The Effect of Seismic Zones on A Twelve-Story Reinforced Concrete Building – A Study

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***Abstract*—A building was modelled, analysed, and dimensioned across the four seismic zones of India: Zones II, III, IV, and V. The research focused on the quantities and properties of the structural materials of the building. Modelling was conducted using ETABS 20V with frame elements, and the analysis utilized the "equivalent static analysis" method. The study featured a twelve-story building with an asymmetrical rectangular floor plan. The objective was to investigate whether the seismic hazard zone influences the quantity of construction materials required for a load-bearing reinforced concrete building by comparing material usage within and outside these zones. The study sought to ascertain the impact and importance of seismic activity, offering insights into how seismicity influences material demands for reinforced concrete building structures.**

Keywords— Earthquake; seismic zone; ETABS; RCC; structure

I. EARTHQUAKE IN INDIA

India, a country characterized by its rich cultural heritage and diverse landscapes, is also known for its significant seismic activity. The country's geographical position on the boundary of several tectonic plates makes it particularly susceptible to earthquakes. This essay explores the seismic landscape of India, examining the causes, historical impact, and contemporary responses to earthquakes in the region.

India's seismic activity is largely influenced by its location at the convergence of the Indian Plate, the Eurasian Plate, and the Arabian Plate. The Indian Plate, which is moving northward, is colliding with the Eurasian Plate. This collision has given rise to the Himalayan Mountain range and continues to exert pressure on the region, making it one of the most seismically active zones in the world. The complex interactions among these tectonic plates result in frequent and sometimes devastating earthquakes. The major seismic zones in India are classified based on their susceptibility to earthquakes. These include:

1. The Himalayan Region: This region, spanning from Jammu and Kashmir to Arunachal Pradesh, is highly seismic due to the ongoing collision between the Indian and Eurasian plates. It experiences frequent earthquakes, some of which have been extremely destructive.
2. The Indo-Gangetic Plain: Located south of the Himalayas, this region is also vulnerable due to the proximity to the seismic activity in the north. The tectonic stresses in this area can trigger significant seismic events.
3. The Western Ghats and the Deccan Plateau: Though less active compared to the Himalayan region, this area is still prone to earthquakes due to the reactivation of ancient fault lines.
4. The Rann of Kutch: Situated in Gujarat, this region has experienced significant seismic activity in the past, including the devastating earthquake of 2001.

India is divided into four primary seismic zones based on the level of seismic risk, as outlined in the Indian Standard IS 1893 (Part 1): 2016. These zones are:

1. Zone II: This zone is considered to have the lowest seismic risk among the four zones. It includes areas with relatively low seismic activity and is characterized by a lower likelihood of experiencing severe earthquakes. Some parts of this zone may include regions on the western coast and parts of southern India.
2. Zone III: This zone represents a moderate seismic risk. It includes regions that experience moderate seismic activity, and while earthquakes are possible, they are generally less severe compared to higher seismic zones. Parts of this zone may include areas in the central and eastern regions of India.

3. Zone IV: This zone is characterized by high seismic risk. Areas in this zone are more likely to experience significant seismic activity and strong earthquakes. It includes parts of northern and northeastern India, including the lower Himalayan foothills and parts of Gujarat.
4. Zone V: This is the highest seismic risk zone, with the greatest likelihood of experiencing severe earthquakes. It includes regions with very high seismic activity, such as the entire Himalayan region (including Jammu and Kashmir, Himachal Pradesh, and Uttarakhand) and northeastern states like Assam and Nagaland.

II. GENERAL PRINCIPAL AND DESIGN CRITERIA

The Indian Standard IS 1893: Criteria for Earthquake Resistant Design of Structures outlines essential principles for designing buildings that can withstand seismic forces. The seismic design philosophy emphasizes three key objectives: ensuring no damage during minor earthquakes, limiting damage during moderate quakes, and preventing collapse during severe shaking to ensure life safety. Structural configuration plays a critical role, with simple, symmetric, and regular designs offering better seismic performance. Irregularities in mass or stiffness can lead to torsional behaviour, so IS 1893 sets guidelines to minimize these effects. The standard also prescribes dynamic analysis methods like response spectrum analysis and time history analysis to understand how structures respond to earthquakes. When designing for seismic loads, engineers consider load combinations involving dead loads, live loads, and earthquake loads, calculating the base shear using factors like the seismic zone, the importance of the structure, and the type of building.

