataset is decomposed into three smaller matrices using SVD: a diagonal matrix of singular values, a right singular matrix, and a left singular matrix.
- This decomposition helps us to identify latent factors that supports our user preferences, even for users who have rated relatively few items or haven't stated their preferences directly.

Implementing the SVD-Based Recommendation Algorithm:

- The recommendation system uses SVD to predict unknown method ratings.
- Recommendations are made based on the predicted ratings, following the methodology outlined in Algorithm 1.
- The feedback from previous users who faced similar issues and were recommended a remedy is used to improve the recommendation system.

Table 4 Sample data from database recommendation system

User ID	Issue	Remedies	User rating	Review by users
1	Weak beam	FRP wrapping	4	Very good smooth work
5	Adjoined buildings	Structural separations	4	Good separation from building
2	Weak beam	Steel plate bonding	3	Worth for money
11	Irregular structural grids	Structural truss system	3	Not satisfied
12	Adjoined buildings	Expansion joints	3	Didn't work well
3	Weak beam	FRP wrapping	3	Finishing of surface is good
3	Storey drifts	Strengthening of frame	3	Just ok

4	Mass irregularities	Mass dampers	4	Works well
4	Stilt storey	Steel bracing	4	Perfect
9	Narrow building	Shear walls	3	Its nice work
7	Crack	Structural stitching	3	Visually not good
5	Mass irregularities	Mass addition	3	Preplanning required
5	Irregular structural grids	RC shear walls	3	Good
13	Stilt storey	Steel bracing	4	Works well
6	Irregular structural grids	RC shear walls	3	Proper design engineer required
6	Crack	Crack injection	4	Easy and good work
7	Stilt storey	Base isolation	3	Costly job
8	Weak beam	Steel plate bonding	3	Surface is rusted after longer use
8	Narrow building	Shear walls	1	Not satisfied
1	Storey drifts	Damping devices	4	Best remedy for drifts
8	Storey drifts	Strengthening of frame	4	Works ok
9	Mass irregularities	Mass dampers	4	Good technology to reduce vibration
9	Torsional irregularities	Change floor layout	4	Floor design is ok
10	Mass irregularities	Mass addition	4	Nice idea
10	Stilt storey	Base isolation	3	Suitable for high rise building
4	Storey drifts	Damping devices	4	Perfect device
4	Torsional irregularities	Change floor layout	3	Floor design is not well planned
11	Weak columns	Concrete encasement	4	Good strength achieved
11	Crack	Crack injection	4	Cracks are not visible
11	Torsional irregularities	Diaphragm enhancement	3	Genuinely good
12	Weak columns	Concrete encasement	4	Good finish
12	Narrow building	Shear walls	3	Good strength achieved
13	Weak columns	Concrete encasement	3	Good
2	Irregular structural grids	Structural truss system	3	Poor idea and function
2	Torsional irregularities	Diaphragm enhancement	3	Good
14	Narrow building	Shear walls	4	Good work
15	Crack	Structural stitching	4	Cracks are joint well
15	Adjoined buildings	Structural separations	4	Worked well

3.0 RESULTS AND DISCUSSION

The results and discussion section of this project presents a comprehensive analysis of the seismic assessment conducted on the buildings under study. This section highlights the key findings and their implications in terms of the buildings' vulnerability to seismic forces. The initial step in the assessment process involved displaying the results of the Rapid Visual Screening (RVS) to determine if further detailed assessment was necessary for each building. Subsequently, the detailed assessment results using ETABS software were presented, encompassing key parameters such as total storey displacement, storey drifts, and torsional or mass irregularities. These comprehensive findings shed light on the seismic performance of the buildings.

3.1 RVS of Buildings

The RVS follows the guidelines in reference [2], while the detailed RVS follows those in reference [6]. The RVS methodology involves a preliminary visual inspection to assess the seismic vulnerability of buildings using criteria such as building type, construction materials, height, and age. Visual inspection parameters include evaluating structural components like beams, columns, and load-bearing walls, as well as non-structural components like facades, partition walls, and chimneys. These elements are assessed for potential weaknesses that could affect the building's performance under seismic loading. Limitations of RVS include its reliance on visual cues, which may overlook hidden vulnerabilities, and the subjective nature of evaluations, potentially leading to inconsistent results. To address these challenges, standardized checklists were used, and supplementary data from architectural plans and previous inspection records were incorporated to enhance the accuracy and reliability of the assessments. Any buildings that necessitate additional further assessment are identified based on their score obtained in the RVS. Buildings with a score above 3 are deemed safe, while those below 3 require further detailed evaluation. The screening results are shown in Table 5.

