

SEISMIC ANALYSIS OF RCC BUILDING USING THE RESPONSE SPECTRUM METHOD

¹ Mr. D. Raghupathi, ² K Kartheek, ³ P Anand, ⁴ K Udaykiran

¹Assistant Professor, ^{2,3,4}Students

Department of Civil Engineering

Siddhartha Institute of Technology & Sciences, Narapally

raghupathi_civil@siddhartha.co.in, 25tq5a0115@siddhartha.org.in, 25tq5a0114@siddhartha.org.in,
24tq1a0105@siddhartha.co.in

ABSTRACT

This study presents the seismic analysis of a multi-storey reinforced cement concrete building using the response spectrum method as described in IS 1893 (Part 1):2016. A large part of India lies in seismic zones III, IV and V, and a considerable number of residential and commercial buildings in these regions are framed structures of moderate height. The behaviour of such buildings during an earthquake depends on their mass, stiffness and the way these properties are distributed over the height of the structure. The study is intended to show how a dynamic analysis procedure captures this behaviour more realistically than a simple static estimate of lateral force.

A G+10 storey RCC moment-resisting frame building with a regular plan of 20 m by 16 m is modelled in ETABS for the purpose of this work. The building is assumed to be located in seismic zone III on medium soil, and it is intended for residential use. Beams, columns and slabs are proportioned using preliminary sizes that are common in practice, and M25 concrete with Fe500 reinforcement is adopted. Dead loads and imposed loads are applied in accordance with IS 875 (Part 1) and IS 875 (Part 2), and the floor slabs are modelled as rigid diaphragms so that the lateral forces are shared between frames according to their stiffness.

Modal analysis is carried out first to obtain the natural periods, mode shapes and modal mass participation of the building. The design acceleration spectrum for medium soil is then applied in both principal horizontal directions, and the modal responses are combined using the Complete Quadratic Combination method. The base shear obtained from the response spectrum analysis is compared with the base shear from the equivalent static method, and the dynamic results are scaled up where required so that they are not less than the static value, as the code demands.

The results are presented in terms of storey displacement, inter-storey drift, storey shear, overturning moment, and the bending moments and axial forces in critical members. The maximum inter-storey drift ratio is checked against the limit of 0.004 times the storey height specified in IS 1893. Beams and columns are then designed according to IS 456:2000 using the load combinations prescribed for earthquake loading, and the reinforcement obtained is checked for ductile detailing requirements of IS 13920:2016.

The study finds that the response spectrum method gives a more rational distribution of lateral forces over the height of the building, particularly in the upper storeys where the contribution of higher modes becomes noticeable. The storey drifts obtained remain within the permissible limit for the adopted member sizes, and the column design is found to be governed mainly by the earthquake load combinations. The work demonstrates that dynamic analysis using commercial software is a practical tool for designers, and it can be extended in future to irregular buildings, soft storey configurations and time history analysis.

I. INTRODUCTION

Earthquakes are among the most destructive natural hazards that affect the built environment. Unlike gravity loads, which act continuously and are relatively well known, earthquake forces arise from the sudden movement of the ground beneath a structure. The building responds to this movement by vibrating, and the internal forces produced depend on how the mass and stiffness of the structure interact with the frequency content of the ground motion. Past earthquakes in India, such as those at Bhuj in 2001 and Sikkim in 2011, caused the collapse of many reinforced concrete buildings that had been designed only for gravity loads or with inadequate attention to seismic provisions.

Reinforced cement concrete framed construction is the most common structural system for multi-storey residential and commercial buildings in Indian cities. These frames are normally designed for dead load and live load with considerable care, but the lateral load resisting behaviour is sometimes treated as a secondary check. When lateral forces are estimated with the equivalent static method alone, the distribution of force over the height is assumed to follow the shape of the fundamental mode. For taller buildings, or for buildings in which stiffness varies from floor to floor, this assumption does not always hold, and higher modes of vibration can increase the forces in the upper storeys.

The response spectrum method provides a way to include the effect of several vibration modes without performing a full time history analysis. The natural periods and mode shapes of the building are first determined, and the peak response of each mode is obtained from a design spectrum that represents the expected ground shaking for the site. These modal peaks are then combined statistically to estimate the total response. IS 1893 (Part 1):2016 makes dynamic analysis mandatory for many categories of buildings, including regular buildings taller than 15 m in zones IV and V and all irregular buildings above a certain height.

