APPLICATION OF SEISMIC ISOLATION FOR AN IMPORTANT BUILDING LOCATED IN A HIGH SEISMIC ZONE IN INDIA

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ABSTRACT

This paper aims to examine the effect of seismic isolation on an important building which is located in a high seismic zone of India. Firstly, the building designed as a fixed base (FB) building as per the requirements of Indian codes and its seismically isolated (SI) version were compared using the non-linear static and dynamic analysis results. The damage states and the response parameters were compared. Secondly, the same building was designed as a fixed base building in the lowest seismic risk zone in India and seismically isolated to check if it can be used in the highest seismic zone or not. The results were positive which suggests that the member sizes can be reduced if seismic isolation is adopted, and hence the initial cost can be offset. To check for the design of elements, the vertical distribution of shear force coefficient was studied for the effect of higher modes and compared with Japanese code equation. In conclusion, it was seen that seismic isolation could be effectively used, particularly in important public buildings which need to be protected against earthquake damage as they serve important functions after an earthquake. Higher modal response using amplified shear coefficients can be applicable for Indian structures with unreinforced masonry infill (URM) walls.

Keywords: Seismic isolation, shear coefficient, higher modal response.

1. INTRODUCTION

India is a highly earthquake-prone country, because of the collision of the Indian plate with the Eurasian plate. However, thousands of people die due to moderate earthquakes in India, because of poor seismic resilience of the constructed environment. Also, seismic isolation is still not a popular construction practice in India. Only a few SI buildings have been constructed to date. Also, the latest revision of the design code IS 1893(1):2016, recommends the use of base isolation and such advanced techniques to prevent loss of life and property. But, there are no specific guidelines or procedure prescribed to follow.

There are four seismic zones, viz., Zone II, III, IV, and V, which define the Zone factor, Z, which is the value of the peak ground acceleration that is considered for the seismic design of structures located in each seismic zones. Four input ground motions normalized to PGV of 50 kines are used for analysis in this study. Seismic isolation design is done with the Japanese seismic design practice.

2. TARGET BUILDING

2.1. Outline

The target building is a telephone exchange building which is located in Guwahati, the capital of Assam,

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which is a state in the Northeastern part of the country. The seismic zone is V, which is the highest seismic zone category in India. The importance factor of the building is taken as 1.5. The elevation and floor plan of the building is shown in Figure 1 and Figure 2 respectively. The soil stratum is considered to be hard soil.

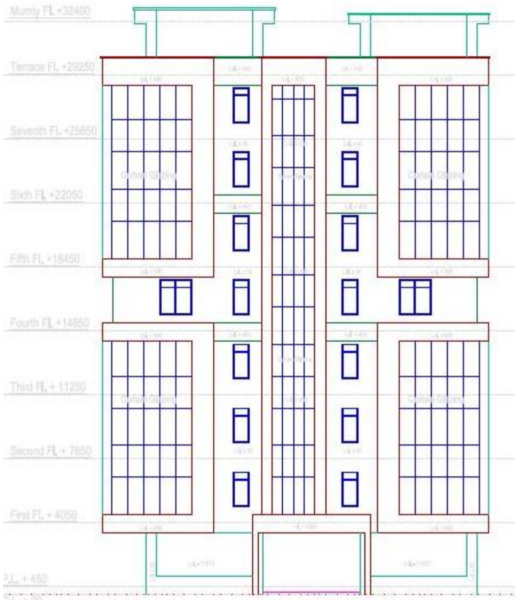

Figure 1. Elevation of the target building.

