

SEISMIC PERFORMANCE OF REGULAR AND IRREGULAR RCC BUILDINGS WITH EFFECT OF DIFFERENT SEISMIC ZONES ON RCC BUILDINGS

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ABSTRACT

Reinforced cement concrete framed buildings form the major part of residential and commercial construction in India, and a large portion of the country lies in regions that are exposed to moderate or severe earthquake shaking. Many of these buildings are not regular in plan or elevation. Re-entrant corners, setbacks, open ground storeys for parking, and unequal distribution of mass or stiffness are common because of site constraints and architectural requirements. Such irregularities change the way a building responds to ground motion and can concentrate damage in a few members or storeys. The present study examines how regular and irregular RCC buildings behave under seismic loading and how that behaviour changes as the building is located in different seismic zones.

A G+7 storey RCC moment-resisting frame with a symmetric rectangular plan is taken as the regular reference model. Three irregular models are derived from it with the same floor area and member sizes: an L-shaped plan with a re-entrant corner, a vertically irregular frame with a setback at the upper storeys, and a frame with a soft ground storey created by removing the infill walls at plinth level. All four models are prepared in ETABS and analysed for Seismic Zones II, III, IV, and V as defined in IS 1893 (Part 1):2016, so that sixteen analysis cases are obtained in total. Dead and live loads are applied according to IS 875 (Part 1) and IS 875 (Part 2).

Both the equivalent static method and the response spectrum method are used. The response parameters compared are fundamental time period, base shear, storey displacement, inter-storey drift, storey stiffness, and torsional irregularity ratio. Member forces in the critical columns and beams are extracted, and the frames are designed according to IS 456:2000 with ductile detailing requirements of IS 13920:2016, so that the change in steel quantity with zone and configuration can also be observed.

The results show that base shear and lateral displacement increase directly with the zone factor, so that a building in Zone V attracts roughly 3.6 times the design base shear of the same building in Zone II. For the same zone, the irregular models show higher displacement and drift than the regular model. The soft storey model shows a sharp jump in drift at the ground storey, and the L-shaped model shows significant torsional response at its re-entrant corner. The setback model shows a concentration of drift and member forces at the storey where the plan area changes.

The study concludes that irregularity becomes a more serious concern as the seismic zone becomes more severe, and that configurations which may be acceptable in Zone II need careful treatment such as shear walls, stiffer ground storey columns, or

separation joints in Zones IV and V. The comparison is intended to help students and practising designers understand the combined effect of configuration and seismicity at the planning stage itself, before member sizes and reinforcement are fixed.

I. INTRODUCTION

Earthquakes are among the most destructive natural events, and the damage they cause is mostly due to the failure of buildings rather than the ground shaking itself. India has experienced several damaging earthquakes in the last few decades, including those at Latur, Jabalpur, Bhuj, and Sikkim, and in each case a large number of RCC buildings were damaged or collapsed. Post-earthquake surveys repeatedly showed that buildings with irregular configurations, weak ground storeys, and poor detailing suffered far more damage than regular and well-detailed structures of similar age and height.

IS 1893 (Part 1):2016 divides the country into four seismic zones, namely Zones II, III, IV, and V, with zone factors of 0.10, 0.16, 0.24, and 0.36 respectively. The zone factor represents the expected peak ground acceleration for the maximum considered earthquake and directly scales the design horizontal seismic coefficient. The code also defines plan irregularities such as torsional irregularity and re-entrant corners, and vertical irregularities such as soft storeys, mass irregularity, and vertical geometric irregularity. For buildings with these irregularities, the code restricts the use of simplified methods and requires dynamic analysis in higher zones.

In practice, urban plots are often narrow or irregular, and architects prefer open parking at the ground floor, setbacks for light and ventilation, and L-shaped or T-shaped plans for better use of space. These choices are not always examined for their seismic consequences at the planning stage. A configuration that performs acceptably in a low-seismicity region may develop large drift, torsion, or storey mechanisms when the same building is constructed in a high-seismicity region. Designers therefore need clear comparative information on how the building form and the site seismicity interact.