Ductile detailing, governed by IS 13920, is crucial for reinforced concrete structures, ensuring they can absorb seismic energy without brittle failure. This includes proper anchorage, confinement of critical zones, and controlling shear forces. The seismic zone factor, importance factor, and response reduction factor determine the intensity of forces structures must resist, varying across India’s four seismic zones (II to V). IS 1893 also addresses structural irregularities like soft stories (often with parking areas) and weak stories, which are more vulnerable during earthquakes. The standard recommends strengthening these areas or avoiding such designs. Additionally, adequate separation between adjacent buildings is necessary to avoid the pounding effect, where buildings collide during quakes. Foundation design must consider both vertical loads and lateral seismic forces, choosing suitable foundations based on soil conditions and structural needs. Collectively, these principles ensure that buildings are resilient and can effectively resist earthquake-induced stresses, safeguarding both property and lives.

III. ANALYTICAL RESEARCH

3.1 Construction Details

Modelling in ETABS software involves creating a detailed and accurate digital representation of a structure to analyse its behaviour under various loads, including seismic forces. The process begins with defining the structural elements like beams, columns, slabs, and walls based on the architectural and structural plans. The geometry, material properties, and section sizes are input into ETABS to establish the framework of the building.
Once the structural model is set up, loads such as dead loads, live loads, and seismic loads are applied according to relevant codes and standards like IS 1893. The software allows for detailed load combinations and assigns them to various load cases for analysis. ETABS also considers factors like story heights, mass distribution, and stiffness irregularities, which are critical in assessing the building's response during an earthquake.
The RCC frame of the building is constructed using M25 grade concrete, with a weight per unit volume of 24.9926 kN/m³ and a mass per unit volume of 2548.538 kg/m³. The Modulus of Elasticity (E) for M25 concrete is 25,000 MPa, with a Poisson’s Ratio (μ) of 0.2 and a Coefficient of Thermal Expansion (α) of 0.000011 /°C. The Shear Modulus (G) for this concrete is 10,416.67 MPa. Similarly, for FE500 grade steel, the weight per unit volume is 76.9729 kN/m³, with a mass per unit volume of 7,849.047 kg/m³. The Modulus of Elasticity (E) for FE500 steel is 200,000 MPa, with a Coefficient of Thermal Expansion (α) of 0.0000117 /°C.

3.2 Geometrical Specification

For a building with a height of 33 meters, the dimensions of structural elements vary depending on the seismic zone. In Zone II, the beam size is 0.23 meters by 0.38 meters, the column size is 0.30 meters by 0.38 meters, and the wall size is 0.23 meters. Moving to Zone III, the beam size increases to 0.30 meters by 0.38 meters, the column size to 0.30 meters by 0.45 meters, and the wall size remains consistent at 0.23 meters. In Zone IV, the beam dimensions remain the same as in Zone III at 0.30 meters by 0.38 meters, with the column size also at 0.30 meters by 0.45 meters, and the wall size still at 0.23 meters. Finally, in Zone V, the beam size further increases to 0.38 meters by 0.53 meters, while the column size adjusts to 0.38 meters by 0.45 meters, and the wall size remains at 0.23 meters. The slab thickness is uniformly maintained at 125mm across all the floors and any reduction in column size along the building height is not considered due to the simplified analysis approach.

