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Earthquake seismic site response analysis by comparison between equivalent linear and nonlinear methods, a case study at Kohat and Muzaffarabad

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Abstract

The effects of natural disasters such as earthquakes on our environment lead to different earthquake analysis. Seismic site response analysis is one of these analyses, which can be done using different methods. The seismic response analysis carried out in this research was based on Equivalent linear and Nonlinear method. Two seismically active regions which are part of Kohat Platue (Shakardarra) and Hazara Kashmir Syntaxes (Muzaffarabad) were selected. The sites were tested for vertical component input ground motions of magnitude 7.0ML (PGA= 0.07g) and 4.9mb (PGA= 0.018g).

The soil profiles for both sites were prepared on the average results of five geotechnical (SPT) upholes data at Muzaffarabad (MUZ) site and twenty seismic upholes data at Shakardarra (SHD). The soil samples collected at MUZ site were sandy gravel, sand and clay and at SHD sandy gravel, sand, clayey sand and clay, for which were tested for damping ratio of 5% using site response analysis programs (NERA and EERA).
The stress-strain models, strain energy models, response models (amplification models, Fourier response models and spectral response models) were constructed for each type of soil sample on the basis of input motions data using NERA and EERA, which were then compared. According to comparison, the soils at sites were under great stresses and these exhibited negligible amount of strains, the PGA values calculated were interpreted as incompatible for intermediate to high man-made buildings.

Keywords: Site response analysis; Stress-strain models; Strain energy analysis; Damping ratio; Shear modulus; Fourier spectra.

1. Introduction

Seismic site response analysis is one of the analyses, which are directly or indirectly link with natural disasters such as natural earthquakes which effect geo-environments and man-made infrastructures. In the last twenty years on the basis of large amount of theoretical as well experimental works by Finn (1991), Bard (1994), Bard and Pitiliakis, (1995) were produced for understanding the factors incurred by seismic site response. Different methods were introduced in order to better understand the nature of ground vibration, so the progress have varied from area to area.

The Equivalent linear Earthquake site Response Analysis (EERA) and Nonlinear Earthquake site Response Analysis (NERA) are updated implementation of the concept of earthquake site response analysis, which was implemented in the past in the original and consequent versions of SHAKE 91 (Schnabel et al., 1972; Idriss and Sun, 1992). An equivalent linear and nonlinear procedure, Idriss and Seed (1968), Seed and Idriss (1970) was used for explanation of the nonlinearity of soils with an iterative procedure to get values for normalized shear modulus, damping ratio and response spectra which are compatible with the equivalent strain (%) in each layer. In equivalent linear analysis is performed based on iterative procedure in frequency domain while analysis using nonlinear is performed in time domain.

In this study, equivalent linear and nonlinear approaches were introduced to conduct seismic site response analysis at SHD and MUZ. A set of soil properties i.e. shear wave velocity (Vs), damping ratio (Equivalent linear and nonlinear), thickness (h) and unit weight of layers from available geotechnical borehole data (CPT, SPT) and seismic uphole data were assigned to each layer of deposited soil. The analysis was then repeated for eight iterations.

The strain-stress models were constructed for each deposited layer. The response spectrum curves i.e. Fourier response, amplification ration and spectral acceleration curves for an input motions of magnitude 7.0ML and 4.9mb, using NERA and EERA were compared for each deposited soil layer at SHD and MUZ sites.

2. Geological aspects of sites

The first site of investigation (Shakardarra) is a part of Kohat Foreland and Thrust belt (Fig. 1) which is represented by Early Tertiary to Pliocene sedimentary rocks (MonaLisa and Khan, 2010). The exposed rocks are older in age and belong to Paleocene consisting of limestone and shale. These rocks were deposited in a restricted fore-deep marine environment due to the loading of the Indian plate margin and represent the first record of the Himalayan convergence (Pivnik and Wells, 1996). This sequence is conformably overlain by a complex assemblage of shale, carbonate, evaporate and clastic rocks deposited in a restricted marine basin (Pivnik and Wells, 1996). In turn the Eocene sequence is unconformably overlain by a thick succession of Miocene and younger molasse sediments of Murree and Siwalik Groups and lithologically represented by sandstone, shale, and conglomerates. This sequence is believed to be the result of Himalayan exhumation.

The second site of investigation (Muzaffarabad) is a part of Hazara Kashmir Syntaxis. There are three main tectono stratigraphic terrains of orogen in Northern Pakistan (Najman et al., 2002): the Asian plate to the north, the Indian plate to the south, and the Kohistan island arc sandwiched between Asian plate to north and Indian plate to south. Geologically the division of Karakoram took place into the Northern Sedimentary terrain of Paleozoic and Mesozoic Formations, the Cretaceous to Miocene age Karakoram Batholith, and the Kohistan island arc. These comprises of calc-alkaline volcanic, Late Cretaceous and younger plutonic belts, amphibolites, and minor metasedimentary rocks (MonaLisa and Khan, 2013).

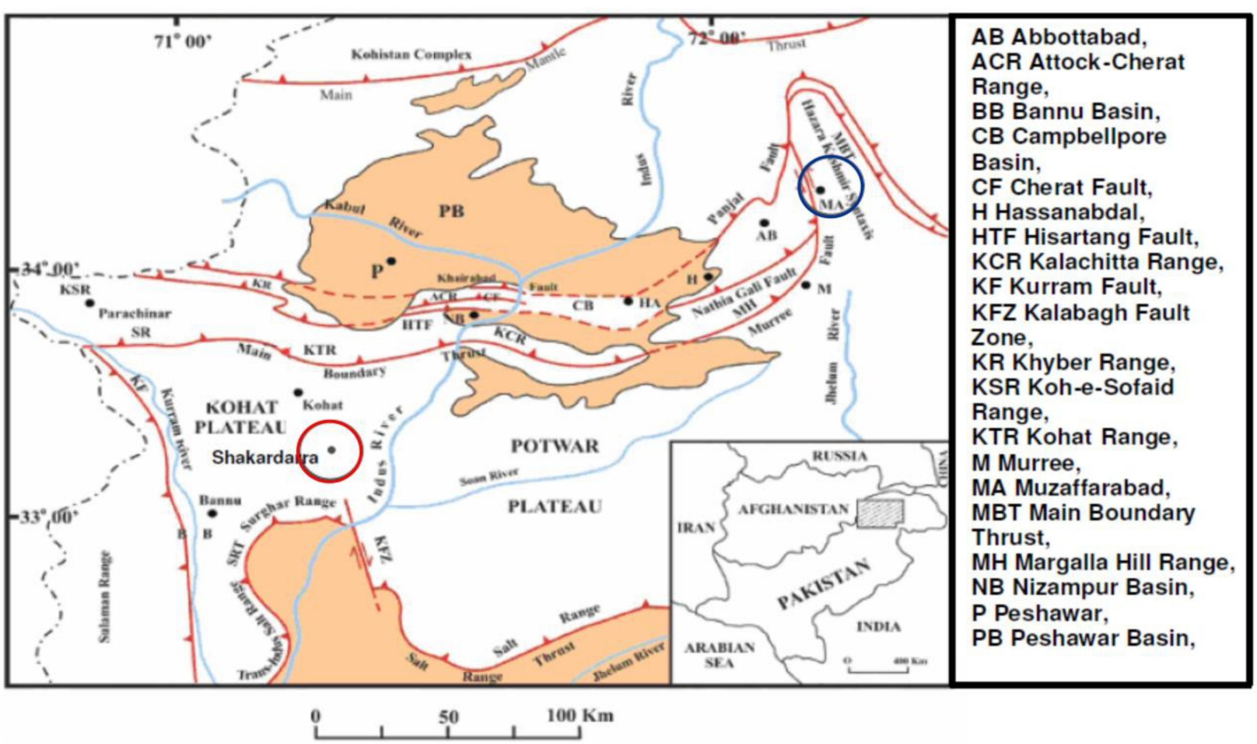

Fig. 1. Location of study area (Shakardarra, Kohat and Muzaffarabad, Hazara Kashmir Syntaxis as shown by circles) with major structural boundaries.

3. Soil characterization

The MUZ site was explored through five geotechnical boreholes. The maximum depth encountered was 10.0 m where Gunset has to be placed. Both standard penetration test and cone penetration test were applied for strength characterization of subsoil. The SPT-N value for whole explored strata varied from 13-15.

The SHD site was explored through twenty seismic uphole data and an average result of these upholes was made for soil profile. The values of shear wave velocity were calculated using equation 3b by neglecting the effect of plastic index and over consolidation ratio (OCR).

4. Damping ratio and shear modulus

Damping is a term to be used for description of the energy-absorbing capacity of a material or structure at its elastic stage (Hu, Liu and Dong, 1996). Simple expressions (1 and 2) are used for calculating damping and corresponding shear modulus with varying shear strain (%) for both sites when dealing in equivalent linear method, while software calculated values were used based on equivalent linear damping values in nonlinear method. The expressions are:

$$G/G_{max} = 1 / (1+\gamma_h) \quad \ldots\ldots (1)$$

$$\xi/\xi_{max} = \gamma_h / (1+\gamma_h) \quad \ldots\ldots (2)$$

Using reference shear strain strain(r) and shear strain (γ), the hyperbolic shear strain can be evaluated as $\gamma_h = \gamma/\gamma_r$, these two relations are used in this study for a material damping (ξ/ξ_{max}) and normalized shear modulus (G/G_{max}).

