Assessment of the Global Ductility of Mid-rise RC Buildings and Comparison with Varying Plan Aspect Ratio in High Seismic Zone

C. K. Sushma and Vijayalakshmi Akella

Abstract A structure in high seismic regions must perform under large forces without failing; hence, in this scenario, inelastic energy dissipation plays an important role in resisting large forces mainly caused by an earthquake. A ductile structure can deform and dissipate energy during an earthquake because it keeps deforming without reaching ultimate failure or collapse. In this study, the ductility of mid-rise RC buildings was compared under high seismic zones for different aspect ratios. Investigations were performed by following the Indian standard code with respect to plan aspect ratios. Reinforced concrete buildings with 10, 20 and 30 stories were modelled using five different plan aspect ratios of 1:1, 1:2, 1:3, 1:4, 1:5 and 1:6 under two categories, viz., category 1 with different plan aspect ratio and category 2 with the same plan area. The buildings were analysed by employing response spectrum and non-linear static analysis to obtain the results using Etabs software.

Keywords Pushover analysis · Mid-rise building · Ductility ratio · Performance point · Hinge

1 Introduction

1.1 Aspect Ratio

When the earthquake occurs, inertia force is distributed in a building, at floor levels where the mass is large and then this force is disseminated to lateral load resisting systems that this is, columns and/or structural walls. When floor slabs do not deform in large quantities in their own plane, due to rigid diaphragm action, a considerably good possibility of the distribution of inertia forces to lateral load resisting systems

C. K. Sushma (✉)
Department of Civil Engineering, DSCE, Bengaluru, India
e-mail: cvl@dayanandasagar.edu

V. Akella (✉)
Department of Civil Engineering, KSSEM, Bengaluru, India
e-mail: hod.civil@kssem.edu.in

T. G. Sitharam et al. (eds.), *Earthquakes and Structures*, Lecture Notes in Civil Engineering 188, https://doi.org/10.1007/978-981-16-5673-6_20

in proportion to their capacities emerges. However, when considerable deformation occurs in slabs in their own planes the inertia force is distributed based on the tributary area which causes members overloading with a low capacity and thus leads to buildings damage. Hence, floor slabs in buildings with a large plan aspect ratio may not provide rigid diaphragm action. Thus, constructing buildings with a large plan aspect ratio is not favorable [1].

1.2 Pushover Analysis

The non-linear static analysis, or pushover analysis, is a reliable procedure for seismic performance evaluation. It is a static analysis that includes nonlinear material characteristics. The non-linear static analysis can be performed to predict redistribution of forces during progressive yielding and thus to predict failure mechanisms or to accurately detect the possibility and location of any premature failure because it considers the inelastic behavior of structures. This analysis can help identify critical members likely to reach critical states during an earthquake to which attention should be paid during design and detailing. The pushover analysis includes several successive elastic analyses, superimposed to estimate the force–displacement curve of the complete structure [2].

1.3 Ductility

"The idea of designing earthquake resistant structures is based on the concept of energy absorption in inelastic deformations. The inelastic deformation capacity of structures is defined by a factor called ductility factor, which is the ultimate deformation to yield deformation. This factor indicates the rate of delay caused by the structure between yield and damage states. Thus, the structure behavior factor depends directly on the ductility factor" [3].

Mahmoodi (2000) studied the behavior of concrete moment resisting frames with different stories by inelastic analysis with a nonlinear static method and considered global and local (members) ductility capacity of the frames. They used displacement and rotational ductility to determine global and local ductility, respectively, and proposed a formula in two states to obtain the global ductility capacity of the structure based on the ductility capacity of beams and on that of columns [3].

1.4 IS Code

"IS 16700: 2017 code provides guidelines to prevent the progressive collapse of tall buildings. Progressive collapse can be defined as the failure that initiates at the local element level and then propagates from element to element, finally leading to the collapse of entire building. As per the code, progressive collapse can be precluded by, selecting a suitable structural system, selecting critical member and providing adequate redundancy to the building. The Code also suggests the use of key elements to safeguard the building from progressive collapse. In addition to the methods indicated in the code to minimize the possibility of progressive collapse, other methods are suggested in various literature; these methods include improvement of member ductility, identification and strengthening of critical locations of buildings and provision of alternate load paths. Section 8.2 of the code emphasizes to ensure various aspects of ductility in tall buildings" [4, 5].

