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A STUDY ON THE SEISMIC RESPONSE OF GROUND AND REINFORCED CONCRETE BUILDINGS IN BELGAUM REGION, INDIA

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ABSTRACT

In the recent years, each unpredictable earthquake (for example Kobe, 1995; Taiwan, 1999; Kocaeli, 1999 and Bhuj, 2001) has revealed its own saga of destruction and failure of engineered structures. Therefore, regional variation in potential earthquake damage should be carefully assessed for better planning towards disaster mitigation. This requires assessment of the seismic ground motion parameters. The present study focus on the seismic response of ground and reinforced concrete buildings in Belgaum region (located in zone III, as per IS 1893–Part1: 2002) in Karnataka state. At present no strong motion records are available in this region and therefore, wavelet-based spectrum compatibility approach is used to generate synthetic earthquake motions for the region. The effect of soil deposits in the region on propagation of seismic motion parameters to the ground surface is investigated based on equivalent linear approach. The Frequency response analysis of buildings of various configurations is carried out with three dimensional numerical modeling. The results indicate the maximum spectral accelerations at the ground surface in the range of 0.68g to 1.29g and peak ground acceleration (PGA) amplifications in the range of 2.16 to 3.13. The predicted fundamental period of soil deposits in the region varies from 0.2 s to 0.4 s. The configuration of buildings susceptible to resonance due to the close matching of resulting wave frequencies of the ground is identified.

INTRODUCTION

Because of the inhomogeneous nature of the near-surface geology, every earthquake produces a spatial variation of ground motion and, consequently, spatial variability in the damage pattern. Earthquakes such as the 1994 Northridge and 1995 Hyogo-ken Nanbu (Kobe) have clearly reinforced the role that site effects play in damaging ground motion (Tsuda, 2006). In Mexico earthquake, ground motion in the lake bed zone was amplified 8 to 50 times with respect to rock zone (Gaull et al., 1995). Zaslavsky et al., (2003) carried out seismic site response studies along the coastal plain of Israel. They found that the loose sediments of sand and alluvium yielded amplification factors of 2 to 3 in the frequency range 1.2 to 3.5 Hz. In stable soils, the seismic waves can propagate through the soil without appreciable loss of shear strength. But the ground motion parameters will be modified depending up on local soil conditions. However, in unstable soils significant loss of shear strength occurs and produces failure such as in the case of liquefaction, large settlement and landslide (Mohamedzein et al, 2006). Therefore, the basic problem to be solved by geotechnical engineers in regions where earthquake hazards exist is to estimate the site-specific dynamic response of layered soil deposits. This problem is commonly referred to as site-specific response analysis or soil amplification study.

In this paper, an attempt has been made by adopting a methodology to carry out site-specific study where no strong motion data or seismic data is available. The methodology uses GSHAP (Global Seismic Hazard Assessment Program) map for seismic data, wavelet-based spectrum compatibility approach to generate synthetic earthquake motions and equivalent linear method for seismic site response analysis. The study area (Belgaum region) is situated in the north-west part of Karnataka state in India. The study area is about 13, 415 Sq. km and population of about 4.2 million (as per census 2001). Belgaum and its surrounding areas are expanding and many high-rise buildings and other important infrastructures are coming up. As per the revised seismic zoning of India (IS 1893- part I: 2002) Belgaum region is located in seismic zone III. Further this region is very close neighboring Maharashtra state that has witnessed several earthquakes in the past with magnitude ranging from M_w = 4.5 to 6.5 (see for example Amateur Seismic Centre Website, *http://www.asc-india.org/*). This indicates the vulnerability of the region to future earthquakes and need for soil amplification study. This will help in estimating strong ground motion parameters required for earthquake resistant design of new structures as well as retrofitting of existing structures. Presently, in Belgaum region no strong motion data of previous earthquakes are available. Therefore it is required to develop synthetic earthquakes for the region to study the effect of local soil conditions on the seismic motion parameters for sites.

GEOLOGY OF STUDY AREA

The geographical formations found in the district of Dharwad are, gneissic system, Kaladagi series and the deccan traps .The Dharwad formation are mostly seen in parts of Bailhongal and Belgaum taluks and western most parts of Khanapur taluks. The gneissic system consists of different types of granite and gneisses. The gneissic rocks form a belt stretching across the southern parts of the district varying in breadth from 3 km to 9.6 km. Achaean gneiss is greatly observed by lateritic or lithomargic deposits towards the west of Dharwad - Belgaum road. Particularly, gneisses are exposed in Khanapur taluk. These rock formations ultimately give rise to clay deposits, exposed in the whole of Khanapur taluk. The sedimentary formations of Kaladagi series are represented by sandstones, quartzites, conglomerates, hematite, quartzite, dolomites and lime stones with intercalations of the shale beds. The sandstones and quartzite forming low ridges are seen in the whole of Ramadurga taluk and part of Belgaum taluks.