Reference strain 'γ_r':

The reference strain for the analysis was calculated using equation 3a, where G_{max} is the normalized shear modulus. The void ratio (e), the shear modulus (G_{max}) and confining pressure (σ_{max}) is in kg/cm^2 (equation 3b of Hardin and Drnevich (1972)). The maximum stress for both sites was obtained using relation 3c. The parameter in equation 3c are static stress coefficient (K_o), vertical effective stress (v), angle of friction (σ_v) and strength parameter (c) expressed in units of Tons/sq. ft.

$$\gamma_r = \tau_{max}/G_{max} \quad \ldots\ldots\ldots\ldots (3a)$$

$$G_{max} = [326\ (2.973-e)^2 \sigma_{max}^{1/2}]/\ (1+e) \quad \ldots\ldots (3b)$$

$$\tau_{max} = [\{(\sigma_v \sin\phi + K_o\sigma_v \sin\phi)/2 + c\cos\phi\}^2 - \{(\sigma_v - K_o\sigma_v)/2\}^2]^{1/2} \ \ldots (3c)$$

5. Seismic site response analysis

In dealing with natural hazards the importance of site response analysis initiated. The site response analysis can be done using different methods and it depends on the type of data availability and cost factor. The step by step site response analysis using equivalent linear and nonlinear methods in this study were Input motion, soil profile (discussed above), Fourier spectrum, amplification spectrum and acceleration spectra.

6. Stress-strain analysis

The energy dissipated during hysteresis stress-strain loop is twice of the area under stress-strain curve (MonaLisa and Khan, 2011). The stress-strain curve of clayey and sandy soil shows nearly straight behavior due to the increase in overburden pressure (Bardet et al., 2001).

The computed maximum stress and strain values for each soil against input motions of magnitude 7.0ML and 4.9mb at SHD and MUZ sites are shown in Table 1 which then graphically shown in Figures (2-4).

The results using equivalent linear and nonlinear methods are very different in the case of SHD (four-layer case) site. There is more disturb range of stress to strain ratio noted in the nonlinear case as compared to that in the equivalent linear case, although the soil deposited less shallow and less exposed to weather. From the analysis the results of both methods, the soil under SHD site is seems to be unstable against shaking level of 4.9mb to 7.0ML

In the case of MUZ, there was shallow deposition of soil and less compacted as compared to soil under SHD site. The analysis from both methods suggests there is narrower pattern of the stress to strain ratio as overburden pressure increases with increases in depth, but the results using equivalent linear method indicates that the area is not stable on the shaking level of 4.9mb to 7.0ML even for larger earthquakes.

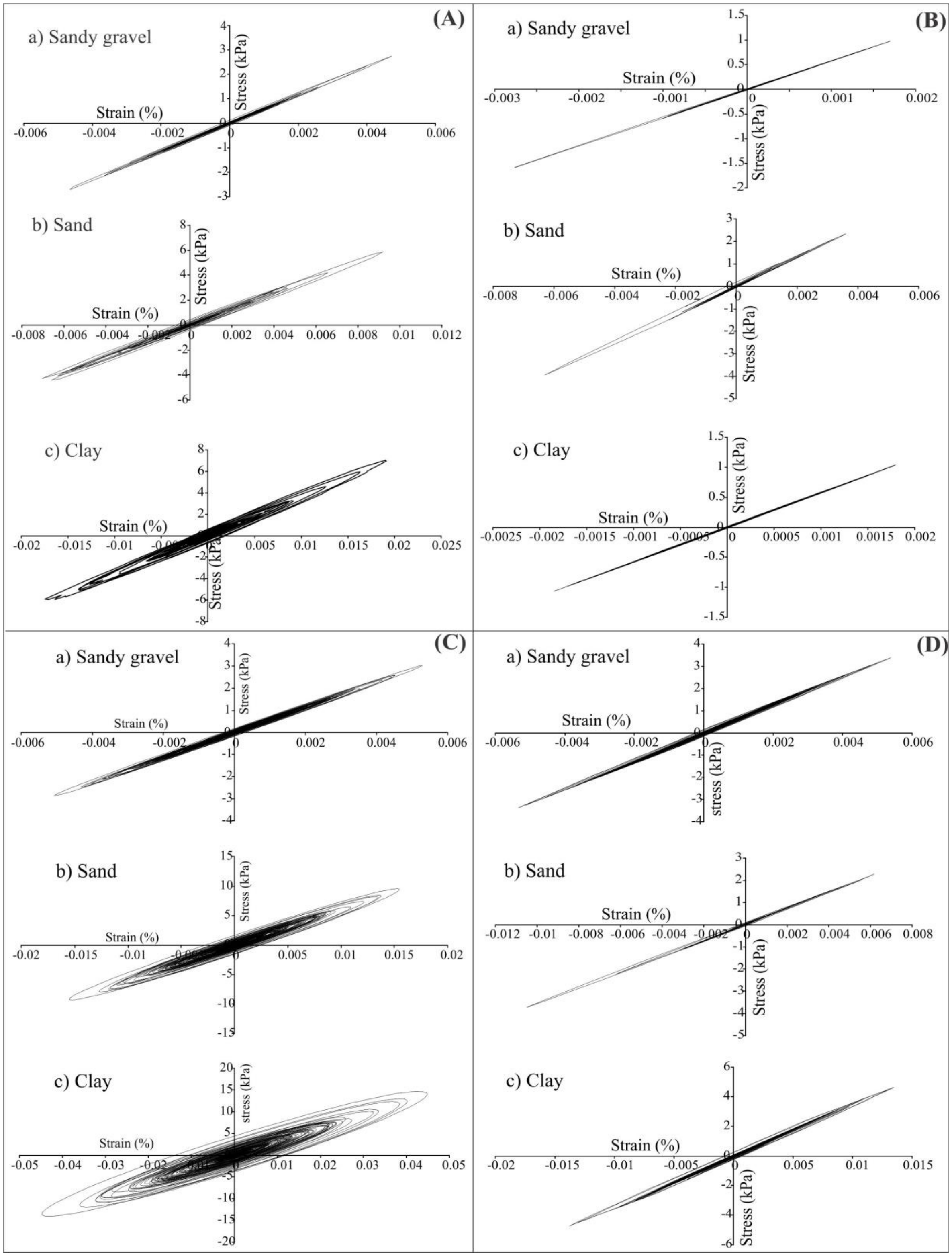

Fig. 2. Stress-strain relationship at MUZ site using: (A) Equivalent linear method (B) Nonlinear method against an input motion of Rakh earthquake (magnitude=4.9mb); and (C) Equivalent linear method (C) Nonlinear method against input motion of Bhuj earthquake (magnitude=7.0ML)

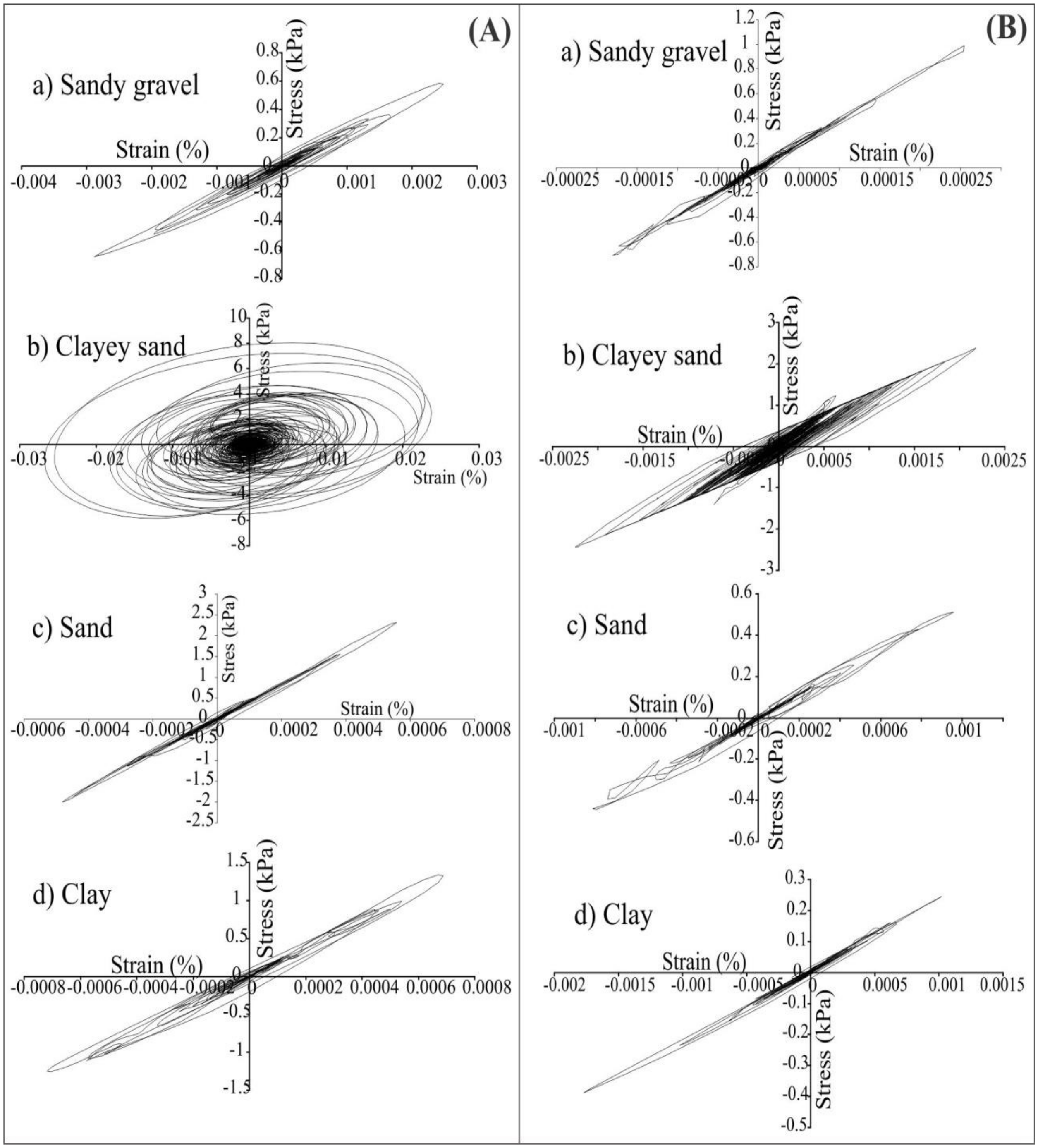

Fig. 3. Stress-strain relationship at SHD site using (A) equivalent linear method and (B) Nonlinear method against an input motion of Rakh earthquake (magnitude=4.9mb).