Table 5 Building RVS Results

Buildi-ng No.	Storey Level	Zonal Classifica-tion	RVS (Color-based)	RVS (Score-based)	Further Evaluation Required
1	G+1	Zone III	Yellow	2.7	Yes
2	G + 1	Zone III	Green	3.2	No
3	G + 2	Zone III	Yellow	1.6	Yes
4	G + 2	Zone II	Yellow	2.1	Yes
5	G + 3	Zone II	Yellow	2.9	Yes
6	G + 3	Zone III	Yellow	2.8	Yes
7	G + 3	Zone III	Yellow	2.7	Yes
8	G + 5	Zone II	Yellow	2.4	Yes
9	G + 5	Zone III	Yellow	2.7	Yes
10	G + 5	Zone III	Yellow	2.9	Yes

3.2 Storey Displacement

Storey displacement during a seismic event is the horizontal movement of top most floor relative to the building's base. It is critical to assess structural integrity and safety during earthquakes. As per IS 1893:2016, storey displacement limits vary based on seismic zone and structural system. In Zone II and III, it's generally 0.004 times the storey height, while in Zone IV and V, it is 0.0025 times the storey height. The storey displacement of the buildings is shown in Table 6.

Table 6 Storey Displacements of the Buildings

Build-ing No.	Buildin-g height (m)	Load case	Major global axis	Major displac ement (mm)	Max. allowed displaceme nt (mm)	Safe / Unsafe
1	6	Seismic	Y	4.29	24	Safe
2	6	Seismic	Y	9.29	24	Safe
3	9	Seismic	X	12.27	36	Safe
4	9	Seismic	X	5.26	36	Safe
5	12	Seismic	X	6.067	48	Safe
6	10.5	Seismic	Y	6.72	42	Safe
7	13	Seismic	X	7.94	52	Safe
8	18	Seismic	X	5.17	72	Safe
9	18	Seismic	Y	12.54	72	Safe
10	18	Seismic	Y	9.98	72	Safe

3.3 Storey Drift

During a seismic event, storey drift refers to the relative horizontal displacement or movement experienced by the different adjacent storeys of a building. As per IS 1893:2016, the storey drift ratio is 0.004 for Zone II and III. The storey displacement of the buildings is shown in Table 7.

Table 7 Storey Drift of the Buildings

Building No.	Building height (m)	Load case	Major drift global axis	Max storey drift	Safe / Unsafe
1	6	Seismic	Y	0.000766	Safe
2	6	Seismic	Y	0.001604	Safe
3	9	Seismic	X	0.018	Unsafe
4	9	Seismic	X	0.0007	Safe
5	12	Seismic	X	0.000685	Safe
6	10.5	Seismic	Y	0.000816	Safe
7	13	Seismic	X	0.00082	Safe
8	18	Seismic	X	0.000566	Safe
9	18	Seismic	Y	0.000897	Safe
10	18	Seismic	Y	0.000822	Safe

In analysing trends from the results shown in Table 6 and Table 7, low-rise buildings generally exhibit lower displacement and drift compared to medium-rise buildings due to their lower center of gravity and stiffer structural components. Medium-rise buildings may show larger displacement at higher storeys due to increased flexibility. Buildings in higher seismic zones (Zone III) typically display greater displacements and drifts than those in lower zones (Zone II), reflecting the higher seismic demands in these areas.

The software runs both analysis equivalent static and response spectrum to arrive the displacement and drift values. Exceeding allowable limits in storey displacements and drifts indicates potential structural and non-structural damage. Excessive displacements can lead to structural failure, while high drifts can damage elements like walls and windows, compromising the building's integrity and safety. Variations in response are influenced by factors such as building height, structural system, material properties, and foundation conditions. High-rise buildings and those in higher seismic zones often require more robust design considerations and retrofitting strategies to meet safety standards. Understanding these results helps engineers identify critical areas needing reinforcement, ensuring buildings can effectively withstand seismic events.