GEOTECHNICAL SITE CHARACTERISATION

To conduct detailed site-specific earthquake response analysis of the region, sub soil information is one of the most essential data. From the large number of geotechnical bore hole data, the soil deposits of the different part of the region such as Belgaum, Bailhongal, Khanapur, Soundatti and Ramadurga are characterised and grouped as Type-1, Type-2, Type-3, and Type-4 respectively based on similar soil conditions. The average geotechnical properties of the sub soil are presented in Table 1. Table 2 shows classification of regions with similar soil deposits along with corrected standard penetration test (SPT) 'N' values.

Table 1 : Geotechnical Properties of Soils

Category	Field Density (KN/m^3)	PI (%)	Shear Strength Parameters	
			Cohesion Strength (KN/m^2)	Friction Angle (degrees)
Type-1	19- 21	NP - 40	100-200	26 - 38
Type-2	18-21	NP- 30	15–30	12 - 44
Type-3	18-20	NP - 25	150–350	10 - 16
Type-4	18-20	NP - 45	200-300	5 - 8

PEAK GROUND ACCELERATION

As per seismic zoning map of India, Bureau of Indian Standards (IS 1893- part I: 2002), Belgaum region, lies in moderate seismic zone (Zone III) with a zone factor of 0.16 and expected earthquake of magnitude 6 to 6.5. Global Seismic Hazard Assessment Program (GSHAP) map which is based on 10% probability of exceedance in 50 years, specifies the peak ground acceleration (PGA) of 1.6 m/s^2 (0.163g) at bed rock level for moderate earthquake zones. Hence, in the present study the maximum peak ground acceleration (PGA) of 0.163g has been selected for Belgaum region to study the effect of local soil conditions due to seismic excitation.

Table 2: Sub Soil Details at Four Locations

	Depth (m)	Sub soil	SPT 'N'
Type-1	0 - 4	Silty sand	30
	4 - 10	Gravel	40 - 50
	10 - 15	Disintegrated rock	50 - 60
Type-2	0 - 4	Silty sand	20
	4 - 6	Silty sand	20 - 35
	6 - 10	Silty sand with gravel	35 - 45
	10 - 15	Disintegrated rock	50 - 60
Type-3	0 - 3	Silty clay	20
	3 - 5	Silty clay	20 - 50
	5 - 8	Silty clay	35
	8 - 15	Brown Silty clay	35 - 60
Type-4	2 - 4	Silty clay	15
	4 - 6	Silty clay	15 - 20
	6 - 10	Silty clay	15 - 40
	10 - 11	Silty clay	15
	11 - 15	Silty sand	15 - 50

DEVELOPMENT OF EARTHQUAKE MOTION

Since, no records of strong ground motion in the study area are available, there is a need for the development of synthetic earthquakes for the region. A wavelet-based method has been used for the generation of spectrum-compatible time-history of earthquake. RSPMatch2005 is a wavelet-based method developed by Jonathan Hancock *et al*. (2006) and the same is used in this study for developing synthetic earthquakes. As a basic step, the methodology requires the use of strong motion records available from historical earthquakes. While selecting a suitable strong motion, several important factors are to be considered. These include similar magnitude, peak acceleration close to the target value, similar fault distance and similar site conditions (Kramer 1996). Based on these factors, four earthquakes (including Northridge earthquake data at two locations with PGA of 0.165g and 0.172g) of magnitude (M) in the range of 6.0 to 6.9 recorded at rock sites (site class ‘A’ as per USGS classification for which shear wave velocity, Vs > 750 m/s) were selected from the earthquake data base. The selected earthquakes represent nearly the similar magnitude of 6 to 6.5 for Belgaum region. Table 3 illustrates four earthquake records and their characteristic obtained from the database compiled by the pacific Earthquake Engineering Research Center (PEER), University of California at Berkeley.

Table 3 : Characteristics of Selected Earthquake Records

Earthquake	**Northridge**	**San Fernando**	**Whittier Narrows**
Date	17/01/94	09/02/71	01/10/87
Magnitude	6.7	6.6	6.0
Peak Acceleration (a_{max})	0.165 g & 0.172 g	0.157 g	0.186 g
Closet to fault rupture (km)	26.8	23.5	21.2
Closet to surface projection rupture (km)	28.9	20.2	-

Figure 1 shows the typical time history of selected strong motions. Based on the desired PGA (0.163g) and target response spectra at 5% damping for rock or hard soil according to IS : 1893 (part I) - 2002, the program RSPMatch2005 was used to generate spectrum compatible time-histories of four earthquakes. A typical response spectrum of selected earthquake motion before and after matching the target spectra for one of the Northridge earthquake having peak acceleration (a_{max}) of 0.165g is shown in Figure 2. Figure 3 shows the corresponding spectral matched time history of acceleration with modified peak acceleration of 0.186g. In similar way remaining three spectral matched time history of accelerations (with modified peak accelerations of 0.212g, 0.203g and 0.171g corresponding to Northridge, Sanfernando and Whittier Narrows) are obtained and are used as input earthquake motions for conducting site response analysis.

