

Investigating Seismic Vulnerability in Buildings with Plan Irregularities

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Abstract:

This study aims to investigate the seismic behaviour of structures with vertical irregularities. The project employs Response Spectrum Analysis (RSA) to assess a vertically irregular reinforced concrete (RC) building. The investigation encompasses the modelling of both a regular and an H-shaped plan irregular building, excluding the ground floor, resulting in a G+7 storey structure. The seismic response of the framed building under consideration during simulated earthquake motions is influenced by the distribution of stiffness, strength, and mass in both horizontal and vertical planes. The primary objective of this research is to conduct a study of the structure's stiffness by examining Regular Structure and Plan Irregular Structure, each with different vertical irregularities. The entire set of building frames is modeled and analysed using Staad.Pro V8i software, and various seismic responses such as base shear, frequency, and node displacement are obtained.

1. Introduction

Previous earthquake incidents have demonstrated that structures featuring uncomplicated and consistent configurations tend to experience lower levels of damage. Conversely, buildings characterized by discontinuities face the concentration of forces and deformations at these points, potentially resulting in the failure of members at the junction and, ultimately, the collapse of the entire structure. The analytical approach used to quantify earthquake forces and assess their impact depends on factors such as the structure's significance and cost. Consequently, the method of structural analysis ranges from linear to nonlinear, adapting to the specific demands of the

situation. Addressing disasters has traditionally fallen within the purview of management experts, government, and semi-government agencies, with engineers primarily engaged in retrofitting and strengthening structures post-disaster. However, the escalating frequency of disasters globally has prompted a shift in focus, leading to increased awareness among engineers, architects, and the general public. This awareness has given rise to various mitigation and prevention strategies.

While international codes now encompass a broader spectrum of disasters, the existing literature predominantly delves into individual aspects of each calamity. Guidelines for earthquake analysis and design have become more standardized, but there is a notable absence of a universal protocol for other disasters like wind, fire, or flood. The challenge lies in handling the

intricate dynamics of real-time forces generated by these disasters.

Proprietary software, while widely used, offers limited flexibility to incorporate specific aspects of disastrous forces. Furthermore, these software solutions often require substantial modeling efforts, and the assurance of a robust model representing real-life scenarios can be challenging. Nonlinear static analyses using a finite element program reveal that setback significantly impacts building performance. Seismic fragility is most evident from setback levels 1 to 4, with notable differences in damage probabilities. For a 50% setback, the probability of damage increases by 12.19%, 30.85%, 37.03%, and 41.16% for slight, moderate, severe, and complete damage states, respectively. Structures with a setback on the fourth floor exhibit poor seismic performance, indicating a high probability of damage [1]. Examines a nine-story reinforced concrete building in Bucharest, designed as a dual system (wall-frame). It assesses plan regularity according to three codes (Eurocode 8, ASCE 7-16, and Romanian seismic design code). Nonlinear static and dynamic analyses reveal seismic behavior, emphasizing the impact of overall torsion on parameters like interstory drifts and vulnerability index [2]. The N2 method, proposed [3] and incorporated into Eurocode 8, is a key nonlinear static approach in the literature. Past studies indicate the reliability of nonlinear static analysis when a building's seismic response is mainly influenced by a single mode of vibration. This holds true for symmetric low-rise structures [4] or those with substantial torsional stiffness [5].

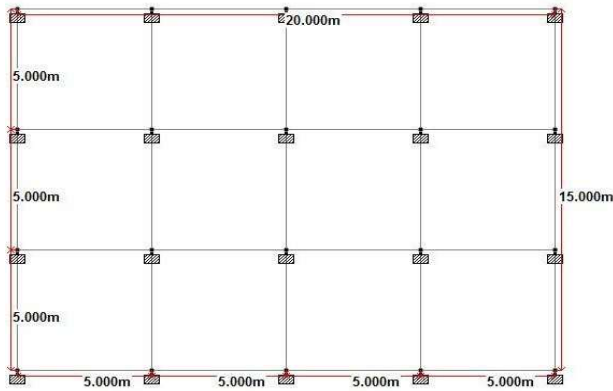
Study conducted rapid visual screening to assess seismic vulnerability of 500 buildings in Northern and Eastern George Town, Malaysia. Modified FEMA-154 (2002) method is applied using data from online sources like Google Maps. Results indicate an immediate need for seismic mitigation, with 90% of buildings requiring detailed analysis. Most buildings are predicted to

