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Construction Sequence Analysis of High-rise Structure with Creep and Shrinkage Effect

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Abstract

This study deals with a time-dependent analysis of reinforced concrete G+40 frame structures considering the construction sequence with the effect of creep and shrinkage analysis. Because of the non-mechanical deformations induced by the time-dependent deformations of concrete, concrete structures usually present different behaviors when the construction sequences are changed, despite having the same structural configurations. Therefore, the time-dependent effects of concrete such as creep and shrinkage must be taken into consideration to simulate the actual behavior of reinforced concrete frame structures. In this study, we considered the static as well as dynamic analysis with the effect of creep and shrinkage analysis. The present work on creep and shrinkage analysis depends on the time-dependent approach, which is considered as 50 years of life span for providing the appropriate results for the bending moment, axial shortening, deflection, displacement in structure due to proper load distribution by considering construction in sequence manner as per realistic approach. That time-dependent property depends on the curing days for the structural elements in the buildings, that curing days considered 28 days according to the floor to floor. Due to this consideration, sequential analysis found results according to the time-dependent deflection after the 28 days on that particular story level, the 50-year life span is considered in the staged operation. We found out the final deflections and bending moments and that the actual behavior in the structure after 50 years of building construction. Methods of analysis must be considered for the serviceability criteria.

Keywords: Time-dependent analysis, construction sequential analysis, creep and shrinkage analysis, nonlinear static analysis

INTRODUCTION

In the world of urbanization and architectural advancement, the construction of high-rise structures has become a symbol of modernity and innovation. These towering giants, reaching for the sky, not only redefine skylines but also present complex engineering and logistical challenges. Understanding the construction sequence of high-rise structures is vital for ensuring their successful completion within time, budget, and safety constraints. The construction sequence analysis of high-rise structures involves a detailed examination and optimization of the various steps and processes required to erect these architectural marvels. From the initial groundwork and foundation preparation to the final topping out, each phase requires meticulous planning, coordination, and execution.

This project aims to delve into the intricate world of high-rise construction, focusing on the analysis of the construction sequence. By utilizing advanced techniques, such as computer simulations, data modeling, and project management methodologies,

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we seek to unravel the complexities and uncover the key factors influencing the construction timeline, resource allocation, and overall project success. Through this analysis, we aspire to gain valuable insights into the optimization of construction sequences, allowing for improved efficiency, reduced costs, and enhanced safety in the construction of high-rise structures. By identifying critical paths, potential bottlenecks, and the interdependencies of various construction activities, we aim to provide valuable guidance and recommendations to construction professionals, project managers, and stakeholders involved in similar endeavors.

This research project not only contributes to the academic understanding of high-rise construction but also holds practical implications for the industry. The findings and recommendations resulting from this study can be utilized to streamline construction processes, minimize delays, mitigate risks, and ultimately deliver high-rise structures that meet the ever-increasing demands of our urbanized world. By bridging the gap between theoretical knowledge and real-world application, this project strives to make a significant contribution to the field of construction engineering, ultimately shaping the future of high-rise construction practices.

AIM AND OBJECTIVES

1. Analysis of the G+40 reinforced concrete (RC) frame high-rise structure with construction stage analysis and conventional method of analysis with creep and shrinkage analysis, system subjected to static and dynamic loadings and to find out the axial shortening of column and shear wall after the 50 years of creep and shrinkage analysis.
2. To compare the displacement, bending moments, axial loads, story shear, and story drift of both the buildings using ETABS software.

LITERATURE REVIEW

Choi and Kim [1] highlight the significance of considering the construction sequence in the analysis of multistory frames. Traditional analysis methods often assume instantaneous or uniform loading, neglecting the time-dependent effects caused by sequential construction. The authors argue that this oversimplification can lead to inaccurate predictions of structural behavior. To address this issue, the authors propose an analytical approach that incorporates the sequential construction process. They discuss the effects of the construction sequence on factors such as column shortening, creep, and construction-induced deformation. The analytical method presented in the paper considers the time-dependent effects and accurately predicts the behavior of multistory frames under sequential gravity loads. The authors validate their approach through a series of numerical examples and comparisons with experimental data.

Choi et al. [2] have studied the significance of sequential dead loads in building analysis and design. Sequential loading, such as the gradual addition of permanent dead loads during construction, can cause nonlinear behavior and structural instabilities. Traditional analysis methods often overlook these effects, resulting in inaccurate predictions of structural response. To address this issue, the authors present the continuous frame method (CFM), which simplifies the analysis process while considering the effects of sequential dead loads. The CFM divides the structure into continuous frames and analyzes each frame separately. By utilizing equilibrium conditions and compatibility requirements at beam-column connections, the CFM accurately captures the redistribution of forces and moments due to sequential loading. The authors validate the CFM through a series of numerical examples and comparisons with experimental data. The numerical examples demonstrate the accuracy and efficiency of the CFM in predicting the structural response under sequential dead loads. The method successfully captures the redistribution of forces and moments, providing a reliable analysis tool for practitioners. Additionally, the paper discusses the design considerations when using the CFM for buildings subjected to sequential dead loads.

Kurc and Lulec [3] have investigated the importance of accurately estimating the axial loads on columns and structural walls in tall buildings. The analysis of axial loads is crucial for ensuring the structural integrity and performance of these elements throughout the building's lifespan. Traditional analysis methods often neglect time-dependent effects and construction sequence considerations, leading to potential inaccuracies in load estimation. To address this issue, the authors compare different analysis approaches, including construction sequence analysis, creep, shrinkage, and time-dependent deformations.

They review existing literature and research studies that investigate these factors and their influence on axial load estimation. The comparative study aims to determine the most appropriate analysis method that accounts for these time-dependent effects and provides accurate estimations of axial loads. The authors discuss the advantages and limitations of each approach, highlighting the key considerations in their application.

Kim and Abdelrazaq [4] have investigated the importance of efficient construction sequencing in high-rise buildings. The construction sequence refers to the order in which different construction activities are performed, and it plays a crucial role in determining the overall project timeline and cost. In the case of high-rise buildings with a flat plate system, the construction sequence becomes even more critical due to the complexity of the structural system. The authors present a comprehensive analysis of construction sequencing in the context of high-rise buildings with a flat plate system. They discuss the key considerations in determining the optimal construction sequence, including the structural system, floor layout, material availability, and construction equipment.

Kwak and Kim [5] provide a comprehensive review of existing literature and research studies that investigate the time-dependent analysis of RC frame structures. The authors discuss the key considerations in modeling creep and shrinkage, including material properties, stress development, and strain redistribution. They also explore the influence of the construction sequence on the development of creep and shrinkage and its implications for the structural response. Through their research, the authors highlight the significance of the prestress-deflection (P-D) effect, which occurs due to the interaction between pre-stressing and time-dependent deformations. They discuss the importance of considering the P-D effect in the time-dependent analysis of RC frame structures and its impact on the structural behavior. The findings of the paper provide insights into the behavior and performance of RC frame structures considering time-dependent effects and construction sequences. The authors demonstrate the importance of accurately modeling creep, shrinkage, and the P-D effect for predicting long-term deformations, stresses, and structural response.

Kim and Shin [6] begin their paper by highlighting the significance of column shortening in the design and construction of tall buildings. Column shortening refers to the vertical compression or settlement experienced by columns over time due to various factors such as concrete creep, shrinkage, and differential settlements. Traditional analysis methods often overlook the impact of construction sequences on column shortening, leading to potential design and performance issues. To address this issue, the authors propose an analytical approach that incorporates lumped construction sequences in the analysis of column shortening. The lumped construction sequence approach simplifies the modeling of construction stages by grouping them into discrete time intervals. By considering the cumulative effects of construction sequences, the authors aim to accurately predict the long-term column shortening behavior.

Yi and Tong [7] highlight the significance of column shortening in medium- to high-rise buildings. Column shortening refers to the vertical compression or settlement experienced by columns over time due to factors such as concrete creep, shrinkage, and time-dependent deformations. Differential column shortening occurs when columns experience varying amounts of shortening, leading to potential structural and aesthetic issues. To address this issue, the authors present a comprehensive analysis of differential column shortening effects in medium- to high-rise buildings. They discuss the key factors influencing differential shortening, including column geometry, loading conditions, material properties, and construction sequencing. The authors emphasize the need for accurate prediction and consideration of differential shortening effects in the structural design process.

