Comparative Seismic Performance of a G+14 RC Building Using Equivalent Static Method and Response Spectrum Method

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Abstract - *Seismic analysis is an essential aspect of structural design for buildings located in earthquake-prone regions. This study presents a comparative evaluation of seismic performance of a G+14 reinforced concrete building using the Equivalent Static Method and the Response Spectrum Method. The structural model was developed using STAAD.Pro and analyzed according to the provisions of IS 1893 (Part 1): 2016 and IS 456:2000. The comparison is carried out based on storey displacement, storey drift, base shear, and natural time period. The results indicate that the Response Spectrum Method provides a more realistic estimation of structural response compared to the Equivalent Static Method, especially for multi-storey buildings.*

***Key Words*: Seismic Analysis, Equivalent Static Method, Response Spectrum Method, RC Building, Storey Drift, STAAD.Pro**

1. INTRODUCTION

The rapid growth of urbanization has led to increased construction of multi-storey buildings. These structures are often subjected to lateral forces such as wind and earthquake loads. Earthquake forces are dynamic in nature and can significantly affect the structural stability of buildings.

Seismic design ensures that structures can resist earthquake forces without collapse and with acceptable levels of damage. In India, seismic design is governed by IS 1893 (Part 1): 2016, while reinforced concrete design is carried out according to IS 456:2000.

Two commonly used seismic analysis methods are:

a) Equivalent Static Method
b) Response Spectrum Method

The Equivalent Static Method is simple and suitable for low-rise buildings, while the Response Spectrum Method is a dynamic approach that considers modal properties of the structure.

This study focuses on comparing these two methods for a G+14 reinforced concrete building.

2. LITERATURE REVIEW

Seismic analysis of reinforced concrete (RC) multi-storey buildings has been a major focus of structural engineering research due to the increasing demand for safe and economical high-rise structures. The behavior of such buildings under earthquake loading depends on several parameters including stiffness, mass distribution, damping, and geometric configuration. Various analytical approaches have been developed to evaluate seismic response, among which the Equivalent Static Method (ESM) and the Response Spectrum Method (RSM) are widely used.

The fundamental principles of structural dynamics and earthquake response were extensively studied by **Chopra (1),** who established that the seismic behavior of structures is governed by their dynamic properties such as natural frequency, mode shapes, and damping. His work demonstrated that static methods may not adequately capture the true response of multi-storey buildings, especially when higher modes significantly influence structural behavior.

Similarly, **Duggal (2)** emphasized the importance of earthquake-resistant design and highlighted that the Equivalent Static Method is suitable for regular low-rise buildings, while dynamic analysis becomes essential for taller structures. He explained that dynamic methods provide a more realistic estimation of seismic forces by incorporating modal characteristics of the structure.

Agarwal and Shrikhande (3) studied the seismic design of reinforced concrete buildings and concluded that the Equivalent Static Method simplifies seismic forces into lateral loads distributed along the building height, whereas the Response Spectrum Method evaluates peak responses considering multiple vibration modes. Their work showed that dynamic analysis generally yields more reliable predictions for displacement and drift.

Several comparative studies have been carried out to evaluate the difference between static and dynamic analysis methods. **Bagheri et al. (4)** compared static and dynamic responses of multi-storey buildings and observed that dynamic analysis provides a more accurate distribution of forces along the height of the structure. Their findings indicated that the Equivalent Static Method may either underestimate or overestimate seismic demand depending on the structural configuration.

Research by **Gottala and Kishore (5)** demonstrated that storey displacement and drift obtained from response spectrum analysis differ significantly from static analysis results. They concluded that dynamic analysis captures the

influence of higher modes, which becomes increasingly important as building height increases.
Similarly, studies by **Meena and Grover (6)** reported that the base shear obtained from the Equivalent Static Method is often higher than the unscaled dynamic base shear. However, dynamic results are typically scaled to match codal requirements, ensuring consistency in design. Their study also highlighted that dynamic analysis provides a more realistic representation of structural response along the building height.

Research conducted by **Mahmoud and Abdallah (7)** showed that dynamic analysis methods such as response spectrum analysis account for modal participation and provide improved accuracy in predicting seismic response. They emphasized that static methods assume a simplified force distribution, which may not reflect actual behavior during earthquake excitation.