The present work carries out this comparison using ETABS. A regular G+7 RCC frame and three irregular variants are modelled with identical floor area, material grade, and member sizes, and each is analysed in all four seismic zones. Storey displacement, drift, base shear, time period, and member forces are compared, and the frames are designed to IS 456:2000. The objective is to identify which type of irregularity is most sensitive to increasing seismicity and to recommend simple measures that improve the performance of irregular buildings in higher zones.

II. LITERATURE SURVEY

Studies on the seismic behaviour of irregular buildings have been reported for several decades, and a common theme is that buildings with a simple, symmetric, and uniform configuration perform better than buildings with abrupt changes in geometry. Researchers who examined damage patterns after major earthquakes observed that the buildings which collapsed often had a structural defect that could have been identified from the architectural drawings alone, such as a soft storey, an eccentric core, or a discontinuous column. These observations led to the inclusion of explicit irregularity definitions in design codes, including the tables of plan and vertical irregularities in IS 1893 (Part 1). Authors have pointed out that these definitions are useful screening tools, but that the degree of penalty or additional analysis required should depend on how severe the irregularity is and on the seismic hazard at the site. Several parametric

studies have therefore combined configuration and zone as independent variables, which is also the approach adopted in the present work.

Plan irregularity, particularly torsional irregularity arising from re-entrant corners and eccentric placement of stiff elements, has received considerable attention in analytical studies. When the centre of mass and the centre of rigidity of a floor do not coincide, lateral load produces a twisting moment in addition to translation, and the columns at the flexible edge experience displacements larger than the average floor displacement. Investigations using three-dimensional models in ETABS and SAP2000 have shown that L-shaped and T-shaped buildings develop maximum-to-average drift ratios well above the limit of 1.2 used in IS 1893 to identify torsional irregularity, and in some cases above 1.4, beyond which the code does not permit such configurations in higher zones. Researchers have also noted that the wings of L-shaped buildings tend to vibrate in different directions, which produces stress concentration at the junction of the wings. Providing a separation joint or adding stiff elements at the re-entrant corner is commonly recommended.

Vertical irregularity in the form of a soft or weak storey is considered the most dangerous configuration for RCC buildings in India because of the popularity of open ground storeys used for parking. Several investigations have modelled the infill walls in the upper storeys as equivalent diagonal struts and compared the resulting frame with a bare frame and with an open ground storey frame. The results show that infills increase the stiffness of the upper storeys several times, so that the ground storey becomes relatively flexible and almost the entire inter-storey drift concentrates at that level. The columns of the open storey then have to resist large moments and shears and may form a sway mechanism. IS 1893 (Part 1):2016 addresses this by requiring the columns and beams of a soft storey to be designed for 2.5 times the forces obtained from analysis, or by requiring the provision of shear walls or bracing. Studies generally agree that the stiffness ratio check should be performed before member sizing begins.

The influence of seismic zone on response has been examined in a number of parametric studies. Because the design horizontal seismic coefficient is linearly proportional to the zone factor, base shear and elastic displacement for the same building increase in direct proportion from Zone II to Zone V. Researchers have shown, however, that the design consequences are not purely proportional. In higher zones the drift limit of 0.004 times the storey height begins to govern member sizes, the percentage of longitudinal steel in columns increases sharply, and ductile detailing requirements under IS 13920 add further transverse reinforcement. Comparative studies of G+5 to G+10 frames report that a building designed with the same member sizes may satisfy drift limits comfortably in Zones II and III but fail the drift or strong-column weak-beam check in Zone V. Authors have recommended that member sizes be revised by zone rather than reused from a standard design, particularly for irregular buildings.