experience moderate-to-substantial damage. The study's findings are shared with the public through a GIS map, "RVS Malaysian Form-George Town Area," generated using ArcGIS [6]. It examines two types of irregularities—plan irregularity with geometric and diaphragm discontinuity and vertical irregularity with setback and sloping ground. These irregularities follow IS 1893 (part1)2002 code. The paper uses analytical approaches to assess seismic demands in both linear and nonlinear methods, considering three lateral load patterns in pushover analysis [7]. Both literature and software fall short in providing engineers with a mechanism to address their customized needs or to study the effects in a post-processor beyond tabulated or two-dimensional graphical outputs. Additionally, there has been a notable absence of attempts to mirror outputs in a virtual environment that accurately reflects the actual behaviour of buildings in real-life situations. This emphasizes the need for a more comprehensive and adaptable approach to disaster management in the realm of structural engineering. The primary objective of this study is to ascertain the seismic capacity of reinforced concrete framed buildings, differentiating between those with regular plans (rectangular) and those with irregular plans following the guidelines outlined in IS 1893-2002. Specifically, the irregular plans include configurations such as L, U, T, and H shapes. This evaluation will be conducted through the utilization of Response Spectrum Analysis, a method that enables a comprehensive understanding of the structures' response to seismic forces, thereby contributing to a more robust understanding of their seismic resilience and performance.

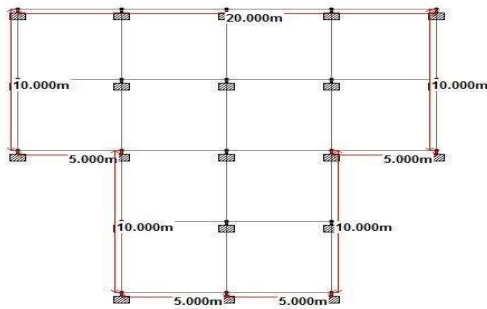
2. METHODOLOGY

The present study is concerned with analysing seismic behaviour of Regular and Irregular buildings. In the

present study two methods namely Equivalent static method and Response spectrum method are used to study the seismic response of irregular buildings using STAAD.Pro software. The geometry in plan is in figure 1 while the figure 2 is representing the elevation of regular shape model in elevation.



Building with regular plan shape



Building with T plan shape

Figure:1 Building with various Plan shape

3. RESULTS AND DISCUSSIONS

Procedure of Analysis building using Staad.Pro

Step 1: Choose type of structure, name the file then file location and unit, Select the type of structure. The type of structure used in this research is 3D building frame. A title can be put for the file. Make sure that the length unit is in meter and the force unit in kilo Newton. Click Next. Make sure the Add Beam is checked. Click Finish.

Step 2: Modelling the geometry of building Click on the Geometry tab. Set the coordinate system in X-Y

plane. Click on Beam tab. Insert the required coordinates in the Nodes table. From the top menu bar of Geometry, choose add beam command to add member between required nodes. Continue the process until obtaining a required building elevation. Go to the Geometry command and choose Translational Repeat command to get a 3-D building shape.

