World Journal of Innovation and Modern Technology, Vol. 8, Issue 3, (Mar) 2025
ISSN 2682-5910

DOI: 10.53469/wjimt.2025.08(03).05

A Review on Seismic Analysis of High-rise Buildings

Zhongyu Wang

Department of Civil Engineering, University of Leeds, School of Civil Engineering, University of Leeds,
Leeds, United Kingdom

Abstract: ***This literature review is an analysis of some of the factors that affect the seismic performance of tall buildings. The increasing number of high-rise buildings globally, especially in seismically active regions, necessitates a better understanding of their seismic performance. This study focuses on the structural response of tall buildings under seismic loading and analyses various design strategies to improve stability and integrity [1]. The study examines different structural systems, including frame and box structures, and evaluates the effect of basement structures on lateral displacement and stiffness. Structural dynamic analysis and finite element modelling through software such as Abaqus are investigated with the aim of predicting and optimising the seismic performance of high-rise buildings. Comparative analyses of material properties and structural configurations were carried out to identify effective design solutions. It is expected that the results of the study will contribute to the development of better seismic strategies to ensure the safety and seismic capacity of tall buildings in earthquake prone areas.***

Keywords: High-rise buildings, Response, Frame, Predict.

1. INTRODUCTION

With the rapid expansion of urban population and land use constraints, high-rise buildings have become an essential feature of modern cities. These high-rise buildings provide a solution to spatial constraints by accommodating large populations while maximising land use. However, as high-rise buildings become more common, ensuring their structural stability, especially in earthquake-prone areas, has become a serious engineering challenge. Seismic forces pose a significant risk to high-rise buildings, necessitating an in-depth study of their dynamic response under seismic loading.

The seismic performance of high-rise buildings depends on a variety of factors, including material properties, structural stiffness, foundation design, and construction methods. Conventional structural design typically focuses on resisting gravity and lateral loads; however, high-rise buildings require additional considerations due to their height and susceptibility to dynamic forces such as wind and earthquakes. Researchers and engineers have developed a variety of seismic analysis techniques, ranging from simplified static methods to complex nonlinear dynamic simulations, to assess and improve the seismic capacity of such structures.

Currently, equivalent static analysis, eigenvalue analysis and response spectrum analysis are widely used to assess seismic effects. While these methods provide insight into structural behaviour, they have limitations in accurately capturing complex seismic loads in the real world. Factors such as material nonlinearity, damping properties and base flexibility have a significant impact on seismic response but are often neglected in simplified analysis methods. Therefore, advanced computational tools such as Finite Element Analysis (FEA) software (e.g. Abaqus) are increasingly used to simulate realistic seismic conditions and to refine structural design methods.

This study examines existing seismic performance assessment studies with the aim of identifying key parameters that affect the stability and integrity of tall buildings during earthquakes. Through a comprehensive review of different seismic analysis techniques, this study attempts to provide insights for optimising structural design to improve seismic resistance.

2. PURPOSE AND OBJECTIVES

2.1 Purpose of the Study

The main objective of this study is to conduct a comprehensive review of seismic analysis methods for tall buildings and to assess their effectiveness in predicting and improving the seismic capacity of structures.

2.2 Research Objectives

In order to achieve this objective, this study focuses on the following key objectives:

To assess the effect of structural stiffness on the seismic behaviour of tall buildings, focusing on lateral displacements and overall stability. To investigate the effect of different building materials (e.g. reinforced concrete, steel and composite materials) on seismic performance and structural integrity. Analyse the role of various structural components (including shear walls, core frames and basement structures) in resisting seismic loads.

Compare different seismic analysis methods, such as equivalent static analysis, response spectrum analysis and nonlinear dynamic analysis, to determine their relative accuracy and applicability. To propose optimal design strategies to improve the seismic capacity of tall buildings by integrating innovative structural configurations and materials.

By achieving these objectives, this study aims to provide valuable recommendations for improving the seismic safety of high-rise building structures, thereby contributing to the advancement of earthquake engineering and urban seismic resilience.

2.3 Research Methodology

2.3.1 Research Methodology

This study adopts a qualitative research methodology and conducts an extensive literature review on seismic analyses of high-rise buildings. The review synthesised previous research findings, focusing on the role of structural design, material selection and analysis techniques in determining seismic performance.

2.3.2 Data Collection and Sources

The study relied primarily on the following sources: Academic journals and conference papers related to earthquake engineering and structural analysis, Industry reports and case studies on high-rise buildings in earthquake-prone areas, Technical guidelines and building codes that regulate seismic design, such as Eurocode 8, ASCE 7, and the Chinese Seismic Design Code.