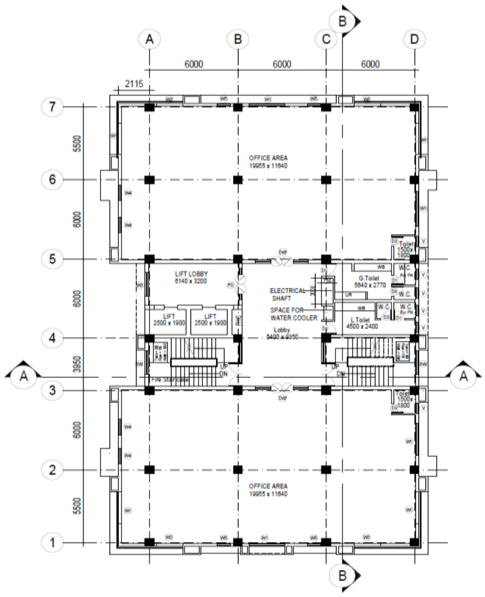

Figure 2. Plan of the target building.

2.2. Non-linear static analysis of the building

Two models were made in STERA-3D software, with and without the effect of unreinforced masonry (URM) infill walls. X-direction was considered for the pushover analysis.

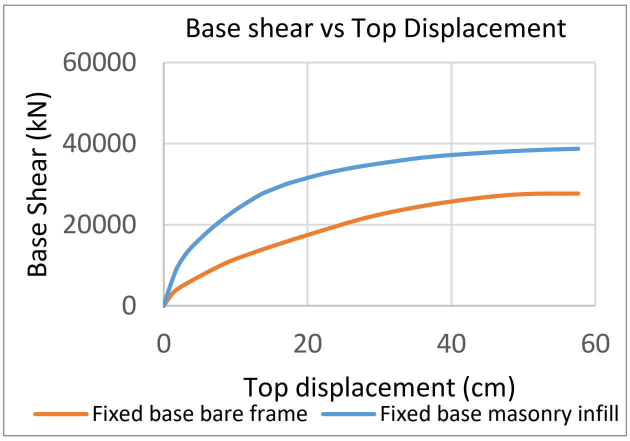

Figure 3. Pushover curves for fixed base buildings.

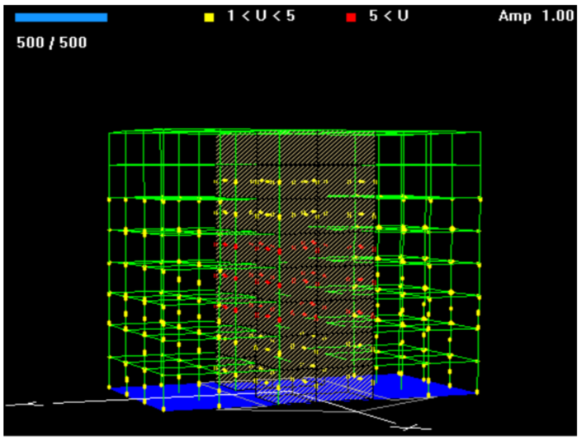

Figure 4. Damage state of FB building with masonry infills after pushover analysis.

3. SEISMIC ISOLATION SYSTEM

The maximum displacement of the seismic isolation system was predicted using Figure 5, which was developed using the Japanese standard of seismic design for hard soils. In general Japanese design practice, isolators with $T_f = 3$s are considered good enough. The shaded area in Figure 5, shows the target

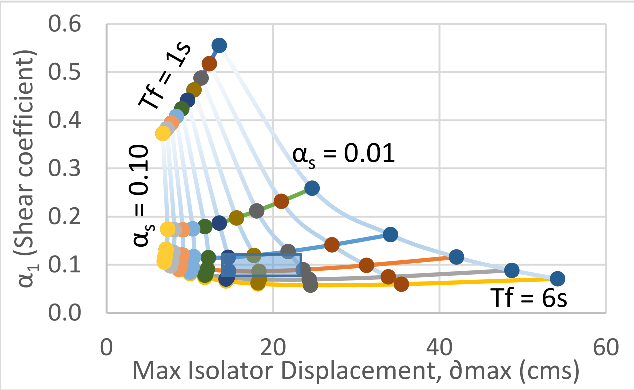

Figure 5. Prediction of maximum displacement.

displacement and the shear coefficient, α_1 for which the isolators were designed.

