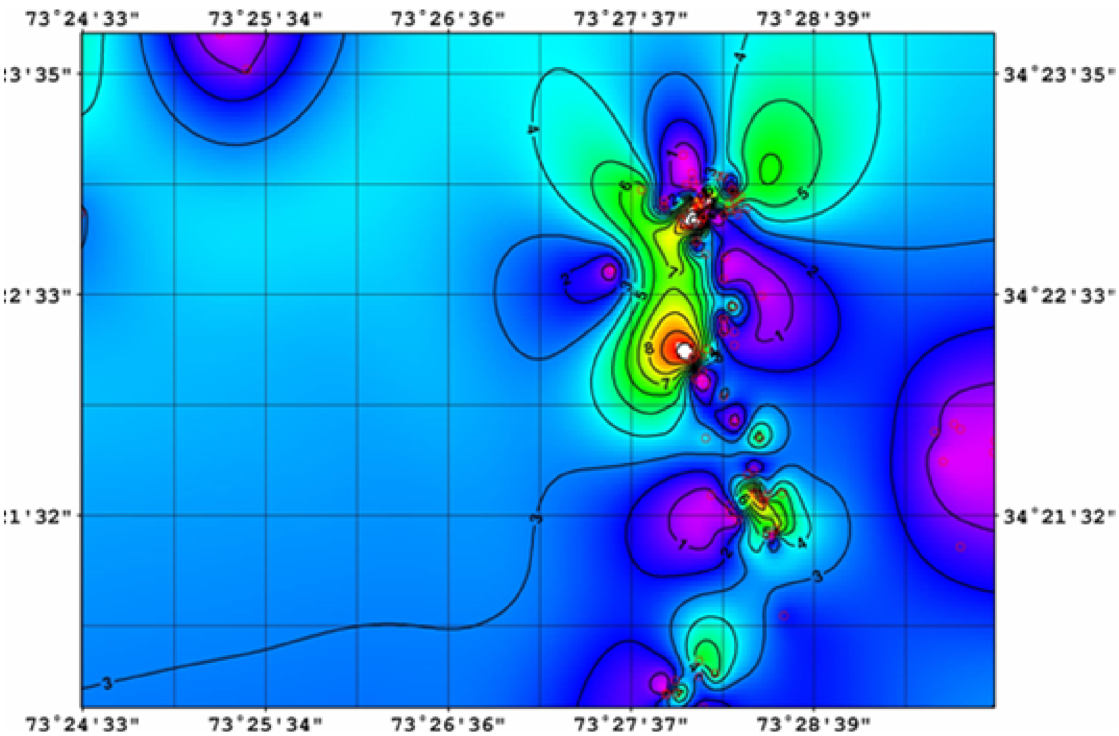
Seismicity in Pakistan during 2008 and Local Site Response in Muzaffarabad and Islamabad, Pakistan



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Appendixes

Summary

Pakistan is tectonically significant and thus needs to be studied. In recent years, Pakistan is growing economically and the population has increased. Pakistan has experienced several disastrous earthquakes in the historical times. About 50% of the population is living under a constant earthquake threat. This results in raising the interest to estimate the seismic hazard through tectonic and seismological studies. Present study has been divided into two parts. Comparison of Pakistan seismic network data (limited available) with international data from PDE and conducted a local site effects study in the two cities (Islamabad and Muzaffarabad) of Pakistan.

The first part describes the seismicity, tectonics of Pakistan, Seismic Network in Pakistan (past, present and future) along with comparison of Pakistani seismic network data with international data from PDE with respect to epicentral earthquakes locations and magnitudes. Fifty four earthquakes detected by both PDE and seismic network of Pakistan are relocated. It has been observed that epicentral locations (PDE and Pakistan seismic network) of the earthquakes do not fit well in general. Another attempt made by selecting comparatively good event from local network but again resulting in the more or less similar difference in epicentral locations of earthquakes calculated by the PDE and local network. Magnitude comparison of the two (PDE and Pakistan seismic network) shows that the local magnitude (Ml) calculated by the Pakistan seismic network is quite close to the PDE (body wave magnitude), coda magnitude calculated by the Pakistan seismic network data is giving high value as compared to PDE magnitude.

In the second part local site effects in the two cities of Pakistan have been conducted.
It has been realized by the seismological society that most of the damage associated with earthquakes could be attributed to local site effects- amplification of the seismic waves from unconsolidated or water saturated loose sediment deposits or the particular topography in the given area.

In this study, two sites have been surveyed for site effects- one sector of Islamabad city capital of Pakistan and the Muzaffarabad city, Pakistan. Non reference site technique proposed by Nakamura has been used for the calculation of fundamental site frequencies in several different sites in the area under investigation. The topographic and geological conditions in the two localities are different.

In Islamabad area the results observed are roughly in agreement with the existing soil conditions. The fundamental frequencies vary, however they show consistent values in general with the expected sediment thickness and compositions. The data coverage and its distribution were not ideal to give more precision and confidence level. Amplification factors obtained are quite low (2-4) and is evenly distributed for the entire area.

In Muzaffarabad, the fundamental frequencies are not clear and vary significantly, this probably due to the nature of the sediments which are mainly coarse grained proximal fluvial deposits are of high energy enrichment

It is well known that Pakistan is situated in an earthquake prone area, we believe that the present study may be of use to the Municipality of the two cities to improve the building codes by taking the site effects into consideration.

1 Introduction

Natural disasters like flood cyclones, drought, forest fire, earthquake, volcanic eruption, epidemic and main accidents are widespread in different parts of our planet. These escorts to the loss of life, property damage and socio-economic disorder. These losses have developed over the years as a result of increase in population and material resources. It is documented that natural disasters have claimed millions lives in the past and badly affected the millions of people with significant financial losses of millions dollars. These losses are more in developing countries because of high population density and poor constructions in terms of earthquakes (Tewari, 2000).

Among the natural disasters earthquakes are one of the most catastrophic events. Every year about one hundred thousands earthquakes of magnitude more than three hit the earth. In total More than 15 million human lives have been lost in disaster throughout the world. In addition the damage worth of billions of dollars has been imposed because of these earthquakes in the recorded history. Some of the disastrous earthquakes so for the world are, Tangshan of China, 1976, Mexico City 1985, Northwest Turkey August 17, 1999, Sumatra 2004 and Kashmir earthquake 2005. The occurrence of earthquakes as it is the case for other natural disasters cannot be prevented. The catastrophic effects of these however, can be minimized significantly by scientific knowledge of their nature, magnitude, causes, rate of recurrence and areas of influence (Tewari, 2000).

Earthquakes are, frightening and disastrous due their impulsive impact and devastation in a matter of few seconds inflicting enormous losses of life and property. Destructive earthquake impact has direct and indirect effects (short term and long term). The first (short term or direct) given by the number of sufferers, damage structures and direct financial losses. Long term or indirect impact is given by the miserable influence on the social/public structure in the subsequent years. In majority of the cases the social structure experiences everlasting damages, while the direct economic losses can be absorbed by the country with international support (Slejko, and Ansal, 1999)

Pakistan is situated in a seismically active region which has experienced many disastrous earthquakes during historical times. The big earthquakes hit that region in the last century are Quetta 1935, Makran coast 1945, Pattan 1974, and Kashmir earthquakes 2005. About 50% of the population of Pakistan is living under constant earthquake threat. There are several active faults existing in the Northern and southern Pakistan. Over the last 30-40 million years the Indian subcontinent has been colliding with the Eurasian subcontinent (Aitchison et al., 2007). Continental lithosphere more than 2000 km has been shortened during this time period to produce massive mountain ranges of central Asia (Bollinger et al., 2004; Molnar and Tapponier, 1975). The continental-continental collision is producing high seismic activity in the region. Several great mountain structures have been produced as a result of this collision (for example, Kiether and sulaiman ranges, Hindukush Mountains, Karakorum Mountains and the Pamir ranges).

Pakistan Meteorological Department (PMD) is responsible to monitor seismic activity in the region. PMD has been working with seismology since 1954 and has the mandate to issue the information to public sector as well as to the government agencies. First seismic network was very small with 6 seismic stations. In 2005-2006 six digital sensors was added in the existing seismic network. Present situation is quite improved. Currently 10 Broad Band seismic stations have been installed and linked through satellite communication system with Karachi seismic center. In addition 10 short period and 30 strong motion sensor have also been installed.

Recently, after the installation of new digital seismic network, better information about seismic activity in the region has become available to investigate the tectonics of the area. Past and recent (Kashmir earthquake, 2005) earthquakes have caused heavy damages in the region. Therefore, this study is important in both regional and local scale. It is also significant as the area is economically growing with high population density.

During an earthquake the shaking of the ground depends on many factors. On of these factors is local site effects. Estimation of local site effects is one of the input parameters of any seismic risk analysis. It accounts for most of the cases significant portion of the damage that occurs during an earthquake. San Francisco 1906, The Kobe 1995, and Loma Prieta (1989) earthquakes all caused devastation mainly due to very high ground shaking and ground amplification which is caused by local site effects. 1985 Mexico Mexico City earthquake is an unusual example in which epicenter of the earthquake was (250miles) 400 kilometers) away from the city of Mexico which was damaged badly due to local site effect. As said by a few authors the relative acceleration amplification of quite a few lake bed sites of the valley of Mexico city attained values between 8 to 56 with regard to one particular selected site placed on rock . Seismological society has realized the importance of the local site response and different techniques have been proposed to assess the site response. In the present study, an empirical approach has been carried out as for the expected local site response in two cities (Islamabad & Muzaffarabad) of Pakistan. For the estimation of local site effects at different sites, several records of ambient seismic noise have been made and analyzed using the H/V technique. At the end, maps presenting the distribution of the fundamental site frequency and of the observed amplification factors are prepared (Nakamura, 1989;, 2000; Singh et al, 1988)

Amplification of the incoming seismic waves due to the local geological site conditions or topographical features in a certain area is a well known problem called local site effects.

It is acknowledged that uppermost poorly consolidated sedimentary deposits, that have acoustic impedance much lower than that of underlying bedrock, can magnify the arriving seismic waves due to the following reasons: First, transmission coefficient at the border between underlying bedrock and uppermost sediments is larger than one. It means that the seismic waves coming from below will propagate in the sedimentary deposit with higher amplitude than the amplitudes they had in bedrock (impedance contrast). Second, the interference will take place among the waves reflected from free surface, transmitting downwards with the waves coming from earth which amplify the ground motion at specific frequencies (Atakan, 1995; Lacave, 1999).Generally velocity structure and thickness of the uppermost layers are used to determine the exact frequencies at which the maximum amplifications will occur. The amplification is up to some extent compensated by the intrinsic attenuation, which is higher in uppermost unconsolidated sediment layers. On the other hand, when specific conditions are fulfilled, the intrinsic attenuation is incapable to completely compensate the amplification effects and high amplification may happen at specific frequencies (Atakan 1995; Lacave, 1999).

The response of building can be considered analogous to an equivalent harmonic oscillator from an engineering point of view and each harmonic is characterized by its fundamental frequency. When fundamental frequency of building and some of peak frequency of the site response spectrum coincides, then an earthquake can produce complete destruction due to resonance effect which will occur. Therefore, urban areas located in earthquake prone areas, it is very important to study the site response for proper construction (buildings) in the area. In several cases the amplification factors of the higher modes of fundamental frequency are to a large extent lower than amplification factor of the fundamental site frequency itself. So knowing the fundamental site frequency may be enough for building engineers in many cases (Atakan 1995; Nakamura 1989;, 2000).

1.1 The city of Islamabad (Capital of Pakistan)

Islamabad is located in the northern part of country, in the south of Margalla hills from where the seismically active fault Main Boundary thrust (MBT) passes (third main deformational front). Historically it has been the part of the cross road between Punjab and North West Frontier Province (NWFP). Islamabad being a capital of Pakistan has several modern and multistory buildings (Embassies, Civil and industrial buildings), number of new buildings are under construction. Economic growth and increased activity of the building industry in an earthquake prone area. This was the reason to take a survey of this city to estimate local site effect part of this city (Capital Development Authority general information)

Seismic hazard in twin cities (Islamabad and Rawalpindi) is associated with numerous faults in the vicinity/ proximity of the area. These include Main Boundary Thrust (MBT) and Margalla, Hazara, Jhelum, Panjal and Murree faults. MBT which is about 270 km in length and extends along Himalayan Front, passing about 1 km south of Margalla Hills. In the north of Margalla Hills at about 26 km passes Panjal Khairabad fault (PKF). The Hazara thrust fault zone (HTFZ) comprises of three branches in the Margalla hills with the closest trace about 15 km of from Islamabad (figure 1.1). 8 October 2005 earthquake M7.6 near Muzaffarabad demonstrates the importance of seismic hazard in the region. The earthquake struck about 100 km northeast of Islamabad caused thousands fatalities and serious structural damage. Mainly the damage was concentrated in the mountainous epicentral region. Significant damage also took place on sediment site in Islamabad and Rawalpindi (Yong, 2008). This was another reason to decide on a survey of site effects in Islamabad.

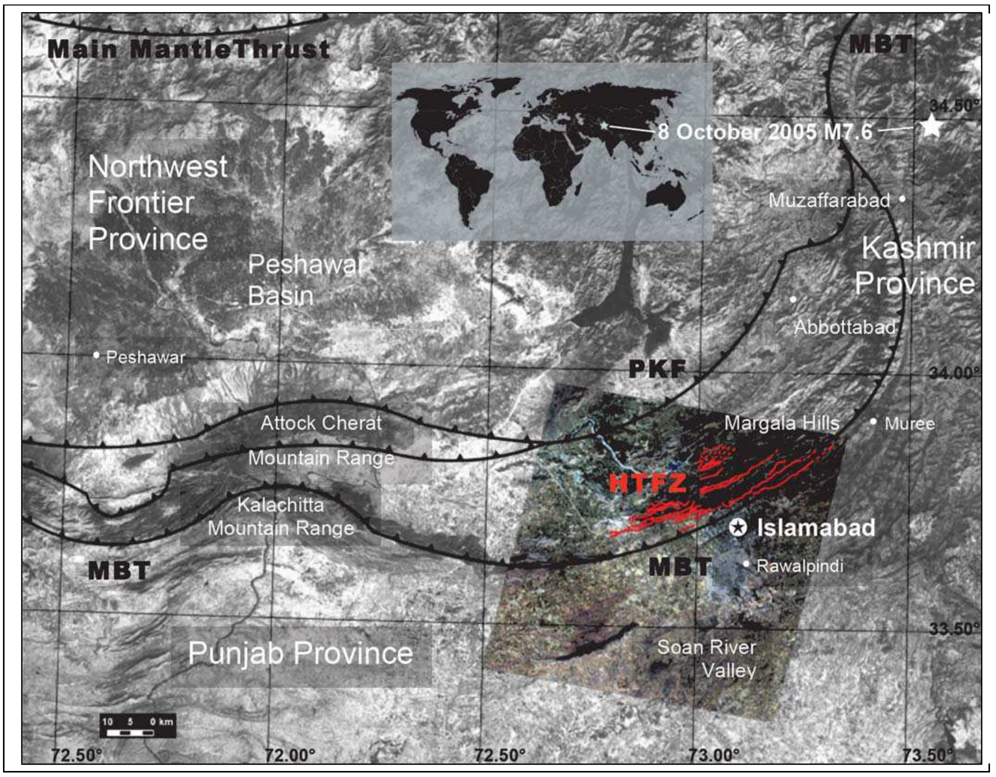

Figure 1.1:- Map of Northern Pakistan showing the main deformational in the region {Hazara thrust fault zone (HTFZ), Main boundary thrust (MBT) and Punjal-Khairabad fault (PKF)} (Yong, 2008)

During 2005 Kashmir earthquake a multi story building collapsed completely resulting in loss of lives and property as shown in figure 1.2. In this study attempt has been mad to see the reason (damage of multistory building) in the context of site response. No studies of local site effects have been conducted earlier. Therefore, any study of local site effects will contribute to reduce the disastrous effects of earthquakes in this region.

Figure 1.2:- View of collapsed Margalla Tower Islamabad, Pakistan (Google earth).

1.2 The city of Muzaffarabad (Capital of Azad Jammu and Kashmir Pakistan)

Muzaffarabad is capital of Azad Jammu and Kashmir and situated at the junction of two rivers (Jhelum and Neelam). Muzaffarabad city comprise a mixture of old and new buildings standing on the banks of Neelum.

The northern area of Pakistan has been a site of numerous devastating earthquakes possessing moderate to high intensity. An earthquake with magnitude M 7.6 occurred in the northeastern part of Himalayan Fold and thrust belt on October 8, 2005 at local time 08: 50 : 38 (USGS). The epicenter of the earthquake was in the Neelum valley, 19 kilometer from the capital of Azad Kashmir (Muzaffarabad) in northeast. Most affected cities are Muzaffarabad, Bagh, Balakot, Mansehra, Batgram, Abbotabad and Islamabad in Pakistan and the adjacent parts of Indian Kashmir (Monalis, 2006; Hussain et al. 2008). This was the largest historic earthquake on Indus –Kohistan Seismic Zone (IKSZ) figure 1.3.This was the prime reason to study the local site effects in this city. As the city was completely demolished during Kashmir earthquake, 2005.

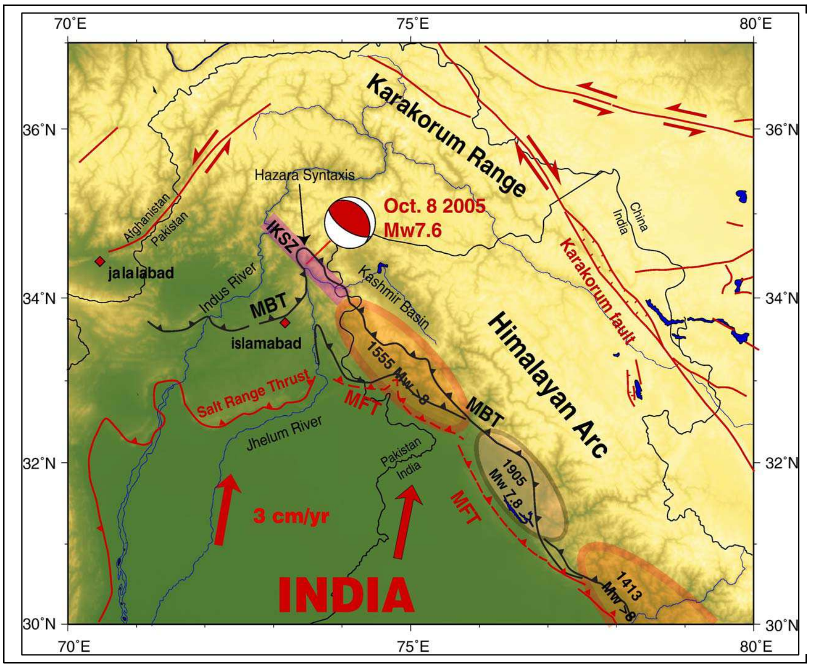

Figure 1.3:- The Muzaffarabad earthquake (October 8, 2005) rupture zone seen in the context of other large earthquakes on the Himalaya Main Boundary Thrust (MBT) (after Avouac *et al.*, 2006)

The main objective of the present study is two folds:

The first part concerns the comparison of reassessment of the seismicity of the area. PMD seismic network data was relocated and compared with international data from PDE. ISC Data compiled from http://www.isc.ac.uk and seismicity map from http://earthquake.usgs.gov/regional/world/pakistan/seismicity.php and used. Common earthquake detected by both (PDE and PMD seismic network) were relocated using SEISAN software (Havskov, 2008) and compared. However, the final results were also evaluated in the context of the general tectonics of Pakistan and surrounding areas. The intension is to obtain better epicenter location, magnitude and compare the efficiency of the local seismic network (PMD) with international agency.

Second part focuses on local site effects in two cities of (Islamabad and Muzaffarabad) Pakistan. One of the objectives of the present study was to find out if a part of the observed damage in the study area was due to local site effects.

The assessment of the local site effects in both cities Islamabad and Muzaffarabad was conducted by using an empirical technique (Nakamura, 1989;, 2000) based on ambient seismic noise measurements. Two data sets were collected for the two cities and analyzed by using the analysis procedure and software developed by the SESAME project (Bard et al., 2004; Atakan et al. 2004;. 2003; Koller et al., 2004)

In this study maps showing spatial distribution of the fundamental site frequency and the amplification factor for the two cities generated. These gave better understanding for the local site conditions in the study area and influence of the connection between them and local geological settings and topography. The major aim is better understanding for the local site conditions in the two cities under investigation.

2 Seismicity and Tectonics

2.1 Geological Settings

Pakistan extends Southwest to Northeast from Latitude 24° N to 37° N and West to East from Longitude 60° E to 75° E (Ahmad, 2006).

Seismicity and local site effects are directly related to geological settings of the area. Therefore, geological settings of Pakistan and its surroundings has been discussed.
As it is well established that the geological settings and topography are two main reasons to give a site effect. Looking into this, it is important to give geological description of the study area (Islamabad and Muzafarabad). In this chapter a short overview of the area in broad spectrum (General geology of Pakistan and surroundings) is given and then focus on the two cities and their surroundings where observations have been taken during the field work for this study.

It is illustrated as much as possible the geological conditions which are observable in the area under investigation and its surroundings. In this way a better understanding about the geology of the cities has been covered, as it has direct relation with the geological evolution of the area. Here, in this study special attention to the sediments which amplify the most seismic waves due its low acoustic impedance has been given for the estimation of local site effects. Also, it is well known that these are the Quaternary sediments.

General geological overview of Pakistan and surrounding areas

The breakup of Gondwana during Mesozoic gave birth to the Indo-Pakistan plate, which began its travel towards the Eurasian plate at about 140 Million years. The drift and rift resulted into folds and crumbles in the sedimentary strata and the resultant structure produced two major basin during Jurassic time, which are named as Indus basin and Balochistan basin, having completely different tectonic and sedimentary environments, (Kazim and Jan 1997, Kearey and Vine, 1996)

The geological framework of the area surrounding Pakistan has two broad geological partitions namely the Gondwana and Tethyan domain. The southeastern portion of Pakistan fits in to Gondwana domain and is uphold by the Indo-Pakistan crustal plate. The northern most and western parts of Pakistan belong to Tethyan domain and present a composite geology and crustal formations. Pakistan may be divided in to large tectonic zones on the basis of plate tectonic settings (geological structures, organic history i.e. age and nature of the deformation, magmatism and metamorphism and lithology) of the area. These major lithotectonic units from north to south are as shown in figure 2.1 (http://www.gsp.gov.pk/paksitan/tectonics_zones.html).

- Karakorum Himalaya Crystalline Thrust Zone
- Himalaya Fold bet
- Monoclinical zones
- Burried Ridges
- Bela Chaman Kuram Fault zones and opholite Belt
- Suleman Fold Belt
- Fore deep
- Zones of Upwrap
- Zones of downwrap and Plateform slope
- Foredeeps
- Chagal Volcanic arc and Cole-Alkaline Magmatic belt
- Makran Flysch basin

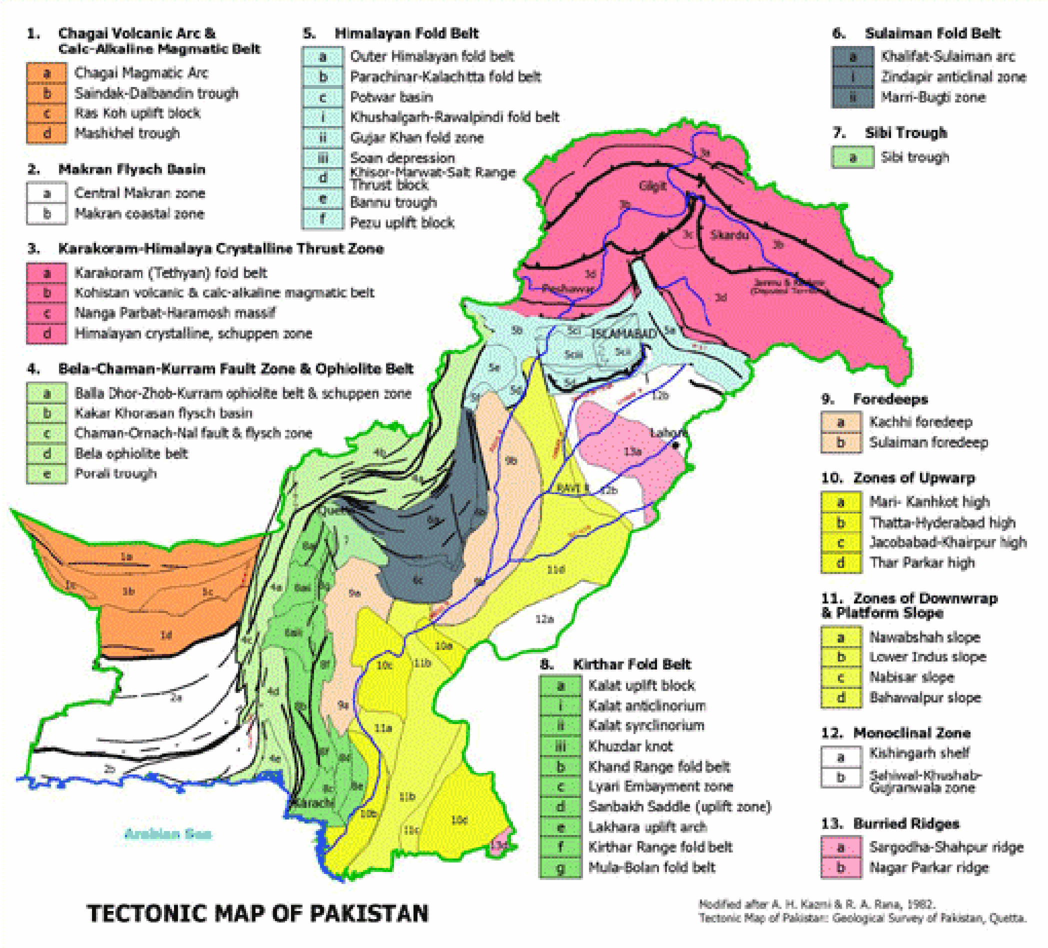

Figure 2.1:- Tectonic zones of Pakistan. (Courtesy of Geological Survey of Pakistan)

The continent-continent collision responsible for the formation of the Himalayan Ranges began in the middle to late Eocene (≈55 Ma), in association with late Cretaceous-Cenozoic spreading along the Carlsberg-southeast Indian Ocean Ridge. The onset of collision and sea floor reconstructions indicate about 2,000 km of subduction has occurred between India and Eurasia. (Kazim and Jan 1997; Kearey, and Vine, (1996); Molnar and Taopponier, 1975; Klootwijk 1992)

The collision zone has been studied intensely east of Kashmir, where sub-divisions of the Himalayas (from north to south- the Tethyan Himalayas, High Himalyas, Lesser Himalayas, Sub-Himalayas, and Gangetic foredeep) are based on structural, stratigraphic, and morphological criteria. In the Central Himalayas, four major structures- Indus-

Tsangpo suture, Main Central Thrust (MCT), Main Boundary Thrust (MBT), and Main Frontal fault-bound these sub-divisions as shown in figure 2.1. However, these structures and sub divisions are not clearly traceable around the Hazara-Kashmir syntaxis (Kazim and Jan 1997 and the reference there in).

In Northern Pakistan the Himalayan trend is divided into four major sub-divisions.
North of the Main Karakoram thrust lie the Karakoram Ranges and Hindu Kush, terrains of the Gondwana affinity sutured to Eurasia in the late Triassic to middle Jurassic. South of the Main Karakoram Thrust (MKT) and north of the Main Mental Thrust (MMT) lies the Kohistan Block, a terrain believed to have formed as an island arc which blocked the Eurasia during the Late Cretaceous to Early Eocene. South of the MMT and north of the MBT are the low ranges of Swat, Hazara and Kashmir, corresponding to the Lesser Himalayas of India. The MMT locked approximately by15 Ma (Pennock, et al., 1989). In the latest phase in Pakistan, thrusting transferred to the Salt Range thrust and sediments overlying the Punjab Plain are deformed (Kazim and Jan 1997 and the reference there in)

2.2 Geology and structure of Potwar Plateau

Islamabad city lies in Potwar platue. Therefore, short description of geology and structure is added. Potwar Plateau has a rugged topography which has a typical chain of parallel crests and valleys, usually trending east-west direction. Geologically, it is a part of the intensely deformed foreland zone of the northwest Himalayan Fold-and-Thrust belt (figure 2.2-2.3) (Moonalisa, 2004).

Due to intense deformation, there is formation of complex structures. Structurally the plateau comprises of

- The Northern folded zone
- The platform zone

The northern part of Potwar Plateau, also referred to as the Northern Potwar Deformed Zone (NPDZ), lies between the MBT and the Soan Syncline. The intensity of deformation is more than the southern Potwar and the Salt Range. The plateau is covered by fluvial sediments. The Siwalik rocks, however, are restricted to the platform zone. The MBT, Salt Range thrust, Kurram and Khairi Murat thrust faults and Jelum and Kalabagh faults are the major faults of the Potwar area. Potwar Plateau is characterized by east west trend.The NPDZ is marked by east west trending and south vergent tight folds which imbricate style of south ward directed thrusts (MonaLiza 2004; Kazim and Jan, 1997).

2.2.1 Tectonics Boundaries Potwar Plateau

Potwar Plateau is bounded on two sides by thrusts and two sides by strike slip faults which are tectonically controlled. Northern and southern boundaries of Potwar Plateau are marked by MBT and Salt range thrust (SRT) respectively, while eastern and western boundaries are marked by left lateral Jhelum Strike Slip Fault (JF) and right laterals Kalabagh Fault (KBF). All tectonic boundaries (figure 2.3). The northern boundary of Potwar Plateau, marked by MBT is characterized by thrusting of older sedimentary strata. The hill ranges of Margalla and Kalachitta have been developed as a result of thrusting on the MBT. Like other areas MBT in Potwar Plateau represents a zone of more or less parallel, east west trending thrusts which tend to merge into each other both sides. Salt range thrust (SRT) is a folded thrust, and is one of the frontal thrust zone of the Himalayas. Western boundary of Potwar Plateau is not very sharp. In its northern part the thrusts of NPDZ are continued west-wards into thr Kohat Plateau while in the southern part the KBF marks the western boundary of Potwar Plateau. Kalabagh fault has been recognized to be a right lateral trench fault. Movement along Kalabagh fault may have resulted from either extensional release of stress in the direction perpendicular to the main stress or due to differential stress across the KBF (Kazim and Jan, 1997).

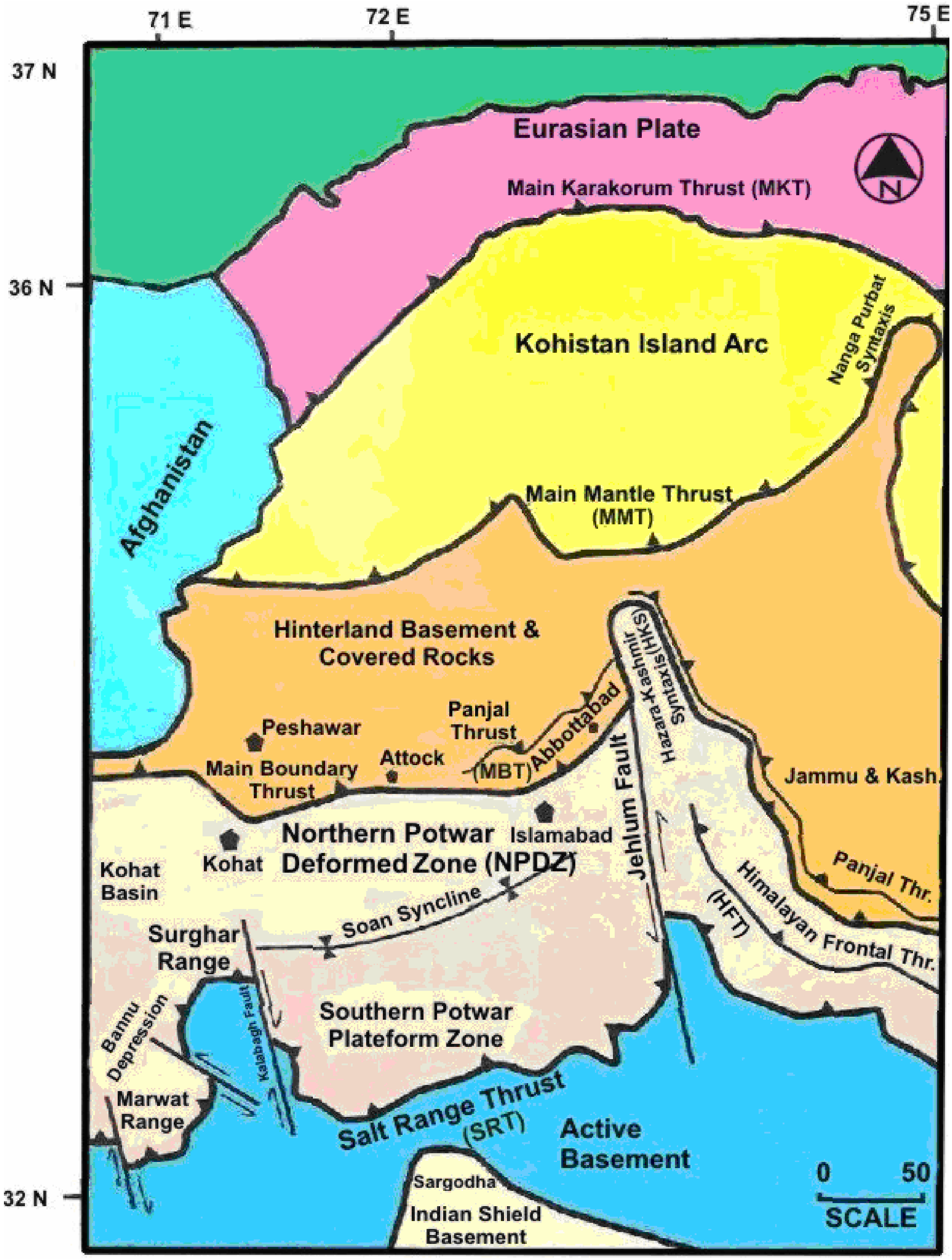

Figure2.2:- Regional Tectonic map of Northwest Himalaya of Pakistan.(MonalIsa, 2004).

