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Assessing Seismic Behavior in RC Buildings with Varied Vertical Aspect Ratios: A Comparative Study

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Abstract
Limited space in cities due to urbanization and population growth has given rise to tall and distinctively designed buildings. This study focuses on how a building's vertical aspect ratio (height-to-width ratio) affects the seismic performance of residential concrete buildings. In earthquake-prone Nepal, seismic analysis is crucial for buildings in high-risk areas. We investigated the impact of vertical aspect ratio, and the presence of masonry infills and soft stories in reinforced concrete frame buildings. Rectangular base models were analysed at 3, 5, and 7 stories. These models were categorized into bare frames, infill frames, and infill frames with soft stories at the ground level. Linear analysis, non-linear analysis and design of building has been performed as per the relevant Indian codes of practice. The effect of infills on dynamic characteristics, yield patterns and capacity has been studied with the help of Non-Linear Analysis. The result of the analysis indicates that the structures have lesser capacity and higher drift with increase in vertical aspect ratio. It also has been observed that infills contribute to a large increase in the stiffness and strength of the structure, so the deformation capacity of the structure gets reduced.

Key words: Nonlinear static analysis, Vertical aspect ratio, Infill frames

Introduction

Urbanization and rapid population growth in cities have led to limited space for buildings, resulting in taller and slimmer structures. The ratio of a building's height to its least lateral dimension of a building is called the vertical aspect ratio.It is not prohibited to build a slender building but it should have enough ductility to sustain during an earthquake. Whether the building is slender or not the most important thing is it should be built resistively against seismic force.

The most recent Gorkha earthquake 2015 with a magnitude of 7.8Mw on April 25, 2015, with the epicenter near Baluwa village [1] has caused extensive damage to buildings, highlighting the need to study how buildings respond to different levels of seismic shaking. To understand how slender buildings with various shapes behave during earthquakes, a method called non-linear static analysis is used. It helps us assess a building's strength by subjecting it to increasing lateral forces, simulating the forces during an earthquake until it reaches its limit.

Literature Review

The ratio of building height (h) to building width (b) is known as vertical aspect ratio or slenderness ratio. With increase in the height of the building, the vertical aspect ratio increases. Researchers have performed seismic analysis for reinforced concrete tall buildings on Kuwait city design conditions in the paper. After seismic analysis it has been concluded that in the paper, the building slenderness ratio is one of the most significant factors affecting the structural behavior of high rise buildings. The building core size and location play a significant role in the structural behavior of high rise buildings [2]. A Canadian firm WSP which has designed 432 Park Avenue in New York having slenderness ratio 1:15, defines that a slenderness ratio of above 1:7 is kind of considered as slender [3]. Twin Towers are considered as slender buildings with a slenderness ratio of 1:8 or so, even Burj Khalifa is a slender building.

Research Objectives

The main objectives of this study are given below:

- To evaluate the capacity of the RC buildings based on varying vertical aspect ratio.
- Evaluate the effect of infill as well as soft story infill buildings in terms of capacity and time period of the building.

Methodology

In order to determine the performance and understand the actual behavior of reinforced concrete frames under seismic loading, it is necessary to study various parameters. For this there are various analysis methods such as elastic (linear) and inelastic (nonlinear) methods. Elastic analysis tells us about a structure's initial strength and where it might yield and help identify critical members likely to reach critical states during an earthquake but can't predict how forces redistribute or where it might fail.

Non-linear static analysis is more accurate because it considers a structure's inelastic behavior. It helps us identify critical parts likely to fail during an earthquake and assess overall seismic performance. A method called pushover analysis, which gradually increases lateral loads while maintaining a specific distribution along the building's height is used due to simplicity and sufficient accuracy to study the non-linear behavior and the capacity of the structures.

The prescribed methodology for achieving the objectives involves the following steps:

- Conduct an extensive review of prevailing literature
- Develop a structural model of the buildings with varying vertical aspect ratios
- Perform a nonlinear analysis of the chosen building model and conduct a comparative assessment of the analysis results.
- Record observations from the obtained results and engage in discussions based on these observations.
- Conclusions and further recommendations, considering the defined scope of this study.

