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Dynamic response of conventional and base-isolated building subjected toearthquake

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Abstract. Generally, in the cities buildings are closely spaced. Response of the buildingsdepends on thefrequencies of the structures and frequency content of the earthquake motions. Structural frequency can be altered with the presence of base isolator. In this paper, two instrumented buildings located in Guwahati region which is considered as the highest seismic zone of India are studied. The buildings consist of RC frame structures with brick infill walls. The buildings are located adjacent to each other and among them one is a base isolated structure and other is a conventional structure. In the base isolated structure first a laminated rubber bearing (LRB)is used and then laminated lead plug bearing(LLPB) isolatoris used. The isolators are located in between plinth level and ground floor level. Real time responses of both the buildings are measured due to real earthquakes. The earthquake response of the conventional structure and base isolated structure when both are situated in soft soil and located close to each other is studied.Response of the conventional building is drastically reduced (by 3 times) due the presence of base isolator. Detailed 3D finite element model has been made considering soil nonlinearity.

Keywords:base isolator, soil structure interaction, structures, real earthquakes

1 Introduction

Many devastating earthquakes, occurred in the past have caused lot of damage to the structures. One of the approach used for reduction of seismic response of the structures is base isolation. In cities, structures are closely spaced and it often occurs that the base isolated structure is situated near the conventional structures. Soil structure interaction is another parameter due to which the structural response due to earthquake varies. It is essential to study the effects of the earthquake response of the conventional structures and base isolated structures when both are situated in soft soil and located close to each other. The complexity of the problem needs to be studied by modeling the structures with soil and performing detailed time history analysis. Moreover, numerically studying the response of these structures subjected to real earthquake and comparing it with the real time measured response will give a proper validation of the problem.

Base isolation is aseismic design approach in which the structural fundamentalfrequency of vibration is reduced to a value lower than the predominantenergy-containing frequencies of the earthquake ground motion. Extensive literaturereviews were carried out in 1986 by Kelly[1] in 1990 by Buckle and Mayes[2]and in 2017 by Jangid[3]. There are basically two types of base isolation approaches. The first approachdecouples the structure from the horizontal components of the earthquake groundmotion by interposing a layer with low horizontal stiffness between the structure and the foundation, and the second approach works by limiting the transfer of shearacross the isolation interface through the use of sliding systems. In the 1980s, Kellyand Hodder[4] first proposed the former approach, in which experimental work wasperformed on laminated rubber bearings (LRBs) and laminated lead plug bearings(LLPBs). In the present work a building located on LRBs and LLPBs is studied. In literature [5-8] lot of studies are carried out on base isolated structures to investigate the effectiveness of base isolation in reducing the earthquake motion transferred to the structure and understanding the parametric behavior of such structures. However, the effect of closely situated location of conventional structure on the seismic response of base isolated structurewith soil structure interaction is not studied till date.

In the present study, two identical buildings are considered in which one of the building is conventional building and other one is base isolated building located on LRBs and LLPBs. Both these instrumented buildings are situated inGuwahati region which is considered as the highest seismic zone in India. The buildings are located close to each other and the buildings are instrumented and subjected to real earthquake time histories. The earthquake response of these similar adjacent structures, one base isolated and other conventional is studied numerically with soil structure interaction and the response obtained is validated with measured earthquake response.

2 Building description and subsoil

Two adjacent three storied buildings, one with conventional and other with base isolated foundation resting on subsoil, are located in Guwahati region of India. Latitude and longitude of this location is 26.1903° N, 91.6920° E. As per the seismic code of India, Guwahati falls into the high seismic zone (Zone V). The buildings consist of Reinforced Concrete (RC) frame structures with brick infill walls. The plan and elevation of the structures are shown in **Fig. 1**. The effective mass of each building is 117 tons. Each building has a plan area of 4.5m by 3.3 m and floor to floor height of the building is 3.3 m. Size of the columns are 0.4m X 0.3m. Foundation of the building is located at 1.2 m below the ground level. The buildings were fully instrumented and the Earthquake data was recorded for the period of 2005 to 2012. In this period, the isolated building is placed over two different isolators which is located in between plinth level and ground floor level. During the period 2005 - 2007 the building was placed on laminated lead rubber bearings. Later in 2007 these bearings were replaced by laminated lead core rubber bearing with central lead core (LLPB) by using hydraulic jacks. LLPB has alternate layers of rubber and steel with a central lead energy dissipating core and Laminated Rubber Bearings (LRB) consists of a laminated rubber and steel bearing with steel flange plates for mounting to the structure. The rubber in the isolators acts as a spring. It is very soft laterally but very stiff vertically. The high vertical stiffness is achieved by having thin layers of rubber reinforced by steel shims. These two characteristics allow the isolator to move laterally with relatively low stiffness yet carry significant axial load due to their high vertical stiffness. The lead core provides damping by deforming plastically when the isolator moves laterally in an earthquake. Both LLPB and LRB had dimension of 460mm X460mm in plan, and 355 mm in height with alternate layers of 28 numbers of 7 mm thick rubber and 28 numbers of 4mm thick steel plates. More over in LLPBin the central location 40mm diameter lead core is used. The horizontal and vertical stiffness of the LRB isolator was obtained as0.7968 kN/mm and 188.96 kN/mm and that of LLPB isolator was obtained as 5.55 kN/mm and 220 kN/mm. The details of instrumentation are presented in literature by Dubey et. Al[9,10].The Earthquake data was recorded for the period of 2005 to 2012.