3.4 Check For Torsion

The methodology for assessing torsional irregularities in buildings involves evaluating modal masses and identifying potential torsional effects using dynamic analysis techniques. Criteria include analyzing the distribution of mass and stiffness in the structure to detect imbalances that cause torsional motion. After modeling the building in ETABS, the analysis is run and the results are examined. To prevent torsion, it is crucial for modal masses to exceed 40% in both x and y directions for the first and second modes diagonally. If this requirement is not met, it indicates the presence of torsion. Torsional irregularities can significantly impact a building's overall stability and structural integrity, leading to uneven stress distribution and potential failure during seismic events. Mitigation measures, such as reinforcing structural elements and ensuring a more balanced mass distribution, adding shear walls or modifying the staircase can mitigate torsional effects and ensure structural stability. The torsion check results for the buildings are presented in Table 8.

Table 8 Torsional Irregularity Check

Building No.	Direction	Torsion check Modal Mass (kg) Mode 1	Mode 2	Safe/ Not safe
1	u_x	1.63	76.59	Safe
	u_y	87.41	2.79	
2	u_x	0.01	88.28	Safe
	u_y	89.56	0.02	
3	u_x	76.26	7.20	Safe
	u_y	5.6	64.2	
4	u_x	82.28	0	Safe
	u_y	0	86.23	
5	u_x	3.04	48.08	Safe
	u_y	70.06	13.37	
6	u_x	0.45	51.44	Safe
	u_y	87.62	1.24	
7	u_x	82.89	5.70	Safe
	u_y	1.3	69.46	
8	u_x	0.02	24.74	Not Safe
	u_y	83.3	0.14	
9	u_x	0.001677	4.48	Not safe
	u_y	82.78	0.76	
10	u_x	78.18	0.0001914	Safe
	u_y	0.03	99.82	

3.5 Major Issues Found In Buildings

Seismic issues in buildings refer to various structural and design vulnerabilities that can compromise the safety and stability of a structure during an earthquake. The issues which are majorly found in the buildings are shown by shaded region in Table 9. Identifying and addressing these seismic issues is crucial to ensure the resilience and integrity of buildings in earthquake-prone areas [12,14]. By implementing proper seismic analysis, design, and construction practices, structures can be better equipped to withstand the forces generated by seismic events and minimize the potential risks to human life and property.

Table 9 Major Issues Found in Buildings

S. No	Issues	Building number 1	2	3	4	5	6	7	8	9	10
1	Weak beams						■	■			■
2	Weak columns		■				■		■	■	
3	Mass irregularities	■				■			■		
4	Stilt storey			■		■		■	■	■	■
5	Irregular structural grids	■		■		■	■		■		
6	Narrow building			■	■	■					
7	More storey drifts or displacement		■	■						■	■
8	Cracks			■		■		■	■		■
9	Torsional irregularities								■	■	
10	Adjoining with adjacent building			■							

Weak beams and columns reduce a building's load-bearing capacity, making them susceptible to collapse during seismic events. These weaknesses often result from poor design, inadequate materials, or deterioration over time. Mass irregularities occur when there's uneven weight distribution across the building, causing imbalanced loads that amplify seismic forces, potentially leading to partial or total structural failure. A stilt storey, commonly used for parking, lacks the lateral strength of other floors, making it particularly vulnerable during earthquakes. This structural weakness can cause the entire building to collapse if the stilt columns fail. Irregular structural grids and narrow buildings result in uneven stress distribution, increasing the likelihood of localized damage and overall instability. Excessive storey drifts or displacements indicate that a building is moving too much during seismic activity, which can lead to significant structural and non-structural damage, such as cracks in walls and deformation of frames. Cracks, whether pre-existing or caused by seismic forces, can severely compromise a building's integrity, making it more susceptible to further damage and collapse. Torsional irregularities, caused by asymmetrical layouts, lead to uneven twisting and stress distribution across the building, increasing the risk of structural failure. Buildings that are too close to each other can transfer seismic forces during an earthquake, exacerbating damage if they collide. Proper separation and reinforcement are essential to mitigate this risk. Addressing these issues through improved design, retrofitting, and regular maintenance is crucial for enhancing seismic resilience and safety.