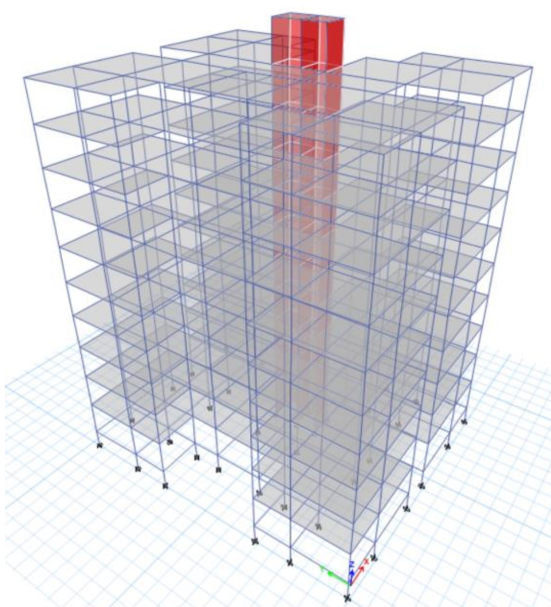

Fig. (1.1): Etabs building model

3.3 Load Applied

The load applied to the structure is categorized into various types, each with specific values and characteristics. The Dead Load has no specified load in kN/m but includes a self-weight multiplier of 1. The Live Load is divided into two categories: 2 kN/m for rooms and 3 kN/m for balconies. The Floor Finish is classified as a Super Dead load with a value of 1.5 kN/m. The Wall Load for a wall thickness of 0.30 meters is also a Super Dead load, amounting to 10.5 kN/m. The Parapet Wall, which is 3 meters high, contributes a Super Dead load of 4 kN/m. Additionally, the Terrace Load, categorized under Roof loads, is 1.5 kN/m. Seismic loads are considered in four directions: EQ +X, EQ -X, EQ +Y, and EQ -Y, although their specific load values are not provided as per IS 1893: Part 1: 2000.

3.4 Construction frame design preferences for IS 456: 2000

The design of the structure follows the IS 456:2000 code, with a step-by-step approach for multi-response case design. A total of 24 interaction curves and 11 interaction points are considered. Minimum eccentricity and additional moments are both taken into account, while P-Delta effects are not included in the design. The design process also considers the B/C capacity ratio and beneficial axial force (Pu) is ignored for beam design. The partial safety factors for steel (Gamma) and concrete are set at 1.15 and 1.5, respectively. User-defined allowable PT stresses are not employed in this design.
For concrete strength at transfer, the ratio of fck to fac is 0.8. The tensile stresses in both the top and bottom fibres during transfer are set at 1 times the square root of fck, and the extreme fibre compressive stress at transfer is limited to 0.8 times fck. In the final stage, the tensile stresses in the top and bottom fibres are maintained at 1 times the square root of fc', while the extreme fibre compressive stress is set at 1 times fac. The sustained extreme fibre compressive stress is also considered, with 25% of the live load taken into account. Additionally, a pattern live load factor of 0.75 is applied, and the utilization factor limit is set at 1.

IV. RESULTS

In this analysis, the building is modelled considering factors like material properties, loading conditions, and structural configurations by relevant seismic codes and IS 456:2000 and IS 1893:2016 standards. The objective is to evaluate the building's response to seismic forces, ensuring safety, stability, and compliance with code requirements. The study involves an equivalent static method to capture the building's behaviour under earthquake excitation.

The results of this analysis, including parameters like base shear, story drift, and lateral displacements, provide valuable insights for optimising the structural design. This analysis helps identify potential weaknesses, ensuring the design is resilient and robust enough to withstand seismic forces. The insights gained are crucial for improving the structural performance and ensuring the safety of occupants during an earthquake event.

1. Zone II covers regions in India where the seismic hazard is considered low, with a basic seismic acceleration coefficient (Z) of 0.10 per the IS 1893:2016 (Part 1) code. The coefficient reflects the expected ground acceleration and is a key parameter in determining the seismic forces that a structure must be designed to withstand. Earthquakes in this zone typically have low magnitudes, rarely exceeding 4.9 on the Richter scale.

