Available online at: www.geo-dynamica.com

ISSN 2345 - 4997

Vol. (2), No. 01, SN:04, (Special Issue on Saravan Earthquake) April 2014
2nd Article- P. XII to XXI

GRIB
Geodynamics Research International Bulletin

Non-Linear Earthquake Response Spectrum Analysis of District Kotli, AJK with Increased Critical Damping Ratio

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Article History:	Received: Mar 30, 2014	Reviewed: Apr 07, 2014
Revised1: Apr 11, 2014	Accepted: Apr 13, 2014	Published: Apr 14, 2014

ABSTRACT

The Kotli area is a part of sub to lower Himalayas, and lies to the south east of the great syntaxial bend. The main objective of the present work was to test the site response analysis to interpret the damping effects after Muzaffarabad, 2005 earthquake on soils deposited at four sites (Fatehpur, Bernala, Plandri, Shensha) of Disstt. Kotli, NW of Pakistan. In the study areas, the site response at the vertical seismograph arrays of Kashmir earthquake (1995) having PGA of 0.017 was analyzed and it is scaled to PGA value of Muzaffarabad Earthquake. A non-Linear program is used, and site response models (damping curves, stress to strain curves, strain energy curves, frequency response curves and acceleration response curves) were constructed using shear and compression wave velocity profiles from upholes, and geotechnical data available at the four sites. In this analysis, other nonlinear and geometrical effects like stiffness reduction and liquefaction were neglected. By using soil parameters, a new damping curves for soils are constructed for the four different sites. The four areas are tested for response spectrum with increasing damping ratio (5%, 10%, 20%, 30% and 40%). The results of PGA, PGV and PGD for each area were obtained using 5% critical damping ratio and plotted on tri-linear diagram.

Keywords: Damping Ratio, Response Spectra, Tri-Linear Diagram.

1. INTRODUCTION

In order to better understand the nature of ground motion and moreover to quantify it, comprehensive review papers (Finn, 1991; Bard, 1994; Bard, and Pitilakis, 1995) on the very large amount of experimental and theoretical works were produced in the last twenty years to understand the factors influencing site response.

Ground response analysis could be done in several ways depending on the availability of the data in the site. There are several ways to perform seismic site specific response analysis depending on the available data in the site. Some data can be grouped into three categories a) field surveys and tests b) laboratory tests and c) special tests (MonaLisa and Khan, 2011).

2. THE STUDY AREA

In the study area, the acquired field tests were classified into: Geotechnical surveys and tests (SPT and CPT), seismic borehole test and dynamics tests (damping ratio) and seismic arrays (ground motion data) (Fig. 1). In order to analyze the site for response of ground motion four sites were selected that are located at:

Site A: Fatehpur, Distt. Kotli.

Site B: Plandri, AJK.

Site C: Barnala, Distt. Bhimber, AJK

Site D: Sehnsha, Distt. Kotli.

Generally, for the site analysis critical damping ratio is accepted as 5%, 10% or 20%. (Kramer, 1996).