SITE RESPONSE ANALYSIS

For ground response study, equivalent linear approach using the computer program SHAKE2000 developed by Idriss & Sun (2004) is used for the analysis. The input parameter for the model such as shear wave velocity of each soil layer has been obtained from the empirical relation between SPT ‘N’ and shear wave velocity as proposed by Japanese Road Association (Lee 1992). But to account for soil behaviour under irregular cyclic loading, the dynamic properties of soils such as modulus reduction and damping versus shear strain curves proposed by Vucetic & Dobry (1991) are used based on plasticity characteristics of respective soil layers in Type-1 to Type-4 sub soil profiles. The output from the computer model includes time history of ground motion parameters, time history of stress and strain at any depth, amplification of ground motion between bedrock and ground surface, fundamental frequency and spectral acceleration at the ground surface.

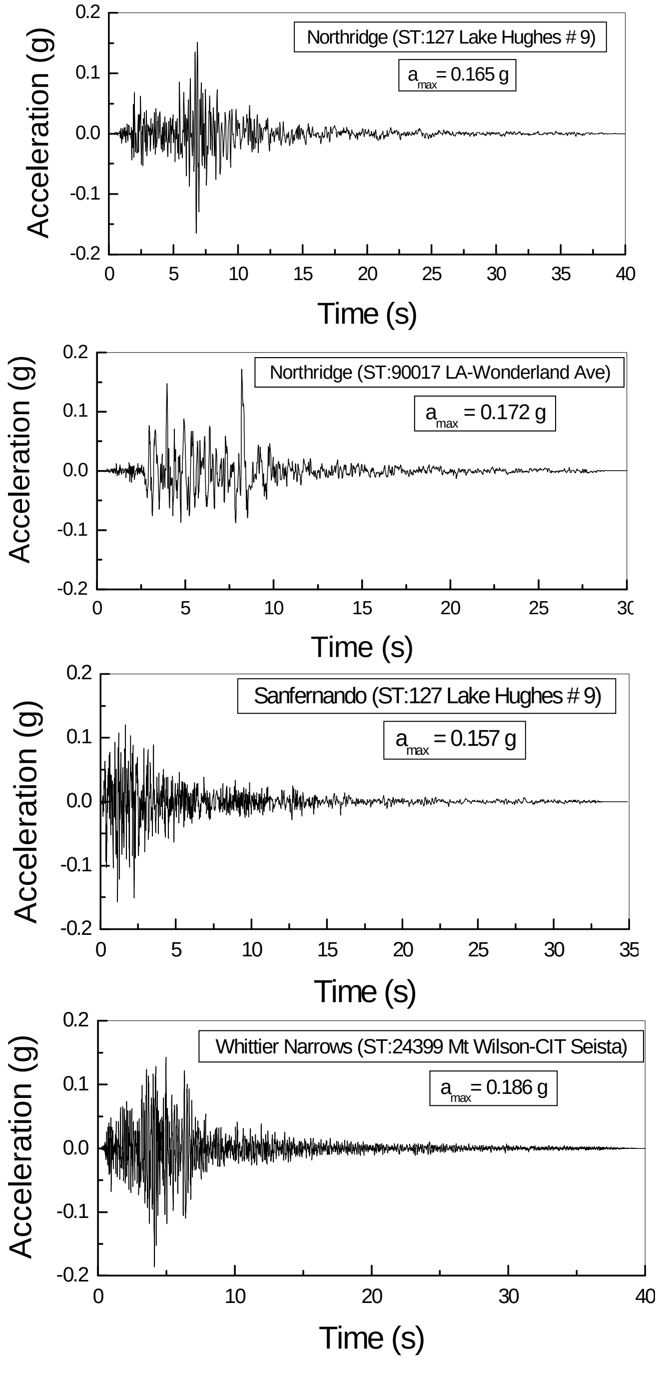

Fig. 1. Time history of selected strong motion records

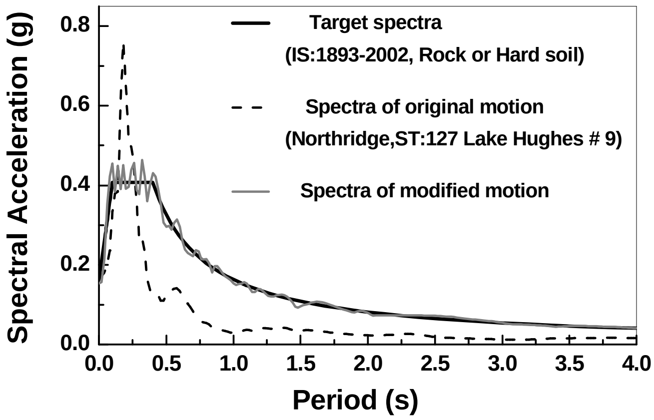

Fig. 2. Comparison of target and response spectrum of Northridge earthquake time history