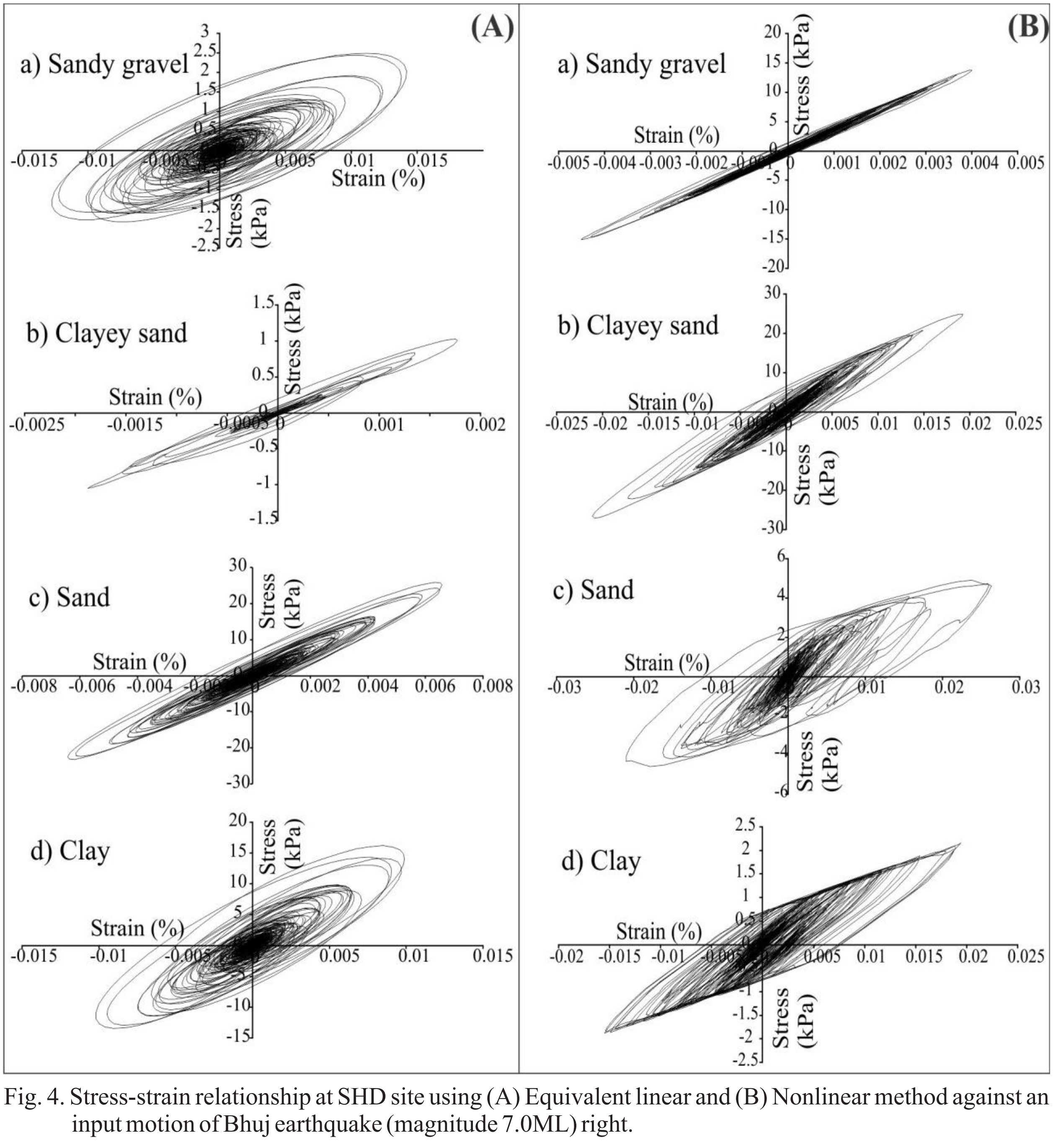

Fig. 4. Stress-strain relationship at SHD site using (A) Equivalent linear and (B) Nonlinear method against an input motion of Bhuj earthquake (magnitude 7.0ML) right.

Table 1. Comparison of stress-strain values when using equivalent linear and nonlinear method of analysis at SHD site as shaking level of 7.0ML and 4.9mb were used as input.

Material	**Input Motion of 7.0ML**									
	Equivalent Linear Method					**Nonlinear Method**				
	Max. Strain (%)	**Max. Stress (kPa)**	**Effective Strain (%)**	**Shear Modulus compatible Strain (MPa)**	**Time (sec)**	**Max. Strain (%)**	**Max. Stress (kPa)**	**Effective Strain (%)**	**Shear Modulus compatible Strain (MPa)**	**Time (sec)**
Sandy Gravel	0.01432	1.9238	0.00859	15.871	44.2	0.0196	2.1634	_	_	43.985
Clayey Sand	6.8 E-3	2.6E+1	4.1E-3	4.2E+2	43	-0.00466	-15.56	_	_	41.0043
Sand	-0.00061	-0.588	-0.00024	60.862	1.232	0.0320	5.302	_	_	41.097
Clay	-8.1E-3	-10.469	-4.8E-3	149.726	39.340	-0.0088	-15.56	_	_	38.806
	Input Motion of 4.9mb									
	Equivalent Linear Method					**Nonlinear Method**				
	Max. Strain (%)	**Max. Stress (kPa)**	**Effective Strain (%)**	**Shear Modulus compatible Strain (MPa)**	**Time (sec)**	**Max. Strain (%)**	**Max. Stress (kPa)**	**Effective Strain (%)**	**Shear Modulus compatible Strain (MPa)**	**Time (sec)**
Sandy Gravel	0.0002	0.1889	0.00008	22.217	1.115	-0.00177	-0.3877	_	_	0.92
Clayey Sand	5.9E-4	2.41	2.3E-4	4.5E-4	1.049	0.000273	1.0371	_	_	1.055
Sand	-0.028	-2.344	-0.0168	29.196	38.855	0.00102	0.5531	_	_	1.016
Clay	2.7E-6	0.4311	1.04E-6	198.711	1.1284	-0.0010	-1.204	_	_	4.715

Table 2. Comparison of stress-strain values when using Equivalent linear and Nonlinear method of analysis at MUZ site as shaking level of 7.0ML and 4.9mb were used as input.

Material	**Input Motion of 7.0ML**									
	Equivalent Linear Method					**Nonlinear Method**				
	Max. Strain (%)	**Max. Stress (kPa)**	**Effective Strain (%)**	**Shear Modulus compatible Strain (MPa)**	**Time (sec)**	**Max. Strain (%)**	**Max. Stress (kPa)**	**Effective Strain (%)**	**Shear Modulus compatible Strain (MPa)**	**Time (sec)**
Sandy Gravel	0.0053	3.0235	0.0032	57.130	44.10	-0.0019	-1.0678	_	_	43.965
Sand	-0.0155	-9.2480	-0.0093	61.7037	43.97	-0.0054	3.3875	_	_	37.945
Clay	0.0449	13.8959	0.0269	32.3549	44.11	-0.014	4.7189	_	_	43.975
	Input Motion of 4.9mb									
	Equivalent Linear Method					**Nonlinear Method**				
	Max. Strain (%)	**Max. Stress (kPa)**	**Effective Strain (%)**	**Shear Modulus compatible Strain (MPa)**	**Time (sec)**	**Max. Strain (%)**	**Max. Stress (kPa)**	**Effective Strain (%)**	**Shear Modulus compatible Strain (MPa)**	**Time (sec)**
Sandy Gravel	0.0047	2.7408	0.0018	257.8006	0.970	-0.0028	-1.584	_	_	0.845
Sand	0.0092	5.8867	0.0036	65.1731	0.980	-0.0063	-3.934	_	_	0.845
Clay	0.0191	6.9468	0.0075	36.2168	0.965	-0.010	-3.728	_	_	0.860

7. Strain energy analysis

Strain energy in soils under compression from all side has great influence on foundation designs. The energy release by soils during overloading and against natural hazards were studied in this research at two different sites.

The strain energy graph is prepared on the basis of data shown in table 1 and table 2 using equivalent linear and nonlinear methods for both SHD and MUZ sites.

The strain energy using nonlinear method for both sites for any input motion indicated sharp edges, which is an indication of complex phenomenon of releasing of energy in the first 4-6 second, so the soil might slump against any shaking level. When using liner method, a linearly release of energy was produced and the soil might also slump. So, the chances for soil to stable against any level of shaking are to release energy moderately such that it should maintain strain energy for large period. The strain energy results are shown in Figures (5-8) for both sites.

