COMPARISON OF RECORDED RESPONSE OF CONVENTIONAL AND BASE ISOLATED BUILDINGS WITH ANALYSIS

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ABSTRACT

Base Isolation is regarded as a promising solution for earthquake resistant design which result in significantly low floor accelerations, and inter storey drifts. This ensures the safety of structural as well as non-structural elements, thereby keeping the building operational even after a severe earthquake. Seismic base isolation technique is very useful for cost effective seismic design of nuclear structures. The effectiveness of a base isolation system is governed by bilinear characteristics offered by the isolators. The present work attempts to study the effectiveness of base isolation over conventional seismic construction, using a case study of identical conventional and isolated building constructed for experimental purposes in Guwahati, a seismically active region in India. The comparisons of analytical results with the records for two low intensity earthquakes indicate the effectiveness of base isolation in the initial stiffness range of the isolation system when none of the isolators yield.

KEY WORDS: Base Isolation, Lead Rubber Bearings, Low intensity earthquakes.

INTRODUCTION

There are several options for seismic design of a building with a given configuration. Linear elastic seismic design for a severe earthquake will result in an uneconomical and impractical building. In conventional seismic design, plastic deformations in beams and columns help in absorbing the damaging effects of earthquakes. This is the most widely used design concept across the world. However, the displacements generated may be large enough to cause the collapse of non-structural elements, thereby preventing the structure from being operational after the earthquake. Base isolation offers a solution for buildings which are required to remain operational after a severe earthquake. For a study of characteristics of base isolated structures, two buildings (Fig-1) with identical configuration have been constructed in IIT-Guwahati [1], located in one of the highly active seismic zone in India. One of the buildings has been constructed using conventional earthquake resistant design procedure, and the other uses seismic base isolation (lead laminated rubber bearings) for mitigating earthquake effects. The buildings are instrumented to record floor accelerations at the first floor and the roof level for real earthquakes. A comparison of the conventional and base isolated buildings subjected to two low intensity earthquakes, with their respective recorded and analytical response is presented.

BILINEAR CHARACTERISTICS

The reduction of storey shears, storey drifts and floor spectral accelerations is realised in base isolation design by two modifications in the dynamic characteristics of the structure - a time period shift by introduction of flexible mounts and additional damping offered by the isolators by hysteretic energy dissipation [2], [3], [4], [5]. When a base isolated building is subjected to a low intensity earthquake, the isolators are subjected to very low horizontal forces, preventing them from yielding. Thus for low intensity earthquakes, the isolators remain in the initial stiffness region. There is, however; a slight time period shift due to the lesser initial stiffness of the isolators compared to the stiffness of the ground storey columns. There is no role of hysteretic damping since yielding of isolators does not take place. Thus whatever reductions occur in shears and spectral accelerations at low intensity earthquake are attributed to the slight shift in the time period [4]. Only for moderate or high intensity earthquakes, both time period shift and additional hysteretic damping contribute in the significant reduction of shears and spectral acceleration.

Fig-1: Conventional Building (Left) & Isolated Building (Right)