Building Details And Modelling For Analysis

Most of the building in Nepal has plan less than 1200 sq.ft, so considering that the plan areas of the buildings are selected to be 1033 sq.ft (96 m2). The site soil condition is taken as medium soil type (Type II).

Building Description: Rectangular Base Buildings with properties of model structure:

- Height: 3.00 m
- Plan Dimensions: 12 x 8 m
- Frame Type: Reinforced Concrete Elements (No shear wall)
- Usage Purpose: Residential Seismic
- Zone: Zone V (According to IS1893:2002)
- Soil Type: II (According to IS 1893:2002)
- Slab Thickness: 130 mm

- Loading Conditions: Floor finish = 1 (KN/m^2), Wall load = 8.60 (KN/m), Exterior wall = 5.57 (KN/m), Interior wall = 3 (KN/m^2), Parapet = 2.5 (KN/m)

For seismic weight, total dead load and 50 percent of live load is considered as per Table 8 of IS 1893 (Part1):2002. For calculation of seismic weight, no roof live load is taken.

Table 1: Description of models with vertical aspect ratio

Case	Model	Description	VAR
Case A	A3	3 story bare frame rectangular base building	1.13
	A5	5 story bare frame rectangular base building	1.88
	A7	7 story bare frame rectangular base building	2.63
Case AI	AI3	3 story rectangular base building with infill frames	1.13
	AI5	5 story rectangular base building with infill frames	1.88
	AI7	7 story rectangular base building with infill frames	2.63
Case AS	AS3	3 story rectangular base building with soft story	1.13
	AS5	5 story rectangular base building with soft story	1.88
	AS7	7 story rectangular base building with soft story	2.63

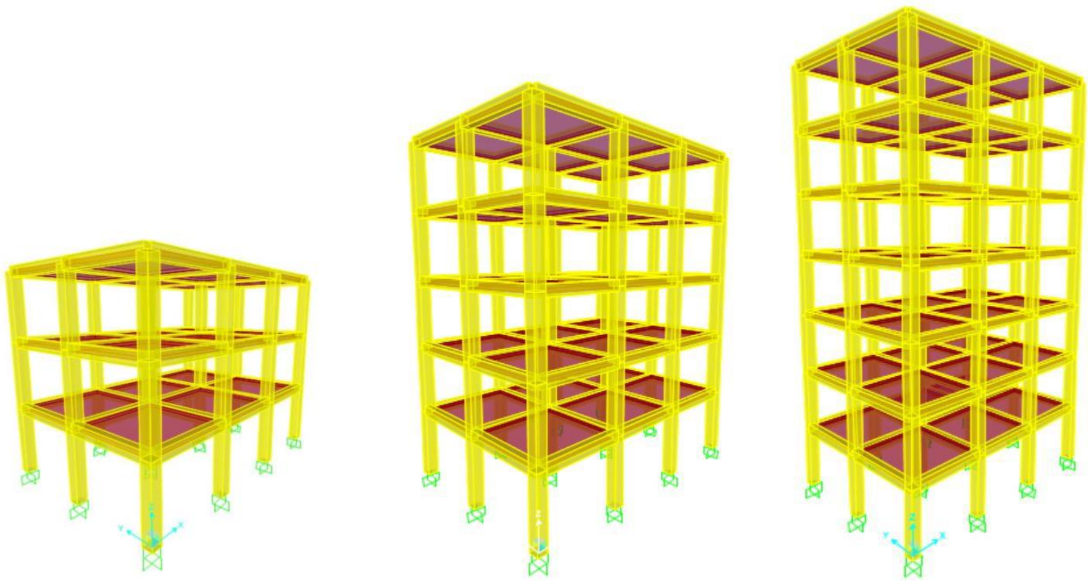


Fig. 1: Model A3: 3 story bare frame rectangular base building, Model A5: 5 story bare frame rectangular base building and Model A7: 7 story bare frame rectangular base building

Seismic Performance Assessment of Designed Structures

1. Natural Structure Time Period

The results of natural time period of the studied rectangular base building obtained from Numerical analysis in SAP 2000 are shown in the graph below:

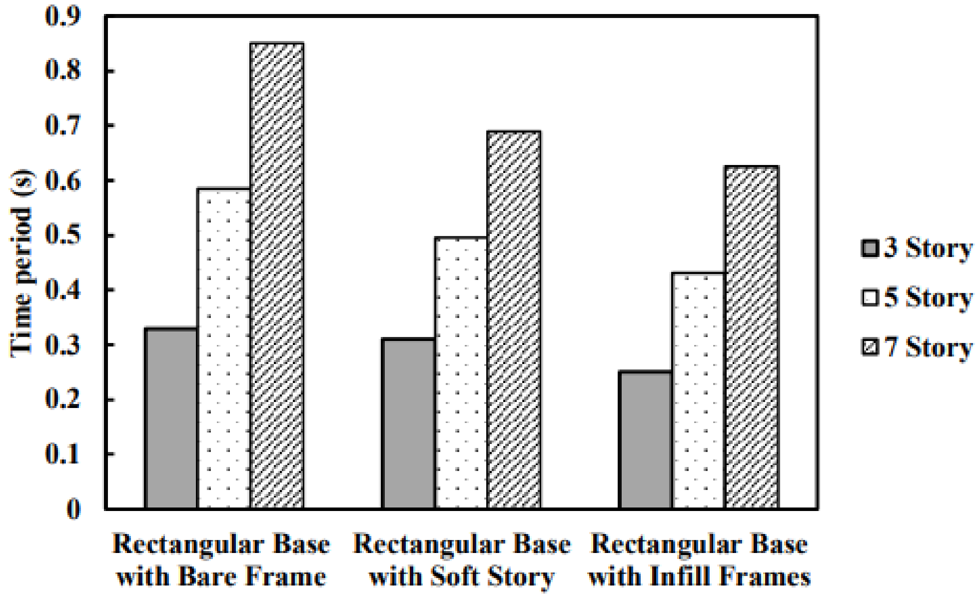
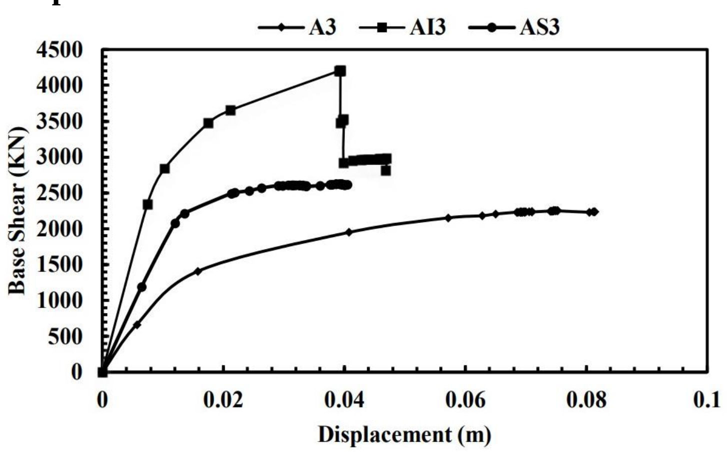


Fig. 2: Time period comparison of rectangular base buildings considering different vertical aspect ratio

It can be observed from the figure that the time periods get drastically reduced due to inclusion of infills in models. The period of vibration of rectangular base building with infill frames decreases by 24%, 26% and 27% for 3, 5 and 7 story buildings compared to rectangular base with bare frame building. Similarly, the time period of rectangular base with soft story infill frame decreases by 5%, 15% and 18% for 3, 5 and 7 story buildings respectively. It indicates a strong influence of infills on the elastic stiffness of the structure. It has also been observed that with the increase in vertical aspect ratio, the time period differences in bare frame and infill frame gradually increases.