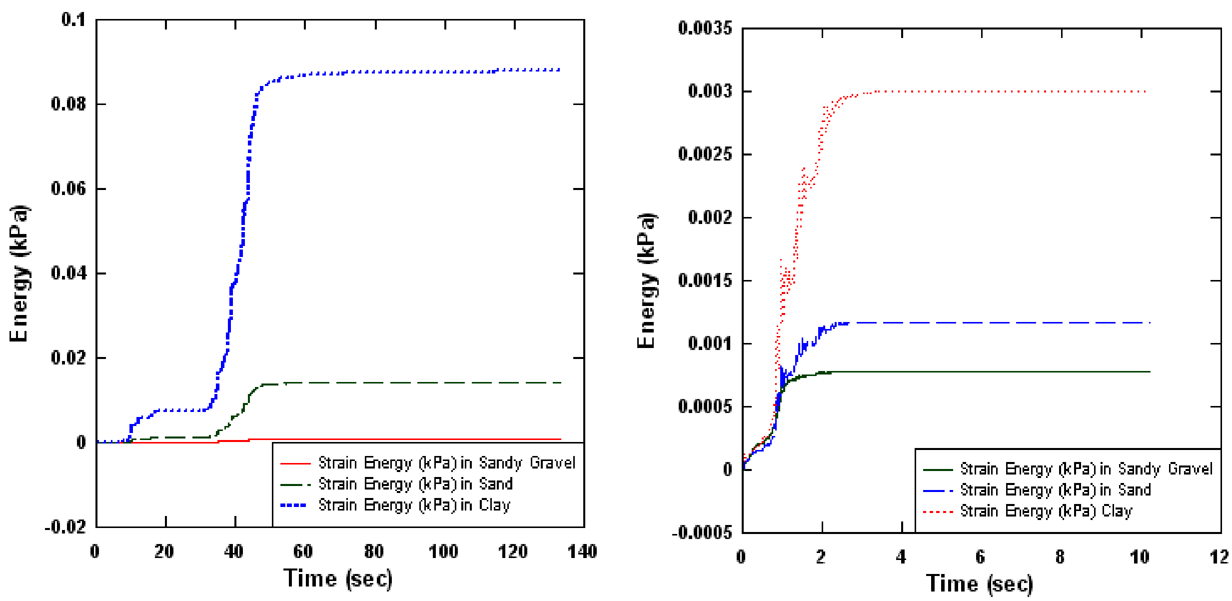

Fig. 5. Strain energy relationship at MUZ site using equivalent linear method against an input motion of Rakh earthquake (magnitude=4.9mb) top and Bhuj earthquake (magnitude 7.0ML) bottom.

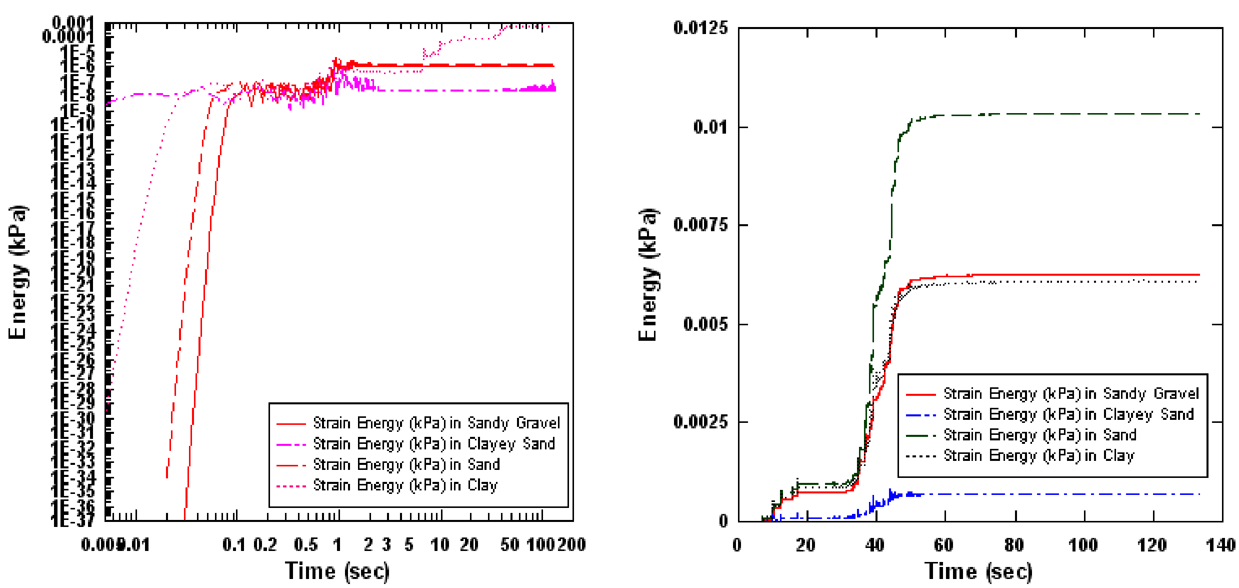

Fig. 6. Strain energy relationship at SHD site using nonlinear method against an input motion of Rakh earthquake (magnitude=4.9mb) top and Bhuj earthquake (magnitude 7.0ML) bottom.

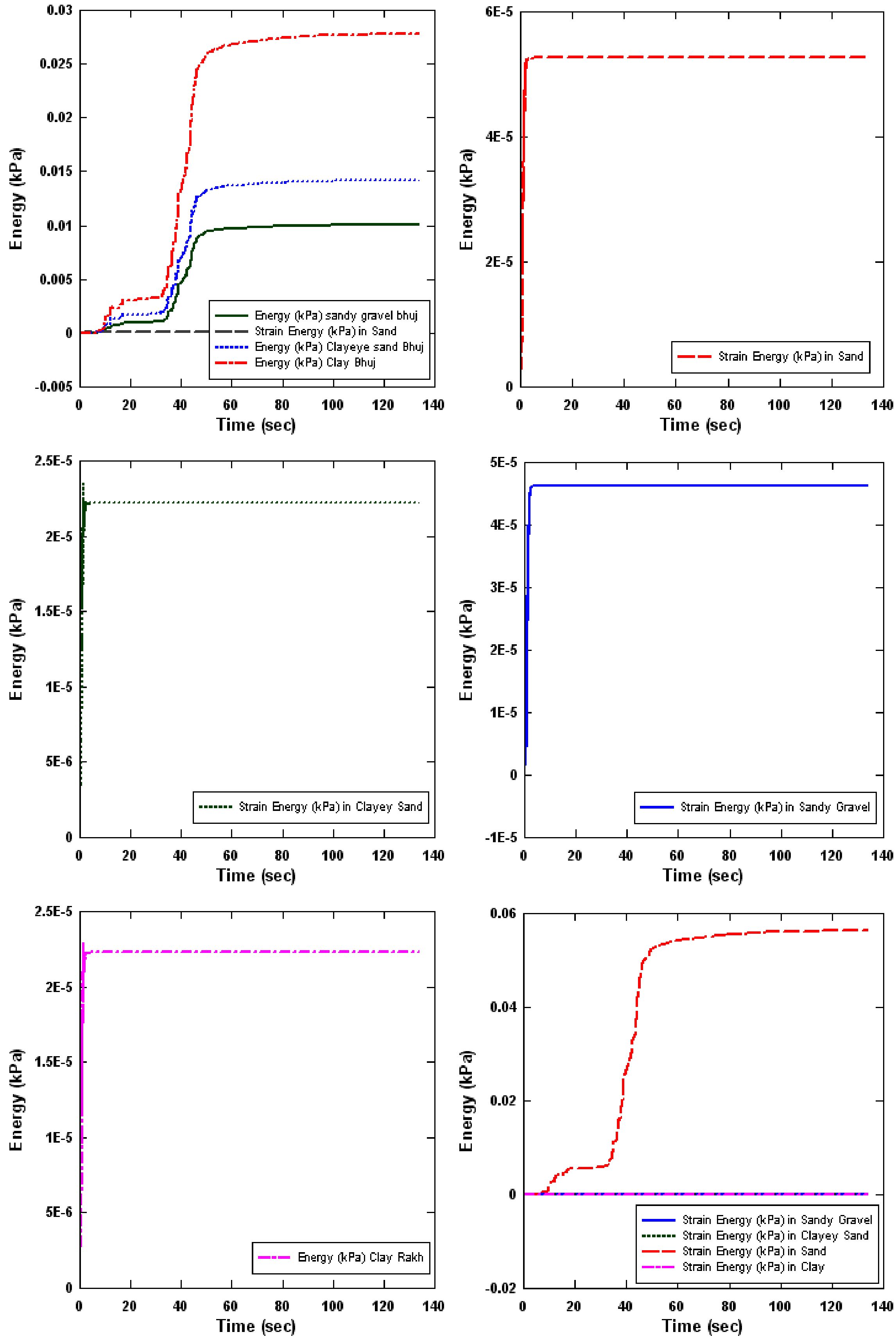

Fig. 7. Strain energy relationship at SHD site using equivalent linear method against an input motion of Rakh Earthquake (magnitude=4.9mb) bottom right and Bhuj earthquake (magnitude 7.0ML) top left.