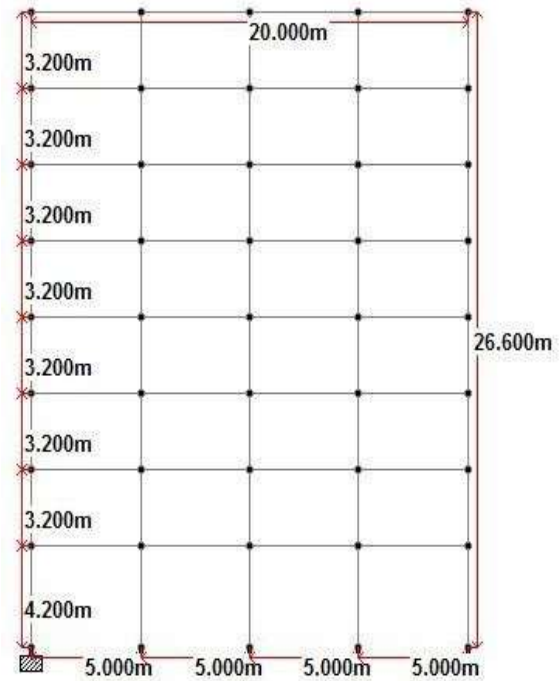
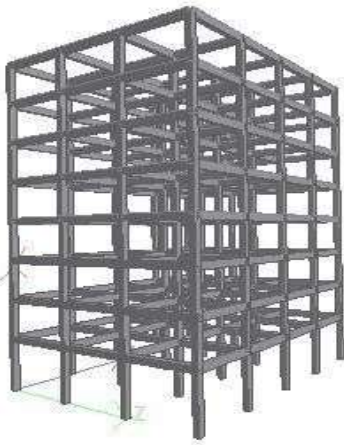


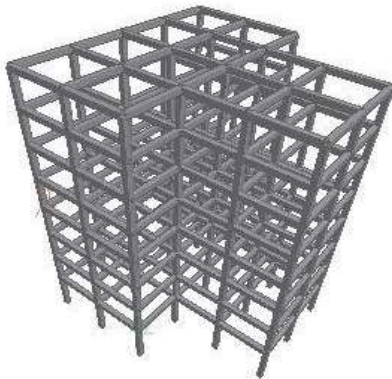
Figure:2 Building in Elevation

Step 3: Assigning section properties and material Choose the General tab and choose the property option. Choose the Define command in dialog box of Property and select material as concrete and type of section as square and insert cross-section dimension as 0.4×0.4m. In the table of property, highlight the section selected and choose Assign to View option.

Step 4: Assigning supports In the General tab choose the support option. In the dialog box of support click on Create option. Choose the Fixed support and Add. Highlight the required support in the Support dialog box and choose Assign to Selected Nodes, click Assign. Click on nodes where required to add support



. Building with regular plan shape

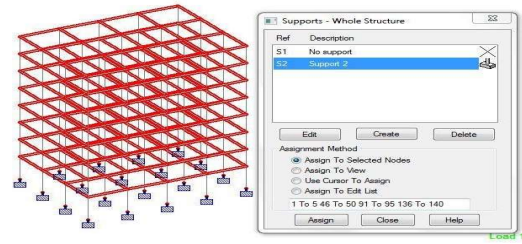


Building with T plan shape

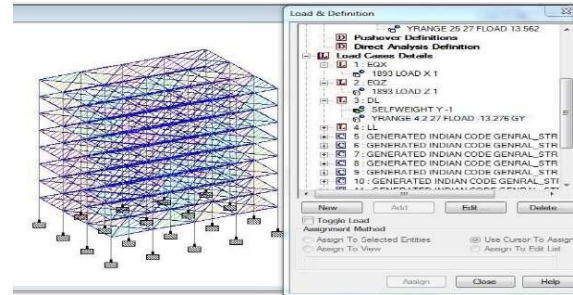
Figure:3 Building in 3D view in STAAD Pro

Step 5: Assigning loadings Still in the General tab choose Load & Definition option. Click on seismic definition and enter the values of zone factor, response reduction factor, importance factor, type of soil, type of structure and damping ratio. Still in seismic definition, enter the values of dead load and live load at different floor levels. Create new primary load case; give the title of load (Seismic Load, Deal Load and Live Load

respectively). Enter the values of seismic Load, deal Load and live Load and different floor levels. For load combinations select Define Combinations in Load Case Details command. Enter the values of factors for different loads as per IS specifications.