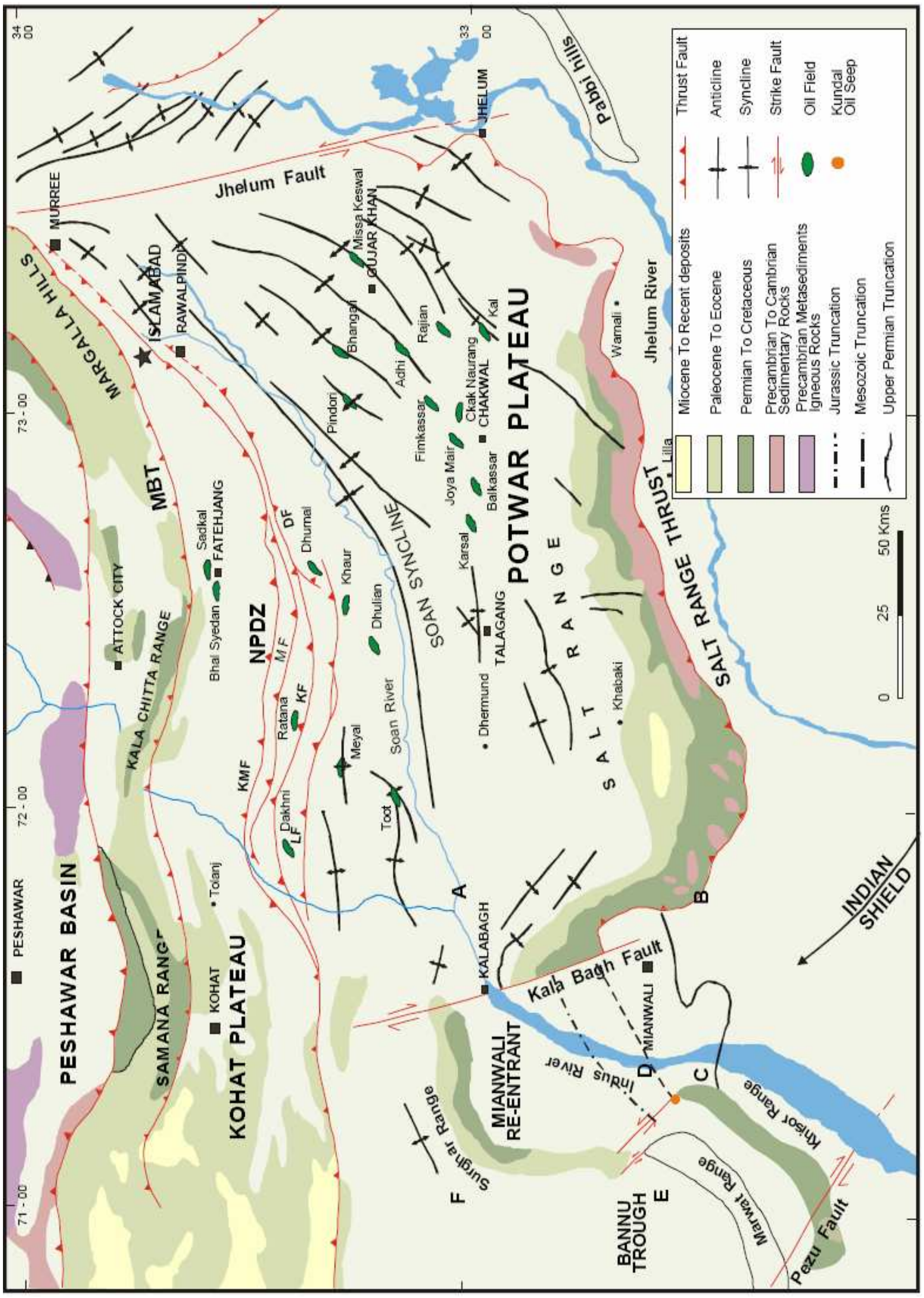

Figure 2.3:-Structural Map of Kohat Potwar Depression (Kazim and Jan 1997).

2.3 Hazara-Kashmir Syntaxis (HKS)

Kashmir earthquake 2005 occurred in HKS, which is recent disastrous earthquake in the study area. Therefore, description of HKS is given in short.

In the northern area of Pakistan between Mirpur and Muzaffarabad and further to the north and northeast, the geological formations and wider geological structures of Himalayas make an unexpected hairpin bends "as if they were bent round a central point obstructing them which was described in detail by Wadia (1931) who gave the name as North-West Himalayan Syntaxis. Many authors have given different names like Punjab Orocline (Carey 1958), Abbotabad Syntaxis (HSC 1960), and Western Himalayan Syntaxis (Gansser 1964,) Hazar Kashmir Syntaxis (Calkins et al: 1975) etc. Several recent authors referred it as the Hazara-Kashmir Syntaxis (Kazim and Jan 1997).

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In the Kashmir region HKS is significant which was formed as a result of change in the Himalayan thrust interface direction from north-east in Kashmir to north-west along the Indus. The MBT and Punjal Thrust are folded around syntaxis and are subject to 90° rotation from one side to the other. The MBT, Punjal thrust and Muzaffarabad thrust are shortened by the active Jhelum fault. (Baig and Lawrence, 1987).

Tectonically HKS is complex zone. Its axial zone is defined by a pile of thrust faults which makes a circle around its axis. The axial zone of the HKS is north northwest oriented which is largely covered by the Murree formation (Oligocene to Miocene). Near Muzaffarabad the sedimentary rocks are exposed in an anticline, which is cross folded, upturned and thrust southward along Muzaffarabad fault. The north of Balakot, the axis of HKS bends northeastward and continues into Kaghan and further into Nagaparbat- Haramosh region, where it is known as Naga Parbat syntaxis (Kazim and Jan 1997 and the reference there in; Coward, 1985).

The HKS region can be divided into three major divisions with respect to the tectonic setting, the sub- Himalaya, the Lesser Himalay and the higher Himalaya. Detail is not needed in this study.

2.4 Recent deposits and their Geotechnical characteristics in Islamabad

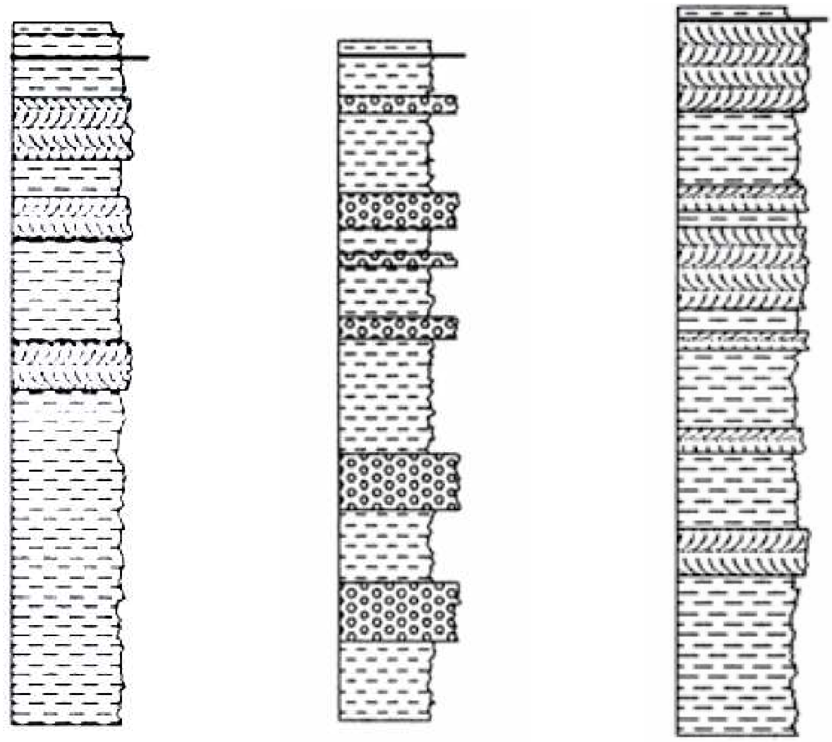
Islamabad Rawalpindi metropolitan area lies between longitude 72.75°E and 73.5°E and latitude 33.5°N and 33.83°N. Quaternary deposits are tectonically deformed. A complicating aspect to estimate potential seismic acceleration in Islamabad area is abnormality of bedrock surface buried underneath the Quaternary silt and gravel. Capital Development Authority test hole in Islamabad went through more than 140 m of unconsolidated gravel and clay without getting bedrock. Commonly Bedrock depth is more than 100m if Rawalpidi and Islamabad area are included. In case of Islamabad area the depth of the bed rock is quite small according to previous study (CDA hydrological test hole 6 bed rock is at 2 m and water table 7 m).Unconsolidated deposits can amplify the earthquake shocks. The unconsolidated eolian silt, such as components of potwar clay, may collapse and liquefy if the ties between the grains are damaged .General terrain in Islamabad and Rwalpindi area is plains and mountainous. There is Nala carries most of the liquid waste from Islamabad and rainy water which is passing through the study area (Environmental study report of Islamabad-Rwalpindi by Iqbal et al.). General cmposite stratigraphy of the Islamabad-Rawalpindi area is given in figure 2.5 and the Physical properties of geological materials in Islamabad-Rawalpindi area are given table 2.2 (Environmental geology of Islamabad and Rawalpindi Area by Iqbal et al).

William et al. (1999) classification of the lithology of Rawalpindi and Islamabad is similar as the lithology is shown in figure 2.4.

The accumulation of silt and gravel takes place at the foot of Margalla hills, which spreads and fills the wide plains of low relief. Due to dry climate of Islamabad, well developed soils are very rare (Yong , 2008).

For soil response study we are more concern about the upper most part of the crust (Quaternary) which can amplify due to incoming earthquake shock.

Capital Development authority (CDA) Islamabad hydrological test holes which are close (CDA 06-31m from observation point ISB065 and 48 m from ISB063, and CDA08- 430 m from ISB 44, 50 and about 500 m from ISB 45) to study area. The lithology of the hydrological test holes (100 m) is given in table 2.1 below and shown in figure 2.4



CDA06 CDA21 CDA08

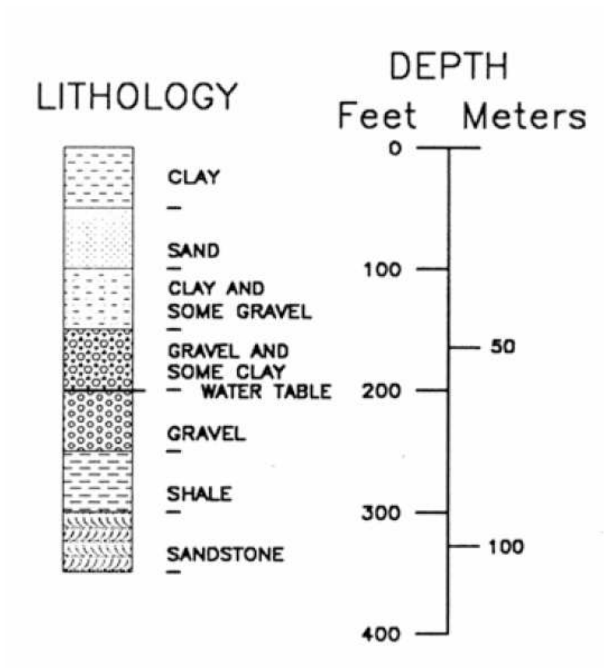


Figure 2.4:- CDA Hydrological Test holes- Lithology of the two holes drilled by the near the observation sites(Sheikh et al.- Environmental geology of Islamabad and Rawalpindi Area).

Cda06 Bed rock at 2m and water table 7m	**CDA08** Bed rock at 2.1m and water table 4m	**CDA21** Bed rock at 133.3m and water table 3m
Shales+Clay	Shales	Shales+Clay
Sand stones	Sand stones	Gravel
Shales+Clay	Shales+Clay	Shales+Clay
Sand stones	Sand stones	Gravel
Shales	Shales	Shales
Sand stones	Sand stones	Gravel
Shales+Clay	Shales	Shales+Clay
	Sand stones	Gravel
	Shales+Clay	Shales+Clay
	Sand stones	Gravel
	Shales+Clay	Shales
	Sand stones	Shales+Clay
	Shales+Clay	Gravel

Table 2.1:- The Lithology of Hydrological test holes near the study area(Sheikh et al.- Environmental geology of Islamabad and Rawalpindi Area).

Generalized Composite stratigraphic section of consolidated rocks in the Islamabad-Rawalpindi area

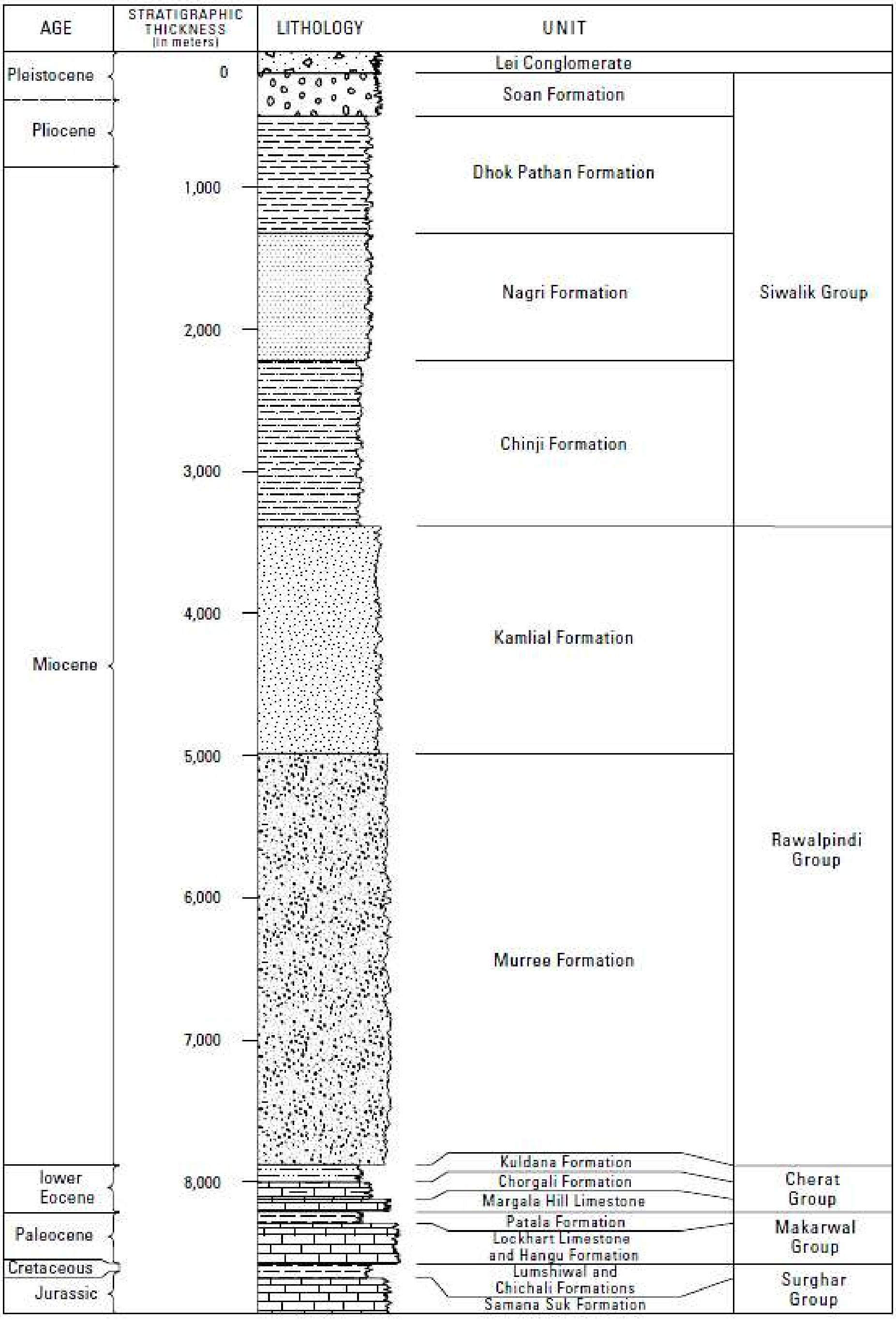


Figure 2.5:- Generalized Composite stratigraphic section of consolidated rocks in the Islamabad-Rawalpindi area (Sheikh et al.- Environmental geology of Islamabad and Rawalpindi Area).

Physical properties of Geological materials in Islamabad-Rawalpindi area

Property	Sand stone	Mud stone	Gravel	Sand	Silt plus clay
Water content (Weight %)					
Average	8.90	7.73	5.70	7.07	15.19
Maximum	15.12	12.8	8.70	13.67	29.20
Minimum	1.40	2.40	4.59	4.65	1.74
No. of samples	6	6	8	25	11
Dry bulk density (g/cm^3)					
Average	1.79	1.97	1.69	1.62	1.64
Maximum	2.52	2.45	2.0	1.69	2.00
Minimum	1.42	1.47	1.56	1.53	1.40
No. of samples	8	6	8	25	8
Porosity (%)					
Average	40.21	39.86	37.85	38.32	41.82
Maximum	42.19	42.63	39.39	40.44	43.22
Minimum	38.13	38.11	37.43	36.41	39.92
No. of samples	5	3	7	25	3
Permeability (darcies)					
Average	1.62	1.51	8.64	1174	0.20
Maximum	5.36	2.37	20.51	30.61	0.44
Minimum	0.14	0.69	0.32	0.38	0.04
No. of samples	5	3	8	25	3
Silt+Clay contents (%)					
Average	--	--	4.78	9.20	80.50
Maximum	--	--	18.00	35.20	99.00
Minimum	--	--	0.00	1.40	40.50
No. of samples	--	--	13	37	14
Liquid limit (% water)					
Average	--	--	20.00	31.00	33.70
Maximum	--	--	21.00	35.00	40.00
Minimum	--	--	19.00	25.00	23.00
No. of samples	--	--	2	4	10
Average	--				
Plastic limit (% water)					
Average	--	--	14.50	20.75	21.00
Maximum	--	--	15.00	24.00	26.00
Minimum	--	--	14.00	17.00	16.00
No. of samples	--	--	2	4	10
Plastic index					
Average	--	--	5.50	10.25	12.70
Maximum	--	--	6.00	13.00	20.00
Minimum	--	--	5.00	6.00	7.00
No. of samples	--	--	2	4	10

Property	Sand stone	Mud stone	Gravel	Sand	Silt plus clay
Consolidation: Void ratio (%)					
Average	--	--	--	--	0.603
Maximum	--	--	--	--	0.650
Minimum	--	--	--	--	0.570
No. of samples	--	--	--	--	3
Compression index					
Average	--	--	--	--	0.15
Maximum	--	--	--	--	0.20
Minimum	--	--	--	--	0.10
No. of samples	--	--	--	--	3
Direct shear: Cohesion (kg/cm2)					
Average	--	--	--	--	0.29
Maximum	--	--	--	--	0.30
Minimum	--	--	--	--	0.28
No. of samples	--	--	--	--	2
Angle of friction (deg)					
Average	--	--	--	--	11.50
Maximum	--	--	--	--	18.00
Minimum	--	--	--	--	5.00
No. of samples	--	--	--	--	2
Unconfined compression: Unconfined compressive strength (kg/cm2)					
Average	109.50	31.96	6.20	--	2.41
Maximum	315.00	90.27	6.20	--	8.40
Minimum	6.00	1.09	6.20	--	0.60
No. of samples	3	3	1	--	5
Strain at failure (%)					
Average	0.95	--	1.20	--	5.12
Maximum	1.00	--	1.20	--	9.10
Minimum	0.90	--	1.20	--	1.40
No. of samples	2	--	1	--	5
Point load (kg/cm2)					
Average	57.50	41.50	--	--	
Maximum	57.50	63.00	--	--	
Minimum	57.50	14.00	--	--	
No. of samples	1	3	--	--	
Organic matter content (%)					
Average	--	--	--	0.04	0.59
Maximum	--	--	--	0.05	1.83
Minimum	--	--	--	0.01	0.16
No. of samples	--	--	--	5	6
Sulfate (%)					
Average	--	--	--	0.001	0.039
Maximum	--	--	--	0.001	0.114
Minimum	--	--	--	0.001	0.001
No. of samples	--	--	--	5	6

Property	Sand stone	Mud stone	Gravel	Sand	Silt plus clay
Sodium chloride (%)					
Average	--	--	--	0.002	0.047
Maximum	--	--	--	0.005	0.137
Minimum	--	--	--	0.001	0.002
No. of samples	--	--	--	5	3
Total dissolved solids (%)					
Average	--	--	--	0.091	0.446
Maximum	--	--	--	0.21	0.748
Minimum	--	--	--	0.65	0.175
No. of samples	--	--	--	5	4
pH					
Average	6.5	--	7.6	--	7.0
Maximum	6.5	--	7.6	--	7.0
Minimum	6.5	--	7.5	--	7.0
No. of samples	1	--	2	--	2
California bearing ratio unsaturated					
Average	--	--	--	38.23	--
Maximum	--	--	--	57.40	--
Minimum	--	--	--	15.20	--
No. of samples	--	--	--	6	--
California bearing ratio saturated					
Average	--	--	--	18.92	--
Maximum	--	--	--	38.10	--
Minimum	--	--	--	6.60	--
No. of samples	--	--	--	6	--
Optimum moisture content (%)					
Average	--	--	--	10.28	15.87
Maximum	--	--	--	10.81	16.60
Minimum	--	--	--	8.71	15.00
No. of samples	--	--	--	4	3
Maximum dry density (gm/cm3)					
Average	--	--	--	2.33	1.82
Maximum	--	--	--	3.08	1.86
Minimum	--	--	--	2.08	1.78
No. of samples	--	--	--	4	3

Table 2.2:- Physical properties of Geological materials in Islamabad-Rawalpindi area (Sheikh et al.- Environmental geology of Islamabad and Rawalpindi Area).

2.5 Recent deposits and geotechnical characteristics of Muzaffarabad

The objective of text is to evaluate the important physico-mechanical characteristics of Muzaffarabad Azad Kashmir area. Keeping in mind three factors which are necessary for the soils for geotechnical or construction purpose.

- The engineering properties of the material
- The stratification of the soil
- Prediction of the performance of the structure

Khan, et al. (1989) studied the small holes, honeycomb structures and fabric of the soils along the road from Muzaffarabad to Kohala and on the top of the soil bed in land slide areas. The joints, cracks and other discontinues are filled with silty and sandy clay. Thicknesses of the beds of the soils are 200 to 400 m and composed of silt, clays, pebbles and cobbles compacted in a clayey matrix. In the middle of the bed lenses of the sands, silts and silty clay are marked. A generalized stratigraphic sequence of Muzaffarabd-Kohala area is given in table 2.3. For site response the emphasis is on the upper most part of the crust (recent and sub recent deposits as mentioned in table 2.3). According to soil study of the area the recent deposits are river deposits, gravel, sands, silt and clayey material and sub recent deposits are lacustrine deposits, light brown, soft calcareous clays, Quaternary with thin silty intercalations (figure 2.6, 2.7).

Difference of height between figure 2.8 upper and lower is about 14 m.

Figure 2.6: - Showing the structure of the upper layer (Height is about 13 m)

Figure2.7: - land slide picture (Height is about 5m)

Figure 2.8: -The height difference between the two (upper and lower) figures is about 14m.

A general Stratigraphic sequence of Muzaffarabad-Kohala area

Formation	Lithology	Age
Surficial Deposits	River deposits, gravel, sands, silt and clayey material Lacustrine deposits, light brown, soft calcareous clays, Quaternary with thin silty intercalations **Disconformity**	Recent Sub-recent
Murree Formation	Purple red greenish Grey stone, Siltstone, mudstone, and subordinate intraformational conglomerates **Disconformity**	Miocene
Margalla Hill Lime stone	Fine to coarse, dark grey, thin to thick bedded, massive, hard and compact limestone with subordinate shales. **Disconformity (Bauxite/Laterite)**	Eocene
Abbottabad Formation Hazara Formation	Fine grained dolomite and cherty dolomite Fine grained, dark gray, thin to thick bedded, highly fractures and sheared slates	Cambrian Precambrian

Table 2.3:- A general Stratigraphic sequence of Muzaffarabad-Kohala area (Khan et al., 1989).

The structure of the Muzaffarabad-Kohala area can be divided in to three groups. Wadia (1931). We are only concern with structure in Muzaffarabad without going in detail of complete study area (Khan, et al., 1989).The major structure in Muzaffarabad is asymmetrical anticline in the east of Muzaffarabad proper. The anticline trend is approximately northwest-southeast. The asymmetrical anticline is thrusted over the older slate series to the west and southwest.

It has been observed by comparing laboratory and filed studies that the cohesion in the soils of Muzaffarabad proper, Chattar, Jalalabad, upper plate Dulai and Bagna is less than Rara and Kohala landslide. The results obtained are listed in table 2.4-2.6.

Stress and strain relationship of soils of Muzaffarabad-Kohala area

Field description	Total Stress PSI	Strain at Failure	Angle of Friction
Disturbed	M-1. 35.2	14.5	16°
Samples	M-2. 60.5	14.0	
Samples	M-3. 86.9	14.5	

Table 2.4:- Stress and strain relationship of soils of Muzaffarabad-Kohala area (Khan et al. 1989).

Hardness of the soil

		PSI	PSI
Hard samples	M-1	35	100
	M-2	20	80
	M-3	30	95
Wet samples			
	K-1	10	35
	K-2	05	20
	K-3	02	04

Where M stands for Muzaffarabad and K- for Kohala

Table 2.5:- Hardness of the soil (Khan et al. 1989).

Bearing Capacity of soils of Muzaffarabad-Kohala

S.No	Number of blows	In situ condition	Allowable bearing capacity tons/SFT
M-1	2	Very loose	0.30
M2	4	Soft	0.30-0.60
M-3	8	Medium	0.60-1.20
		Stiff	1.20-2.40
K-1	15	Very stiff	2.40-2.80
K-2	30	hard	7.40-8.00
K-3	730		

Table 2.6:-Bearing Capacity of soils of Muzaffarabad-Kohala (Khan et al. 1989).

2.6 Seismicity and Tectonics of Pakistan

Pakistan and its neighboring countries has experienced high rate of recurrence of earthquakes which in some cases resulted in great loss of life and destruction like, Quetta 1935 M7.4, Pattan 1974 M6.0 and Kashmir earthquake 2005, M7.6.

The earthquake activity in Pakistan and surroundings areas is due to collision of Indian plate with Eurasian plate. Figures 2.9 and 2.10 shows the earthquake activity over last 16 and 41years respectively and reveal how the major deformational regions are confined to the mountain areas. Major fault zones have been identified by the Pakistan Geological survey of Pakistan shown in figure 2.11. Figure 2.9 mainly shows the shallow earthquake activity, while Hindukush, Pamir and Karakoram are illustrated by the deep and concentrated earthquake activity. Hindukush and Pamir is one of the most seismic active areas in the world. The Himalaya and Sulaiman arc are the front and backward parts of the major collision zone. It is also clear from figure 2.11 that how the Chaman fault meets with Heart fault and in Pamir region, where these structures curves eastward and break into Karakoram and Altayan tagh fault systems (Tectonic map of Pakistan-Geological survey of Pakisan).

The northwest Himalayan fold and thrust is one of the most seismically active intercontinental regions in the world. This complex tectonic situation has been producing several destructive earthquakes in the area (India, Pakistan, Iran, Afghanistan and Tibet). (Monalisa et. al. 2005) as it can be seen in figure 2.9-2.10 too.

The whole area of Pamir and its surroundings is an active seismic zone. It is due to the northward penetration of Indian plate into Asia which causes the shortening and thickening of the crust as a result of this process the seismicity is produced in the region Lithospheric slabs are being underthrust beneath the Pamir and Hindukush which is believed reason for these earthquake occurrences. The depth of intermediate earthquake zone reaches to 300 km in Hindukush region (figure 2.9). High seismic wave velocity has been observed in the region of intermediate depth of the seismic region. Low P and S wave velocity in the upper 200 km of the mantle close to Hindu Kush suggesting that not only the mantle but also the continental crust has been subducted until 150 km (http://www.gsp.gov.pk/HindukushRegion.htm).

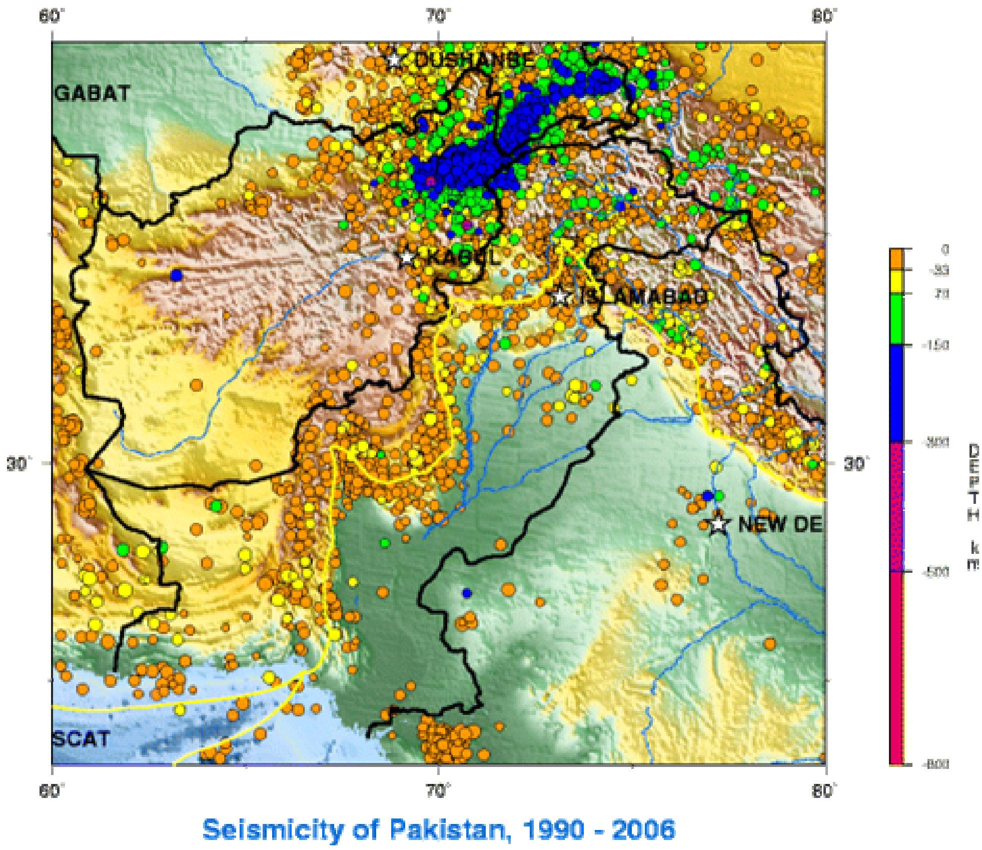


Figure 2.9: - Seismicity map of Pakistan
(http://earthquake.usgs.gov/regional/world/pakistan/seismicity.php)

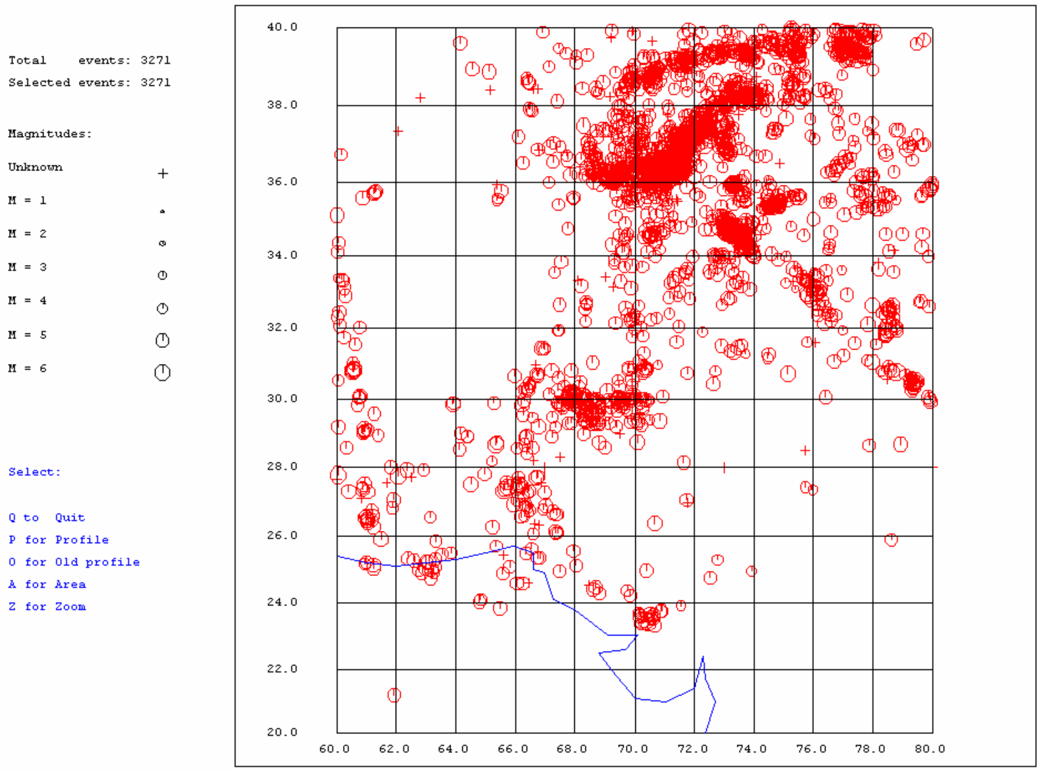


Figure 2.10: - Seismicity map of Pakistan and surrounding areas (blue line is coastal line of Pakistan) with ISC data (1965-2006)

Coastal region of Pakistan consists of plains of southern Sindh province and Makran coast in the west. The coast line of Pakistan along Arabian sea is about 1050 km,

The coastal area of Pakistan contains Karachi which is the largest industrial city and backbone of the economic activities of the country. There are also other major installations along the coastal line like fish harbors at Pasni and Ormara, Gwadar deep sea port and Naval complex at Jiwani. The seismicity of the Makran area is comparatively low with its neighboring regions, which have been devastated frequently by large quakes (Jackob and Quittmeyer, 1979). It has the history of great earthquake in 1945. The great earthquake occurred on November 28, 1945 and generated destructive tsunami in the northern Arabian Sea along the Makran coast of Pakistan (Khan et al., 2003), (http://www.drgeorgepc.com/Tsunami1945Pakistan.html).

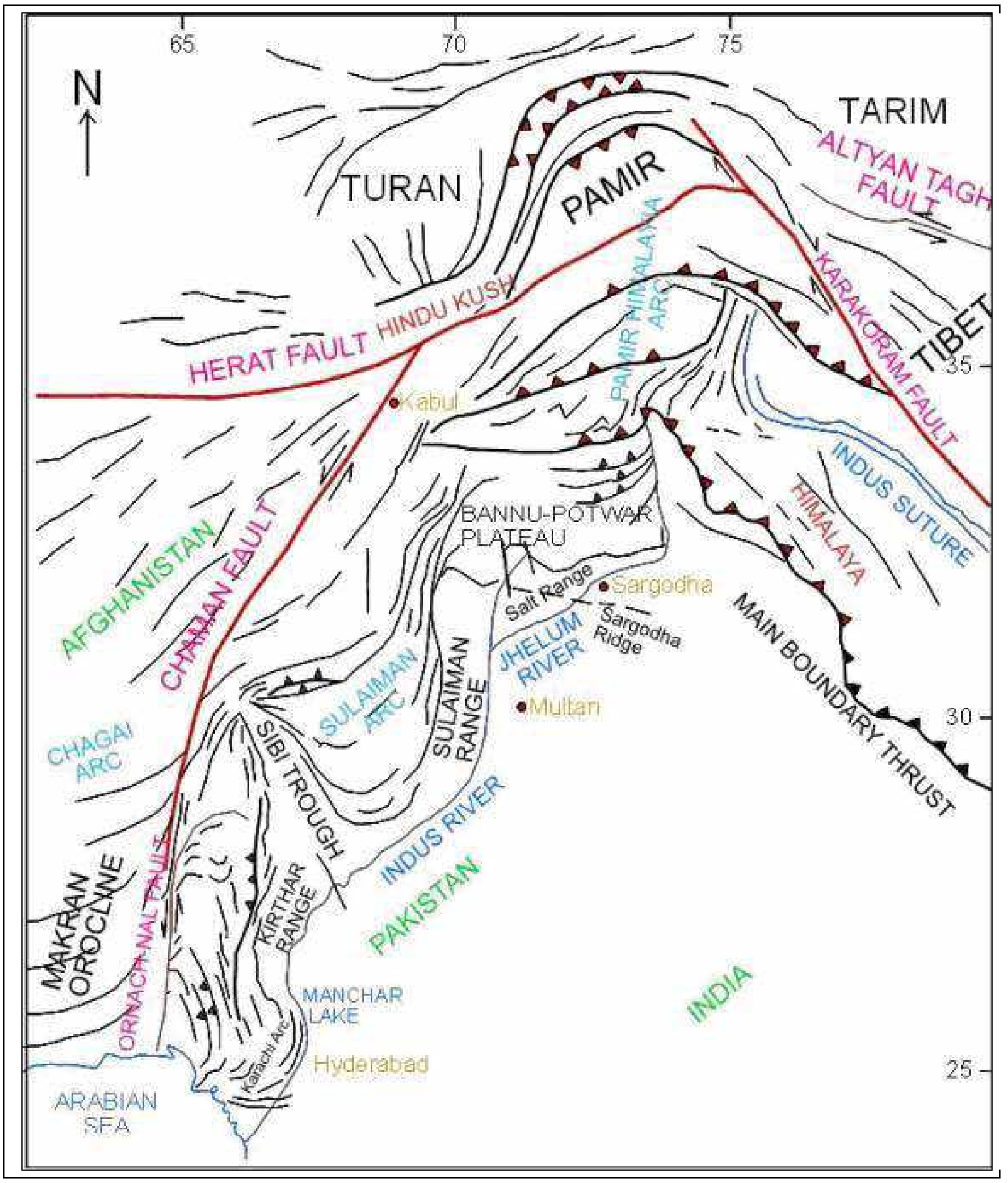


Figure 2.11:-Major tectonics of Pakistan and surrounding areas (Geological survey of Pakistan).