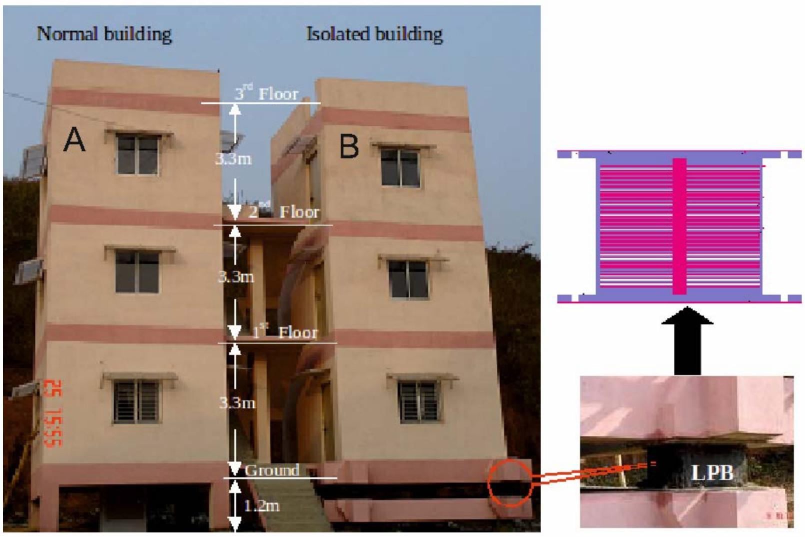


Figure 1: Test building at IIT Guwahati campus.

Shear wave velocity of soil was obtained through Multi Channel Analysis of Surface Waves (MASW) tests. Tests were conducted under the base isolated building. Survey lines and shearwave velocity profiles are shown in **Fig. 2.** Shear wave velocity variation of 150 m/sec to 300 m/sec was obtained up to depth of 5m below GL.

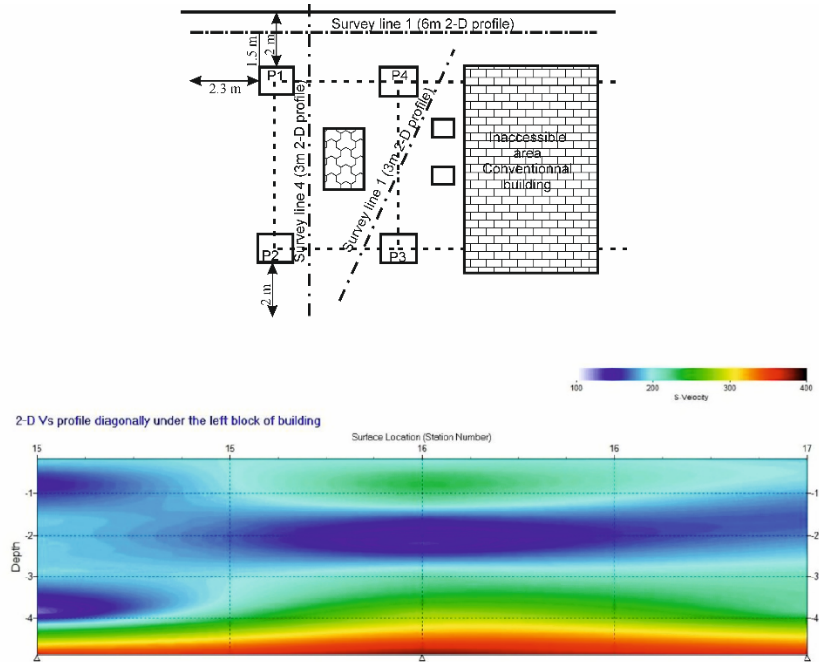


Figure 2: Shear wave velocity profile below the buildings at Guwahati.