This paper applies the response spectrum method to a G+10 storey RCC residential building located in seismic zone III. The objective is to model the building in ETABS, carry out modal and response spectrum analysis, compare the results with the equivalent static method, check storey drifts and displacements against code limits, and design the main structural members as per IS 456:2000. The study is intended to give undergraduate students a clear picture of how seismic analysis is carried out in current design practice and how the results influence the sizing and detailing of structural members.

II. LITERATURE SURVEY

Research on the seismic response of reinforced concrete frames has a long history, and many studies have compared the equivalent static method with dynamic procedures for buildings of different heights. Investigators who analysed regular frames of four to twenty storeys generally found that the equivalent static method gives reasonable base shear values for low-rise buildings but tends to misrepresent the distribution of shear over the height of taller buildings. In buildings above about ten storeys, the contribution of the second and third modes becomes significant, and the static method underestimates the storey shear and moment in the upper floors. Several authors have also noted that the fundamental period estimated from the empirical code formula is usually shorter than the period obtained from modal analysis. Because the design spectrum decreases with increasing period, the static method frequently yields a higher base shear, which is why codes require the dynamic results to be scaled to the

static value. These observations form the basis on which dynamic analysis has been made compulsory for many building categories.

The provisions of IS 1893 (Part 1):2016 have been studied in detail by researchers seeking to understand how the revision changed design forces compared with the earlier 2002 version. The revised code introduced a separate design spectrum for analysis methods, modified the approximate period formula to account for the presence of masonry infill, and specified a minimum design horizontal acceleration coefficient irrespective of the computed period. Studies comparing both editions for identical buildings reported moderate increases in design base shear for buildings on soft soil and in higher zones. Researchers also highlighted the importance of the importance factor and the response reduction factor, since the ratio of these two terms directly controls the level of force for which the structure is designed. The adoption of R equal to 5 for special moment-resisting frames assumes that ductile detailing according to IS 13920 is provided, and many authors have warned that this assumption becomes unsafe when detailing requirements are ignored on site.

The choice of modal combination rule has been examined in a number of analytical studies. The Square Root of Sum of Squares rule is simple and accurate when the natural periods of the contributing modes are well separated, but it can underestimate or overestimate the response when two or more modes have closely spaced periods. The Complete Quadratic Combination method accounts for the correlation between modes through cross-modal coefficients that depend on the damping ratio and the ratio of modal frequencies. Studies on symmetric and asymmetric buildings found that the difference between the two rules is small for regular plans but can become considerable in torsionally sensitive buildings, where translational and torsional modes have similar periods. IS 1893 therefore recommends the CQC method as the general procedure, and researchers have also emphasised that enough modes must be included to capture at least 90 percent of the total seismic mass in each direction so that the higher mode effects are not lost.

The importance of storey drift as a performance indicator has been widely discussed in the literature on seismic design. Excessive inter-storey drift damages non-structural elements such as masonry partitions, glazing and service lines, and it also increases the secondary moments caused by the axial load acting on the displaced columns. Studies of buildings damaged in past Indian earthquakes observed that many failures occurred at storeys where the stiffness was suddenly reduced, as in the case of open ground storeys used for parking. Researchers who analysed such soft storey buildings with the response spectrum method reported drift concentrations at the weak storey that were several times higher than at the floors above. These findings led to the stiffness and strength irregularity checks now included in the code. Several authors also noted that the rigid diaphragm assumption, which is commonly used in software models, is reasonable for regular buildings with cast-in-situ slabs but may need to be reviewed for plans with large openings or re-entrant corners.

The use of commercial analysis software such as ETABS, STAAD.Pro and SAP2000 for seismic analysis has been the subject of many comparative studies. Researchers who analysed the same building in different programs reported that the natural periods, base shear and storey displacements generally agreed within a few percent when the modelling assumptions were kept identical. Differences mainly arose from the treatment of rigid end offsets at beam-column joints, the stiffness modifiers applied to cracked sections, and the handling of mass source definitions. Several studies

recommended applying cracked section stiffness factors of about 0.35 for beams and 0.70 for columns, since uncracked stiffness underestimates the period and overestimates the forces. The literature also points out that software output must always be checked by simple hand calculations of total weight, base shear and approximate period, so that modelling errors are detected early. The present study follows this approach by combining ETABS modelling with manual verification of key quantities.