Yield shear force coefficient of elasto-plastic damper is denoted by α_s. Three values of α_s (0.03, 0.05 and 0.10) were used for three different combinations of isolators. The three different bearings systems were designed, and the best representative systems were chosen from the Bridgestone product catalogue, 2017. Increasing values of α_s means that the yield force is getting higher and the initial stiffness increases too.

4. NON-LINEAR TIME HISTORY ANALYSES

4.1. Input earthquake strong motions

Four strong ground motions mentioned in Table 1, were used for input, after normalizing the PGV to 50 kines, to make it realistic in Indian context. These earthquakes were selected because two of them are short-period earthquakes, and one is long-period.

Table 1. List of EQ strong motions used for NTHA.

S. No.	Ground Motion	Scaled to PGV
1	El Centro NS, 1940	50cm/s
2	Hachinohe EW, 1968	50cm/s
3	Uttarkashi NS, 1991	50cm/s
4	Kobe NS, 1995	50cm/s

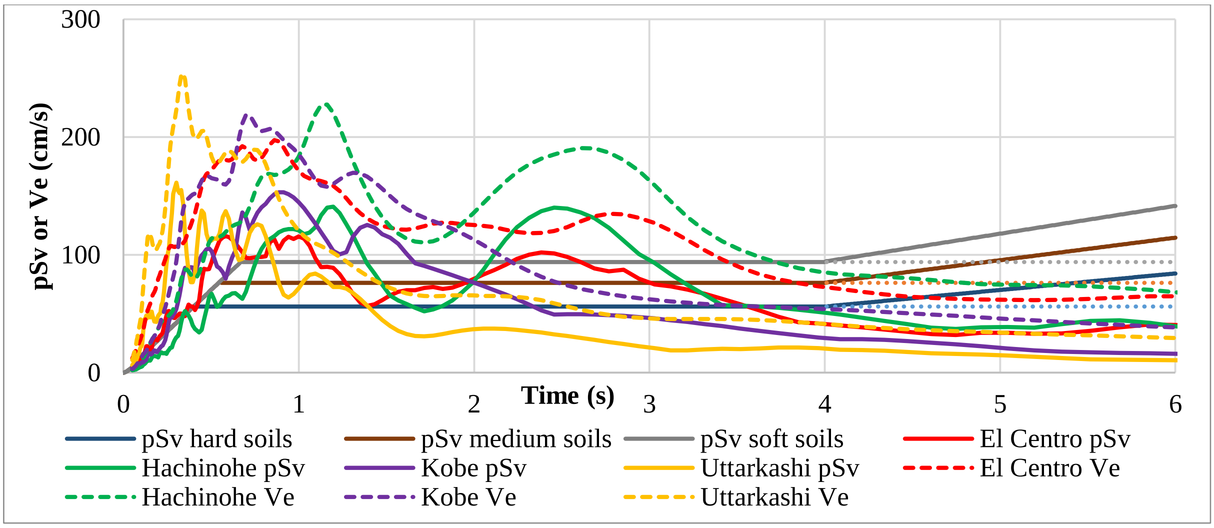

Figure 6. Pseudo velocity response and energy spectra for EQs considered with Indian code pSv.

The four earthquakes that are used in this study are plotted for their spectral velocity response spectrum along with the defined spectra in the Indian code for hard soils, medium soils and soft soils (Figure 6). Also, the equivalent velocity of earthquake input energy, V_E for the strong ground motions are plotted. Now, the V_E was assumed to be 100 cm/s for hard strata, as per the Japanese design code. But, as per Indian code, for hard soils, pSv ≈ 55 cm/s. Therefore, the assumption was appropriate for preliminary design, but in some cases, it was an underestimation. It is an interesting observation that after 4 s, the pSv increases. It is because the defined spectral acceleration is constant after T=4 s. Therefore, to convert to pSv, we need to multiply by T/2π, and hence it becomes linear.