2 Present Work

Objective

1. To understand the effects of lateral force distribution on the lateral force-resisting system for different plan aspect ratios.
2. To understand the global ductility of buildings under investigation.

Three RC buildings of 30, 20, and 10 stories were considered in this study. Six models were prepared under each story for different plan aspect ratios of 1:1, 1:2, 1:3, 1:4, 1:5, and 1:6 for each story. The models have been discussed in detail in the below sections.

2.1 Modeling

Category 1

Six 30-, 20-, and 10-storied building were modeled using Etabs software, Table 1 presents the description of the input considered for modeling (Fig. 1).

Category 2

Six 30-storied buildings with the same area and the following input description were modeled (Table 2).

2.2 Analysis

The nonlinear analysis of the structures under static and dynamic loading was performed "ETABS" software. The response spectrum and pushover analyses were performed to determine maximum displacement and yield displacement of the whole

Table 1 Description of the model

Sl. no	Particulars		Remarks
1	Model 1	1:1	Area = 182.25 SQM
2	Model 2	1:2	Area = 364.5 SQM
3	Model 3	1:3	Area = 546.75 SQM
4	Model 4	1:4	Area = 723.6 SQM
5	Model 5	1:5	Area = 904.5 SQM
6	Model 6	1:6	Area = 1085.4 SQM
7	Zone	4	
8	Soil type	2	
9	Grade of concrete	M35	
10	Grade of steel	FE500	

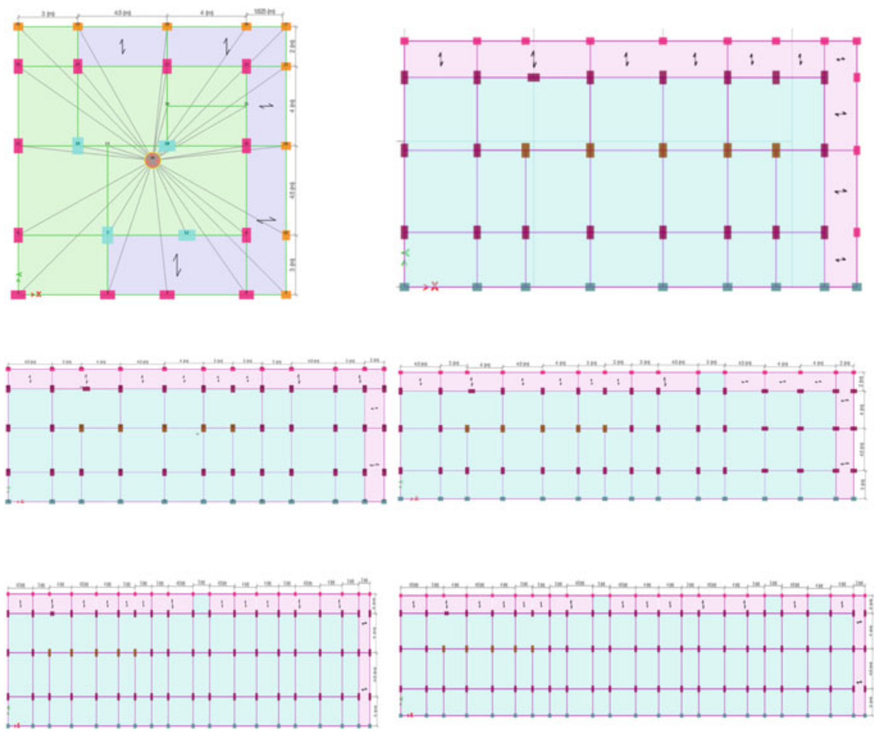

Fig. 1 Plan of the building with varying aspect ratio 1:1, 1:2, 1:3, 1:4, 1:5, and 1:6