2.3.3 Seismic Analysis Techniques

In order to compare different seismic analysis methods, the following widely used methods are reviewed in this study: Equivalent Static Analysis (ESA) - A simplified method that assumes a linear elastic response and is often used for preliminary seismic evaluations. Response Spectrum Analysis (RSA) - a more refined method that considers multiple modes of vibration to estimate the dynamic response under seismic loading.

Finite Element Analysis (FEA) using Abaqus - a computational modelling technique that simulates actual seismic conditions, incorporating non-linear material behaviour and time-dependent loading. Comparative case studies - Evaluating existing high-rise buildings with different structural configurations to assess their seismic capacity.

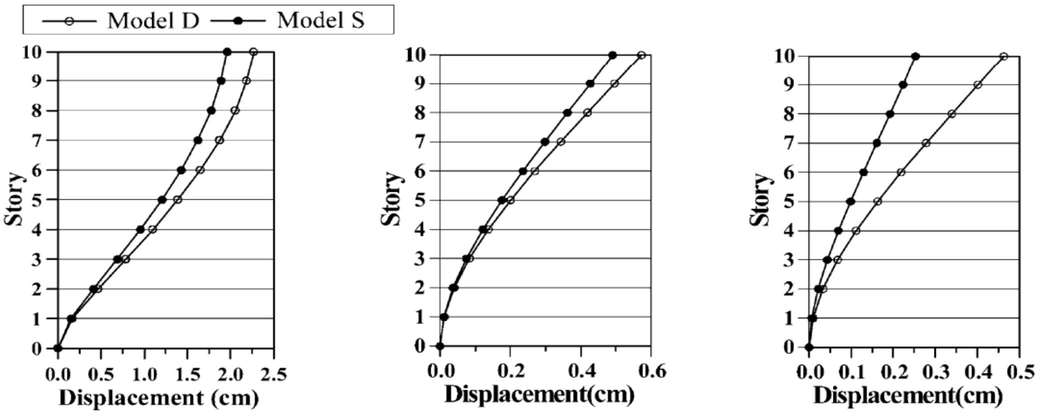
By critically evaluating these methods, this study aims to highlight the strengths and limitations of the various analysis techniques and ultimately guide the selection of the best seismic design strategy.

3. LITERATURE REVIEW

3.1 Seismic Response of Different Building Systems

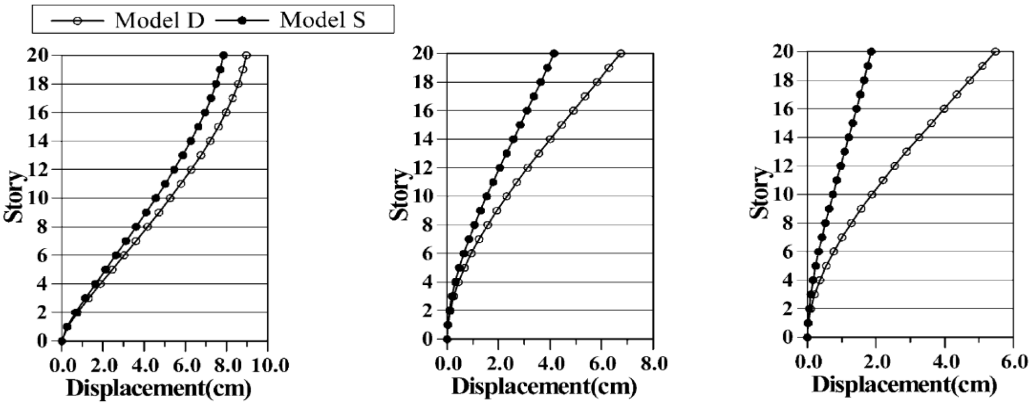
In order to study the effect of floor slabs on the seismic response, equivalent static analyses, eigenvalue analyses and response spectrum analyses have been carried out for frame and box system structures. In these analyses, two models are included for each plan type namely Model D: Rigid Diaphragm Walls (conventional method), which does not include the flexural stiffness of the floor slabs, and Model S, which introduces the flexural stiffness of the floor slabs by using slab units [2].

Three plan types were analysed for 10- and 20-storey structures. The lateral displacements from the equivalent static analyses are shown in Figures. The results of the lateral equivalent static analyses are shown in Figures 1 and Figure 2 for the 10-storey and 20-storey structures respectively.