SYSTEM DEVELOPMENT

The present study was conducted by sequential analysis of a prominent northern Mumbai building of G+40 RC frame structure height 121 m from ground level and only with shear wall. The floor details are given in Table 1. The aim of the study was to find out the differences in displacement, bending moments, axial loads, story shear, and story drift of a plan irregular-shaped high-rise building using ETABS software for comparing the sequential analysis and conventional analysis of high-rise RC frame structure with static and dynamic analysis in seismic zone III (response spectrum analysis and time history method) (Table 1) [8].

Table 1. Floor details.

Details	Calculations
Number of floors	G+40
Typical floor to floor height	2900 mm
Total height of the building	121.6 m
Width in X-direction	18.10 m
Width in Y-direction	20.85 m
Thickness of external wall	230 mm
Thickness of internal wall	150 mm and 230 mm
Grade of concrete	M40, M50, and M60
Grade of steel	Fe415 and Fe500
Sizes of beams	230 × 600 mm 300 × 600 mm 300 × 700 mm 400 × 700 mm 500 × 700 mm
Thickness of shear wall	230 mm and 300 mm

LOAD CONSIDERATION

The loads that are considered for this analysis are dead loads, live loads from IS code 875:2015 and earthquake loads from IS code 1893:2016.

Dead load: IS code 875 part 1 (code of practice for design loads – dead load)

1. The dead load includes the self-weights of the beam, column, and slab.
2. Floor finish = 1.5 kN/m^2 (page no. 29 IS code 875 part 1)
3. Terrace water proofing = 1.5 kN/m^2
4. External wall loads on periphery = 7.22 kN/m^2

Load calculation, external wall load = external wall thickness × unsupported length of wall × unit weight of concrete hollow block

5. Internal wall load = 3.22 kN/m^2

Live load: IS 875 part 2 (code of practice for design loads – imposed load)

1. Live load on all floors = 3 kN/m^2
2. Live load on top floor = 2 kN/m^2

Earthquake Load: IS Code 1893:2016 (Criteria for Earthquake Resistant Design of Structure)

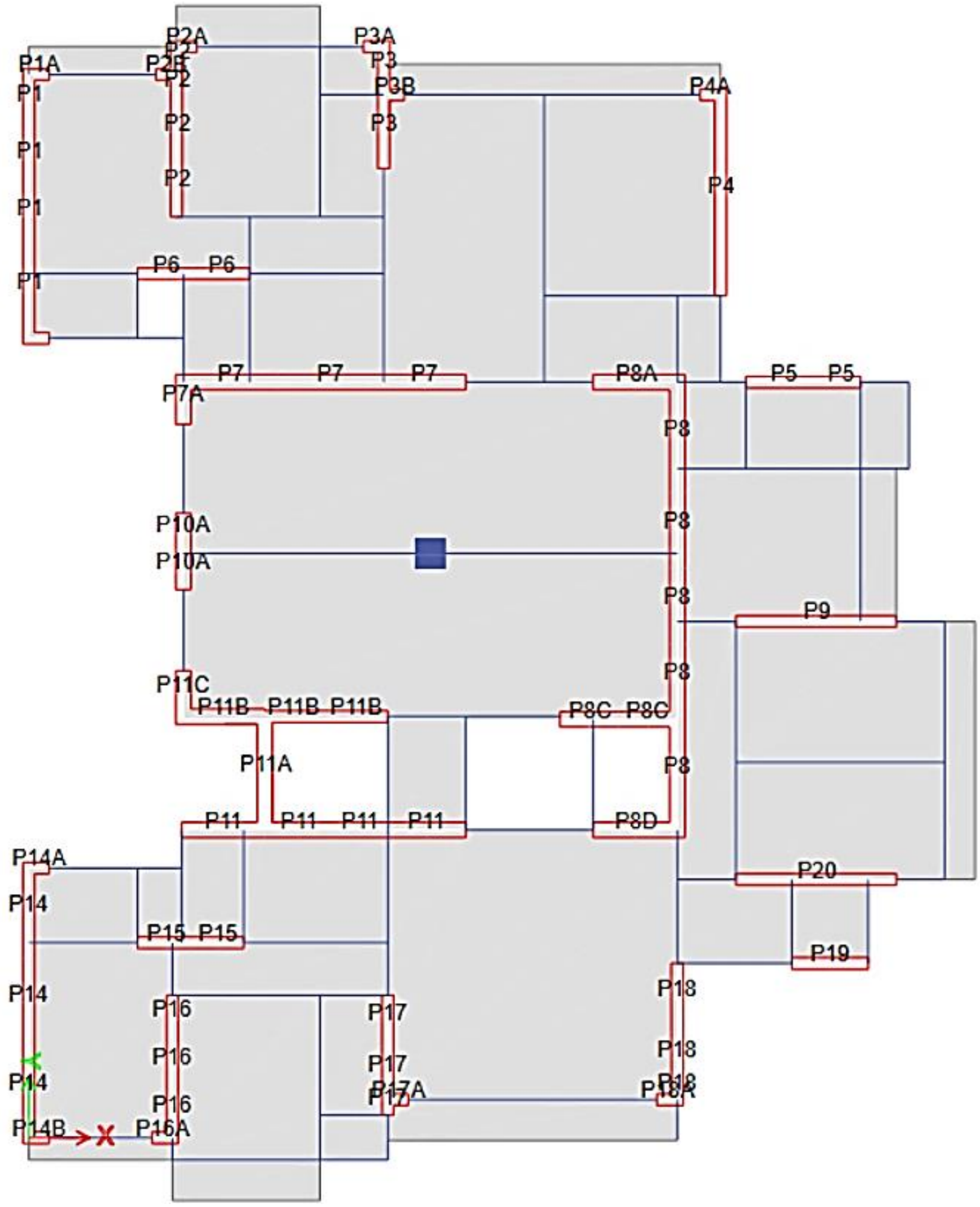
1. Seismic zone = III (Mumbai)

2. Importance factor = 1.2 (residential and commercial building with occupancy more than 200 persons)
3. Response reduction factor, *R* = 4 (building with RC ductile structural wall)
4. Type of soil = medium soil

PLAN AND 3D VIEW OF STRUCTURE IN ETABS SOFTWARE

Response Spectrum Method

The term "spectrum" refers to a graphical representation summarizing the response of buildings across a wide range of time periods in a single graph. Linear elastic response spectrum analysis is applicable to various types of structures. Response spectra are curves that depict the peak response of a single-degree-of-freedom system in terms of displacement, velocity, and acceleration against its natural frequency, considering specified earthquake ground motion or a set of such motions. Imagine a response spectrum as a visual representation of the dynamic response of a series of progressively longer cantilever pendulums, each with increasing natural periods, subjected to a common lateral seismic motion at the base of the structure (Figure 1) [9].