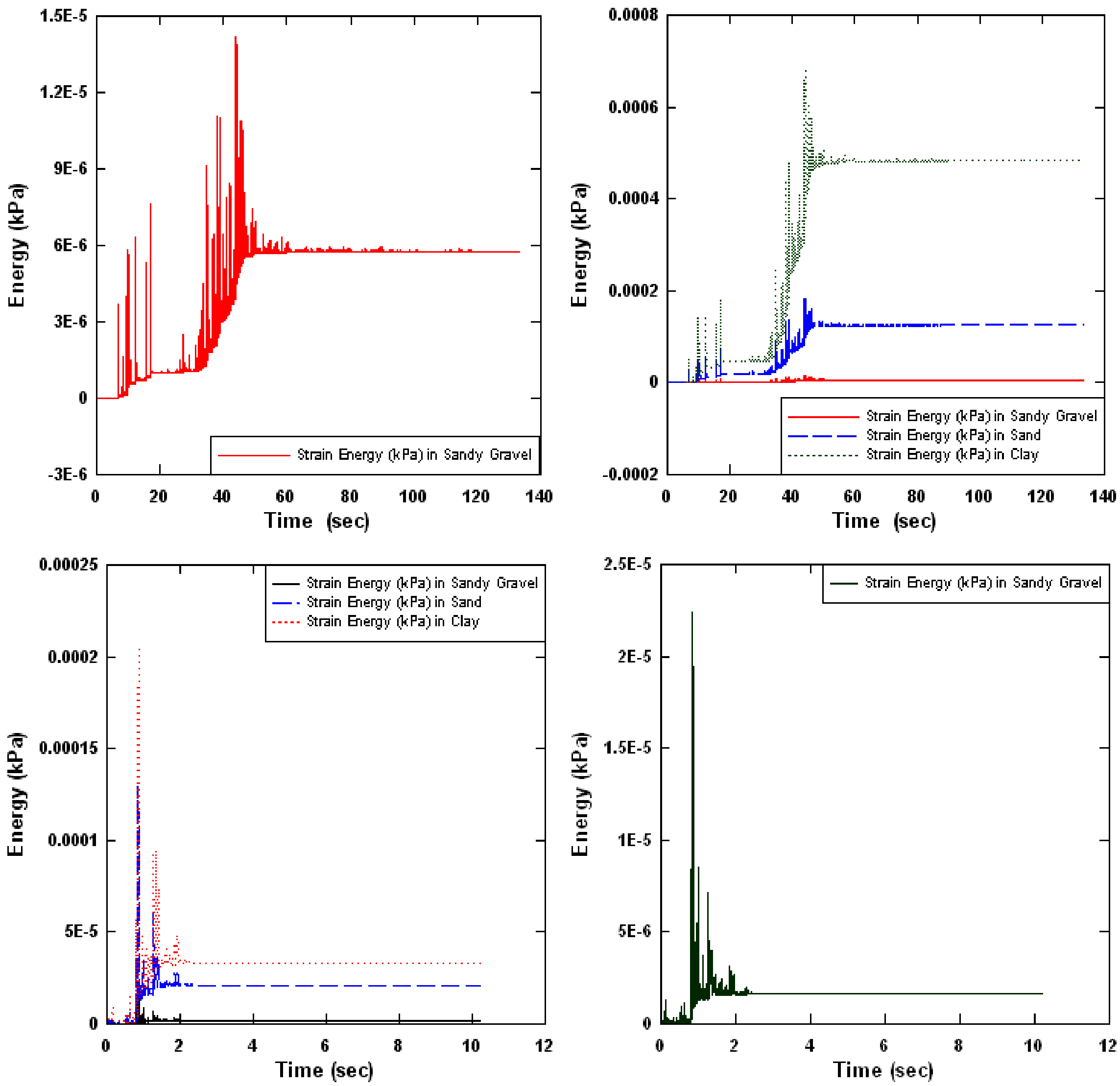

Fig. 8. Strain energy relationship at MUZ site using nonlinear method against an input motion of Rakh Earthquake (magnitude=4.9mb) bottom left and Bhuj earthquake (magnitude 7.0ML) top right.

8. Fourier spectrum analysis

Acceleration and its Fourier spectrum is a pair of Fourier transformations (MonaLisa and Khan, 2010). Mathematical methods might use to find the required Fourier spectrum which is used as the statistical characteristics for ground motions:

$$F = Vs / (4 * H) \quad (4)$$

Where; F is the fundamental frequency, Vs is the shear wave velocity and H is the thickness of each layer. This formula also represents the first mode (resonant) frequency if we replace the shear wave velocity with the arithmetic average of it within the thickness of soil considered (MonaLisa and Khan, 2010).

The Fourier spectrum gives the idea about variation of Fourier amplitude with respect to change in frequency in hertz and the Frequency spectrum is the important step in the site response analysis. The fundamental frequency values used in generating Fourier spectrum are listed in table 3. The average fundamental frequency values used by clayey sand at SHD site was 4.22 Hz when using equivalent linear method and it was 32.014 Hz when using nonlinear method against input motion of 7.0ML.

For clay at SHD the fundamental frequency was 6.90 Hz in equivalent linear method and 77.21 Hz in nonlinear method against input motion of 4.9mb. At MUZ site the average fundamental frequency for clay varies was 4.69 Hz in equivalent linear method and it was 17.63 Hz using nonlinear method against input motion of 4.9 mb. Hence a big change in the results of both methods are obtained, this might give clue that the soil behaves more nonlinearly against any input motion then linearly.

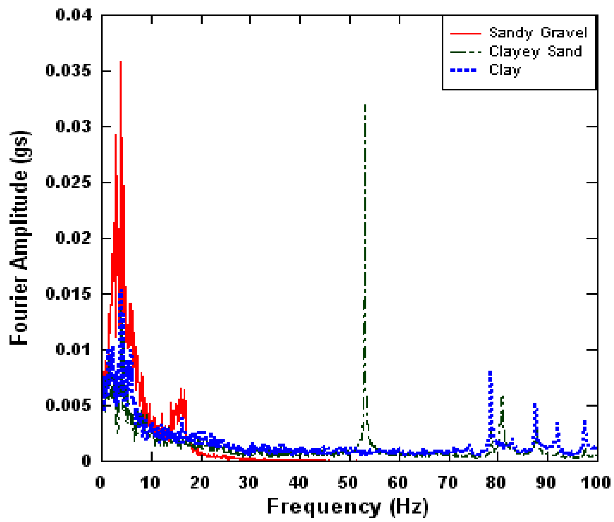

Fig. 9. Fourier response spectrum analysis at SHD site using nonlinear method against an input motion of Rakh earthquake (magnitude=4.9mb) right and Bhuj earthquake (magnitude 7.0ML) left.

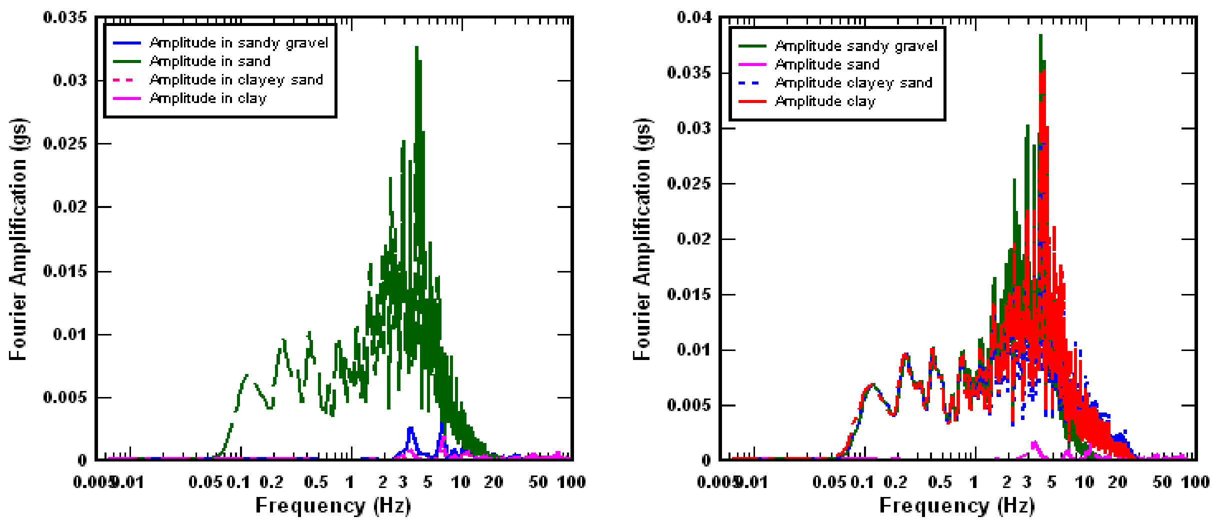

Fig. 10. Fourier response spectrum analysis at SHD site using equivalent linear method against an input motion of Rakh earthquake (magnitude=4.9mb) left and Bhuj earthquake (magnitude 7.0ML) right.

Table 3. Comparison of fundamental frequency values calculated using equivalent linear and nonlinear method.

Material	**Bhuj earthquake Magnitude =7.0ML Fundamental Frequency (Hz)**		**Rakh earthquake Magnitude =4.9mb Frequency for Amplification (Hz)**	
	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method
Sandy Gravel	3.96	4.22	6.59	4.74
Sand	3.80	4.00	6.59	4.69
Clay	2.98	4.11	17.63	4.40