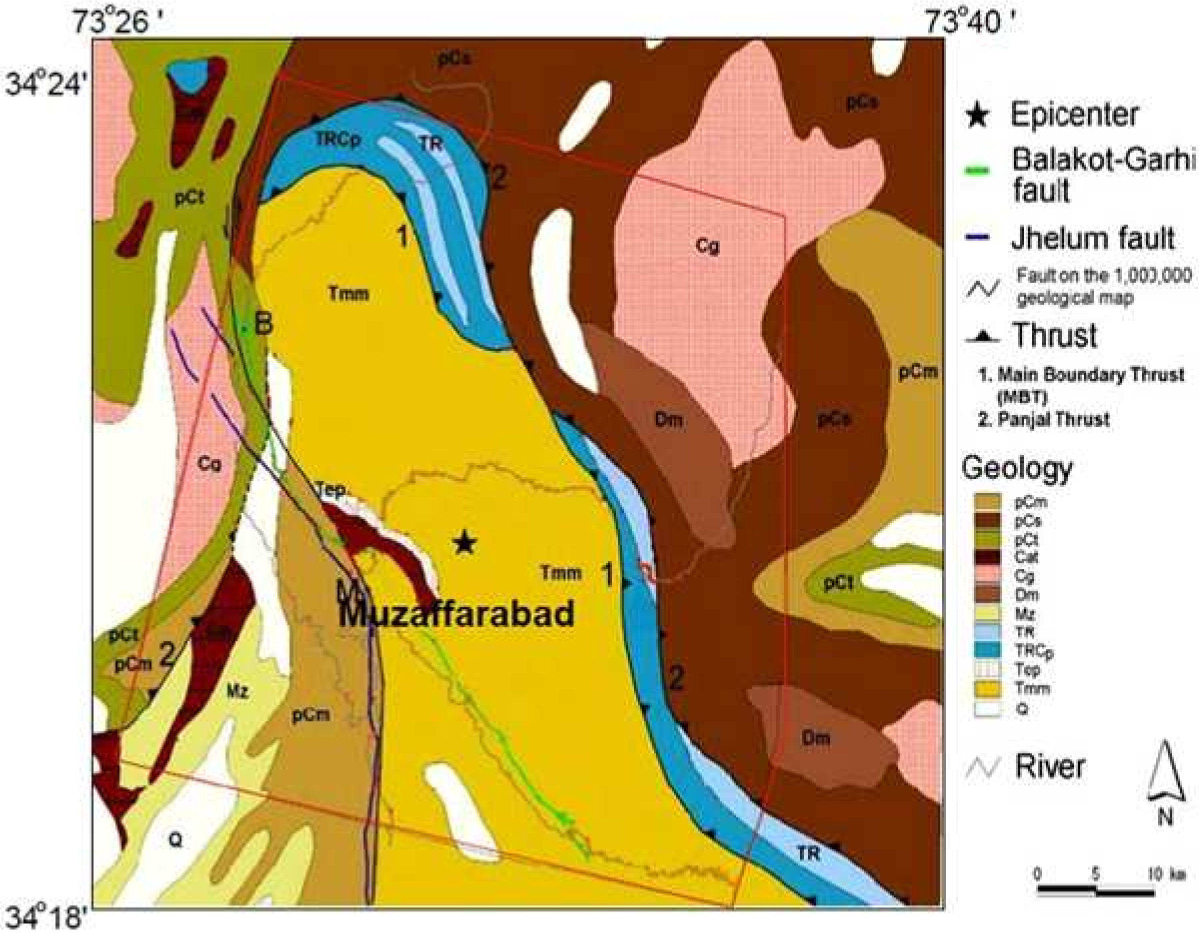


Fig 1. Geological map of Muzaffarabad area (Geological Survey of Pakistan, 1993). In this figure B stands for: Balakot, 1: MBT and 2: Panjal thrust. Red solid line indicates coverage area and the Legend and explanation of the geological map is shown in table1 below.

2. 1. GEOLOGICAL ASPECTS

In northern Pakistan the orogen is composed of three main tectonostratigraphic terrains (Najman *et al*., 2002): the Asian plate to the north, the Indian plate to the south, and the Kohistan island arc sandwiched between these two.

The Kohistan arc is separated from the Asian plate by the Northern or Shyok Suture and from the Indian plate by the Main Mantle Thrust (MMT). The Kotli area is a part of sub to lower Himalayas, and lies to the south east of the great syntaxial bend. Stratigraphic units exposed in the area range in age from Precambrian to recent ages; and mainly consist of sedimentary rocks with few sills and dykes of basic igneous composition.

The rocks consist of limestones, dolomites, argillaceous rocks and sandstones. Structurally, the area of interest lies to the southwest of the Hazara-Kashmir syntaxial bend. The major structures of the area include Main Boundary fault, the Bangang fault, Tattapani-Karela anticline, Palana-Devigarh anticline and Barmoch syncline. (Derrick and Geo, 2010)

3. RESULTS AND DISCUSSION

3. 1. DYNAMIC DEFORMATION CHARACTERISTICS OF SOIL

It is generally realized through laboratory tests and field investigations that ordinary soil shows very strong nonlinearity, i.e. the important mechanical properties, such as the modulus and damping, are strong functions of strain (Ishihara, 1981; Ohsaki, 1982).

There are two ways to represent the nonlinear properties of the soil; one is by giving the nonlinear stress-strain relationship of the soil, and the simplified one is by giving the deformation related equivalent modulus and damping; both are commonly used.

3. 1. 1. ENERGY DISSIPATED DURING STRAIN CYCLES

The strain energy that degenerates during stress-strain is twice of the area under stress strain curve. The computed maximum stress and strain values are shown graphically for the four sites. These curves indicate that the sites are under different strain levels where unequal stresses are applied by side rocks. Thus, here the stress-strain curve is equal to energy dissipation in case of sandy and clayey soil while near the surface, soils have widened stress-strain curves which is the indication of loose material near the surface, because the more the compaction, the narrower will be the stress strain curve. (Fig. 2-3)

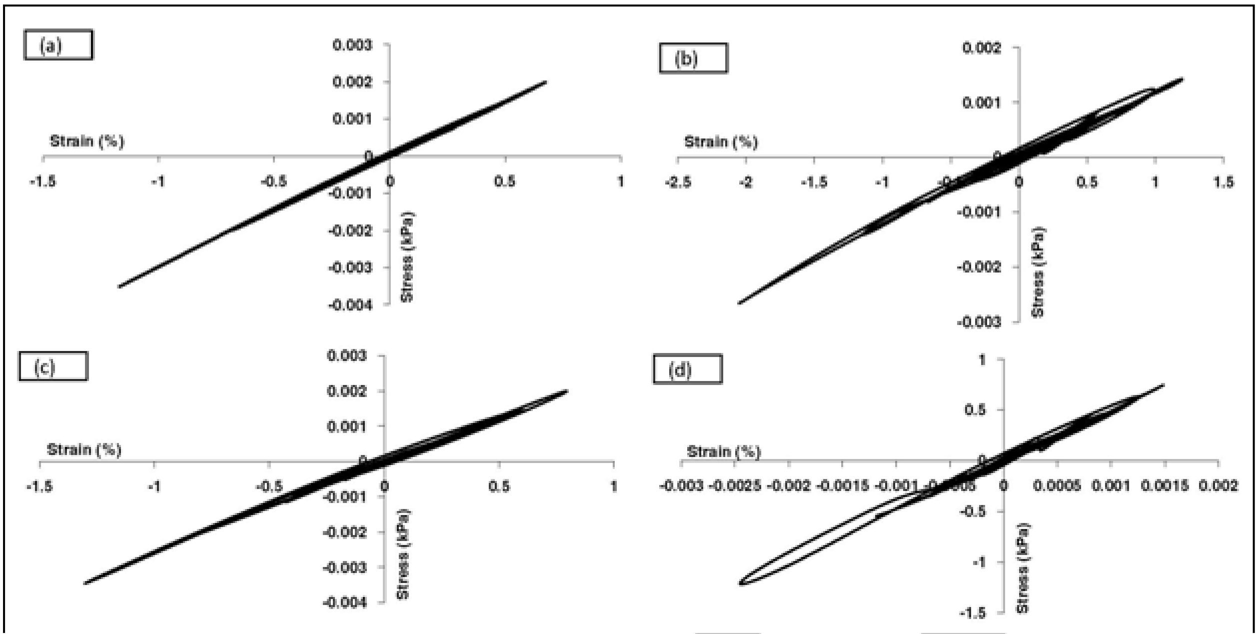


Fig 2. Stress-strain relationship between soils deposits at four sites a) Barnal distt. b) Plandri, c) Shensha distt., and d) Fatehpur distt