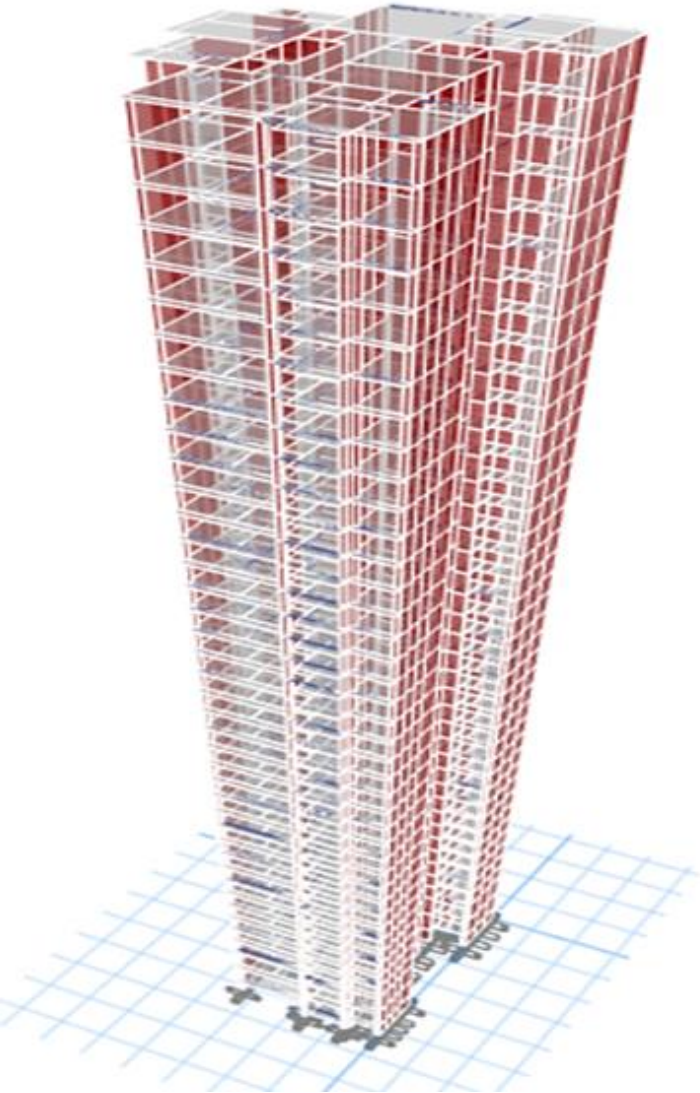
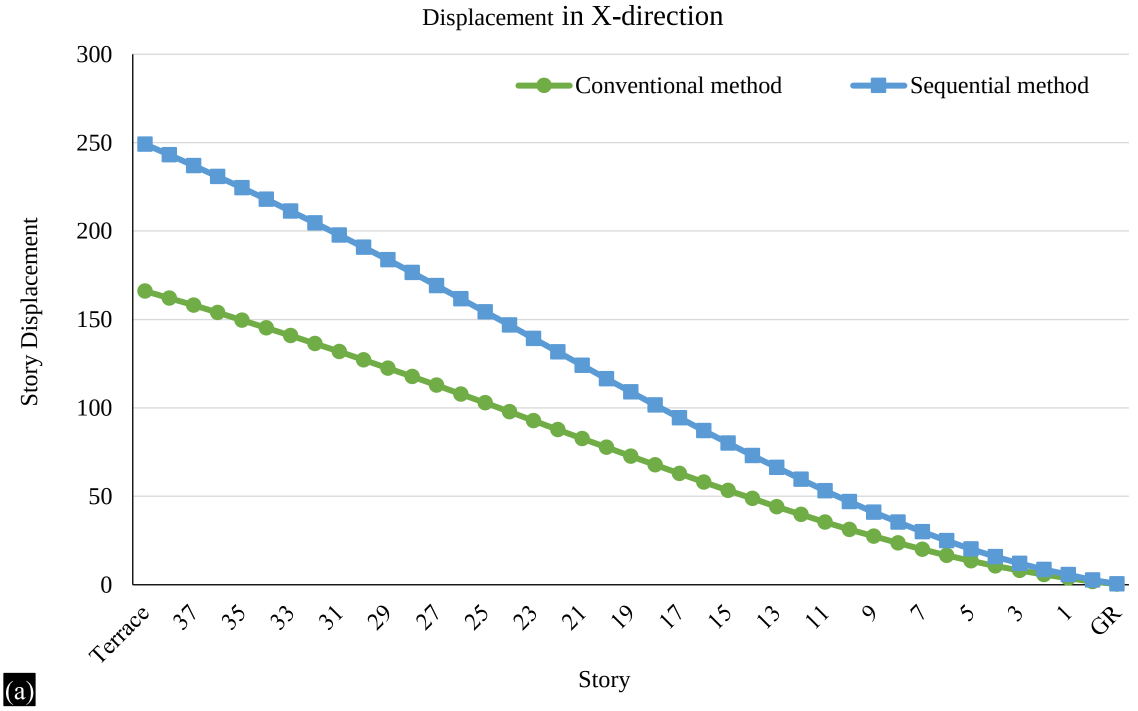


Figure 1. Plan and three-dimensional (3D) view of structure in ETABS mode.

RESULTS AND DISCUSSION

The present study considered three different models which are G+40 RC frame structure in zone III Mumbai region. Construction sequence analysis with creep and shrinkage analysis is considered, which is also called nonlinear static analysis. In this analysis, all data and limitations are used by Indian Standards codes IS 456:2000 for the concrete properties and IS 1893:2016 for the dynamic analysis in consideration of all the code provisions. The various seismic parameters like story displacement, story drift, axial forces, and bending moments at various locations are considerations for dynamic analysis of models with and without construction sequential analysis. Tabular and graphical comparison is carried out for each parameter as shown below. The displacement limit is 281 mm for total height of the structure [10].

Figures 2 (a and b) display the story displacement in X-direction at every story considering the equivalent static method of analysis in case of construction sequential analysis and conventional analysis. Maximum displacement that occurred in the terrace level at the top location is 166.09 mm in conventional method and 249.138 mm in sequential method of analysis. That is, there is 33.33% more displacement at top level of structure. Average of increase displacement in the sequential analysis case is 32% [11].



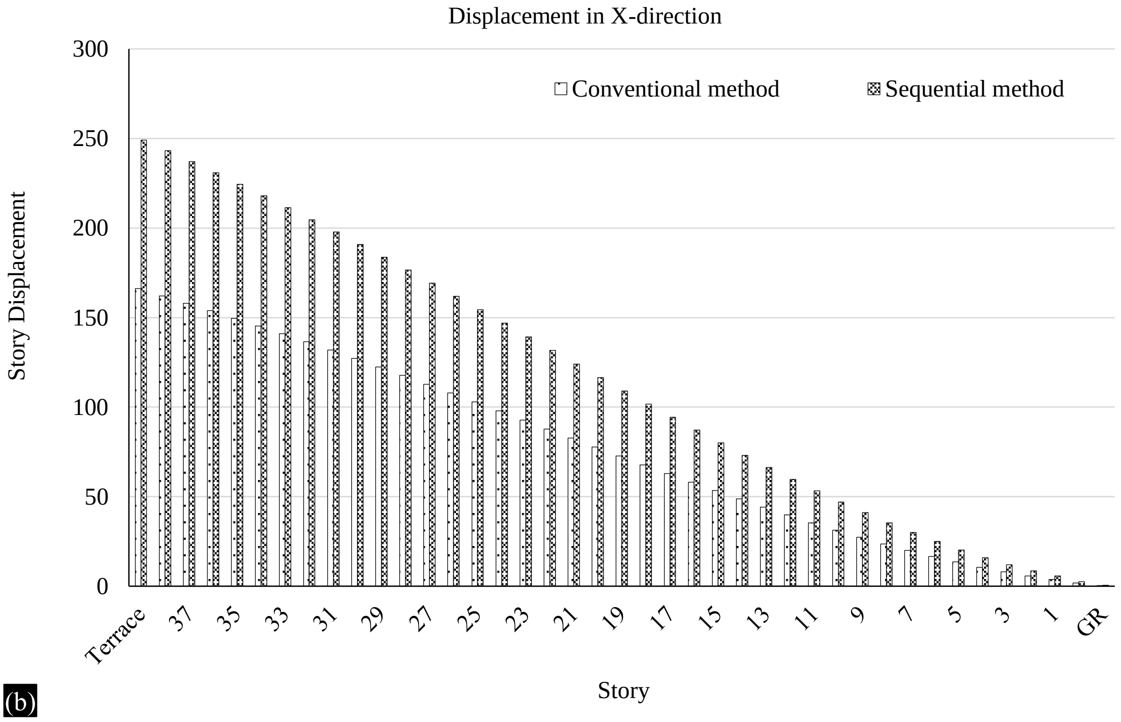


Figure 2. (a and b) Displacement in X-direction by the effect of earthquake load in linear static case and sequential case.

Figures 3 (a and b) display the story displacement in Y-direction at every story considering the equivalent static method of analysis in case of construction sequential analysis and conventional analysis. Maximum displacement that occurred in the terrace level at the top location is 175.39 mm in conventional method and 263.08 mm in sequential method of analysis, which is 33.33% more displacement at top level of structure. Average of increase displacement in the sequential analysis case is 32% [12].