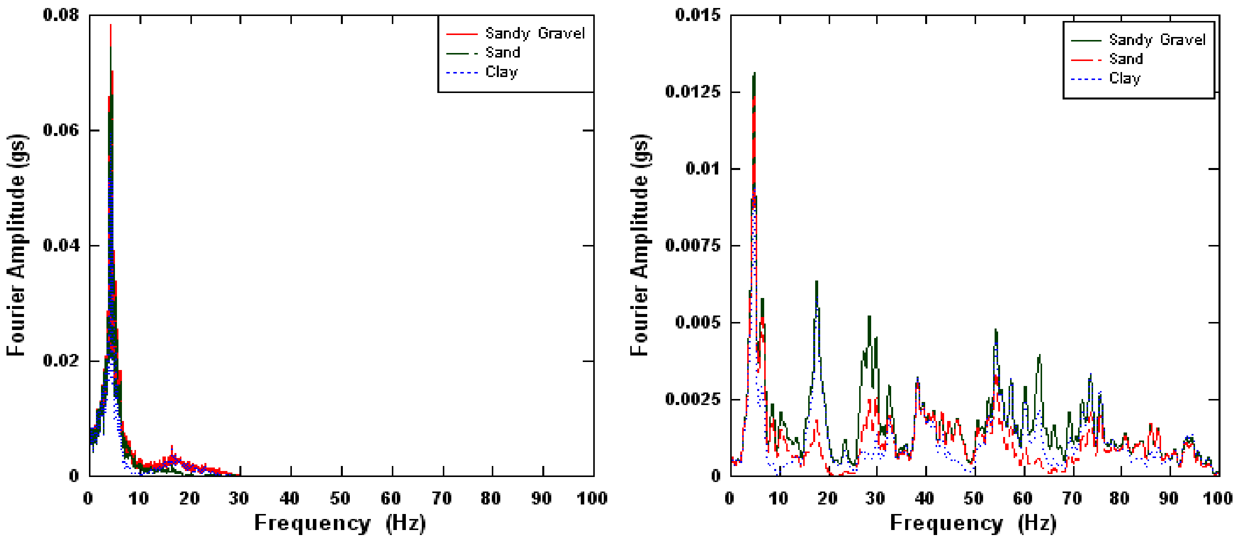

Fig. 11. Fourier response spectrum analysis at MUZ site using equivalent linear method against an input motion of Rakh Earthquake (magnitude=4.9mb) right and Bhuj earthquake (magnitude 7.0ML) left

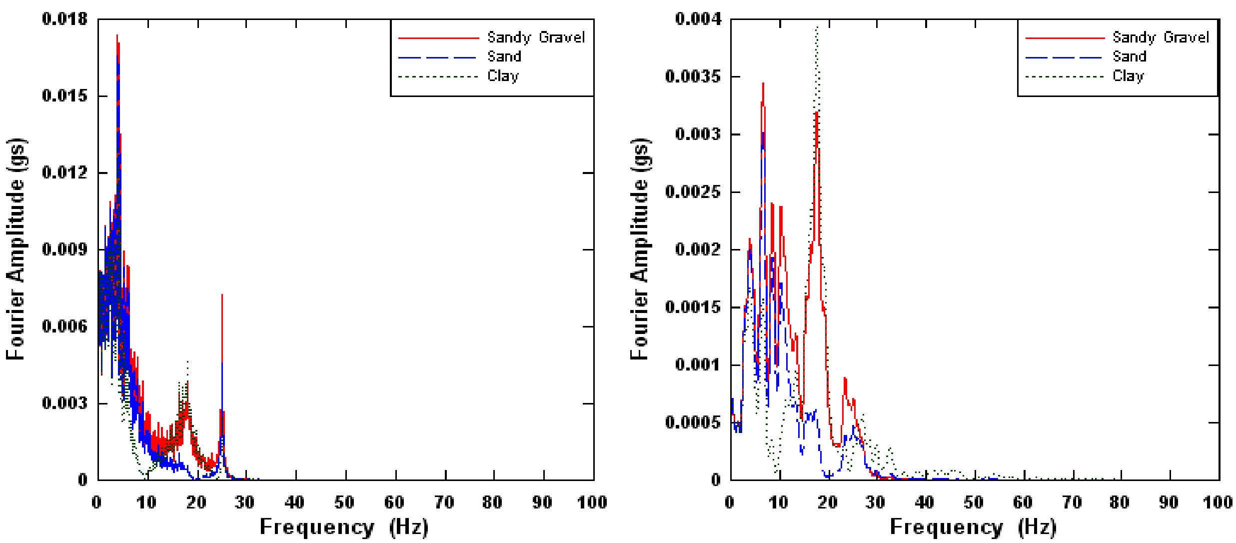

Fig. 12. Fourier response spectrum analysis at MUZ site using nonlinear method against an input motion of Rakh Earthquake (magnitude=4.9mb) right and Bhuj earthquake (magnitude 7.0ML) left

9. Amplification spectrum analysis

Amplification is indirectly interlinked with Fourier spectrum, because the frequencies are used in amplification spectrum to give outputs in response spectrum. The amplified values are the final parameter for the engineers to use in constructions of buildings/dams etc.

The maximum amplification values are listed in table 4 (MUZ site) and table 5 (SHD) site, and graphically shown in Figure (13-16). The results using fundamental frequencies are obtained using equivalent linear method and nonlinear method which indicate that at MUZ site the maximum amplification is 46.42 using equivalent linear method and it is12.189 using nonlinear method against input motion of 4.9mb.

At SHD site the maximum amplification results were 3.028 (sandy gravel), 4.082 (sand), 1.229 (clayey sand) and 1.139 (clay using equivalent linear method and it was 6.45 (sandy gravel), 3.024 (sand), 3.244 (clay) and 8.85 (clayey sand) using nonlinear method against input motion of 7.0ML. So, the amplifications in soils at both sites, behaved more nonlinearly and had high peaks against any input motion and behaved less linearly (the curves are relatively smooth).

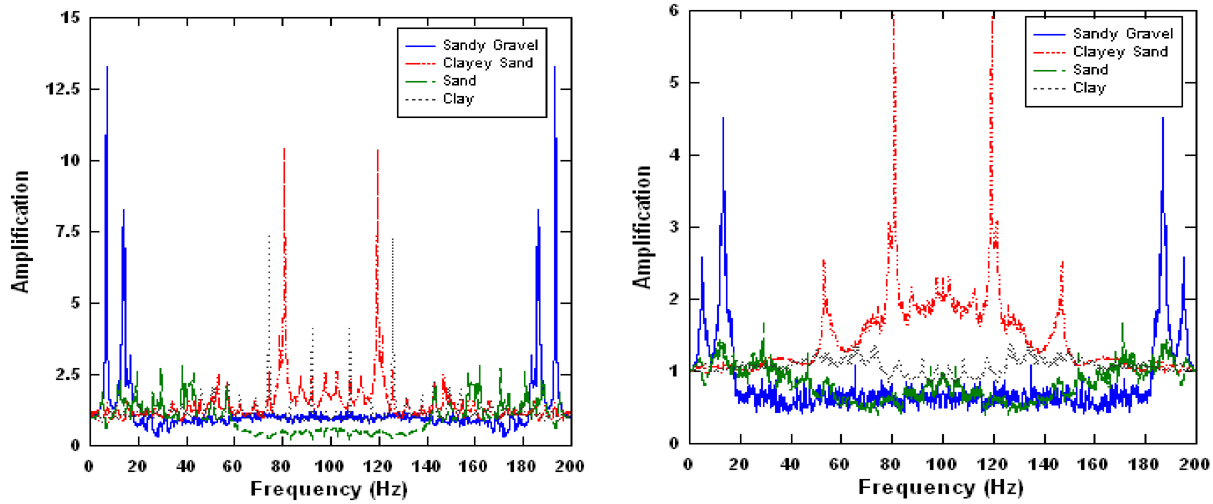

Fig. 13. Amplification spectrum analysis at SHD site using nonlinear method against an input motion of Rakh Earthquake (magnitude=4.9mb) left and Bhuj Earthquake (magnitude=7.0ML) right.

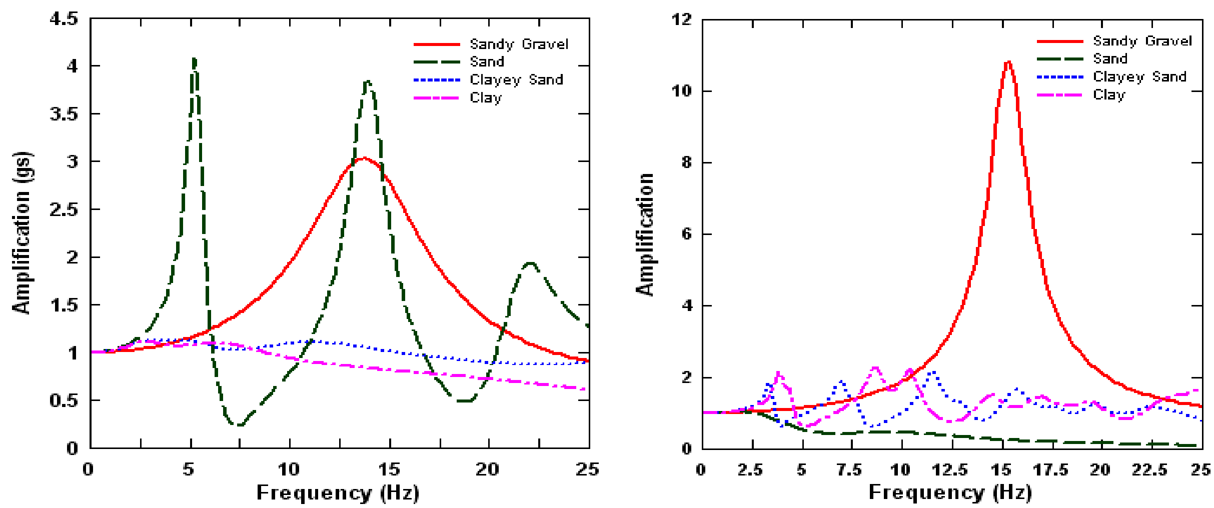

Fig. 14. Amplification spectrum analysis at SHD site using equivalent linear method against an input motion of Rakh Earthquake (magnitude=4.9mb) right and Bhuj Earthquake (magnitude=7.0ML) left.