3.6 Strengthening Techniques for The Buildings

To resolve and make the defected R.C.C residential buildings to be earthquake resistant, several features can be introduced to enhance its structural integrity and mitigate the effects of seismic forces [12,14]. The corresponding earthquake-resistant features for the issues are shown in Table 10.

3.7 Experimental Results of SVD Recommendation Phase

The three variables issue, user ID and rating are considered to forecast user ratings. Statistical accuracy metrics are used as it is the most popular evaluation criteria for prediction accuracy to determine the overall efficacy. Statistical accuracy metrics, such as MAE and RMSE, are used in this method to assess the correctness of the system through evaluating the recommendations values against the real user values for the user-item relations in the data set being tested.

Table 10 Strengthening Techniques

S. No	Issues	Strengthening techniques
1	Weak beams	• **Fibre Reinforced Polymer (FRP) Wrapping:** Applying FRP sheets or strips to enhance the load-carrying capacity and stiffness of weak beams. • **Steel Plate Bonding:** Affixing steel plates, increase the flexural strength of weak beams.
2	Weak columns	• **Concrete Encasement**: Applying additional layers of reinforced concrete around weak columns to increase their strength and ductility. • **Steel Bracing**: Installing steel braces or frames to provide lateral support and improve the overall stability and strength of weak columns.
3	Mass irregularity	• **Tuned Mass Dampers (TMD):** Installing TMD systems, consisting of additional masses and dampers, to mitigate the dynamic response and control vibrations. • **Supplementary Mass Addition:** Adding supplementary masses strategically to the structure to counteract the effects of mass irregularities and improve overall structural performance.
4	Stilt storey	• **Base Isolation:** This system that physically decouples the superstructure from the foundation, reducing the transfer of seismic forces and protecting the silt storeys from excessive shaking. • **Steel Bracing:** Incorporating steel bracing elements, such as diagonal braces or cross-bracing systems, to enhance the lateral stiffness and strength of the ground floor, increasing its resistance to seismic forces.
5	Irregular structural grids	• **Structural Truss Systems:** Installing structural truss systems within the irregular grid to enhance its load-bearing capacity and provide additional stiffness, ensuring better distribution of loads and reducing the impact of irregularities. • **Reinforced Concrete Shear Walls:** Strategic placement of reinforced concrete shear walls within the irregular grid to enhance resistance to lateral forces, provide additional stiffness and stability, & minimize the impact of irregularities on the structural behavior.
6	Narrow building	• **Shear Walls:** Incorporating reinforced concrete or steel shear walls along the length of the narrow building to provide lateral resistance and enhance its overall stiffness, reducing sway and improving structural integrity.
7	More storey drift or disp.	• **Supplementary Damping Devices:** Incorporating supplemental damping devices such as viscous dampers or tuned mass dampers to absorb and dissipate energy, reducing the storey drift or displacement during seismic events. • **Structural Strengthening of Weak Elements:** Strengthening weak elements such as columns, beams, and connections to improve their load-carrying capacity and enhance the overall stiffness of the structure, thereby reducing drifts or displacements.
8	Cracks	• **Crack Injection:** Injecting epoxy or polyurethane resins into the cracks to fill and seal them, restoring the structural integrity & preventing further propagation of the cracks. • **Structural Stitching:** Drilling holes on both sides of the crack and inserting steel rods or plates with epoxy adhesive to reinforce the cracked section and prevent further crack propagation.
9	Torsional irregularity	• **Structural Diaphragm Enhancement:** Strengthening the building's floor and roof diaphragms to improve their rigidity and enhance their ability to transmit torsional forces, minimizing the torsional irregularities in the structure. • **Reconfiguration of Building Layout:** Reconfiguring the building layout to reduce torsional irregularities, such as optimizing the positioning of cores, walls, or structural elements to improve the overall symmetry and distribution of forces within the structure.
10	Adjoining with adjacent building	• **Expansion Joints:** Incorporating expansion joints between the adjoining buildings to accommodate differential movement and minimize the transfer of forces between the structures. • **Structural Separation:** Creating structural separation between the buildings by introducing a physical gap or isolating elements to limit the transfer of forces and minimize the potential for damage propagation during seismic events.