3 Instrumentation of the building

In order to measure the response of the buildings due to earthquake, instrumentation of the buildings was installed. Two numbers of biaxial accelerometers were placed on 1st floor and 3rd floor of conventional building as shown in Fig. 3. One biaxial and one tri-axial accelerometer were installed at 1st and 3rd floor level respectivelyof base-isolated building as shown in Fig. 3. Response of the building during earthquakes was measured during the period of 2005 to 2012. Longer direction of the building is designated as 'X direction' and other perpendicular direction is considered as 'Direction Y'.Similar nomenclature is used throughout the paper.One tri-axial force balance accelerometer has been installed on the ground just below the conventional building, to capture earthquake induced ground motion. One accelerometer was located at the 1 km away from the buildings which is free from any construction, and the acceleration measured by it is represented here as 'free field' motion.

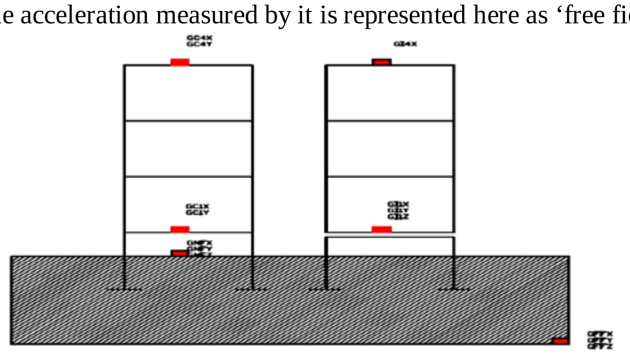


Fig 3: Schematic instrument location of both the buildings.

4 Earthquake records

Two instrumented buildings experienced 14 numbers of earthquakes of different earthquake magnitudes during the period of 2005 to 2012. Among these 10 records have both far field near field and building responses. In this paper only motion in 'X' directions and 'Y' directions are reported. Earthquake event dates epicenter location and earthquake magnitudes are reported in table-1. In this paper, analytical simulation of two of the earthquakes, viz. Assam earthquake which took placein Myanmar regionon 3/11/2009 having magnitude 5.9 and an epicenter distance of 353.0 km and Assam earthquake on 06/11/2006 having magnitude 5.2 with an epicenter distance 383 km are discussed.

Table-1: List of earthquakes and their epi-central distances.

Date	Magnitude (Mw)	Epicenter	Distance from source (Km)	Region
12/8/2006	4.9	24.696˚N, 92.755˚E	**191**	Assam
06/11/2006	5.2	24.736° N, 95.223° E	**383**	Assam
29/05/2009	4.2	26.4° N, 91.8° E	19	Darrang, assam
15/2/2009	4.4	26.0°N, 90.2°E	**150**	Assam-meghalaya border
24/2/2009	4.8	25.9°N, 94.3°E	**257**	India(nagaland) myanmar bord. Reg.
25/04/2009	4	26.4°N, 91.7°E	29	Kamrup, assam
19/8/2009	4.9	26.6 N, 92.5 E	91	Sonitpur,assam
3/11/2009	5.9	24.3 N, 94.6 E	**353**	Myanmar-india border region
17/04/2008	4.2	26.07°N, 92.224°E	51	Assam
10/09/2006	4.2	24.635°N, 94.597°E	**333**	Myanmar – india border

5 Numerical modelling of soil structure interaction

Soil is modeled with 8 nodded continuum elements and structure is made of a combination of beam and shell element as shown in **Fig. 4**. Depending upon the shear wave velocity, soil strata is divided into three layers of 3m,3m, and 4m with v_s of 150m/s, 300m/s and 400m/s respectively. Due to the lack of laboratory soil testing data of dynamic characteristics of the study area, Seed and Idriss [11] mean curve of shear modulus degradation and damping ratio curve with shear strain shown in **Fig. 5**is used.Propermeshing rules are also applied in the soil material model.The two buildings are modeled using beam elements for columns and beams and shell elements for slabs. Brick infill walls are incorporated in the model with equivalent springs and the spring stiffness is obtained using formulation given in IS1893,2016 [12] . The isolators of the base isolated structures are represented byequivalent horizontal and vertical springs and the values of the springs obtained from tests on isolators are 0.7968 kN/mm and 188.96 kN/mm respectively for LRB bearings and 5.55 kN/mm and 220 kN/mm for LLPB bearings . The effect of infinite boundary conditionsis simulated using stress free periodic boundary conditions. Seismic motion measured away from the buildings usingone of the accelerometer located one km away is considered as free surface motion. After de-convolution of the free surface motion the motion at 10 m below is obtained and applied at the base of numerical model. Two type of analysis are performed. 1^{st} free vibration analysis is performed to get the fundamental frequencies of buildingsand then time history analysis is performed considering soil nonlinearity.The data of 03/09/2009 and 06/11/2006 Assam earthquakes having epicenter 353 km and 393km respectively from the site were recorded and used in the present work.Both the ground motion time histories and their corresponding FFT and response spectra are shown in Fig 6 and Fig 7.