Table 2 Description of the model

Sl. no	Particulars		Remarks
1	Model 1	1:1	Area = 1100 SQM
2	Model 2	1:2	Area = 1100 SQM
3	Model 3	1:3	Area = 1100 SQM
4	Model 4	1:4	Area = 1100 SQM
5	Model 5	1:5	Area = 1100 SQM
6	Model 6	1:6	Area = 1100 SQM
7	Zone	4	
8	Soil type	2	
9	Grade of concrete	M35, M30	
10	Grade of steel	FE500	

structure, respectively. According to IS 1893:2016, Zone 4 and Soil type 2 were considered for the analysis. The building models were analyzed and the designing process was conducted according to the IS codes 456 and 13920. Subsequently, global ductility was calculated using the formula

$$\mu(\text{global}) = \Delta\text{max} / \Delta\text{y},$$

where Δmax is = the maximum displacement at the roof level and Δy is the yield displacement of the whole building.

3 Results and Discussion

3.1 Maximum Displacement

According to the results of maximum displacement at each story, a trend of increase in displacement value from lower stories to the roof was observed and this trend occurred for all the aspect ratios (Figs. 2, 3, 4, 5, 6, and 7).

The maximum displacement at the roof level for aspect ratio 1:4 decreased by 76.5% in comparison with the aspect ratio 1:5 which decreased by 69.12%.

The percentage increase from 4th story to 30th story is approximately 78%, however for the building with an aspect ratio of 1:4, the percentage increase from 4th to roof level is 73%.

After the 24th floor in all the buildings, the increase in displacement is decreased by 4%.

In the building with the plan aspect ratio of 1:4 at the roof level the displacement is decreased by 0.23 mm in comparison with that on the 28th story.

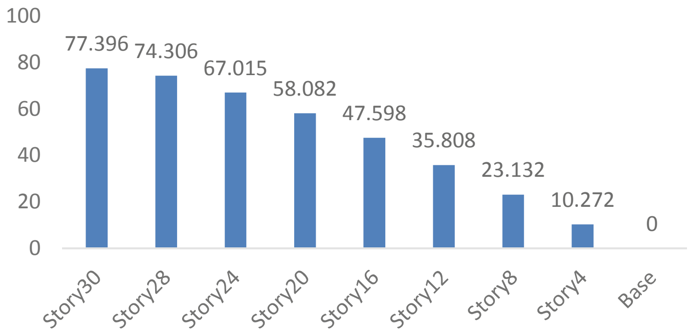

Fig. 2 Maximum displacement for the building with aspect ratio 1:1 story versus displacement

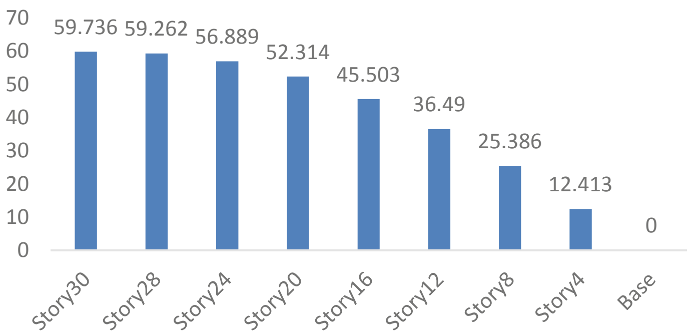

Fig. 3 Maximum displacement for the building with aspect ratio 1:2 story versus displacement

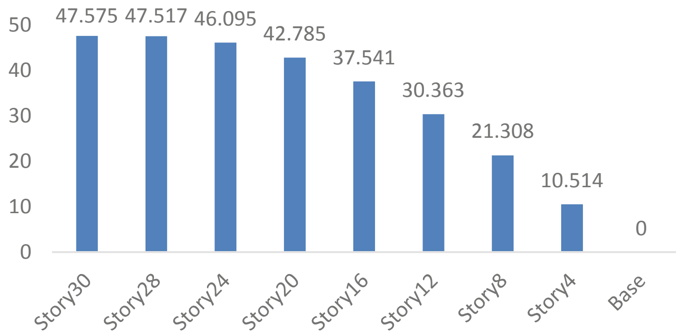

Fig. 4 Maximum displacement for the building with aspect ratio 1:3 story versus displacement

3.2 Story Drift

The story drift values obtained from the different plan aspect ratios are as follows (Figs. 8, 9, 10, 11, 12, and 13).