Research on analysis methods has compared the equivalent static method, the response spectrum method, and nonlinear pushover and time-history methods for regular and irregular buildings. For regular low-rise frames, the equivalent static and response spectrum methods give similar base shears once the code scaling is applied. For irregular frames, the response spectrum method captures the contribution of higher and torsional modes and generally predicts a different distribution of storey shear over the height. Studies using pushover analysis have further shown that

irregular buildings reach their ultimate capacity at lower roof displacement and develop hinges in fewer members, which indicates a less favourable collapse mechanism. Commercial programs such as ETABS and STAAD.Pro are now widely used for this purpose because they automate modal analysis, load combination, and code checking. The present study uses linear static and response spectrum analysis in ETABS, which is the level of analysis normally performed in design offices, and focuses on the combined effect of configuration and zone.

III. SYSTEM ANALYSIS

The structural problem addressed in this study is the change in seismic response of RCC framed buildings when both the building configuration and the seismic zone are varied. A G+7 storey moment-resisting frame with a plan of 20 m by 15 m, storey height of 3.0 m, and bay spacing of 5 m is taken as the regular model. Three irregular models are derived from it: an L-shaped plan with re-entrant corners exceeding 15 percent of the plan dimension, a vertical setback at the sixth storey, and a soft ground storey without infill. Columns of 450 mm by 450 mm, beams of 300 mm by 450 mm, and slabs of 150 mm thickness are used in all models with M25 concrete and Fe500 steel. Dead load includes self-weight, floor finish of 1.5 kN/m², and masonry wall load, and a live load of 3 kN/m² is applied according to IS 875 (Part 2). Seismic loads are calculated for Zones II to V using medium soil, an importance factor of 1.0, and a response reduction factor of 5 for special moment-resisting frames.

Existing System

In conventional practice, many small and medium RCC buildings are designed by hand calculation or by simple two-dimensional frame analysis. The engineer computes gravity loads, distributes them to beams and columns by tributary area, and estimates seismic base shear using the equivalent static method of IS 1893 with an approximate time period formula. The base shear is distributed over the height in a parabolic pattern and applied to a representative plane frame, which is then solved by approximate methods such as the portal method or moment distribution. Torsion is either neglected or added as a simple percentage increase. Irregularities such as re-entrant corners and soft storeys are often not identified formally, and the stiffness ratio and torsional irregularity checks are rarely performed. When a building is to be built in a different zone, the same member sizes are frequently retained and only the reinforcement is increased. This practice is quick for regular buildings but gives little insight into the three-dimensional behaviour of irregular structures and can underestimate drift and member forces at critical locations.

Disadvantages of Existing System

- Two-dimensional plane frame analysis cannot capture torsional response of irregular plans.
- Approximate period formulas ignore the actual mass and stiffness distribution of the building.
- Soft storey and stiffness irregularity checks of IS 1893 are often not carried out.
- Higher mode effects in setback and tall irregular frames are not represented.
- Manual load combination for several load cases and zones is slow and prone to error.
- Storey drift is seldom computed at every level and at the flexible edge of the floor.

- Member sizes are reused across zones without verifying drift and strength limits.
- Comparing several configurations and zones by hand requires excessive time and effort.
- Accidental eccentricity and orthogonal effects are difficult to include consistently.
- Results are not easily presented in graphical form for comparison and review.

Proposed System

The proposed approach uses three-dimensional modelling and analysis in ETABS to compare the regular and irregular models across all four seismic zones. Each building is modelled with frame elements for beams and columns and shell elements for slabs, and rigid diaphragms are assigned at every floor so that in-plane floor behaviour and torsion are represented correctly. Material properties for M25 concrete and Fe500 steel are defined, and gravity loads are applied according to IS 875 (Parts 1 and 2). Seismic loads are defined through the built-in IS 1893 (Part 1):2016 procedure for the equivalent static method and through the design response spectrum for medium soil, with accidental eccentricity of 5 percent included. Load combinations of IS 1893 and IS 456 are generated automatically. Modal analysis gives natural periods and mass participation, and response spectrum results are scaled to the static base shear. Storey displacement, drift, stiffness, and torsional ratios are obtained for all sixteen cases, and concrete frame design to IS 456:2000 gives reinforcement for comparison.