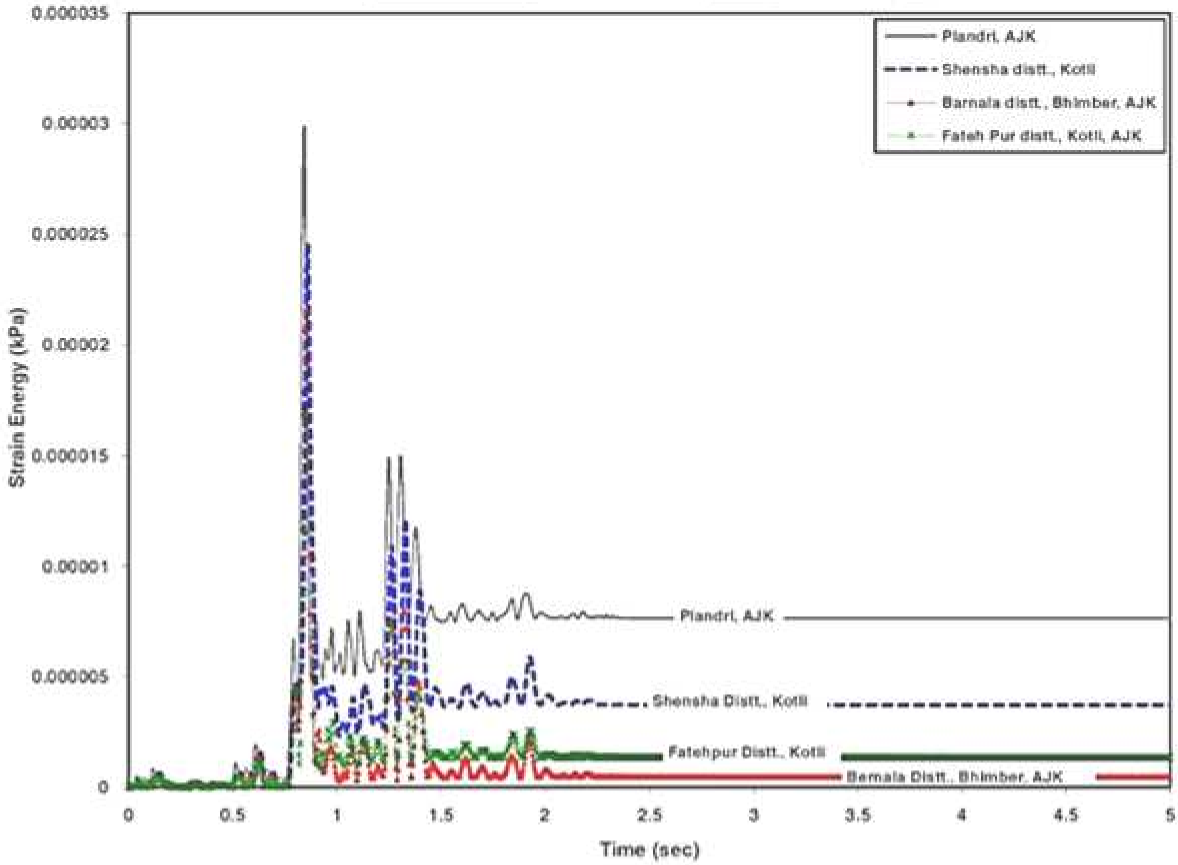


Fig 3. Strain energy relationship for soils deposits at four sites.

3. 1. 2. VARIATION OF SHEAR MODULUS AND DAMPING RATIO WITH SHEAR STRAIN

In earthquake engineering, damping problems may be classified into two categories: internal and external.

Internal damping is also called material damping, which represent the energy dissipated as heat by the internal friction of the material (Hu et al., 1996). For a structure, this will be in the form of friction at joints between members.

Nonlinear damping ratio curves based on the data are constructed for each soil layer at four sites. (Fig. 4)

The shear modulus decreases with the increase in shear strain corresponding to the increase in damping ratio in case of nonlinear analysis, the critical damping ratio is taken as 5% but for response spectrum it is taken as 5%, 10%, 20% and 40%.