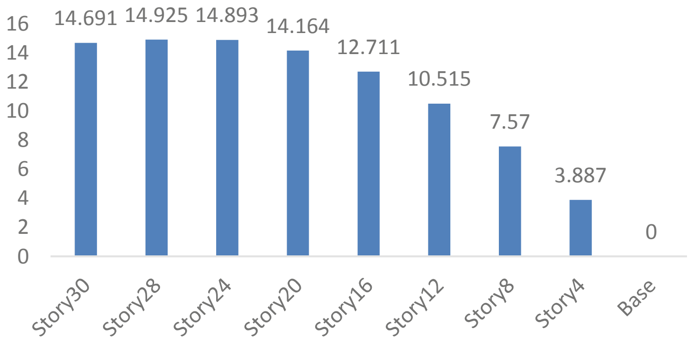

Fig. 5 Maximum displacement for the building with aspect ratio 1:4 story versus displacement

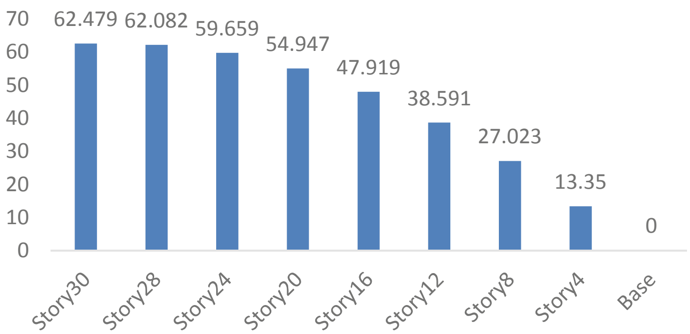

Fig. 6 Maximum displacement for the building with aspect ratio 1:5 story versus displacement

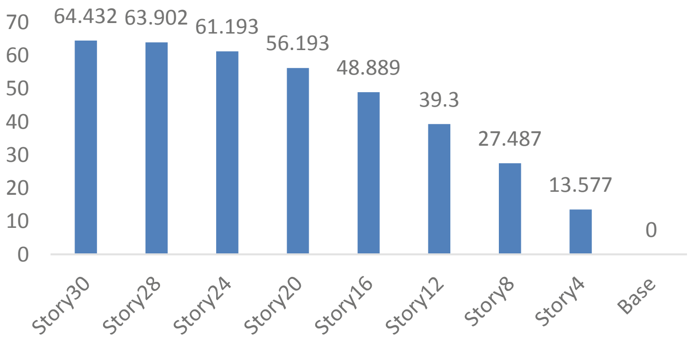

Fig. 7 Maximum displacement for the building with aspect ratio 1:6 story versus displacement

The story drift shows a decreasing trend from the ground floor to the roof level.

The building with the plan aspect ratio 1:4 exhibits behavior where the story drift at the 28th story decreases compared with that at the lower stories, but the story drift increases by 59% at the roof level.