2. In Zone III, the seismic acceleration coefficient (Z) is 0.16 as per IS 1893:2016 (Part 1). This coefficient indicates the design horizontal acceleration as a fraction of gravity and is used to calculate the seismic forces acting on structures. The region falls under the category of moderate seismic activity, with earthquakes in this zone potentially ranging from mild tremors to moderate and even severe quakes with magnitudes up to 6.9 on the Richter scale. Earthquake Zone III in India represents a moderate-risk area where careful seismic design and adherence to building codes are essential. The region's widespread coverage across densely populated and economically significant areas necessitates a comprehensive approach to seismic safety to protect lives and property in the event of an earthquake.

3. Seismic design in Zone IV is extremely important because there is a high chance of powerful earthquakes. If not addressed properly, these earthquakes can have devastating consequences. By using strong seismic design principles, following the relevant codes, and retrofitting older structures, the potential risks can be significantly reduced. In this high-risk zone, it's crucial to ensure that buildings and infrastructure can withstand seismic forces. This is not just a legal requirement, but also a moral and economic necessity to protect lives and support communities.

4. Seismic design in Earthquake Zone V is of paramount importance due to the very high risk of strong and destructive earthquakes. The stakes in this zone are incredibly high, given the dense populations, critical infrastructure, and active tectonic regions. Adhering to stringent seismic design codes, ensuring ductility, and retrofitting older buildings are crucial steps in safeguarding lives, protecting property, and maintaining the stability of communities in this high-risk area. Robust seismic design is not merely a technical requirement but a vital necessity for disaster resilience and risk reduction in Zone V.

A. Joint displacement at +X direction

- Zone 2: Being a low-risk zone, it shows the lowest response values at each story. The top-floor response (12.855 mm) is much lower compared to higher zones
- Zone 3: This moderate-risk zone shows a considerable increase in response (top-floor value of 30.623 mm), nearly double that of Zone 2.
- Zone 4: This high-risk zone has similar values to Zone 3 (slightly higher), indicating a notable increase in seismic forces (top-floor value of 30.755 mm).
- Zone 5: The highest-risk zone shows the greatest response, with a top-floor value of 34.787 mm, highlighting the significant impact of severe seismic activity.

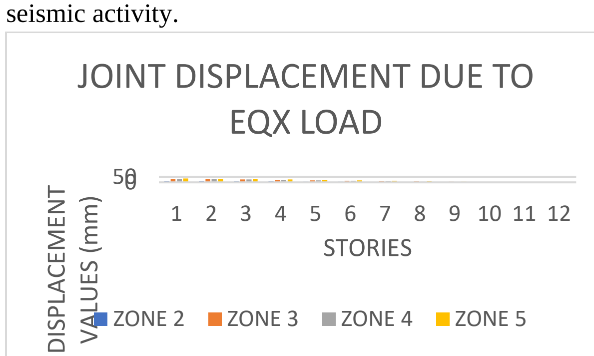

Fig. (1.2): Joint Displacement due to EQX

B. Joint displacement at +Y direction

- Zone 5 consistently has the highest values across all stories, followed by Zone 4, Zone 3, and Zone 2.
- The difference between the zones grows more pronounced as you move up the stories. For example:
  - At Story11: Zone 2 = 13.529 mm, Zone 3 = 31.478 mm, Zone 4 = 33.029 mm, Zone 5 = 35.484 mm.

- At Story1: Zone 2 = 0.178 mm, Zone 3 = 0.626 mm, Zone 4 = 0.455 mm, Zone 5 = 0.655 mm.

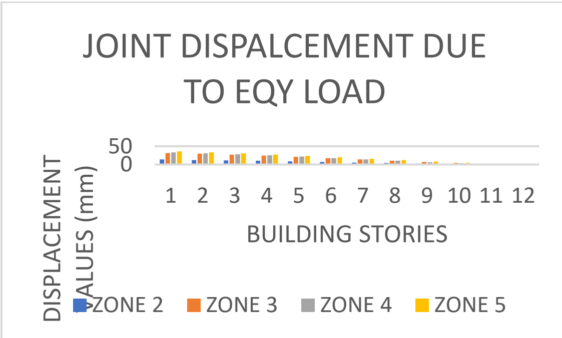

Fig. (1.3): Joint Displacement due to EQY

C. Story drift at +X direction

- Zone 5 generally shows the highest drift values, particularly in the upper stories, indicating that this zone may experience more significant lateral displacement.
- Zone 3 consistently has slightly lower values than Zone 5 but remains higher than Zone 2.
- Zone 2 shows the lowest drift values among all zones.