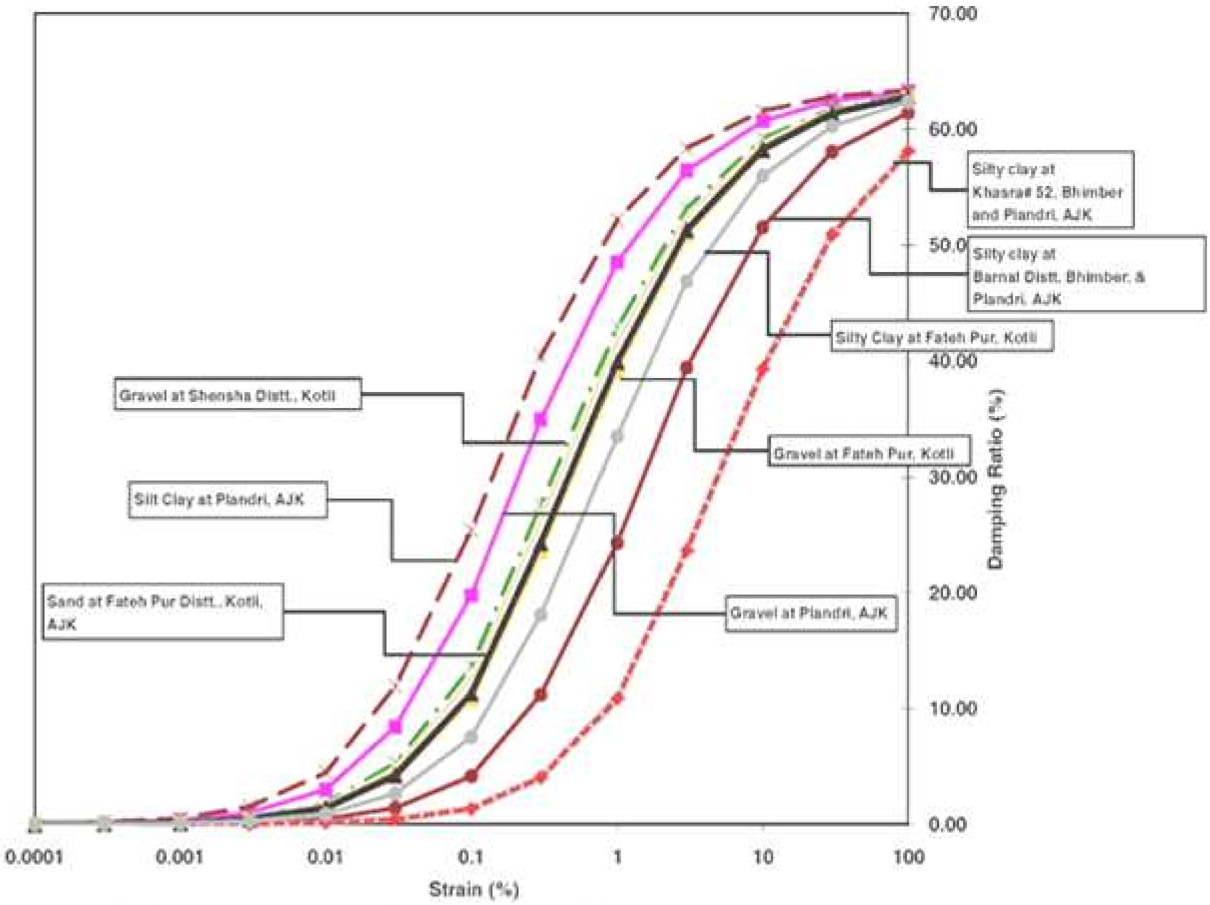


Fig 4. Nonlinear Damping ratio calculated for soils deposits at four sites.

3. 2. SUBSOIL STRENGTH CHARACTERISTICS

The sites were explored through boreholes named BH-1, BH-2, BH-3, BH-4 at site [A], site [B], site [C] and site [D] respectively, that are drilled maximum up to 10.0 m from the present ground level and boreholes named BH1-′, BH2-′, BH3-′, BH4-′ at site[A], site[B], site[C] and site [D] respectively, are drilled up to 10.0 meter where Genset has to be placed.

The strength characteristics of subsoil foundation material were investigated employing both standard penetration and unconfined compression tests. At site [A], the unconfined compressive strength (qu) for clayey strata varied from 1.29 to 1.52 tons/sq.ft and it falls under the consistency Stiff. The SPT-N value for the whole explored strata varied from 13 to 15.

At site [B], the 'qu' for coarse strata varied from 0.95 to 2.5 tons/sq.ft, and SPT-N value for the whole explored strata varied from 10 to >50. At site [C], the 'qu' for clayey strata varied from 0.88 to1.0 tons/sq.ft. and it falls under the consistency very stiff. The SPT. N value for the whole explored strata varied from 7 to 8. At site [D], the 'qu' for coarse strata varied from 0.80 to 1.12 tons/sq.ft. The SPT-N value for the whole explored strata varied from 8 to 12. The results of in-situ moisture contents and bulk density and unconfined compression strength are given in (Table 1) and the SPT-N values are recorded in the field borehole log (Table 2).

3. 2. 1. LABORATORY TESTING

Soil samples that are collected during sub-surface investigations were tested using sieve analysis, plastic limit, specific gravity and direct shear test for physical, chemical and engineering characteristics.

Table 1 Results of insitu moisture contents, bulk density and unconfined compressive strength

Sr. #	Location	Depth (m)	Insitu Moisture Content %	Bulk Density (gm/cc)	Unconfined Compressive strength (qu) (kN/m^2)
			Site [A]		
1.	BH-1	2.0	6.2	1.95	121.3
2.	BH-1	2.7	6.5	1.98	121.5
3.	BH-1	3.0	6.7	1.20	121.7
4.	BH′-1	1.0	5.8	1.97	121.5
5.	BH′-1	1.5	6.1	1.99	121.8
6.	BH′-1	1.7	6.5	1.22	121.9
			Site [B]		
1.	BH-2	2.2	6.2	1.62	116.0
2.	BH-2	2.6	6.5	1.64	116.4
3.	BH-2	3.0	6.8	1.68	116.7
4.	BH′-2	1.0	6.0	1.61	116.2
5.	BH′-2	1.5	6.3	1.66	116.5
6.	BH′-2	2.0	6.6	1.69	116.9
			Site [C]		
1.	BH-3	2.1	6.7	1.28	105.48
2.	BH-3	2.4	6.9	1.30	105.50
3.	BH-3	2.7	7.3	1.33	105.56
4.	BH′-3	2.1	6.8	1.29	105.49
5.	BH′-3	2.4	7.2	1.32	105.51
6.	BH′-3	2.7	7.4	1.33	105.55
			Site [D]		
1.	BH-4	2.4	7.2	1.44	105.4
2.	BH-4	2.7	7.5	1.47	105.6
3.	BH-4	3.0	8.1	1.52	105.8
4.	BH′-4	1.0	7.4	1.43	105.1
5.	BH′-4	1.5	7.8	1.46	105.5
6.	BH′-4	2.0	8.3	1.49	106.2

Table 2 Results of direct shear test.