There is transform fault zone (Oven Fault zone) in Arabian Sea related with tectonic boundary. It expands from Gulf of Aden in a northeast direction in the direction of Makran coast where it goes into in Balochistan province area. After this continues as a land fault system known as famous Chaman fault system. It starts from Kalat, passes near Quetta city and continue to Afghanistan. It has the history of great earthquake (Quetta earthquake 1935). Chaman fault has been a site of infrequent moderate to large earthquakes. Focal mechanism of 1975 earthquake shows left lateral strike slip fault motion which in agreement with the geological filed evidence (Quittmeyer et al., 1979, Lawrence and Yeats 1979).

In addition other main thrust zones exit along Sulaiman, Salt range and Kirthar ranges of Pakistan. Karakoram Range is in the northeast of Pakistan close to Azad Kashmir which is site for many devastating earthquakes like Pattan Earthquake (1974) and Kangra earthquake (1905).

Sulaiman seismic zone is characterized by the shallow seismic activity of moderate to high magnitude (5-7). In this zone there is high seismicity belt. In this high seismicity belt several faults exist trending northeast, east west and northwest. The earthquake activity in this region may be due to movement of single fault or may be due to seismic activity similarly oriented on many faults. Another high seismicity belt also exits in this region. These high seismicity bands agree with left lateral active faults and lineament.

Fault pane solutions on few earthquakes from this region show the strike slip faulting (Kazim and Jan 1979 and the reference there in). In rest of Pakistan the seismicity is relativity low.

2.7 Historical Earthquakes

Pakistan has the history of devastating earthquakes. Seismicity of the region is openly related to the geo-tectonic processes. The historical earthquake catalogue (table 2.7) has been compiled by the PMD. The historical database comprises of fifty eight (58) earthquakes from 25 AD to 1905. A few events have been added from Quittmeyer and Jacob, 1979. Database table provides the short description and estimates of maximum intensity and the epicenter location map of historical catalogue is shown in figure 2.12 and 2.13 (PMD Hazard Report, 2007).

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Date	Lat (N)	Lon (E)	Intensity	Remarks
25 A.D	33.7	72.9	X	TAXILA EARTTHQUAKE The main centre of Budhist Civilization at that time was turned into ruins. Epicentre of the earthquake was around 33.7 N, and

Date	Lat (N)	Lon (E)	Intensity	Remarks
				72.9E. Maximum documented Intensity was X.
50 A.D	37.1	69.5	VIII_IX	AIKHANUM EARHQUAKE Epicentre of the earthquake was around 37.1 N, and 69.5E. Maximum documented Intensity was VIII-IX . Caused extensive damage in Afghanistan, Tajikistan and N.W.F.P and was felt upto N.India.
893-894AD	24.8	67.8	VIII_X	DABUL EARTHQUAKE Epicentre of the earthquake was around 24.8 N, and 67.8E. Maximum documented Intensity was VIII-X. An Indian ancient city on the coast of Indian ocean was completely turned into ruins. 1, 80,000 people perished.
1052-1053	32.85	69.13	VII-IX	URGUN; Quittmeyer and Jacob, 1979
June 1504	34.5	69.0	VI-VII	Quittmeyer and Jacob, 1979
6/7/1505	34.6	68.92	IX-X	Paghman; Quittmeyer and Jacob, 1979
6/7/1505	34.6	68.9	VIII_IX	HINDUKUSHEARTHQUAKE Epicentre of the earthquake was around 34.6 N, and 68.9E. Maximum documented Intensity was VIII-IX. It was an immense Earthquake causing famine and extensive damage & loss of life in Afghanistan.
3/1/1519	34.8	71.8	VI-VII	JANDOLVALLEYEARTHQUAKE Jandol valley was severely rocked. Epicentre of the earthquake was around 34.3 N, and 71.8E. Maximum documented Intensity wasVI-VII.
May 1668	24.8	67.6	VIII-IX	SAMAJI OR SAMAWANI Town of Samaji or Samawani sank into ground. 80,000 houses destroyed. Epicentre of the earthquake was around 24.8 N, and 67.6E. Maximum documented Intensity was VIII-IX.

Date	Lat (N)	Lon (E)	Intensity	Remarks
4/6/1669	33.4	73.2	VI-XI	MANDRA EARTHQUAKE Epicentre of the earthquake was around 33.4 N, and 73.3E. Maximum documented Intensity was VII .
22/6/1669	34	76	VI-VII	Kashmir eq. Quittmeyer and Jacob, 1979
23/6/1669	33.87	72.25	VIII-IX	Attock Earthquake; Quittmeyer and Jacob, 1979
1780	34	76	V-VII	Kashmir; Quittmeyer and Jacob, 1979
16/6/1819	23.3	68.9	IX-X	RUNN OF CUTCH It reduced to ruins.2000 people died. Epicentre of the earthquake was around 23.3 N, and 68.9E. Maximum documented Intensity was IX-X.
24/9/1827	31.6	74.4	VIII-IX	LAHORE EARTHQUAKE In this earthquake the fort kolitaran near Lahore was destroyed.About 1000 people perished.A hill shaken down into river Ravi.
6/6/1828	34.1	74.8	X	KASHMIR EARTHQUAKE In this earthquake 1000 people died and 1200 houses destroyed.
1831	31.75	70.35	VIII-IX	Daraban; Quittmeyer and Jacob, 1979
1831	33.5	72.0	IV-VII	HINDUKUSH EARTHQUAKE It was severe earthquake felt from Peshwar to D.G Khan Maximium documented Intensity was VII at Peshwar VI at Srinagar and IV at D.G Khan.
22/01/1832	36.9	70.8	VIII-IX	HINDUKUSH EARTHQUAKE It was severe earthquake Which rocked Afghanistan, Northern and central parts of Pakistan and NW India.Maximium documented Intensity was VIII-IX at Kalifjan,Jurm,Kokcha Valley,and VI at Lahore.
21/2/1832	37.3	70.5	VIII-IX	HINDUKUSH EARTHQUAKE The epicenter of this earthquake was in Badakhshan Province.Earthquake

Date	Lat (N)	Lon (E)	Intensity	Remarks
				felt at Lahore and NW India.
26.1 1840	34.53	69.17	VI-VIII	Kabul; Quittmeyer and Jacob, 1979
19/2/1842	34.3	70.5	VIII-IX	HINDUKUSH EARTHQUAKE Epicentre of the earthquake was near Kabul .Maximium documented Intensity was VIII-IX Alingar valley, Jalalabad and Tijri and VI-VII at Teezeen and VII-VIII at Budheeabad.The earthquake was felt from Kabul to Delhi Over an area of 2,16,000 sq.miles.Jalalabad and Peshawar damaged,.
19/6/1845	23.8	68.8	VII-VIII	RUNN OF CUTCH Documented epicentre of this earthquake was lie between 23.8 N, 68.8 E, and Maximium intensity was VII-VIII.Lakhpat was badlt effected.
17/1/1851	32.0	74.0	VI-VIII	PUJAB PLAIN EARTHQUAKE Maximium Documented intensity was VIII ,and VI-VII at Wazirabad ,Ferozpur and Multan,VI at fort Munro. Quittmeyer and Jacob, 1979
19/4/1851	25.1	62.3	VII	GAWADAR EARTHQUAKE Epicentre of the earthquake was around 25.1 N, and 62.3E. Maximum documented Intensity was VII at Gwadar.Another earthquake of same intensity occurred on 25th July,1864 at Gawadar.
24/1/1852	34.0	73.5	VIII	MURREE HILLS EARTHQUAKE Epicentre was in Murree hills and Kajnan about 350 people died.Maximium Documented Intensity was VIII.
1862	29.88	69.22	VIII	Kohu Valley; Quittmeyer and Jacob, 1979
10/7/1863	34.08	74.82	VI-VII	Srinagar, Also felt in Lahore; Quittmeyer and Jacob, 1979
25/7/1864	25.12	62.33	VI-VIII	Gwader; Quittmeyer and Jacob, 1979
22/1/1865	34.00	71.55	V-VII	Peshawar, Quittmeyer and Jacob, 1979
	29.2	68.2	VII	LAHRI EARTHQUAKEThe

Date	Lat (N)	Lon (E)	Intensity	Remarks
1867				epicentre of earthquake was around 29.2 N,68.2 E, Maximium Documented Intensity was VII at Lahri.
10/11/1868	32.5	71.3	VIII	BANNU EARTHQUAKE The epicentre of earthquake was around 32.5N,71.3 E. Maximium Documented Intensity was VIII at Bannu.
11/8/1868	34.0	71.6	VII-VIII	PESHAWAR EARTHQUAKE The epicentre of earthquake was around 34. 0N,71.6E,near Peshwar. Maximium Documented Intensity was VII-VIII.Another earthquake same Intensity Occurred same place in April 1869.
24/3/1869	32.92	73.72	V-VII	Jehlum, Quittmeyer and Jacob, 1979
April 1869	34.0	71.55	VII-VIII	Peshawar, Quittmeyer and Jacob, 1979
20/12/1869	33.6	73.1	VII-VIII	RAWALPINDI EARTHQUKE The epicentre of earthquake was around 33.6N,73.1E. Maximium Documented Intensity was VII-VIII at Rawalpindi,V-VI at Lawrancepur and Attock. It caused cracks in walls in many houses at Rawalpindi.
April 1871	34.0	76.0	VII-VIII	KASHMIR EARTHQUAKE The epicentre of earthquake was around 34.0N,76.0E,in Kashmir. Maximium Documented Intensity was VII-VIII. It was also felt with Intensity VI at Rawalpindi and Murree.
20/5/1871	36.9	74.3	VII-VIII	GILGIT EARTHQUAKE The epicentre of earthquake was around 36.9N,74.3E,in former Gilgit agency. Maximium Documented Intensity was VII-VIII. Quittmeyer and Jacob, 1979 claim that this event occurred 22 May.with coord. 35.92 and 74.32
15/12/1872	29.2	68.2	IX-X	Lehri, Quittmeyer and Jacob, 1979

Date	Lat (N)	Lon (E)	Intensity	Remarks
18/10/1874	34.5	69.2	IX	KABUL EARTHQUAKE The epicentre of earthquake was around 34.5N,69.2E .Maximium Documented Intensity was IX at Kabul,Jabal-al-saraj and Gulbahar and VIII in Kohistan area of N.W.F.P.
12/12/1875	34.0	71.55	VII-VIII	LAHORE-PESHAWAR EARTHQUAKE The epicentre of earthquake was around 31.6N,74.4E .Maximium Documented Intensity was VII-VIII at Peshawar and Lahore. Note: coordinates from Quittmeyer and Jacob, 1979
2/5/1878	33.58	71.4	VII-VIII	KOHAT-PESHAWAR EARTHQUAKE The epicentre of earthquake was between Kohat and Peshawar. .Maximium Documented Intensity was VII-VIII at Kohat and Peshawar,VI-VII at Attock ,Abbotabad,Rawalpindi and Jhelum,V-VI at Bannu,Nowshera,Mardan,Lahore and Simla. Note coordinates are from Quittmeyer and Jacob, 1979 who also claim that the event occurred 2 March 1878
1883	28.08	66.08	VI	Khalat; Quittmeyer and Jacob, 1979
April 1883	34.0	71.55	VI-VII	Peshawar, Quittmeyer and Jacob, 1979
15/1/1885	34.08	74.82	VI-VII	Srinagar; Quittmeyer and Jacob, 1979
30/5/1885	34.1	74.8	IX-X	KASHMIR EARTHQUAKE The epicentre of earthquake was around 34.1N,74.8E .Maximium Documented Intensity was IX–X in the epicentral area.VIII-IX at Sopur.Gulmarg,Gingal and Srinagar.VI-VII at Punch,Muzzafarabad area.Extensive damage was about 47 sq.miles

Date	Lat (N)	Lon (E)	Intensity	Remarks
				between Srinagar,Baramula and Gulmarg.Total felt area was 1,00,000 sq.miles.About 3000 people parished and some villages were completely destroyed.
6/6/1885	34.2	75.0	IX-X	KASHMIR EARTHQUAKE The epicentre of earthquake was around 34.2N,75.0E .Maximium Documented Intensity was IX-X.
28/12/1888	30.2	67.0	VIII-IX	QUETTA EARTHQUAKE The epicentre of earthquake was around 30.2N,67.0E, at Quetta.Maximium Documented Intensity was VIII-IX.
1889	27.7	67.2	VIII	JHALAWAN EARTHQUAKE The epicentre of earthquake was around 27.7N,67.2E at Jhalawan .Maximium Documented Intensity was VIII.
1890	30.4	68.6	VII	LORALAI EARHQUAKE The epicentre of earthquake was around 30.4N, 68.6E .Maximium Documented Intensity was VII at Loralai.
20/12/1892	30.9	66.4	VIII-IX	CHAMAN EARTHQUAKE The epicentre of earthquake was around 30.9N, 66.4E near Chaman.Maximium Documented Intensity was VIII- IX at Chaman and VII at Sanzal. In this earthquake great damage to buildings,bridges,railoads and other structure etc.The earthquake was caused by the movement of Chaman fault on the west bank of Khojak range passing through the north west railway between Shelabagh and Sanzal.At Shelabagh the railway station building was severly damaged.
13/2/1893	30.2	67.0	VIII-IX	QUETTA EARTHQUAKE The epicentre of earthquake was around 30.2N,67.0E .Maximium Documented Intensity was VIII- IX

Date	Lat (N)	Lon (E)	Intensity	Remarks
				at Quetta.
25/11/1893	34.0	71.55	VI-VII	PESHAWAR-NOWSHERA EARTHQUAKE The epicentre of earthquake was between Peshwar and Nowshera .Maximium Documented Intensity was VI-VII at both places. Coordinates from Quittmeyer and Jacob, 1979
1900	30.4	67.0	VIII	QUETTA-PASHIN EARTHQUAKE The epicentre of earthquake was around 30.4N, 67.0E .Maximium Documented Intensity was VIII.
20/1/1902	35.9	71.8	VII-VIII	CHITRAL EARTHQUAKE The epicentre of earthquake was around 35.9N, 71.8E near Chitral.Maximium Documented Intensity was VII-VIII.
1902	30.6	66.8	VII	GULISTAN-PASHIN EARTHQUAKE The epicentre of earthquake was around 30.4N, 67.0E .Maximium Documented Intensity was VIII VII.
23/12/1903	29.5	67.6	VII	DADHAR EARTHQUAKE The epicentre of earthquake was around 29.5N, 67.6E .Maximium Documented Intensity was VII.
4/4/1905	32.13	76.28	X	Kangra. Quittmeyer and Jacob, 1979

Table 2.7:- Historical earthquake collected by Pakistan Meteorological Department (PMD Hazard Report 2007)

The 1905 Kangra earthquake (M 8.0)

The Kangara earthquake with magnitude 8 was the first devastating earthquake in the 20th century to occur in northern India. The death toll was more than 20000 and about 100000 buildings were destroyed. The north-western Himalaya has the history of great earthquakes. The kangara earthquake is the first devastating event in the history of instrumental seismology (PMD Hazard Report 2007).

The size of the Kangara earthquake influenced the estimates of the largest probable earthquake that might happen in the western Himalaya. Moderate earthquakes take place each few decades along the small loop that describes the southern border of the Tibetan Plateau. But there is no evidence of historical earthquakes that have been ruptured the surface by the side of the Main Frontal Thrusts bordering Himalaya foothills (Bilham, 2001; Kumar et al., 2001; Kumar and Mahajan, 2001)

The 1935 Quetta earthquake

In May 30, 1935 an earthquake of magnitude 7.7 occurred in Quetta (capital of Balochistan province). Balochistan had the lowest population densities on the subcontinent of India in 1935. This earthquake occurred in the area where the majority of the inhabitants lived. This was a very shallow earthquake reported (10 km depth by Ramanthan and Mukerherji,1938). The earthquake resulted in the largest number of fatalities of any earthquake on the Indian subcontinent.

Singh and Gupta (1980) estimated the surface wave magnitude of Quetta earthquake from 25 station magnitudes is 7.7. These ruptures are associated with Ghazaband fault zone (large north-south left lateral strike slip system) that has room for plate boundary shear by Lawrence et al. (1992); Yeats et al.(1997). Microseismicity was focused close to the ends of the 1935 earthquake rupture examined by the temporary seismic network operated in 1978 (Armbruster et al., 1980). Left-lateral faulting trend has been confirmed by the fault plain solutions in the area. This seems to be most probable mechanism for 1935 earthquake.

Generally the damages houses were made of mud brick. Death toll in Quetta was about 30,000. The total death toll including outside Quetta is about 35,000, but trustworthy figure is lacking (Old chart at Geophysical centre Quetta, Pakistan)

The 1945 Makran earthquake

The earthquake occurred off the Makran coast on 28th November 1945(at 21: 56 UTC), with an epicentre location about 90 km SSW of Churi, Balochsitan, Pakistan. The magnitude was reported Mw 8.0, Ms 7.8 with the coordinates of epicentre 24.5N, 63.0E. A tsunami occurred in the Kuch region at the southern coast of Makran, Pakistan, with wave height about 12 m in the Makran port and 11 to 15 m in the Kuch area on the west coast of India. The death toll about 4000 due to earthquake and tsunami generated. These numbers are non scientific based collection of more unreliable.

If a 1945 wave height of 12 m can be confirmed for Makran Coast, it is surely rational to presume that a comparable earthquake can occur again (Mokhtari et al., 2005; Ramachandran, 2005; Jain et al., 2005; Quittmeyer et al., 1979)

The 1974 Patten earthquake (M6.0)

A destructive earthquake occurred on December 28 1974 near Pattan and followed by after shocks series. The depth of main shock initiated at about 12 km depth and average body wave magnitude 6.0. The shaking of Pattan earthquake was very forceful, especially in the upper side of the village where people found it difficult to stand. Residents of the area reported thunderous noises connected with main shock and some of the largest after shocks (PMD Hazard Report, 2007).

The main shock of Pattan earthquake recorded at Terbela about 139 km away from the Pattan (SMAC B1-2 accelerographs). Maximum acceleration recorded on the rock was about 1.4%g with a predominant period of 0.14s. Acceleration on alluvium with frequencies about 10 Hz reached 3.5% g. Maximum acceleration did not exceed 1.5% g at frequencies 5 Hz at both the bottom and top of the earth fill dam of Terbela (Ambraseys et al., 1981).

The 2005 Muzaffarabad Earthquake (M 7.6)

The earthquake of October 8, 2005 occurred in Kashmir region. The United States Geological Survey (USGS) has reported the epicentre of Kashmir earthquake in the Hazara Kashmir Syntaxis, While Indian Meteorological Department reported more in west. After shock studied by USGS lie in the NW of the main shock (Indus Kohistan Seismic Zone (IKSZ)).

The earthquake occurred on pre existing faults as shown in the figure 1.3. The recently deformed area occupies a 90-100 km long northeast trending strip extending from Balakot Pakistan, southeast through Azad Kashmir. It cuts across the Hazara Kashmir syntaxis, reactivating the Tanda and Muzaffarabad faults. Surface rupture roughly coincides with MBT in the north of Muzaffarabad, on the south western side of the syntaxis. The rupture lasted for 25 s and travelled up dip and bi-laterally with rupture velocity of almost 2 km/s. In the northwest of Muzaffarabad the fault off set was 4 m on average and peaks to 7 m (Avouce et al., 2006)

In the north of Muzaffarabad heavily damaged area shows the maximum deformation. There are recognized dynamic faults stretching to the NW and SE near epicentre, which expose some uplift on northern side and dextral, right lateral strike slip activities (Fujiwara et al., 2006). Active faults have been divided in to two groups, Tanda fault, SE of Muzaffarabad and the Muzaffarabad fault, NW of Muzaffarabad (Nakata et al., 1991)

According to seismic point of view, the most active geological structures of this area are considered to be capable of producing large seismic events. However, it is not reasonable to equate MBT with IKSZ, as the tectonic histories of these two are pretty different. The seismic activity along IKSZ is much more intense as compared to the MBT (PMD Hazarad Repot, 2007).

Kashmir earthquake occurred in the area which is under study. Specially the two main cities (Muzaffarabad and Islamabad) where the disaster is associated with this earthquake.

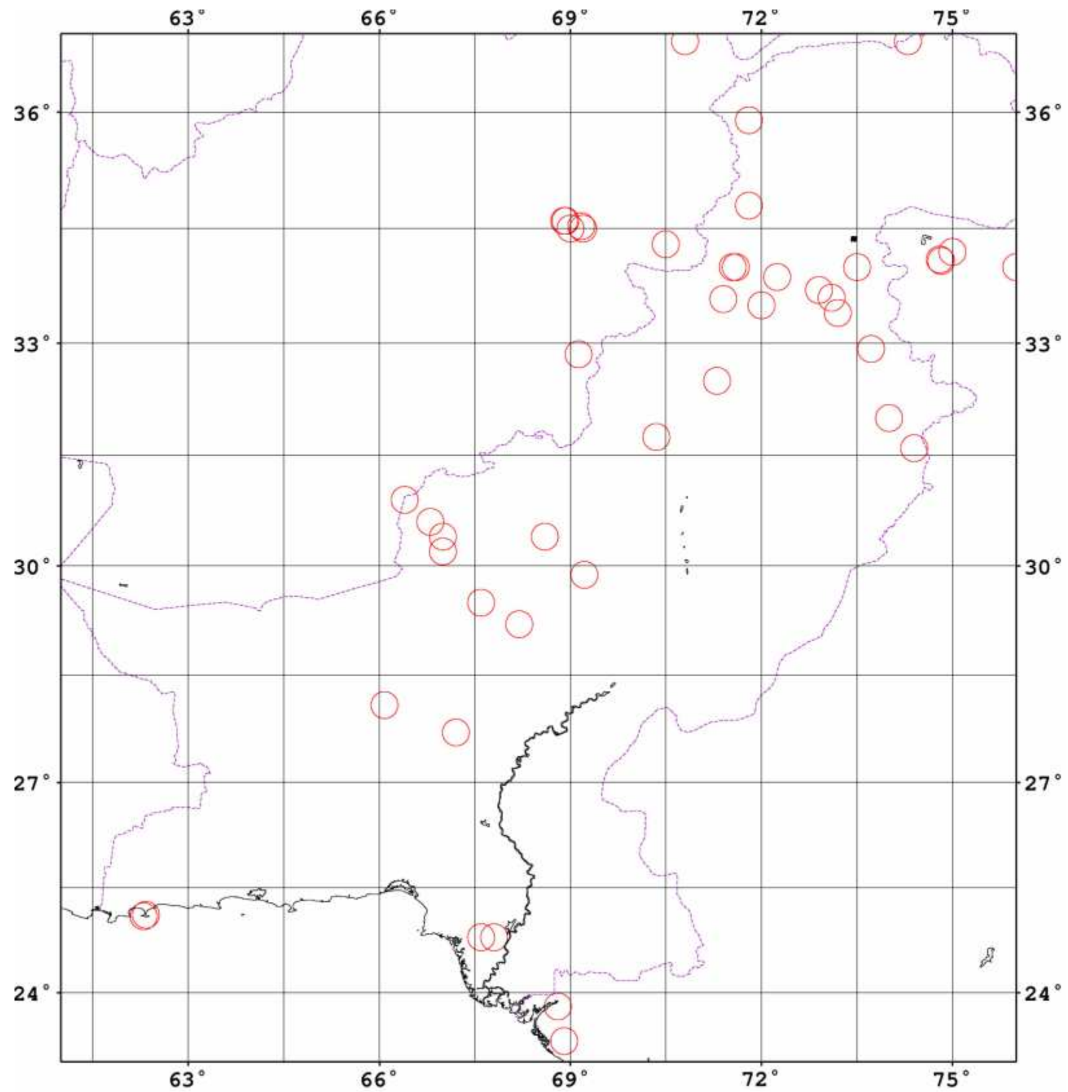

Figure 2.12: - Location map of Historical catalogue.

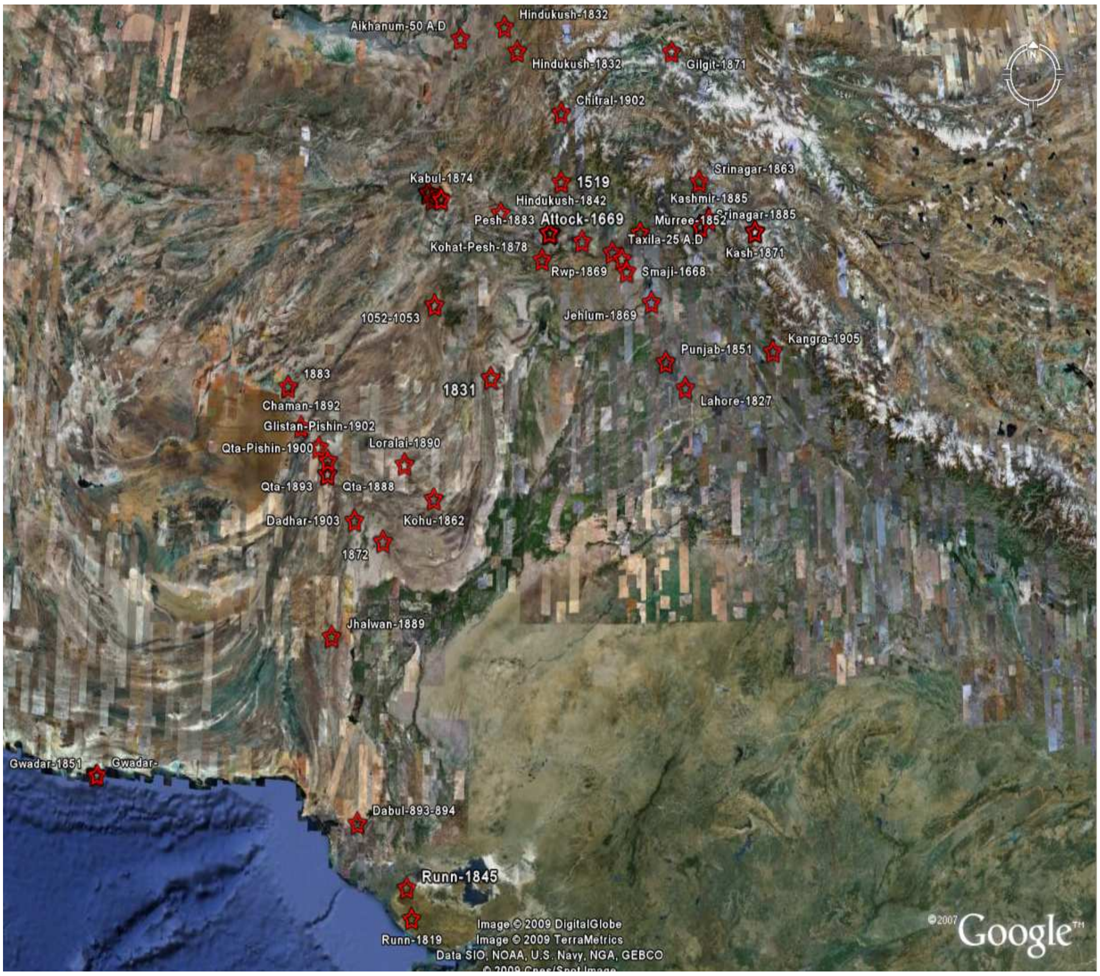

Figure 2.13: - Location map of Historical catalogue plotted on Google earth.

3 Seismic Network in Pakistan and Data analysis

3.1 Background

Pakistan Meteorological Department (PMD) is a scientific as well as service department and function under the Ministry of Defence. PMD is responsible for providing meteorological services throughout Pakistan to broad variety of interest and for several public activities and projects which need weather information. The department's responsibility goes beyond the national boundaries in case of aviation services to meet the international agreements to provide facilities regarding the aviation meteorology.

Besides meteorology, the department is also concern with Agrometeorology, Hydrology, Astronomy and Astrophysics, Seismology, Geomagnetism, Astronomy and Atmospheric electricity and studies of the Ionosphere and cosmic rays. PMD is also bears the responsibility to look into the factors responsible for global warming, climate change its impacts and evaluation. PMD has been operating the seismic network in Pakistan since 1954 (PMD local repots).

3.2 Major Functions of PMD

To give information on Meteorological and Geophysical issues with the aim of traffic protection in air, on land and sea, mitigation of disasters due to weather and geophysical phenomena, development in agricultural sector based on climatic prospective of the country, prediction and modification of weather forecast.

PMD has established in pursuance of its objective

- A network of meteorological and geophysical (Seismological) observatories to generate meteorological and geophysical data.
- For the dissemination of a telecommunication system
- Meteorological and Seismological offices to analyze the data for issuing forecast, warnings in the concerned fields.

- There are units for data processing for examining, evaluating and publishing data for the assessment of long term weather trends and earthquakes.
- Research and development(R & D) center to identify, understand and solve the problems in major concerned fields (Meteorology, Hydrology, Seismology).
- To provide expertise and advisory services to the policy makers and planners to address the emerging problems related to climatic change, agriculture, water resources and environment hazards.

As mentioned earlier that Pakistan is situated in seismic prone area. Therefore, a dense seismic network is needed for the mitigation of losses to life and property due to earthquake as well as related Tsunami disasters.

This is meant to bring further developments in the following socio-economic services of human activity:

- Safety of infrastructure, both in the Public & Private sectors, by minimizing damages due to earthquakes & associated Tsunami disasters.
- Promotion of civil engineering & housing activities by providing reliable advisory services to the planners, builders and engineers.
- Improvement in human resource development in the field of seismology.
- Communication facilities for the distribution of seismic and Tsunami information through electronic media to the concerned government authorities and other users (Ahmad, 2006).

3.3 Seismic Network in Pakistan since 1954

PMD has been working with seismology since 1954 and has the mandate to issue the information to public sector as well as to the government agencies. The first seismic station was installed at the geophysical center Quetta in 1954. Later on 5 more stations were installed (Peshawar, Islamabad, Khuzdar, Karachi and Lahore) as shown in figure 3.1. A detail of equipments installed is given in table 3.1. Quetta and Islamabad seismic stations are equipped with worldwide standardized Seismographic Network (WWSSN) recording system. Peshawar has short period Benioff equipped with visible heat sensitive/photo film visible pen-ink recording system. All the seismographs are very old and have become outdated, out of six only two (Quetta and Peshawar) are in working condition. Seismometers have been installed in conventional vaults. Because of urbanization, the noise level has increased greatly forcing the lowering of the magnification considerably at all the stations. Thus the detection level of the seismological network of Pakistan has declined. All the stations were working independently (Ahmad, 2006).

S.No	**Station**	**Equipments installed**	**Remarks**
1	Karachi	Sprengnether not in operation) Strong Motion Accelerograph	Short period
2	Khuzdar	Sprengnether (not in operation due to technical fault)	Short period
3	Quetta	World Wide Seismograph System	Short period and long period
4	Islamabad	World Wide Seismograph System	Short period and long period
5	Lahore	Sprengnether.(not in operation)	Short period
6	Peshawar	Sprengnether Strong Motion Accelerograph	Short period

Table 3.1:-The old Pakistan Meteorological Seismic Network technical details.

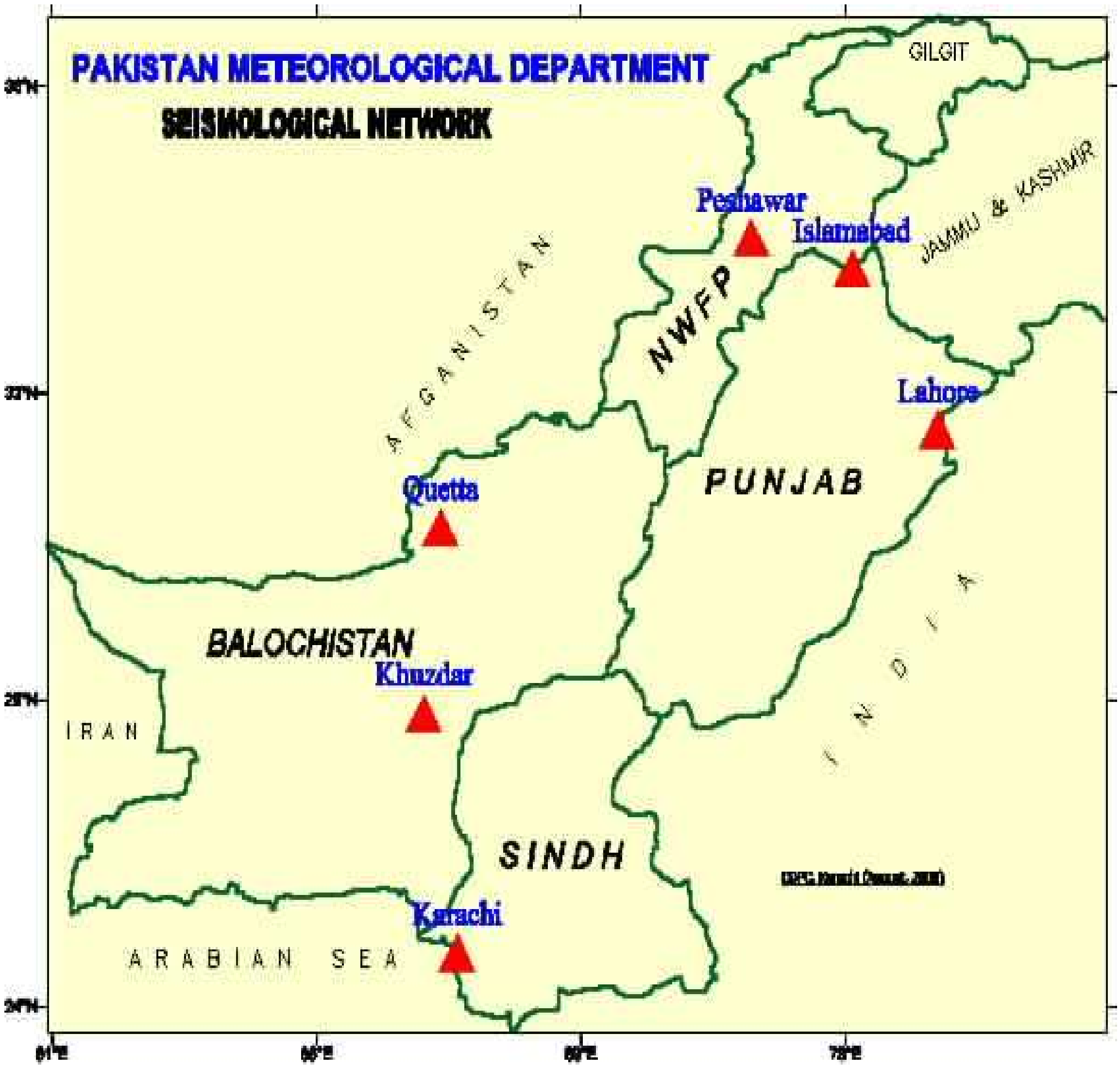

Figure 3.1:- Seismic Network in Pakistan before 2006-2007 (Ahmad, 2006).

Upper Atmospheric Research Station Peshawar (UARS) was responsible to issue press release until (2007-2008) for the electronic and print media. Now Karachi seismic center is responsible for the issuance of press release regarding earthquakes occurring in the region.

3.4 Seismic Network in Pakistan since 2006-2007

A project draft was submitted by the PMD to government of Pakistan for the up-gradation of the seismic network before 2004. The project draft was already in pipeline when Sumartra earthquake occurred (December 26, 2004). This big disaster draws the attention of the concerned authorities towards the project relating to earthquake (up-gradation of Seismic network)

Government of Pakistan realized the need of a larger and modern seismic network after disastrous earthquake in 2004. The upgrade of the existing network was approved in 2005. Initially 6 short period sensors (Guralp) were purchased and installed at the sites given in table3.2 and location map is the same as figure 3.1 except one station was installed in Balakot city which is not shown in figure 3.1.