4.2. Non-linear Time History Analysis (NTHA) Results

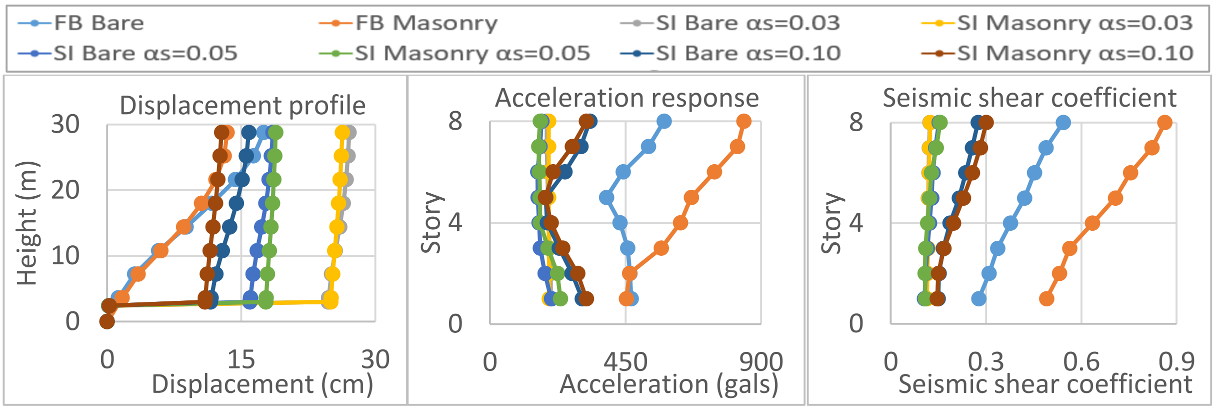

Figure 7. Displacement profile comparison for El Centro.

Figure 8. Acceleration comparison for El Centro.

Figure 9. Shear coefficient comparison for El Centro.

The designed isolator bearings for target period, T_f=3s for the three α_s values, were modeled in the fixed base building above the first story columns, for both bare frame and with URM infill walls and non-linear time history analyses (NTHA) were performed for the FB and the SI buildings. Figures 7-9 show the comparisons for El Centro EQ only. The analyses were conducted for all the 4 EQ motions.

4.3. Low seismic risk zone-II building

In this section, the same target building was considered to be located in zone-II and designed as a fixed base building, to ascertain if this reduced-section building could be applied with seismic isolation and if it could be used in the highest seismic zone V. From an economic point of view, a possibility of reduction of the section sizes can be considered. A quick comparison is made between the Zone-V and Zone-II buildings for only one earthquake ground motion, i.e., Hachinohe EW (PGV-50kines). Both the buildings were seismically isolated at the same first story level as before.

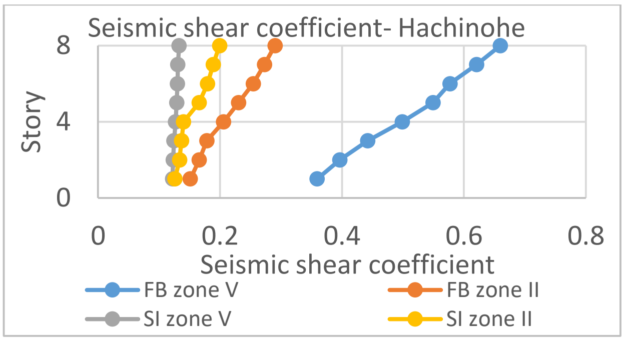

Figure 10. Zone-V and Zone-II comparison.

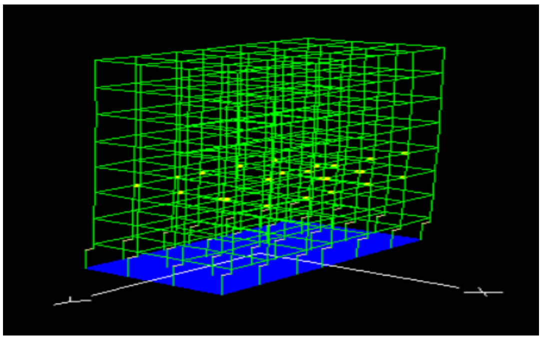

Figure 11. Damage state of SI zone-II building.