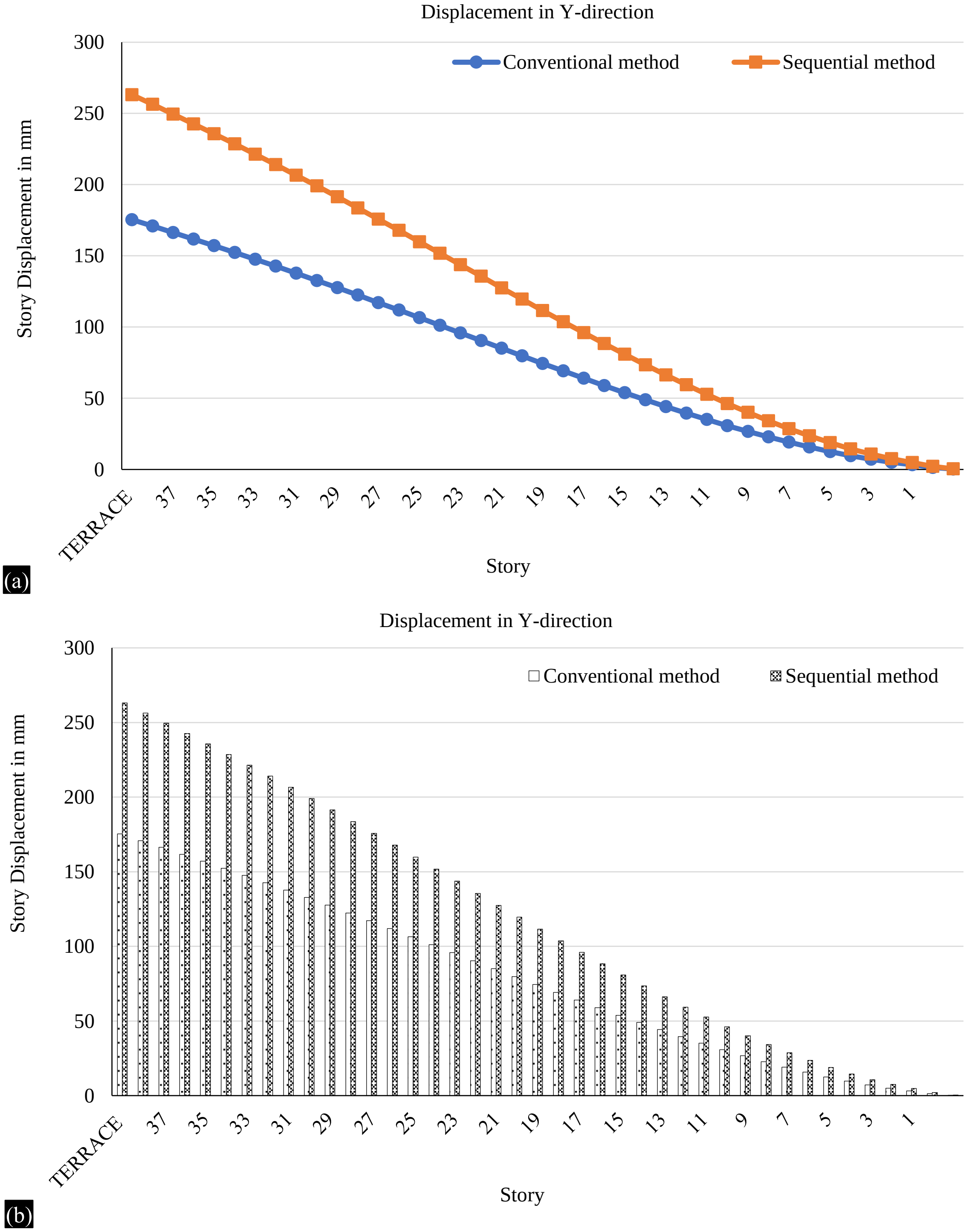
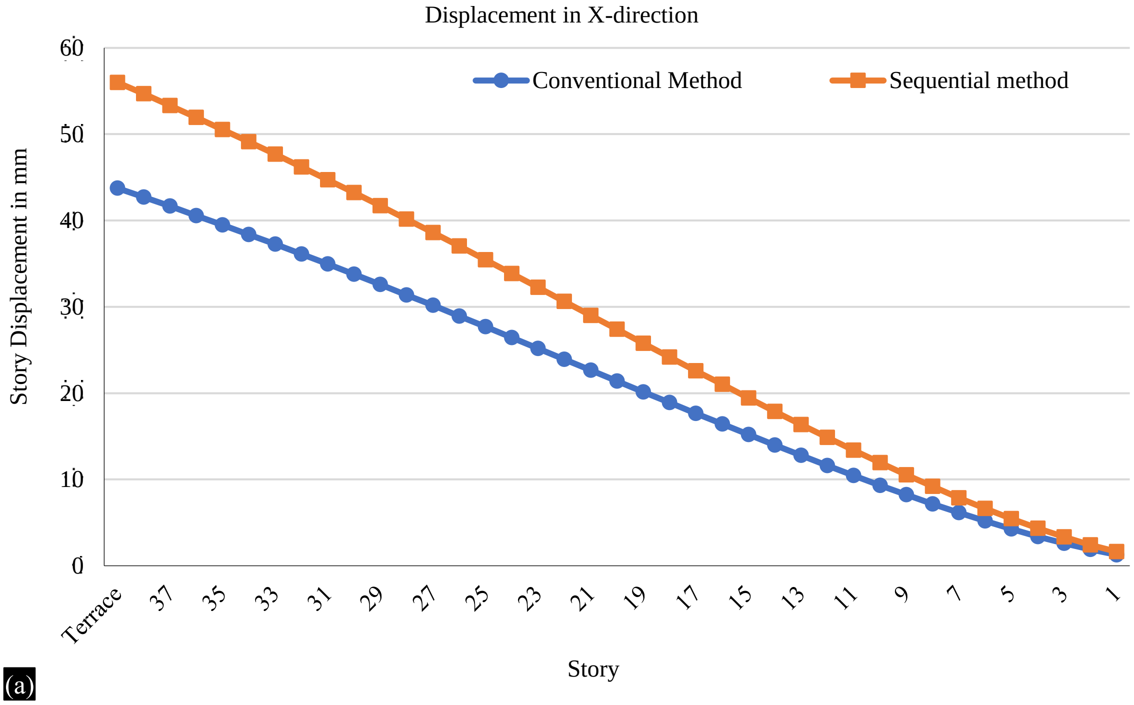


Figure 3. (a and b) Displacement in Y-direction by the effect of earthquake load in linear static case and sequential case.

Figures 4 (a and b) show the story displacement in X-direction at every story considering the response spectrum method of analysis in case of construction sequential analysis and conventional analysis, Maximum displacement that occurred in the terrace level at the top location is 43.752 mm in conventional method and 56.002 mm in sequential method of analysis, which is 27.99% more displacement at top level of structure. Average of increase displacement in the sequential analysis case is 26% [13].



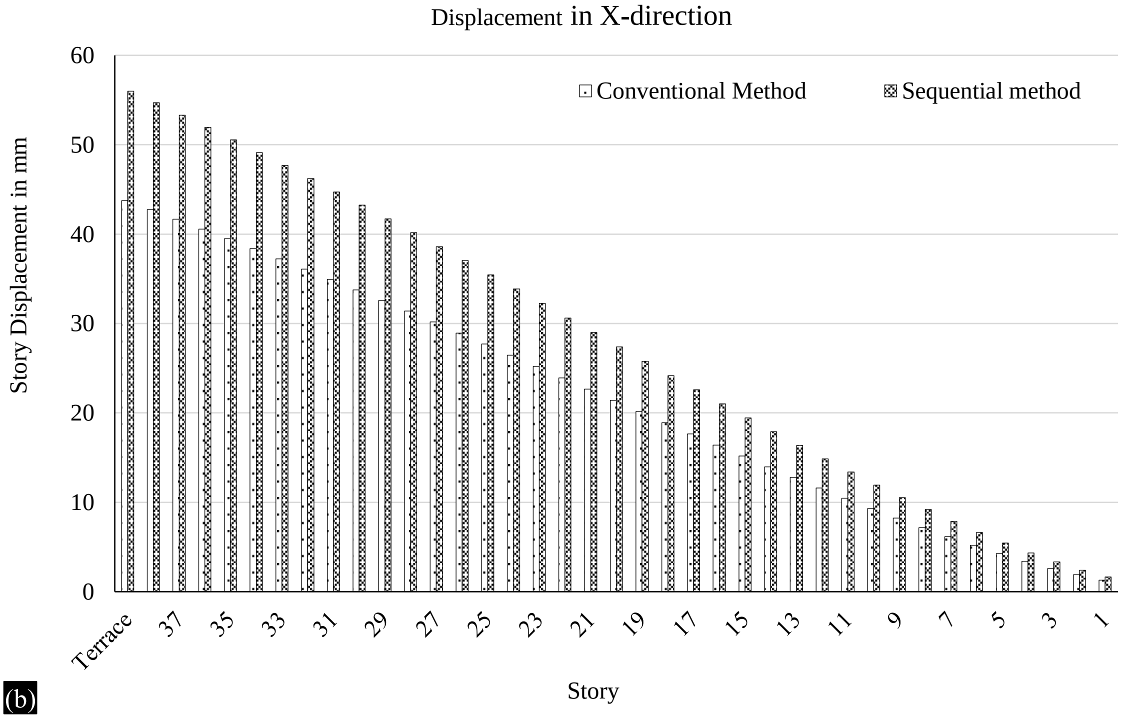


Figure 4. (a and b) Displacement in X-direction by the effect of response spectrum in linear static case and sequential case.

