DYNAMIC RESPONSE ANALYSIS OF IRREGULAR REINFORCED CONCRETE BUILDINGS WITH ETABS

Kota Naveen Varma[1], D. Jagadeesh[2], A. Nagaraju[3]
[1]*PG Scholar, Vardhaman College of Engineering,* Narkhuda, Nagarguda - Shamshabad Rd, Kacharam, Telangana 501218, *Naveenvarma2208@gmail.com*
[2, 3]Assistant Professor, Vardhaman College of Engineering
Email: jagadeeshdharma6@gmail.com, Email: nagarajuavari@gmail.com

ABSTRACT
The analysis and design of buildings for static forces has become a routine task due to the widespread availability of affordable computers and specialized software programs capable of performing such analysis efficiently. In contrast, dynamic analysis remains a more complex and time-consuming process, requiring additional input such as the mass distribution of the structure, along with a thorough understanding of structural dynamics to accurately interpret the analytical results. Reinforced concrete (RC) frame buildings are the most common type of construction in urban India, and these structures are subjected to various forces during their service life, including static forces from dead and live loads, as well as dynamic forces caused by wind and earthquakes. During seismic events, structural failure typically initiates at points of weakness, which often arise due to discontinuities in mass, stiffness, or geometry. Structures exhibiting such discontinuities are classified as irregular buildings, and they represent a significant portion of the urban infrastructure. Among various types of irregularities, vertical irregularities are a major cause of structural failures during earthquakes, as they significantly alter the seismic performance of buildings. Variations in stiffness and mass along the height of a building change its dynamic characteristics compared to a regular structure, leading to amplified responses under earthquake loading. These irregularities may result from non-uniform distribution of mass, strength, and stiffness throughout the height of the structure. The analysis of such buildings can be effectively conducted using structural analysis software like STAAD Pro, ETABS, SAP2000, and Tekla, among which ETABS is particularly popular across the country due to its powerful capabilities and user-friendly interface. The reliability of ETABS has been validated through reference studies, where its results were compared against benchmark data in terms of storey overturning moments, storey drifts, storey displacements, and storey shear, demonstrating its accuracy in the seismic analysis of vertically irregular RC frame structures.

Keyword: Dynamic Analysis Reinforced Concrete (RC) Buildings, Irregular Structures

I. INTRODUCTION

The dynamic response of buildings during seismic events is a critical aspect of structural engineering, particularly for irregular reinforced concrete (RC) structures. Irregularities in plan and elevation—such as setbacks, soft stories, torsional asymmetry, or discontinuities in mass and stiffness—can significantly amplify seismic demands, leading to unexpected performance during earthquakes. Accurate assessment of such responses is essential for ensuring safety, serviceability, and compliance with modern seismic design codes.

ETABS (Extended Three-dimensional Analysis of Building Systems), a widely used finite element-based structural analysis software, offers powerful tools for the dynamic evaluation of multi-story buildings. It facilitates detailed modeling of material properties, geometric irregularities, and load patterns while enabling various dynamic analysis techniques such as response spectrum and time history analysis.

This study focuses on the dynamic response analysis of irregular RC buildings using ETABS to investigate how different types and degrees of irregularities influence seismic performance. The analysis aims to highlight critical structural behaviors, such as inter-story drift, base shear, and modal characteristics, and to provide insights for more resilient design strategies in seismically active regions.

II. METHODOLOGY

The methodology adopted for the dynamic response analysis of irregular reinforced concrete buildings using ETABS involves several systematic stages. These include the selection of building models, identification of irregularities, structural modeling, dynamic analysis, and interpretation of results. The overall workflow is detailed below:

1. Selection of Building Models

A set of RC buildings with varying degrees and types of irregularities are selected for the study. These typically include:

- **Regular Building** (for comparison)
- **Plan Irregular Building** (e.g., L-shaped or T-shaped plan)
- **Vertical Irregular Building** (e.g., soft story or mass irregularity)
- **Torsionally Irregular Building**

Each building model is designed as a multi-story frame, conforming to general construction practices and relevant design codes (such as IS 1893, ACI 318, or Eurocode 8, depending on location).