Mean Absolute Error (MAE) is a measure of errors between paired observations expressing the same phenomenon. It is calculated as the average of the absolute differences between the predicted values and the actual values. It is utilized to determine the average of all absolute value differences between the rating that the algorithm predicts and the actual rating. Accuracy increases with a reduced MAE. The highest error, or Infinity, is represented by the rating scale of the assessed application and can generally range from 0 to Infinity. The following is the MAE formula as in eq. (4).

$$A = \frac{1}{y}\sum_{x=1}^{y}|m_a - n_a| \tag{4}$$

Where, A is MAE, m_a is the actual rating, n_a is the predicted rating, y is the amount of ratings.

Root Mean Square Error (RMSE) is another measure of the differences between predicted values and observed values. It is calculated as the square root of the average of the squared differences between the predicted and actual values. In this we calculate the average of the squared differences between the predicted ratings and the actual ratings. It then takes the square root of this average. RMSE is particularly useful when large errors are undesirable. The formula for RMSE is as in eq. (5).

$$R = \sqrt{\frac{1}{y}\sum_{x=1}^{y}(m_a - n_a)^2} \tag{5}$$

Where, R is RMSE, m_a is the actual rating, n_a is the predicted rating, y is the amount of ratings.

Both MAE and RMSE are commonly used metrics for evaluating the accuracy of regression models. MAE is easier to interpret as it represents the average error, while RMSE provides a measure of error that heavily penalizes large mistakes. RMSE is more sensitive to large errors compared to MAE because it squares the error before averaging. This means that larger errors will have a disproportionately large effect on RMSE, making it useful when you want to penalize larger errors more significantly.

Cross-validation is a technique for evaluating the performance of a statistical model by dividing a dataset into multiple subsets and using them to train and test the model [18]. It involves splitting the dataset into 't' equally sized partitions, where 't' is a specified number. These partitions are divided into divisions for training and testing, with one of them defined being the test partition. The model is trained using the training partitions, and its performance is then evaluated on the test partition. This process is repeated until each partition has served as the test partition. Cross-validation allows for a more accurate assessment of a model's performance by providing multiple opportunities to test the model on different subsets of the data.

Singular Value Decomposition (SVD) based Collaborative Filtering (CF) is utilized in this remedy recommendation phase and evaluated its performance [19,20]. The experiment involved cross-validation, where the training data was used to train the model and the test set was used to compute the Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE). The results, presented in Figure 6, indicate that the SVD-based CF achieved an average RMSE of 1.04 and an average MAE of 0.80 in accurate recommendation of remedial measure for the predicted issues.

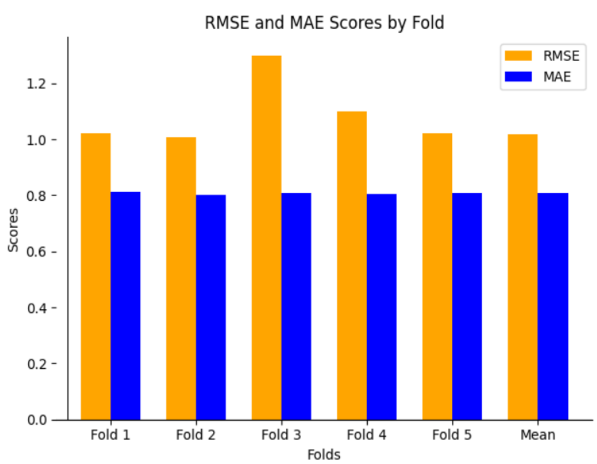


Figure 6 Result of CF based on SVD

Analysis of Accuracy and Reliability

Accuracy Analysis:

- RMSE and MAE Performance: The SVD-based recommendation system demonstrated strong performance in both RMSE and MAE metrics. Lower values in these metrics indicate high accuracy in the predictions, with RMSE being particularly useful in highlighting larger errors.