Figures 5 (a and b) display the story displacement in Y-direction at every story considering the response spectrum analysis in case of construction sequential analysis model and conventional analysis model. The maximum displacement that occurred in the terrace level at the top location is 44.949 mm in conventional method and 55.96151 mm in sequential method of analysis, which is 24.55% more displacement at top level of structure. Average of increase displacement in the sequential analysis case is 23.36% [14].

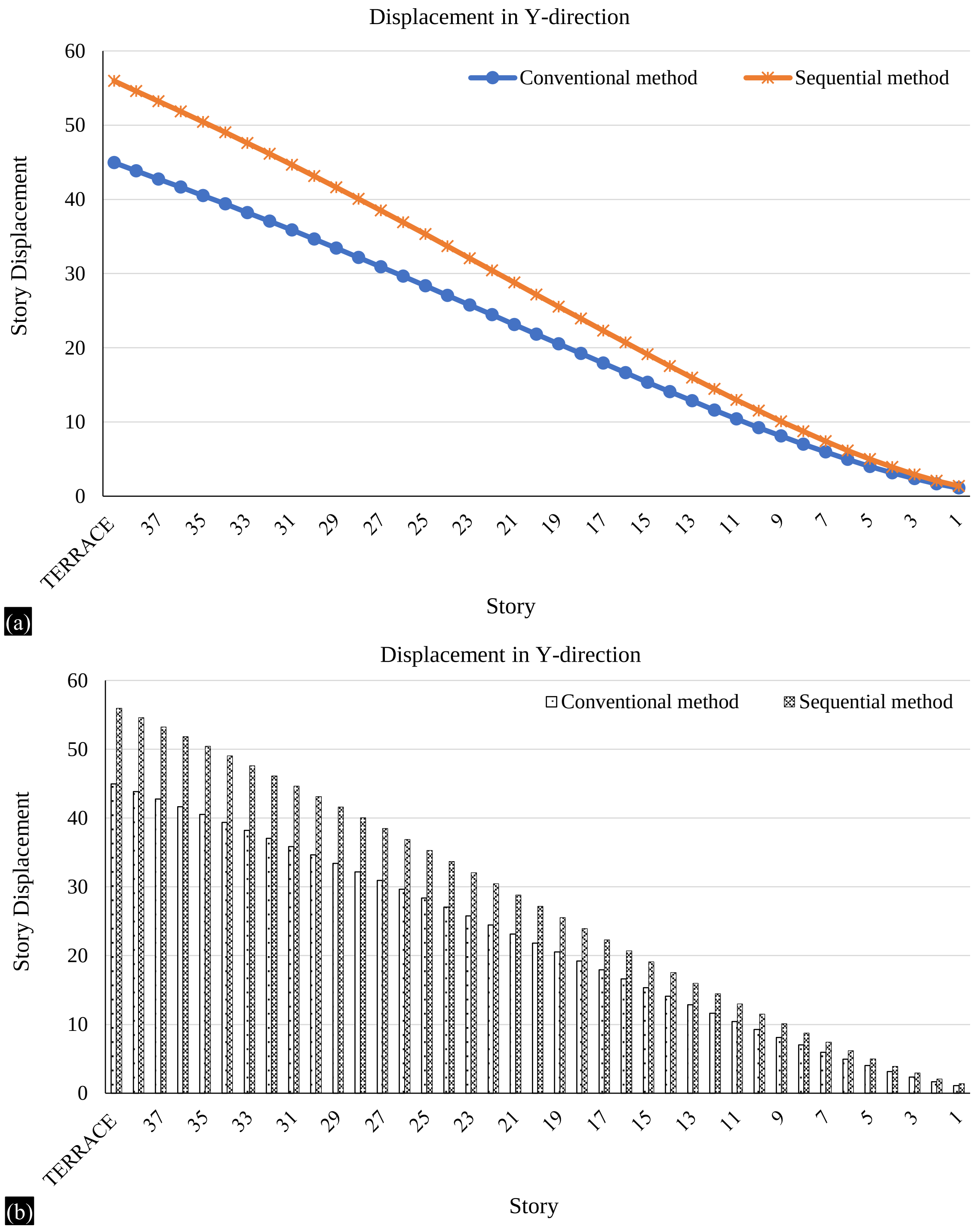


Figure 5. (a and b) Displacement in Y-direction by the effect of response spectrum in linear static case and sequential case.

Figures 6 (a and b) show the story drift at different story level according to the response spectrum analysis. The linear static model is compared with sequential analysis model. There is story drift at ground level found in sequential model, which is 0.001416 and in conventional model is 0.001538. At ground level, story drift is increased at 8% and average percentage of drift increment is 11.85%. Story drift is conservative on the sequential analysis, which is more critical for the analysis and design purposes. Sequential analysis gives more accurate results as compare to the conventional method of analysis [15].

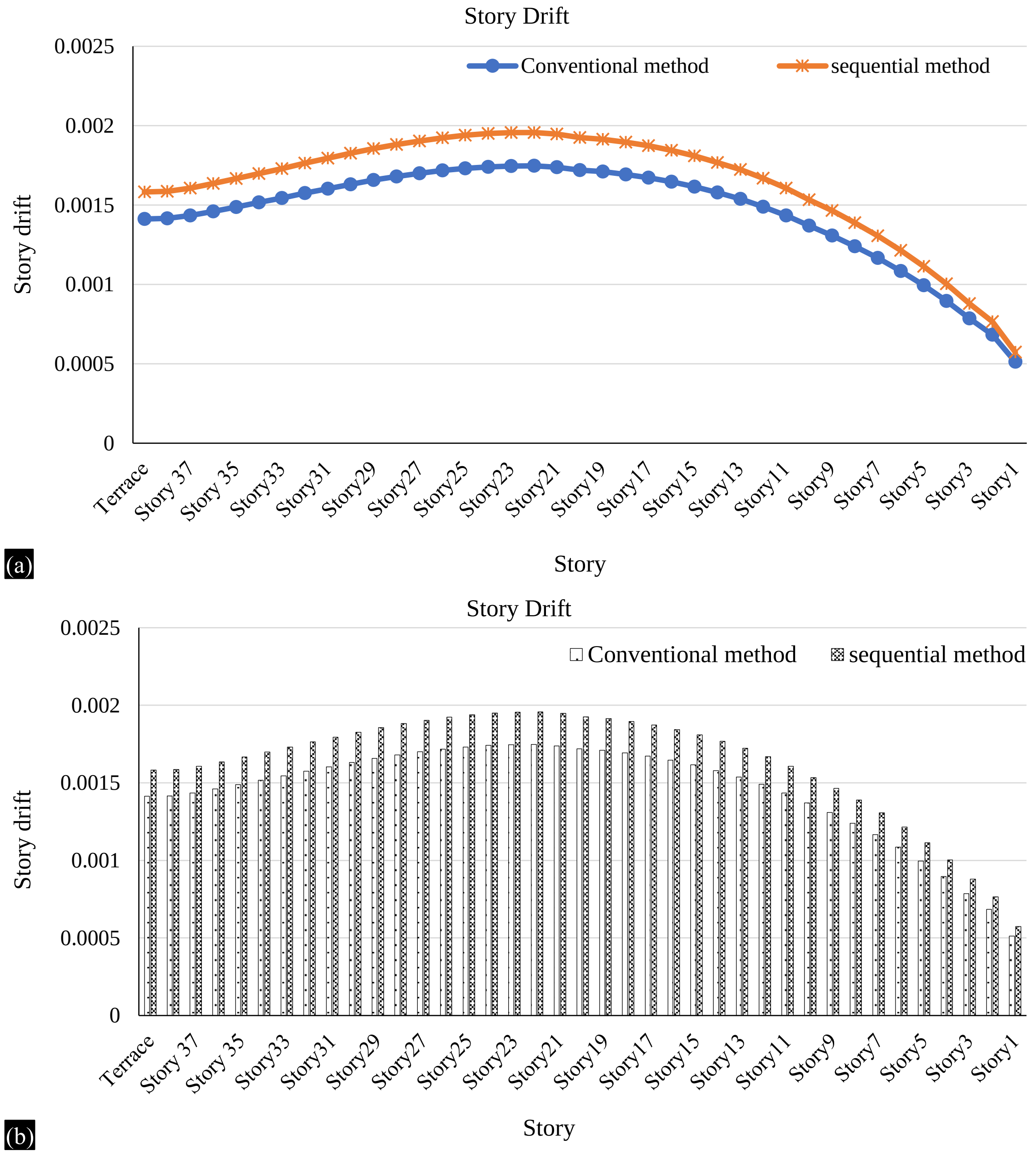


Figure 6. (a and b) Story drift by the effect of response spectrum in linear static case and sequential case.