2. Definition of Irregularities

The irregularities are introduced based on code definitions (e.g., IS 1893:2016 or FEMA 356), which include:

- **Plan Irregularities:** Re-entrant corners, diaphragm discontinuities
- **Vertical Irregularities:** Setbacks, soft stories, stiffness and mass irregularities
- **Torsional Irregularities:** Asymmetric stiffness and mass distribution

3. Structural Modeling in ETABS

Each building is modeled in ETABS using the following procedure:

- **Geometry Definition:** Accurate input of plan dimensions, story heights, and irregular features.
- **Material Properties:** Assignment of concrete and steel properties as per standards.
- **Section Properties:** Columns, beams, and slab sections are defined using standard sizes.
- **Load Application:** Dead loads, live loads, and seismic loads as per building code provisions.
- **Boundary Conditions:** Fixed supports or appropriate base conditions are assigned.
- **Meshing and Diaphragm Modeling:** Appropriate meshing is used for slabs; rigid or semi-rigid diaphragms are modeled as needed.

4. Dynamic Analysis Techniques

Two primary dynamic analysis methods are performed:

- **Modal Analysis:** To determine the natural frequencies and mode shapes.
- **Response Spectrum Analysis:** To evaluate the building response under seismic loading using a design response spectrum.
- *(Optional)* **Time History Analysis:** If specific earthquake records are used for detailed time-domain simulation.

5. Output Parameters and Evaluation

The results obtained from ETABS are used to evaluate key response parameters:

- Natural frequencies and mode shapes
- Base shear and its distribution
- Inter-story drifts and story displacements

- Torsional behavior and center of mass/stiffness shifts
- Comparison of regular vs. irregular building responses

6. Validation and Code Comparison

Results are checked against code-prescribed limits (e.g., drift limits, torsional irregularity indices) to assess the structural performance and compliance.

III. LITERATURE REVIEW

1. Seismic Performance of Irregular Structures

Irregularities in building geometry or mass distribution can lead to concentration of forces and unexpected failure mechanisms during earthquakes. According to Chopra (2012), buildings with vertical or plan irregularities exhibit complex dynamic behavior due to changes in stiffness, mass, and damping properties across the height and plan of the structure. Torsional irregularities, in particular, can result in excessive displacement and stress concentrations.

Paulay and Priestley (1992) emphasized that vertical irregularities such as soft stories and setbacks significantly affect base shear distribution and inter-story drift. They concluded that these irregularities often lead to early failure or collapse if not properly addressed in design.

2. Use of ETABS in Seismic Analysis

ETABS is a robust structural analysis software widely used for the seismic analysis of high-rise and mid-rise RC structures. The software allows engineers to model complex geometry and perform both linear and nonlinear dynamic analysis with relative ease.

Patil and Sangle (2015) used ETABS to study the seismic response of vertically irregular buildings and reported that buildings with soft stories experienced significantly larger drifts and base shear forces compared to regular configurations. Their study confirmed the importance of modeling such irregularities in the analysis phase for accurate performance prediction.

Kumar et al. (2018) performed response spectrum analysis of G+10 RC frames with plan irregularities using ETABS. The study concluded that plan irregularity causes eccentric loading paths, increasing torsional responses and uneven lateral displacement.

3. Codal Guidelines and Irregularities

Design codes such as IS 1893:2016 (India), ASCE 7 (USA), and Eurocode 8 provide detailed classifications and recommendations for dealing with structural irregularities. These codes define limits for mass, stiffness, and geometry variations and emphasize the need for dynamic analysis in irregular structures.

Research by Agrawal and Shrikhande (2006) shows that compliance with seismic codes reduces the risk of catastrophic failure in irregular buildings. They suggest that response spectrum analysis or time-history analysis must be used for irregular buildings, where static methods may not be sufficient.

4. Comparative Studies

Several researchers have conducted comparative studies on regular and irregular structures to highlight the effects of irregularity:

- **Rao and Murty (2001):** Found that irregular buildings have higher mode coupling and demand more accurate analysis methods.