2. Base Shear and Displacement



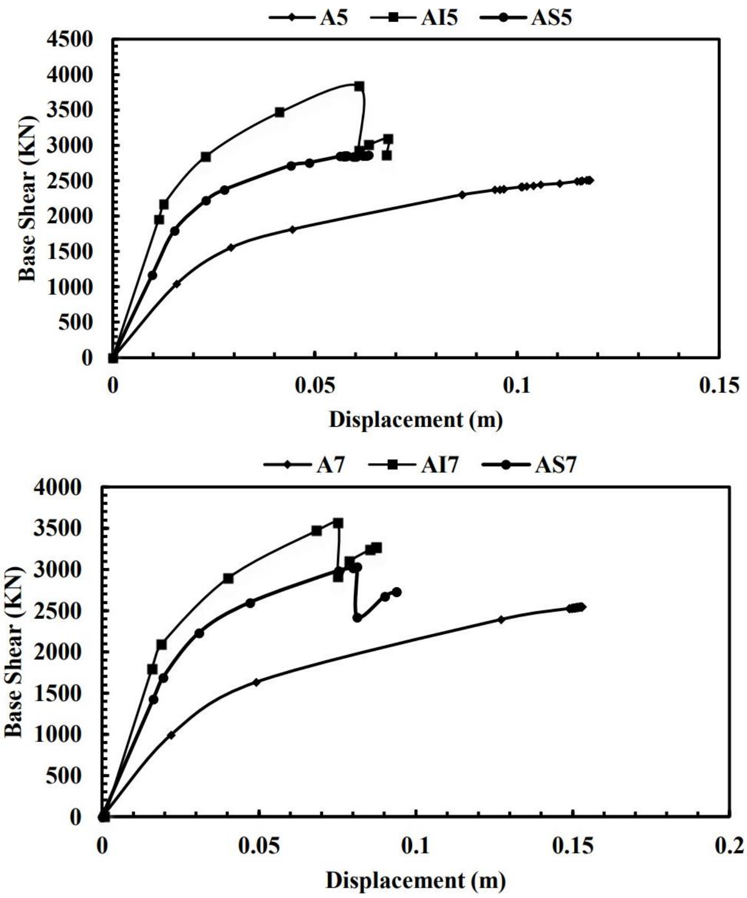


Fig. 3. Comparison of capacity curves of Bare, Infill and Infill frame with soft story of 3 story, 5 story and 7 story rectangular base buildings respectively.

Fig. 3 shows the comparison of capacity curves of Bare, Infill and Infill frame with a soft story of rectangular base buildings in x-direction. It can be seen from the capacity curves that the maximum base shear of rectangular base infilled frame building increases between 40 to 87% and the base shears of rectangular base infilled frame with soft story building increases between 14 to 18 % compared to that of corresponding bare frame building.

It can be seen from the capacity curves that the strength and stiffness of the infilled frame buildings are increased considerably, but ductility is reduced than that of the corresponding bare frame buildings. The overall performance of the buildings, in terms of drift at performance point, has improved due to inclusion of infill. It has also been observed that more ductility is available in frames with higher vertical aspect ratio. This can be observed by comparing the capacity curves of buildings with different heights. It can be concluded that in case of infilled frame buildings, strength capacity increases than that of bare frame buildings but ductility capacity is reduced. This effect reduces with the increase of the height of the building.