Sr. #	Location	Depth (m)	Angle of Internal Friction ($\phi°$)	Apparent cohesion 'c' (Tons/sq.ft.)
			Site [A]	
1.	BH-1	2.0	31.2	0.64
	BH-1	2.7	31.4	0.67
2.	BH′-1	1.0	31.0	0.61
	BH′-1	1.5	31.3	0.63
			Site [B]	
1.	BH-2	2.2	30.0	0.21
	BH-2	3.0	30.1	0.25
2.	BH′-2	1.0	30.0	0.23
	BH′-2	1.5	30.3	0.27
			Site [C]	
1.	BH-3	2.1	29.33	1.0
	BH-3	2.4	29.34	1.2
2.	BH′-3	2.1	29.32	1.0
	BH′-3	2.7	29.34	1.1
			Site [D]	
1.	BH-4	2.4	30.7	0.32
	BH-4	3.0	30.8	0.35
2.	BH′-4	1.0	30.5	0.30
	BH′-4	1.5	30.8	0.33

The results showed that the subsoil is mostly coarse-textured, therefore as a whole, falls in GM, CL and CH (site [B] and site [D]) and CL-ML (site [C]) groups of Unified Classification System based on textural characteristics. While at site [D] the subsoil is mostly coarse-textured and is underlain by sandy clay and gravel and therefore, as a whole, falls in "GW, SW and ML" group of Unified Classification System based on textural characteristics. The soil strata were tested using Direct Shear Test for evaluating the angle of internal friction and cohesion.

Site [A]: "ϕ^o" varies from 31.2^o to 31.8^o while cohesion 'c' is 0.64 Tons/sq.ft.

Site [B]: "ϕ^o" varies from 30.0^o to $>41^o$ while cohesion 'c' is 0.21 Tons/sq.ft.

Site [C]: "ϕ^o" varies from 29.0^o to 29.3^o while cohesion 'c' is 0.87 Tons/sq.ft.

Site [D]: "ϕ^o" varies from 29.6^o to 30.7^o while cohesion 'c' is 0.32 Tons/sq.ft.

3.3. SEISMIC ARRAYS

Input motion for a site response analysis is selected according to the values of moment magnitude and peak acceleration. Response spectrum and amplification graph is hard to compare when data are abundant and there is time constraints. In order to run the nonlinear program (NERA), the vertical component of input motion of recorded by Rakh station having PGA of 0.017g is selected (Figs. 5, 6). The selected motion is recorded at outcrop and an outcrop site analysis is carried because the soils are mostly exposed at the surface.

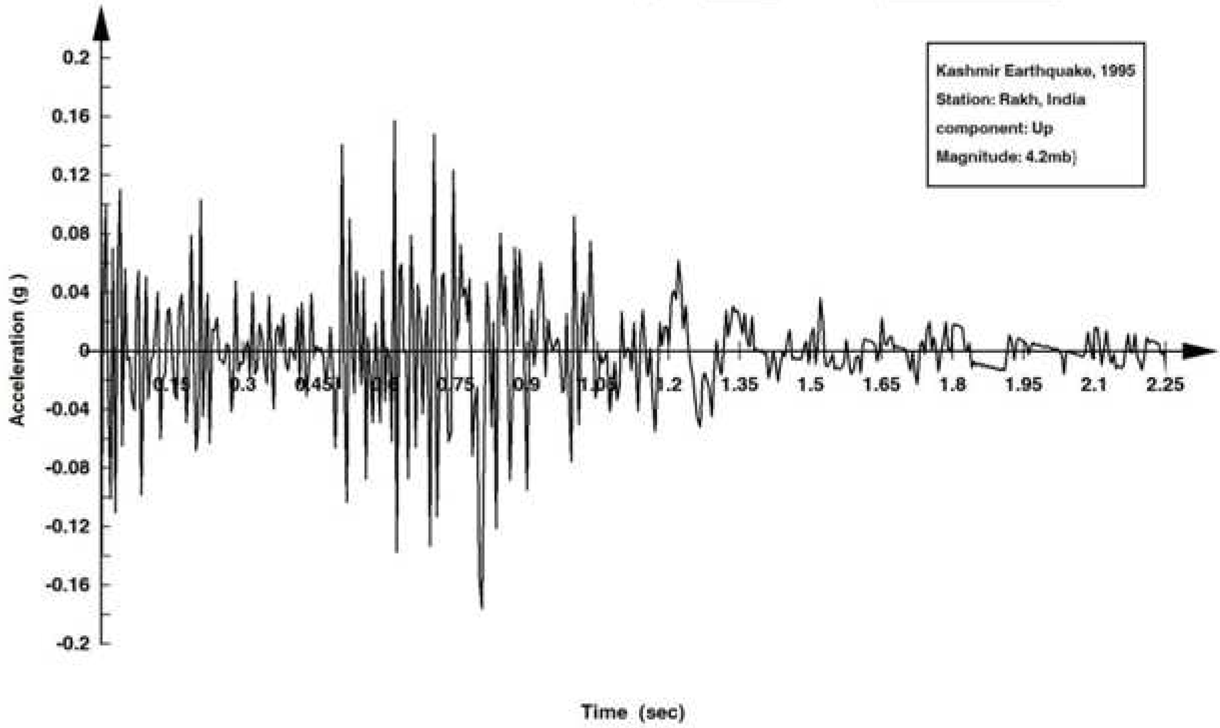


Fig 5. Record of digital accelerograph of Vertical component at Kashmir Earthquake 1995 at Rakh Station, obtained from COSMOS virtual data center.

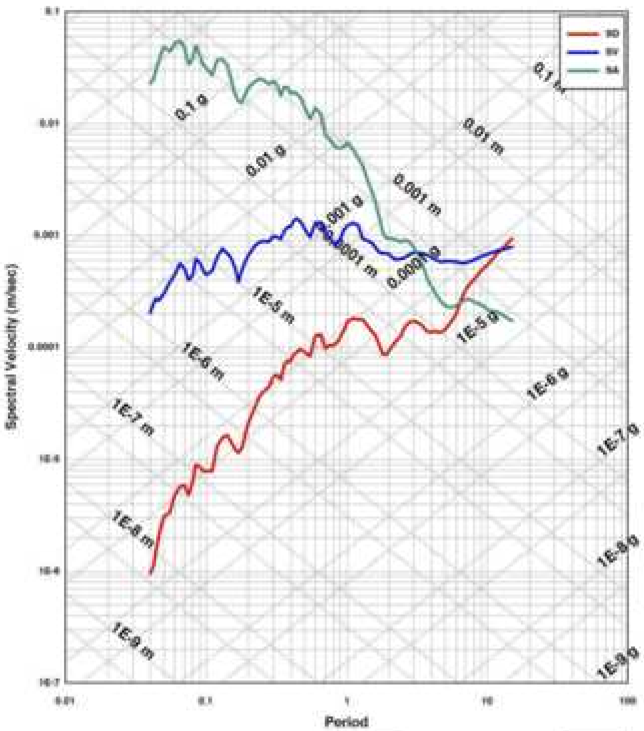


Fig 6. Trilinear diagram of response spectrum curves for input motion for the four sites.