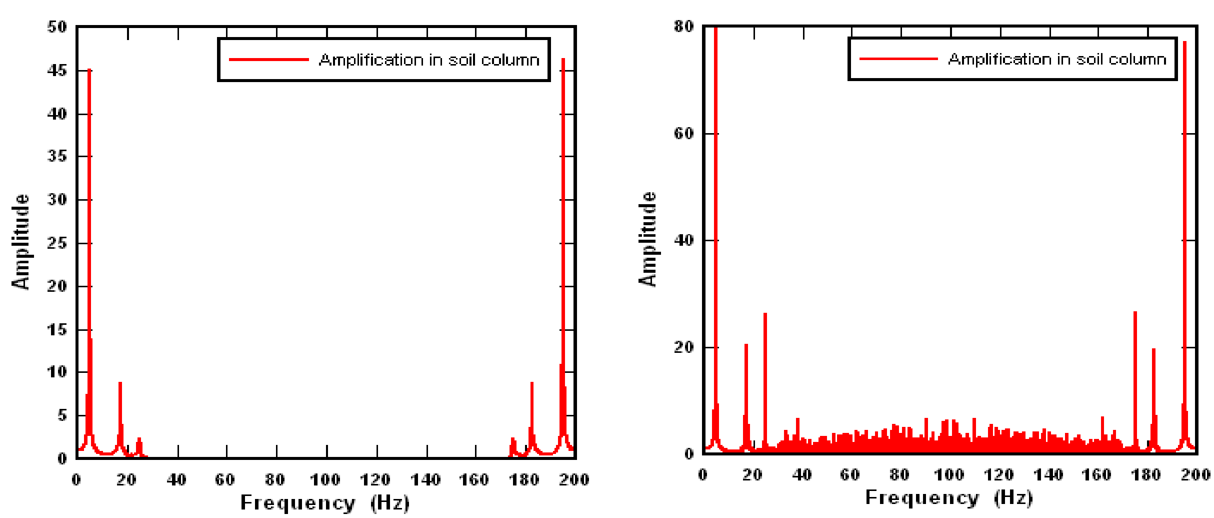

Fig. 15. Amplification spectrum analysis at MUZ site using nonlinear method against an input motion of Rakh Earthquake (magnitude=4.9mb) left and Bhuj Earthquake (magnitude=7.0ML) right.

Table 4. Comparison of computed values of amplification ratio using equivalent linear and nonlinear methods at MUZ site.

Event	**Amplification**		**Frequency for Amplification (Hz)**	
	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method
Bhuj earthquake Magnitude =7.0ML	79.58	4.224	4.97	4.60
Rakh earthquake Magnitude =4.9mb	46.42	12.89	195.07	4.80

Table 5. Comparison of computed values of amplification ratio using equivalent linear and nonlinear methods at SHD.

Material	**Bhuj earthquake Magnitude =7.0ML**				**Rakh earthquake Magnitude =4.9mb**			
	Amplification		**Frequency for Amplification (Hz)**		**Amplification**		**Frequency for Amplification (Hz)**	
	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method
Sandy Gravel	6.45	3.028	95.88	13.8	20.87	10.808	189.83	15.2
Clayey Sand	8.85	1.229	99.39	17.7	14.83	2.64	112.106	9.6
Sand	3.024	4.082	137.5	5.2	8.53	1.03	57.66	2.0
Clay	3.244	1.139	96.286	5.2	13.516	3.55	95.021	9.5

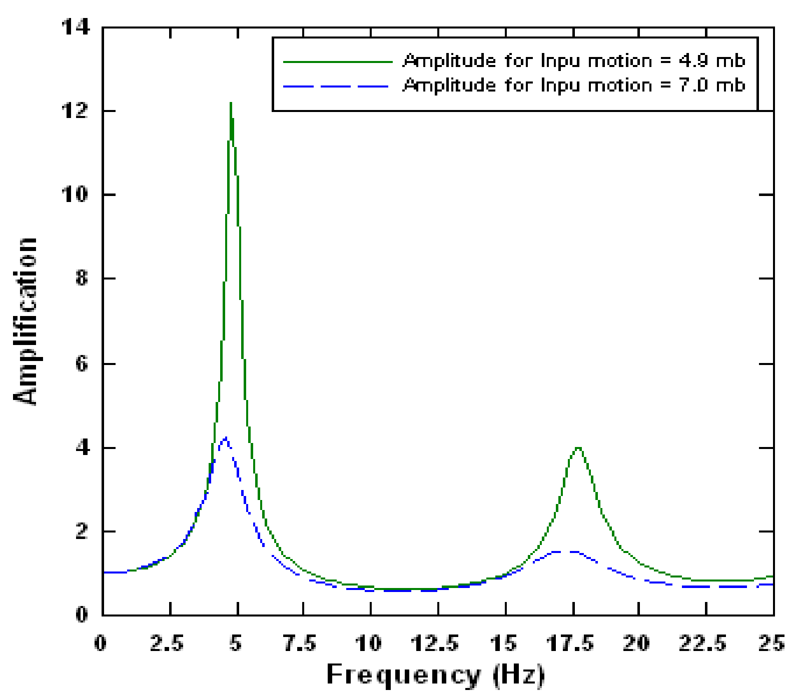

Fig. 16. Amplification spectrum analysis at MUZ site using equivalent linear method against an input motion of Rakh earthquake (magnitude=4.9mb).and Bhuj earthquake (magnitude=7.0ML)

10. Response spectrum analysis

Acceleration response spectra represents the peak values of the absolute accelerations of single degree of freedom oscillators (SDOFO) with different periods (frequencies) of vibrations (Hu, Liu and Dong, 1996).

The response spectrum is the most important part of seismic site response analysis. The response spectrum for soils deposited at SHD and MUZ site were obtained using equivalent linear and nonlinear method and then compared as shown in table

The results obtain for soils using equivalent linear method at SHD site were 0.38g (sandy gravel), 0.07g (sand), 0.28g (clayey sand) and 0.36g (clay) and using nonlinear method it was 0.35g (sandy gravel), 0.20g (sand), 0.23g (clay) and 0.19g (clayey sand) against input motion of 7.0ML. At MUZ using the sane input motion the result using equivalent linear method were 0.83 (sandy gravel), 0.79g (sand) and 0.62g (clay) and using nonlinear method 0.21g (sandy gravel), 0.20 (sand) and 0.17g (clay) were obtained.

Therefore, it is concluded that the spectral acceleration depends on the soil characteristics (thickness, depth and velocity) mainly and on method used for analyzing soil stability against natural shaking level.

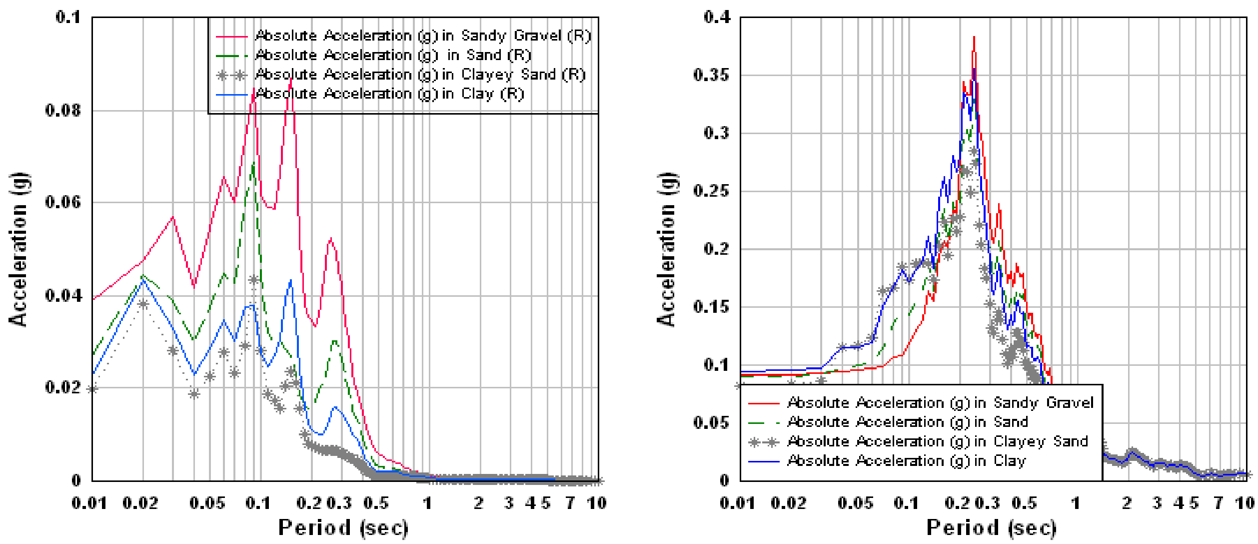

Fig. 17. Acceleration spectra analysis at SHD site using equivalent linear method against an input motion of Rakh earthquake (magnitude=4.9mb) left and Bhuj earthquake (magnitude=7.0ML) right.

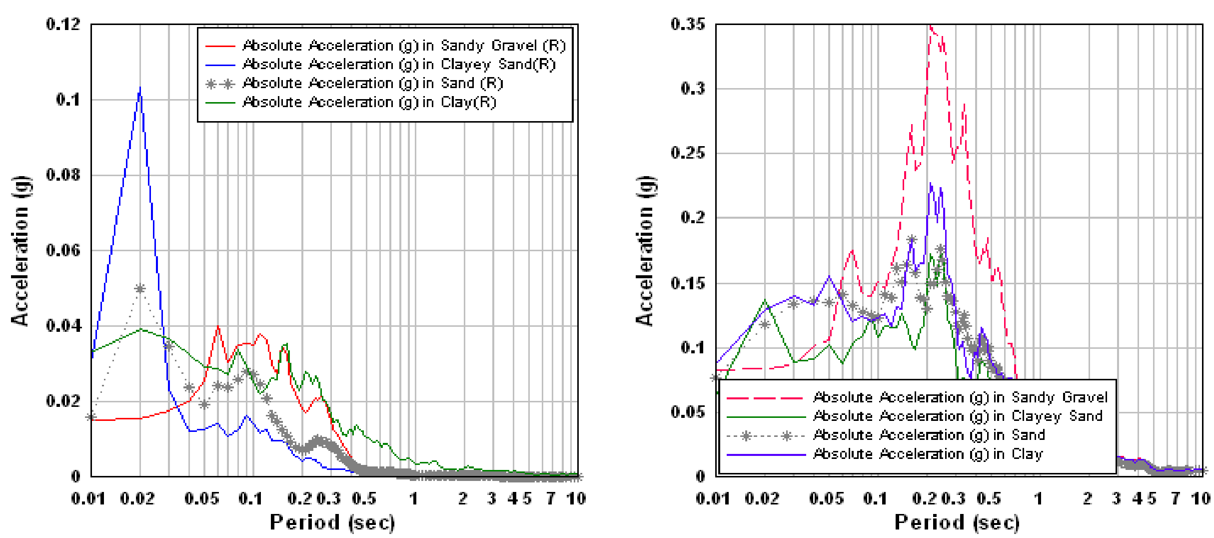

Fig. 18. Acceleration spectrum analysis at SHD site using nonlinear method against an input motion of Rakh earthquake (magnitude=4.9mb) left and Bhuj earthquake (magnitude=7.0ML) right.