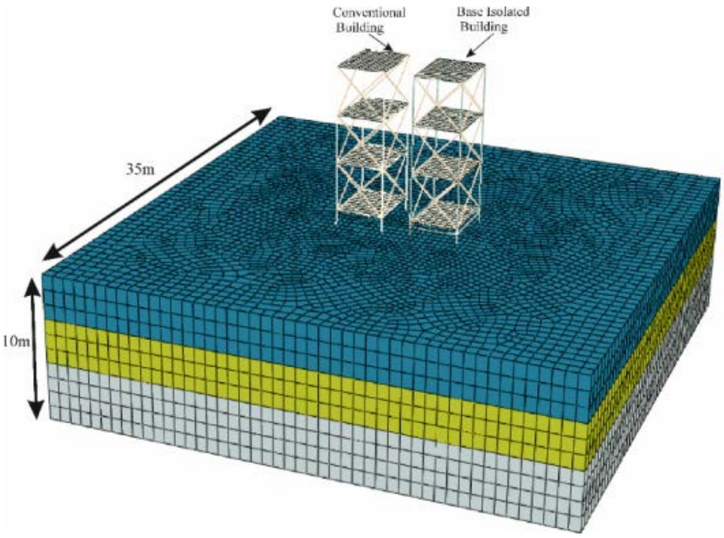


Figure 4: Finite element meshing of soil structure interaction.

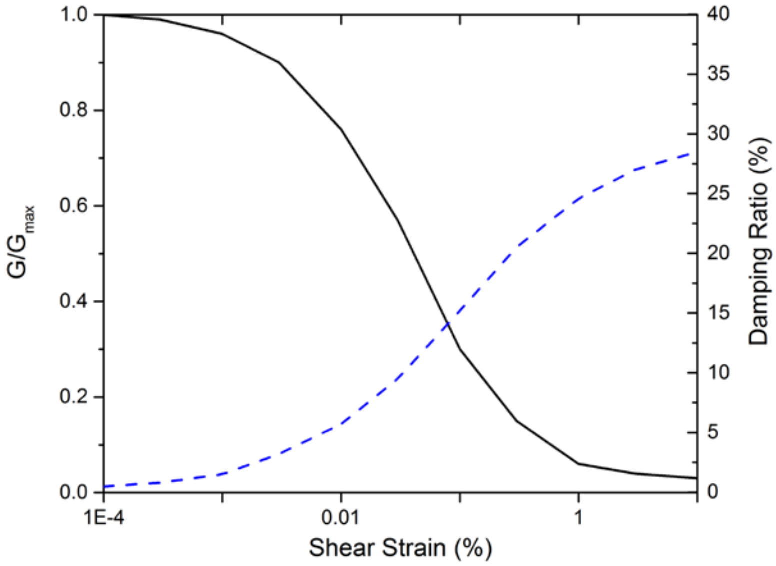


Figure-5 Shear modulus degradation curve of soil. (Seed& Idrss mean curve (1970))

Figure 6: 6/11/2006 Earthquake time history, FFT and Response spectra in (a)X and (b)Y direction respectively

Figure7: 3/09/2009 Earthquake time history, FFT and Response spectra in (a)X and (b)Y direction

6 Results and discussions

The fundamental frequency of the buildings with soil structure interaction is obtained as 1.98 Hz and 4.46 Hzforisolated building (with LLPB bearings) and for conventional building respectivelyin X direction. The fundamental mode obtained in the numerical model is in good agreement with the actual structure. but in case of 2^{nd} fundamental mode of the structure, numerical model predicts 9.86 Hz conventional building, where as observed value is 12.0 Hz. Two fundamental mode shape of both the buildings in X direction are shown in Fig 8.