3. 3. 1. SPECTRUM ANALYSIS

The spectral acceleration indicates the peak values of the absolute accelerations of single degree of freedom oscillators (SDOFO) with varying frequencies of shaking (Hu et al., 1996). A combined result of average PSA is shown in figure 6 in which PSA for site [A] is 0.08, for site [B] 0.11g, for site [C] 0.10g and for site [D] 0.105g are recorded using nonlinear program. From these values it is quite noticeable that the soil under site [B, C, D] is in exerted by a relatively equal amount of stresses and hence spectral response is nearly the same. The soil under site [A] exhibits some complex PGA values. (Fig. 7)

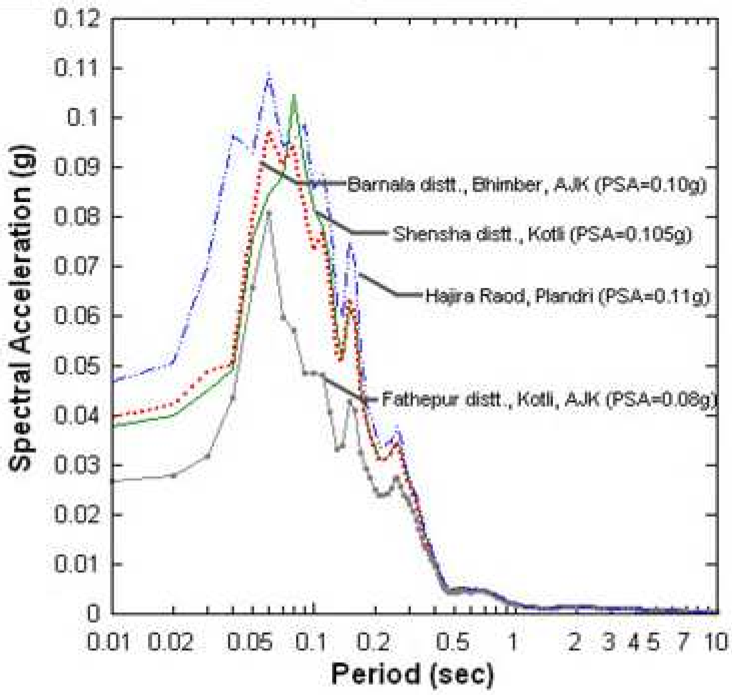
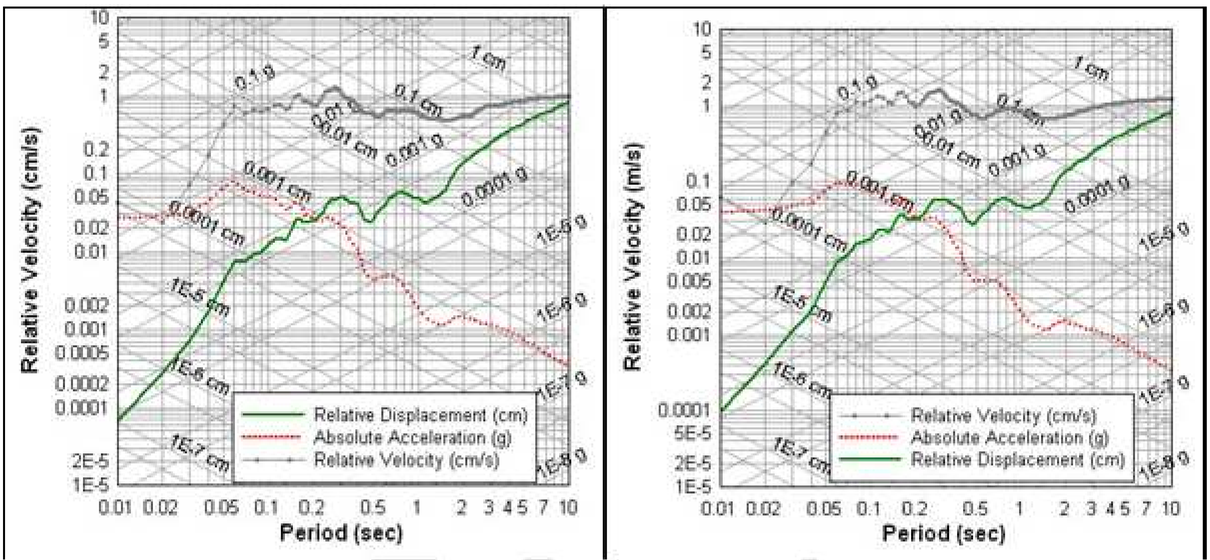