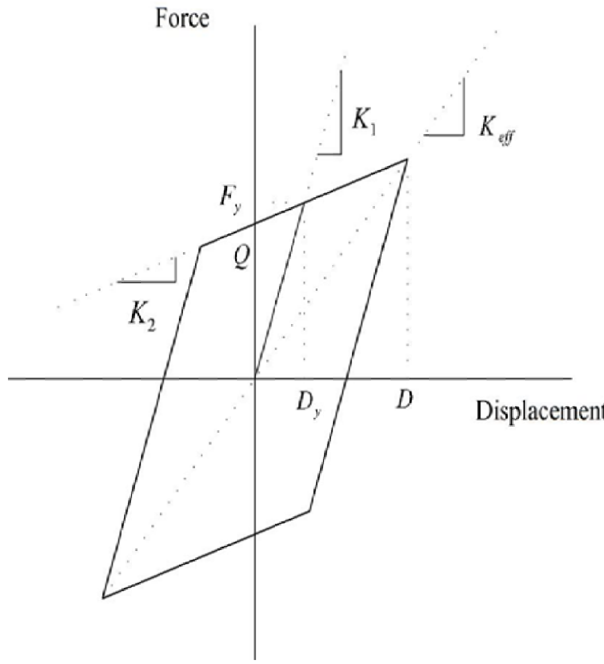

Fig-2: Bilinear Force Deformation Curve

The behavior of almost all of the isolator devices is represented mathematically by a bilinear force-deformation curve as depicted in Fig-2 [4], [6], [7]. The characteristic strength Q, initial stiffness K_1, post yield stiffness K_2 are sufficient to define the bilinear behavior of any type of isolator, and are referred to as bilinear characteristics. The bilinear characteristics Fig-2 have been related to the material properties of the isolator and its geometry [3], [4], [7]. For analysis of a base isolated building, an experimental cyclic shear test of the prototype isolator device is mandatory [8], [9], and the resulting force-deformation curve is used to define the required bilinear characteristics. In this paper, the study of base isolated buildings is limited to the use of lead laminated rubber bearings (LLRB) for seismic isolation. The experimental force deformation curve obtained for the lead laminated rubber bearing used in the isolated building is shown in Fig-3 [1]. The bilinear characteristics obtained from a cyclic shear test of the isolator used for the experimental building are presented in Table-1. In base isolated buildings, the superstructure behaves in a linear elastic manner as the inter storey drifts in the building are considerably low even in a severe earthquake. The hysteretic energy dissipation due to large plastic deformations is localized and limited to the isolators. Isolators are designed to maintain their vertical load carrying capacity under large shear deformation.

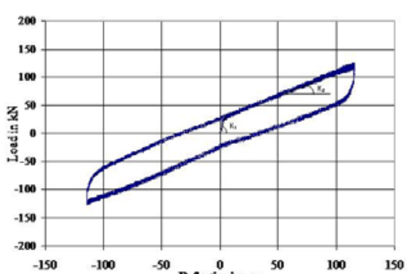

Fig-3: Experimental Force-Deformation Curve

Table-1: Experimental Bilinear Characteristics

Quantity	Value
Characteristic strength (kN), Q	25.7
Initial stiffness (kN/m), K_1	13525
Post-yield stiffness (kN/m), K_2	838
Yield force (kN), F_y	27.4
Yield Displacement (mm), D_y	2.03

ANALYSIS FOR RECORDED LOW INTENSITY EARTHQUAKES

An analytical 3-D model of the building is generated in SAP-2000 [10], accounting for the effects of infill and soil structure interaction [11]. The impedances for equivalent soil springs [12], [13], used to model the effects of soil stiffness are evaluated and soil springs are modeled using link element [11]. The building is analyzed for two low intensity earthquakes that have actually occurred (designated as EQ-1 (Fig-4) occurred on 6-November, 2006 and EQ-2 (Fig-5) occurred on 10-November, 2006).