5. VERTICAL DISTRIBUTION OF SHEAR FORCE COEFFICIENT

To check for the damage in superstructure, the accurate calculation of shear force coefficient is required. In this section, the comparison is made between the non-linear time history analysis (NTHA) results, with the theoretical Japanese standard predictions. But for the contribution of higher mode responses, one more proposal by Kobayashi and Matsuda (2012) is studied and compared with the above two.

The proposed equation by Kobayashi and Matsuda is given below:

$$\alpha_i = \alpha_f + \beta_i . A_i . \alpha_s \quad (1)$$

where α_i, α_f, and α_s are the shear force coefficient of *i*-th story, elastomeric isolators and elasto-plastic dampers respectively. β_i is amplification factor for A_i distribution to take into account response amplification. β_i is formulized by isolation ratio, *I* and equivalent viscous damping ratio, h_{eq}.

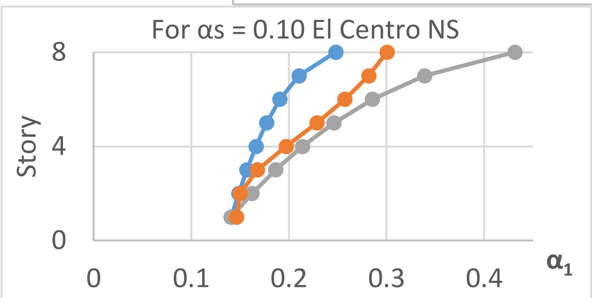

Figure 12. α_i distribution for El Centro (α_s=0.10).

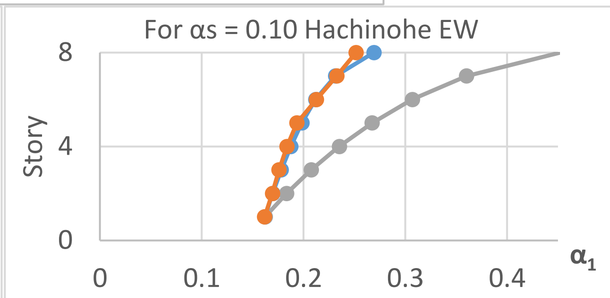

Figure 13. α_i distribution for Hachinohe (α_s=0.10).

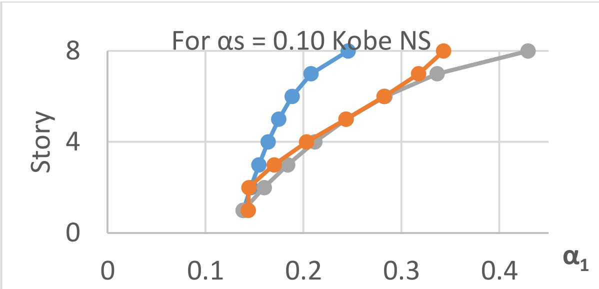

Figure 14. α_i distribution for Kobe (α_s=0.10).

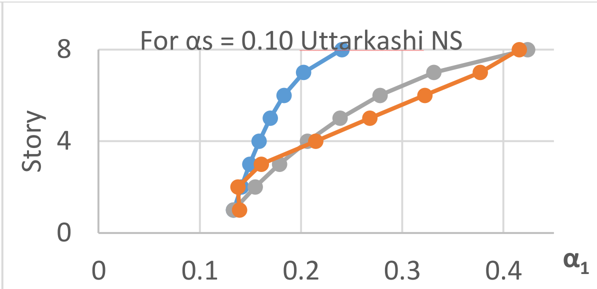

Figure 15. α_i distribution for Uttarkashi (α_s=0.10).

6. DISCUSSIONS

The SI buildings showed good behavior when subjected to the input strong ground motions.