4.1 Defining the material properties in ETABS

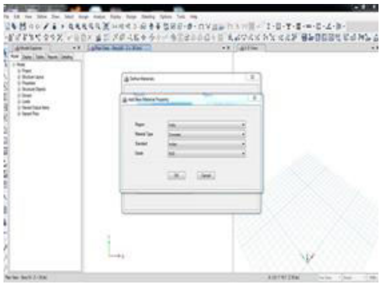
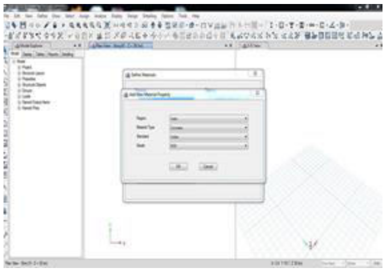


Fig 5: Concrete details in ETABS software



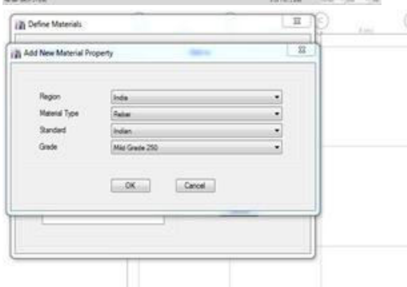
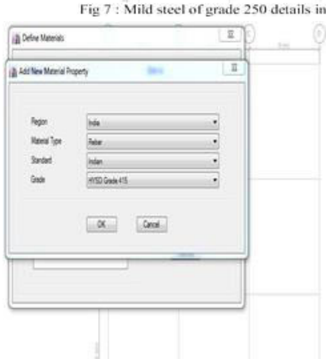


Fig 7 : Mild steel of grade 250 details in ETABS



4.2 Load Details

4.1.2 HYSD Steel bars of grade 415

4.2.1 DEAD LOADS(DL):

All permanent constructions of the structure form the dead loads. The dead load comprises of the self-weight, weight of walls, partitions floor finishes and the other permanent constructions in the buildings. The loads considered in this project are as per IS 456 2000.

- Weight of concrete = 7.18 KN/m^2
- 4½ inches thick wall weight = 2.39 KN/m^2
- 9 inches thick wall weight = 4.78 KN/m^2
- Weight of glass area = 0.478 KN/m^2
- Weight of elevator = 2 tons
- Weight of ceiling and finishing = 1.197KN/m^2

4.2.2 LIVE LOAD(LL):

Live load or imposed load is defined as the load on the structure due to moving weight. Imposed load is produced by the intended use or occupancy of a building including the weight of movable partitions, distributed and concentrated loads, load due to impact and vibration and dust loads. Imposed loads do not include loads due to wind, seismic activity, snow, and loads imposed due to temperature changes to which the structure will be subjected to, creep and shrinkage of the structure, the differential settlements to which the structure may undergo.

- Live load on lobbing = 4.78 KN/m^2
- Live load on corridors = 4.78 KN/m^2
- Live load on stairs = 4.78 KN/m^2
- Live load on restaurants = 4.78 KN/m^2
- Live load on assembly hall = 4.78 KN/m^2
- Live load on bed room = 1.915 KN/m^2

- Live load on roof = 0.95 KN/m^2

4.2.3 SEISMIC LOAD CALCULATION (Based on code IS 1893-2002)

During an earthquake, ground motions develop in a random manner both horizontally and vertically in all directions radiating from the epicenter. The ground motions develop vibrations in the structure inducing inertial forces on them. Hence structures located in seismic zones should be suitably designed and detailed to ensure strength, serviceability and stability with acceptable levels of safety under seismic forces.

The satisfactory performance of a large number of reinforced concrete structures subject to severe earthquake in various parts of the world has demonstrated that it is possible to design structures to successfully withstand the destructive effects of major earthquakes.

The Indian standard codes IS: 1893-1984 and IS: 13920-1993 have specified the minimum design requirements of earthquake resistant design probability of occurrence of earthquakes, the characteristics of the structure and the foundation and the acceptable magnitude of damage. Determination of design earthquake forces is computed by the following methods,

1) Equivalent static lateral loading.
2) Dynamic Analysis.