S.No	**Station**	**Equipments installed**	**Remarks**
1	Karachi	Digital 40 T Guralp Strong Motion Accelerograph	Short period
2	Balakot	Digital 40 T Guralp	Short period
3	Quetta	Digital 40 T Guralp Strong Motion Accelerograph	Short period and
4	Islamabad	Digital 40T Guralp Strong Motion Accelerograph	Short period
5	Lahore	Digital 40T Guralp Strong Motion Accelerograph	Short period
6	Peshawar	Digital 40T Guralp Strong Motion Accelerograph	Short period

Table 3.2:- New equipment installed 2006-2007.

The stations are recording independently except Balakot and Karachi where short period has been replaced by Broad Band.

3.5 New National Seismic Network of Pakistan Meteorological Department

In addition to the initial upgrade, further strengthening of the Seismic Network of Pakistan Meteorological Department has been approved by the government of Pakistan (2005) and is under implementation as shown in figure 3.2. The project is intended at as an upgrade and expansion of existing Seismological Network of Pakistan for providing source parameters of earthquakes, especially having Tsunami generating potential, within minutes of their occurrence through real time computerized processing of recorded data.

Plan for New Network

The new network will consist of a national coverage network and three local networks (in addition to the initial upgrade), figure 3.2.

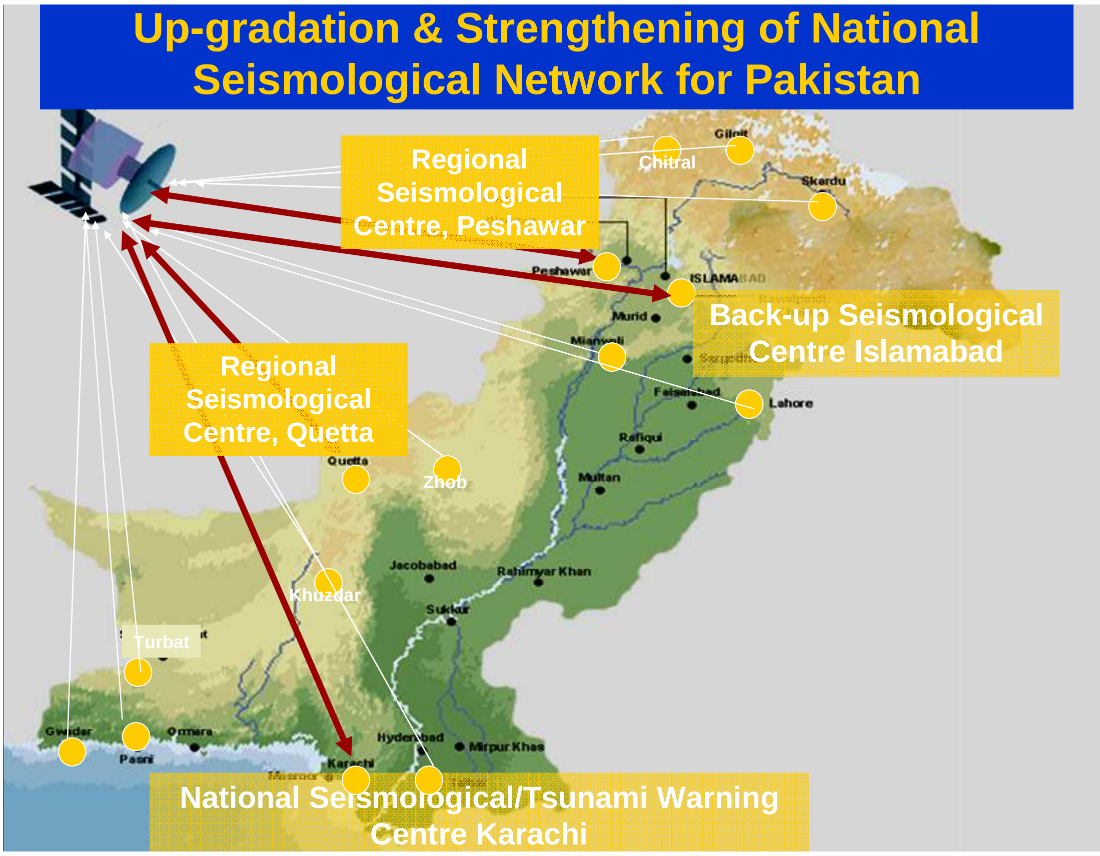

Fig 3.2:- Proposed location for new seismological centers in Pakistan (PMD proposal for the Up-gradation and strengthening of Seismological Network).

So far (2009) 10 Broad Band (BB) stations have been installed as location map is shown in figure 3.3 and description is given in table 3.3. Each observatory is equipped with broad band sensor, digitizer, communication system and strong motion sensor.

National Seismic Monitoring Centre at Karachi.

Karachi will act as a central analysis centre. The data will be collected from all regional centers through available communication system (radio link or internet) and will be analyzed at this centre. The analyzed data will further be disseminated to different agencies and the public. Three regional networks will run under this centre (not yet installed).

Islamabad Regional Centre.

A back up seismic station at Islamabad has also been proposed under Phase-I (Installation of Guralp 10 Broad Band, 50 short period and 50 strong motion) of the project. The whole analyzed data set and reports will be stored at this station. All the previous documentation regarding earthquakes in Pakistan and other countries will also be available at this data center which also will be used for tsunami warning.

Phase-II is consisting of Chinese system of 10 broad band stations. According to the plan, five out of ten stations will be installed by the end of 2009.

Quetta Regional Centre.

The seismic data collected from Sindh & Balochistan provinces through radio links or any suitable available communication system will be analyzed at this station for onward dissemination to the national centre at Karachi.

Peshawar Regional Centre.

The seismic data will be collected at this centre from Punjab, NWFP & Northern areas of Pakistan through any suitable available communication system and after research and analysis it will be transmitted to national centre at Karachi.

Borehole seismic sensors will be used for the sites where noise level is high. In addition, the national network will have 50 short period seismic stations in rest of the country.

The local seismic networks will be consisting of short period sensors. Each network will consist of 20 to 25 short period single components (vertical) with natural frequency 1 Hz and one three-component sensor (Short Period) in every local network. In local networks sensors will transmit seismic data via any suitable available communication system to the main Regional Hub (Regional seismic recording center) and further this hub would be linked with National Seismic Monitoring system through satellite communication.

3.6 Current situation

Currently the 10 Broad Bands (BB) Guralp, stations have been installed and linked through satellite commutations with Karachi Seismic centre. This centre is receiving data from all 10 stations now (2009). The processing of data has been started with personals at Karachi center, however they have limited processing experience. Similarly processing is taking place at Islamabad. In addition to BB stations 10 Short period and 30 strong motions Guralp have also been installed. The data from these stations is being collected by visiting personally once 15 to 30 days. Most of the Phase I plan has been completed.

Station Name	Station Code	Latitude	Longitude	Height
Balakot	BLKT	34.5333	73.3333	995
Chitral	CHTL	35.8833	71.7833	1498
Khuzdar	KHUZ	27.7833	66.6012	1248
Karachi	KCHI	24.9167	67.1333	38
Quetta	QUET	30.2333	66.9833	1640
Muzaffarabad	MUZF	34.3646	73.4938	1169
Umarkot	UMKT	25.3333	69.7166	33
Turbat	TURB	25.9833	63.0166	141
Zhob	ZHOB	31.3375	69.4511	1421
Bahawalnagar	BNGR	29.9500	73.2500	161

Table 3.3:- Broad band station of the new seismic network in Pakistan with station names and geographical position.

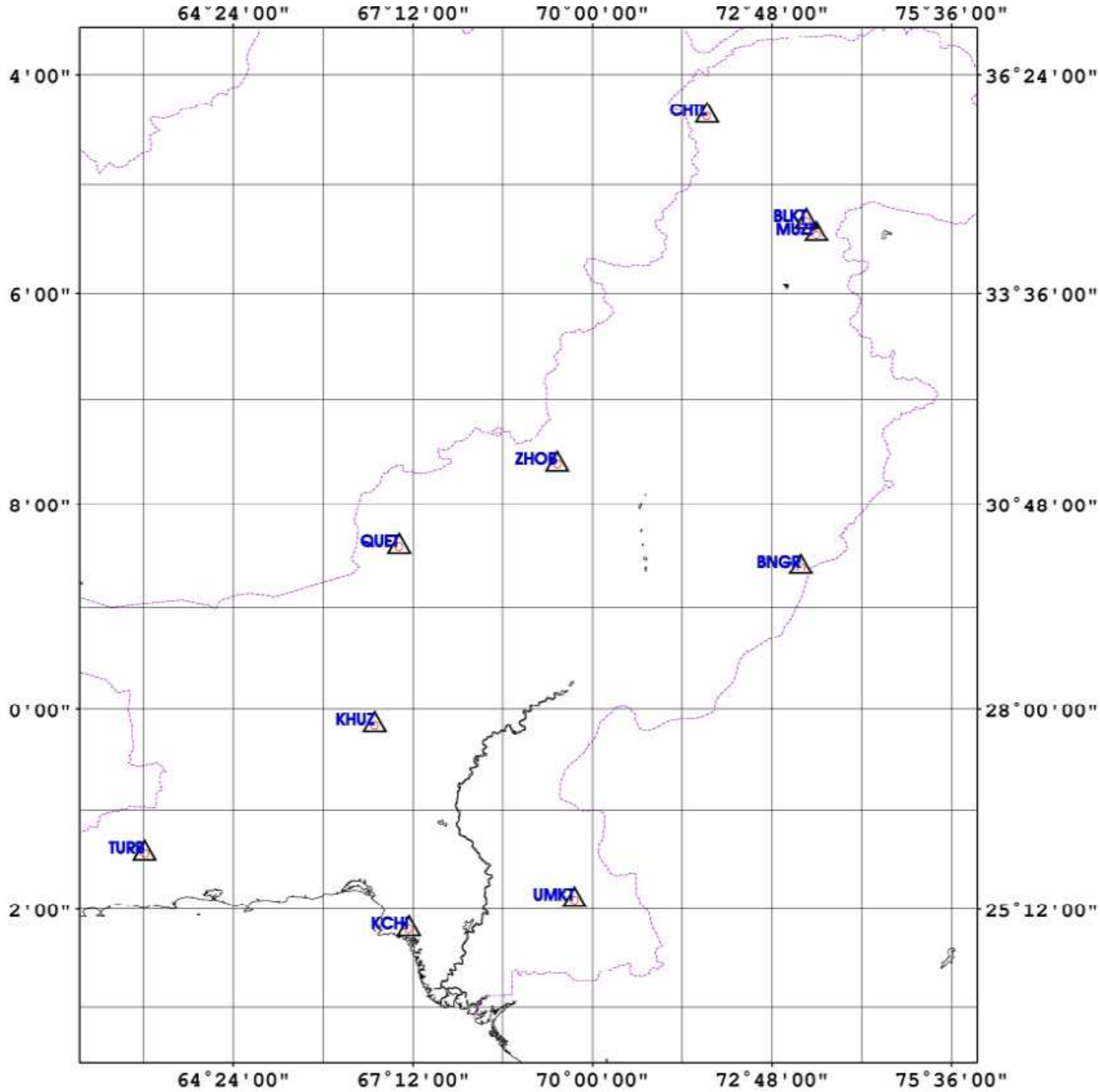

Figure 3.3:- Black triangles shows new national seismic network broad band stations in Pakistan.

Data flow

Guralp sensor sends data to digitizer and then to the Data Communication Module (DCM) which can store and transmit data with out any loss. All of the data from DCM goes to satellite router and then to central Hub which makes data available to the main server (Scream software is available) from which the data can be distributed according to choice of the user. The server sends this data to main display computer and the analyzing computer. At the same time the data is sent to the computer where SeisComp3 is installed the data flow block diagram is shown in figure3.4.

Seiscomp3 provides automatic detection and epicenter location of the earthquakes . There is an option to relocate earthquake to make sure that the epicenter location given is precise. The coverage of this system is international. We are receiving many international (more than 50) seismic station data for the purpose of tsunami warning system. For the epicenter location purpose the minimum number of stations required by the Seiscomp3 is 6. (Personal communication with Zahid Rafi-PMD-Focal person for Seismic Network).

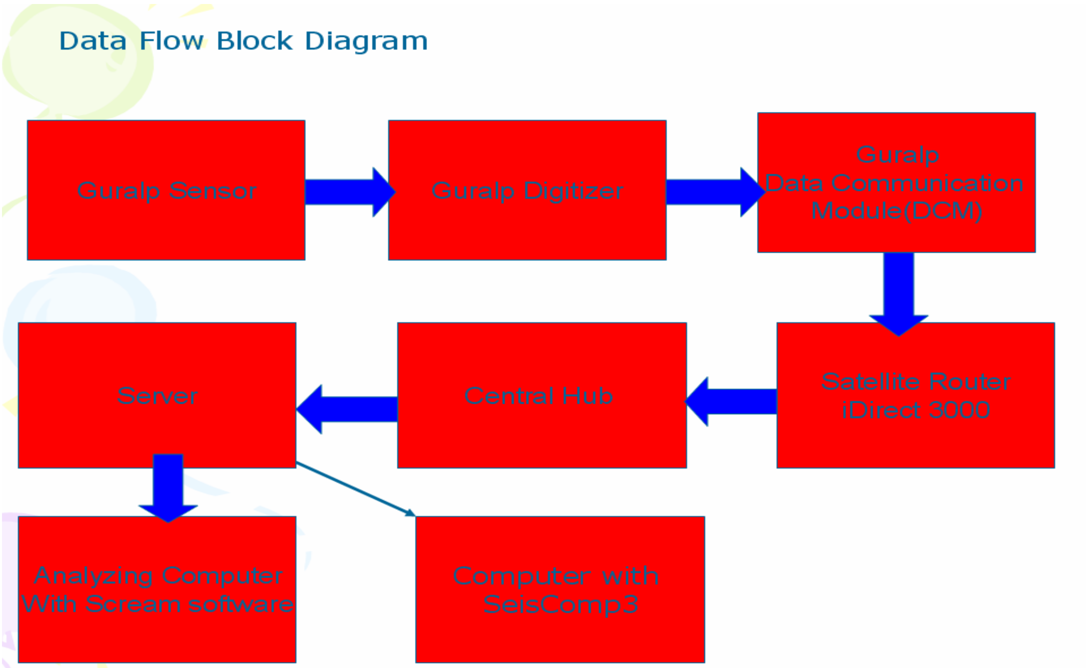

Figure 3.4:- Data Flow Block diagram National Seismic Network of PMD.

In SeisComp3 system there are three main tasks in interactive processing. (1) Monitoring the status of the network and complete manual event detection. This is used to give overview of network status and the actual situation of the region of interest.

(2) Displaying the actual waveforms of selected stations with good distribution and quality. This display gives the possibility to user to get overall impression of the waveform data. It is a simple way to control the trigger information shown in as shown in figure 3.5.

(3) Triggered information and gaps are displayed.

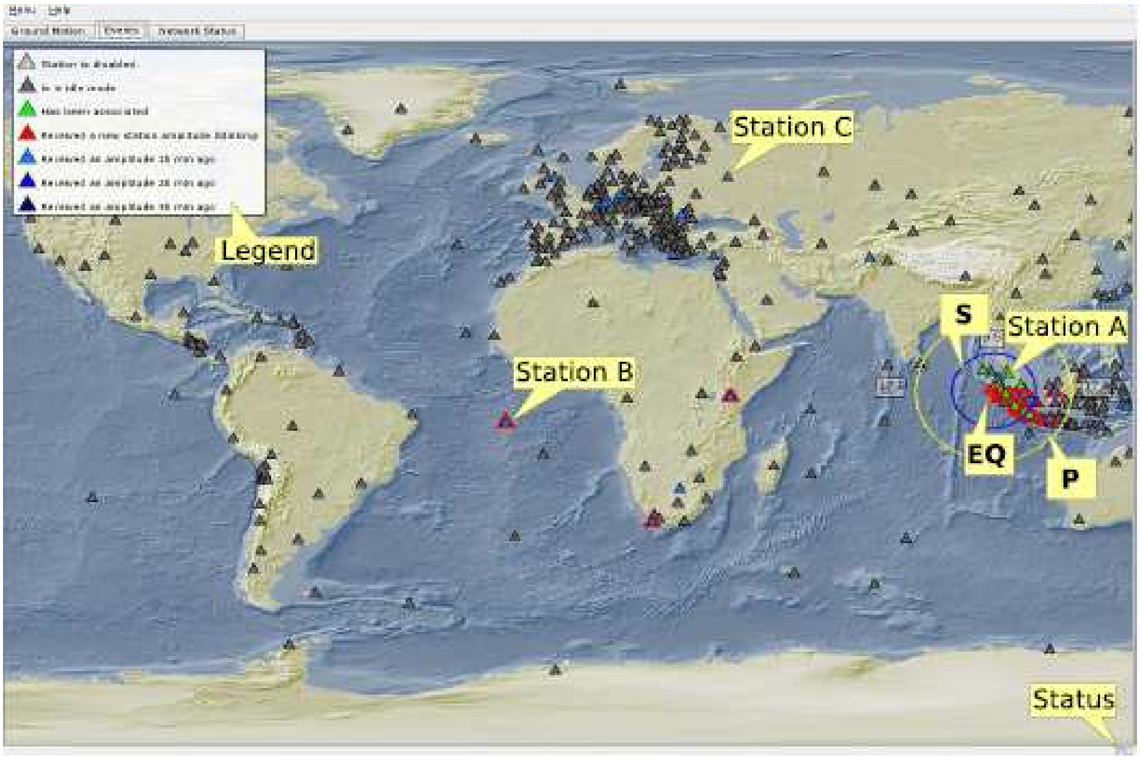

Figure 3.5:- Display View of SeisComp3 screen.

Figure 3.5 is showing Station A- triggering and related station to last event (green blinking), station B-station triggered 10 minutes ago (red blinking), Station C-station is in idle mod, EQ- location of earthquake, P-P-wave spreading, S- S wave spreading, Status-symbol for status of receiving data, Legend-Legend of event

3.7 Current Data Processing

In order to understand the current situation, the data processing today at the different centers will be described. An overview of data processing in 2006-2007 and earlier is given in table 3.4.

S.No	Stations	Work
1	Karachi	Reading of primary and secondary wave time and distance.
2	Khuzdar	Reading of primary and secondary wave time and distance.
3	Quetta	Reading of primary and secondary wave time, location of epicenter, determination of depth, distance, magnitude, phase analysis, preparation of bulletins, exchange of seismic data with the national and international agencies.
4	Islamabad	Reading of primary and secondary wave time and distance.
5	Lahore	Reading of primary and secondary wave time and distance.
6	Peshawar	Reading of Primary and secondary waves, location of epicenter, determination of depth, distance, magnitude, issuance of press release and warning etc.

Table 3.4:- Data processing work chart before 2006-2007

In 2006-2007 and before, the data processing was done manually at all stations, as mentioned in table 3.4, and they were all working independently. As soon as the earthquake occurred and recorded on the different stations, the person on duty was reading Primary (P), Secondary (S) phase arrival time and sending it to the Peshawar station for the location and magnitude calculation process. Peshawar station was responsible for the issuance of press release. This center calculating magnitude and picenter location of the earthquake with the reading received from other seismic stations.

Now responsibility of the issuance of press release is with Karachi seismic center.

Current situation in Pakistan is quite different in case of data processing even. As mentioned earlier that 10 broad band station data is being received at Karachi center directly through satellite communication system. Data is being processed automatically by using SeisComp3 system which provides automatic detection and location of the events. Every event is being relocated before it put into a data base. At the same time SEISAN software is also used for location purpose independently (Personal communication with Zahid Rafi).

Data for this thesis

It has not been possible to get data from the new Pakistan network, so data from the initial digital Pakistan Network was used instead. The data received has been examined and most of the time only one station had sufficient data. Data was available in patches, so it was difficult to calculate epicenter location of the earthquakes. Since data available is mostly form one station only. Therefore, it was decided to concentrate on available data (one station) for 2008 in order to do some testing. The station with the most data available is the Islamabad station (A411). A few events were available on two stations but timing error between the stations constrained to use data from two stations. The time period for this data set is 200801 to 200807.

3.7.1 Data processing

Initial processing

All data (triggered event files) for 2008 were put into a SEISAN data base and examined. Out of 222 'events', 142 were found to be real events. 139 out of 142, events have been detected by local network. 44 events were recorded at two stations. Figure 3.6 shows examples of events recorded by two stations.

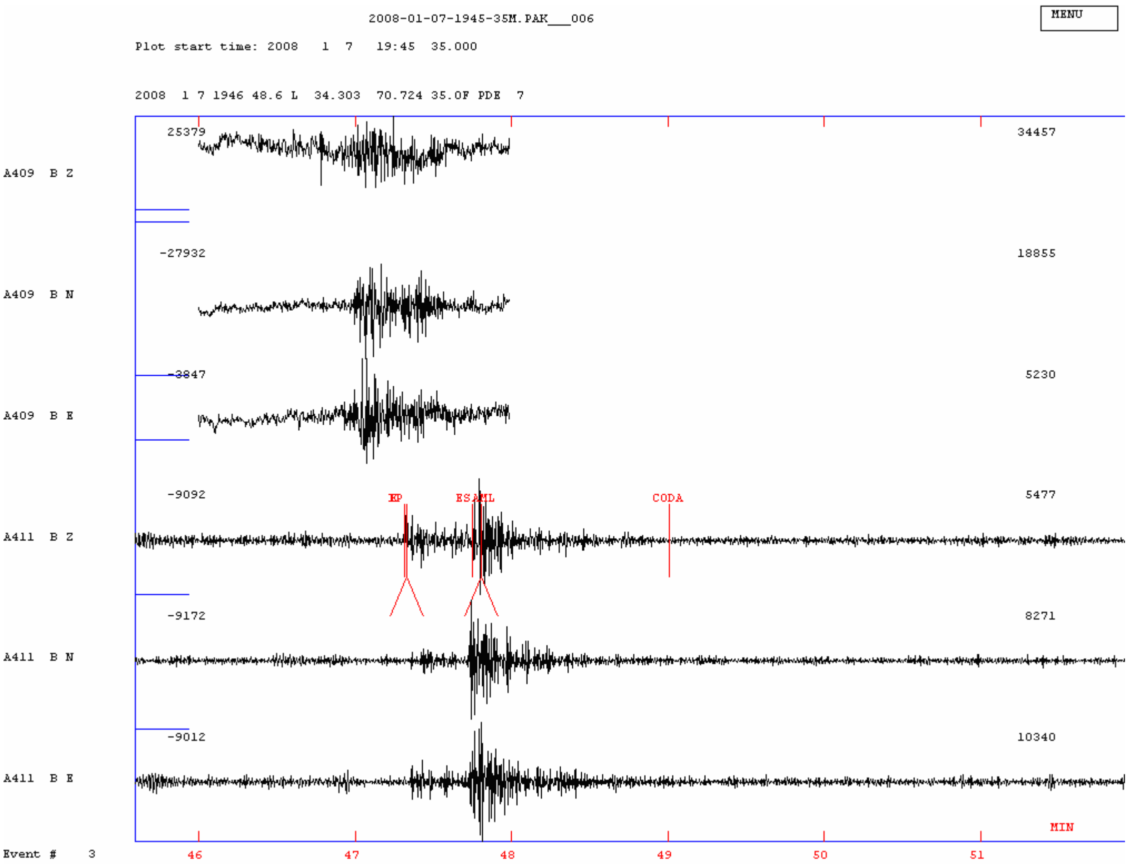

Figure 3.6:- Plot shows the event recorded on two stations by seismic network of Pakistan .

Calibration

The following parameters (table 3.5) have been used for the calibration (Sensor-installed Islamabad station-A411) and the corresponding response curve is shown in figure 3.7.

S.No	Parameters	Values
1	Seismometer period	1.0 second
2	Generator constant	2000 V/M/S
3	Damping ratio	0.707
4	Amplifier gain (db)	0
5	Recording media gain	300 000 counts/volt

Table 3.5:- Detail of calibration parameters (Calibration sheets for sensor-Guralp).

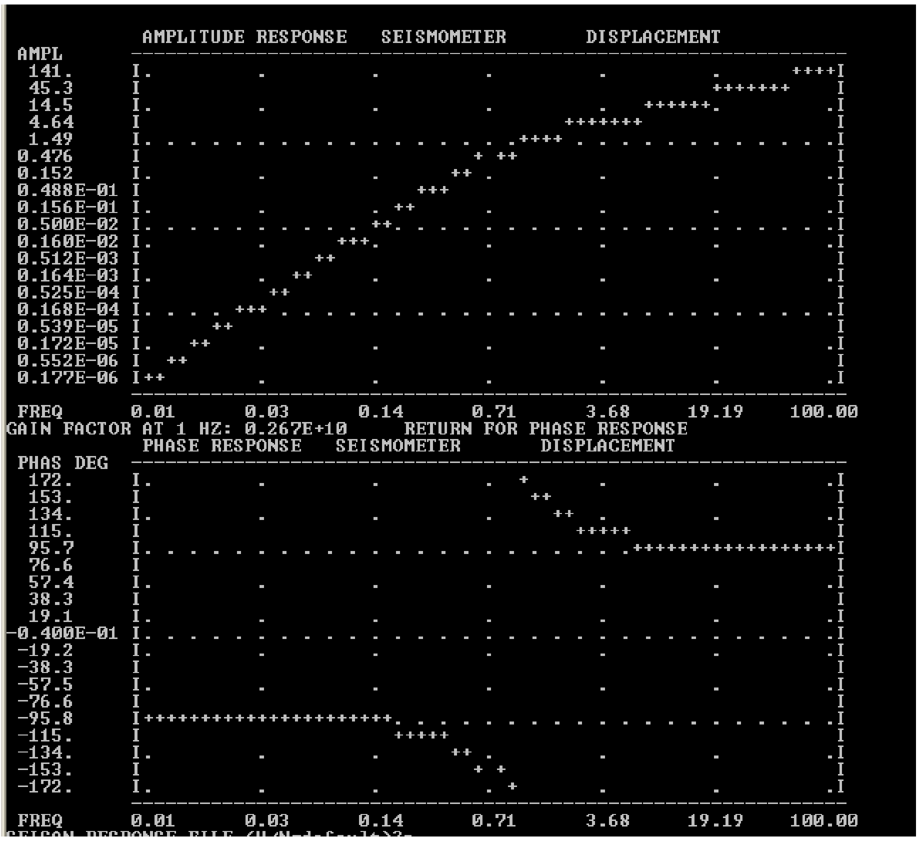

Figure 3.7: - Response curves for sensor for sensor.

Noise spectrum shown gives the idea about the quality of the site and the variability of the noise- Three spectra are shown in figures3.8-3.10. It is indicated from the spectrum that it is noisy place. It gives a high noise as shown in spectrum. In the day time it is even higher than night time. The sensor is installed in the office premises (out side the building) at about 3 m from the multistory building and also two main roads are passing at about 200-250 m on both sides of the vault. From spectrum it is clear it goes to high value at 3.2 Hz and above which is almost clear from all of the three spectra but more prominent day time spectrum. Below 0.3 Hz the sensitivity of the 1 Hz sensor is too low to give a reliable spectrum so it is just an instrument noise. Between 1 and 0.3 Hz range site is quite good. (figure 3.8, 3.9). During night the trend is better as compared to day time in case of high frequency side. (figure 3.10).

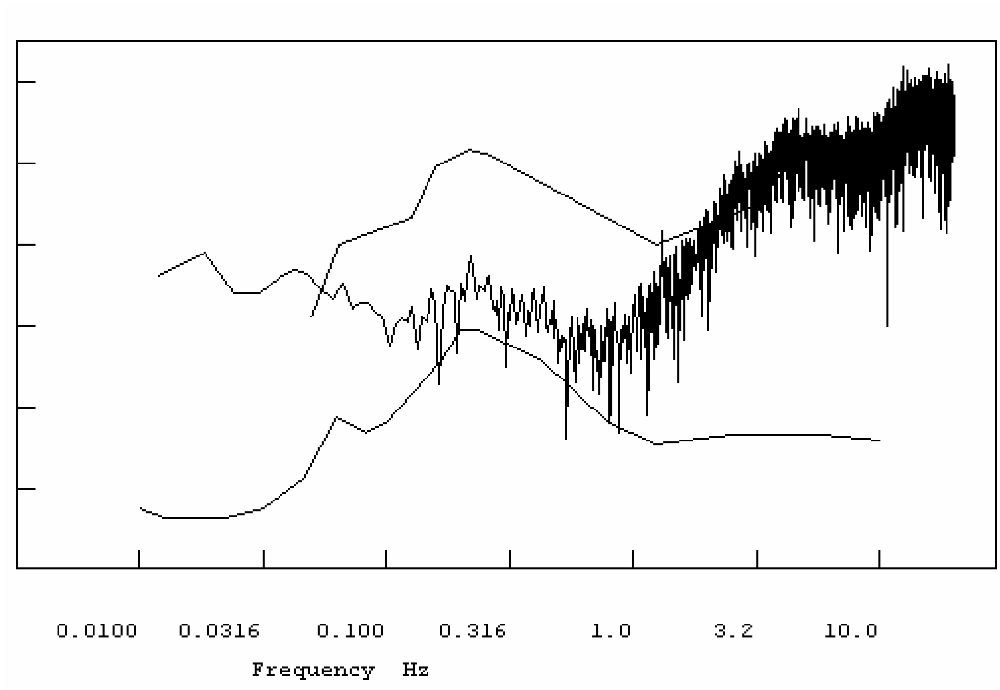

Figure 3.8:-Noise spectra at 09 40 am day time Islamabad Station (A411).

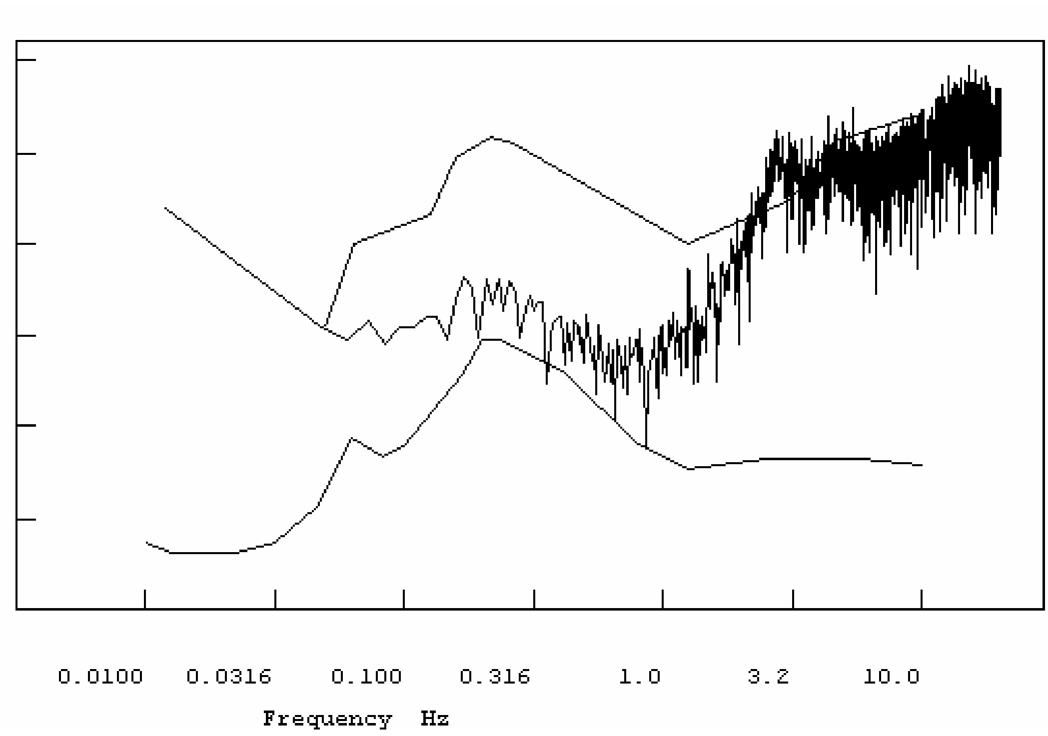

Figure 3.9:-Noise spectra at 1340 day time Islamabad Station (A411).

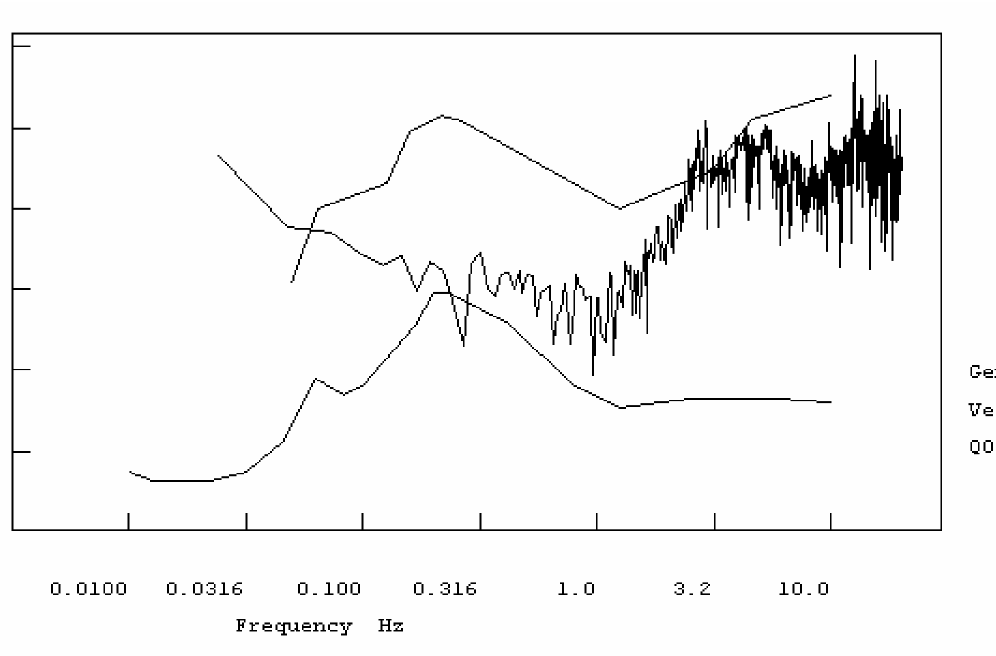

Figure 3.10:-Noise spectra at 2240 night time Islamabad Station (A411).

Selection of data

Since little can be done with one station data, it was decided to further process only those Earthquakes which were reported by PDE in order to compare one station source parameters with PDE. Since many events are recorded in and around Pakistan. The time period and area under investigation gives PDE reported 232 events (figure 3.11). Not all events reported by PDE were recorded by Islamabad station (A411) and comparison has been made with PDE and local data available (table3.7). It is seen that several events are missing from local network(A411) as compared to PDE .Since many events M >= 4 are not recorded, this is probably due to missing data more than lack of detectability. Events recorded on both PDE and Local network are 54. Events triggered by the local network are 139 in number. After carefully testing data the 69 events have been selected for further processing. Out of these 69 events only 14 are marked with " * " to indicate good ones (figure 3.14). All these events (good ones) lies in area (32-38 N° & 68-78 E°).

Figure 3.12 showing the epicenter locations Pakistan seismic network (common data base). The events have the magnitude range mb 3.4 to 5.3 as given by PDE, CPAK (3.3-6.2) and LPAK (3.3-5.4).

Where CPAK and LPAK represents coda magnitude and local magnitude by Pakistan Network respectively.

Processing

Epicenter Location: Single station location method (Azimuth) has been used to locate the earthquakes. The model used for location is given in table 3.6 (Johnson and Vincent, 2002). Many events have a poor signal to noise ratio and the azimuth determination was uncertain.

Magnitude: Local magnitude Ml and coda magnitude Mc are calculated. Since there is no local scale available for Pakistan the standard scales for California have been used.

Formula used to calculate local magnitude (Ml) is (Havskov and Ottmoller, 2008)

$$Ml = a * \log(amp) + \mathrm{b} * \log\left(\mathrm{dist}\right) + \mathrm{c} * \mathrm{dist} + \mathrm{d}$$

where a, b, c, d are constants and log is logarithm to base 10, amp- maximum ground amplitude in nanometers, dist hypocentral distance in kilometers. The standard scale for California has been used, so by using the California default constants the formula is

$$Ml = \log(amp) + 1.11\log(dist) + 0.00189 \times dist - 2.09$$ (Hutton and Bore, 1987)

It has been assumed that gain of the Wood-Anderson instruments is 2080.