III. SYSTEM ANALYSIS

The structure studied is a G+10 storey reinforced concrete residential building with a regular rectangular plan of 20 m by 16 m and a typical storey height of 3.0 m, giving a total height of 33 m above the plinth. The lateral load resisting system is a special moment-resisting frame with columns at a spacing of 4 m in both directions. The building is located in seismic zone III with a zone factor of 0.16, on medium soil, with an importance factor of 1.0 and a response reduction factor of 5. Dead load includes self-weight of members, floor finish of 1.0 kN/m² and wall loads from 230 mm external and 115 mm internal masonry, while an imposed load of 2.0 kN/m² is applied on floors and 1.5 kN/m² on the roof as per IS 875 (Part 2). For seismic weight, 25 percent of the imposed load is considered on floors. The parameters studied are the natural periods, modal mass participation, base shear, storey displacement, inter-storey drift, storey shear and the design forces in beams and columns.

Existing System

In conventional practice, many low and medium-rise RCC buildings are designed using manual calculations supported by spreadsheets, and the seismic force is estimated only by the equivalent static method. The designer calculates the seismic weight of each floor, estimates the fundamental period from the empirical formula given in IS 1893, reads the spectral acceleration coefficient, and computes the design base shear. This base shear is then distributed over the height using a parabolic formula that assumes the building vibrates predominantly in its first mode. The lateral forces obtained are applied to plane frames that are analysed one at a time by approximate methods such as the portal method or the cantilever method, or by simple two-dimensional frame programs. The effects of torsion, higher modes, and the actual distribution of stiffness in the building are either ignored or included through simplified factors. Drift checks are often skipped because displacements are difficult to compute by hand, and the design of beams and columns is carried out member by member using SP 16 charts, which makes it slow to revise the design when member sizes change.

Disadvantages of Existing System

- Lateral force distribution assumes a first-mode shape and ignores higher mode effects.
- The empirical period formula may not represent the actual stiffness of the building.
- Analysing plane frames separately ignores the three-dimensional interaction of frames.
- Accidental and natural torsion are treated only through approximate factors.
- Storey displacements and drifts are difficult to compute accurately by hand.
- Irregularities in mass or stiffness are not easily identified or quantified.
- Manual handling of many load combinations increases the chance of calculation errors.

- Revising member sizes requires repeating a large amount of calculation.
- Approximate methods give only rough values of member forces at critical joints.
- Results are difficult to present clearly for review and checking by other engineers.

Proposed System

The proposed approach models the complete building as a three-dimensional frame in ETABS and carries out response spectrum analysis according to IS 1893 (Part 1):2016. Beams and columns are modelled as frame elements with cracked section stiffness modifiers, slabs are modelled as membrane elements with rigid diaphragm action at every floor, and the supports are fixed at the foundation level. Mass is defined from the dead load and 25 percent of the imposed load, and modal analysis is performed to obtain at least twelve modes so that more than 90 percent of the mass participates in each direction. The design spectrum for medium soil is applied in the X and Y directions with 5 percent damping, and modal responses are combined by the CQC method. Accidental eccentricity of 5 percent of the plan dimension is included. The dynamic base shear is compared with the static base shear and scaled where necessary. Load combinations from IS 1893 and IS 456 are then used to design beams and columns, and drift and displacement are checked against code limits.

Advantages of Proposed System

- Captures the contribution of higher vibration modes to storey forces and displacements.
- Uses natural periods obtained from the actual mass and stiffness of the model.
- Analyses the building as a complete three-dimensional structure with diaphragm action.
- Includes torsional effects and accidental eccentricity directly in the analysis.
- Gives storey displacements and inter-storey drifts for direct comparison with code limits.
- Makes irregularities in stiffness or mass visible through modal and drift results.
- Handles all required load combinations automatically and consistently.
- Allows member sizes to be revised and the model reanalysed quickly.
- Produces member forces and reinforcement requirements for every beam and column.
- Presents results in tables and diagrams that are easy to review and verify.

IV. METHODOLOGY

The study begins with the collection of architectural data, including the plan dimensions, storey heights and intended use of the building, followed by the selection of preliminary member sizes of 300 mm by 450 mm beams, 450 mm by 450 mm columns and 150 mm slabs. Material properties for M25 concrete and Fe500 steel are defined in ETABS, and the grid, storeys and structural members are modelled. Dead loads, imposed loads and wall loads are assigned according to IS 875 (Parts 1 and 2), and the mass source is defined for seismic weight. Modal analysis is carried out to obtain natural periods and mass participation. The equivalent static method is then applied to find the static base shear, and the response spectrum load cases are defined in both directions using the IS 1893 spectrum for medium soil. After scaling the dynamic base shear, storey displacements, drifts and storey shears are extracted and compared. Finally, beams and columns are designed for the governing load combinations as per IS 456:2000 and checked for ductile detailing.