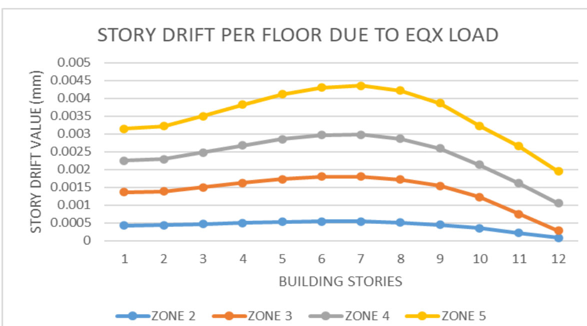

Fig. (1.4): Story Drift due to EQX

D. Story drift at +Y direction

- Zone 5: Shows the highest drift values across all stories, indicating that this zone might be more susceptible to lateral displacement.
- Zone 3 and Zone 4: Have moderately high drift values, with Zone 4 slightly exceeding Zone 3 in some stories.
- Zone 2: Consistently shows the lowest drift values across all stories.

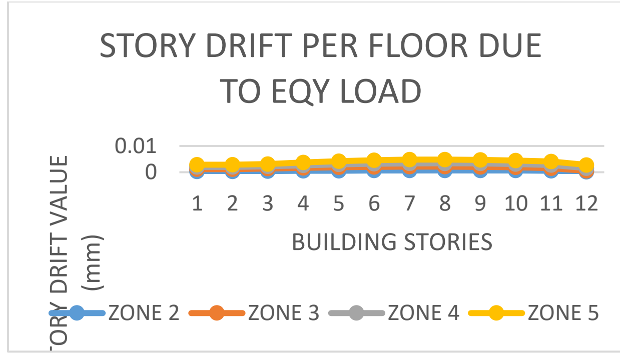

Fig. (1.5): Story Drift due to EQY

E. Story force at +X direction

- Zone 4 consistently shows the highest force values across all stories. For example:
  - At Story11, Zone 4 has a force of -34.9472 KN.
  - At the Base, Zone 4 reaches a peak force of -2683.31KN.
- Zone 3 follows a similar pattern but with slightly lower magnitudes than Zone 4.
- Zone 2 also shows significant force values, though lower than Zones 3 and 4.
- Zone 1 has the lowest forces among all zones, especially in the upper stories.

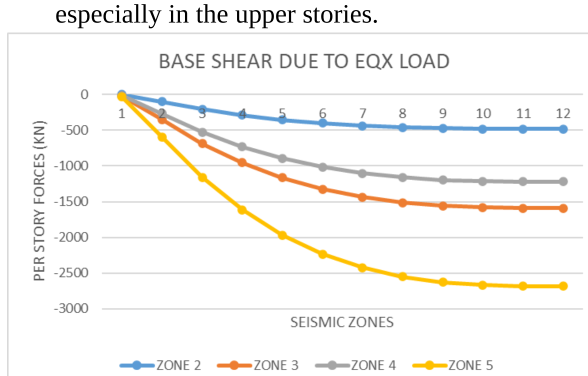

Fig. (1.5): Base Shear due to EQX

F. Story force at +Y direction

- Zone 4 has the largest force values across all stories, especially near the Base. For example:
  - At the Base, Zone 4 has a force of -3199.75 KN, the highest across all zones.
- Zone 3 also shows high force values, followed by Zone 2.
- Zone 1 has the lowest force values overall, indicating that it might be the least critical in load-bearing capacity.