(a) (b) (c)

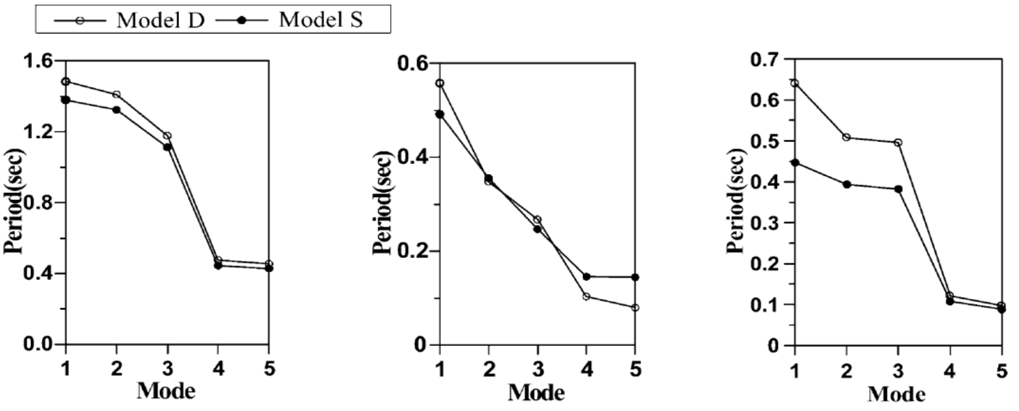
Figure 1: Displacement of 10-story. (a) Type A, (b) Type B,(c) Type C



(a) (b) (c)

Figure 2: Displacement of 20-story. (a) Type A, (b) Type B,(c) Type C

In the 10-story and 20-story analyses, the results are similar for type A; this effect is more pronounced in the 20-story box system structure; the top plate displacement of the box system structure is reduced, especially in the plots of type B and type C.



(a) (b) (c)

Figure 3: Natural periods of vibration for 10-story structures. (a) Type A, (b) Type B,(c) Type C

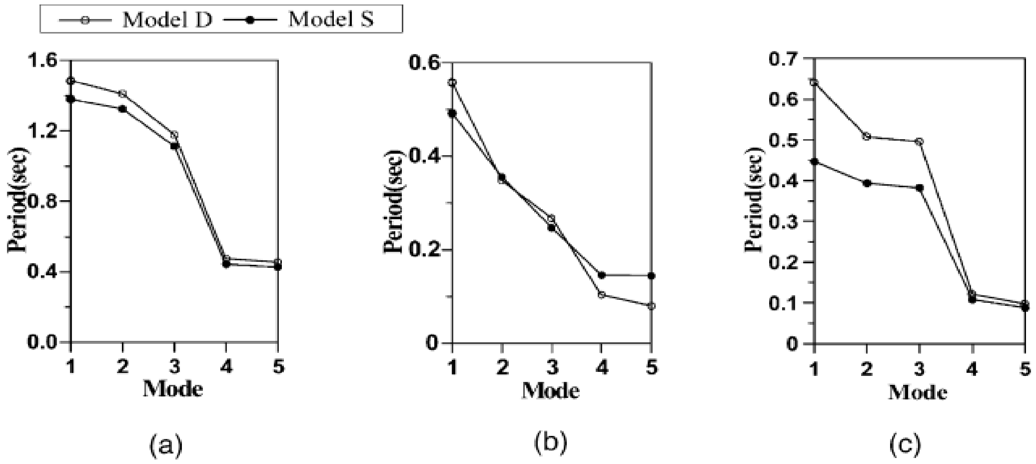


Figure 4: Natural periods of vibration for 20-story structures. (a) Type A, (b) Type B,(c) Type C

Figures 3 and 4 show the intrinsic vibration period of the example structure for 10- and 20-storey structures, respectively, to demonstrate the accuracy of the results analysed by the methodology in this dissertation.

It shows that the natural period is short in all cases when the flexural stiffness of the plate is included. Both models' results are very similar in both 10-story structure and 20-story structure. Floor effects are more pronounced in taller box system structures.

The different natural periods result in different seismic responses of the structures. The data are summarised in the Table 1 below.

Table 1: Base shear calculated from response spectrum

Plan Type	A		B		C	
Model	D	S	D	S	D	S
10-Story	19.0	19.8	36.8	38.4	66.0	71.6
20-Story	25.8	26.8	42.0	47.8	78.8	90.0

As shown in Table 1The base shear of model D is less than that of model S. Therefore, in order to obtain more accurate results, the flexural rigidity of the floor slab must be fully considered according to the actual conditions of the building. For the case of a 16-storey building, divided into four sections connected to each other by vibration isolation systems, the corresponding Fixed-Base (FB) and conventional Base-Isolated (BI) models were used [3].