Advantages of Proposed System

- Three-dimensional models capture torsion and coupling between the two horizontal directions.
- Modal analysis gives the actual time periods and mode shapes of each configuration.
- Response spectrum analysis includes higher mode contribution in irregular buildings.
- Load combinations of IS 456 and IS 1893 are generated and applied consistently.
- Storey drift and displacement are obtained at every floor for comparison with code limits.
- Stiffness and torsional irregularity checks can be carried out directly from the results.
- Changing the seismic zone requires only a change of the zone factor in the load definition.
- Member design to IS 456:2000 is performed for all members in a single run.
- Results can be tabulated and plotted for clear comparison between models and zones.
- The effect of remedial measures such as shear walls can be evaluated quickly.

IV. METHODOLOGY

The methodology begins with the selection of the building plan, storey height, bay dimensions, and material grades for the regular reference model. Grid lines and storey levels are created in ETABS, and beams, columns, and slabs are assigned with section properties and M25 and Fe500 materials. Supports are fixed at the base, and rigid diaphragms are applied at each floor level. Dead load, floor finish, wall load, and live load are assigned following IS 875 (Parts 1 and 2), and the mass source is defined as full dead load plus 25 percent of live load as required by IS 1893. Seismic load cases

in both horizontal directions are defined for Zone II, and a response spectrum case is created from the code spectrum for medium soil. Load combinations are generated for limit state design. The model is analysed, and modal periods, base shear, displacement, and drift are recorded. The zone factor is then changed to III, IV, and V and the analysis repeated. The same steps are followed for the L-shaped, setback, and soft storey models, after which frame design is run and all results are compared.

SYSTEM ARCHITECTURE

Seismic Performance of Regular and Irregular RCC Buildings with Effect of Different Seismic Zones on RCC Buildings

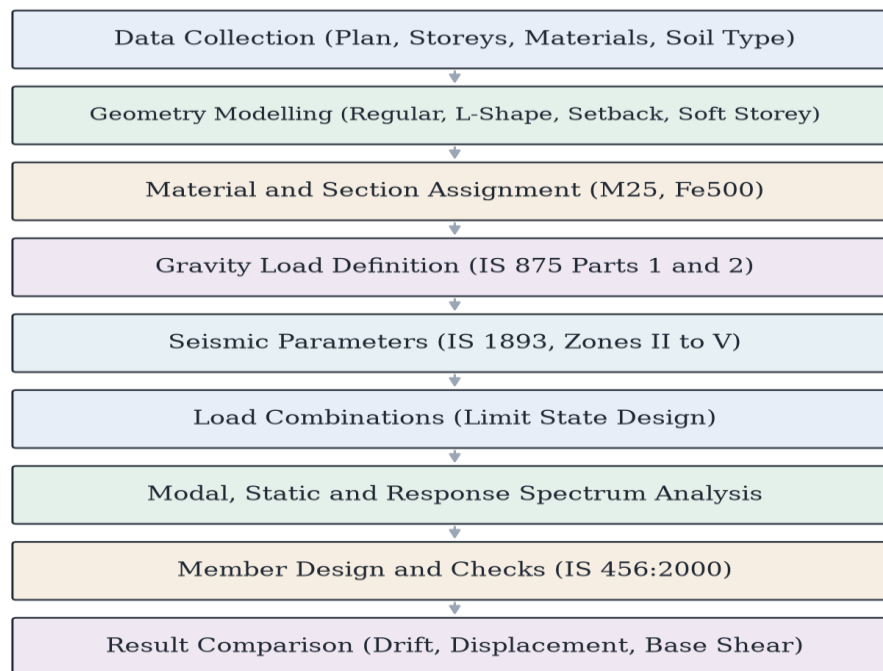


Fig. 1 System Architecture

The workflow of the study is arranged as a sequence of stages that lead from basic data to a comparison of results. The Data Collection stage fixes the building dimensions, storey heights, material grades, and site parameters such as soil type and importance factor. The Geometry Modelling stage creates grids, storeys, and structural members for the regular model and the three irregular variants. The Material and Section stage assigns concrete and steel properties and section sizes to beams, columns, and slabs. The Load Definition stage applies dead, live, and wall loads according to IS 875 and defines the mass source. The Seismic Parameter stage defines the equivalent static and response spectrum cases for each of the four zones according to IS 1893 (Part 1):2016. The Load Combination stage generates the design combinations. The Analysis stage runs modal, static, and spectrum analysis. The Design stage checks and designs beams and columns according to IS 456:2000, and the Result Comparison stage tabulates displacement, drift, base shear, period, and steel quantity across configurations and zones.