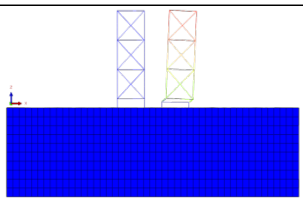
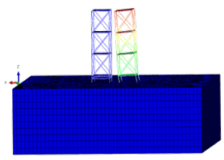
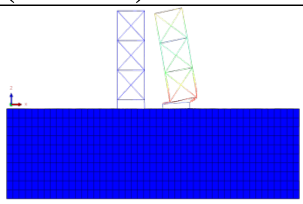
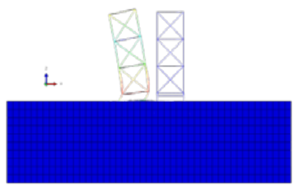
	
1^{st} fundamental mode shape of base isolated structure lateral dir frequency 1.98Hz (X direction)	1^{st} fundamental mode shape of normal structure lateral dir frequency 4.46 Hz. (X direction)
	
2^{nd} fundamental mode shape of base isolated structure lateral dir frequency 6.65Hz. (X direction)	2^{st} fundamental mode shape of normal structure lateral dir frequency 9.86 Hz. (X direction)

Fig 8: Fundamental frequencies ofboth the buildings.

Fig 9 shows the building response of 06/11/2006 Assam earthquake with earthquake magnitude 5.2 for first floor and 3rd floor with and without isolators(LRB). It is observed that, fundamental frequency of the conventional structure 4.46 Hz.For Xdirection motion(Fig. 9)peak floor response acceleration is higher in actual case than the numerical results. The reason behind this may be there is a slight shift in fundamental frequencies between observed and numerical analysis. But Y direction motion (Fig. 9)predicts well in terms of peak floor acceleration value and peak floor spectral value. Peak floor acceleration at 1^{st} floor and 3rd floor is 0.00423and 0.009g respectively for Y direction. Details of observed peak floor acceleration and numerically found peak floor accelerations are given in table 2.

At the time of earthquakes isolated building is placed over LRB on 06/11/2006. Response of the base isolated building is in line with the response of the observed data, but here 2^{nd} mode of the structure (both numerical and actual structure) excites due to earthquake than the 1^{st} mode of the structures. This 2^{nd} mode excitation of the structure may be due the local mode of the floor which matches with the globalmode of the structures. In numerical analysis 2^{nd} mode of the structures predicts 8.9 to 9.5 Hz in in X and Y directions respectivelywhile actually measured response by accelerometers gives the value of 6.45 to 7.45 Hzin X and Y directions respectively. The peak acceleration of the 3rdfloor of the structure is reduced from 0.0066g to 0.00139g in X direction and it is reduced from 0.00949 to 0.00175 in Y direction due to LRB located at the base of the structure. Thus reduction in response due to LRB is 4.78 times in X direction and 5.43 in Y direction due to presence of LRB isolators.

Fig 10 shows the response of the both normal building and base isolated building for Assam earthquakes dated 3/11/2009 with magnitude 5.9 for first floor and 3rd floor with and without isolators(LLPB). During this earthquake base isolated building is placed over lead core rubber bearing with central lead core. It observed that 1^{st} fundamental frequency of theconventionalbuilding from actually measured response is 4.9 and 4.23 Hzin X and Y directions respectively. While from numerical analysis it is obtained as 5.40 and 4.65 Hz, in X and Y directions respectively. It is observed that the change in fundamental frequency of the normal structure measured in 2009 from the previous case (that measured in 2006) was observed to be 4.6 Hz from 5.4 Hz. Earthquake dated 3/11/2009 with magnitude 5.9 is stronger than previous earthquakes. So, soil nonlinearity and structure soil structure interaction effects may be the reason for the shift in the fundamental frequency of the conventional structure from 5.4 Hz to 4.5 Hz.

Fig 10 shows the numerical and observed response acceleration of normal building for 1^{st} floor and 3^{rd}floor in X direction and Y direction respectively. It is observed that peak floor acceleration is 0.014 g and 0.03g on 1^{st} and 3^{rd}floor respectively in X direction.Here, numerical results predict the responses well with observed data. In numerical analysis peak floor acceleration is 0.021g and 0.0305 g on 1^{st} and 3rd floor respectively in X direction. However, in Y direction numerical predicts higher peak floor acceleration than observed ones. One of the major reason may be energy dissipation is actual structure due to cracking is more in actual structure due to cracking of the column members than the value which is achieved in numerical simulation. But response is similar pattern with observed data.

The frequency of base isolated structure (with LLPB) is reduced to 2 Hz from 4.5 Hz for conventional structure. In case of base isolated structure (Fig. 10) numerical results shows similar results of peak floor accelerations than the observed values. The observed peak floor acceleration value in 1^{st} floor and 3^{rd} floor is 0.007g and 0.008 g respectivelyboth in X and Y directions. In numerical analysis observed peak value on 1^{st} and 3rd floor is 0.0055g and 0.008 g respectively in X direction and 0.004g and 0.006g in Y direction. In the cases, peak floor amplification along the height of the building is 1.15 times. However, the peak 3rd floor acceleration is the same as that of PGA in 2009 case building with LLPBs. This is because the LLPBs are in linear range and yielding of lead does not occur for the peak ground acceleration of 0.008g. Moreover, the frequency of the structure with LLPB is 2.1 Hz. In 2006, the peak 3rd floor accelerations of the structure with LRB isolatorsis in the range of 0.0014g to 0.0017gin X and Y direction which is lesser than PGA of 0.002g. This is because frequency of structure with LRB is 1 Hz at which less acceleration is attracted by the structure.