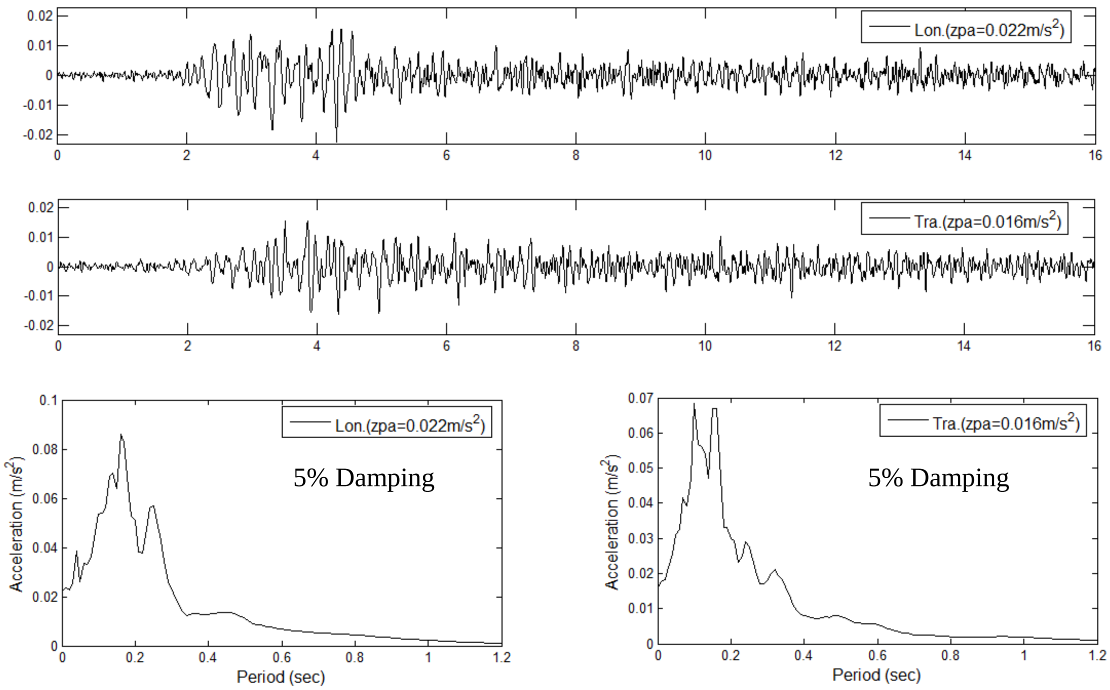

Fig-4: EQ1—Longitudinal and Transverse motions and their Acceleration Spectra

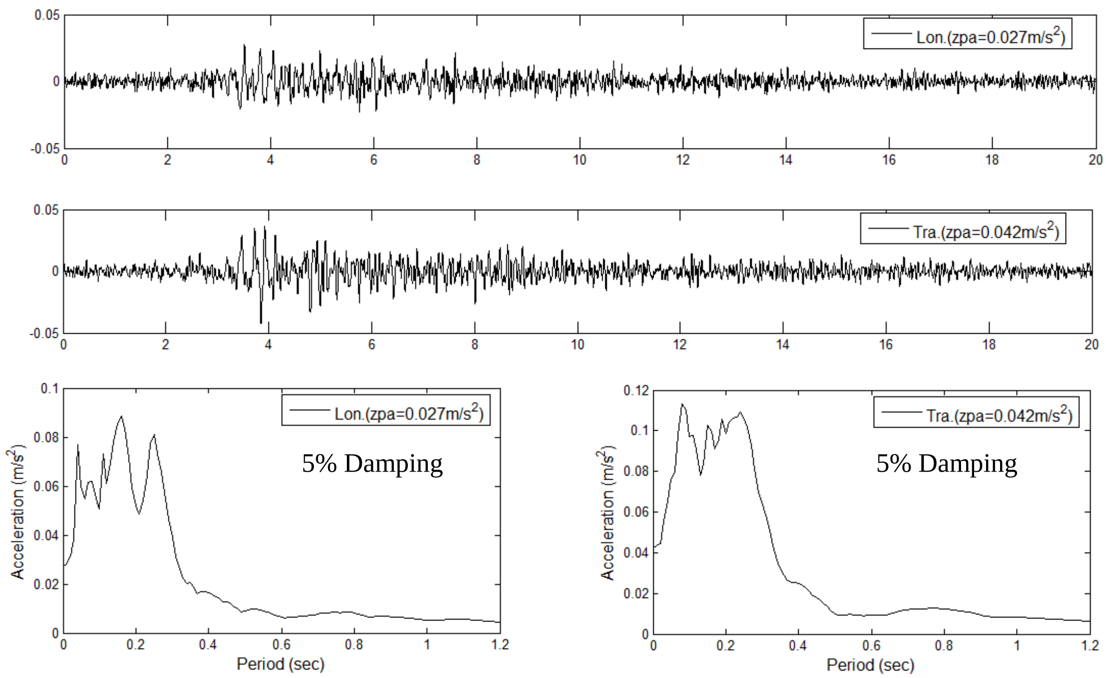

Fig-5: EQ2—Longitudinal and Transverse motions and their Acceleration Spectra

The isolators are modeled in SAP by using the link element [11]. The initial stiffness, yield force and the post yield stiffness ratio are specified as obtained (Table-1) from the experimental force deformation curve.

Modeling of the superstructure and soil is similar to that done in case of the conventional building. The isolated building is analyzed for the two recorded earthquakes- EQ-1 (Fig-4) and EQ-2 (Fig-5).