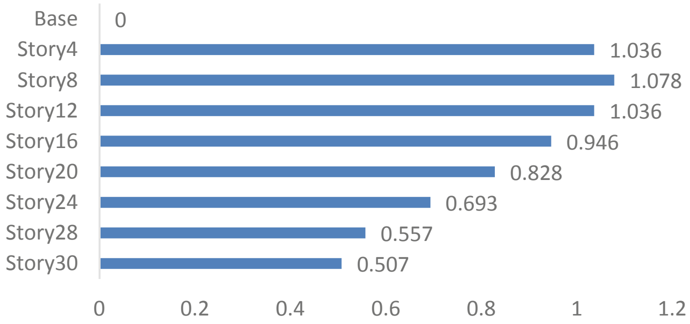

Fig. 8 Story drift for the building with aspect ratio 1:1

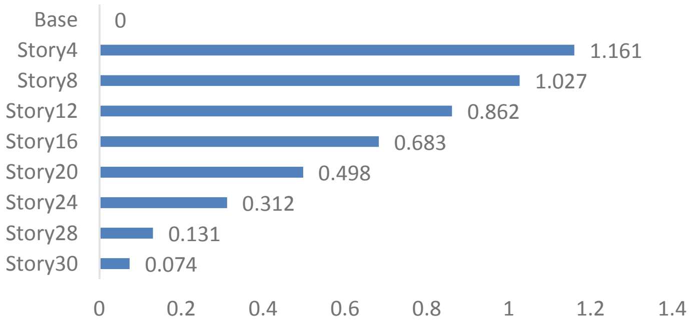

Fig. 9 Story drift for the building with aspect ratio 1:2

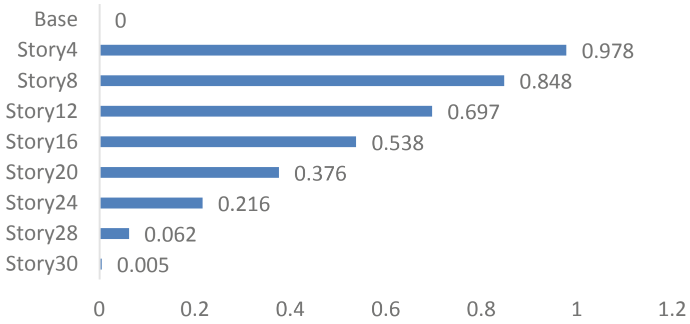

Fig. 10 Story drift for the building with aspect ratio 1:3

For the buildings with the aspect ratios of 1:2, 1:3, 1:4, 1:5, and 1:6 story drift decreased by approximately 93% However for those with an aspect ratio of 1:4 the story drift decreases by 86% and for those with the aspect ratio 1:1 the story drift decreases by 51%.

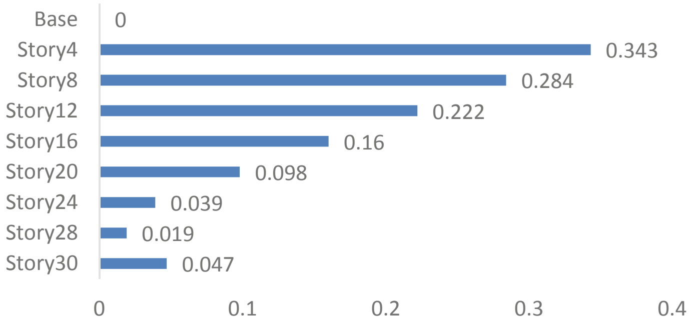

Fig. 11 Story drift for the building with aspect ratio 1:4

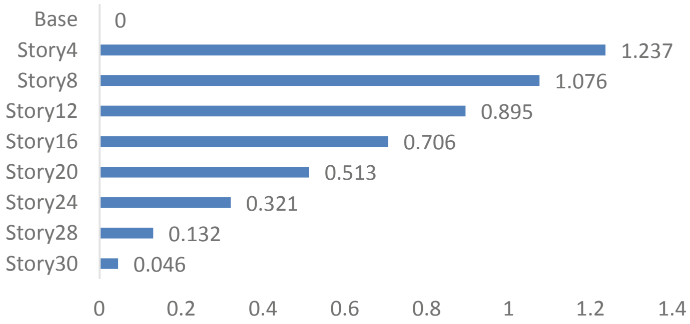

Fig. 12 Story drift for the building with aspect ratio 1:5

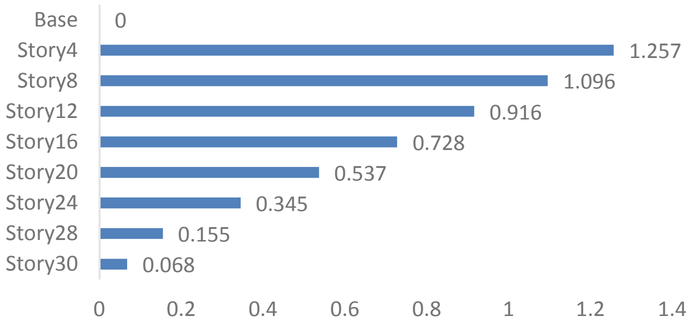

Fig. 13 Story drift for the building with aspect ratio 1:6

Story Stiffness

The presence of stiffness irregularity, together with strength irregularity, along the building height leads to undesirable performance throughout severe earthquake shaking, including the localization of lateral deformations in select stories and initiation of story collapse mechanism. The existence of stiffness and strength irregularity, contributes to the undesirable output during an extreme earthquake, along the construction height, including the location of lateral deformations in the selected stories and to the mechanism of story collapse. The lateral stiffness Ks of a story is defined as the ratio of the story shear to story drift.