Further studies by **Meleka et al. (8)** and **Khan et al. (9)** compared static and dynamic analysis techniques and concluded that response spectrum analysis yields better results in terms of displacement, drift, and internal forces. These studies also confirmed that dynamic methods are more suitable for high-rise buildings and structures located in higher seismic zones.

According to general seismic analysis principles, the Equivalent Static Method assumes that the building responds primarily in its fundamental mode, which is valid only for low-rise and regular structures. However, as building height increases, higher mode effects become significant, making dynamic analysis necessary for accurate evaluation (10).

Recent studies using structural analysis software such as STAAD.Pro and ETABS have further reinforced these findings. Researchers have demonstrated that computational tools enable detailed modeling and accurate analysis of multi-storey buildings, allowing engineers to evaluate parameters such as storey displacement, storey drift, base shear, and modal time periods efficiently.

Overall, the literature indicates that while the Equivalent Static Method is simple and useful for preliminary design, it does not capture the dynamic behavior of structures effectively. In contrast, the Response Spectrum Method provides a more realistic assessment of seismic performance by considering modal characteristics and dynamic response.

Therefore, for a G+14 reinforced concrete building, especially in higher seismic zones, a comparative study of these two methods is essential to understand variations in displacement, drift, and base shear, and to ensure safe and economical structural design.

3. METHODOLOGY

The methodology adopted in this study involves modeling, analysis, and comparison of seismic performance of a G+14 reinforced concrete building using two different approaches: the Equivalent Static Method (ESM) and the Response Spectrum Method (RSM). The entire process is carried out using STAAD.Pro in accordance with relevant Indian Standard codes.

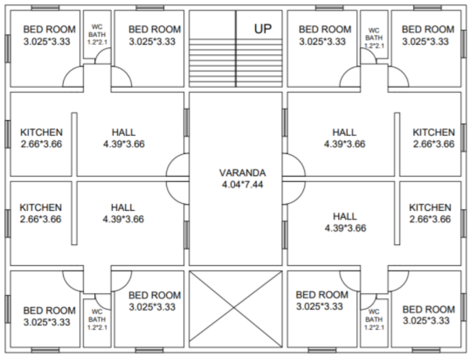

Figure 1. Building Plan

3.1 General Approach

The study follows a systematic procedure:

a) Selection of building geometry and structural configuration
b) Modeling of the building in STAAD.Pro
c) Assignment of material properties
d) Application of loads (dead load, live load, seismic load)
e) Definition of seismic parameters
f) Analysis using Equivalent Static Method
g) Analysis using Response Spectrum Method
h) Extraction of results
i) Comparative evaluation of results

3.2 Building Modeling

The building is modeled as a three-dimensional reinforced concrete frame structure using beam and column elements.

a) The structure consists of **G+14** storeys.
b) Each storey has a height of **3 m.**
c) Total height of the building is **45 m.**
d) The plan configuration is considered regular and symmetrical.

Structural Member Sizes:

Columns: 400 mm × 600 mm
Beams: 230 mm × 500 mm
Slab thickness: 150 mm

The supports are assumed to be fixed at the base, representing rigid foundation conditions.

3.3 Material Properties

Material properties are defined as per:

- IS 456:2000
- Concrete Grade: M30
- Modulus of Elasticity: 5000√fck
- Steel Grade: Fe500

These properties are assigned to all structural members in the model.

3.4 Load Considerations

Loads are applied according to:

- IS 875 (Part 1): 1987 – Dead Load
- IS 875 (Part 2): 1987 – Live Load

(a) Dead Load

Self-weight of structural members (automatically calculated)

- Floor finish: 1 kN/m²
- Wall load: 12–15 kN/m

(b) Live Load

Typical residential load: 3 kN/m²

3.5 Seismic Load Parameters

Seismic loads are applied according to:

- IS 1893 (Part 1): 2016

Table 1. Seismic Parameters

Parameter	Value
Zone Factor (Z)	0.36
Importance Factor (I)	1.0
Response Reduction Factor (R)	5
Damping	5%
Soil Type	Medium

3.6 Equivalent Static Method (ESM)

In this method, the total seismic base shear is calculated using:

$$V_b = A_h \times W$$

Where:

- V_b = Base shear
- A_h = Horizontal seismic coefficient
- W = Seismic weight

The base shear is distributed along the building height as per IS 1893 provisions.