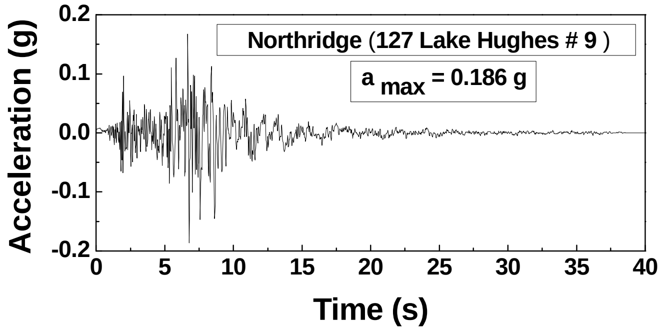

Fig. 3. Spectrum compatible time history of strong motion

<u>Response Spectra</u>

Figures 4 to 7 show the variation of spectral accelerations (S_a) with period corresponding to 5% damping for location Type-1 to Type-4 for region based on four earthquakes. For Type-1, the maximum spectral acceleration varies from 0.69 to 1.05 g based on four earthquake input motions. Similarly, the maximum spectral accelerations in the range of 0.63 to 0.89 g, 0.79 to 1.67 g and 0.65 to 0.76 g for locations Type-2, Type-3 and Type–4 respectively are obtained. However, based on the average of all four earthquakes, the maximum spectral accelerations of 0.84 g, 0.72 g, 1.29 g and 0.68 g may be obtained for respective locations corresponding to the periods 0.23, 0.16, 0.17 and 0.37 respectively.

<u>Amplification of peak ground acceleration</u>

Due to wide range of peak accelerations (0.171g to 0.212g) of the spectrum compatible time histories of input motions, the maximum acceleration at the ground surface varies over a range from 0.37 to 0.65g for Type-1 soil deposits. Similarly, the maximum acceleration at the ground surface for Type-2 location varies from 0.43 to 0.63g, for Type–3 location from 0.54 to 0.64g and for Type-4 location from 0.37 to 0.49g. For practical purposes, based on all four events, an average value of peak ground acceleration (PGA) of 0.55g, 0.50g, 0.59g and 0.41g can be adopted for Type-1, Type-2, Type-3 and Type-4 locations respectively. Further, the soil deposits of these types exhibit an average PGA amplification of 2.85, 2.62, 3.13 and 2.16 respectively.

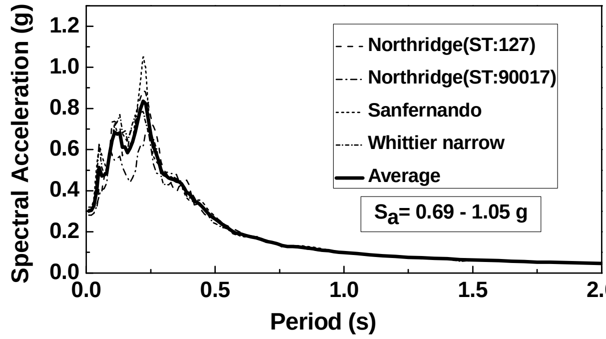

Fig. 4. Response spectra at ground surface for location Type–1 (5% damping)

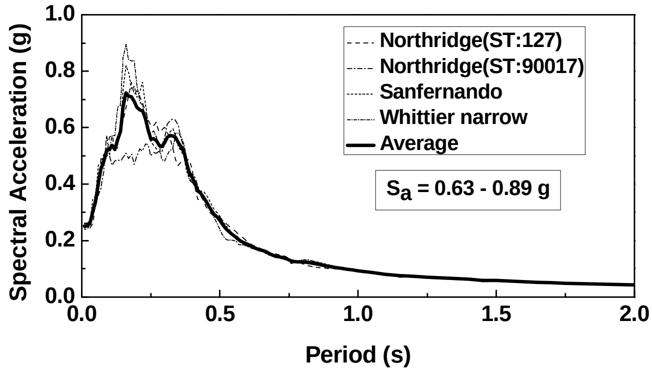

Fig. 5. Response spectra at ground surface for location Type–2 (5% damping)

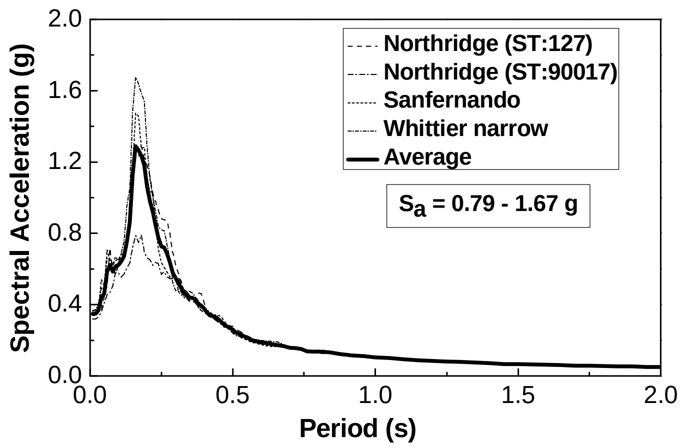

Fig. 6. Response spectra at ground surface for location Type–3 (5% damping)