SYSTEM ARCHITECTURE

Seismic Analysis of RCC Building Using the Response Spectrum Method

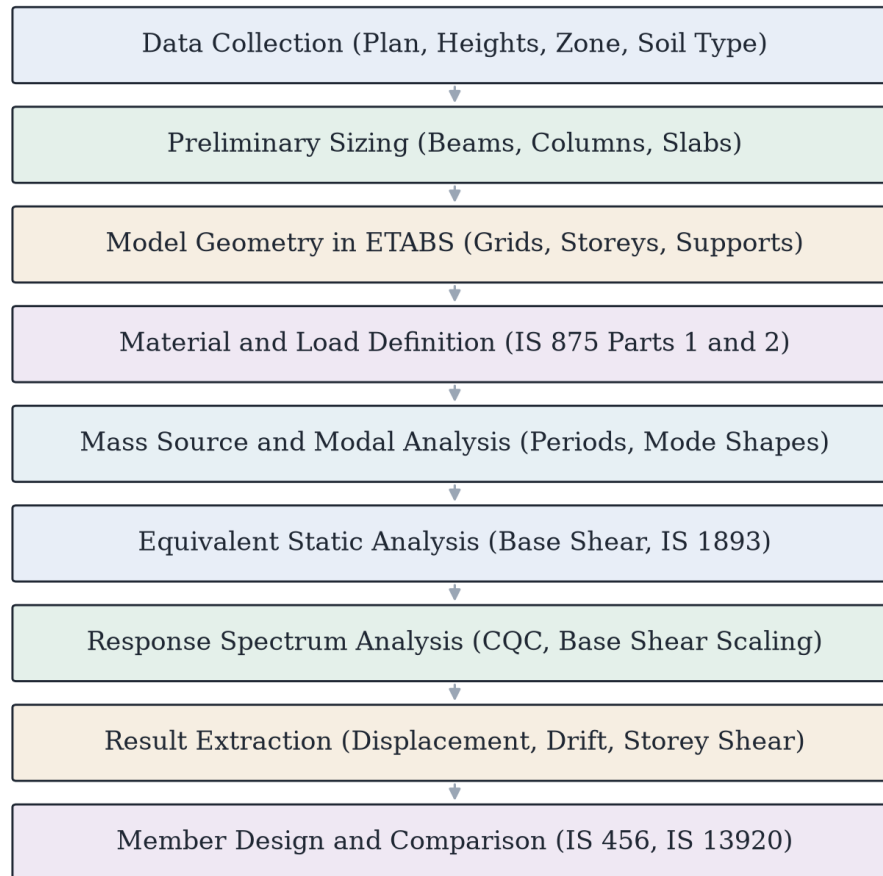


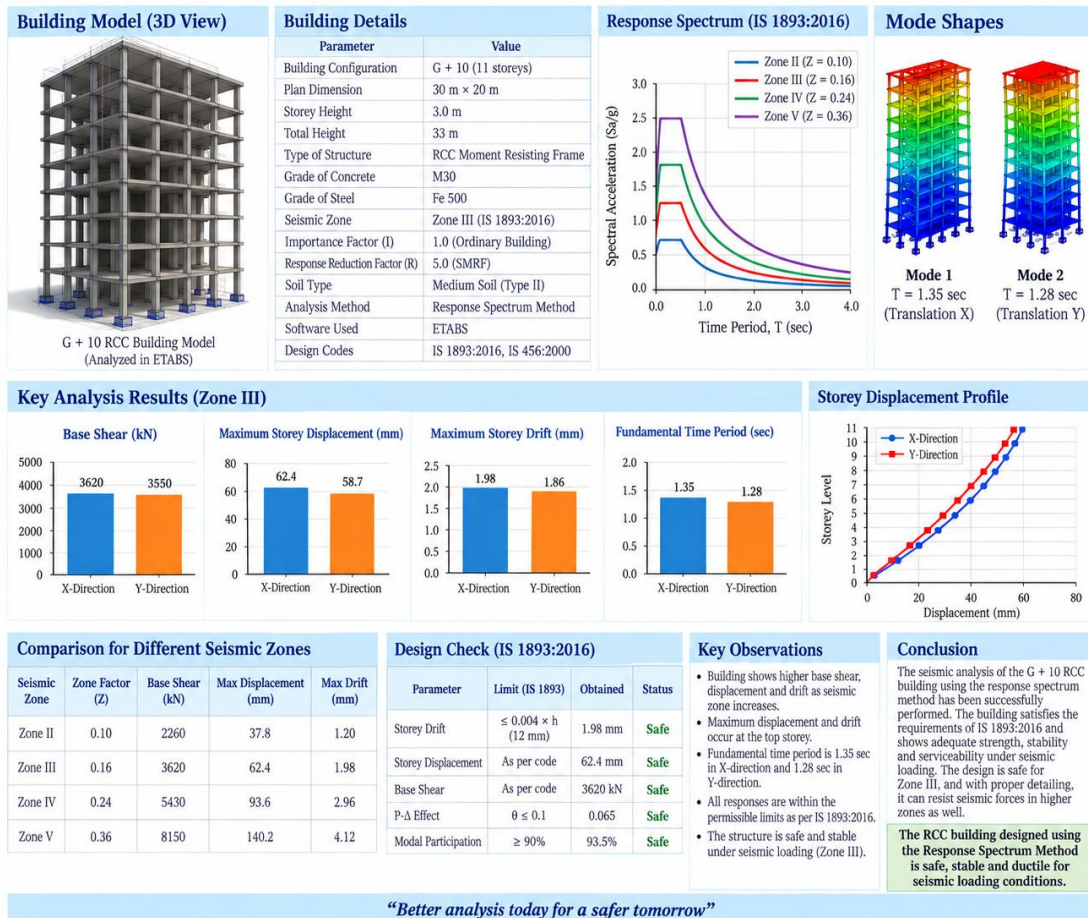
Fig. 1 System Architecture

The workflow of the study is arranged as a sequence of stages that lead from basic building data to final design results. The Data Collection stage gathers the plan layout, storey heights, occupancy and site seismic parameters. The Preliminary Sizing stage fixes trial dimensions of beams, columns and slabs based on span and load. The Model Geometry stage creates the grid, storeys and frame members in ETABS and assigns sections and supports. The Material and Load Definition stage assigns concrete and steel properties and applies dead, imposed and wall loads. The Mass Source and Modal Analysis stage defines seismic weight and computes periods and mode shapes. The Static Seismic stage computes base shear by the equivalent static method. The Response Spectrum stage applies the IS 1893 spectrum and combines modes by CQC with scaling of base shear. The Result Extraction stage reads displacements, drifts, storey shears and member forces, and the Design and Comparison stage designs members to IS 456 and compares static and dynamic results.

V. RESULT AND OUTPUT

Seismic Analysis of RCC Building Using the Response Spectrum Method

Analysis as per IS 1893:2016 and Design as per IS 456:2000



"Better analysis today for a safer tomorrow"

VI. CONCLUSION

The seismic analysis of a G+10 storey RCC residential building in zone III has been carried out using the response spectrum method in ETABS, following the provisions of IS 1893 (Part 1):2016. The three-dimensional model with rigid floor diaphragms and cracked section properties gave natural periods that were longer than the value obtained from the empirical code formula. Twelve modes were sufficient to achieve more than 90 percent modal mass participation in both principal directions, which confirms that the dynamic response of the building was adequately represented.

The comparison of the two analysis methods showed that the equivalent static method produced a higher base shear because of its shorter estimated period, and the response spectrum results were therefore scaled up to the static value as required by the code. After scaling, the dynamic analysis gave a more realistic distribution of storey shear over the height, with slightly higher forces in the upper storeys due to the contribution of the second and third modes. This distribution is important for the design of upper floor beams and columns, which would otherwise be under-designed if only the parabolic static distribution were used.

The maximum inter-storey drift obtained was well within the limit of 0.004 times the storey height, and the roof displacement was within acceptable values, which indicates that the adopted member sizes provide adequate lateral stiffness. The design of beams and columns according to IS 456:2000 showed that the earthquake load

combinations governed the design of most columns and the end regions of beams, and ductile detailing according to IS 13920:2016 is necessary for these members to develop the ductility assumed by the response reduction factor.

The study shows that response spectrum analysis using commercial software is a practical and reliable procedure for the seismic design of multi-storey RCC buildings. Future work can extend the analysis to buildings with plan and vertical irregularities, open ground storeys, shear wall and dual systems, and the effect of soil-structure interaction. Nonlinear static pushover analysis and time history analysis using recorded ground motions can also be performed to assess the actual performance of the building beyond the elastic range.

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