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# A Review on Seismic Analysis of RCC and Steel Structures using Linear and Non-linear Static Analysis

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**Abstract:** An earthquake can cause significant harm to various aspects, including buildings, general life, and particularly multi-story structures. In India, structures constructed in earthquake-prone regions, as defined by IS 1893: 2002, must be designed to withstand the loads, stresses, and consequences of earthquakes. Several techniques are available for assessing multi-story structures in this context, such as the Response Spectrum Method, Equivalent Lateral Force Method, Time History Method, and adhering to specific code provisions. Numerous researchers have undertaken studies to analyze multi-story buildings using one or more of these methods. However, there exists still a confusion about an effective and efficient method preferred for seismic design of multi-story buildings. Among the various approaches, the seismic coefficient method and response spectrum method are the most widely used. This comparative investigation aims to review research reports that have employed the Equivalent Lateral Force Method and Response Spectrum Method to analyze multi-story buildings in earthquake-prone areas. The design response spectrum serves as the initial reference point for most established seismic design and assessment procedures. It primarily dictates the inertia forces that buildings and structures must withstand during an earthquake. This paper aims to introduce and discuss contemporary concepts regarding the creation and utilization of earthquake design response spectra. Additionally, the paper highlights the various methods of seismic analysis being investigated in the past literature. It also gives an overview of various investigations being carried out using linear and non-linear static analysis of RCC structures. Many of the ideas presented are specifically aimed at aiding engineers who work in regions with low to moderate seismic activity. The main objective is to inform engineers about modern approaches to developing response spectra. This knowledge can then be applied effectively in both analytical and design contexts when dealing with earthquake-related challenges.

**Keywords:** Equivalent Lateral Force Method, Response Spectrum Method, Multistorey buildings, RCC structures, Steel structures.

## I. INTRODUCTION

Constructing reinforced concrete (RC) structures poses various challenges related to construction timelines, financial investments, and potential economic advantages. Therefore, it's advantageous to choose strategically located sites like hills and plains for building essential facilities such as hospitals, educational institutions, hotels, and office complexes that employ reinforced concrete framing techniques. In earthquake-prone regions, these constructions face greater forces like shears and torsion compared to traditional building methods. Their performance may vary depending on the local soil conditions. The choice between RC and steel structure buildings depends on factors such as available materials, project budget, and completion timeline. In recent times, steel structures are increasingly preferred due to factors like their long-term return on investment. They are lightweight, reducing soil-bearing pressures and the required foundation size, which results in cost savings. Steel structures also minimize material transportation and wastage, including aggregates, formwork, and reinforcement placement. Presently, steel structures offer both economic benefits and faster construction compared to RC structures. Each client's preferences and requirements present unique challenges for engineers. Modern steel structures also offer distinctive aesthetics and designs that are visually appealing, setting them apart from RC structures.

### A. Earthquake & its Behaviour on Building

A natural calamity like an earthquake is one of the most unpredictable and deadly in the world. Not only have they caused enormous devastation in terms of human lives lost, but they have also had a significant financial impact on the impacted region. The growing awareness of and need for earthquake-resistant structural layout is a direct result of the earthquake threat.

Designer's architects, and engineers must make these constructions earthquake-resistant with their ideas. Building an earthquake-resistant structure requires expertise in earthquake physics form qualities and configuration structural behaviour in earlier earthquakes and applicable authorities' instructions and codes.

#### *B. Earthquake Resistant Design of Buildings*

The ductile chain should serve as a model for the design of buildings. Consider of a typical residential condominium building in a city: a multi-story reinforced concrete structure. Participants include horizontal and vertical beams and columns. Beams and columns transfer ground-level inertia to the floor. More ductile building additives are needed. Highly concentrated effects are caused by a column's failure, whereas the entire structure is affected by a beam's failure. As a result, beams, rather than columns, should be used as the ductile vulnerable linkages. Designing RC houses using this manner is referred as as the robust-column weak-beam plan. When designing structures for non-earthquake impacts, designers may not be able to achieve a ductile structure. As a way to improve the structure's flexibility, engineers need certain design allowances. Special seismic layout codes, such as IS:13920-1993 for RC structures, usually include such requirements. These guidelines also ensure that the participants' ductility is sufficient to prevent any damage from occurring.

#### *C. Earthquake Resistant Buildings*

Engineers no longer attempt to construct earthquake-proof dwellings in an effort to avoid damage even during the occasional but large earthquake; such structures are both excessively tough and expensive. Instead, the goal of earthquake engineering is to create structures that can withstand the effects of ground shaking without collapsing. These structures will be severely damaged during a strong earthquake, but they will not be destroyed. People and property are thereby safeguarded in earthquake-resistant dwellings, and a disaster is avoided as a consequence. Seismic design codes all around the globe include this as one of their primary goals.