The following results show the variation in the stiffness for different stories and aspect ratios (Figs. 14, 15, and 16).

Global Ductility

The Global Ductility graph indicates that the ductility ratio decreases for the building with respect to the aspect ratio of 1:2 by 23% compared with the aspect ratio 1:1 and then increases for the aspect ratio 1:4 and again shows a trend of decrease by 36% for the aspect ratios 1:5 and 1:6.

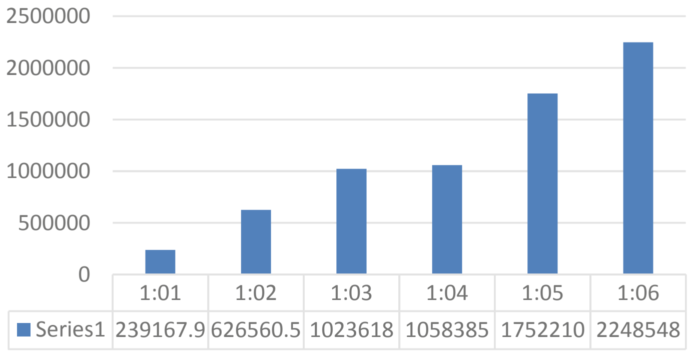

Fig. 14 Stiffness for 10 story along X-axis

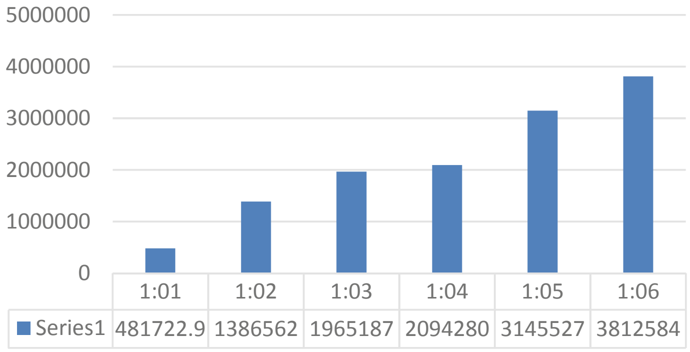

Fig. 15 Stiffness for 20 story along X-axis

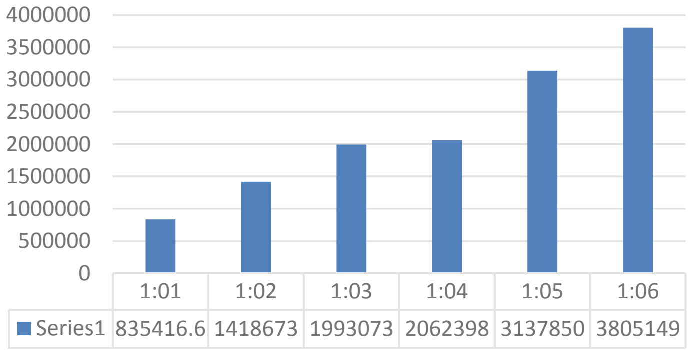

Fig. 16 Stiffness for 30 story along X-axis

4 Conclusion

This paper mainly focuses on the behavior of buildings with respect to the plan aspect ratios. In this paper, the calculation of global ductility for a high-rise building with a symmetrical plan and is mainly emphasized. Ductility is not directly proportional to the aspect ratio. Figures 17, 18, 19, and 20 indicate the variation pattern of the ductility ratio.

A detailed study was conducted by comparing the ductility ratio by varying the plan aspect ratio with the building height. When the number of stories increases from 10 to 30, the variation pattern becomes considerably similar. The ductility ratio decreases at 1:2 ratio and shows an increasing trend till the plan aspect ratio of 1:4 and then decreases at plan aspect ratio 1:5 and again increases for the aspect ratio of 1:6.

Ductility for the aspect ratio of 1:4 decreased by 29% and 36.2% compared with that for the aspect ratio of 1:3 and 1:5, respectively.