For coda magnitude the formula used is (Havskov and Ottmoller, 2008)

$$Mc = a * \log(coda) + \mathrm{b} * \mathrm{dist} + c\,)$$

where a (2.0), b(0.0035), c (-0.87) are constants (Lee et al., 1972) and coda is coda length in seconds.

Now epicenter locations and magnitude are calculated for all events where it is possible. The hypocentral depth was fixed to the depth given by PDE since by single station location depth cannot be obtained and if a wrong depth is used, the epicenter will also be wrong. This is particularly a problem for Pakistan with many deep events.

3.7.2 Crustal Model

Crustal model used for the epicenter location for PMD seismic network of Pakistan is given in table 3.6.

P-wave velocity km/sec	Depth in km	Name of the boundary
5.6	00	
6.5	23.0	
8.4	50.0	Moho
8.7	200.0	

Table 3.6:- Crustal model used (Johnson and Vincent, 2002).

Comparison of epicenters

Naturally epicenter locations calculated from PMD seismic network are very uncertain because of the method used (single station method). For the comparison of the epicenter locations common data base (PMD and PDE) with PDE locations, map has been produced (figure 3.18. The red circles indicating the PMD seismic network epicenter locations (common data base) where as the blue ones are the epicenter locations from PDE. The local seismic network (PMD) locations and PDE locations are not in good agreement except few events. After this a map of good selected events (14 events) from common data base has been produced (figure3.14). Another attempt made to compare the epicenter location difference between PDE and local seismic network by using only 14 events (good selected from common data base). The difference between the epicenter locations has been shown (figure 3.15) by drawing a line between the similar event (14 good ones from local seismic network (PMD) and corresponding 14 events from PDE) located by PDE and local network. In general the difference is high. Only a few are close to each other. The epicenter map of all the PDE locations is seen in figure 3.11. It shows a nice trend. The trend follows the main geological settings of the area. Epicenter location map follows Main frontal thrust, Hazara Kashmir syantaix, Induskohistan seismic zone and also goes to northwest (Hindukush) across the geographical boundary towards Afghistan.

For local seismic network (PMD), International Model for India-Pakistan region has been used (Johnson and Vincent, 2002). In some cases these epicenter locations are quite good but general trend given doesn’t follow the PDE location trend (figure 3.13).

Comparison of magnitudes

In case of magnitude comparison there are three types of comparison made by using the available data.

Local magnitude by Pakistani network (LPAK) with PDE body wave magnitude (BPDE). The average values for BPDE and LPAK are 4.14 and 4.34 respectively. The Number of earthquakes available for this comparison are (figure 3.18).

Coda magnitude by Pakistani network (CPAK) with PDE body wave magnitude (BPDE). The average values for BPDE and CPAK are 4.17 and 4.65 respectively. The Number of events available for this comparison is 47. (fgure 3.17)

Local magnitude by Pakistani network ((LPAK) with Coda magnitude by Pakistani network (CPAK). The average values for LPAK and CPAK are 4.70 and 4.31 respectively. The Number of events available for this comparison is 54 (figure 3.19). 54 events are detected locally and with PDE any magnitude which could be located because the rest was too bad to locate.

There 69 events in total in data base with common events. A comparison of magnitude (BPDE, LPAK & CPAK) has been shown graphically in figure 3.16. This graph indicates that local magnitude (Ml) calculated is in good agreement with body wave magnitude of PDE but coda magnitude (Mc) is showing a high values.

Data Comparison (PDE and Local Network)

Month	Locally detected	All Triggered events files	Real Events found	Total PDE, all magnitudes and also no magnitude	Only PDE > 4, not detected locally	PDE >=4 detected locally	Number of events detected locally and with PDE, any magnitude	Total events in PPD data base	Number of Events on 2 stations	Good events selected
January	32				3	6	10		7	
February	27				6	1	13		7	
March	23				9	5	14		11	
April	21				5	00	05		9	
May	17				4	2	06		6	
June	18				9	2	05		6	
July	1				8	00	01		--	
total	139	222	142	232	44	16	54	69	44	14

Table 3.7:- Data comparison 2008 (PDE and initial digital Network in Pakistan).

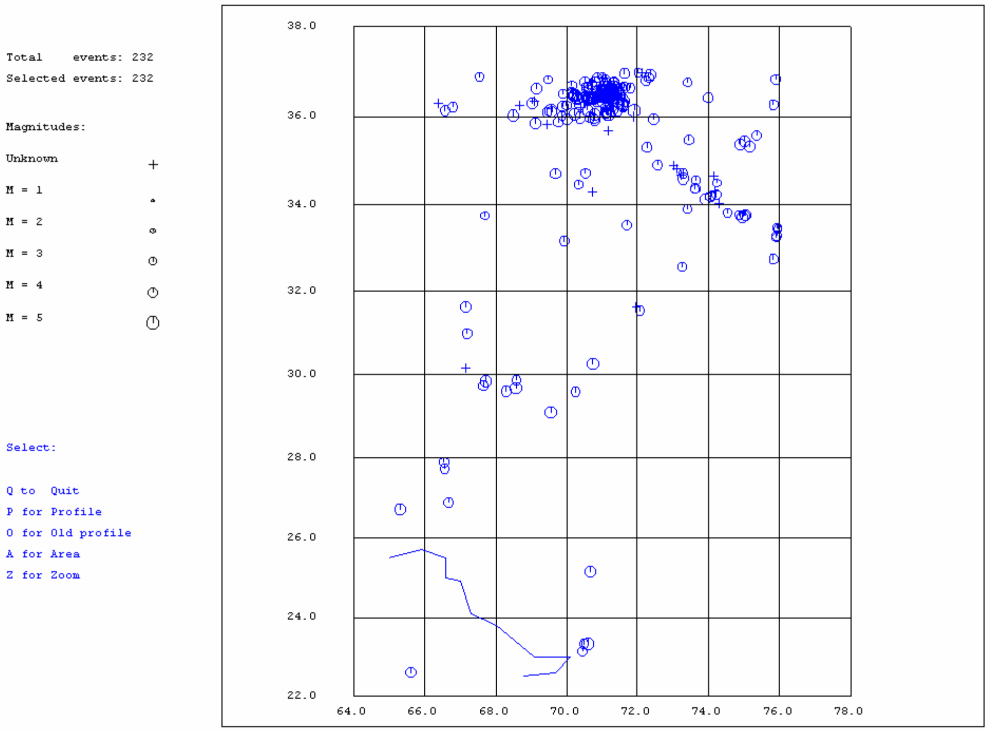

Figure 3.11:- PDE epicenter location map with 232 earthquakes-blue line represents the coastline of Pakistan.

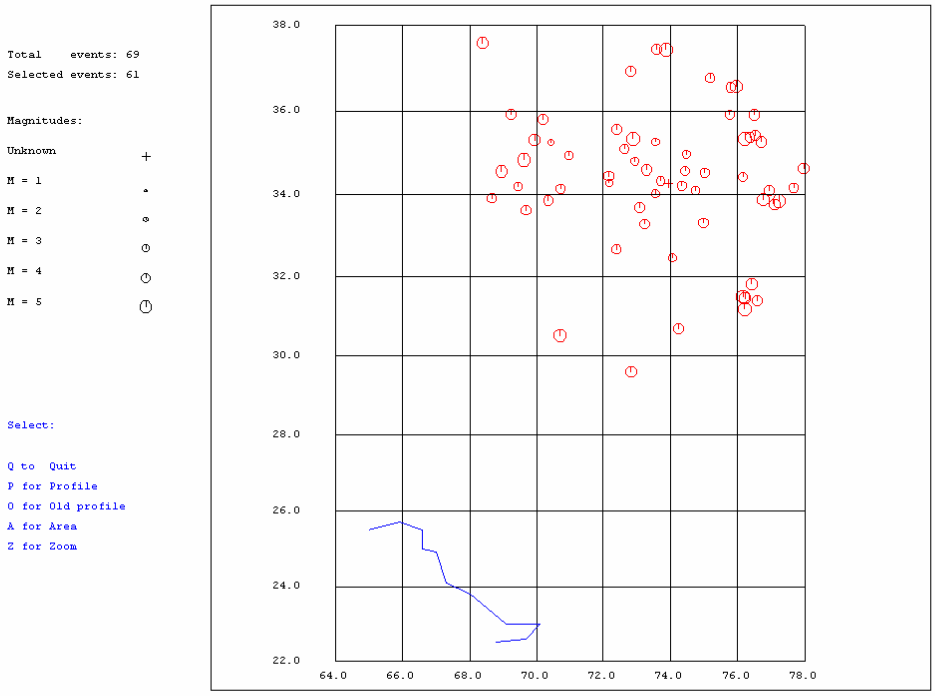

Figure 3.12:- Epicenter location map of all earthquakes common database Pakistani seismic network blue line represents the coastline of Pakistan.

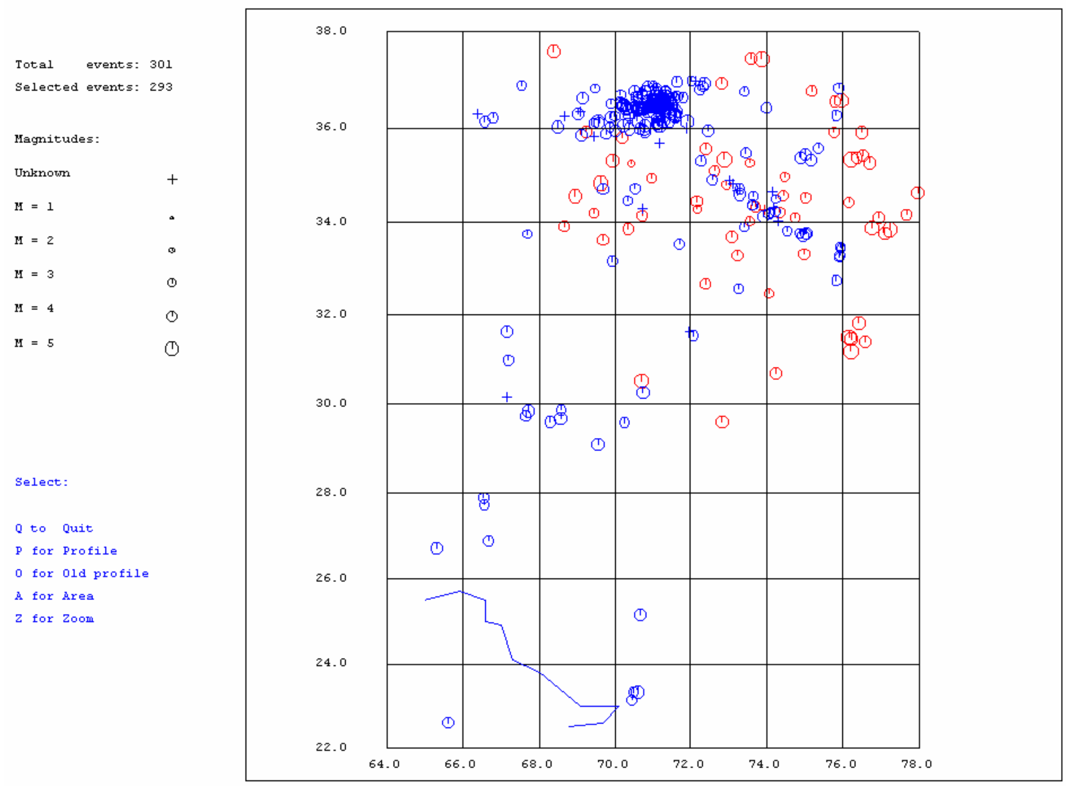

Figure 3.13:- Comparison of common data base epicenter locations (red circler) with PDE epicenter locations (blue circles).

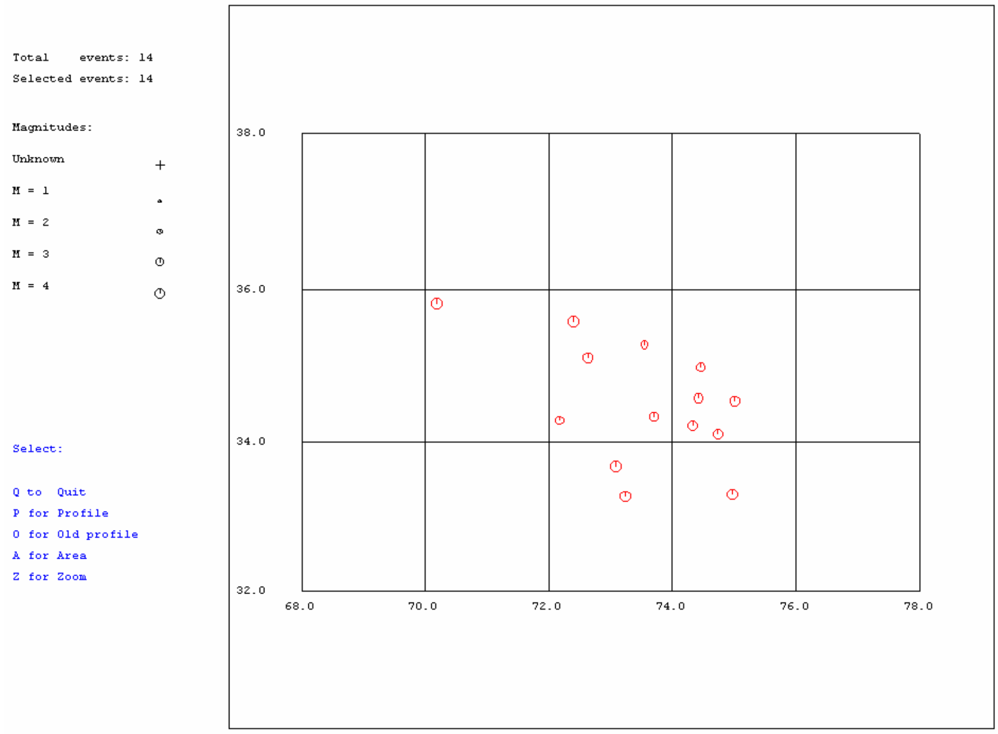

Figure 3.14:-Epiceter location map (our locations) of all good events selected from common database (14 eartquakes).

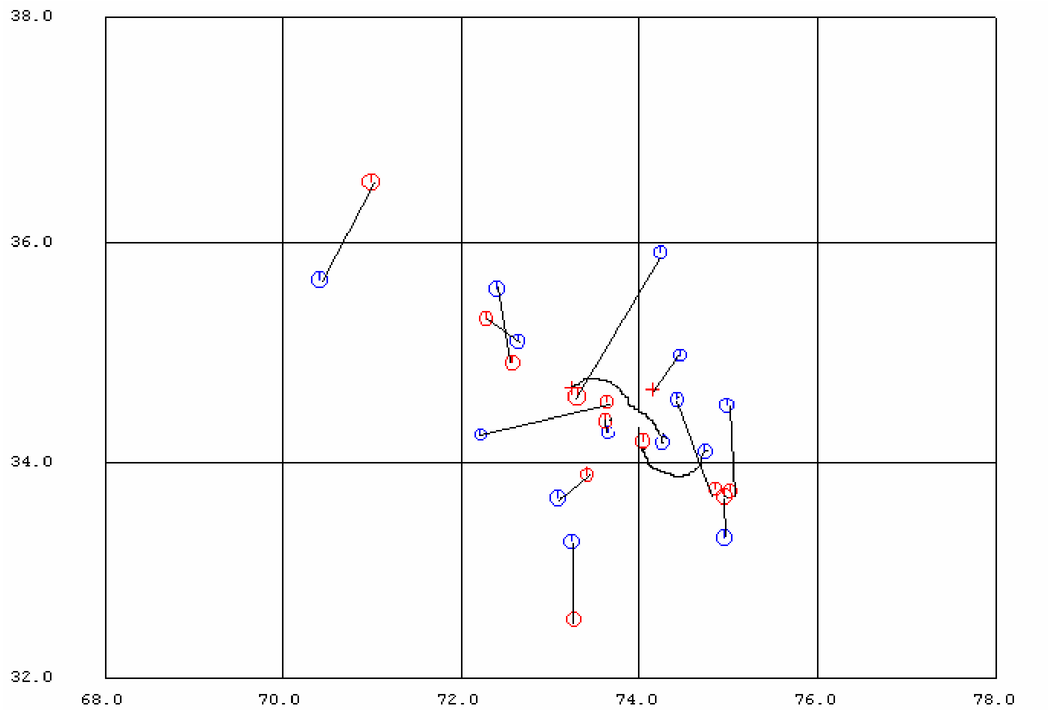

Figure 3.15:-Epicenter location map with line showing the difference between the epicenter location calculated from PMD data (red circle) and PDE (blue circles) of the 14 good earthquakes.

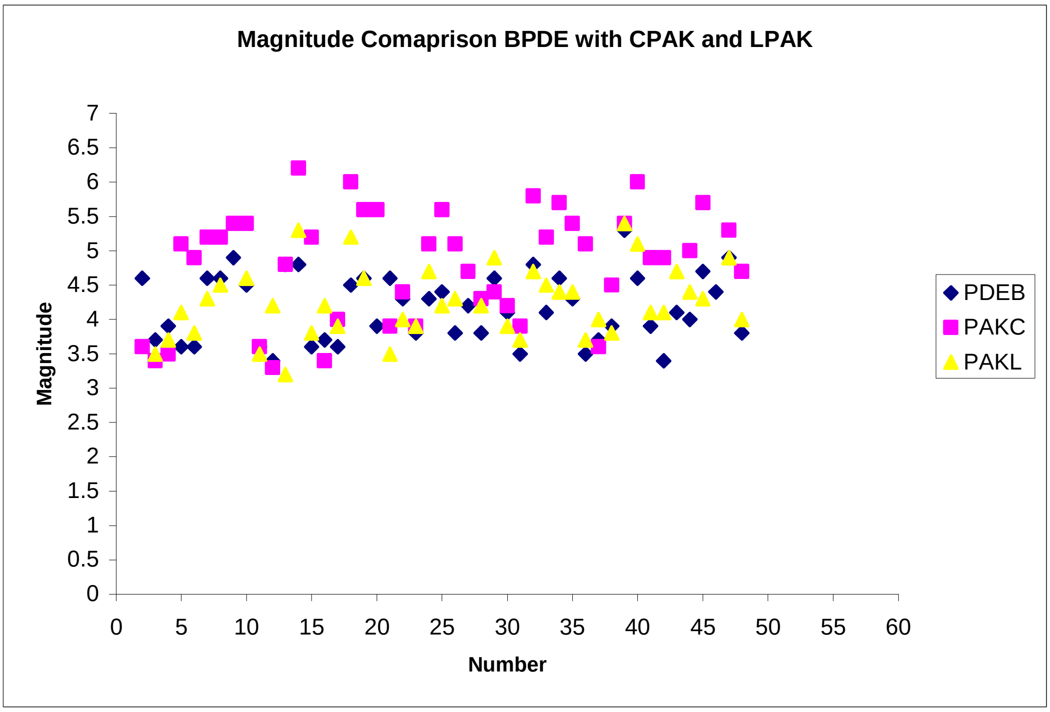

Figure 3.16:- Graphical comparison of the BPDE with CPAK and LPAK magnitude.

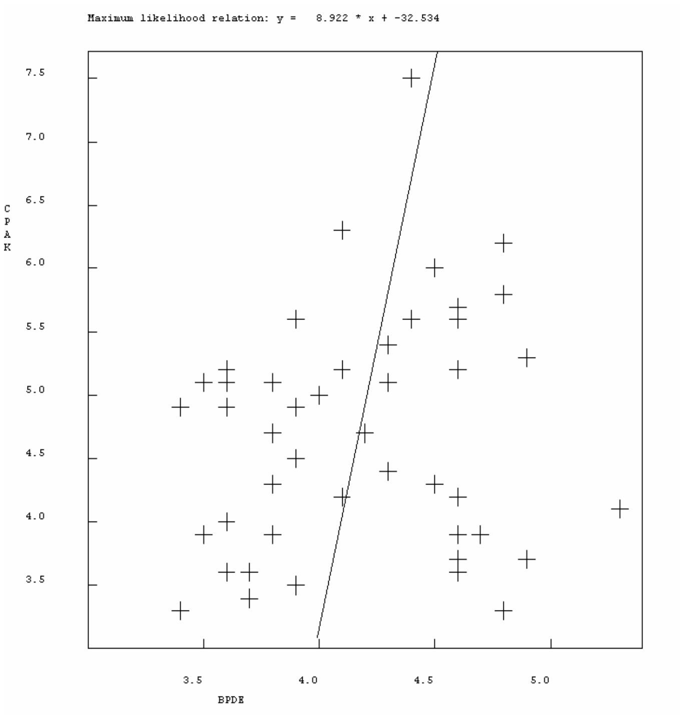

Figure 3.17:-Comparison of magnitudes BPDE and CPAK (4.17 and 4.65 average value respectively).

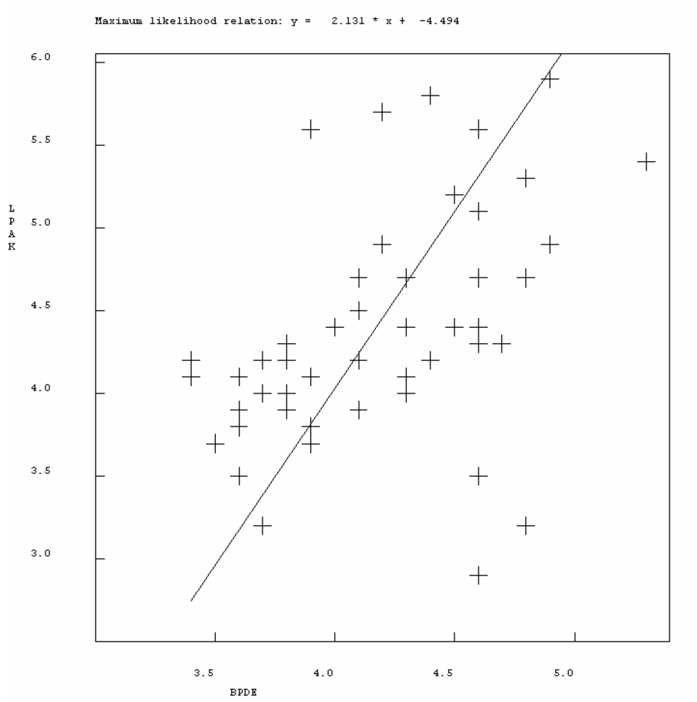

Figure 3.18:-Comparison of magnitudes BPDE and LPAK (3.92 and 3.88average value respectively)

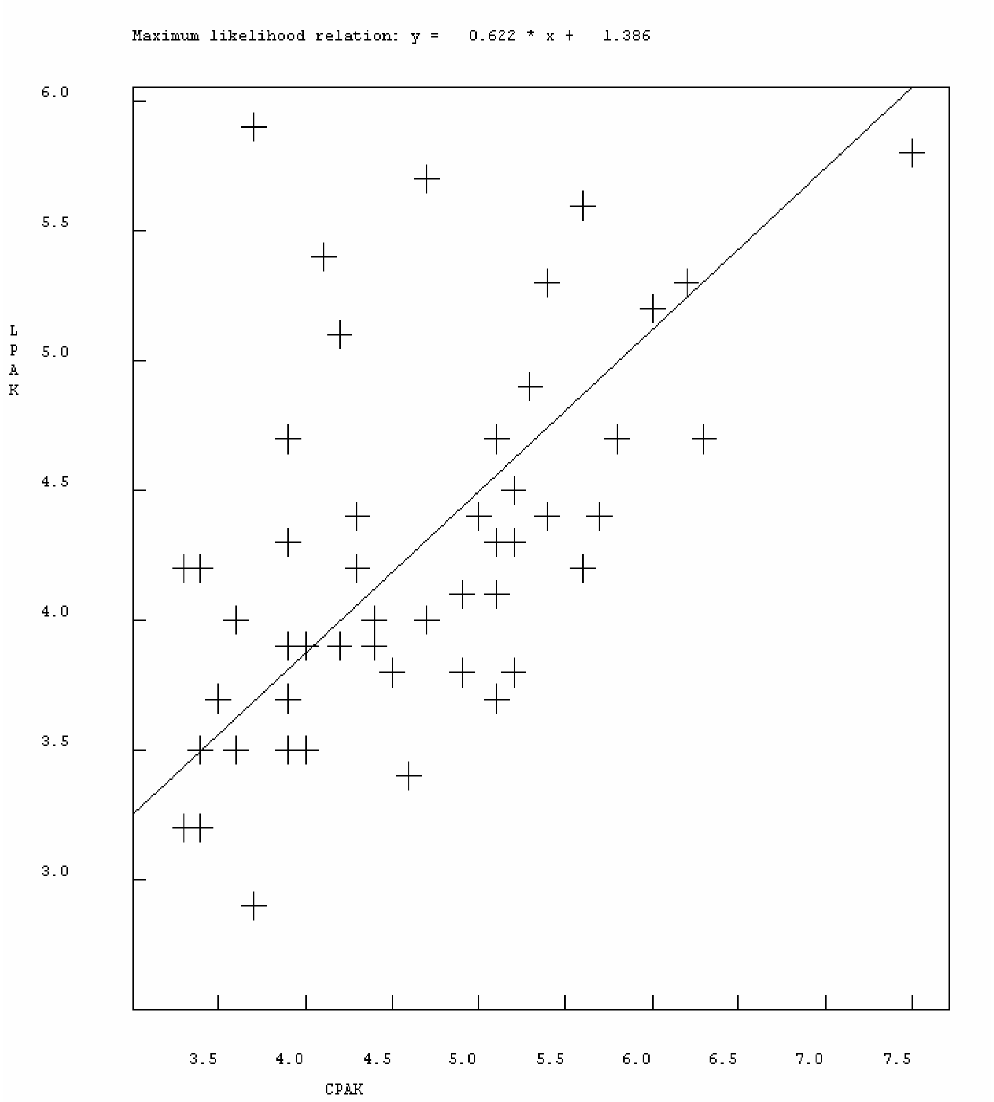

Figure 3.19:-Comparison of magnitudes CPAK and LPAK (4.70 and 4.14average value respectively).

3.8 Discussion

Epicenter location of an earthquake calculated by using single station method (Azimuth) is very uncertain. The good earthquakes are selected after careful analysis from PMD earthquake data but still the epicenter locations compared to PDE are not good (figure 3.13).

Magnitude may be reliable if the distance is fine by using even a single station method (azimuth). Magnitudes comparison of local magnitude (PMD data) with body magnitude from PDE is quite close but magnitude calculated with PMD data by coda formula comparatively is not in good agreement with body magnitude by PDE. Therefore, it is recommended that local magnitude formula may be used until the development of own local formula (Pakistan) for the calculation of the magnitude. Graphical comparison of three magnitudes local magnitude, coda magnitude (PMD data) and body magnitude reported by PDE is shown in figure 3.16. It clearly indicates that the coda magnitude is generally high as compared to PDE magnitudes. Coda magnitude may be used with certain adjustments. It is also suggested that the coda formula may be adjusted to get a good agreement with PDE magnitude.

It has been concluded from the epicenter locations and magnitude comparisons (PDE and PMD) the PMD seismic network has some technical deficiencies to be improved and certain technical problems(Data base management, synchronization of timing of different stations, calibration files, registration of station codes) to be addressed properly. The comparison gives the profile of the two data sets due to small data available from Pakistani Network. As mentioned earlier that the current situation is quite different and improved with 10 BB, 10 Short period and 30 strong motion sensors have been installed and data is being collected. This will provide a sufficient data to compare and evaluate the network efficiency with international seismological agencies. Phase I is almost completed and Phase II is under implementation. As soon as the modernization and strengthening of the seismic network of Pakistan Meteorological Department (Phase I & II) will be completed. PMD seismic network would be a one of the modern and efficient seismic network in the world.

4 Local site response in Muzaffarabad and Islamabad

4.1 Background

It is generally acknowledged in earthquake engineering society that soft soil can play a prime role in ground shaking and must be incorporated in seismic zonation. Devastating earthquakes have noticeably revealed that near surface geological and topographical settings play a key role in the level of ground shaking. In post-catastrophe restoration as in mitigation, information on soft soil response to big earthquakes becomes of the most importance. In seismic prone areas, zones at risk can be identified by mapping of predominance frequency of resonance and amplification of soil. It can also be used as a tool for deterrence planning and also to characterize protection zones for rebuilding after a destructive earthquake (Research Article by Rosset et al. from Internet).

Damages caused by earthquakes are mostly associated with man made structures except in case of secondary landslides. Earthquakes mostly caused death by the destruction of structures like buildings, dames, bridges and other man made structures. Several damages patterns in the historical earthquakes also considerable effect of local soil conditions on seismic response of the ground. In case of Loma Prieta earthquake (1989) 98% of property damage was due to ground shaking, amplified ground shaking was responsible for 70% of the overall property loss. Several researchers concluded that main source of the damage was local site amplification by Holocene clay –silt deposits in the San Francisco Bay (Gitterman, 1996).

Local site effect measurements provide information about the amplification of ground motions produced by the local geological settings. Many studies of large earthquake have shown that damages during devastating earthquakes are mainly due to magnification of seismic waves in topmost sedimentary layers. Therefore, assessment of local site effect is important to evaluate the seismic hazard potential of the region under investigation (Atakan, 1997).

4.2 Empirical techniques for estimation of Local Site Effects

Assessment of local site effects reliably is one of the key features of seismic hazard, which generally cause ground motion amplification and raises the damage potential of a large earthquake. The methods to determine the site response can be divided in to two groups, the analytical and empirical techniques. The analytical (theoretical) approach is based on inversion techniques which need brilliant information of the geotechnical factors to constrain the results. On the other hand empirical methods are more efficient due to the fact that they are based on calculating the frequency spectrum directly from the recorded ground motion for the site under investigation. The spectral ratio techniques are widely used among the empirical methods. (Atakan, 2009).

4.2.1 Standard Spectral ratio (SSR) - Reference Site Technique

The most frequently used direct technique, which provides the most even and reliable results, is Standard spectral ratio (SSR) technique(Atakan, 1995) also referred as Classical Spectral ration technique like (Ozel, 2002). In this study SSR will be followed. The method was originally suggested by Borcherdt (1970) to examine the effects of the local geology on the ground motion near the San Francisco bay area. The main theme at the back the method is to evaluate the probable local site effects from a future earthquake with the estimation of the local site response of the sedimentary site with respect to a crystalline rock site in the same area. There is assumption behind the technique (SSR) that the source and path spectral terms for two different sites are equal if they are near to each other and at the same time sufficiently far away from the source (far-filed approximation). The theoretical rationale of the method is simple as mentioned by Borcherdt (Borcherdt, 1970).

Consider $I_i(t)$ is the input source function, and $S_i(t)$ Seismogram out put for two sites. One is reference site situated on bedrock (i=b) and the other site for which the site response has to be evaluated (i=s). The functions reflecting the influence of the crust of the earth, local geology under the site and influence of the instruments for the two sites respectively are $H_{ei}(t)$, $H_{gi}(t)$, $H_{ri}(t)$. These can be related following way in time domain

$$S_i(t) = I_i(t) * H_{ei}(t) * H_{gi}(t) * H_{ri}(t), \text{ i = s,b} \qquad (4.1)$$

*   Convolution operator.

In frequency domain the relation is as follows.

$$s_i(f) = i_i(f) \times h_{ei}(f) \times h_{gi}(f) \times h_{ri}(f), \text{ i = s,b} \qquad (4.2)$$

In this case it is simple multiplication of Fourier spectra of the respective function. It has been assumed that the two sites are close enough so the source and path conditions are considered to be similar. It means that $I_s(t)$ equal $I_b(t)$ and $H_{es}(t)$ equal $I_{ib}(t)$. Similarly it follows for their Fourier transformation. Influence of the instruments used will be same if same instruments are used for both sites in time and frequency domain. In case the instruments are not same, instrument response is known always and can be explained for the response. By dividing the spectra of the two seismograms and taking the absolute value

$$\frac{|s_s(f)|}{|s_b(f)|} = \frac{|h_{gs}(f)|}{|h_{gb}(f)|} \qquad (4.3)$$

From equation 4.3, it is clear by taking the ratio of the absolute values of the site spectrum and the reference site a quantitative measure of the site response is achieved at a specified site with respect to reference site. In case of time domain the operation corresponds to deconvolving the outputs from the influence of the source, instruments and path conditions after this deconvolving the influence of the local geology of the reference site from that of the expected site (Borcherdt, 1970).

Reliable results can be obtained by using data from dense local array even if the source is far away from the network. If the dense seismic network is not available and network to source distance is equivalent to the distances between the stations, results should be treated carefully. If we do not have data from dense local array, other technique exist to invert for the source and path term using different scaling techniques and path conditions recipes (Roger, 1984; Bard, 1994).

Borcherdt, (1970) used this method for the estimation of the influence of the local geology on the ground motion near San Francisco bay. The 1906 San Francisco earthquake, data from microseism, strong motion data from 1957 earthquake and a week motion data from many far-away nuclear tests in Nevada was used. It has been shown that by using three different data set the results obtained was very similar (from the comparison of the computed site response spectra). Comparatively the site response spectra determined from earthquake data and nuclear test had superior quality than those determined from microseism data. A good agreement was found between the computed amplification coefficients with the intensities observed at the same site from large San Francisco (1906) earthquake (Borcherdt, 1970).

To estimate the local site response in different parts of Mexico City by a dense digital strong motion array was installed in 1987 in the city (Singh et al; 1980).
It has been shown that for Mexico City the spectral ratios are approximately dependent of magnitude, azimuth and depth for the events having epicenters 200 $\geq$ km from the city. Singh and his co-workers (Singh et al; 1980) calculated the relative spectra for different parts of the city by using the several measurements from strong earthquakes occurred in the region from 1985 to 1987. They defined the area in which a particular threshold stage for the relative amplification has been exceeded for setting a frequency range approximately as the natural frequency of the site. They established that this area is that most effected (serious damage and collapse of buildings) during Mexico City (1985) earthquake (Singh, 1988).

Disadvantages of the SSR technique are as follows
Mostly it is difficult to find reasonable reference site as it should be situated on flat surface and crystalline rock. Sometimes reference site is located on other type of rocks (sedimentary rock), which may influence the assessment (Roger, 1984).

Data can be divided in four groups Microtremors, weak motion data, Strong motion data and data from synthetic sources. Site response spectrum will be estimated with different quality depending upon the type of data used. To compute SSR the most reasonable type is strong motion data as influence of the target event is directly reflected. For a specific site under investigation this will give us not only the dominant frequencies but also the amplification factor. Weak motion data are usually used to compute SSR for the areas with low seismicity. The amplification factor calculated from weak motion data has a tendency to overestimate the actual amplification value for strong earthquake. This is because of the non-linear behavior of the soil (general trend is that increasing magnitude level will decrease the amplification factor). Therefore, if SSR has been computed with weak motion data one has to keep in mind that the amplification factor may be not constrained although the dominant frequency can be obtained. However, it is generally accepted that nonlinearity exists in few cases. It is difficult to find the evidences from data for the nonlinear behavior of the soil. Spectral amplifications computed by using weak(Nuclear test) and strong motion(San Francisco 1957 earthquake) data is well in agreement but not at minute level as mentioned by Boecherdt. For Izmit 1999 earthquake there were not big differences between the amplification factors calculated by using weak and strong motion data (Ozel et al., 2002).

It is observed that the cities situated on hill tops experienced more damage than the cities situated on the foot hills. It has been argued by authors that instrumental confirmations exit that the surface topography influences the amplitude and frequency contents of the motion. The focusing and defocusing of the incoming seismic waves may be due to particular topographic features of the area of interest. So it is expected that if the reference site is located near a hill top the computed reference site spectrum may be influenced by the topographic features. (Bard, 1994; Lacave, 1999).