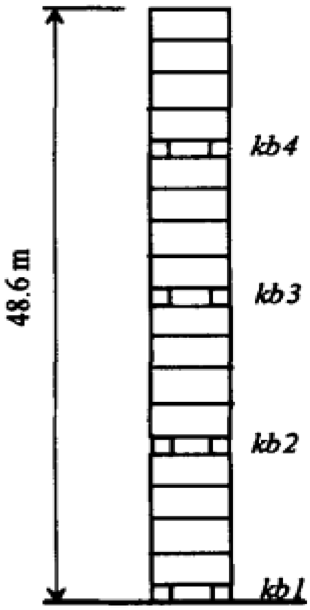


Figure 5: Example of segmental

Table2: Lateral stiffness of isolation systems

	K_{b1} (10^8N/m)	K_{b2} (10^8N/m)	K_{b3} (10^8N/m)	K_{b4} (10^8N/m)
BI model	0.68	-	-	-
SG model	1.11	12.9	6.76	2.14

Table 3: Natural frequencies (Hz)

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
FB model	1.02	2.24	4.18	5.25	6.54
BI model	0.5	1.69	3.05	4.63	6.26
SG nodel	0.54	1.35	2.48	3.92	4.61

Table 4: Participation factors

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
FB model	3.54	1.54	0.95	0.89	0.36
BI model	4.11	0.44	0.18	0.04	0.03
SG nodel	4.35	1.1	0.36	0.15	0.08

Tables 3 and 4 outline the intrinsic frequencies and participation factors for the first five modes of FB, BI, and SG models. It's noteworthy that, according to Table 3, the SG building exhibits a slightly elevated fundamental frequency compared to its BI counterpart. This suggests that if the BI building is adequately designed to withstand wind loads, the SG building should perform similarly or better under wind conditions. Furthermore, the SG buildings consistently show lower frequencies for the second and subsequent modes. Table 4 indicates that, similar to the BI building, the participation factors for the second and higher modes in the SG building are insignificant compared to the first mode factor. Consequently, higher order modes are nearly orthogonal to horizontal seismic inputs, making it challenging to transmit seismic energy at these frequencies to the structure. Like the BI building, the SG building effectively redirects ground motion energy through higher order mode orthogonality.

4. EFFECT OF BASEMENT ON SEISMIC RESPONSE OF HIGH-RISE BUILDINGS

An examination of the seismic response of a high-rise building incorporating a basement was conducted using two examples: a typical frame structure (designated as structure type A) and a frame structure augmented with a reinforced concrete core (structure type B). Both structures featured five basement levels, and their behavior was assessed by altering the number of basement floors from one to five. A comprehensive analysis, including equivalent static analysis, eigenvalue analysis, response spectrum analysis, and time history analysis, was performed on all structures. The two types of structures under consideration are illustrated in [4].

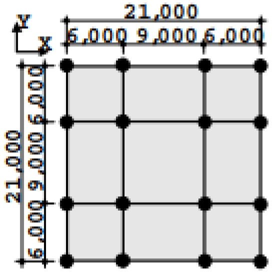


Figure 6: Structure A0& Structure B0

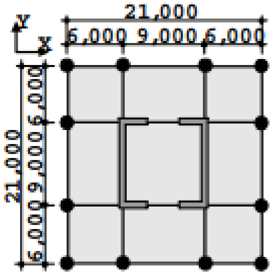


Figure7: Comparision of type A and type B latertal displacements

As the number of basement floors increased, the rotation at the bottom of the ground floor columns increased due to the flexibility introduced in the basement structure. Due to this phenomenon, the lateral displacement stiffness decreases, resulting in an increase in the lateral displacement.

This tendency is more pronounced especially in frame structures with cores. Figure 8 compares the intrinsic vibration period of the example structure.