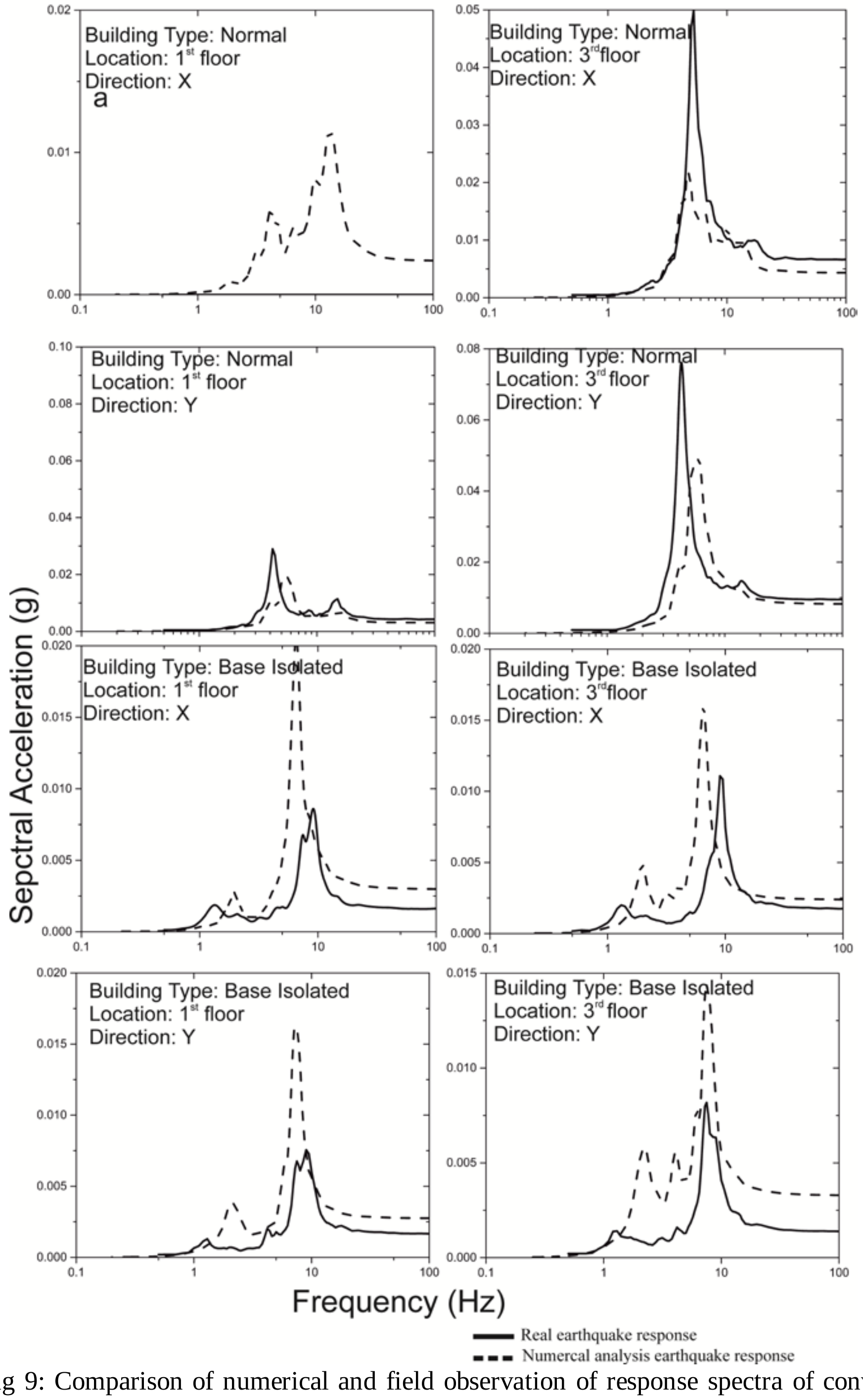


Fig 9: Comparison of numerical and field observation of response spectra of conventional building and base isolated building(on LRB) of Assam Earthquake dated 6/11/2006 and magnitude 5.2.