4.2.2 Surface-Borehole Spectral Ratio Technique (SBSR) - Reference Site Technique

SBSR is the most reliable method among the methods for the estimation of the site response. This technique was fist introduced by Liu (1992) for the evolution of site effects of the Marina District of San Francisco that suffered extensive damage during the Loma Prieta 1989 earthquake (Liu, 1992). The idea is to compute the spectral ratio for earthquake data recorded with two stations (one on the surface and other on the bed rock) simultaneously. Two identical stations have been used to carry out the experiment in Marina District San Francisco. Eight events (with high signal to noise ratio) have been recorded and ground motion acceleration spectrum has been calculated for the both (for surface and bed rock). It has been observed from the results that the lowest frequency spectral ratio peak for all earthquakes occur at the same frequency, but in case of locations of higher frequency peaks are scattered due to fact that high frequency part of the surface to borehole spectral ratio is dependent on earthquake location and direction of the motion. The amplification factor varies in large even for the lowest frequency spectral ratio peak. It has been observed for the two very near earthquakes from the same data set the amplification factors for the lowest frequency peak are not close to each other (reliance of the spectral ratio on Magnitude). Dataset was divided in to two by sorting out approximately the earthquakes as per their location and calculating the spectral ratios individually for each of the two datasets. It has been observed that not only the lower frequency spectral ratio peak is rational but the higher frequency spectral ratio peaks are also become consistent. So the reliable estimation for frequency content of the site response may be achieved by preparing the dataset cautiously. In this way one can find the frequencies on which highest amplification of ground motion may occur. As the site response is dependent on earthquake location and magnitude that is why the amplification factor for each frequency still can not be constrained so well. Apparently it gives the impressions that the frequency content of the spectral ratio spectrum is dependent on the location, while the amplification factors for different frequencies dependents on magnitude (Liu, 1992; Aki, 1993; Borcherdt, 1970).

The major advantage of the technique is we are recordings are concluded on the same site, one at the surface and other at the depth. Therefore, the source and path effects are nearly the same, certainly depending on the distance of the recorded event and on the depth of the borehole. However there are some disadvantages of the SBSR technique

i)-A number of boreholes must be drilled for the estimation of the site effects and it will be very expensive.

ii)-The major disadvantage using the SBSR technique is that there will be feed back from the surface to borehole sensor because it will not record only the incident waves coming from the source but also those reflected from the surface. So the sensor in the borehole will contain bore record and part of surface record. It can produce wrong estimates of the actual site response function due to the coupled borehole record (Safak, 2001).

iii)-The high frequency (man made noise) depends on depth. The level of such noise at the station deployed in the borehole is much lower due to attenuation of the noise with depth (Liu, 1992).

4.2.3 Nakamura Technique- Non-Reference Site Technique

It has been observed from many studies that damages are caused by the latest earthquakes are accomplished as a direct consequence of local geological setting distressing the ground motion. Direct observation of seismic ground motion is the best approach to recognize the ground conditions, but such studies are constrained to seismic prone area or with comparatively high rates of seismicity. Because of these restrictions in other methods, such as high rates of seismicity and the accessibility of a sufficient reference site, non reference site methods have been applied to site response studies. To estimate the effect of surface geology on seismic motion exclusive of requiring additional geological information microtremor is an incredibly suitable tool (Nakamura, 2000).

Reference site techniques provide reliable results about the local site effects but these comes at a certain cost because one has to install a seismic network or boreholes where one can install instrument. If site response spectra has to be calculated for several sites. Several stations are needed at many points to collect data for a long time or we have to make bore at many places for boreholes, which are not possible always and expensive (If area under observation is densely populated). Therefore it will be very difficult to use two methods (Standard Spectral Ratio and Surface borehole spectral ratio) due to these constrains. These methods are expensive as well as time consuming.

Keeping in view the limitations of each method, easy and inexpensive method was proposed in 1989 by Nakamura (Nakamura1989) for the assessment of the local site effects. In this technique ambient seismic noise is used which is always present in the earth. Nakamura states that the ratio between horizontal and vertical ambient noise records is related to the fundamental frequency of the soil under the site and thus the amplification factor. The theory and hypotheses are not collectively accepted by the scientific society but comparisons with other methods have demonstrated the suitability and competency of the technique (Rosset et al.-Reaserch article-). It is based on the spectral ratio (horizontal and vertical component of seismic trace) and gives a reliable approximation of the fundamental frequency of specific site. It is the most significant from seismic hazard point of view because this is the frequency (fundamental frequency) on which amplification occur because of local site effects.

This technique based on three main hypotheses developed by Nakamura 1989

i) Ambient noise is generated by reflection and refraction of shear waves within shallow earth layers and by surface waves.
ii) Cultural noise sources do not influence ambient noise at the base of the unconsolidated structure.
iii) Soft earth layers do not amplify the vertical component of ambient noise.

It is based on the spectral ratio of the horizontal and the vertical components of the short seismic records, gives a reliable estimate of the fundamental site frequency. This is the frequency on which the strongest amplification occurs due to local site effects, so it is the extremely significant for seismic hazard prospective.

Transfer function (S_T) for surface sedimentary layers is defined as

$$S_T = {S_{HS}}/{S_{HB}} \qquad {S_{HS}}/{S_{HB}} \qquad (4.4)$$

Where S_{HS} is the horizontal shaking spectrum observed on the surface and S_{HB} is ground motion spectrum on the boundary between the bed rock and the surface layer. The horizontal shaking spectrum on the surface is affected by the surface waves in that layer which is there as Rayleigh waves (Atakan 1995, Nakamura 2000). Rayleigh wave's effect should be reproduced on the vertical spectrum of the surface layer S_{VS}, but it is not included in the vertical shaking spectrum of the bed rock S_{VB}

So the effect of Rayleigh waves on the vertical tremor should be represented by the transfer function E_S which can be written as ¨

$$E_S = \frac{S_{VS}}{S_{VB}} \qquad (4.5)$$

In the absence of Rayleigh wave E_S = 1. By assuming E_S = 1 on bed rock/sediment interface. Another transfer function will be obtained after dividing the transfer function S_T without any affect on it.

$$S_T = \frac{\frac{S_{HS}}{S_{HB}}}{\frac{S_{VS}}{S_{VB}}} \qquad (4.6)$$

Simplifying the equation

$$S_T = \frac{S_{HS}}{S_{VS}} \times \frac{S_{VB}}{S_{HB}} \qquad (4.7)$$

It has shown experimentally by Nakamura (1989) that the Ratio $\frac{S_{VB}}{S_{HB}}$ = 1. Considering it correct. Therefore transfer function S_T may be expressed in terms of spectral ratio of the horizontal to vertical components

$S_T = \frac{S_{HS}}{S_{VS}}$ This technique is also known as Nakamura`s technique or H/V spectral ratio technique.

The method has the following advantages and disadvantages

1- This technique avoids the necessity of having reference site. In case of Spectral spectrum ratio method it is not possible always to find suitable reference site. Sometime the reference spectrum is not perfect (abnormal peaks or troughs may manipulate the computed spectra). By using Nakamura method reference site is not required at all. (Bard 1994, Field and Jacob 1995, Nakamura 1989).

2- Avoid the necessity of waiting for seismic event. Standard spectral ratio technique we have to record continuously in order to record some seismic events. It is not required by the Nakamura method. The record can be made any time and make it just as long as our computing algorithms needs.

3- This method is convenient and low cost with respect to other techniques (SSR, SBSR and HVSR). Records can be made or analysis can be done by using one or few portable stations. (Ref. Site effect assessment at small scale….)

However, there are some disadvantages as well;

1- Reliability is low for the assessed amplification factors. As said by Nakamura, the similar conclusions made for the spectra estimation can be done regarding the amplification factors at the frequencies of interest. On the other hand other argues that the relationship between amplification factor acquired with SSR and HVSR for the similar site is meager (Atakan, 1995; Bard, 1994).

2- It is not possible to acquire higher harmonics of the fundamental site frequency. Some scientists mentioned that higher harmonics of the site response spectrum, estimated by using H/V spectral ratio method are not reliable estimation (Lacave, 1999). Fine relationship between the site response spectra for the similar site attained by using different techniques is established only for the fundamental site frequency (Bard 1994; Bard 2004, Lacave 1994). Nakamura technique is not reliable mean for the estimation of higher harmonics of the site response spectrum.

Lermo and Chavez-Garcia 1993 used the idea of horizontal to vertical ratio but they used the intense S-wave portion of the records of real small earthquakes instead of

microtremors. They admit that it is difficult to explain why a technique considered for Rayleigh waves should work for the intense S-wave part of the seismograms. They propose two probable causes. The first argument, it has been observed that the vertical component of the displacement had the same character and amplitude irrespective of the nature of soil under the station but it is not the case for horizontal component. The second argument comes from simple 1D numerical modeling illustrated in the paper; we are not going in detail here. The final results acquired by the authors (Lermo and Chavez-Garcia) are extremely attractive. They demonstrate for three different sites with diverse subsurface geological circumstances.
The standard spectral ratio technique and Nakamura technique applied on S-wave are extremely fine concord for fundamental mode and they can be used to assess site effects because of either soft sedimentary deposits or topography effects (Chavez-Garcia, 1993).

Other authors mentioned like (Lacava, 1999), the end results obtained by computing H/V ratio for S-waves demonstrate really nice investigational stability and accord with subsurface geology, on the other hand they also point out that determination of the amplification factor is not an easy task.

During an earthquake the shaking of the ground depends on many factors. One of these factors is the soil conditions of the site of the earthquake affected area. The observation of stronger shaking on certain soils is simply understandable and so significant that soil classification with discrete spectral features is an important part of each building codes. Different soil type with different spectra is shown in figure 4.0 and soil classification with description is given in table 4.0. The simplest method to calculate natural frequency and amplification factor for soil structure overlying a rock is given in equations 4.8 and 4.9 respectively. Natural frequency is directly proportional to the shear wave velocity (Vs) in the layer (H) and inversely proportional to the thickness of the layer (H), whereas the amplification is direct function of impedance contrast. (Chavez-Garcia, 1993).

$$f_0 = \frac{V_s}{4H} \qquad (4.8)$$

$$C = \frac{\rho_2 V_{S2}}{\rho_1 V_{S1}} \qquad (4.9)$$

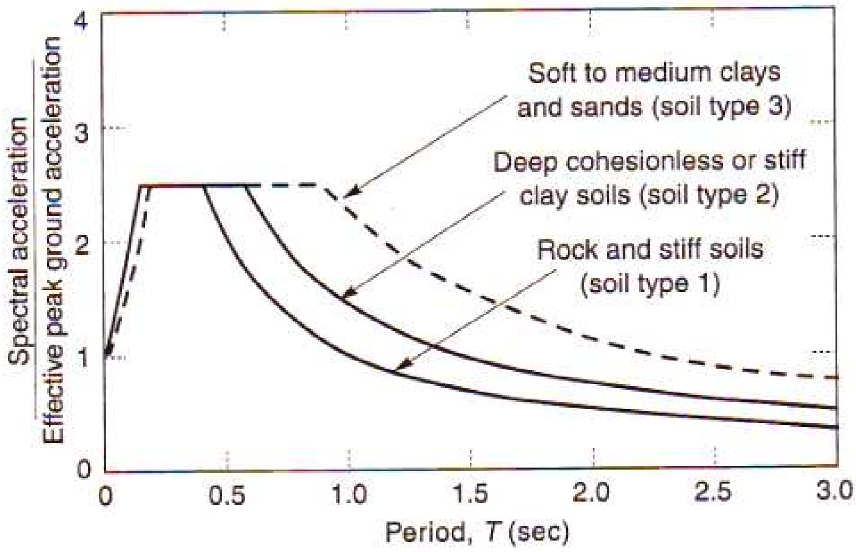

Figure 4.0:- Different Response spectra for different soil types (UBC, 1994; Kramer, S.L, 1996).

Where f_0 is fundamental frequency and C is amplification factor, Vs shear wave velocity, H thickness of the sediments layer, ρ_1 and ρ_2 are the densities of the sediment layer and hard rock and V_{S1} & V_{S2} are shear wave velocities in the sediment layer and hard rock respectively, analogous to the densities ρ_1 and ρ_2.

Ground type	Description
S1	a)Rock or rock like formation, characterized by a shear wave velocity greater than 800m/s or by other reasonable means of classification or b) Medium-dense to dense or medium- stiff to stiff soil condition where the soil depth is less than 66m
S2	A soil profile with predominantly medium-dense to dense or medium- stiff to stiff soil condition where the soil depth is more than 66m
S3	A soil profile containing more than 7m of soft to medium stiff clay but not mare than 13m of soft clay
S4	A soil profile containing more than 13m soft clay characterized by the shear wave velocity lass than 166 m/s

Table 4.0: - The soil description (UBC, 1994; Kramer, S.L, 1996).

4.3 Instrument Description

SN04- Noise Tester

Sensor	3 geophone
Sensor Natural Frequency	4.5 Hz
Recording Capacity	None
Damping	0.7
Digitizer	24 bit
Gain	$33.1 \times 10^6 \ {}^{Counts}\!/_{Volts}$
Filters	1 pole anti alias filter at 9 Hz
Seismometer Generator Constant	78 V/(m/s)
Power	9 Volts Dry Cell
Power Consumption	0.6 W
Communication	Serial Line
Weight	0.8 kg

Table 4.1:-Technical specifications of the SN04- Noise Tester Seismic station (Havskov and Alguacil, 2004; Mariotti, 2005).

4.4 Software used

SEISAN- The earthquake analysis software (Havskov and Ottmoller, 2008)

The SEISAN seismic analysis system is a complete set of programs and data base for analyzing earthquakes from digital and analog data. It includes a set of programs written generally on FORTRAN, a few in C attached to the same database. Majority of the programs can run in a data base manner or in straight way by using single file with several events. In addition SEISAN includes some integrated research type programs for example coda Q, synthetic modeling and an entire system for seismic hazard computation. SEISAN runs under SUN, SOLARIS. LINUX, Mac OSX and Windows 95, Windows 98, Windows 2000. Format conversion is not required to move data files (binary and ASCII) between the systems if one of the typical formats (SEISAN, GSE, SEED, SAC ASCII) is used. SEISAN is dedicated software available for all non commercial use.

For data recording in two cities Islamabad and Muzaffarabad two programs of SEISAN package has been used- DIRF and WAVETOOL.

DIRF is valuable program for making a file with a numbered list of files from DIR (ls on SUN) command. This program generates a file names filenr.lis. Then one can process all the files in a given directory by using filenr.lis file rather than inserting every file separately.

WAVETOOL is a program that extracts all or selected time sections of waveform data, optionally applies some signal processing and then creates the output file. The input formats supported are SEISAN, SEED, MINISEED, GSE and SAC (UNIX Only) and the output format are SEISAN, MINI SEED, GSE and SAC (only for UNIX). This program can also be used as conversion program among these formats. This program can also take out data from a SEISAN continuous data base.

A public domain data acquisition system SEISLOG was initially developed for the Norwegian Seismic Network. It is operating on Intel machines under the real time, UNIX- like real time operating system, QNX, under Windows and under Linux. During field work SEISLOG system was used for the computer used (laptop) to acquire data.

J-SESAME (Atakan et al. 2004) is a JAVA program to provide graphical interface for calculating H/V spectral ratios from measurements of ambient seismic noise. A general view is shown in fig 4.1.

There are four basic modules of this program- Browsing module, Window selection module, Processing module and Display module. The major functionalities are incorporated by a graphical user interface, which is a component of browsing module.

In case of browsing module one can arrange data in individual projects. We create project for each area and the different points in that area, for which we have measurements, are displayed as subfolders of the project folder. These subfolders are created by executing the command: insert site: from the screen menu.

In these subfolders we add data which are the seismic waveform files recorded at site and converted to GSE format through SEISAN software. We insert the noise record by clicking on insert data file from screen menu. One may insert as many files as he has for the specific site. After inserting the files we may plot the seismic noise record individually and perform different operations (Window selection, filtering and processing) on them. The filtered and unfiltered traces are displayed together one above the other for comparison if we decide to filter the traces after plotting them.

In case of window selection module one can select time windows from the recorded traces with different lengths. One wants to make sure that only stationary parts of the recorded ambient seismic noise included in the computations. The objective is to avoid the transients often associated with particular sources (Heavy machinery, nearby traffic, walks). Manual windows selection way is the best, but it is most time consuming and it is not suitable for processing a large amount of data such as two surveys data of the cities (Islamabad and Muzaffarabad, Pakistan). There is an option developed by the author in this program to select the automatic windows selection algorithm. Here objective is opposite, common aim of the seismologists who wants to distinguish signals, have developed particular trigger algorithm to trace the abnormal fleeting. In this case an antitrigger algorithm used. This algorithm is based on principle of short term average (STA) and long term average (LTA) STA/LTA triggering. The rule for this algorithm is to average the signal level over one short and long time window. There are upper and lower thresholds for STA/LTA ratio. We will like ratio to remain below some preset value (around 1.5-2.0) over a long enough duration so that no energetic transients are included in selected windows. Simultaneously we also want to avoid abnormally low amplitudes, so we also define a minimum threshold and it is desired that the signal will remain above it. If the signal drops under that preset lower bound then corresponding window is not chosen by the algorithm.

We may also want to exclude signals with amplitudes above 99.5% of the maximum observed amplitude in our noise records in order to avoid signal saturation.

As soon as the window is selected the algorithm looks for new window. The neighboring windows will generally overlap and overlap amount is either set by the user or 20% by default.

The display module is used to display the traces, plot the outcome or carry out dissimilar operations on the traces such as zooming or manual window selection. Simply the results of the performed manipulations on the records can be seen on the display module but not the process themselves.

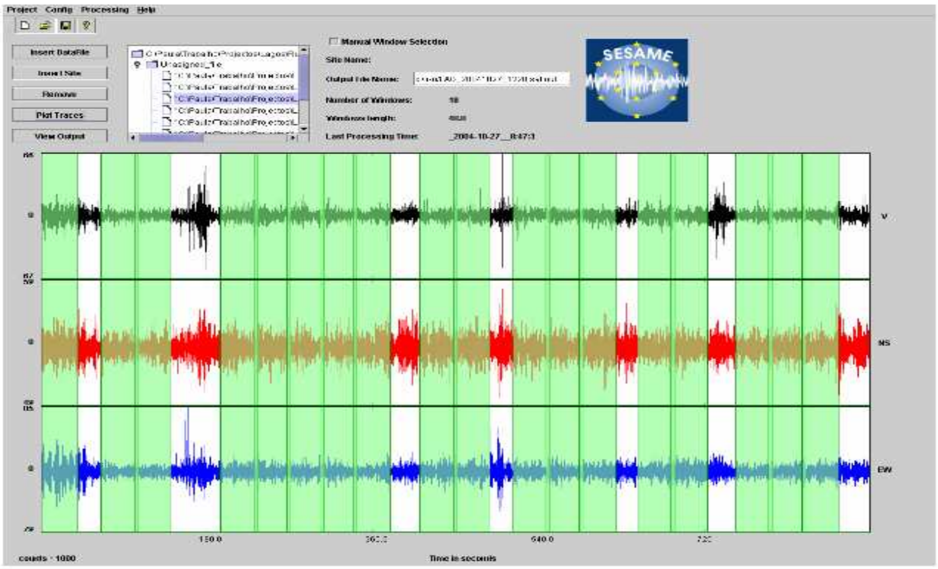

Figure 4.1:- General view of J-SESAME (Bard et al, 2004).

4.5 Data Collection

Data has been collected in two field work during December 2007-January 2008 and summer break 2008. In the first trip data has been collected from Muzaffarabad city, Azad Kashmir, Pakistan. This city was mostly affected during Kashmir earthquake 2005.

Unfortunately the political situation was unstable during this visit. Another reason was reconstruction projects were in progress in the city which constrains to take observation according to the plan. At 90 sites observation were made by using the SN04-Noise tester. Due to reconstruction and densely populated area sites were not ideal, compromised sites had been selected. The observations were taken during the period (Dec-2007-Jan-2008). The average daily maximum temperature was around 20 °C.

Google map was used to determine the sites to be measured. The distribution of the sites is random because of constrains due to demolished buildings, reconstruction work, topography and uncertain political situation. Although it was tried during survey the best to minimize the cultural noise as much as possible. In this regards few measurements were made during night time. This was the first data set collected.

The second data set was collected during the survey in the F-10 sector Islamabad capital of Pakistan consist of 115 sites. These measurements were performed in the pre selected one sector of Islamabad where a multistory building was collapsed during Kashmir (2005) earthquake. This field work was carried out during summer (July-August 2008). The average temperature was + 40°C during the filed work. Contrary to Muzaffarabd Islamabad is a plan city. Some difficulties were due to traffic, densely populated area and thick green areas (trees).

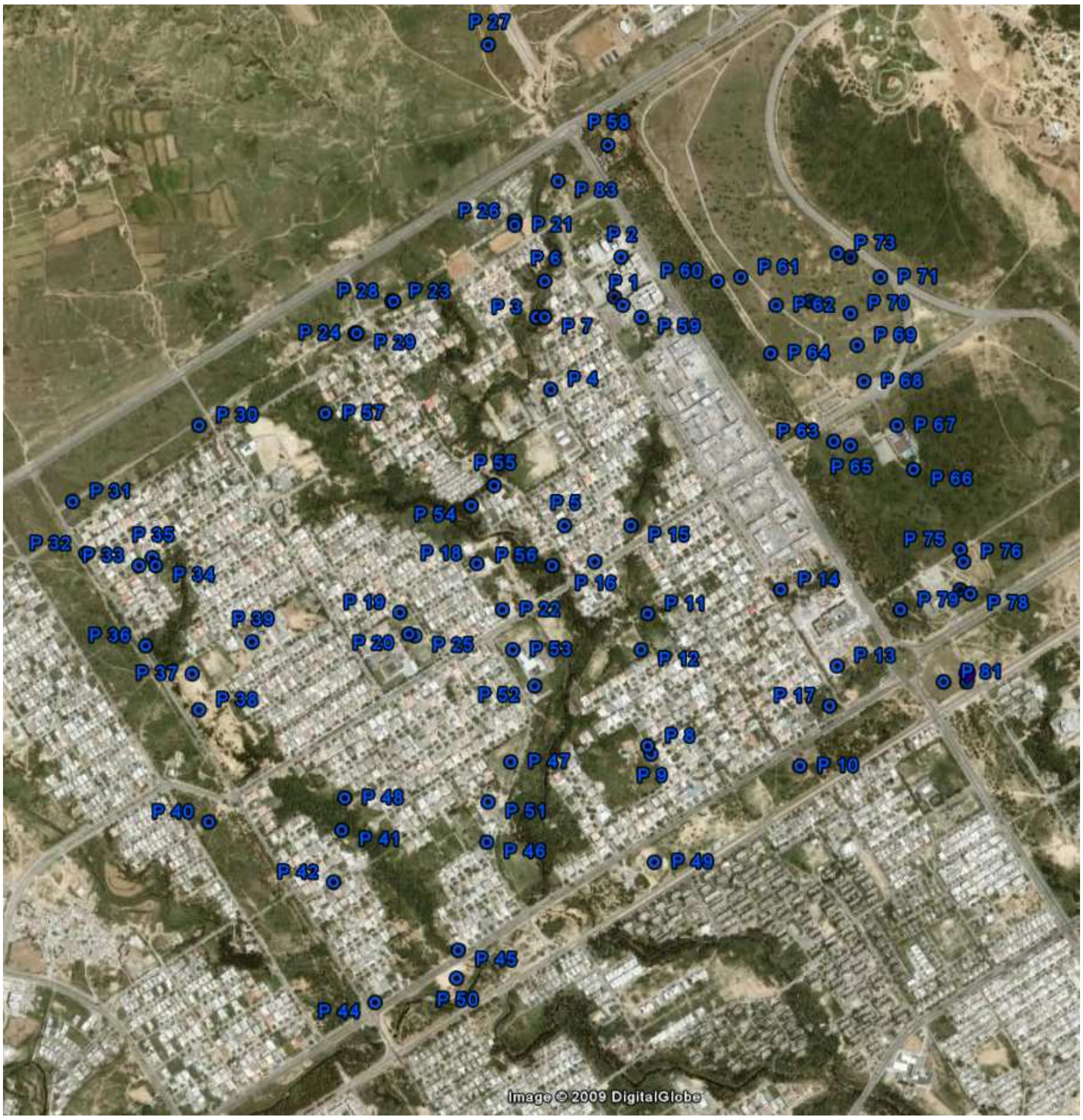

Figure 4.2:- Map of Islamabad F-10 sector showing the location of sites as blue circles at which ambient seismic noise observations were taken plotted on Google earth.

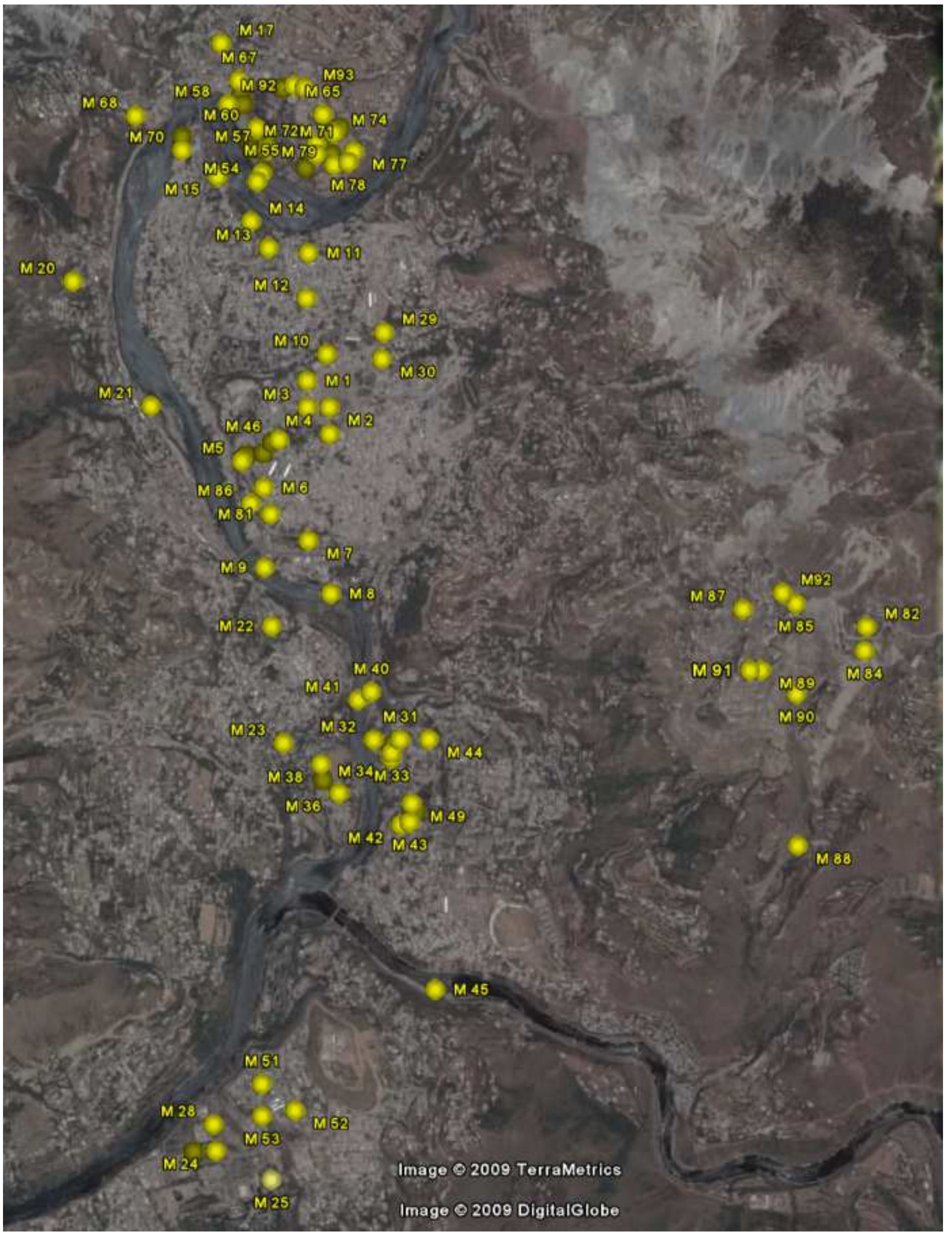

Figure 4.3:- Map of Muzaffarabad city showing the location of sites as yellow circles at which ambient seismic noise observations were taken plotted on Google earth.

4.6 Analysis and results

There are two types of empirical methods to determine dominant frequency and amplification factor, reference site and non reference site method. Nakamura 1989 introduced a simple and inexpensive technique which is widely used method to find the resonance frequency of the site. This method is based on horizontal to vertical (H/V) spectral ratio of the ambient noise records (Mundepi, 2009).

The method used to estimate the site response spectra in both of the cities (Muzaffarabad and Islamabad) of Pakistan is non reference site technique for the assessment of site response using ambient seismic noise which is also called the Nakamura method (Nakamura 2000). The method has already been discussed in previous chapter. The method has been refined and software (dedicated) has also been developed during the extensive three years project *site effects assessment using ambient excitations* (SESAME). This project was funded by the European Commission (Atakan et. al, 2004. 2003, 2002, Bard, et al., 2004, Koller, et al., 2004). Complete details about the project could be found web page http://sesame-fp5.obs.ujf-grenoble.fr/ .

4.6.1 Description of the measurements series

For the estimation of site response spectra from micro tremors is based on taking ratio of horizontal (H) and vertical (V) component of the recorded ground motion (Nakamura 2000, 1989). The ambient Seismic noise present in the ground is the main source for this ground motion. In this study recordings have been made for ambient seismic noise in different places (Muzaffarbad and Islamabad, Pakistan). On the basis of these recorded observations J-SESAME program used to compute the corresponding results (spectral ratios) (Atakan et al., 2003, 2004).Nakamura approach is reliable for the determination of the fundamental site frequencies but it has also been observed that frequencies of higher order cannot be reliably determined by using this approach. Since fundamental frequency (site response) is the prime important from an engineering point of view. The higher modes of this frequency (fundamental frequency of site response) are infrequently some important. Nakamura method has another disadvantage it cannot control well the precise amplification factor of the fundamental site response frequency. By using this approach one can get some general in sight about the amplification factors. One should always keep in mind that amplifications are feebly constrained. If it is desired to have better control over the amplification factor, other techniques may be used at one site of interest so that amplification factors can be compared.

User may obtain fundamental site response frequency at several different sites at low price and comparatively in short periods of time by using Nakamura approach which is a significant advantage. This is not possible by using other methods. Generally measurement at one point or site lasts about 40 minutes. Time takes to move the equipment from one place to another (distance between sites 150-200 m) is on average about 20-25 minutes on foot and use any transport like car about 10-12 minutes. Thus on average time for one measurement is about 50-55 minutes. According to this in one working day one may take 6-8 observations. A data base of 185 points can be collected by single person in 20-30 days. Comparatively if using other method like standard spectral ratio may take couple of months and need several persons to maintain continuous operation of the seismic network for collection of data for site response spectra. In this case again the output would be site response spectra for few sites and the cost for setting up and function of the network will be considerable. One of the selected cities (Muzaffarabad) was demolished badly during Kashmir (October 2005) earthquake, heavy construction was in progress which was also one of the major constrain to select a site for observation. In addition to earlier mention constrains the area under investigation (Muzaffarabad) is thickly populated area and it is not a planned city. These constrains do not allow me to take site measurements as planned. The grid points are not even because of ground realities mentioned earlier.

Seismic noise is always present in the ground which is used in case of Nakamura technique for assessment of site response; again it is an advantage over the other techniques (Standard spectral ratio and Surface to borehole spectral) which required to registering many earthquakes to determine the site response spectra. (Field and Jacob 1995, Liu 1992)

4.6.2 Steps to perform

We use Google earth map and mark the points for measurements. These sites for measurements should be uniformly distributed to cover the pre-selected area. In order to get good quality contour maps, one needs to have evenly distributed points of measurements. From Google map by using the grid option, the coordinates of the grid points are taken for site measurements. Due to heavy construction in progress, debris, complex topography and thickly populated area, unable to obtain even distribution of the sites of measurements for both of the cities(Muzaffarabad & Islamabad). In case of Islamabad comparatively close to the pre-set target (Uniform distribution of measurement sites) as the city is well planned. Sometimes there are unavoidable reasons to measure exactly at the desired site (may be middle of the street or front of the shopping center). In this case tried to find a suitable place as much as close to the desired point. The site should be as far as possible from working machinery, multistory buildings, tall trees, heavy traffic streets, factories which may bring in ground motion with a specific frequency. Sensor and computer should not be set under direct sunlight if feasible (This was not achieved in case of Islamabad survey which was conducted during summer June-July). It has been realized during filed work that by keeping away from direct heat on the equipments, provide the best achievable performance of the sensor and computer and make longer battery life. As sensor used is not water proof sensor. Observations should not be taken when it is raining as it generates seismic noise. Observation must not be taken by putting the sensor on tall grass. If it is not possible to change the site then one should tramp the gross before placing the sensor at such sites.

After selecting site we use a magnetic compass to find the north direction and then orient the device to the north (as indicated on the instrument). Instrument must be leveled before starting observation; it can be done by using level. Once the instrument has been set we use global positioning system (GPS) receiver to find the coordinates (Latitude and longitude) of the point of observation. GPS takes some time to give precise coordinates. In some cases we have to repeat the latitude and longitude measurements in order to make sure that the coordinates are exact. All the electromagnetic devices and electromagnetic wave emitting equipment should place away from the sensor just to avoid any electromagnetic interaction between sensor and electronic device. During the survey before starting the instrument coordinates were taken and GPS was usually switched off.

After this turn on the instrument and connect it to a laptop computer through serial line. For data acquisition Seislog has already been installed in laptop. First time when we turn on the system, we must configure the device and channels properly as instructed in the manual. Channels must be configured and physically picked one by one. After configuration it is good to test the instrument whether it is working properly or not. It can be done by monitoring each channel for some time and performing jump test to check system shows the signal appropriately. Then the system set to record some time (5-10 minutes) in Bergen (park adjacent to university) at few places just to check the system and learn about the system before leaving for field trip to Pakistan. We must note start and end time of recording when record (event) will be dumped from computer or wrist watch or stop watch. Usage of stop watch is a better option technically. We used the timing from computer start and end time when record was dumped during field work.

When instrument has been set and is on for observation then we should make notes, sketches to illustrate the observation point as instructed in the guidelines for the field work. It is important to keep the track of information (date, GMT time, geographical coordinates, weather conditions like wind, rain and temperature) required later on regarding the observation points. During the field work we must note the nearby noise sources which can affect the real data collected for the site. The observer may collect/ note other information that can be used or helpful during analysis and interpretation of the data. This information may be particular for each observation point that occurred during the measurement. The measurements have been recorded carefully daily during field work. At the end of the day, when we have completed the planned observation for the day. We pack the equipment, bring back to residence and then store it in proper place (dry). In some cases when using rechargeable battery, one has to connect it for charging. We have to make sure before leaving for filed work from the residence that battery has been charged fully. Usually we did not use the battery during filed work. In sensor SN04, 9V dry battery was used and laptop battery was recharged as and when required. We also tried to connect the laptop with power directly whenever it is possible during the observation. It was also connected to power during any break (lunch or tea) just save time. Data were stored in different directories giving them specific number like ISB001, ISB002 for Islamabad city and so on and for Muzaffarabad MZD001, MZD002. At the end of everyday data were stored in USB as back up.

After completing the field work processing of data started, we used commands (DIRF AND WAVE TOOL) from SEISAN software to convert the data in GSE format which is acceptable by J-SESAME software. Now the data is ready to use J-SESAME software. At this stage we use J-SESAME to compute H/V spectra for every site and site response frequency.

4.6.3 Comparison of Two data quality in cities

Both of the studies involved measuring and recording the observations (ambient seismic noise) in two cities (urban areas) and collecting information about the local site conditions observed during the field work in the area under investigation. It was seen during two surveys that ground conditions like traffic, building were different. The Muzaffarabad city was badly affected by the October 2005 earthquake. The reconstruction work was in progress during the field work. At many places heavy construction machinery was on when the filed work was conducted. This was one of the major reasons that we are unable to take measurement evenly as planned. This city is not planned. Topography is also complex. The city is situated on the bank of Neelum River. Islamabad is a planned city and its topography is quite smooth as compared to Muzaffarabad city. This led us to anticipate that the two data set collected may not be very closely comparable. Here we will compare the quality of two data banks using two parameters inferred from noise traces and obtained site response spectra, number of selected windows and percentage of clear peaks.