Reliability Insights:

Factors Influencing Performance:

- **Data Sparsity:** The density of the dataset plays a crucial role in the performance of the SVD-based system. Sparse datasets can lead to overfitting, whereas denser datasets provide more robust training.
- **Feature Engineering:** The choice and quality of features used in the decomposition significantly impact the system's accuracy. Including relevant structural parameters and historical performance data enhances the model's predictive power.
- **Hyperparameter Tuning:** Adjusting the number of singular values retained (kk) and other hyperparameters can optimize the balance between model complexity and performance.

Potential Areas for Improvement:

- **Enhanced Data Collection:** It suggests increasing the volume and variety of data collected i.e., improved, improvements include more detailed sensor readings and additional historical seismic performance data, can improve model accuracy.
- **Regularization Techniques:** it suggests implementing regularization methods that can reduce overfitting, particularly in sparse datasets by penalizing excessive complexity in our proposed model.
- **Hybrid Models:** it suggests the combination of SVD with other recommendation techniques, such as collaborative filtering or neural networks, could further enhance performance by capturing different aspects of the data.

4.0 CONCLUSION

The seismic survey results offer valuable insights into the construction boundaries of a specific area on a large scale. This information is beneficial for future construction projects to ensure adherence to appropriate construction methods. The study helps identify common mistakes or errors in construction, whether intentional or unintentional, leading to improved building practices and avoiding previous pitfalls. Seismic analysis plays a critical role in assessing the structural integrity and safety of buildings during earthquakes. Techniques like equivalent static, response spectrum, and time history analysis aid engineers in evaluating a building's response to seismic forces and overall performance. Factors such as inter-storey drifts, storey displacements, and modal mass participation are considered to assess the adequacy of the structure's design and implement necessary adjustments or retrofitting measures to enhance its seismic resistance. Compliance with relevant codes and standards, such as the Indian Standard Code IS 1893:2016, ensures that buildings meet permissible limits for various parameters.

In this project, an extensive review of literature on the seismic analysis of R.C.C residential buildings are conducted, accompanied by the collection and documentation of building data. Suitable RVS assessment methods are chosen for each building, commencing with color-based assessment and progressing to a score-based evaluation. Subsequently, buildings are subjected to further assessment, involving modelling in ETABS software and conducting two linear seismic analyses, equivalent static analysis, and response spectrum analysis, followed by non-linear time history analysis. The results are tabulated, allowing for the assessment of the risk of failure during seismic events. Identified structural issues are documented, and corresponding seismic strengthening methods are proposed. Later on, a sample review from users of suggested strengthening methods is then created. Through the Singular Value Decomposition technique, suggestions are derived based on collaborative filtering of the collected review data. In conclusion, the seismic analysis project enables the creation of resilient buildings capable of withstanding seismic events and safeguarding human life and infrastructure.

The seismic survey results reveal significant vulnerabilities in regional construction practices, highlighting critical areas for improving seismic resilience. These insights can guide future projects towards enhanced building practices that prioritize structural integrity and safety against seismic hazards. Addressing weaknesses like weak beams, columns, mass irregularities, and torsional effects will help the industry adopt robust designs, leading to safer, more resilient buildings. The study emphasizes the urgent need to address structural issues to mitigate failure risks during seismic events. Identifying weak points like stilt storeys, irregular structural grids, and excessive storey drifts provides a basis for targeted retrofitting. Implementing proposed strengthening techniques, such as reinforcing critical components and improving mass distribution, can significantly enhance seismic performance, reducing the likelihood of catastrophic collapse and ensuring better protection for occupants.

Equivalent static, response spectrum, and time history analysis effectively assess buildings' seismic responses, providing detailed insights into weaknesses and dynamic behavior under seismic loads. These techniques facilitate precise recommendations for retrofitting and design improvements. In summary, simplified seismic assessments are efficient for quick initial evaluations but may lack precision, while detailed assessments provide comprehensive insights but require more time and resources. Combining both methods can optimize seismic safety evaluations, ensuring buildings are adequately assessed and retrofitted to withstand seismic events. Compliance with relevant codes and standards, particularly the Indian Standard Code IS 1893:2016, is crucial for ensuring buildings' seismic resilience. Adhering to these guidelines helps mitigate risks associated with seismic activity, promoting safer construction practices and protecting lives and properties in earthquake-prone areas.