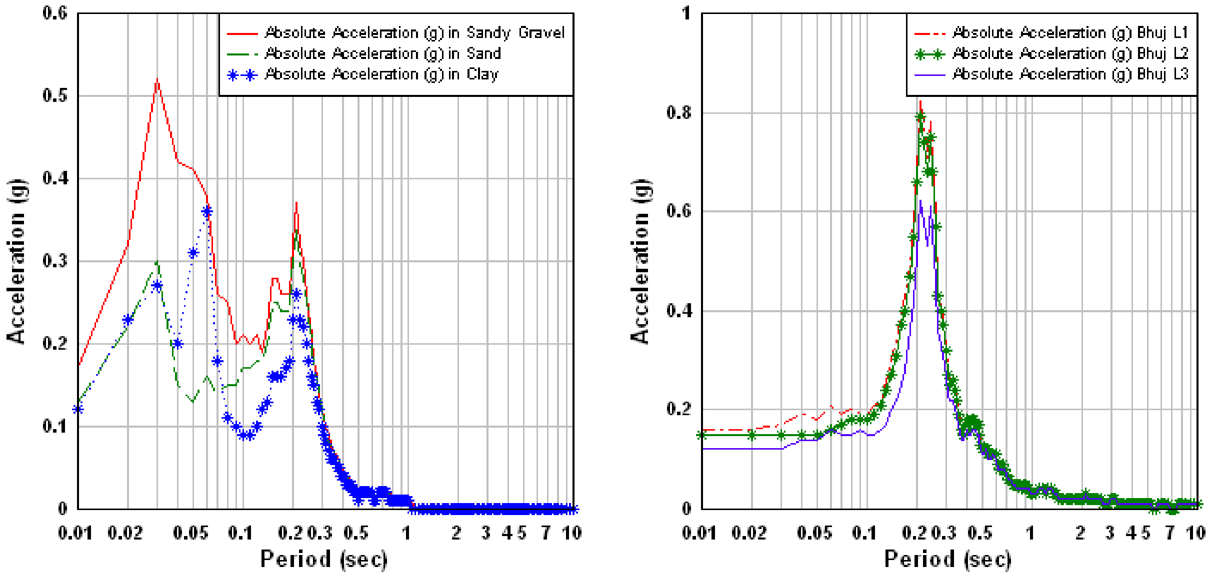

Fig. 19. Acceleration spectrum analysis at MUZ site using equivalent linear method against an input motion of Rakh earthquake (magnitude=4.9mb) left and Bhuj earthquake (magnitude=7.0ML) right.

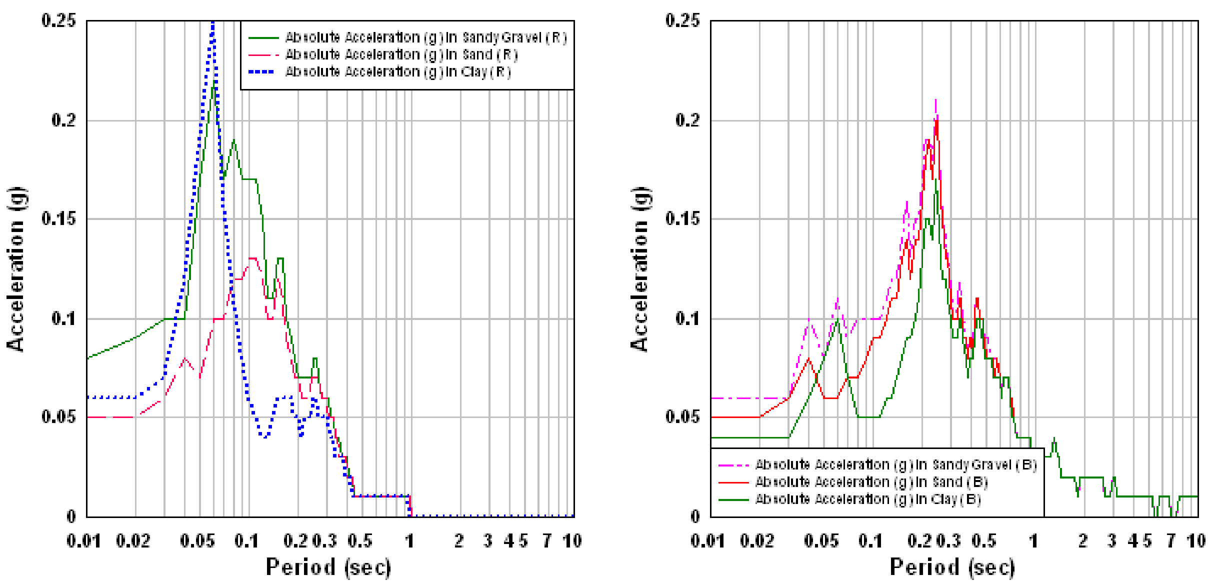

Fig. 20. Acceleration spectrum analysis at MUZ site using non linear method against an input motion of Rakh earthquake (magnitude=4.9mb) left and Bhuj earthquake (magnitude=7.0ML) right.

Table 6. Comparison of computed values for deposited soil using equivalent linear and nonlinear methods at MUZ site.

Material	**Bhuj earthquake Magnitude =7.0ML**				**Rakh earthquake Magnitude =4.9mb**			
	Maximum Spectral Acceleration (g)		**Maximum Spectral Velocity (Cm/Sec)**		**Maximum Spectral Acceleration (g)**		**Maximum Spectral Velocity (Cm/Sec)**	
	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method
Sandy Gravel	0.21	0.83	10.18	29.59	0.22	0.52	3.65	12.04
Sand	0.20	0.79	10.18	28.17	0.13	0.34	3.38	11.31
Clay	0.17	0.62	10.16	22.52	0.25	0.36	2.44	8.51

Table 7. Comparison of computed values for deposited soil using equivalent linear and nonlinear methods at SHD site.

Material	Bhuj earthquake Magnitude =7.0ML				Rakh earthquake Magnitude =4.9mb			
	Maximum Spectral Acceleration (g)		Maximum Spectral Velocity (Cm/Sec)		Maximum Spectral Acceleration (g)		Maximum Spectral Velocity (Cm/Sec)	
	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method	Nonlinear Method	Equivalent linear Method
Sandy Gravel	0.35	0.38	14.91	13.85	0.04	0.10	0.966	2.31
Clayey Sand	0.19	0.36	10.17	13.10	0.10	0.05	0.42	1.02
Sand	0.20	0.07	8.67	1.34	0.06	0.33	0.50	12.71
Clay	0.23	0.28	10.19	10.74	0.05	0.05	1.37	0.60

11. Conclusion

Using equivalent linear approach, the earthquake parameters were difficult to evaluate, particularly in the case of large magnitude and duration, which resulted in exceedance of the shear strength of soil, and in turn resulted in high strain values. While using nonlinear method parameters were relatively easy to compute and exceedance of shear strength in soil is noted at both sites.

Unrealistic values are obtained at the places where there was shallow upholes present because of the unknown depth of bedrock in these upholes. In both of the area, rocks were exposed to surface and therefore were heavily compressed and fractured.

Tectonic forces and other natural and artificial forces acting on the subsurface deposited materials due to which low to moderate amount of strain against stresses applied from either direction in the depositional settings were noticed in both methods. Moreover, the stress-strain relationships derived from the given data although not it gave a good picture but gave a clue about the compaction that is near to fracture with depth.

At SHD site relatively sharp peaks and more complex values of strain energy were noted which were relatively smooth against similar earthquake level. This might be due to overburden pressure and soil thickness.

The strain energy released by subsurface strata was not so complex at MUZ and therefore rather interpreted as slow amount of energy released, which was reversed in case of nonlinear method i.e. relatively sharp peaks were noted.

Both of the sites were analysed for Earthquake stability to rocks for the foundation of man-made building using minimum to maximum magnitudes (4.9 mb and 7.0 m). So, it is interpreted as incompatible. The profiles of maximum shear strain, and spectral amplification ratios at the both sites using nonlinear and liner methods were quite different.

Some fundamental frequency values in Hz for both the areas using equivalent linear and nonlinear methods were noticed to be same; this might be the reason of similar nature of deposition.

The spectral acceleration depended on the soil's characteristics (thickness, depth and velocity) mainly and on method used for analyzing soil stability against natural shaking level. The area was fractured, and it was not suit for intermediate to heavy structure building as the strain energy models showed.

Authors' Contribution

Sarfraz Khan, proposed the main concept, collected field data and involved in write up. Muhammad Waseem, did provision of relevant literature, and review and proof read of the manuscript.

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