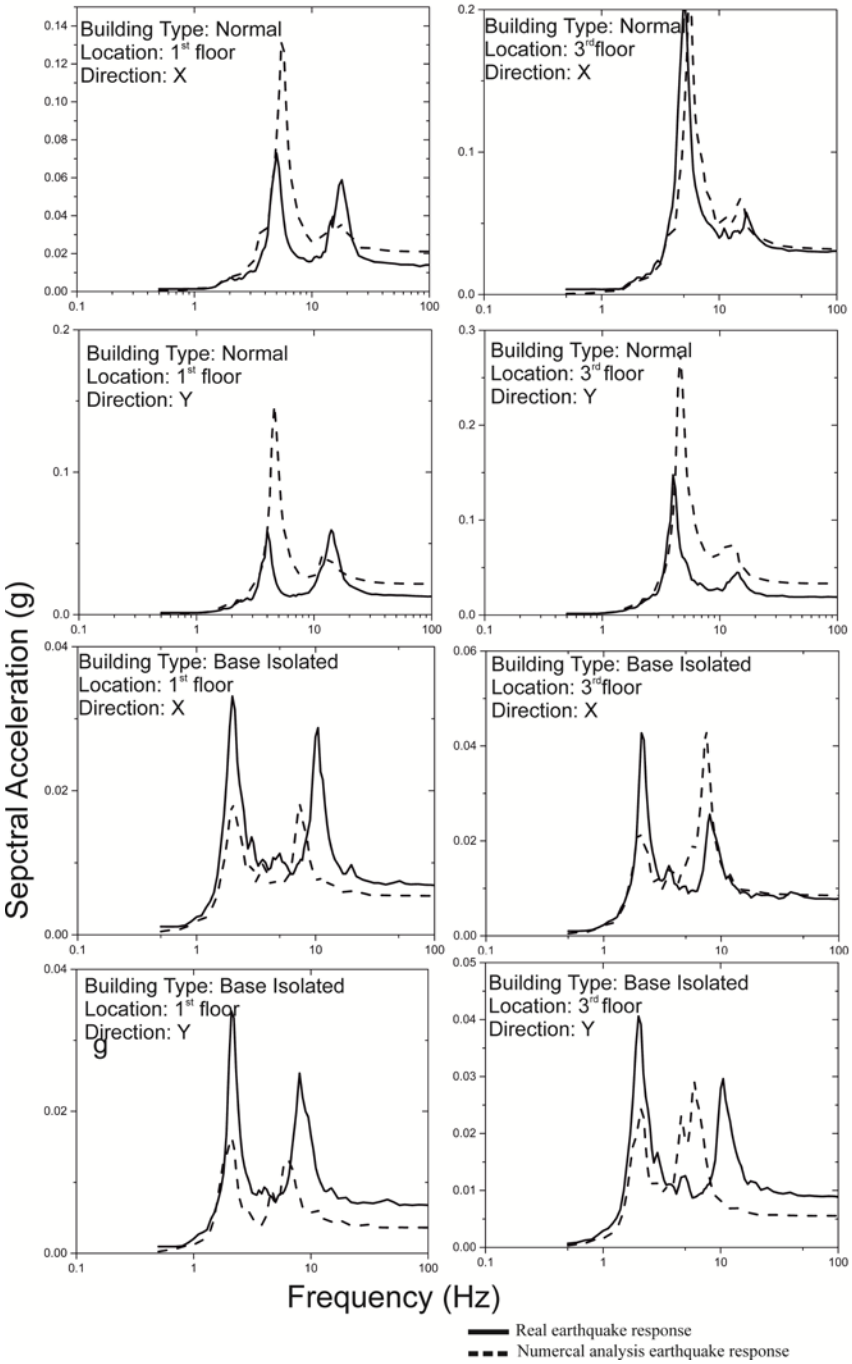


Fig 10: Comparisons numerical and field observation of response spectra of conventional building and base isolated building(on LLPB) of Assam Earthquake dated 3/11/2009 and magnitude 5,9

Table 2: Peak response at various location of the buildings.