Figurers 4.4 and 4.6 are bar graphs, show the number of selected windows for each point for the data sets collected in Islamabad and Muzaffarabad, Pakistan respectively. For most of the sites in the two data sets we made about 20 minutes records on the average. From the two bar diagrams we have seen that number of selected windows for each point for the data set collected in Muzaffarabad are comparatively less than the number of selected windows for each point for the data set collected in Islamabad. The average number of selected windows for each point in Muzaffarabad is 45 as calculated and shown in figure 4.7 with red thick line. However in case of Islamabad the average number of calculated selected windows for each point are 50 as shown in figure 4.5 red thick line. This may be because of the fact that measurements made in Muzaffrabad carry more noise from external sources (unwanted noise) as compared to Islamabad measurements. Since the number of selected windows for each point in Muzaffarabd is smaller than that of Islamabad, we may say that the quality of data set collected in Islamabad is better as compare to data set collected in Muzaffarabad. It has been known from the old studies that for trustworthy calculation of the site response spectra one need to have 10 windows 20 seconds each (Atakan 2004, 2003, Bard 2004). The two data sets show that the average numbers of windows are good enough what is required for the reliable computation of a site response spectrum. On the basis this we anticipate that both of the data sets must have the same class/quality with respect to calculated/computed site response spectra and also the taken out fundamental site frequency and amplification factor.

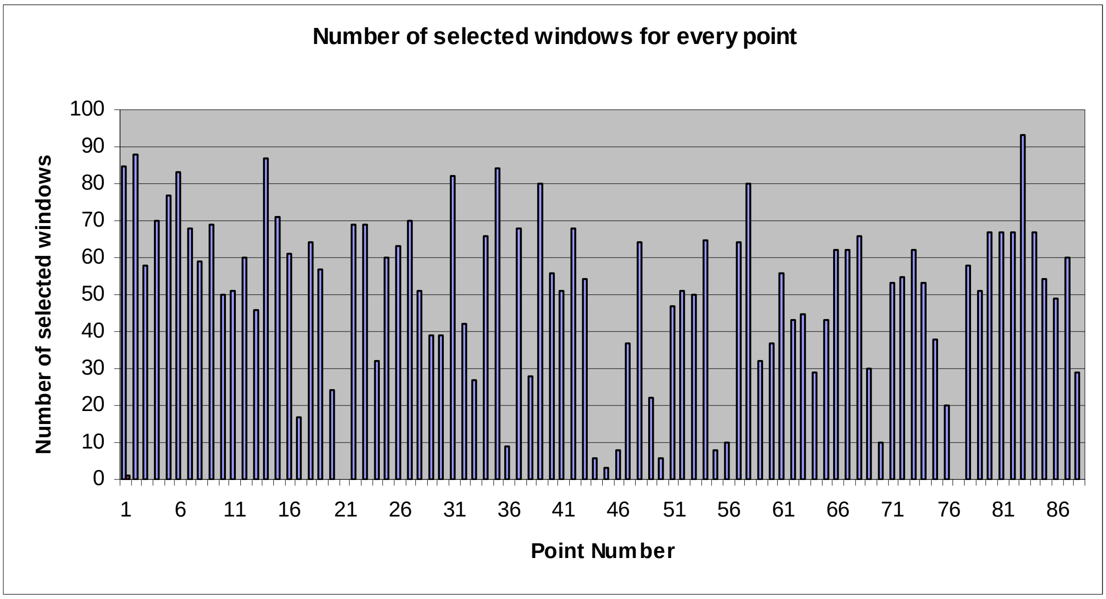

Figure 4.4:- Bar graph showing the number of windows selected for each point for the data set collected in Islamabad, Pakistan

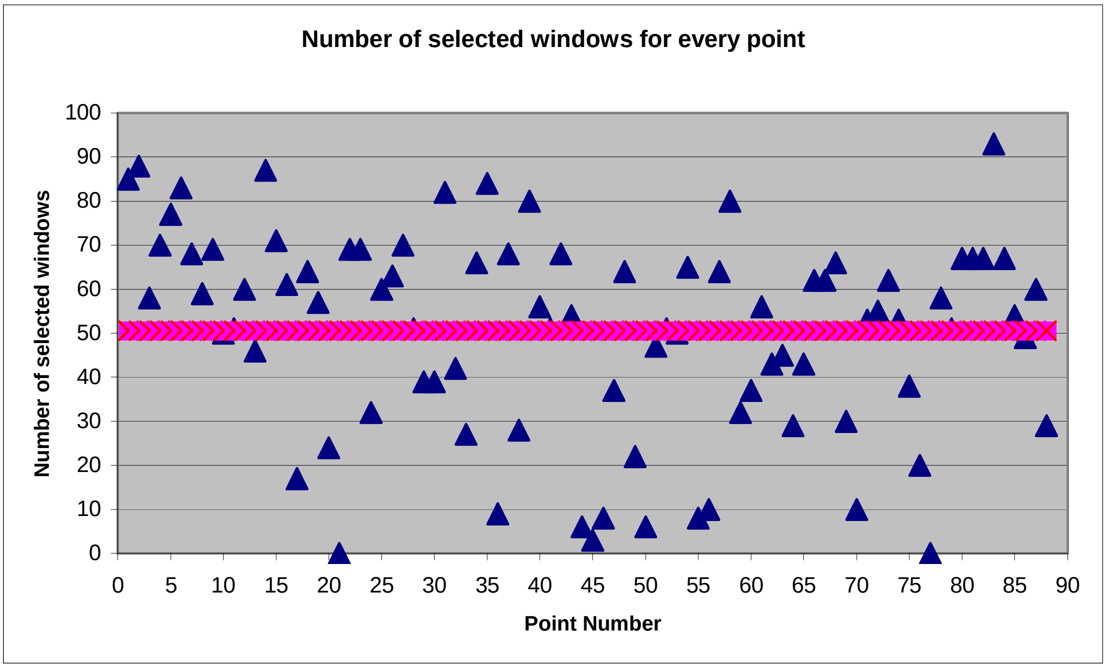

Figure 4.5:- Diagram showing the average number of selected windows for each point (thick Red line) and a number of selected windows for each point (blue triangles) for the data set collected in Islamabad, Pakistan

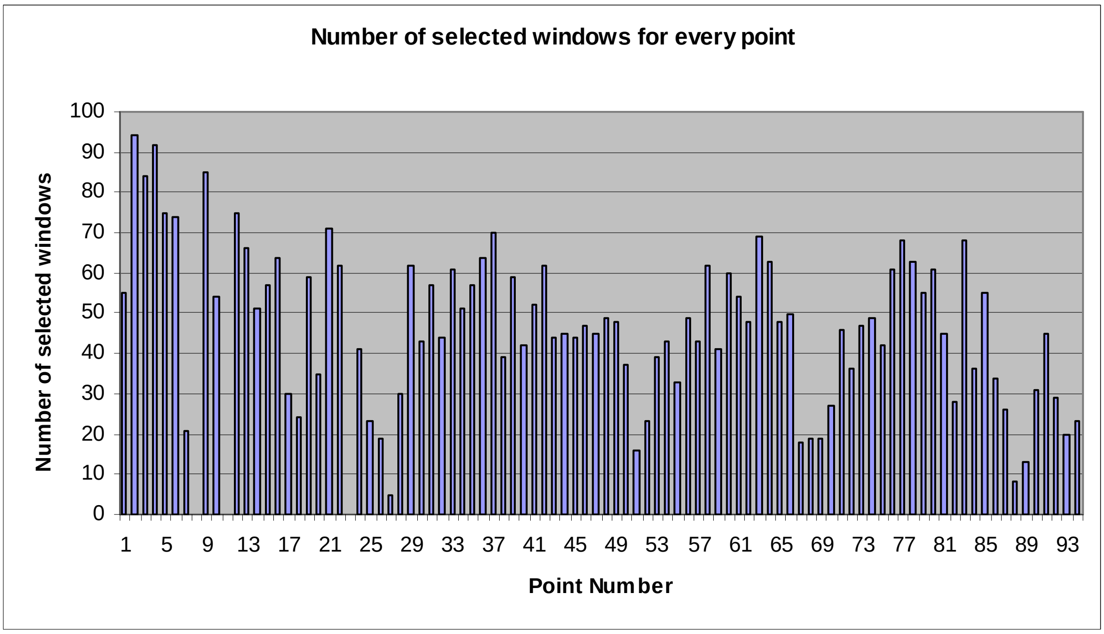

Figure 4.6:- Bar graph showing the number of windows selected for each point for the data set collected in Muzaffarabad, Pakistan

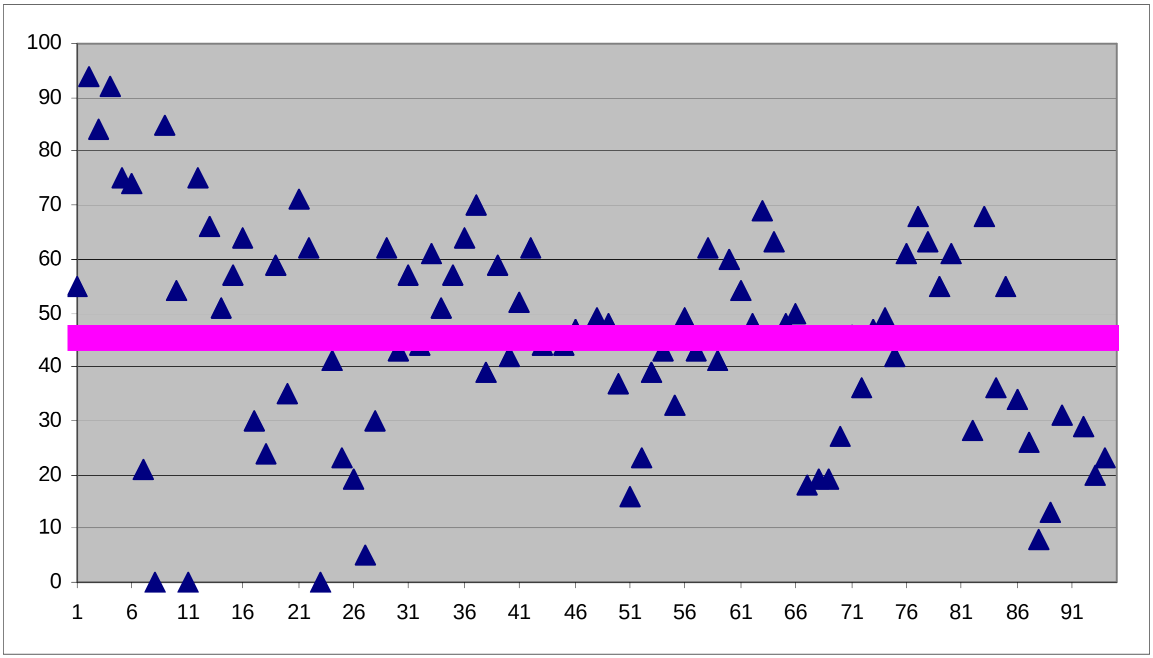

Figure 4.7:- Diagram showing the average number of selected windows for each point (thick Red line) and a number of selected windows for each point (blue triangles) for the data set collected in Muzaffarabad, Pakistan.

4.7 Classification of Spectra

The site response spectra computed from the data sets collected from the two cities (Islamabad and Muzaffarabad) can be categorize in the following three groups.

- Response spectra with single clear peak
- Response spectra with two or more peaks
- Response spectra with several peaks
- Response spectra with no clear peaks or very difficult to identify

Few examples are given for each groups mentioned above for the two data sets. All of the other spectra are available in appendixes in electronic form.

Statistics of the frequency Spectra computed for Islamabad and Muzaffarabad.

It has been seen clear spectra 80% in case of Islamabad database while 82% in case of spectra computed from data set collected from Muzaffarabad. Therefore, it can be concluded that the results obtained from analyzing the two datasets must have similar quality because the percentage of the clear spectra computed for both of the datasets is almost same.

However, it has mentioned earlier that in Muzaffarabad spatial distribution of the measurements points is not uniform (due to heavy construction in progress and cultural noise). Maps for Muzaffarabad have lower quality as compared to Islamabad.

4.7.1 Islamabad data base Response spectra with single clear peak

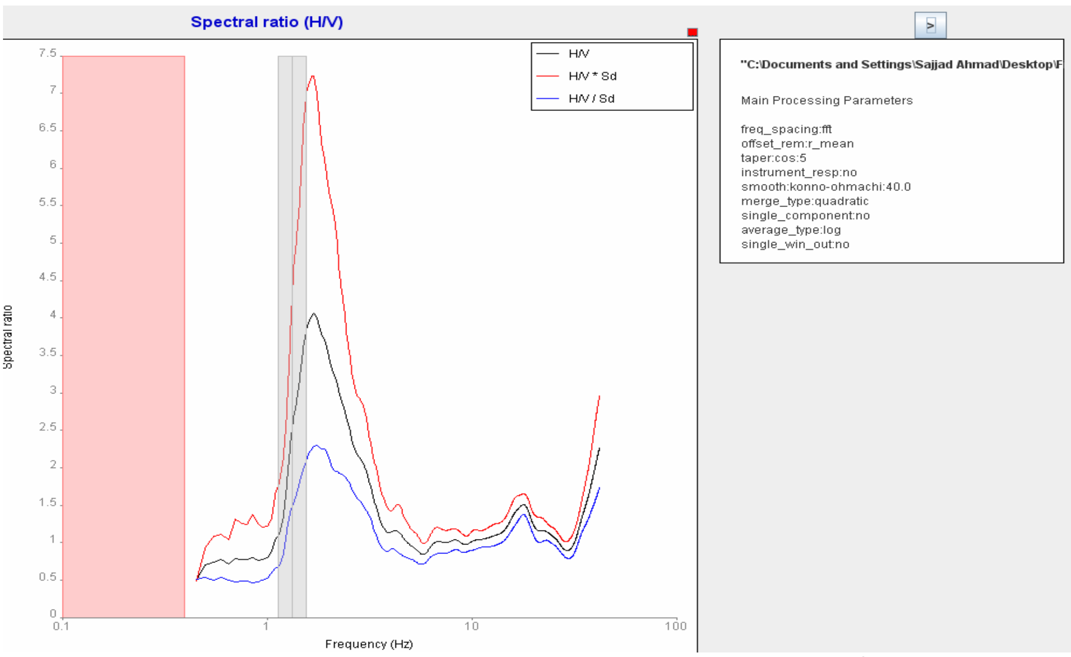

Figure 4.7:- Site response spectrum computed at site ISB085 showing a clear peak from the database collected in Islamabad.

Examples of site response spectra having a single clear peak are shown in figures 4.7-4.8 for the observation points ISB085 and ISB002 respectively. The peak frequency of this group is about 1 Hz. Majority of the spectra have peak close to 1Hz. The thickness of the sediments is not even in Islamabad area as mentioned earlier. It varies 30 to 100 (Sheikh et al.- Environmental study report).

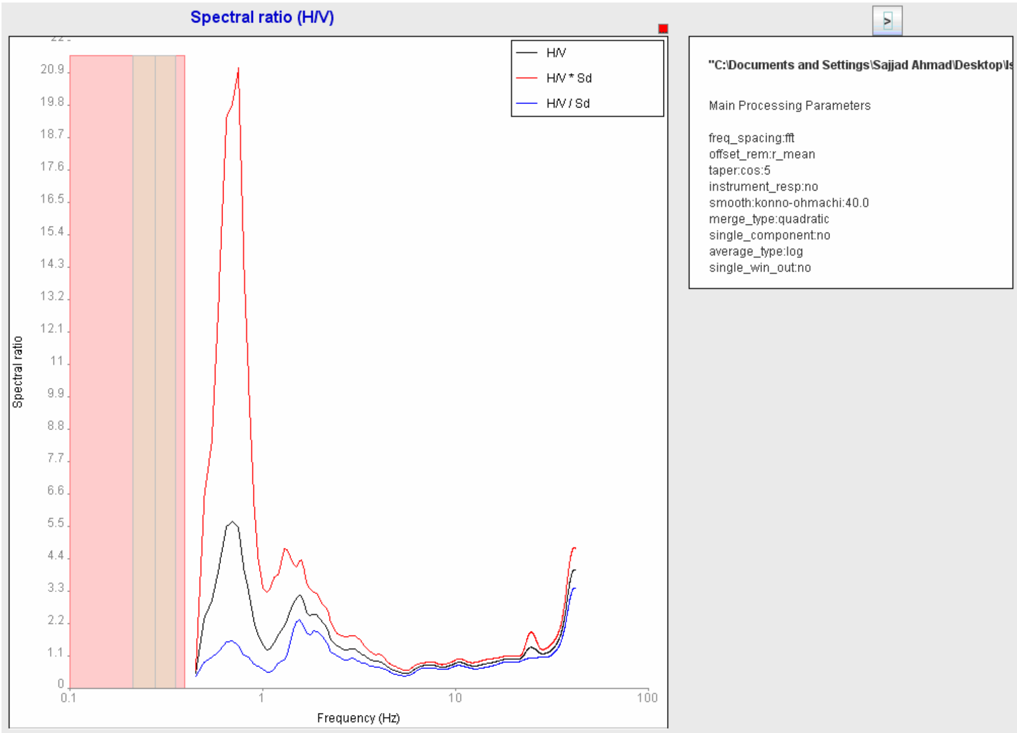

Figure 4.8:- Site response spectrum computed at site ISB002showing a clear peak from the database collected in Islamabad

Response spectra with two peaks

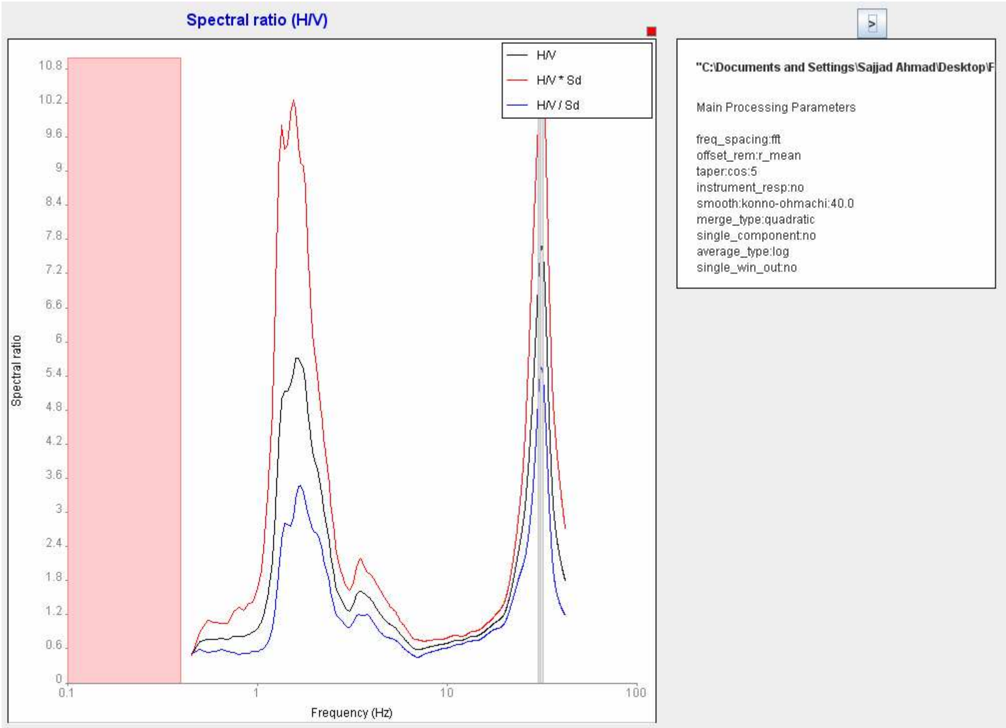

Figure 4.10:- Site response spectrum computed at site ISB081 showing two clear peaks from the database collected in Islamabad

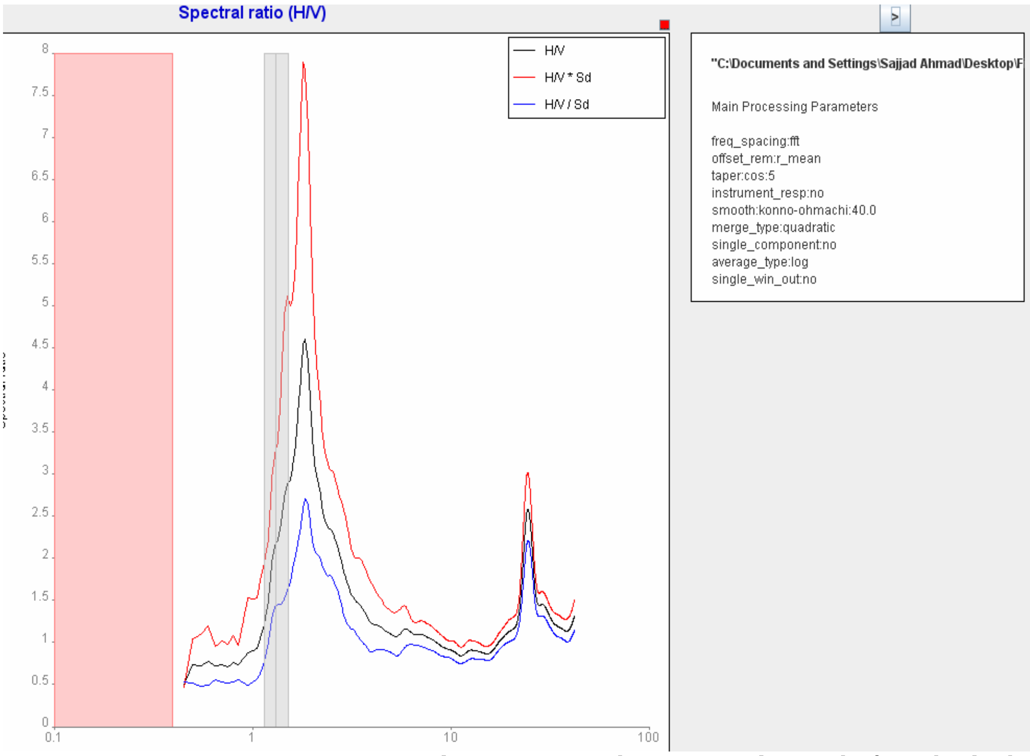

Figure 4.11:- Site response spectrum computed at site ISB048 showing two clear peaks from the database collected in Islamabad.

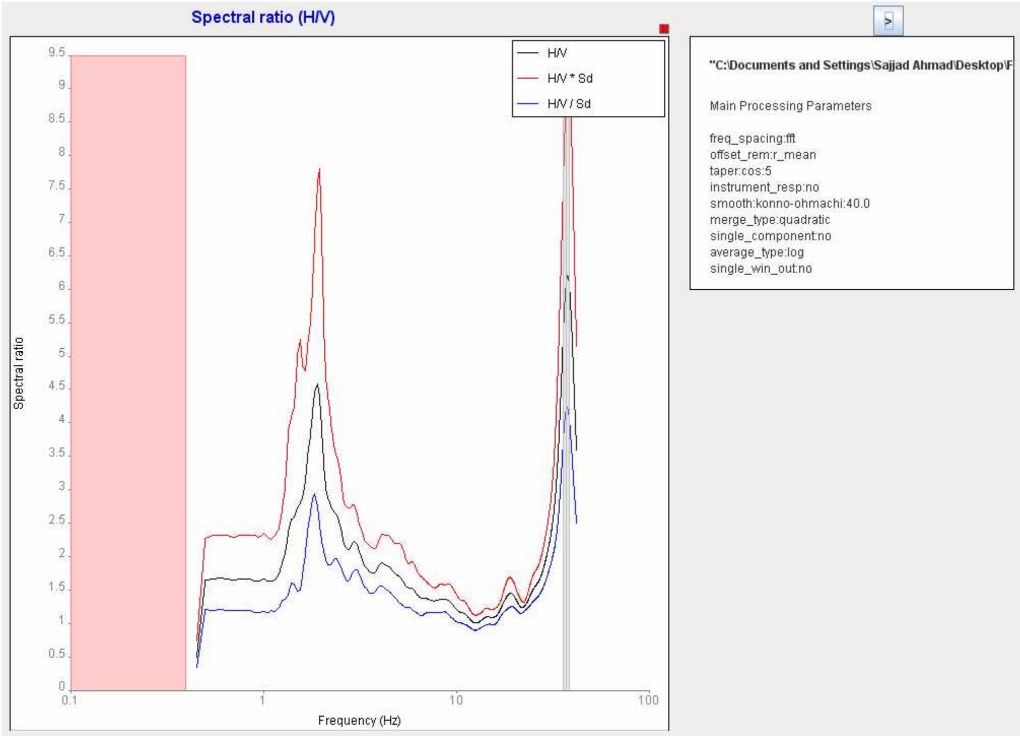

Figure 4.12:- Site response spectrum computed at site ISB017 showing two clear peaks from the database collected in Islamabad.

Site response spectra having two peaks are (ISB017, ISB048 and ISB081). The first peak in all of the spectra is close to one while the second peak is having the higher values. It seems to be due to noise present near the measurement site. There was frequent traffic near ISB017 and ISB048 at the time of observation. In case of ISB081 grass cutting machine was on at distance of about 16m, producing continuous noise.

Response spectra with several peaks

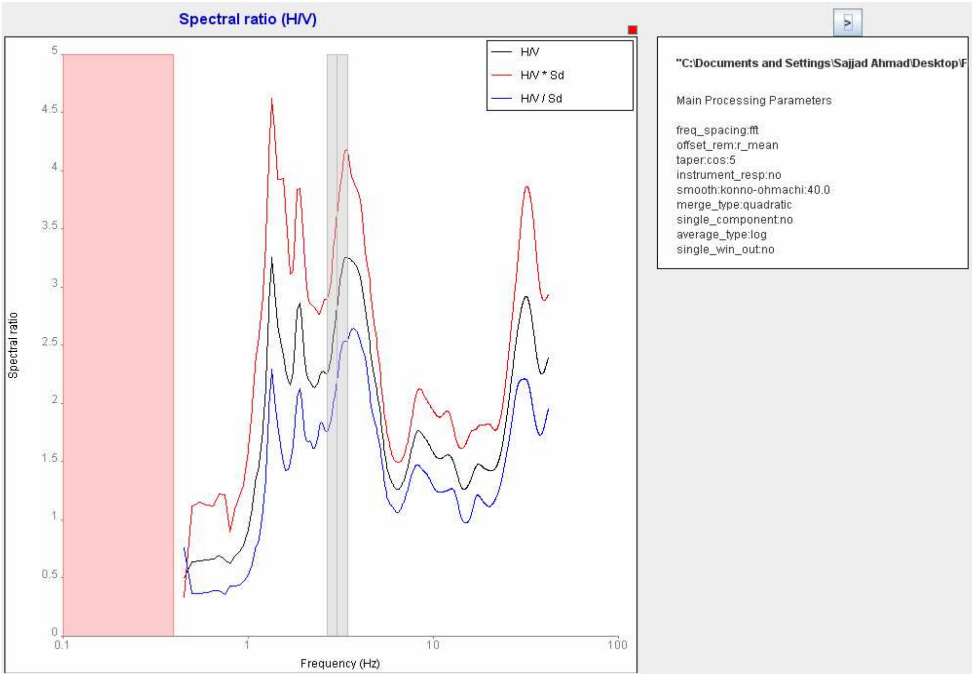

Figure 4.13:- Site response spectrum computed at site ISB073 showing several peaks from the database collected in Islamabad

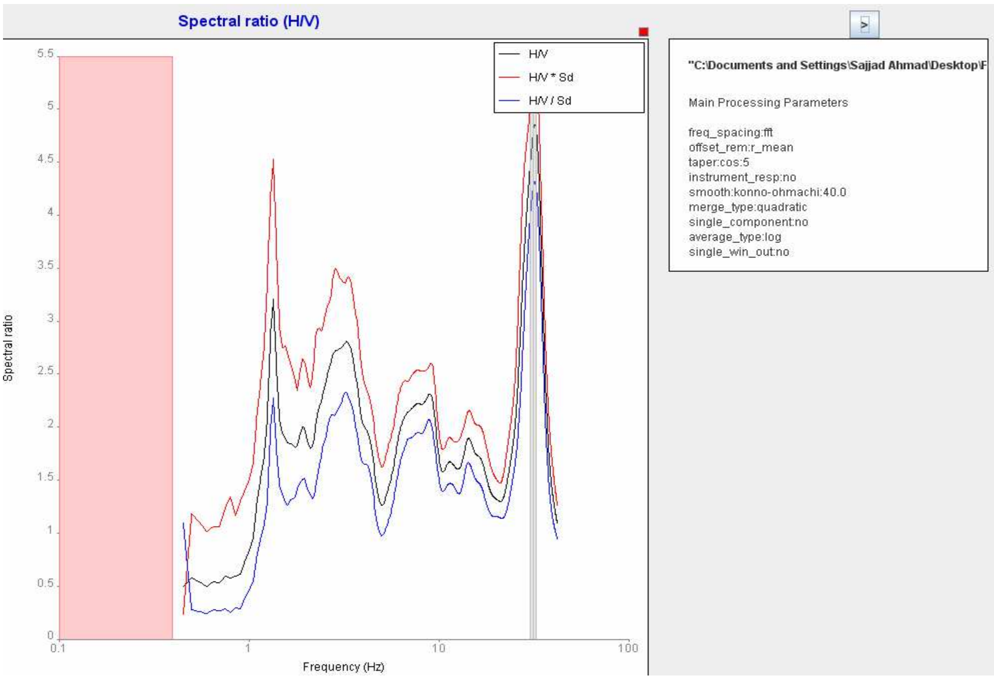

Figure 4.14:- Site response spectrum computed at site ISB075B showing several peaks from the database collected in Islamabad.

In case of response spectra with several peaks examples are (ISB011, ISB73, and ISB075) shown in figures 4.13-4.15. ISB075 and ISB073 are sites in big park where cultural noise was unavoidable. This may be one of the possibility (construction was also in progress at the time of observation) to give high frequency spectrum. Secondly may the sediment underneath the site variable (Lithology and thickness).

Complex Response spectra

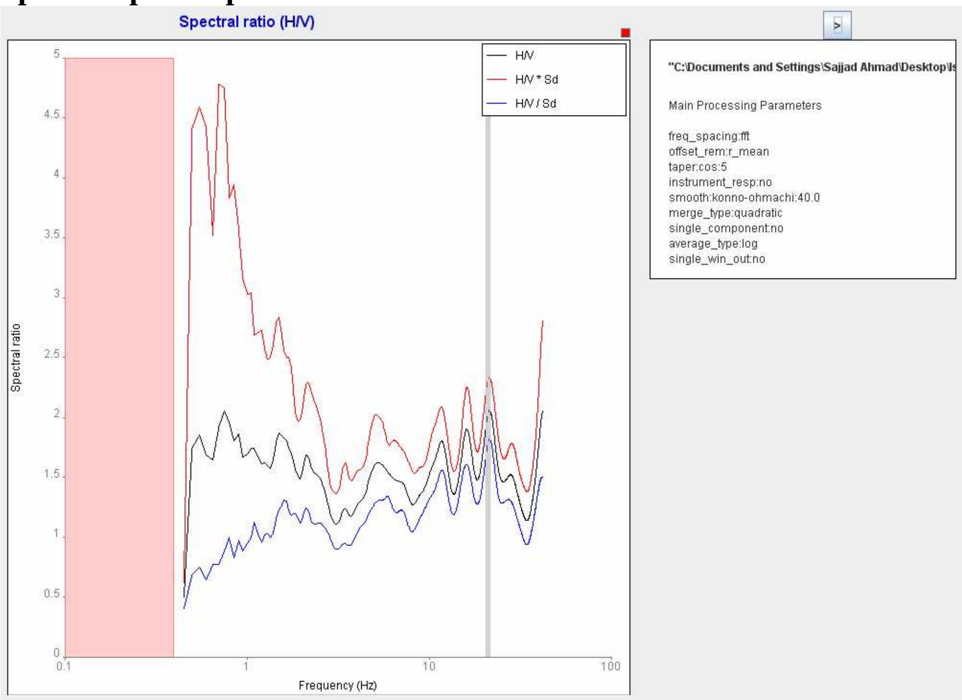

Figure 4.15:- Site response spectrum computed at site ISB011 showing a complex shape and no clear peak can be recognized from the database collected in Islamabad**.**

Complex response spectra have been calculated for several points in the data base. In this case it is difficult to figure out clear peak. Such spectra were computed at ISB46 and ISB50 shown in figure 4.16-4.17. In such cases it is not clear which is the fundamental site frequency even with the information in hand about the spectra components (north-south and east-west). This may be due to a combination of complex underground conditions or presence of noise sources.

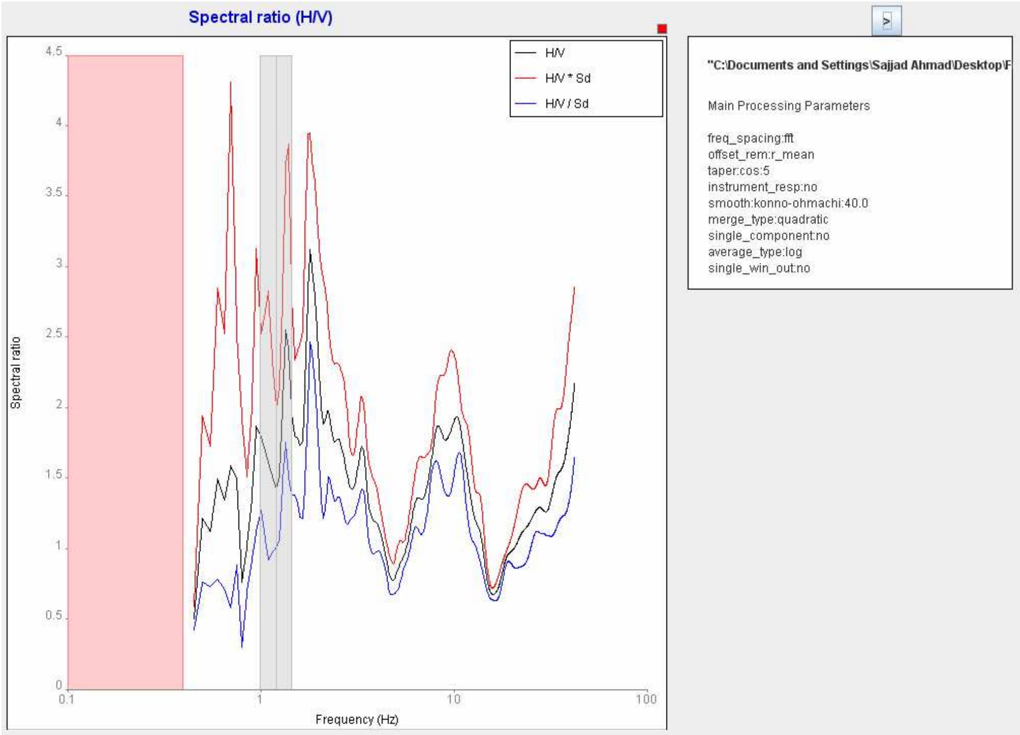

Figure 4.16:- Site response spectrum computed at site ISB050 showing a complex shape and no clear peak can be recognized from the database collected in Islamabad

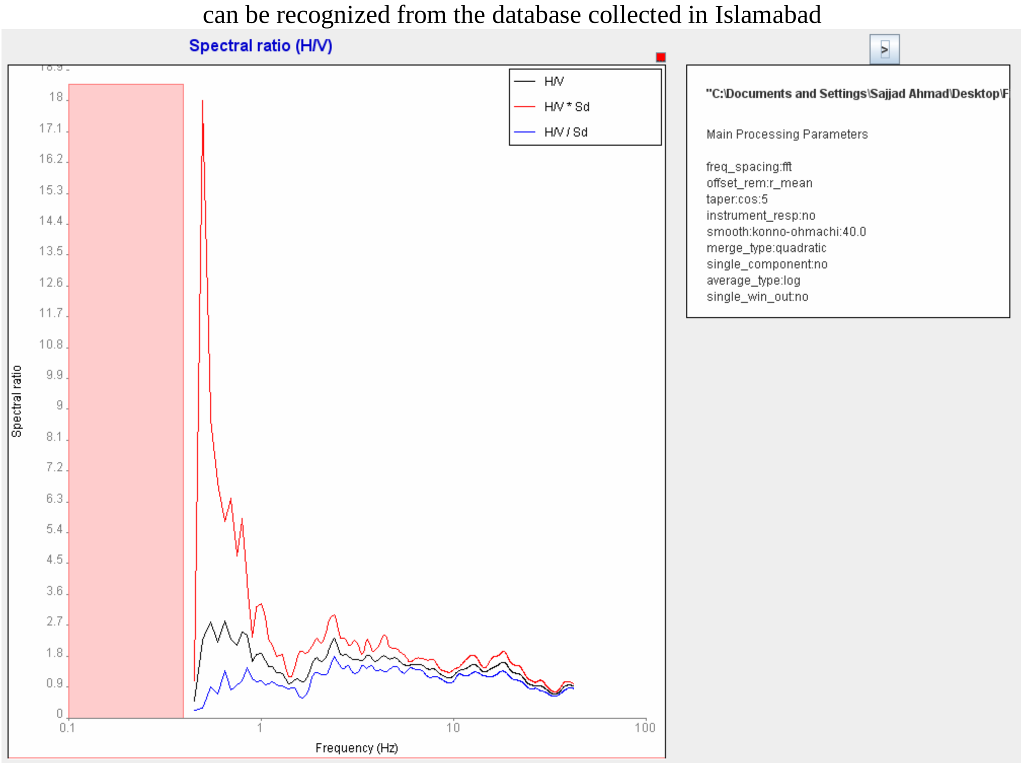

Figure 4.17:- Site response spectrum computed at site ISB046 showing a complex shape and no clear peak can be recognized from the database collected in Islamabad.