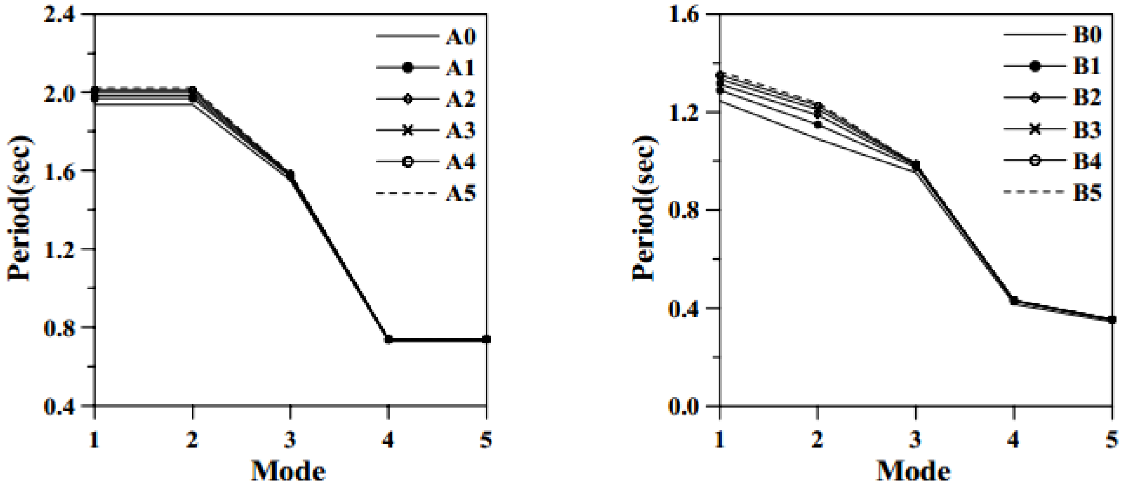


Figure 8: The effects of the basement on the type A and B natural periods

Figure 8 illustrates that as the number of basement levels rises, the natural period of both Type A and Type B structures extends. Notably, the disparity in natural period is more pronounced in lower modes compared to higher ones. This is attributed to the greater rotation of column bases in the first and second modes of vibration compared to higher modes.

Table 5: Base shear from the response spectrum analysis (unit: tonf)

Number of stories in basement	Structure type A	Structure type B
0	320.5	281.1
1	350.4	279.2
2	318.3	274.1
3	316.5	270.6
4	314.8	268.4
5	313.6	266.7

Table 5 presents the basal shear values of the sample structure derived from response spectrum analysis. Consequently, when the substructure is incorporated into the analytical model, the seismic loads in the response spectrum analysis tend to be relatively lower. Despite the minimal difference in period, the spectral acceleration difference becomes more significant at shorter periods due to the steepening slope of the response spectrum.

5. CONCLUSION

This summary outlines key factors influencing the earthquake resilience of tall buildings, especially in areas prone to seismic activity. With the global proliferation of high-rise structures, ensuring their stability during seismic events is paramount. The focus is on evaluating structural reactions and exploring design approaches to bolster their strength and integrity. Various structural frameworks, like framed and boxed designs, are scrutinized, alongside the role basement structures play in lateral movement and stiffness.

The overview touches on seismic assessment methods, such as static equivalents, eigenvalue evaluations, and response spectrums, commonly applied to gauge seismic impacts. Nevertheless, these techniques face challenges in precisely capturing intricate seismic forces, leading to the adoption of sophisticated tools like Finite Element Analysis (FEA) software (e.g., Abaqus) to mimic realistic earthquake scenarios. A comparison of seismic reactions among different architectural systems, taking into account floor slab flexibility, is conducted. Analyzing buildings of 10 and 20 stories, it's found that incorporating floor slab stiffness mitigates lateral shifts, notably in boxed structures. Furthermore, the influence of basement levels on the seismic behavior of high-rises is explored through framed structures, both with and without reinforced concrete cores. Findings suggest that incorporating the substructure into analytical models can lessen seismic loads in response spectrum assessments. In essence, this summary seeks to offer guidance on refining structural designs to enhance tall buildings' seismic tolerance, aiding in the formulation of improved seismic strategies for earthquake-hit zones.

REFERENCES

[1] Abhishek K. K1, Rajeeva S. V. Effect of Bracing Systems on Seismic Behavior of Typical RC Tall Building, Int. J. Res & Sci Inn. IV (IX) (2017) 44–49. [3] Shaikh Muffassir, L.G. Kalurkar. Comparative Study on Wind Analysis of Multi-story RCC and Composite Structure for Different Plan Configuration, J. Mech. & Civil. Eng. 13 (4) (2016) 42-49.
[2] Lee, D.-G., Kim, H.-S., & Hah Chun, M. (2002). Efficient seismic analysis of high-rise building structures with the effects of floor slabs. Engineering Structures, 24(5), 613–623. doi:10.1016/s0141-0296(01)00126-2
[3] T.-C. PAN, S.-F. LING AND W. CUI Seismic Response of Segmental Buildings. Earthquake Engineering and Strucxural Dynamics, vol. 24, 1039-1048 (1995)
[4] D.-G. Lee & H.S. Kim, Efficient seismic analysis of high-rise buildings considering the basements, NZSEE Conference, 2001