#### *D. Earthquake Design Philosophy*

The theory of seismic design posits that a building's primary structural elements, which bear the responsibility of transferring both vertical and horizontal loads, ought to remain intact during moderate but frequent seismic events. However, it is plausible for non-load-bearing components to undergo structural damage. In scenarios with intermittent but mild earthquake occurrences, it is plausible to consider that some primary elements may be amenable to repair, whilst other sections of the edifice may sustain damage necessitating replacement subsequent to the seismic incident. In the occurrence of a robust and sporadic seismic event, it is plausible for the primary structural components to undergo permanent harm. Nevertheless, it is expected that the building's structural integrity will remain intact so that the building can be fully functioning in a short period of time and with little repair costs after mild shaking. In addition, the building might be operable after minor shaking if the damaged key contributors are repaired and strengthened. After a powerful earthquake, the building may become unusable, but it will remain standing so that people may be evacuated and valuables retrieved. It's important to consider the long-term effects of damage in the design process. Hospitals and hearth stations, for example, are critical for post-disaster activity and must continue to function as usual as soon as the earthquake has passed. Those structures should be able to withstand earthquakes with minimal damage, and they should be constructed to be more earthquake resistant. There is the potential for secondary flooding if dams fail during an earthquake and cause their upstream portions to flood. Therefore, dams (and nuclear power facilities) must be built to withstand much greater earthquakes.

#### *E. Importance of Seismic Design Codes*

Earthquake shocks at some point in an earthquake cause structural deformations and stresses. Such stresses and deformations need the construction of structures that can withstand them. As a result of the use of seismic codes, structures can be improved in order to resist earthquakes with minimal loss of life or property. Seismic codes are used across the world to help design engineers plan, design, specify, and construct structures. There are four advantages to constructing a structure that is earthquake resistant: exact its size, shape, and hundreds of structural gadgets allow a straight and clean transfer of inertia forces to the floor.

Maximum lateral electricity: The damage inflicted does not result in disintegration at this maximum level of horizontal force. Its lateral load resisting system is rigid enough to protect its contents from minor earthquake deformations. Right ductility: the ability to deform massively during strong seismic shaking, even when yielding is developed by favourable layout and detailed tactics. These aspects are covered under seismic codes.



#### *F. Seismic Methods of Analysis*

The seismically induced forces in systems can be analyzed. Based on external motions, structural behaviour, and structural model, structural evaluation can be done. Evaluation systems can be broken down into subcategories. The approach of assessment can be categorized based on the characteristics of the variables being evaluated. Analyses may be classified into four types depending on how they evaluate external action and shape behavior: linear static, static, non-linear, and non-linear dynamic. Linear static analysis or equal static assessment can be employed for low-height systems. Response spectrum or elastic time history can be used for linear dynamic analysis. The amplitude and utilization of forces at the form's apex varies substantially between sequential static and limited component evaluations. Non-linear stable analysis is better than linear statically or dynamically for inelastic structures. Simply said, the approach is easy to use and may give valuable information on the shape's vitality and ductility. When designing and specifying a building, it's useful for pinpointing the individuals most at risk for entering a limit condition as a result of an earthquake. In contrast, the non-linear static methodology relies on a series of assumptions that do not account for loading techniques, higher states of vibration, or resonance. For systems that react in general to the main mode, this approach, defined as pushover analysis, gives a simple computation of the total world deformation capability.

Non-linear dynamic analysis or inelastic time-history assessment are simpler ways to explain seismic events. The structural element's elastic-plastic deformation is taken into account by precise integrals of the linear differential equations. The content of this work is focused on the most fundamental techniques of dynamic assessment, such as the seismological factor approach, dynamic evaluation, and a short introduction to time-history analysis. In the next parts, we'll go into further depth.

#### *G. Basic Assumptions*

The following elements are made regarding earthquake-resistant system layouts: When an earthquake strikes, it sends shockwaves through the earth's crust that can be confusing and unnatural to witness in person because of the rapid changes in period and amplitude that occur. Because it would take time to build resonant amplitudes of the sort seen under constant-state sinusoidal excitations, this form of resonance will no longer occur. However, long-distance waves and towering buildings built on deep, fragile soils have been shown to produce resonance-like circumstances. Winds, effective floods, and high sea waves are unlikely to occur at the same time as an earthquake. High winds and most sea waves are unlikely to accompany a major earthquake. Therefore, it is reasonable to assume that these potentially dangerous conditions are not happening simultaneously. The cost of a substance's elastic modulus may be used for static analysis anywhere it is essential, unless a more particular value is needed in one of these cases, in which case a more specific value must be used. Remember that the modulus of elasticity of various industrial materials might vary substantially.