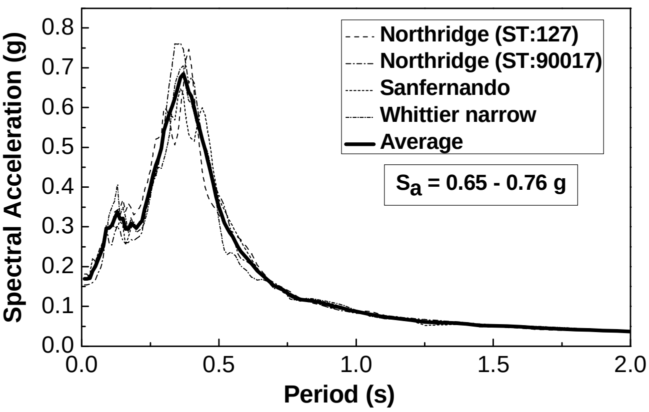

Fig. 7. Response spectra at ground surface for location Type–4 (5% damping)

Ground motion amplification and fundamental Period

The maximum amplification of ground motion parameters considering four spectrum compatible input motions for Type- 1 location is shown in Fig. 8. As observed from this figure, the maximum amplification ratio (A) varies over a narrow range of 10.03 to 10.13 for the corresponding frequency (f) ranging from 4.45 to 4.46 Hz (≈ 0.22 s). Similar observations of narrow amplification range can made from Type-2, Type-3 and Type-4 locations at corresponding frequencies of 3.08 to 3.13 Hz (≈ 0.32 s), 5.2 to 5.4 Hz (≈ 0.2 s) and 2.5 to 2.6 Hz (≈ 0.4 s) respectively. These results clearly indicate that the amplification factor at Belgaum region is significant.

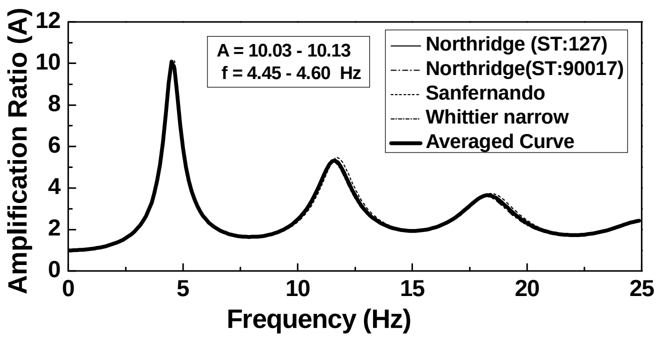

Fig. 8. Amplification of ground motion parameters for Type-1 location

FREQUENCY RESPONSE OF RC BUILDINGS

Most building structures, which are normally medium to low-rise reinforced concrete frames, are usually not designed to resist moderate or major earthquakes. The design of such buildings is usually done by considering gravity loading only without considering the earthquake loads, which makes these buildings vulnerable during the event of an earthquake. It is therefore essential to consider the earthquake loads while designing the building to mitigate the effects of earthquakes.
The district of Belgaum and its adjoining areas are fast expanding and many high-rise buildings and other important infrastructures are coming up. Therefore the present study focus on finding the fundamental natural period of reinforced concrete (RC) buildings of different configurations since it is one of the vital dynamic characteristics in seismic design. This will enable to check out for resonance in the buildings by comparing with the fundamental natural period of ground as obtained from the site specific response analysis of Belgaum region.

Study on regular reinforced concrete building frame models with and with out infill masonry walls is carried out by performing the eigen value analysis using Extended Three dimensional Analysis of Building Systems **(**ETABS) for determining the fundamental natural periods of the buildings. The buildings are assumed to be designed for gravity loads as per IS: 456 - 2000 code provisions.

Frequency response analysis

Different building models consisting of 1-Bay, 2-Bay and 3-Bay up to ten storeys of symmetric and asymmetric buildings are selected as representatives for different infill patterns and their stiffness irregularities. The buildings are assumed to be firmly fixed at the bottom storey. The building are analysed only for gravity loads. The slabs are given membrane type behavior to provide in plane stiffness. The slab sections are modeled as rigid diaphragms so that the mass of the floors are automatically lumped at their centre of gravity.

Masonry infill (MI) walls are remarkable in increasing the initial stiffness of reinforced concrete frames, and being the stiffer component, attract most of the lateral seismic shear forces on buildings, thereby reducing the demand on the RC frame members. However, the behavior of MI is difficult to predict because of significant variations in material properties and failure modes that are brittle in nature. As a result, MI walls have been often treated as nonstructural elements in buildings and their effects are not included in the analysis and design procedure. However, it is to be noted that MI may have significant effects on the global behavior of buildings and, therefore, should be addressed appropriately. The effects of masonry infill are generally included by considering it as a diagonal strut.