Recorded motion of the buildings for EQ-1 and EQ2, in form of roof acceleration time history for longitudinal as well as transverse directions is available for both the buildings. In addition longitudinal and transverse acceleration time history records at the ground floor just above the isolation plane are available. Acceleration time history for transverse direction on the ground floor of the conventional building is also available. From analysis, the corresponding acceleration response time histories are obtained. A comparison of 5% damped acceleration spectra of these analytical and recorded time histories are presented in Figs.6-11. For a relative comparison of response of conventional and isolated building, their spectra are plotted to the same scale.

EFFECTIVENESS OF SEISMIC ISOLATION

The recorded earthquakes EQ-1 and EQ-2 are of low intensities with the maximum peak ground acceleration of $0.022 m/s^2$ and $0.047 m/s^2$ respectively. A higher time period of the isolated building as compared to the conventional building is responsible for the reduction of its acceleration response as seen in Figs.6-11. Further it is seen that the reduction in peak spectral acceleration of the records is more significant as compared to the peak spectral values obtained from the analysis. This implies that the time period shift which is responsible for the reduction in response has been under estimated in the analysis, which leads to a conclusion that the actual initial stiffness of the isolators is much less than the initial stiffness used in the analysis (determined from experimental cyclic shear test).

The difference in the peak values of recorded floor acceleration in comparison with analysis are tabulated in Table-2. The values indicate that difference in analysis and records of base isolated building is more significant as compared to conventional building. Moreover, while the analytical peak floor accelerations in conventional building are an under estimate of the peak accelerations obtained from instrumental records, analysis of base isolated building gives much higher peak floor accelerations than the instrument records. Here it is expected that a modified analysis of conventional building should yield higher floor acceleration as compared to the present analysis and a modified analysis of the isolated building should yield lower floor accelerations as compared to the present analysis.

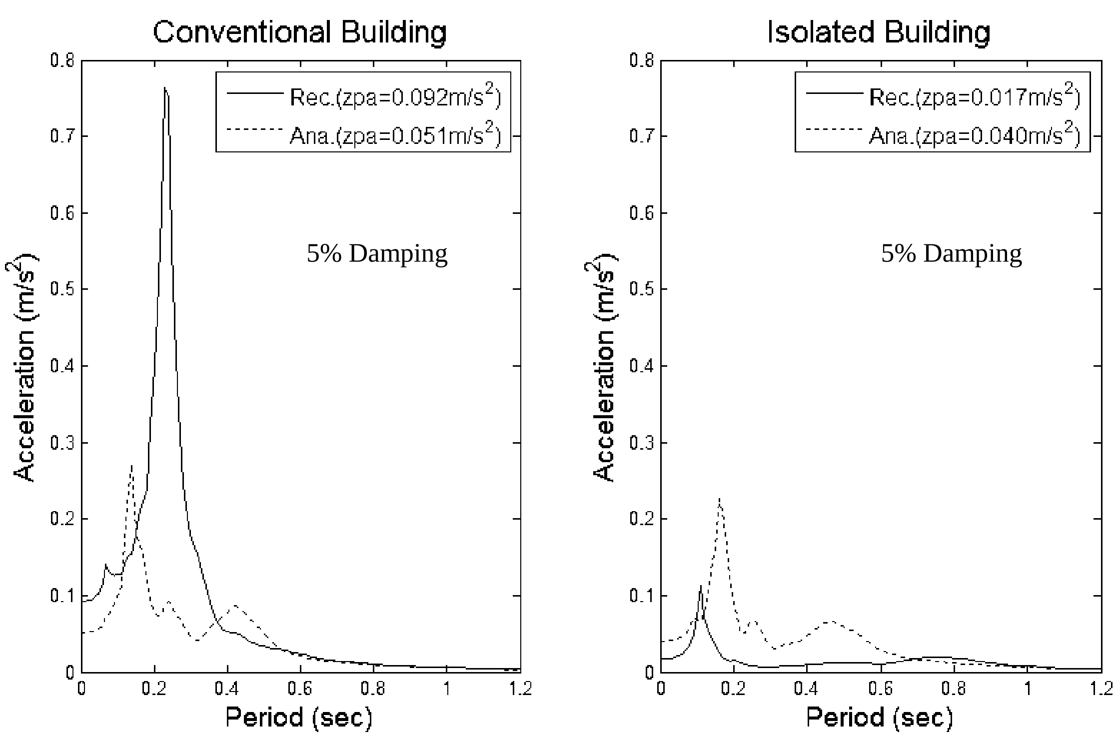

Fig-6: Comparison of <u>Roof</u> Acceleration Spectra for EQ-1—Longitudinal Direction