In Figures 7 (a and b), the axial loads on the given shear wall labeled P8 and P10A base to the 10th floor level of that structure in linear static and nonlinear static method, which depends on the loads transfer through the building height. In Figures 8 (a and b) sky blue bar is showing conventional method that is linear static method and other one is showing nonlinear static method. Axial load in graph shows higher value of shear wall P8 by normal method and lower axial loads in sequential method due to proper load distribution like story to story after construction in sequential method and give the proper deflection, moments, and axial shortening of columns as per curing days and depends on the time-dependent properties. In a structural plan, P8 is connected with long core walls as well as other supporting members and that is the reason to provide the higher loads in the normal method and heavy girder loads are maximum load transferred to the P10A due to the maximum axial loads are acting on the P10A. There is no other core wall supported in the P10A, so it is concluded in the axial loads that loads depend on the load transfer on the members and others supporting elements.

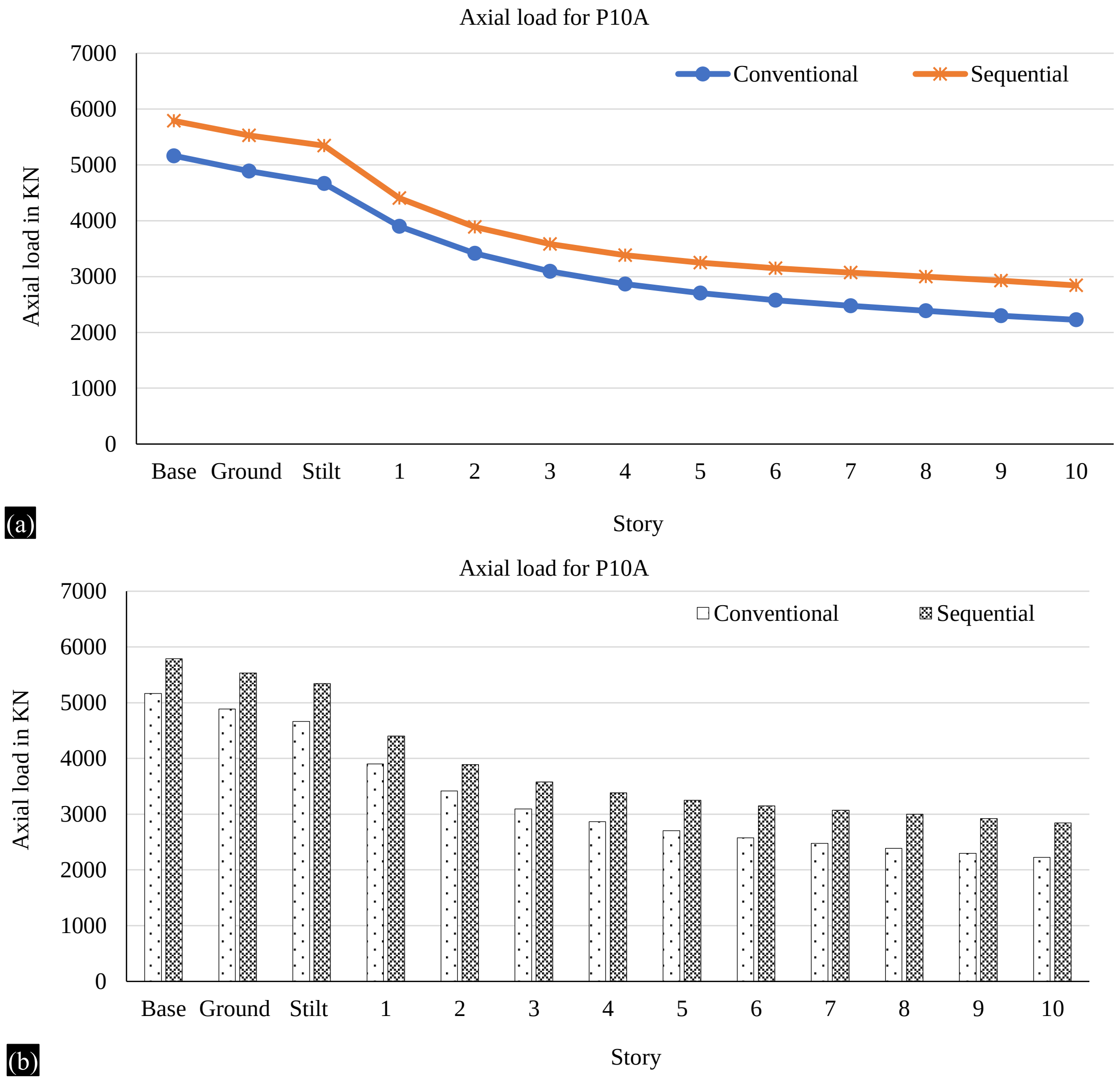
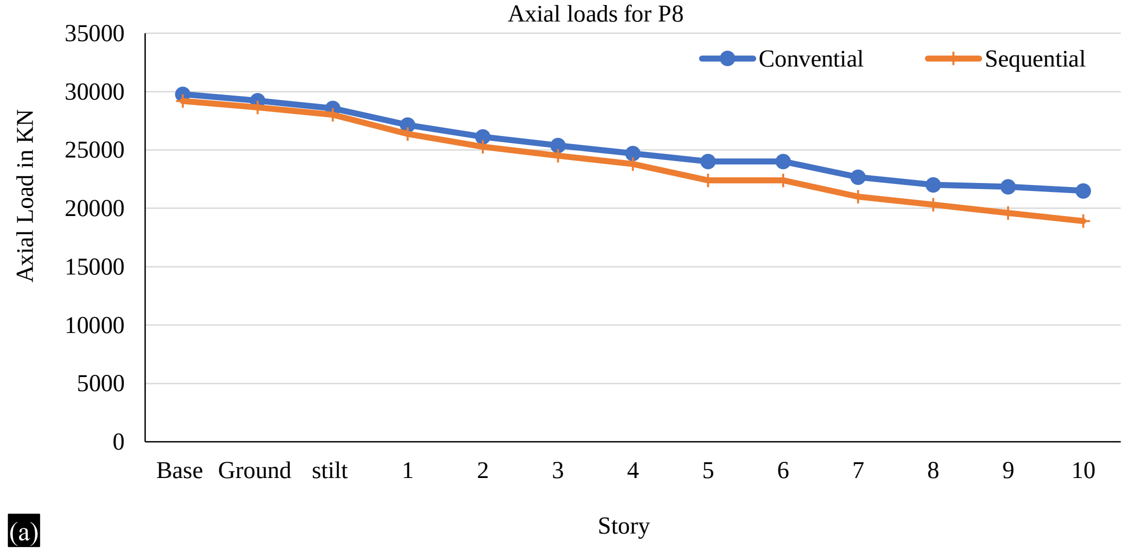


Figure 7. (a and b) Axial loads of P10A by the effect of dead and live loads in static and linear static cases.