Masonry infill walls confined by RC frames on all four sides play a vital role in resisting the lateral seismic loads on buildings. It has been shown experimentally that MI walls have a very high initial lateral stiffness and low deformability. Thus introduction of MI in RC frames changes the lateral load transfer mechanism of the structure from predominant frame action to predominant truss action. The most popular method of determining the time periods of all the modes of vibration in the buildings is by solving the eigenvalue problem (Eq. 1).

$$[K] - \omega_n^2 [M] = 0 \quad (1)$$

Here [K] is the stiffness matrix, ω_n, the frequency and [M] is the lumped mass matrix. The relationship between frequency (ω) and time period (T_n) is given by

$$\omega_n = \frac{2\pi}{T_n} \quad (2)$$

Eigenvectors are obtained for each eigenvalue of ω_n. The eigenvector gives the deformed shape of the building when vibrating at the corresponding frequency. The lateral loads generated correspond to the seismic zone III and *5%* damped response spectrum given in IS: 1893-2002. The natural period values are calculated by solving the eigen value problem of the model. Thus, the total earthquake load generated and its distribution along the height corresponds to the mass and stiffness distribution as modeled in the numerical analysis. Here, as in the equivalent static analysis, the seismic mass is calculated using full dead load plus 25% of live load.

The reinforced concrete multistorey building plane frames for different configurations of number of bays each of 5m span in both X and Y directions for regular buildings (Fig. 9) and bays of each of 4m span in X direction and 6m span in Y direction (Fig. 10) up to 10 storeys are selected for irregular buildings. For all the buildings the height of each storey is kept equal to 3.5m

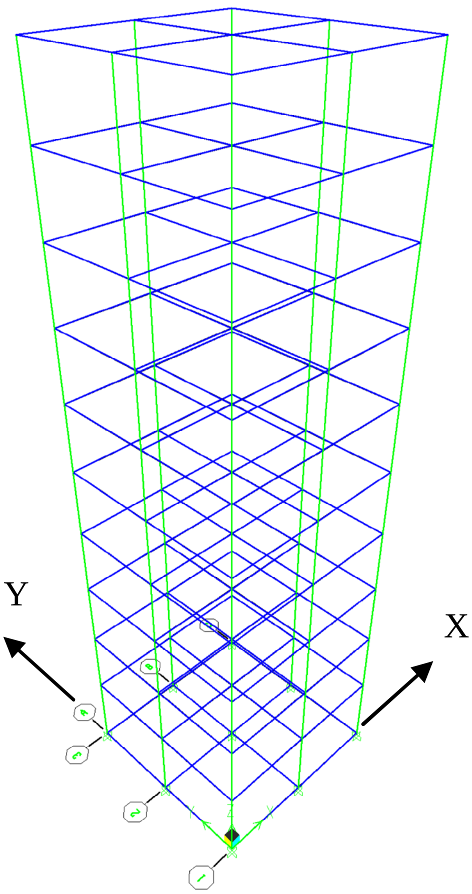

Fig. 9. Regular 2-Bay frame model without infill having ten storey

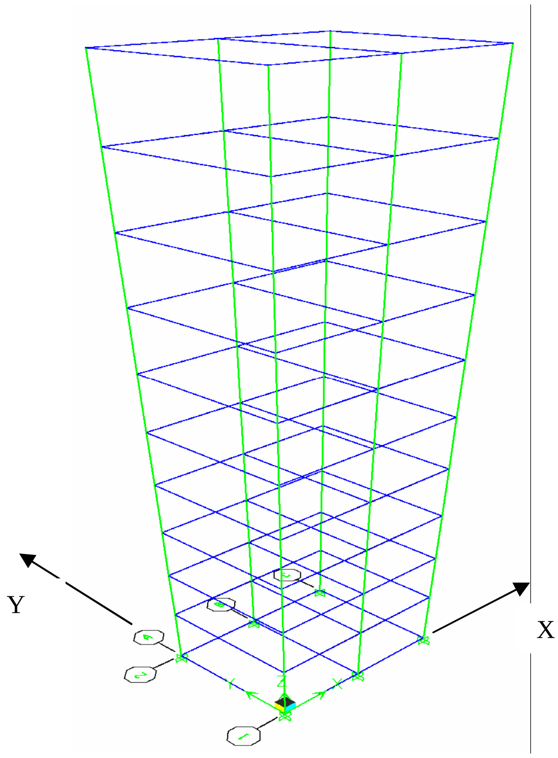

Fig.10. Irregular 2-Bay (along X) frame model without infill having ten storey

The dimensions of structural elements adopted in the analysis are given in Table 4.

Table 4: Dimensions of structural elements

Member	Size (mm)
Beam	230 x 450
Column	230 x 600
Slab thickness	125
Thickness if infill	230

The fundamental natural frequency of the building models in the transverse direction for various configuration of buildings with and with out slab as well as with and with out infill are shown in figures 11 to 16.