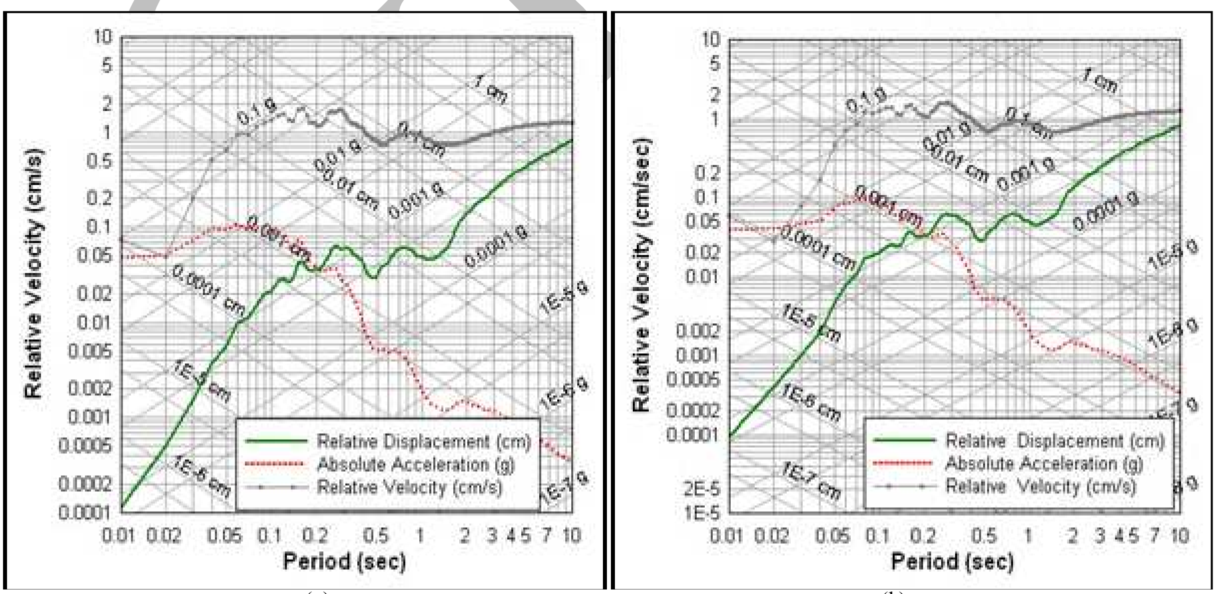
Fig 7: The response spectrum curves for soils encountered in upholes and correspondent points for the earthquake scenarios at KOT site. The Fatehpur site has different spectral acceleration then others.

The spectral amplification ratio between ground surface and soil-bedrock and also between different layers of soil is computed for particular acceleration levels. In the analysis, the Fourier acceleration amplitude spectra were smoothened using a three point moving average that is repeated four times. This technique eliminates some noisy signals in the amplification spectra for the given fundamental frequency. The sites were also tested for damping ratio of 10%, 20%, 30% and 40% in order to clear the complexity of soils deposited at sites [A, B, C, D]. By plotting the effective spectral velocity, spectral displacement and spectral acceleration values (McGuire, 1974) on a trilinear diagram and with increasing damping ratio it was noticed that the variation in pga values are not only due to soil type but the over consolidation ratio, shearing strength, porosity and water table effects the local sites foundation, this is why the sites are not suitable for heavy man-made structures. (Fig. 8a-8d)



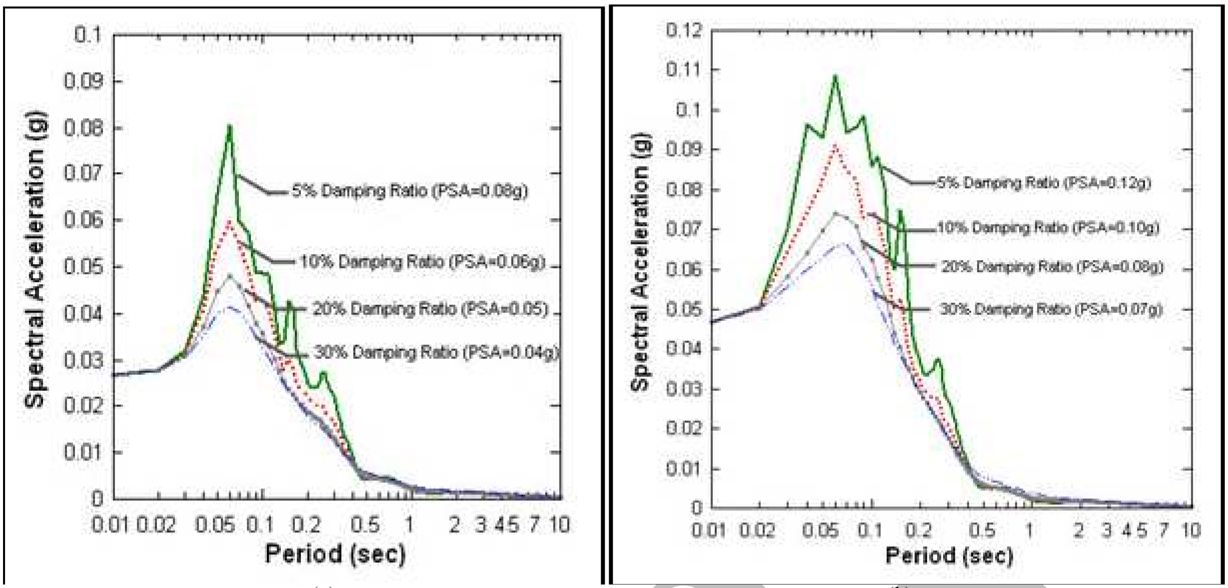
(a) (b)

Fig 8a: The Trilinear diagrams of response spectrum curves for each site show variation of PSA, PSV and PSD a) Bernala distt., b) Fatehpur