## **II. METHODS OF ELASTIC ANALYSIS**

The linear assessment of the construction with the design segment for inelastic objects is the approach that is used most often to estimate the results of yielding, and thus serves as the foundation for analytical methods. The forces and displacements of each horizontal element in an idealized building with one lateral degree of freedom compatible with the ground in the ground movement factor are calculated one at a time. Evaluation can be done using the equivalent lateral force method (static) or response spectrum analysis (dynamic). The elastic time-records approach is another delicate dynamic assessment method. For both lateral pressure and response spectrum evaluations, the floor motion element generates lateral forces. With regard to lateral forces above the building's apex, there are significant discrepancies between these two techniques. The equal lateral pressure method is particularly well suited to the early stages of a building's design. An elastic time-recording technique or other delicate method is utilized to evaluate the reaction spectrum based on the basic design of the building.

#### *A. Equivalent Lateral Force Method (Seismic Coefficient Method)*

The hypothesis that the horizontal displacement is equal to the real (dynamic) loading is still used in seismic design of maximum constructions. Instead of requiring periods and forms of improved natural mode of vibration, this strategy only necessitates the fundamental duration. In order to determine the total lateral pressure at the bottom shear, the structure's mass, essential length of motion, and associated form must be taken into consideration. In accordance with the coding system, the base shear is transported with the structure's peak in terms of lateral forces. Using two orthogonal lateral instructions, two different planar models are examined side by side. The outcomes and many repercussions, includes torsional movements with in structure to obtain effective standard floor plan.

### *B. Response Spectrum Analysis*

Mode superposition or modal approach is another name for this procedure. For systems in which modes other than the critical one have a significant impact on shape response, this technique is appropriate. When it comes to modal deformation, each mode has its own specific way of deformation, as well as its own frequency, and it also has its own damping. An SDOF oscillator containing attributes reflective of the specific mode and the degree to which it is activated by the seismic movement may be evaluated to determine the historical record of each modal response. Because an earthquake's response is typically caused by lower modes of vibration, it's best to start analyzing reactions in the first few modes. A complete modal analysis provides the records of a structure's reaction forces, displacements, and deformations to exact ground acceleration data. However, for design purposes, the whole responsiveness history is rarely required; the highest reaction values during the course of the earthquake are usually sufficient. Since the SDOF oscillator's reply represents each vibrational mode, the seismic response spectrum can immediately calculate the mode's maximum reaction. Merging modal maxima can approximate the maximum volume of total response. This linear response assessment approach may be used to any three-dimensional structural system in its most generic form. To simplify the overall scenario, it may be applied only to aircraft lateral motion for the purpose of designing houses. The findings of the two studies, as well as the results of rotational movements of the structures, are combined for each of the orthogonal lateral recommendations. Structures that are unbalanced or have discontinuities or irregularity in their linear range of action might benefit from this technique. Medium-depth ground shaking creates a huge yet linear reaction within a building, making it helpful for measuring forces and cyclic loads in multi-story buildings.

### *C. Elastic time-history Method*

In the absence of non-linear behavior, linearization analysis (THA) may solve all of the drawbacks of modal response spectrum analysis. Evaluating the interaction at discrete times is more difficult using this method since it demands more processing power. In one of these methods, the relative signals of responses are kept in the evaluation histories. When interaction outcomes are taken into account as a pressure resultant, this is critical.

### *D. Equal-lateral Force and Response Spectrum Analysis Limitations*

Equal-lateral force and response spectrum analysis assume the same:

- 1) For determining forces and deformations, unbiased assessments of a planar idealization of the building can be combined with torsional moments from an empirical foundation for each lateral aspect of ground movement.
- 2) Using the linear structural system for inelastic constructions can estimate non-linear structural response with reasonable precision. Both approaches are likely to fail when the structure's dynamic action deviates greatly from these assumptions and when rotational and perpendicular motions are strongly connected. In other words, when both of these conditions are met, the techniques will be inadequate. Residences with coupled lateral-torsional movements have large eccentricities on storey resistance facilities compared to floor mass facilities due to near declining mode frequencies and identical mass and resistance centers. Unbiased evaluations of the two lateral guidelines will not enough for such buildings, and the idealized model should cover at least three basic components per floor-translational movements and one torsional motion. Analyzing the version may be done using the modal method and relevant extensions of the idea in question. It is important to remember that natural modes of vibration can be aroused by both horizontal and longitudinal ground movement, and that longitudinal ground movement can excite torsional modes. Natural transmissions of a structure having linked lateral torsion movements.