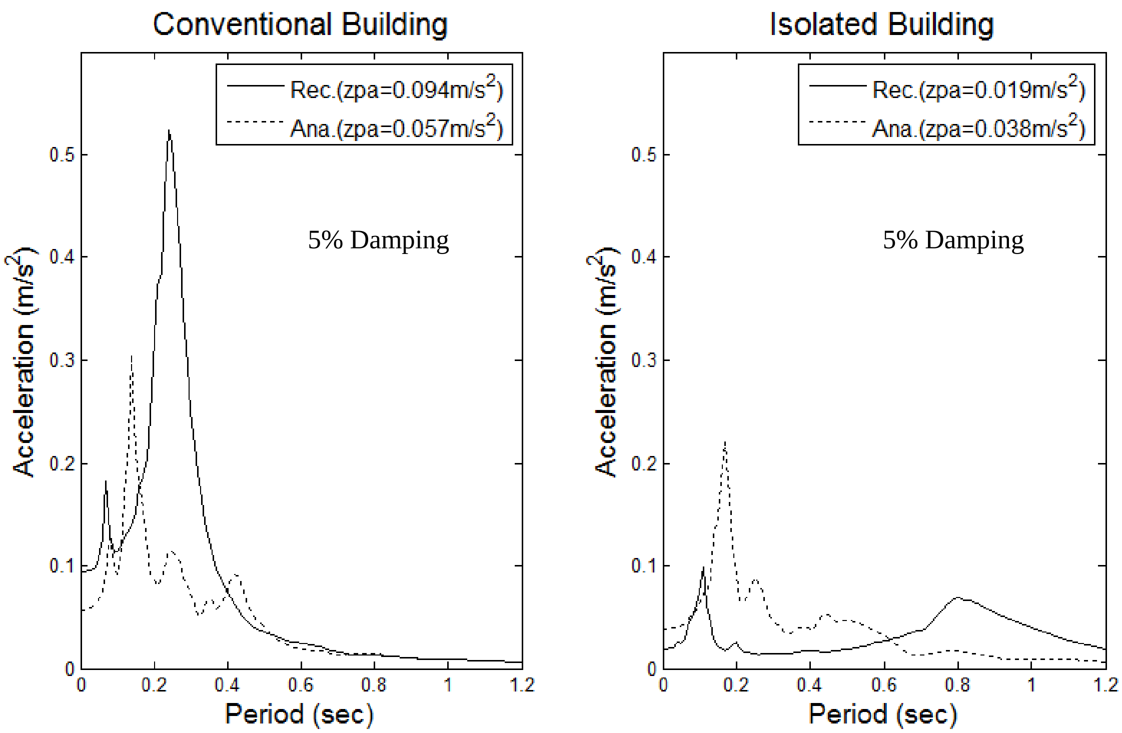

Fig-7: Comparison of <u>Roof</u> Acceleration Spectra for EQ-2—Longitudinal Direction