Acknowledgement

We would like to express our sincere gratitude for the technical assistance received from colleagues and the resources provided by the institution.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

Author Contribution

The authors confirm contribution to the paper as follows: study conception and design: Shrinath B, Helen Santhi M, Abinaya S, Avi Aaryan Jeet; data collection: Shrinath B, Avi Aaryan Jeet; analysis and interpretation of results: Helen Santhi M, Shrinath B, Abinaya S; draft manuscript preparation: Shrinath B, Helen Santhi M, Abinaya S, Avi Aaryan Jeet. All authors reviewed the results and approved the final version of the manuscript.

References

[1] Bektas et al., 2022. Conventional RVS Methods for Seismic Risk Assessment for Estimating the Current Situation of Existing Buildings: A State-of-the-Art Review, *Sustainability. 14(5): 2583*. DOI: https://doi.org/10.3390/su14052583

[2] Kumar et al., 2020. A Primer on Rapid Visual Screening (RVS) Consolidating Earthquake Safety Assessment Efforts in India, Technical Report. DOI: 10.13140/RG.2.2.35546.21442

[3] Lakshmi Prabha, 2020. Seismic evaluation of existing RCC buildings, Method, DOI: 10.13140/RG.2.2.11820.49281

[4] Harirchian et al., 2020. Earthquake Safety Assessment of Buildings Through Rapid Visual Screening, *Buildings* 10(3): *51,* DOI: https://doi.org/10.3390/buildings10030051

[5] Kamasani, et al., 2019. Seismic Analysis of High-Rise Buildings (G+30) by Using ETABS, *International Journal of Technical Innovation in Modern Engineering and Science*, 5(3): 14600-14614, https://www.ijirset.com/upload/2017/july/287_ANALYSIS_RK.pdf

[6] Naik, et al., 2017. Performance evaluation of 9 storey RC building located in North Goa, *Procedia Engineering* 173: 1841 – 1846, DOI: https://doi.org/10.1016/j.proeng.2016.12.231

[7] Arya A. S. et al., 2014. Rapid Visual Screening of RCC Buildings, *Earthquake Spectra 26(3)*: 709-729. DOI: https://doi.org/10.1193/1.3456711

[8] Gandhi et al., 2014. Literature Review on Rapid Visual Survey and Seismic Vulnerability, *Journal of The Institution of Engineers (India) Series A 94(3):*187-197, DOI: https://doi.org/10.1007/s40030-013-0048-5

[9] Kai Hua et al, 2012. Study on High-rise Structure with Oblique Columns by ETABS, SAP2000, MIDAS/GEN and SATWE, *Procedia Engineering 31:* 474 – 480. DOI: https://doi:10.1016/j.proeng.2012.01.1054

[10] Sinha et al., 2004. A National Policy for Seismic Vulnerability Assessment of Buildings and Procedure for Rapid Visual Screening of Buildings for Potential Seismic Vulnerability, *In Report to Disaster Management Division; Ministry of Home Affairs, Government of India: New Delhi, India.* https://www.civil.iitb.ac.in/~rsinha/Vulnerability_Assessment.pdf

[11] Chaimahawan et al, 2007. Simple Seismic Evaluation Methodology for Gravity-Designed Reinforced Concrete Building, *Research and Development Journal. 18(1): 32-42,* https://www.thaiscience.info /Journals/Article/R%26DT/10897174.pdf

[12] Murty C. V. R., 2005. IITK - Earthquake Tips - Learning Earthquake Design and Construction, *IIT Kanpur, In report to Ministry of Urban Development & Poverty Alleviation, India*

[13] Rai D. C., 2005. Review of Documents on Seismic Evaluation of Existing Buildings, *IIT Kanpur-GSDMA-EQ03-V1.0,* https://www.iitk.ac.in/nicee/IITK-GSDMA/EQ03.pdf

[14] Rai D. C., 2004. Seismic Evaluation and Strengthening of Existing Buildings, *IIT Kanpur-GSDMA-EQ24-V2.0* https://www.iitk.ac.in/nicee/IITK-GSDMA/EQ06.pdf