### *E. Equal Lateral Force vs. Response Spectrum Analysis*

Horizontal pressure system and reaction spectrum assessment method are based on the same assumptions and apply to homes with dynamic reaction behaviour that matches the lateral pressure system evaluation assumptions. Base shear and lateral force distribution have a significant role in the differences between these two approaches. There are simple formulas for distribution of forces suitable for homes with normal mass and stiffness distribution over height, but the modal approach uses composite intervals and mode shapes of various modes of vibration to calculate force. However, the comparable lateral technique approximates the essential length and employs simple mathematics. The equal lateral pressure strategy may work for homes with neighboring homes. Floor masses, moments of inertia, and structural element go-sectional areas do not fluctuate more than 30% across adjacent floors. All floors have the same seismic pressure-resisting mechanisms. The following stages can be used to determine if the modal analysis approach is required for other buildings.

- 1) Use the equal horizontal pressure system to calculate horizontal loads and storey shears.
- 2) Structural participants' size should be estimated.
- 3) Calculate the structure's lateral displacements as a result of the lateral pressures applied in step 1 (design in step 2).

The displacements obtained in this stage are used to calculate new units of lateral forces and storey shears. Modal analysis should be performed on the structure if the recomputed storey shear (steps 4) changes by more than 30% from the accompanying unique value (step 1). The modal assessment approach is redundant if the difference is smaller than this cost, and the form should be created using the storey shears collected in step 4; they indicate an enhancement over the findings of step 1.

This method of determining modal analysis is both environmentally friendly and effective. When compared to the modal evaluation procedure, it takes a lot less computing work. In determining if the equivalent horizontal pressure system is adequate, consideration should be given to the region's seismicity and the possibility for building failure. If a home is not in a better seismic zone or doesn't house the necessary facilities for post-catastrophe stability or an extremely large number of people, the equal lateral loads system may be used to do a modal evaluation in accordance with the criteria specified.

### III.LITERATURE REVIEW

Mazza and Labernarda (2018) described the potential for producing displacement inside the isolation system and resulting in hammering between closely spaced structural components occurs due to the existence of extended, high-intensity horizontal velocity pulses in close proximity to active faults. The subject of examination is to a commercial edifice located in Augusta, Sicily, which was constructed in adherence to the seismic regulations established by the Italian authorities. The incorporation of a base isolation mechanism is a notable aspect of the construction. The implementation of a hybrid approach facilitates the seismic isolation of a rectangular structure made of reinforced concrete, which consists of a basement and three stories above ground level. The system consists of a total of sixteen high-damping-rubber bearings (HDRBs) and twenty steel-PTFE low friction flat sliding bearings. The lift shaft, constructed with a steel frame, exhibits a lack of symmetry and continues vertically through the isolation level, maintaining alignment with its longitudinal axis. The computer algorithm employed for nonlinear seismic analysis on reinforced concrete (R.C) framed structures incorporating base isolation is increased through the incorporation of advanced models of High Damping Rubber Bearings (HDRBs) and Lead Rubber Bearings (LFSBs). The comprehensive analysis of the Augusta building involves the utilization of a nonlinear dynamic assessment, incorporating near-fault earthquakes sourced from the Pacific Earthquake Engineering Research Centre's database. The seismic events' magnitudes have been appropriately adjusted to align with the design hypothesis.

Sameer, M., & Dahake, H. B (2017) examined in seismic zones III and IV of G+10 and G+15 buildings, this study evaluates reinforced concrete and composite constructions. This study compares R.C.C with Composite Structure column importance. Story Drift, Displacement, and Self-Weight control outcomes. Although seismically comparable, composite and reinforced concrete buildings differ. Different from R.C.C., composite buildings and bridges were used. Speed and cost make composite constructions appealing. Shear connections glue steel-concrete composite building systems together.

Wagh, S. A., and Waghe, U. P. (2014) described Steel-concrete composite construction is presently used extensively worldwide as an alternative to steel and concrete. Compared to other developing nations, India uses less steel in its building. India would lose out if it didn't use steel when it was available or as a less expensive option because the country's current development needs had the potential to significantly expand the amount of steel used in building. This study looks at four multistory commercial buildings (G+12, G+16, G+20, and G+24) using STAAD-Pro. When MS-Excel is used for design and cost estimation, it is possible to compare R.C.C. with composite constructions.