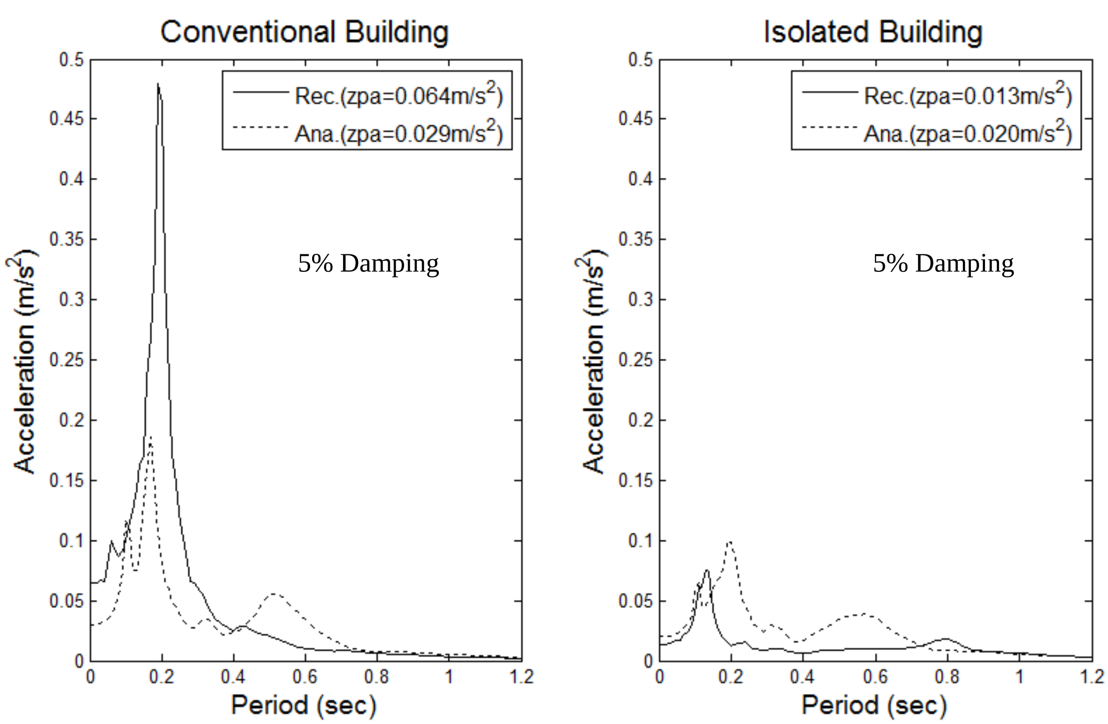

Fig-8: Comparison of <u>Roof</u> Acceleration Spectra for EQ-1—Transverse Direction

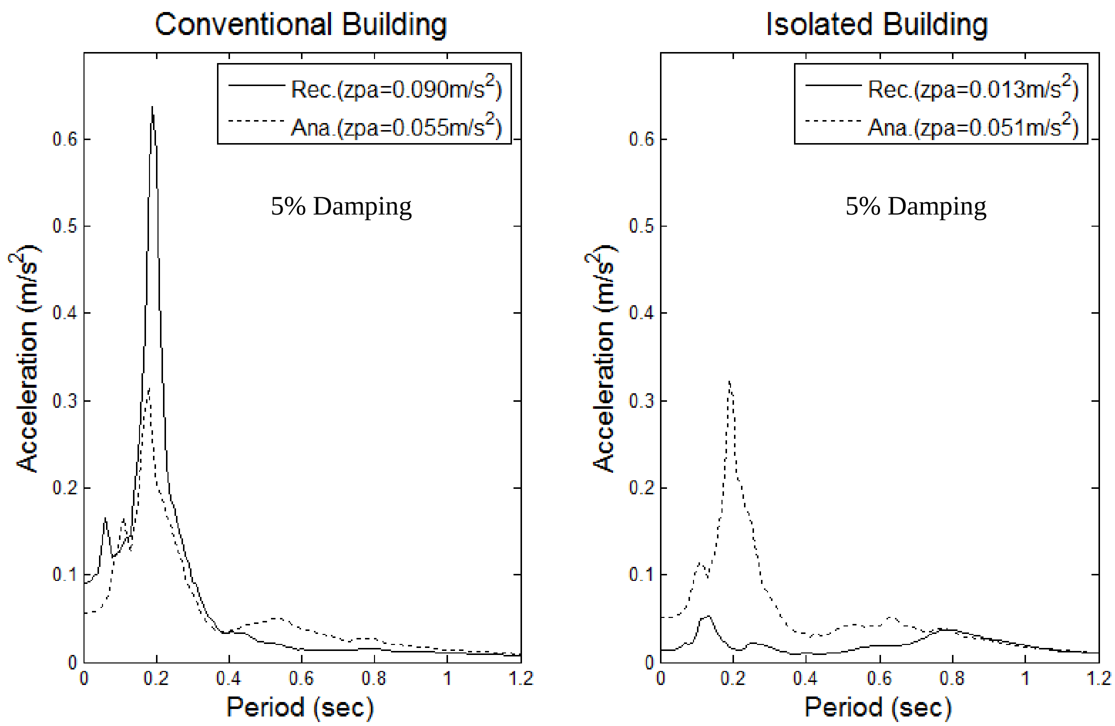

Fig-9: Comparison of <u>Roof</u> Acceleration Spectra for EQ-2—Transverse Direction