3. Story and Story Displacement

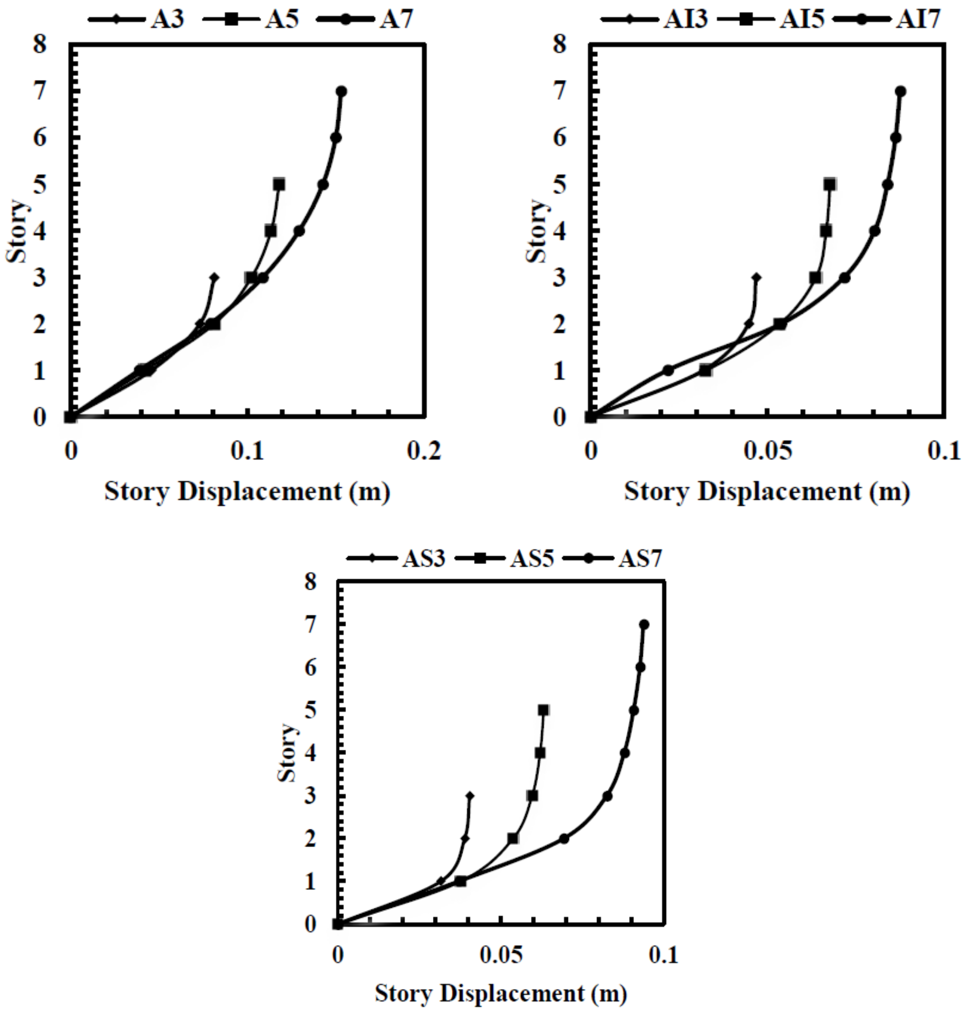


Fig. 4: Comparison of Story displacement and story of 3 story, 5 story and 7 story Rectangular base building with Bare, Infill and Infill frame with soft story respectively in x-direction

From the figure we can understand that with the increase in the vertical aspect ratio the displacement of the building is increased. It has been observed that within a few stories the displacement of all buildings are similar but after that the displacement is changed further drastically within the same plan buildings with different vertical aspect ratio. In rectangular base bare frame building the displacement in 3 story is increased by 26% and 34% in model A5 and A7 respectively when compared with 3 story rectangular base building.

Conclusion

In conclusion, our analysis of buildings with varying vertical aspect ratios, including displacement, yield patterns, capacity curves, and time periods, indicates that as the vertical aspect ratio increases, all these parameters worsen during seismic activity. Additionally, our findings show that the presence of infills enhances a structure's resistance to seismic activity compared to frames without infill.

- It has been observed that infills have a drastic effect on capacity curves of the infilled frames and base shear has been found to increase by 40 to 87% as compared to the bare frames for the rectangular base buildings.
- Yield pattern of the structure is also observed to be dependent on vertical aspect ratio i.e. smaller aspect ratio may develop a column sway mechanism in ground storey. This may be because of increase in axial force in columns due to inclusion of infills in the frames and some of the columns may develop net tension.

- It has been observed that ductility capacity of infilled frame buildings is reduced. As the displacement of infilled building is reduced by 42% than that of bare framed rectangular base bare frame building.
- Story drift for infill frame is less when compared to bare frame building by 30-70 % in different vertical aspect ratio of rectangular base building. For soft story building the drift is maximum at the level of soft story. Maximum story drifts were observed at the lower stories for all the building including all infill frame buildings
- With the increase in vertical aspect ratio, the time period of a structure with infill when compared to that building without infill frame decreases gradually. The period of vibration of rectangular base building with infill frames decreases by 24%, 26% and 27% for 3, 5 and 7 story buildings compared to rectangular base with bare frame building.

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