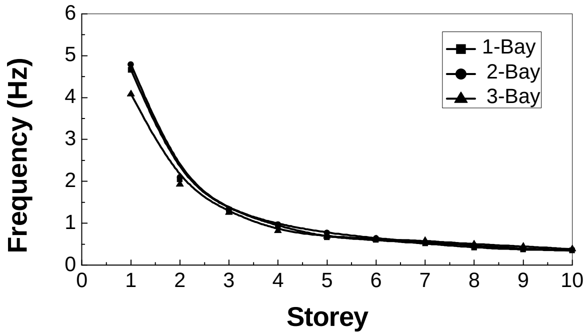

Fig. 11. Regular buildings without slab and without infill

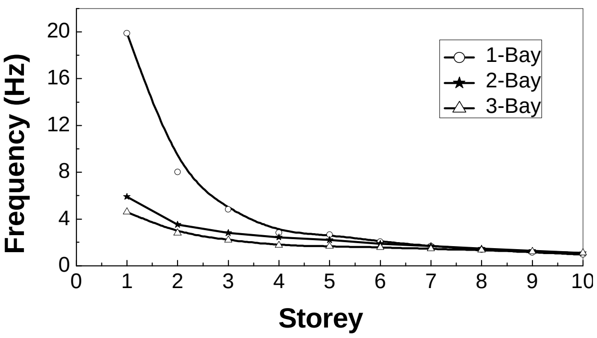

Fig. 12. Regular buildings without slab and with infill

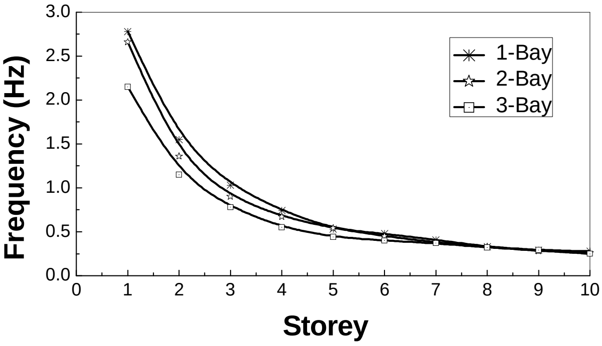

Fig. 13. Regular buildings with slab and with out infill

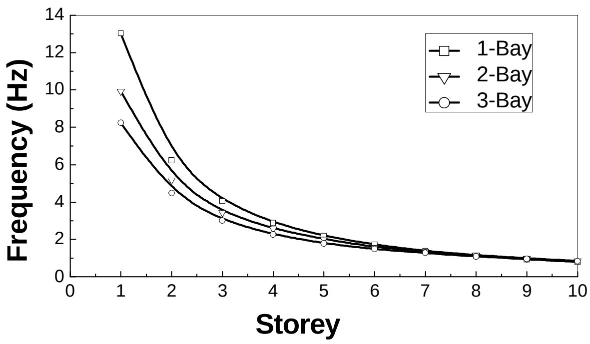

Fig. 14. Regular buildings with slab and with infill

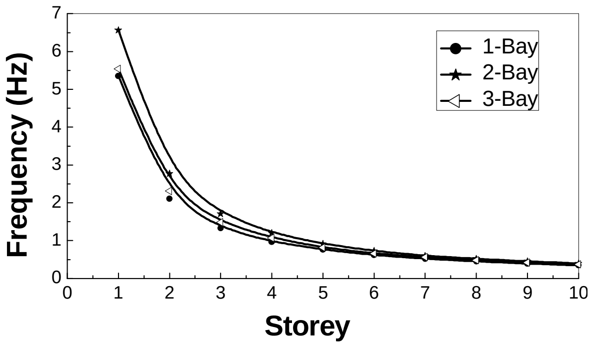

Fig. 15. Irregular buildings without slab and without infill

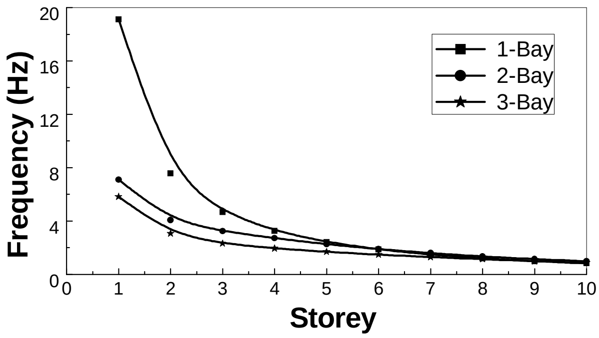

Fig. 16. Irregular buildings without slab and with infill

It is observed from these figures that the fundamental natural frequency of vibration get affected due to presence of masonry infill, which is a function of stiffness, mass, and damping characteristics of the building. The fundamental frequency in case of bare frame model is smaller than that obtained in the frame with infill wall for a given storey height. Further, this frequency decreases as the storey height increases.

A distinct variation in natural frequency of the regular buildings with and without infill can be noticed from Figs. 11 and 12. There is a sharp increase in the frequency for buildings with infill for single bay and storey height up to three and thereafter the presence of infill becomes insignificant on the frequency response. Similar kind of frequency response can be observed in case of irregular buildings (see Figs. 15 and 16). However up to three number of bays and storey height six has significant influence on the frequency response of these buildings.