V. RESULT AND OUTPUT

Seismic Performance of Regular and Irregular RCC Buildings with Effect of Different Seismic Zones on RCC Buildings

Building Models



Regular RCC Building

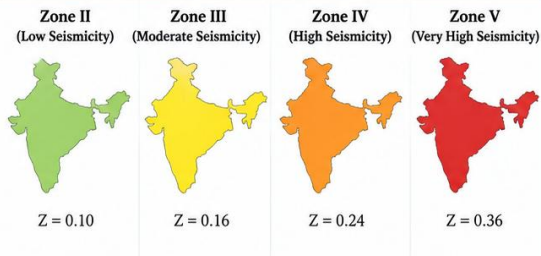
- Symmetric in plan and elevation
- Uniform distribution of mass and stiffness
- No geometric irregularities



Irregular RCC Building

- Irregular in plan/elevation
- Uneven distribution of mass and stiffness
- Presence of setbacks, open storey, etc.

Seismic Zones Considered (IS 1893:2016)



Results and Comparison



Key Observations

- Base shear increases with increase in seismic zone from Zone II to Zone V.
- Irregular buildings show higher base shear, displacement and drift compared to regular buildings.
- Regular buildings perform better due to uniform distribution of mass and stiffness.
- Irregularities such as setbacks, open storey, and plan irregularity significantly reduce seismic performance.
- The effect of seismic zone is prominent, with Zone V showing the highest demand on the structure.
- Design and detailing as per IS 1893:2016 and IS 13920:2016 is essential for better seismic safety.

Conclusion

Regular RCC buildings exhibit better seismic performance with lower displacement and drift compared to irregular buildings. Seismic demand increases significantly from Zone II to Zone V, and the effect is more critical for irregular buildings. Proper planning, symmetrical configuration, and adherence to seismic code provisions are essential for safe and economical design of RCC buildings in seismic-prone regions.

**Regular configuration + Proper seismic design =
Safer RCC buildings**

VI. CONCLUSION

This study compared the seismic performance of a regular G+7 RCC frame with three irregular variants, namely an L-shaped plan, a vertical setback, and a soft ground storey, in all four seismic zones of IS 1893 (Part 1):2016. Using ETABS, sixteen models were analysed by the equivalent static and response spectrum methods, and their time periods, base shears, displacements, drifts, and member forces were compared. The approach made it possible to separate the effect of configuration from the effect of site seismicity and to observe how the two combine.

Base shear and lateral displacement increased in direct proportion to the zone factor for every configuration, as expected from the code formulation. The irregular models, however, showed higher response than the regular model in every zone. The soft storey model developed the largest inter-storey drift at the ground level and failed the stiffness irregularity check, while the L-shaped model showed maximum-to-average drift ratios above 1.2 at the re-entrant corner, indicating torsional irregularity. The setback model showed a concentration of drift and column forces at the storey where the plan area reduced.

In Zones II and III, all models satisfied the drift limit of 0.004 times the storey height with the chosen member sizes, although the irregular models needed more reinforcement. In Zones IV and V, the soft storey and L-shaped models exceeded or approached the drift limit and required larger column sections or additional lateral

load resisting elements. The results confirm that irregularity which appears harmless in low seismic zones becomes critical in high zones, and that member sizes should not be reused across zones without checking drift, torsion, and strength.

Future work may extend the study to pushover and nonlinear time-history analysis to examine the collapse mechanism of each configuration, include soil-structure interaction for soft soil sites, and evaluate remedial measures such as shear walls, bracing, and seismic separation joints in quantitative terms. Taller buildings and other irregularities such as floating columns and mass irregularity could also be added to widen the scope of the comparison.

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