Steps followed:

a) Calculate seismic weight of the structure
b) Determine design horizontal seismic coefficient
c) Compute base shear
d) Distribute lateral forces at each storey
e) Perform static analysis

3.7 Response Spectrum Method (RSM)

The Response Spectrum Method is a dynamic analysis technique that considers multiple modes of vibration.

Steps followed:

a) Perform modal analysis to obtain:
b) Natural time periods
c) Mode shapes
d) Define response spectrum curve as per IS 1893
e) Apply seismic loads in both X and Y directions
f) Combine modal responses using:
g) SRSS (Square Root of Sum of Squares) or
h) CQC (Complete Quadratic Combination)
i) Scale results to match base shear (if required)

This method captures the dynamic characteristics of the structure more accurately.

3.8 Load Combinations

Load combinations are applied as per IS codes:

- 1.5 (DL + LL)
- 1.2 (DL + LL ± EQ)
- 1.5 (DL ± EQ)
- 0.9 DL ± 1.5 EQ

These combinations ensure safety under different loading conditions.

3.9 Parameters Evaluated

The following response parameters are extracted for comparison:

- Storey Displacement
- Storey Drift
- Base Shear
- Natural Time Period

These parameters are used to evaluate structural performance.

3.10 Comparative Analysis

Results obtained from both methods are compared based on:

- Variation of displacement along height
- Drift limits as per code
- Difference in base shear
- Influence of dynamic effects

This comparison helps in identifying the most suitable method for seismic analysis of high-rise buildings.

4. RESULTS AND DISCUSSION

The seismic analysis of the G+14 reinforced concrete building was carried out using both the Equivalent Static Method and the Response Spectrum Method in STAAD.Pro. The results obtained from both methods are compared to evaluate structural performance.

4.1 Storey Displacement

Storey displacement is an important parameter that indicates the lateral movement of the building under seismic loading.

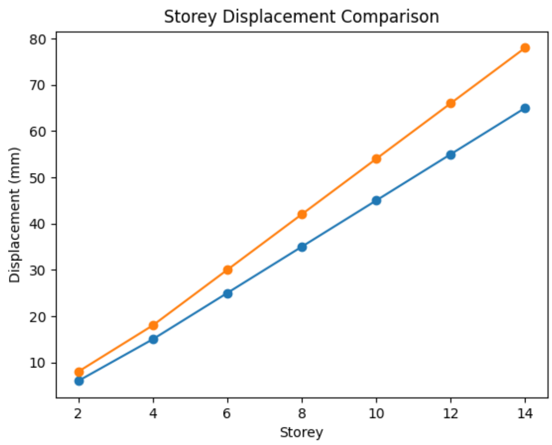

Chart 1. Storey Displacement Comparison

Table 2. Storey Displacement Comparison

Storey	Static (mm)	Dynamic (mm)
14	65	78
13	60	72
12	55	66
11	50	60
10	45	54
9	40	48
8	35	42
7	30	36
6	25	30
5	20	24
4	15	18
3	10	12
2	6	8
1	2	3

Discussion:

- Displacement increases with height
- Maximum displacement occurs at top storey
- Response Spectrum Method gives higher values
- Static method underestimates actual response

This is because dynamic analysis considers modal participation

4.2 Storey Drift

Storey drift is the relative displacement between two consecutive storeys.

Permissible drift as per IS 1893 (Part 1): 2016:

Drift Limit = 0.004 × Storey Height

For 3 m height → Limit = 0.012 m (12 mm)