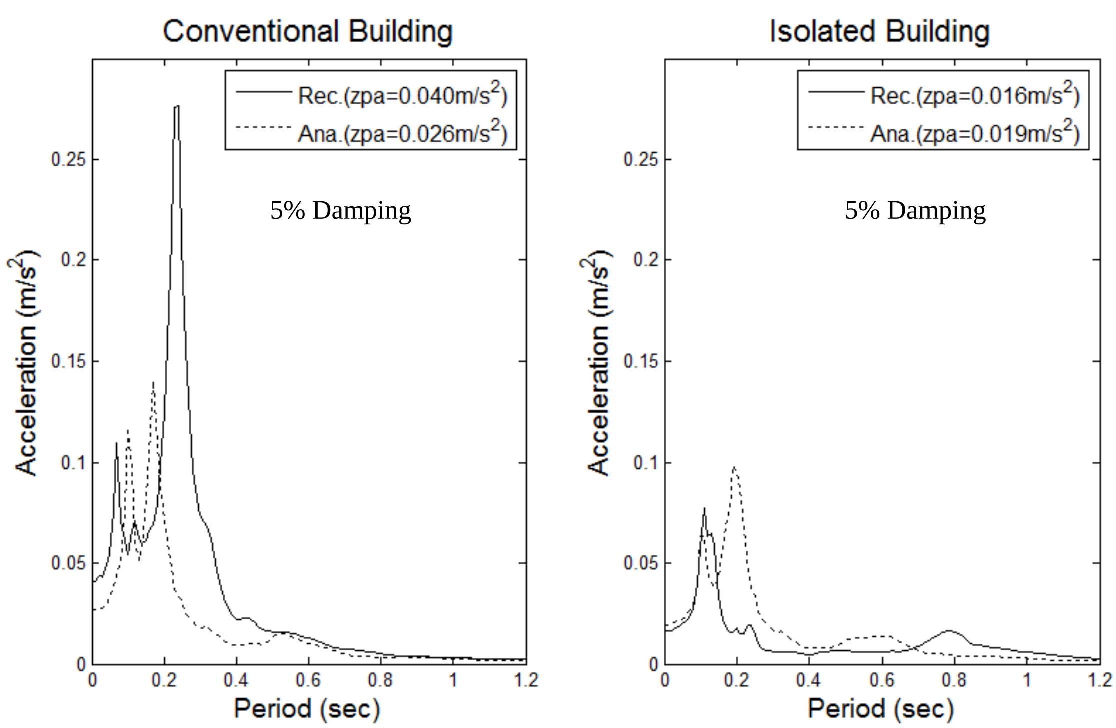

Fig-10: Comparison of <u>Ground floor</u> Acceleration Spectra for EQ-1—Transverse Direction