Dead Load to the Building Model



Load Cases to the Building Model

Figure:4 Load Case in STAAD Pro

Analysis of models using STAAD.Pro

1: Analyzing building models Click the Analysis/Print tab, Select Perform Analysis option. Choose No Print. Click Add. Select Post Print option and click on Define Commands. A dialog box will appear from which select Joint Displacement option, Member Forces option, Support Reaction option, Mode Shapes, Storey Drift and Analysis Result option and add all of them. In the top menu bar of Analyze, choose Run Analysis. Click Run Analysis for STAAD Analysis.

Step 2: View results of analysis To view the output results, choose view output file option. Click on Results option and view results by selecting Eigen solution, Mass Participation Factors, Analysis Results for various parameters.

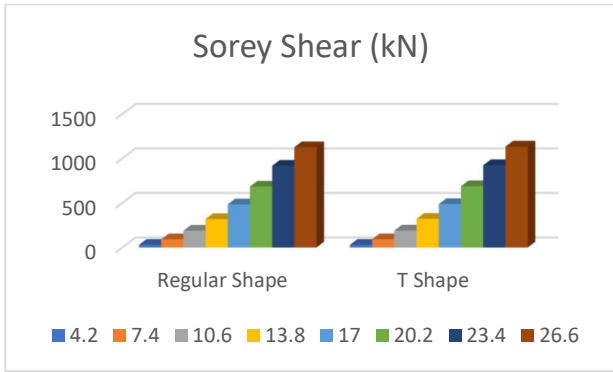


Figure:5 Story Shear with height for Regular and T shape model

Table:1 Observation for the regular shape model

Height (m)	Max Drift X(cm)	Max Drift Z(cm)	Avg. Dis. X(cm)	Avg. Dis. Z(cm)
4.2	5.159	5.1602	5.159	5.1602
7.4	3.7234	3.7286	8.8824	8.8895
10.6	3.5902	3.5997	12.4726	12.4891
13.8	3.4341	3.4772	15.9067	15.9363
17	3.1511	3.1671	19.0578	19.1034
20.2	2.7074	2.7257	21.7652	21.8292
23.4	2.0737	2.0939	23.8389	23.9231
26.6	1.257	1.2751	25.0959	25.1982

Table:2 Observation for the T shape model

Height (m)	Max Drift X(cm)	Max Drift Z(cm)	Avg. Dis. X(cm)	Avg. Dis. Z(cm)
4.2	5.3013	5.4082	5.3013	5.4082
7.4	3.7607	3.9275	9.662	9.3358
10.6	3.6177	3.7909	12.6797	13.1266
13.8	3.4548	3.6296	16.1345	16.7563
17	3.1645	3.3339	19.2989	20.0902
20.2	2.7124	2.8683	22.0113	22.9586
23.4	2.0682	2.2019	24.0796	25.1604
26.6	1.2381	1.3347	25.1377	26.5051

Figure 3 illustrates the 3D representation of the building in STAAD Pro for both models, while Figure 4 showcases the consideration of dead load and various load cases in the building model's analysis using STAAD Pro. The storey shear (in kN) is depicted in Figure 5 for both the regular and "T" shape models, revealing an increase in storey

shear with the building's height. Table 1 provides an overview of observations made during the analysis of the tall building model with a regular-shaped high-rise structure. Additionally, Table 2 presents various data related to the analysis of the "T" shape building model in STAAD Pro, including maximum drift in X and Z directions, as well as average displacement in X and Z directions concerning the building's height.

4. CONCLUSION

In the present paper an analytical investigation of both regular and irregular shaped building is carried out using response spectrum method.

It is performed on the building model G+7 storey of different shapes to study and identify the seismic behaviour of the building.

- With increasing irregularities in a building, the base shear decreases while displacement remains constant compared to a regular building.
- In this analysis, it is observed that if the height and plan area of a building remain constant, the maximum displacement of the building is influenced by the building's orientation and the percentage of irregularity in its shape.

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