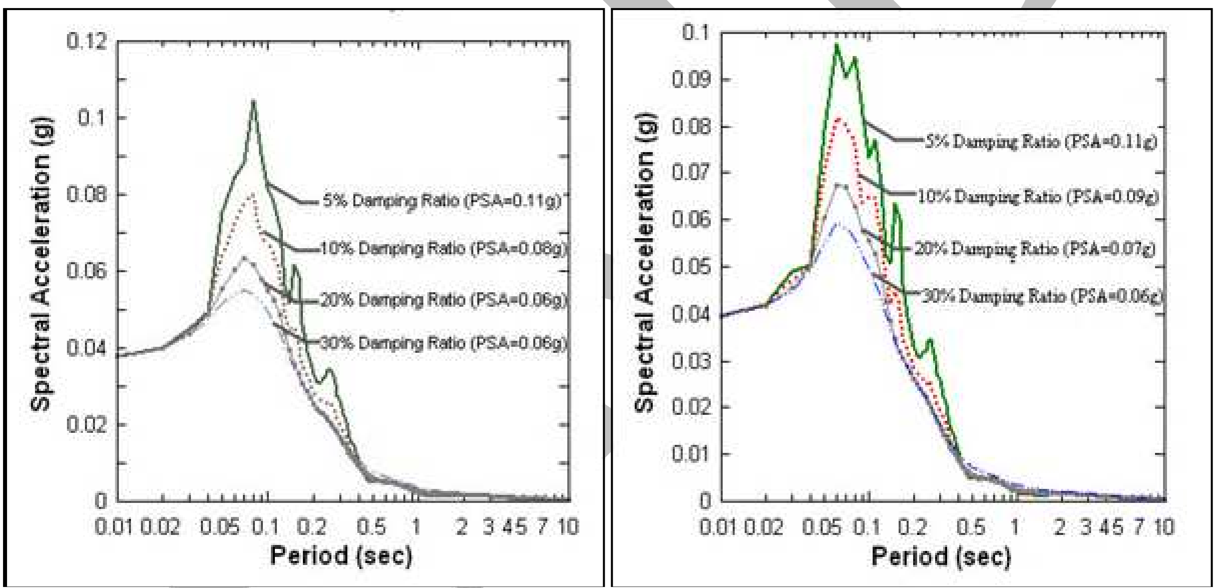
(a) (b)

Fig 8b: The Trilinear diagrams of response spectrum curves for each site shows variation of PSA, PSV and PSD a) Shensha distt., and b) Plandri



(a) (b)

Fig 8c: The combined result of response spectral acceleration with increasing damping ratio for a) Plandri. and b)Fatehpur Distt.



(a) (b)

Fig 8d: The combine result of response spectral acceleration with increasing damping ratio for a) Bernala Distt., and b) Shensha Distt.

4. CONCLUSION

The damping ratio calculated using nonlinear relation for similar soils at different sites are quite different which might be due to compaction and soil properties.

Water to be used in construction should be tested for harmful quantity of salts. In case the salts are in excess of the permissible limits, this water should not be used for construction/curing.

The strain energy curves are correlated with input motion and give clear interpretation of maximum release of energy with time period.

Excessive and undue watering to compact the backfill material should be avoided, as it will lead to the reduction in shearing strength of the soil beneath the foundations.

The response spectrum curves in the form of trilinear diagrams give different results for the same soil material deposited at four sites against similar input motion. This gives the clue that the velocities are different in soils as it depends on porosity, permeability and rock properties.

The displacement curves are indicative of very small changes in soil deposits near the surface, but it is the opposite in case of soils that deposit at some depth.

With increasing nonlinear damping ratio, the response spectrum in soil deposits at four sites behave linearly. This is again the cause of shallow deposition and has low porosity.

With increasing damping ratio, it is noticed that the area is not well suited for construction of heavy buildings even if the foundation is selected for critical damping ratio of 5%.

ACKNOWLEDGMENT

The author wishes to thank the Geotech Inc. (Pvt.) Ltd., for his contribution of data and valuable information for the sites.

REFERENCES

Bard, P.Y. (1994) Effects of surface geology on ground motion. *Recent Results and Remaining Issues, Proceedings of the 10th European Conference in Earthquake Engineering, Vienna*, 305-323.

Bard, P.Y. and Pitilakis, K.D., (1995) Seismic Zonation and Ground Interface. *Report and Discussion, Proceedings of 5th Int. Conference on Seismic Zonation, Nice,* 2127-2151.

Derrick, S. and Geo, P. (2010) NI 43-101 *Technical Report on the Mining Leases Registered* A.D. 814-7 (A.D. 262-65) and 1283-86 Kotli district of Azad Kashmir. Pakistan, Cooper Minerals Inc. of 306-595 Howe Street, Vancouver, British Columbia, V6C- 2T5.

Finn, W.D.L. (1991) Geotechnical engineering aspects of microzonation. *Proceedings of the Fourth International Conference on Seismic Zonation, Stanford University*, 199-259.

Geological Survey of Pakistan (1993) *Geological map of Pakistan*, scale 1:1,000,000.

Hu, Y.X., Liu, S.C and Dong, W. (1996) *Earthquake Engineering*. CRC Press, United State, California, 490 p.

Ishihara, I. (1981) Dynamic Soil Properties. *Proceedings of UCMZ, IEM.*

Kramer, S.L. (1996) Geotechnical earthquake engineering, *Prentice Hall*, Inc, Upper Saddle River, New Jersey, 653.

McGuire, R.K. (1974) Seismic structural response risk analysis, incorporating peak response regressions on Earthquake Magnitude and Distance. Res. Rept. R74-51, MIT, Department of civil Engineering.

Lisa, M. and Khan S. (2010) Non linear earthquake site response analysis of the layered soil deposits at Shakardarra and Muzaffarabad. *PAPG/SPE Annual technical conference*, 415-423.

Lisa, M. and Khan, S. (2011) Equivalent linear characteristics of layered soil deposits at Shakardarra and Muzaffarabad, *Journal of Himalayan Earth Sciences (JHES)*, 43.

Najman, Y., Pringle, M., Godin, L. and Oliver, G. (2002) A reinterpretation of the balakot formation: implications for the tectonics of the NW Himalaya, Pakistan, *Tectonics*, 21 (5), 1045.

Ohsaki, Y. (1982) *Dynamic nonlinear model and one-dimensional nonlinear response of soil deposits*. Research Report 82-02, Department of Architecture, University of Tokyo.