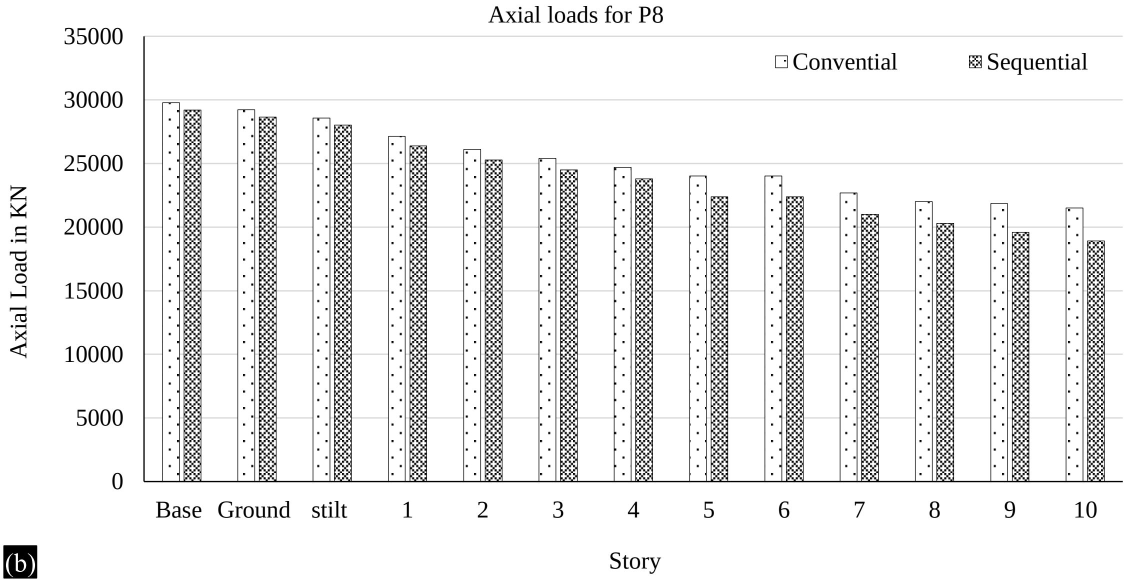
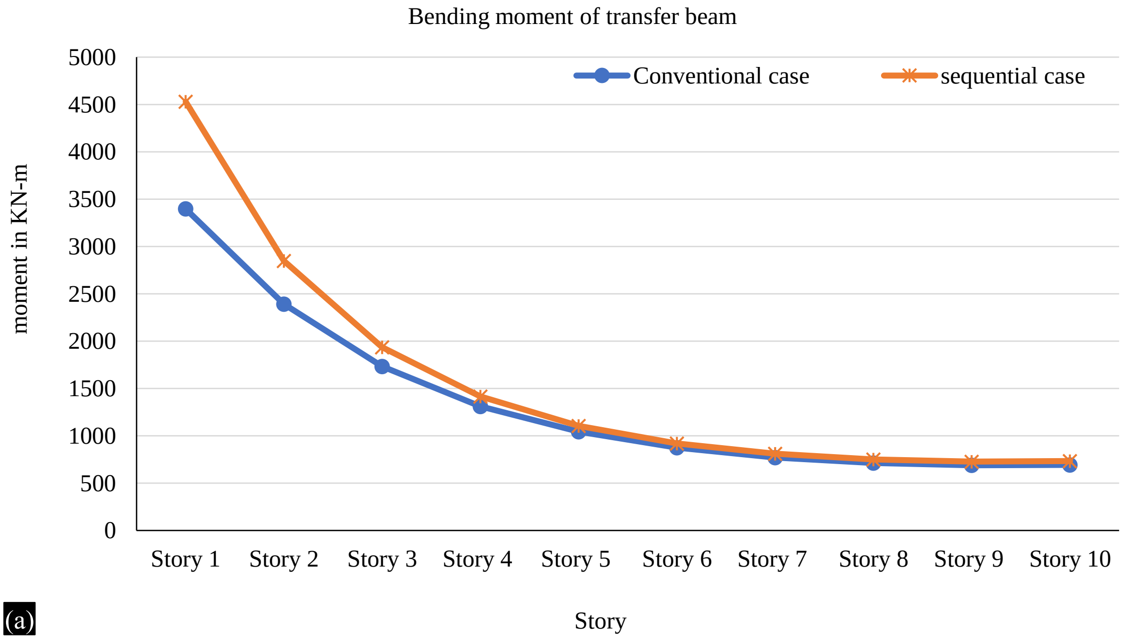


Figure 8. (a and b) Axial loads of P8 by the effect of dead and live loads in static and linear static cases.

Figures 9 (a and b) show that the bending moment at transfer girder with the carrying of floating columns that moment depends on the span of beam and proper load distribution. That result is found by using construction sequence and conventional method of analysis, which is linear static and nonlinear static case. The bending moments is much higher in nonlinear static case. The maximum bending moment at the mid span is 4528.45 kN-m in sequential case and 3396.53 kN-m in conventional case.

Figures 10 (a and b) show the deflection from 1st story to the 20th story in a transfer girder beam width 1200 mm and depth 1500 mm with carrying floating columns. The particular beams considered are G+40 RC frame structure by using linear static method of analysis and construction sequential method of analysis. There is maximum deflection in B39 of 20.06 mm at story 10, which is is also more conservative in construction sequential case due to higher deflection in that case. The deflection on transfer beam increases gradually from below story to above story of structure. The increasing percentage is 35% at the 20th floor and average difference between both cases is almost 30%.



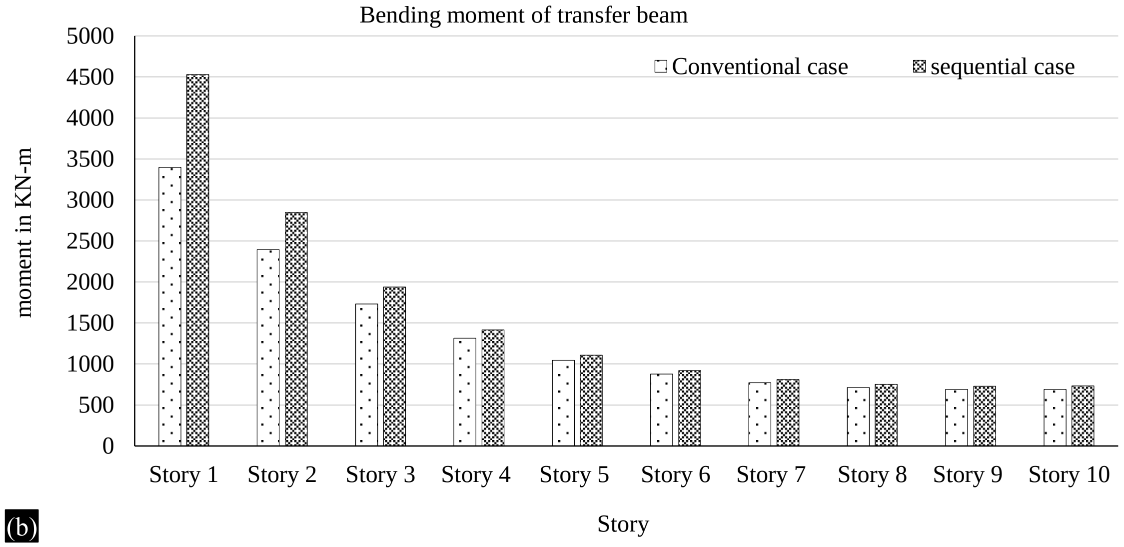


Figure 9. (a and b) Bending moment in a beam by the effect of response spectrum in linear static case and sequential case.