Srivastava, V., Joshi, R., Kumar, K., Resatoglu, R., Zain, M., & Singh, A. (2023) examined Modern light steel framing is growing due to its advantages over RCC construction. RCC structures are heavy and seismically active. The ductility of light steel constructions improves building seismic performance. Combining RCC and steel structures adds fire protection and speed to composite construction. This study favors light steel frame construction over RCC. In this work, Equivalent Static Method seismic analysis is used to analyses a G + 3 residential building in Earthquake Zone II. Individual 3D models for RCC, composite, and light steel buildings are compared. Results are compared using ETABS 2016 software for tale drift, maximum story displacement, shear force, and bending moment. The material cost of all building frames is also determined.

Divya, R., & Murali, K. (2021) described Today, time is more valuable than money, and many construction methods take a long time. Fast-erection steel structural buildings are a revolution in modern construction. Choosing a construction type based on conditions and functional needs is the best way to design a smart and effective structure.

The "Comparative study on design of Steel Structures and RCC frame Structures based on columns span" will assist us in selecting the most appropriate construction for the given circumstances and structure. This study's main focus is the column span, which, combined with building height, affects structure design and analysis and building cost. This article compares the design, analysis, and construction costs of RCC and steel structures with long and short columns. The project involves designing and analysing G+8 RCC and Steel Structures using ETABS-2018 software.

Kumar, A., & Maru, S. (2021) examined Developing countries are adopting composite constructions. Medium and High-Rise Rcc Structures Are Uneconomical Due to Dead Weight, Span Restriction, Low Natural Frequency, and Hazardous Formwork. The safety and popularity of steel and concrete composite constructions are growing. Buildings today should be steel and concrete. The G+25 Story Commercial Building in Earthquake Zone Iv is compared to Steel Concrete Composite, Steel, and R.C.C. It's equivalent static analysis. E-tabs Software Models Steel, R.C.C., and Composite Structures using Affordable Composite.

TABLE I  
COMPARISON OF LITERATURE REVIEW

Reference	Topic	Methodology/Approach	Findings
Mazza and Labernarda (2018)	Seismic isolation with base isolation mechanism	Nonlinear dynamic assessment with HDRBs and LFSBs	Displacement within isolation system due to high-intensity velocity pulses. Hybrid approach for seismic isolation in a rectangular reinforced concrete building. Near-fault earthquakes considered in analysis.
Sameer, M., & Dahake, H. B (2017)	RCC vs. Composite Structures in Seismic Zones	Evaluation in seismic zones III and IV, Story Drift, Displacement	Composite and RCC buildings differ but are seismically comparable. Speed and cost favor composite structures with shear connections.
Wagh, S. A., and Waghe, U. P. (2014)	Steel-Concrete Composite Construction	STAAD-Pro analysis, MS-Excel for cost estimation	Composite construction as an alternative to steel and RCC in multistory commercial buildings. India's potential to increase steel usage.
Srivastava, V., Joshi, R., Kumar, K., Resatoglu, R., Zain, M., & Singh, A. (2023)	Light Steel Framing vs. RCC	Equivalent Static Method analysis with ETABS, Material cost	Light steel framing favored for seismic performance, fire protection, and speed. Comparison of G+3 buildings in Earthquake Zone II.
Divya, R., & Murali, K. (2021)	Steel vs. RCC in Design and Cost	Comparative study of design and analysis with ETABS-2018	Focus on column span and building height's impact on design and cost. Comparison of G+8 RCC and steel structures.
Kumar, A., & Maru, S. (2021)	Composite vs. RCC vs. Steel in G+25 Building	Equivalent Static Analysis with E-tabs, Affordable Composite	Adoption of composite constructions in developing countries. Comparison of G+25 story commercial building.



#### IV. CONCLUSIONS

Depending on the desired accuracy of results and the importance of the building under consideration, various seismic analysis methods can be employed, including Linear Static Analysis, Nonlinear Static Analysis, Linear Dynamic Analysis, and Nonlinear Dynamic Analysis. In this study, we have thoroughly examined all of these analysis approaches.

It's crucial to note that an incorrect model, especially one that simplifies certain aspects inaccurately, can yield significantly different results from the actual building behavior. This issue becomes particularly critical in seismic conditions because if a section is designed to yield but ends up being stronger than intended, it might cause the wrong part of the structure to yield, potentially leading to structural failure. In the case of smaller structures, it may not be justified to invest significant effort in constructing a highly detailed model to investigate the effects of seismic loading. In such cases, response spectrum analysis or equivalent static analysis can be employed with minimal effort.

However, when an extremely accurate and precise analysis result is essential, non-linear dynamic analysis should be conducted. It's important to note that this method is more complex and computationally intensive. Additionally, obtaining relevant time histories for the chosen location can pose a challenge. Consequently, alternative methods may be required.

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