In the first method, different partial safety factors are applied to dead, live, wind earthquake forces to arrive at the design ultimate load. In the IS: 456-2000 code, while considering earthquake effects, wind loads assuming that both severe wind and earthquake do not act simultaneously. The American and Australian code recommendations are similar but with different partial safety factors.

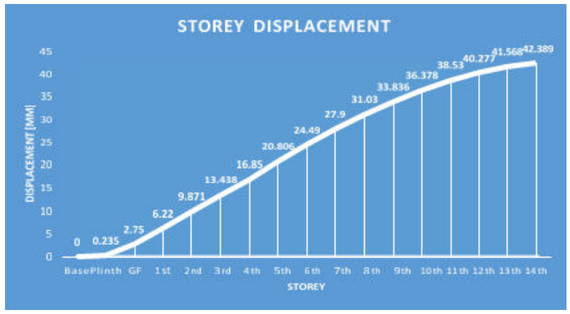
The dynamic analysis involves the rigorous analysis of the structural system by studying the dynamic response of the structure by considering the total response in terms of component modal responses.

5.1 RESULTS

TABLE 2 : Data from dynamic analysis performed

5.1.1 STOREY DISPLACEMENT:

Story displacement is defined as the total displacement of any storey with respect to ground.



5.1.2 STOREY SHEAR:

Storey shear is defined as the sum of design lateral forces at all levels above the storey under consideration.

Fig 9: In the above graph the X-axis represents the storey of the building and Y- axis represents

Fig 8: In the above graph the X-axis represents the storey of the building and Y-axis represents the displacement in mm. It is minimum at the base level and gradually increases with respect to storey. The maximum displacement is at the top storey.

5.1.3 STOREY DRIFT:

Storey drift is defined as ratio of displacement of two consecutive floors to height of that floor.

the shear force. The shear force is maximum at the first storey and it decreases with respect to the storey height.

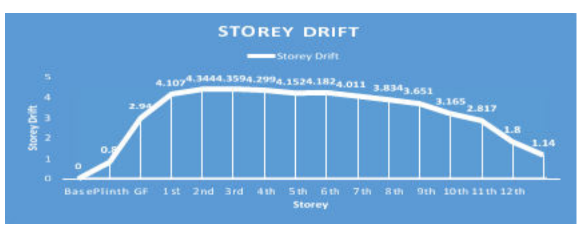


Fig 10: In the above graph the storey drift is maximum at the fifth storey and it is minimum at

base plinth level.

5.1.4 STOREY OVERTURNING MOMENT:

It is taken as the sum of the moments on the column and any shear on the column multiplied by the distance from the base of the column to the base of the footing.

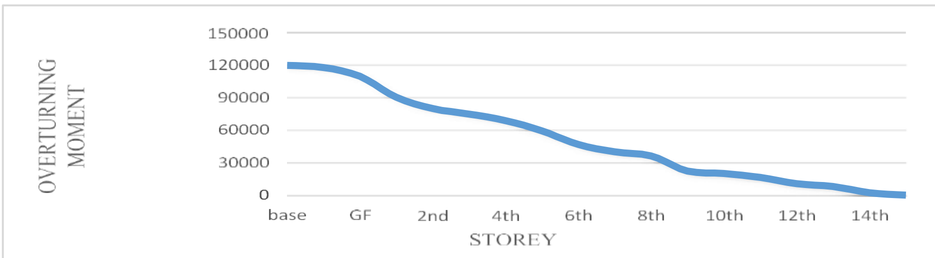


Fig 11: In the above graph the X- direction represents the storey of the building and y-direction represents the over turning moment in KN. The over turning moment is maximum at the base level and gradually decreases with respect to height of the storey.

5.2 MODEL OF THE STRUCTURE

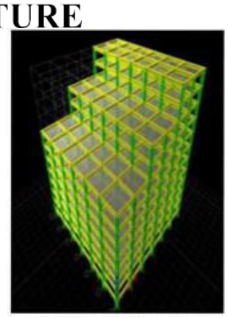


Fig. ETABS model of the structure