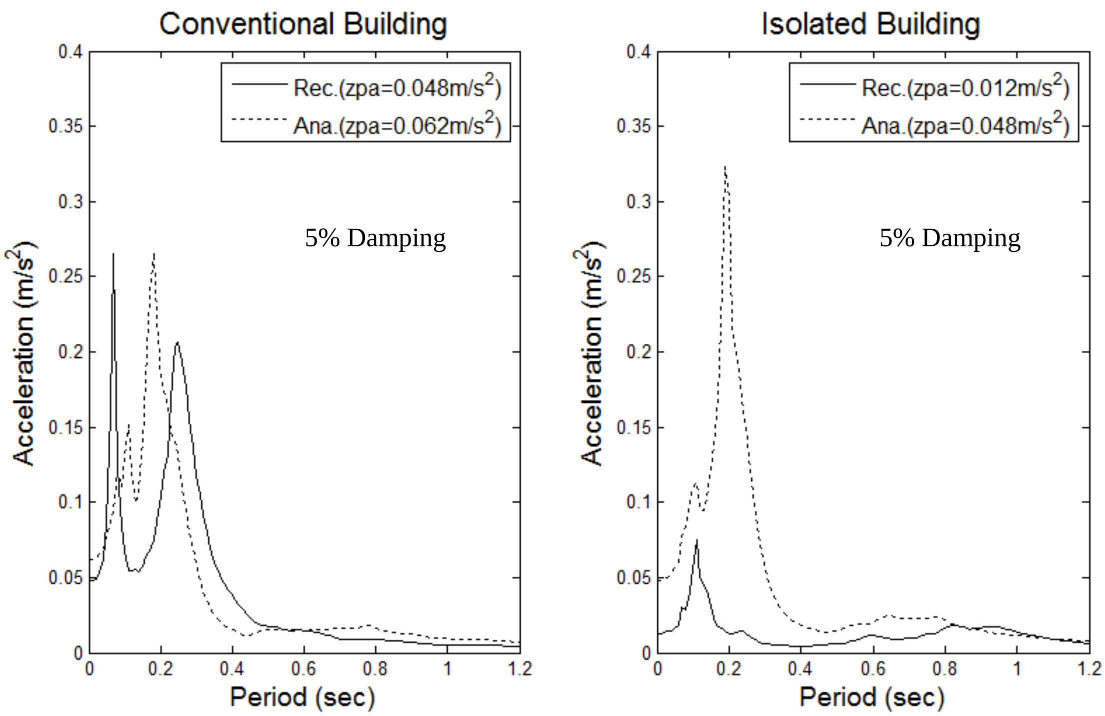

Fig-11: Comparison of Ground floor Acceleration Spectra for EQ-2—Transverse Direction

Table-2: Percentage Difference between Recorded and Analytical Peak Acceleration Response

		Longitudinal		Transverse	
		Conventional	Isolated	Conventional	Isolated
EQ-1	Roof	44.6	135.3	54.6	53.8
	Ground	-	-	35.0	18.8
EQ-2	Roof	39.4	100.0	38.8	292.3
	Ground	-	-	29.2	300.0

-Instrumental records not available for ground floor in longitudinal direction

The difference between the results of analysis and the values obtained using instrumental records for the conventional building can be explained as followed:

- Infills are modelled as a diagonal strut. The earthquake is of a considerably small intensity. There is a possibility of the entire infill acting as a shear panel (for the low intensity earthquakes considered). This would significantly increase the stiffness of the conventional building.
- In modelling the frame, gross cross sectional area for the columns and beams have been taken. A free vibration testing of the frame structure would have given a better estimation of stiffness at low level excitations
- At low intensity earthquake, a conventional structure is expected to exhibit low damping. The present analysis assumed 5% damping in all modes. An assumption of reduced damping values is required for an accurate estimation of the spectral acceleration.

The difference in analysis and observations of the base isolated building can be explained as followed

- The large differences in the analysis and records of base isolated building indicate that the actual value of initial stiffness at a low level intensity is much smaller than the value evident from the experimental cyclic shear test. A free vibration testing of the base isolated structure would have given a better estimation of the initial stiffness of isolators at low level excitations.
- The rubber compound used in the LLRB may have a considerable amount of damping. Considering this damping in the analysis would reduce the spectral acceleration. Therefore damping of the isolator need to be evaluated accurately.
- The infill modelling as explained for conventional building would significantly alter the stiffness of the base isolated building.

CONCLUSIONS

In this paper, a comparative study of conventional and base isolated buildings at actual low level excitation is carried out. A complete 3D model of the buildings considering the effects of infill and soil stiffness is used for the analysis. The comparison observed in the analysis and the instrumental records for both conventional and base isolated buildings indicate a similar trend in the spectral accelerations. However, some differences are evident. These discrepancies indicate a modelling deficiency with respect to stiffness and damping of the structural elements, infill and the isolators. In the analysis, gross cross sections of the beams and columns have been considered. There may be some effective reduction in the gross stiffness at low level excitations, which has not been considered. The earthquakes considered in the present study are of a very low intensity. At such low intensity excitations, the conventional building is expected to exhibit low value of damping in contrast to 5% damping which is assumed in the present analysis. It is also possible that the infill wall acts as a shear panel for such low intensity excitations, whereas the present analysis considers the infill acting as equivalent diagonal strut. The stiffness and damping characteristics of the isolators that have been used are derived from an experimental cyclic shear test, where the isolator was subjected to significantly large deformations. The applicability of these values of stiffness and damping at low level excitations is questionable. The comparison of analysis of the base isolated building with the instrumental records indicate that the initial stiffness of the isolator for low level excitation should be much less than its value for an excitation resulting in significant shear deformation of the isolators. A free vibration test of the two structures would have given a better estimation of the stiffness and damping characteristics of the test structures at low intensity excitations.

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