[15] FEMA Washington D.C., 2002. FEMA 154 - Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook, *Prepared for Federal Emergency Management Agency, Washington, D.C.*https://www.fema.gov/sites/default/files/2020-07/fema_earthquakes_rapid-visual-screening-of-buildings-for-potential-seismic-hazards-a-handbook-third-edition-fema-p-154.pdf

[16] Ramalingeswara Rao B 2000. Historical Seismicity and deformation rates in the Indian Peninsular Shield, *Journal of Seismology 4: 247–258* DOI: https://doi:10.1023/A:1009863312431

[17] Chen, H., Sheng, S., Xu, C. Y., Li, Z., Zhang, W., Wang, S., & Guo, S. 2021. A spatiotemporal estimation method for hourly rainfall based on F-SVD in the recommender system, *Environmental Modelling & Software. 144 (2): 1-11,* DOI: https://doi.org/10.1016/j.envsoft.2021.105148

[18] Abinaya, S., & Kumar, K. U. 2024. Enhancing Multicriteria-Based Recommendations by Alleviating Scalability and Sparsity Issues Using Collaborative Denoising Autoencoder. *Computers, Materials & Continua*. 78(2): DOI: https://doi.org/10.32604/cmc.2024.047167

[19] Abinaya, S., & Ramya, R. 2024. Enhancement in Context-Aware Recommender Systems–A Systematic Review. In 2024 Second International Conference on Emerging Trends in Information Technology and Engineering (ICETITE) 1-13. IEEE. DOI: 10.1109/ic-ETITE58242.2024.10493725

[20] Abinaya, S., Alphonse, A. S., Abirami, S., & Kavithadevi, M. K. 2023. Enhancing context-aware recommendation using trust-based contextual attentive autoencoder. *Neural Processing Letters,* 55(5): 6843-6864. DOI: https://doi.org/10.21203/rs.3.rs-1813771/v1

Appendix

Step By Step Implementation Of Algorithm:

The tables below represent the steps we would follow to solve the user-remedy using SVD and find it's missing values(represented as 0 in the matrix) so that we can recommend best two remedies for the users.

Table i User-remedy matrix

6.944	7.316	6.944	1.116	1.116
1.14	-0.19	1.14	-6.555	-6.555
0.52	-1.04	0.52	0.117	0.117

	Remedy 1	Remedy 2	Remedy 3	Remedy 4	Remedy 5
User 1	1	1	1	0	0
User 2	3	3	3	0	0
User 3	4	4	4	0	0
User 4	5	5	5	0	0
User 5	0	2	0	4	4
User 6	0	0	0	5	5
User 7	0	1	0	2	2

Table ii U matrix

0.13	0.02	-0.01
0.41	0.07	-0.03
0.55	0.09	-0.04
0.68	0.11	-0.05
0.15	-0.59	0.65
0.07	-0.73	-0.67
0.07	-0.29	0.32

Table iii VT matrix

0.56	0.59	0.56	0.09	0.09
0.12	-0.02	0.12	-0.69	-0.69
0.40	-0.80	0.40	0.09	0.09

Table iv ∑ Matrix

12.4	0	0
0	9.5	0
0	0	1.3

Table v Reconstructed matrix

1. $B=\sum * V^T$:
2. Final resultant matrix U*B:

0.92032	0.95768	0.92032	0.01281	0.01281
2.91124	3.01746	2.91124	-0.0048	-0.0048
3.90100	4.04830	3.90100	0.01917	0.01917
4.82132	5.00598	4.82132	0.03198	0.03198
0.70700	0.53350	0.70700	4.11090	4.11090
-0.69452	1.34762	-0.69452	4.78488	4.78488
0.32188	0.23442	0.32188	2.01651	2.01651

From the above matrix the best two remedies for each user are:

1. User 1: Remedy 2 (0.95768) and Remedy 1 (0.92032)
2. User 2: Remedy 2 (3.01746) and Remedy 1 (2.91124)
3. User 3: Remedy 2 (4.04830) and Remedy 1 (3.90100)
4. User 4: Remedy 2 (5.00598) and Remedy 1 (4.82132)
5. User 5: Remedy 4 (4.11090) and Remedy 5 (4.11090)
6. User 6: Remedy 4 (4.78488) and Remedy 5 (4.78488)
7. User 7: Remedy 4 (2.01651) and Remedy 5 (2.01651)