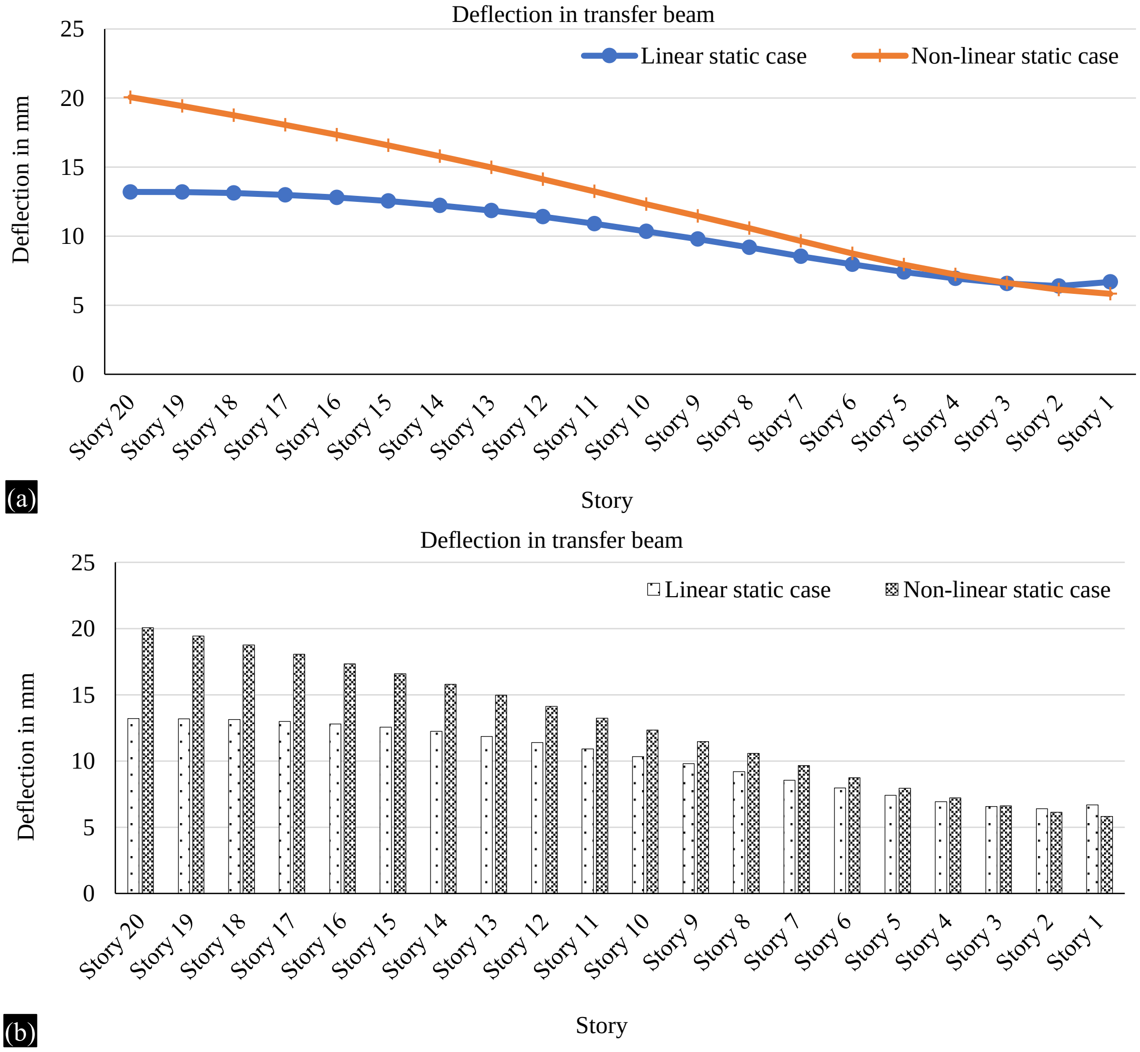
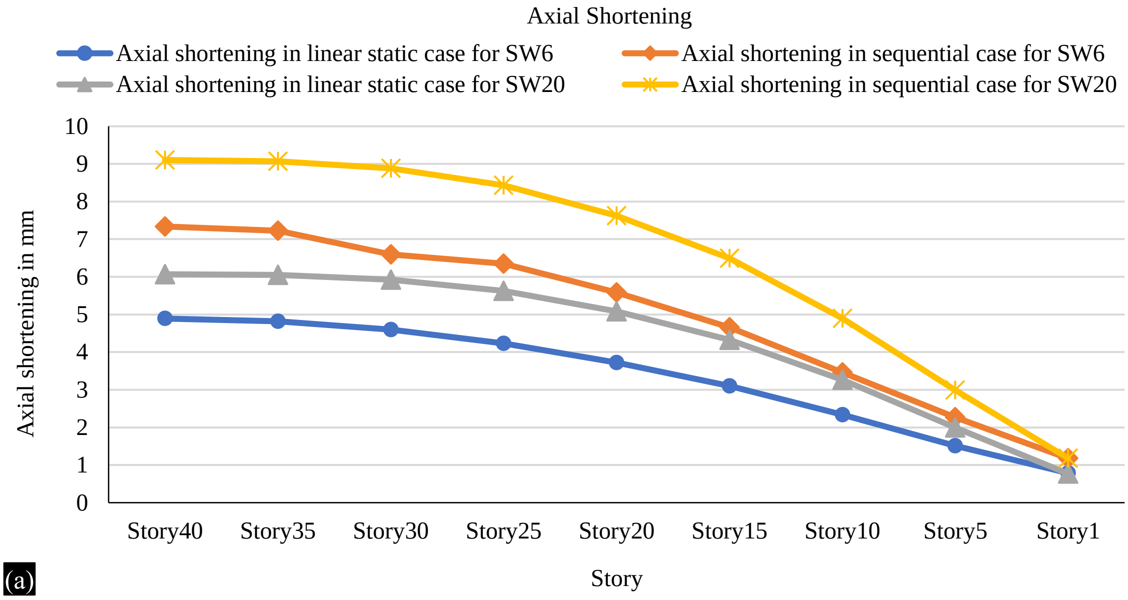


Figure 10. (a and b) Deflection of beam B39 by effect of response spectrum in linear static case and sequential case.



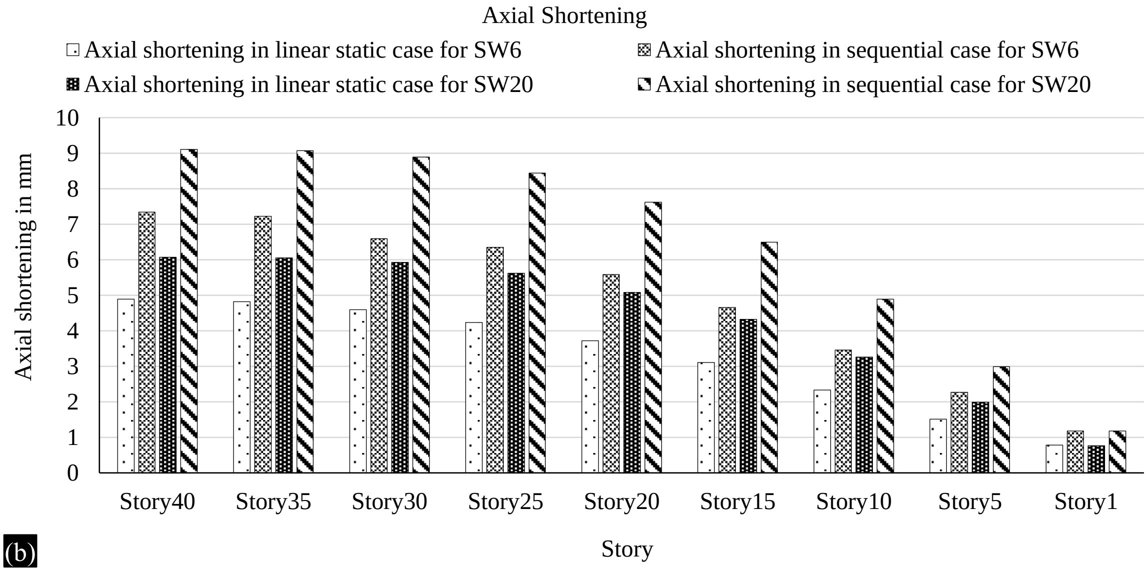


Figure 11. (a and b) Axial shortening of shear walls W6 and W20 by effect of response spectrum in linear static case and sequential case.

Figures 11 (a and b) show the axial shortening in shear walls W6 and W20 by using linear static and construction sequential method of analysis at 5th story. Axial shortening at 1st story in linear static case is 0.786 mm in shear wall W6 and highest axial shortening at 40th story. The average axial shortening in the whole structure is 33.332 mm. In sequential case, average axial shortening is 4.999 mm, which increases to 33.33% axial shortening in the sequential case. For shear wall W20, the highest axial shortening is 7.337 mm at 40th story and 1.179 mm at 1st story. Hence the axial shortening is more conservative in case of construction sequential analysis and that method provides more accurate result than linear static method of analysis.

CONCLUSIONS

In this investigation, two method of analysis are considered – one is construction sequence analysis and the other is creep and shrinkage analysis. These are non-linear static analyses. In this study, we considered G+40 RC frame structure by using static and dynamic analysis, which is response spectrum analysis compared with linear static analysis.

The following conclusions are drawn:

- Greater differential column shortenings and bending moments are developed when the construction sequence and the time-dependent deformations of concrete are considered, 35% to 40% difference in both cases are obtained.
- According to the previous results for bending moments and deflection in the structure that difference is 25% to 40%. The creep and shrinkage analysis is important for public structure especially long life structure then non-linear analysis is important to consider in a serviceability criteria; that is, it depends on the time-dependent properties.
- Nonlinear static analysis gives a greater difference as compared to the linear static analysis. Nonlinear static method provides a greater value.
- The design engineers should be very careful about the analysis results and there should always be questions about assumptions of analysis methods that are considered.
- The way the building is modeled and the type of analysis significantly influenced the column/wall axial loads and deformation.
- IS code 16700:2016 says, engineers should consider construction sequence analysis when the structure height is more than 150 m and long span beams/girder are present in the structure.

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