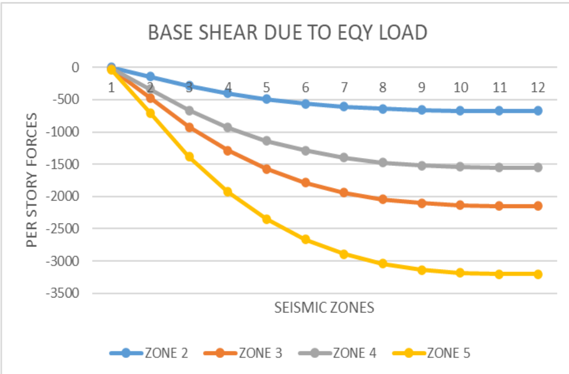

Fig. (1.6): Base Shear due to EQY

V. MATERIAL QUANTITY

4.1 Measured rebar

- As the seismic activity increases from Zone 2 to Zone 5, the required percentage of rebar also increases.
- Zone 5, being the most earthquake-prone, requires the highest rebar percentage (1.65%), while Zone 2, with the least seismic risk, requires the lowest (1.35%).
- The jump in rebar percentage from 1.41% in Zone 3 to 1.53% in Zone 4 indicates a significant increase in the need for reinforcement. This reflects the higher risk associated with more intense earthquakes. The additional rebar contributes to the overall stability and durability of structures, making them better equipped to survive in a more earthquake-prone environment.
- This incremental increase in rebar percentage ensures that the structures are reinforced adequately to withstand potential seismic forces.

4.2 Measured Concrete

- Moving from Zone II to Zone III results in a moderate increase of approximately 13.77% in concrete quantity.
- However, from Zone III to Zone IV, there is a slight decrease of 4.74%, indicating a reduction in quantity.
- From Zone IV to Zone V, the concrete quantity experiences a significant jump, increasing by about 22.84%.

This analysis shows that while the trend generally involves increasing concrete quantity as the zone level increases, there is a dip in Zone IV before sharply rising again in Zone V.

VI. CONCLUSION

- The data demonstrates that as the seismic zone level increases from Zone 2 to Zone 5, the seismic responses at each story become significantly more intense. The largest disparities are observed in the upper stories, where forces are typically highest. In Zone 5, the critical zone, structures must be designed with the utmost attention to seismic resistance, incorporating advanced materials, robust detailing, and resilient construction techniques to ensure safety.
- The data shows that the joint displacement is highest at the top stories and decreases as you move towards the Base. Zone 5 experiences the most significant movement, suggesting that it might be a critical area for additional reinforcement. Structural elements like shear walls, bracing, or tuned mass dampers may be necessary at the higher levels to control drift and ensure that the building meets serviceability criteria under lateral loads. The lower drift values near the Base indicate that these levels effectively resist movement, providing a stable foundation for the structure.
- The data suggests that the upper stories experience greater drift, with Zone 5 showing the most significant drifts. This pattern is typical in structures under lateral forces where higher levels tend to sway more.
- The data reveals that story drift increases with height, with Zone 5 consistently experiencing the highest drifts. This suggests that the structure's lateral stiffness may vary across zones, leading to different displacement responses. Attention should be given to Zone 5 and the middle-to-upper stories (Story 5 to Story 8) where the drifts are significant.
- The data indicates that the forces increase substantially from the top story (Story11) to the Base. Zone 4 consistently experiences the highest forces, making it a critical zone to consider for structural stability. The analysis suggests that the lower stories, particularly near the Base, are crucial for bearing the cumulative loads from the upper stories. In structural design, additional reinforcement might be needed in these areas to

ensure that the structure can safely carry these forces without failure.

- The analysis shows that the forces progressively increase from the top story (Story11) down to the Base. Zone 4 experiences the highest forces, making it a critical focus area in the structural design. The lower stories, particularly near the Base, are essential for supporting the cumulative forces from above. Structural reinforcements, such as additional bracing or stiffer materials, may be required in these areas to ensure the building's stability under these load conditions.

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