Earthquake Name	Instrument location	Earthquake Direction (X) Observed Response peak in g	Earthquake Direction (X) Numerical Response peak in g	Earthquake Direction (Y) Observed Response peak in g	Earthquake Direction (Y) Numerical Response peak in g
		Normal Building			
6/09/2006	1st floor	N.A	0.0024	0.00423	000309
	3rd floor	0.00665	0.00434	0.00949	0.00828
3/11/2009	1st floor	0.014	0.021	0.01276	0.0216
	3rd floor	0.031	0.0305	0.01894	0.03315
		Base Isolated Structure			
6/09/2006	1st floor	0.00161	0. 00239	0.00166	0.00279
	3rd floor	0.00139	0.00299	0.00175	0.00329
3/11/2009	1st floor	0.00687	0.00541	0.00678	0.00363
	3rd floor	0.00785	0.00851	0.00887	0.00555

7 Conclusion

In the present paper numerical simulation for the structures situated in Guwahati region was carried out for two real earthquakes (2006 and 2009). The structures were with and without base isolators. FE modeling of the buildings is done with flexible soil base by modelling the soil strata and natural frequency of the buildings is obtained by free vibration analysis. Nonlinearity of soil is also considered in the analysis. Dynamic analysis is conducted to validate the observed real earthquake instrumented response. The numerical responses are compared with recorded responses using floor response spectrum for conventional and base isolated structures(located on LRB and LLPB) . The following conclusions can be drawn from the results of numerical simulations done here:

1. The data recorded for the two earthquakes of 2006 and 2009 and the numerical results infers that the frequency of the conventional structure is changed for earthquake occurring in 2006 than that occurring in 2009. This is due to the effect of soil structure interaction in which the 2009 earthquake has higher PGA of 0.008g in which soil nonlinearity occurs and thus the structural frequency reduces from 5.4 Hz to 4.6 Hz.
2. The numerical results predict the peak floor acceleration, however the there is amplification of the floor spectra in the fundamental frequency range which doesnot always match with the observed measured response. This is due to local mode of the structure which is not simulated perfectly in analysis.
3. The frequency of base isolated structure with LRB is reduced to 1.2 Hz from 5.4 Hz for conventional structure both for analysis and actual response. The frequency of base isolated structure with LLPB is reduced to 2.1 Hz from 4.6 Hz for conventional structure both for analysis and actual response.
4. It is observed that there is 4 to 5 times reduction in the peak 3rd floor acceleration of the structure due to base isolation using LRB in 2006 earthquake

for X and Y direction responses. It is also observed that there is 2 to 3 times reduction in the peak 3rd floor acceleration of the structure due to base isolation using LLPB in 2009 earthquake X and Y direction responses. The reduction is less in case of LLPB isolators as the response of structure with isolators is in linear range of LLPB isolators and frequency of structure with LLPB isolators is 2.1Hz. In case of both the base isolated structures only 1.1 time amplification is noticed in 3rd floor level than 1st floor level.

References

1. Kelly JM. Aseismic base isolation: review and bibliography. Soil Dyn Earthq Eng.;5(3):202-216.(1986).
2. Buckle, I.G. and Mayes, R.L. : Seismic isolation history, application and performance—A world view. Earthquake Spectra, 6, 161-201. doi:10.1193/1.1585564.(1990)
3. Jangid, R.S. : Optimum lead-rubber isolation bearings for near-fault motions. Eng. Struct., 29(10), 2503-2513. (2007).
4. Kelly, J. M., and Hodder, S. B., "Experimental Study of Lead and Elastomeric Dampers for Base Isolation Systems," Report No. UCB/EERC-81/16, Earthquake Engineering Research Center, Univ. of California, Berkeley, 1981.
5. Jangid, R.S. and Kelly, J.M. Base isolation for near-fault motions", Earthq. Eng. Struct. *D.*, 30(5),691-707. (2001).
6. Nagarajaiah, S. and Xiaohong, S.: Response of base-isolated USC hospital building in Northridgeearthquake, J. *Struct. Eng.-ASCE,* 126(10), 1177-1186. (2000)
7. Naeim, F. and Kelly, J.M.:Design of seismic isolated structures: From theory to practice, JohnWiley & Sons, Inc., New York.(1999)
8. Braga, F. and Laterza, M.: Field testing of low-rise base isolated building. *Eng. Struct.*, 26(11),1599-1610. (2004)
9. Nath, R. J., Deb, S. K., & Dutta, A: Base isolated RC building-performance evaluation and numerical model updating using recorded earthquake response. Earthquakes and Structures, 4(5), 471-487. (2013).
10. Dubey, P.N., Reddy, G.R., Deb, S.K., Vaze, K.K., Ghosh, A.K. and Kushwaha, H.S.: Performance of base isolated RCC framed building under actual earthquake. Proceedings *of 1st Intl. Conf. on Earthquake Hazards and Management*, Guwahati, India (2007).
11. Seed H.B., Idriss I.M: Soil moduli and damping factors for dynamic response analyses, Technical Report EERRC-70-10, University of California, Berkeley. .(1970).
12. Standard, Indian. "Criteria for earthquake resistant design of structures." Bureau of Indian Standards, Part 1 (1893).