<u>Buildings susceptible to resonance</u>

Earthquake response analysis of various soil deposits of Belgaum region are discussed in previous sections. From the results of the study it has been shown that the soil deposits have tendency to increase the amplification of ground motion parameters at fundamental frequencies of 4.5 Hz, 3.13Hz, 5.24 Hz and 2.45 Hz for Type-1 (Belgaum), Type-2 (Khanapur), Type-3 (Bailhongal) and Type-4 (Soundatti & Ramadurga) areas respectively. These fundamental frequencies at the respective ground surface are compared with the fundamental frequency of the buildings of various configurations as obtained earlier. The configurations of buildings susceptible to resonance due to the close matching of resulting wave frequencies of the ground (at which the buildings undergo severe damage) are identified. Tables 5 and 6 illustrate the typical buildings with and with out infills that are experiencing resonance in the frequency range close to the ground frequencies. Table 7 and 8 shows the irregular buildings subjected to resonance with out slab but with and with out infill.

Table 5: Regular buildings with slab and without infill

Location	Fundamental Frequency of Ground (Hz)	Fundamental frequency of building (Hz)						Buildings susceptible for resonance
		1-Bay	Storey	2-Bay	Storey	3-Bay	Storey	
Type -1	4.50	-	-	-	-	-	-	-
Type -2	3.13	-	-	-	-	-	-	-
Type -3	5.24	-	-	-	-	-	-	-
Type -4	2.45	2.78	1	2.66	1	2.15	1	1-Storey of 1-Bay , 2-Bay and 3-Bay

Table 6: Regular buildings with slab and with infill

Location	Fundamental Frequency of Ground (Hz)	Fundamental frequency of building (Hz)						Buildings susceptible for resonance
		1-Bay	Storey	2-Bay	Storey	3-Bay	Storey	
Type -1	4.50	4.05	3	-	-	4.47	2	3-Storey of 1-Bay and 2-Storey of 3-Bay
Type -2	3.13	-	-	3.44	3	3.00	3	3-Storey of 2-Bay and 3-Bay
Type -3	5.24	-	-	5.19	2	-	-	2-Storey of 2-Bay
Type -4	2.45	2.88	4	2.56	4	2.27	4	4,5-Storeys of 1-Bay and 2-Bay and only 4-Storey of 3-Bay
		2.18	5	2.02	5	-	-	

Table 7: Irregular buildings without slab and without infill

Location	Fundamental Frequency of Ground (Hz)	Fundamental frequency of building (Hz)						Buildings susceptible for resonance
		1-Bay	Storey	2-Bay	Storey	3-Bay	Storey	
Type -1	4.50	-	-	-	-	-	-	-
Type -2	3.13	-	-	-	-	-	-	-
Type -3	5.24	5.35	1	-	-	5.54	1	1-Storey of 1-Bay and 3-Bay
Type -4	2.45	2.11	2	2.77	2	2.31	2	2-Storey of 1-Bay, 2-Bay and 3-Bay

Table 8: Irregular buildings without slab and with infill

Location	Fundamental Frequency of Ground (Hz)	Fundamental frequency of building (Hz)						Buildings susceptible for resonance
		1-Bay	Storey	2-Bay	Storey	3-Bay	Storey	
Type -1	4.50	4.67	3	4.05	2	-	-	3-Storey of 1-Bay, and 2-Storey of 2-Bay
Type -2	3.13	3.26	4	3.23	3	3.06	2	4-Storey of 1-Bay, 3-Storey of 2-Bay and 2-Storey of 3-Bay
Type -3	5.24	-	-	-	-	-	-	-
Type -4	2.45	2.42	5	2.26	5	2.32	3	5-Storey of 1-Bay and 2-Bay and 3-Storey of 3-Bay

CONCLUDING REMARKS

The effect of site conditions on propagation of seismic motion parameters to the ground surface at Belgaum region is investigated based on equivalent linear approach. The required peak ground acceleration at bed rock for the region was obtained from Global Seismic Hazard Assessment Program (GSHAP) map. Spectrum compatible time histories of input motions were developed from wavelet based target spectrum matching technique. Frequency response analyses of buildings of various configurations were carried out with three dimensional numerical modeling. Based on the study, it is interesting to note that the site conditions exhibit PGA amplifications in the range of 2.16 to 3.13. Maximum spectral accelerations of 0.68 to 1.29g obtained for different locations in Belgaum region demonstrate clearly the influence of sub soil conditions to seismic excitations. The high frequency (low period) motions obtained at different locations indicate the rock or hard soil sites in the region.

Buildings of regular and irregular configuration with and without infill were analysed for fundamental natural frequency using ETABS widely used software for three dimensional structural analysis of buildings. The fundamental natural frequency of buildings subjected to vary due to the presence of masonry infill when compared to building frames with out infill. This variation is mainly due to stiffness, mass and damping characteristics of the building with infill. A cross checks on the resonance condition for typical buildings in different regions indicate a need for new structural designs as well as retrofitting of existing buildings against the earthquake forces in the region.

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