It was seen that the migration of the response took place from the non-linear range of the pushover curve to the linear range when subjected to seismic isolation (Figure 16).

Firstly, the base shear and the response acceleration are greatly reduced, which reduces the seismic demand for the members and hence, the possibility of reduction of the member sizes can be considered.

Secondly, the effect of the masonry infill walls is evident, and it is an important aspect that should be taken into account.

Thirdly, there was significant reduction in story drift in SI building, which means the superstructure behaved elastically.

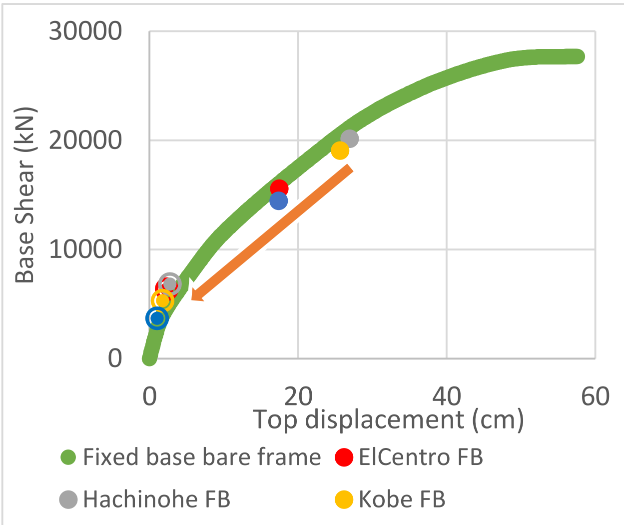

Figure 16. FB bare frame pushover curve. (α_s = 0.03).

α_s, also affect the behavior of the structures. The lower α_s values showed good behavior and more reduction of base shear and the acceleration response compared to the higher α_s values.

Lastly, with such good performance of SI buildings, structural damage is altogether prevented. Especially, for important buildings like hospitals, etc., even non-structural damage can be minimized.

For vertical distribution of shear force coefficients, Figures 12-15 show when masonry infill walls were considered, and particularly for higher values of α_s, the proposed Kobayashi method gave a proper or conservative evaluation of the shear forces, while the Japanese code method underestimated. So, this comparison confirms that if the isolators have high stiffness, then the contribution of higher modes is increased. Now, higher mode contribution is seen in Uttarkashi and Kobe earthquakes only. The reason being that these two are short-period earthquakes, and the second natural period of the isolated structure for α_s=0.05, is 0.351 s. and for α_s=0.10, is 0.340 s, which almost matches the time period for the peak of the response spectrum for Uttarkashi and Kobe earthquakes (Figure 6).

7. CONCLUSIONS

Application of SI system is hugely beneficial for important buildings in the high seismic zone because all critical response parameters are reduced significantly.

Important buildings when designed with the codal provisions may still suffer some structural damage and a lot of non-structural damage in the event of a strong earthquake, because of the design philosophy adopted in the Indian codes. But in Seismic Zone-V in India, especially important buildings which serve critical post-disaster functions need to be protected against even rare earthquakes. Seismic isolation is one such idea, which to a large extent, prevents structural and non-structural damage.

α_s =0.03 was selected as the preferred choice for installing the isolation system because of the high reduction in base shear, acceleration response and story drifts. Higher α_s values are suitable in places which have space constraints, but the target building has no such restrictions. Hence 0.03 α_s value can be used even though the displacement of the isolation layer is relatively high. The effect of masonry infill walls should be included in all analysis results as seen in the study.

For Zone-V building, it was seen that the seismic base shear coefficient was reduced to the zone-II levels after application of seismic isolation. But for Zone-II building, the seismic isolation works well, but the superstructure doesn't behave elastically or like a rigid body.

It is important to check for the amplification of the vertical distribution of the shear force coefficients. The Japanese design code method gives acceptable results in some cases, however, for certain situations like high α_s value, and superstructure not behaving like a rigid body, it may give underestimated results. Kobayashi method is thus, applicable to Indian structures with URM infill walls.

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