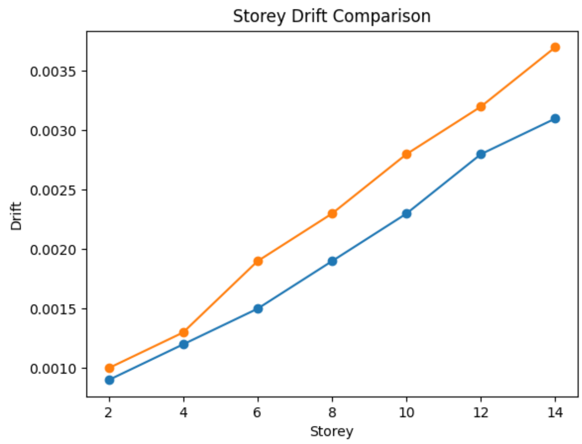

Chart 2. Storey Drift Comparison

Table 3. Storey Drift Comparison

Storey	Static Drift	Dynamic Drift
14	0.0031	0.0037
13	0.0029	0.0034
12	0.0028	0.0032
11	0.0025	0.0030
10	0.0023	0.0028
9	0.0021	0.0026
8	0.0019	0.0023
7	0.0017	0.0021

Discussion:

- Drift values are within permissible limits
- Maximum drift occurs at mid-height

- Dynamic method gives slightly higher drift

It indicates safe structural behavior.

4.3 Base Shear

Base shear represents total seismic force acting at base.

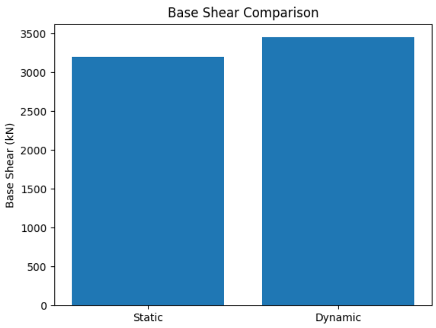

Chart 3. Base Shear Comparison

Method	Base Shear (kN)
Equivalent Static	3200
Response Spectrum	3450

Table 4. Base Shear Comparison

Discussion:

- Dynamic analysis gives higher base shear
- Indicates more realistic seismic demand
- Static method is simplified approach

4.4 Natural Time Period

Table 5. Natural Time Period

Mode	Time Period (sec)
1	1.45
2	0.92
3	0.64

Discussion:

- Time period increases with flexibility
- Important for response spectrum calculation
- Dynamic method uses actual stiffness

4.5 Overall Comparison

Table 6. Overall Comparison

Parameter	Static Method	Dynamic Method
Displacement	Lower	Higher
Drift	Lower	Slightly Higher
Base Shear	Lower	Higher
Accuracy	Moderate	High

Key Observation:

- Response Spectrum Method provides more accurate and realistic results
- Equivalent Static Method is suitable only for preliminary design

5. CONCLUSION

A comparative seismic analysis of a G+14 reinforced concrete building was carried out using the Equivalent Static Method and the Response Spectrum Method with the help of STAAD.Pro in accordance with the provisions of IS 1893 (Part 1): 2016.

Based on the results obtained from the analysis, the following conclusions can be drawn:

1. The storey displacement increases progressively with height for both methods; however, the values obtained from the Response Spectrum Method are consistently higher than those from the Equivalent Static Method. This indicates that static analysis tends to underestimate lateral deformation in multi-storey buildings.

2. Storey drift values obtained from both methods are within the permissible limits specified by the code, confirming that the structure satisfies serviceability requirements. However, the dynamic method shows slightly higher drift values, especially in the middle storeys.

3. The base shear calculated using the Response Spectrum Method is marginally higher than that obtained from the Equivalent Static Method. This suggests that dynamic analysis provides a more realistic representation of seismic forces acting on the structure.

4. The natural time period obtained from modal analysis reflects the actual stiffness and mass distribution of the building, which is not explicitly considered in the Equivalent Static Method.

5. The Equivalent Static Method is simple, less time-consuming, and suitable for preliminary design or low-rise regular structures. However, it does not capture the dynamic characteristics of tall buildings effectively.

6. The Response Spectrum Method, being a dynamic analysis approach, considers modal participation and provides a more accurate and reliable estimation of seismic response for multi-storey buildings.

Overall Conclusion:

For high-rise reinforced concrete buildings such as G+14 structures, especially in higher seismic zones, the Response Spectrum Method is recommended over the Equivalent Static Method for accurate evaluation of seismic performance. The comparative study highlights the importance of dynamic analysis in ensuring structural safety, reliability, and code compliance.

The findings of this study can be useful for structural engineers in selecting appropriate seismic analysis methods for the design of multi-storey reinforced concrete buildings."

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