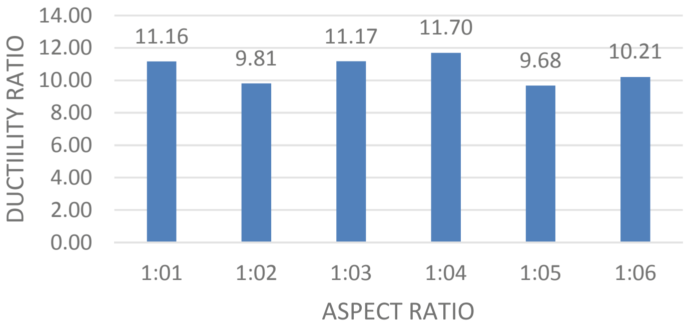

Fig. 17 Global ductility demand of the 10-story building

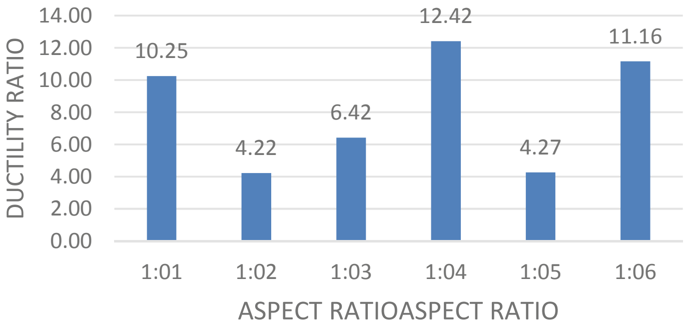

Fig. 18 Global ductility demand of the 20-story building

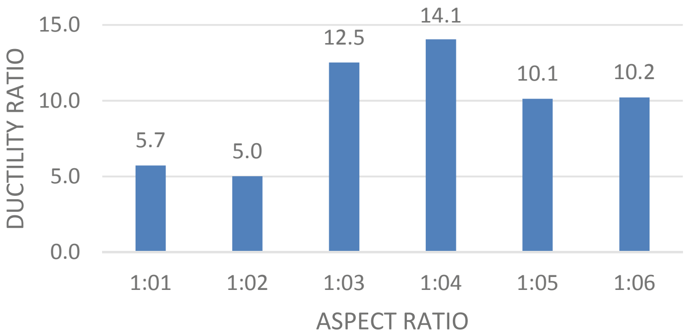

Fig. 19 Global ductility demand of the 30-story building

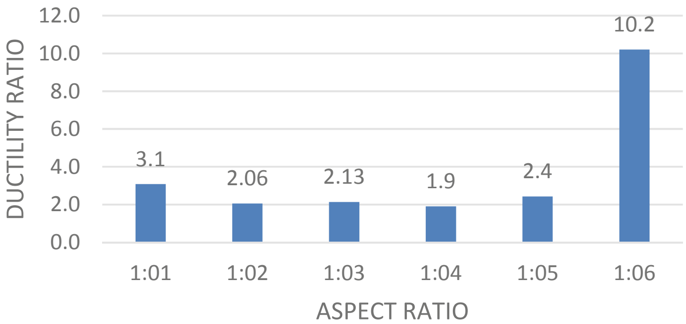

Fig. 20 Global ductility ratio for the 30-story building with the same area

In this study, the building dimension was kept constant along the Y-axis and the number of bays was increased along the X-axis. The maximum displacement at the roof level along X-axis shows a trend of decrease with an increase in the plan aspect ratio.

Figures 14, 15, and 16 show the variations in buildings stiffness. The ductility ratio is directly influenced by the stiffness variation.

References

1. Murty CVR, Goswami R, Vijayanarayanan AR, Mehta VV (2012) Some concepts in earthquake behavior of buildings
2. Aswin PT (2013) Thesis on seismic evaluation of 4-story reinforced concrete structure by non-linear static pushover analysis. NIT, Rourkela
3. Kia SM, Yahyai M (2004) Relationship between local and global ductility demand in steel moment resisting frames. In: 13th world conference on earthquake engineering, Paper no. 885
4. Krishna GV, Kumar R, International conference on issues in design of tall concrete buildings in India with reference to IS 16700: 2017 code
5. IS 13920 (2016) Ductile design and detailing of reinforced concrete structures subjected to seismic forces—code of practice