4.7.2 Muzaffarabad data base

Response spectra with single clear peak

Majority of the site spectra computed from the data base collected from Muzaffarabad city have clear peak around ten. This probably due to the nature of the sediments which are manily coarse grained which in agreement with recent deposts in Muzaffarabad shown in figure 2.6-2.7 in chapter 2 . In case of single clear peak examples (MZD012, MZD014, MZD017, MZD019, MZD058, MZD063) MZD076, MZD074) shown in figures 4.18 to 4.23.

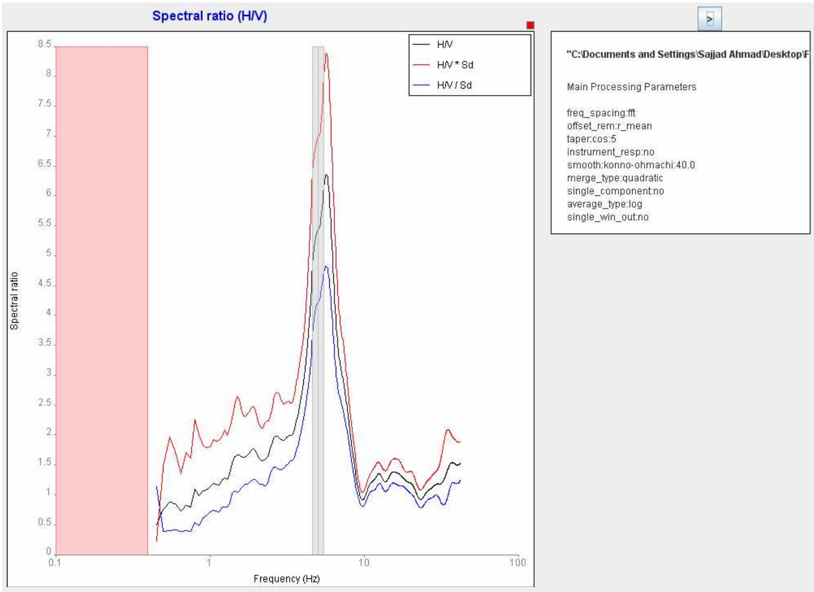

Figure 4.18:- Site response spectrum computed at site MZD012 showing a clear peak from the database collected in Muzaffarabad

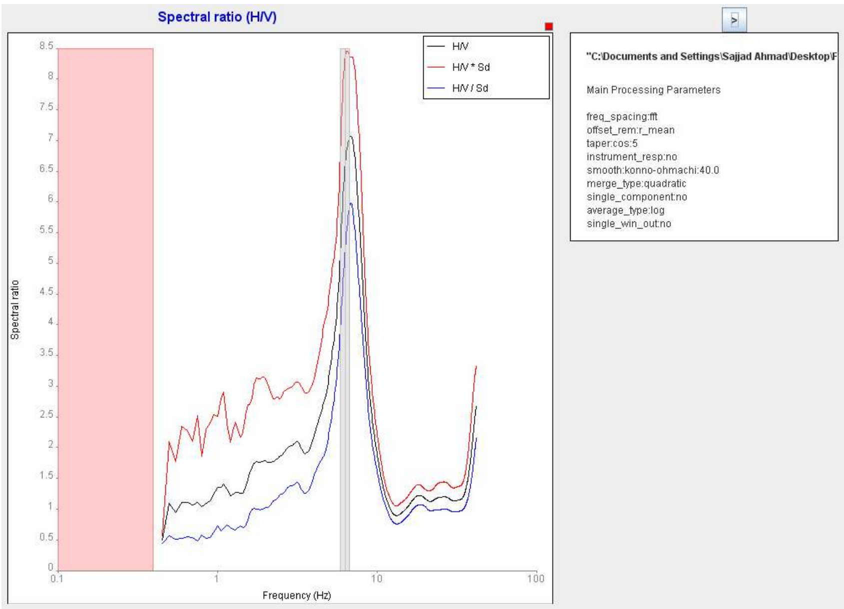

Figure 4.19:- Site response spectrum computed at site MZD014 showing a clear peak from the database collected in Muzaffarabad.

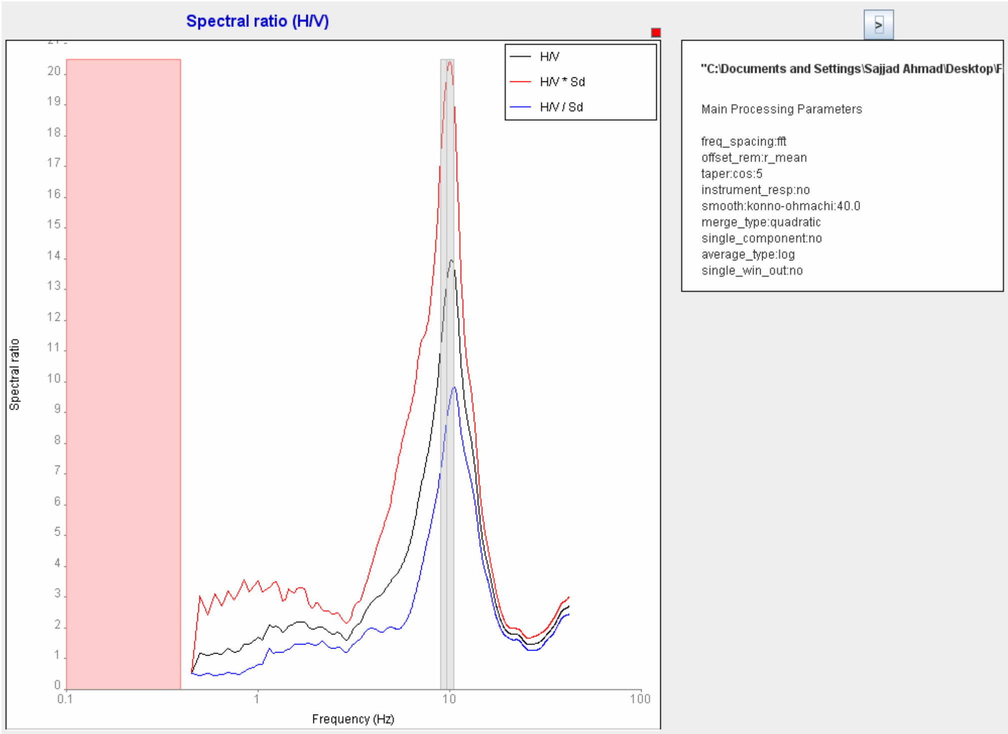

Figure 4.201:- Site response spectrum computed at site MZD017 showing a clear peak from the database collected in Muzaffarabad.

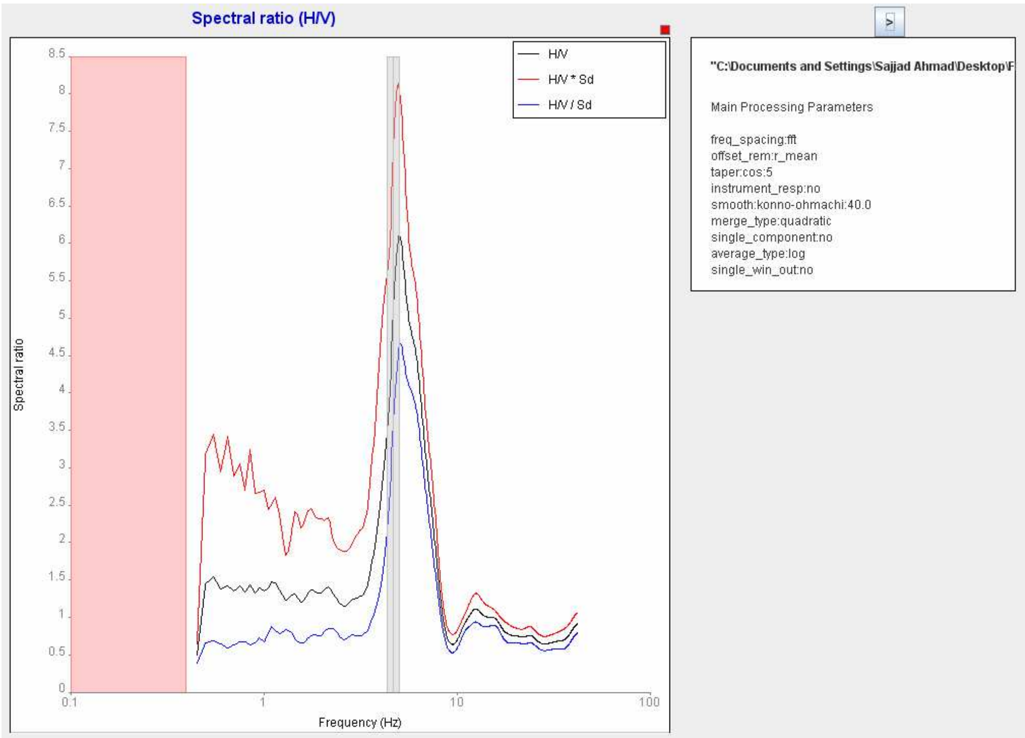

Figure 4.212:- Site response spectrum computed at site MZD019 showing a clear peak from the database collected in Muzaffarabad.

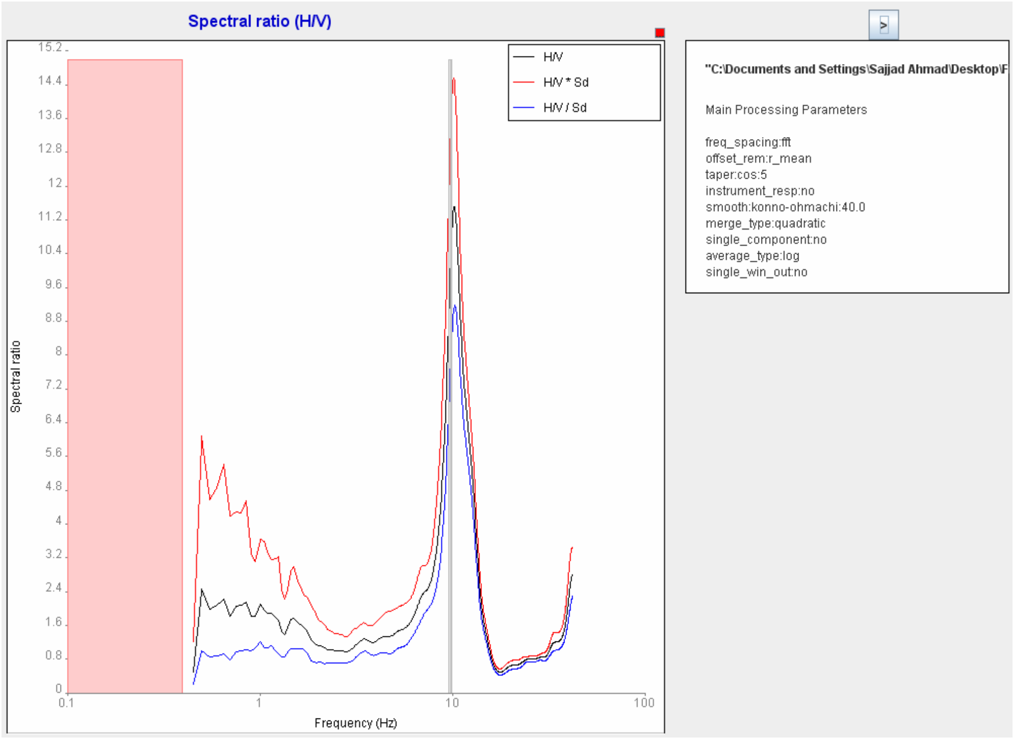

Figure 4.22:- Site response spectrum computed at site MZD058 showing a clear peak from the database collected in Muzaffarabad**.**

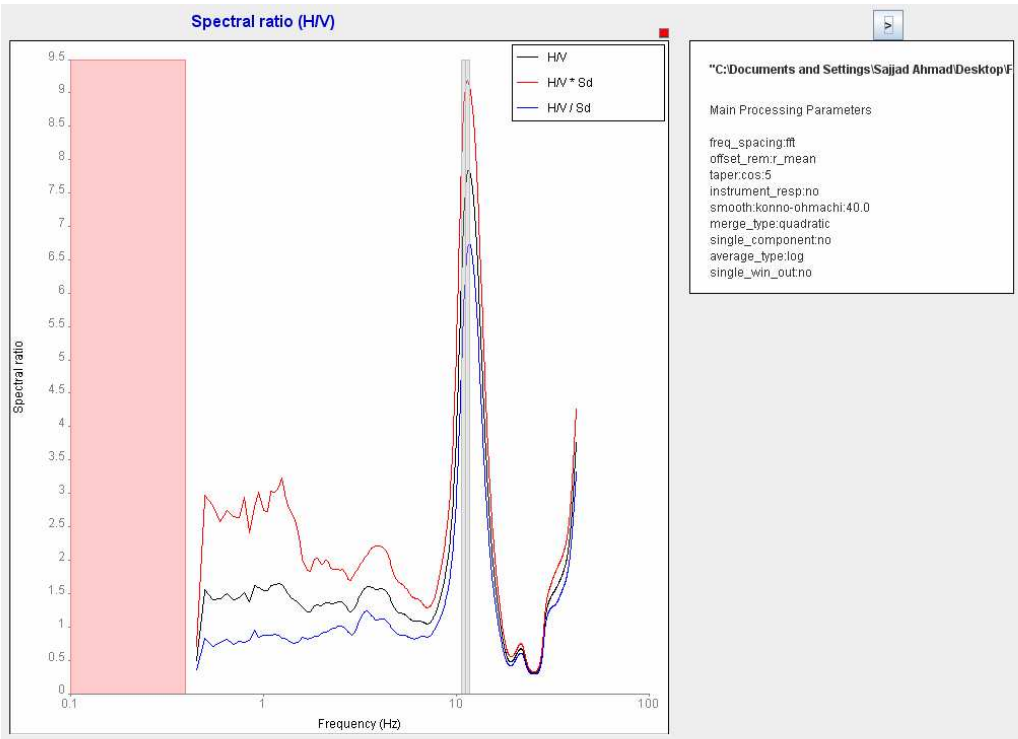

Figure 4.23:- Site response spectrum computed at site MZD063 showing a clear peak from the database collected in Muzaffarabad

Response spectra with two peaks

Examples of response spectra with two peaks are MZD047, MZD056 and MZD074, andMZD076, shown in figures 4.24 to 4.27. Possible reason may be the industrial noise as the observation were taken in the thickly populated city with heavy construction in progress or may be due to frequent traffic. Another possible reason may be variation of the thickness of the sediments in underneath the observation points.

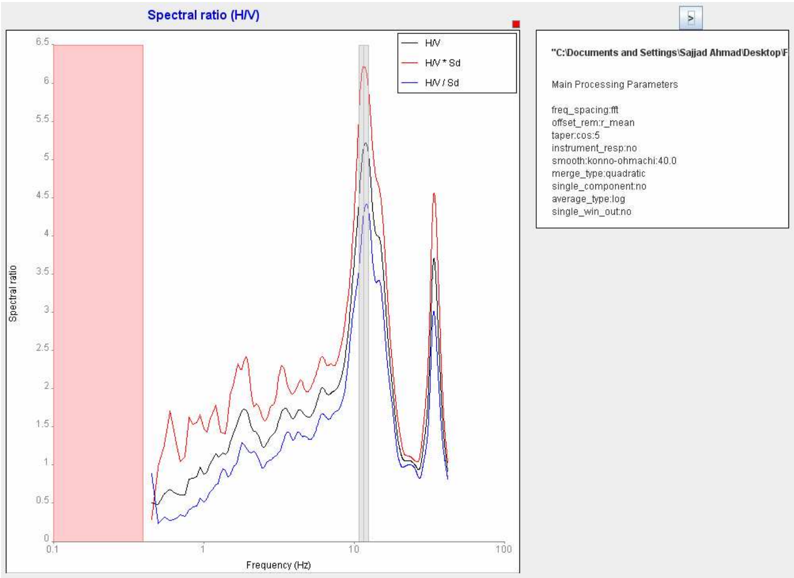

Figure 4.24:- Site response spectrum computed at site MZD076 showing two clear peaks from the database collected in Muzaffarabad.

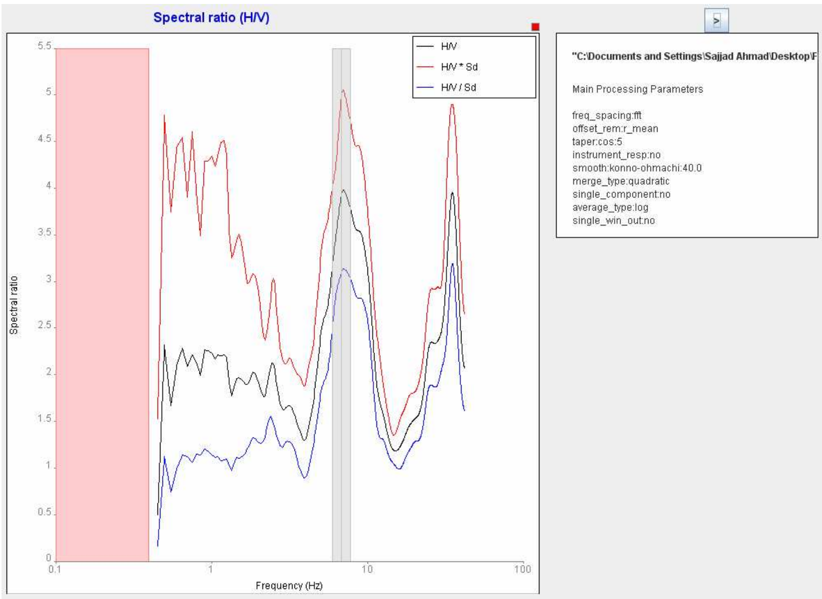

Figure 4.253:- Site response spectrum computed at site MZD074 showing two clear peaks from the database collected in Muzaffarabad.

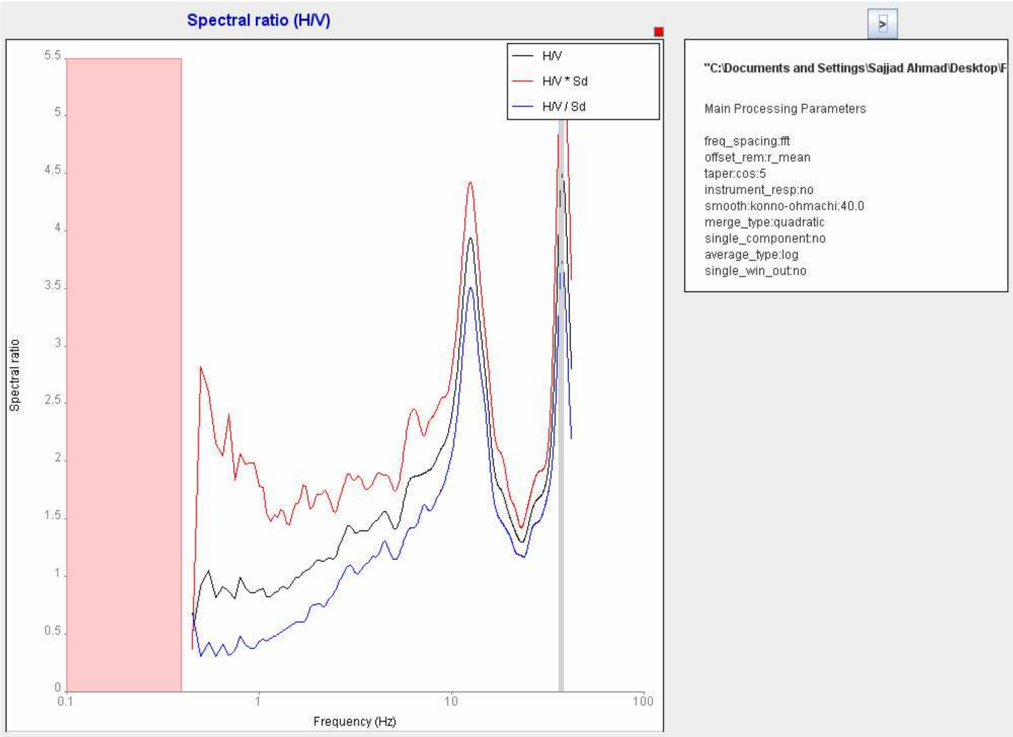

Figure 4.26:- Site response spectrum computed at site MZD056 showing two clear peaks from the database collected in Muzaffarabad**.**

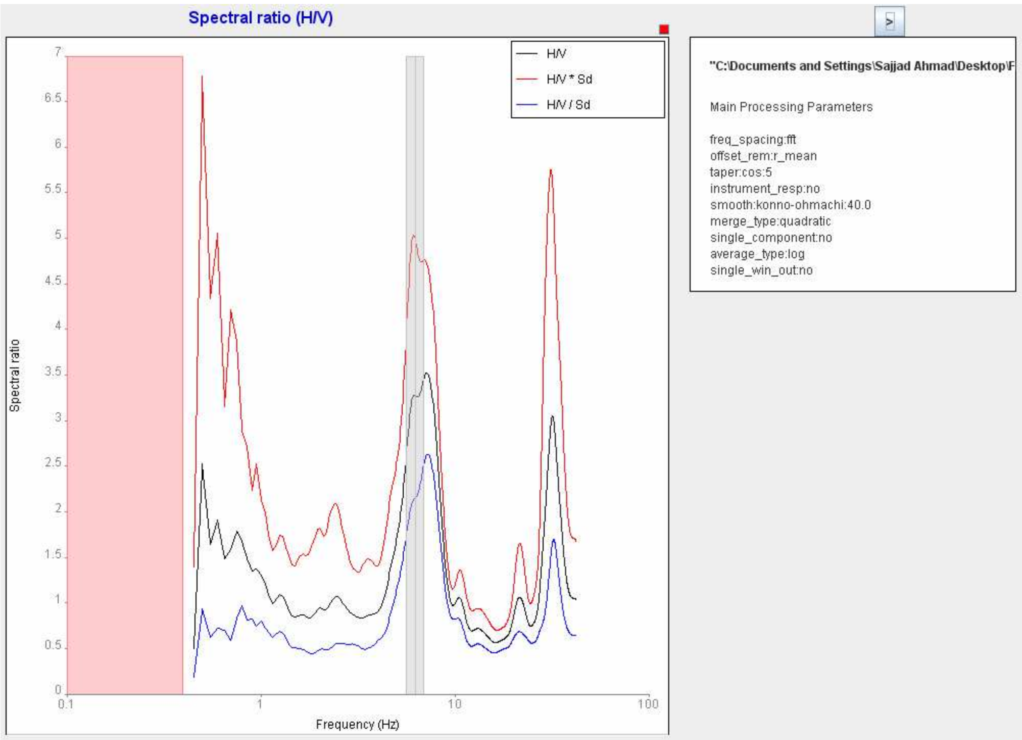

Figure 4.274:-Site response spectrum computed at site MZD047 showing two clear peaks from the database collected in Muzaffarabad

Response spectra with several peaks

Response spectra with several peaks (figure 4.28 to 4.30) are seen in case of observation points MZD022, MZD027, MZD045, MZD079 and the reason may be variation in the sediment thickness or type of unconsolidated material (figure 2.6-2.7). Second possible reason may be cultural noise. In some cases an artificial noise was present near observation point like MZD045 and MZD022, cultural noise and industrial was present respectively.

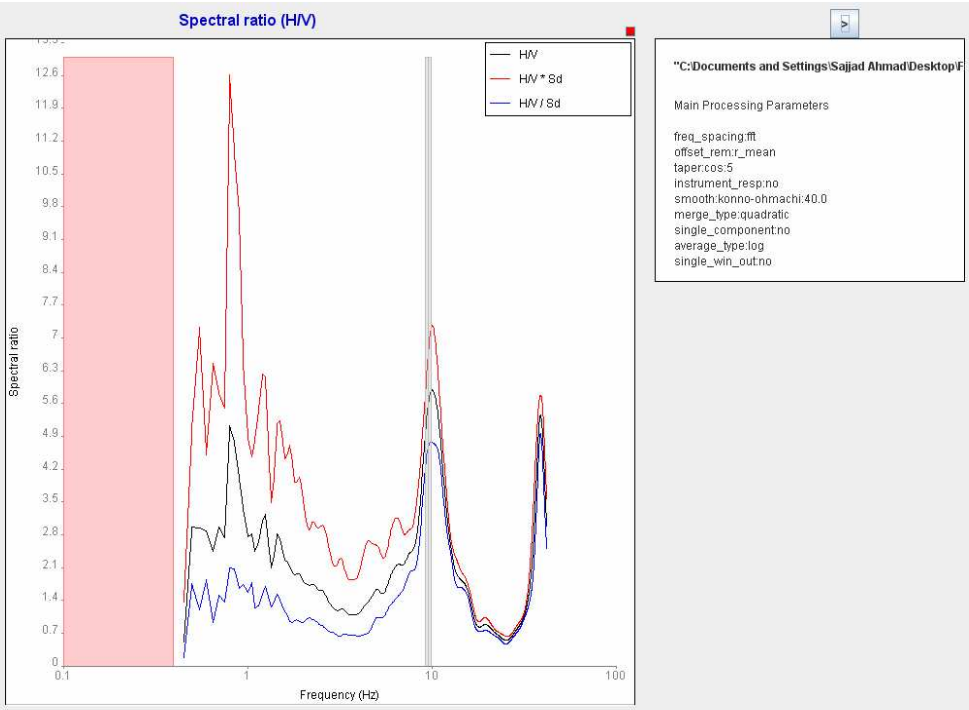

Figure 4.28:- Site response spectrum computed at site MZD045 showing several peaks from the database collected in Muzaffarabad**.**

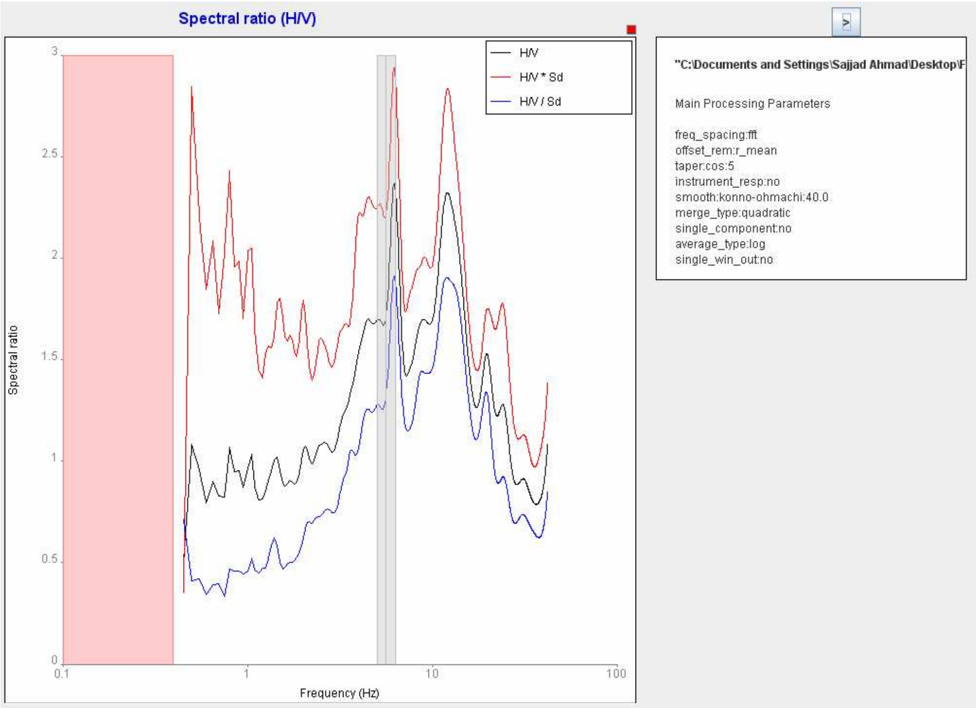

Figure 4.29:- Site response spectrum computed at site MZD045 showing several peaks from the database collected in Muzaffarabad

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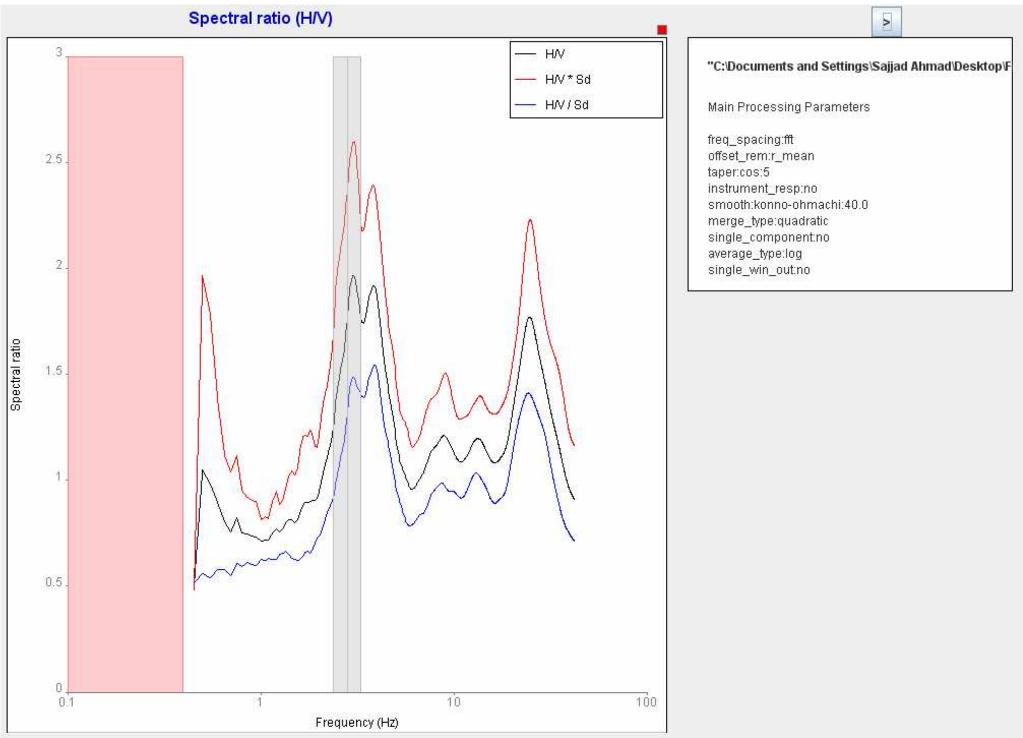

Figure 4.30:- Site response spectrum computed at site MZD022 showing several peaks from the database collected in Muzaffarabad.

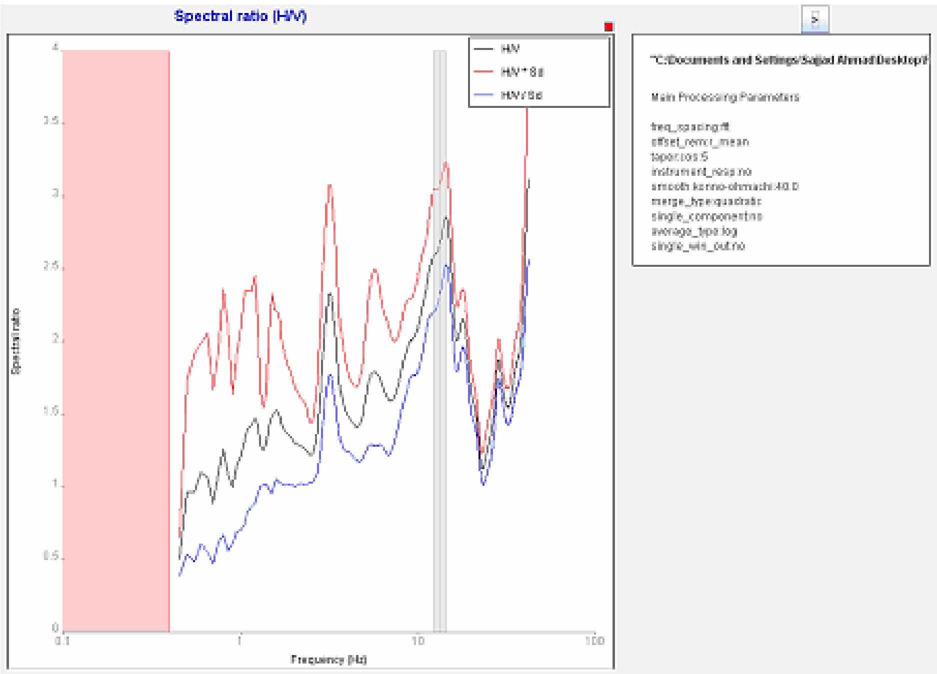

Figure 4.31:- Site response spectrum computed at site MZD079 showing several peaks from the database collected in Muzaffarabad.

Complex Spectra

Complex spectra with no clear peak for the observation points MZD027 and MZD090 has been computed. The reason may be the complex structure underneath the observation points or may be due to noise.

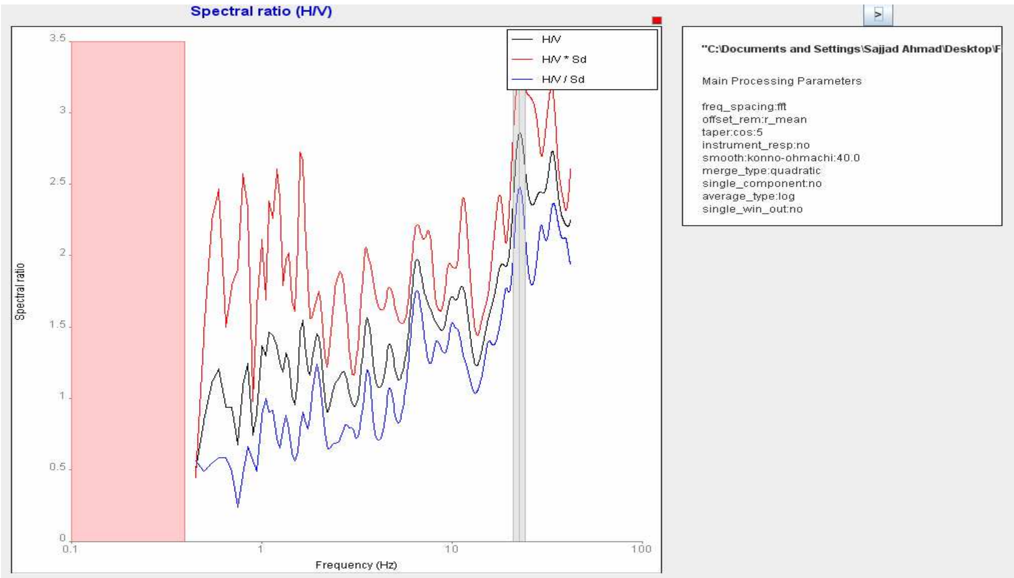

Figure 4.32:- Site response spectrum computed at site MZD027 showing complex shape and no clear peak can be recognized.

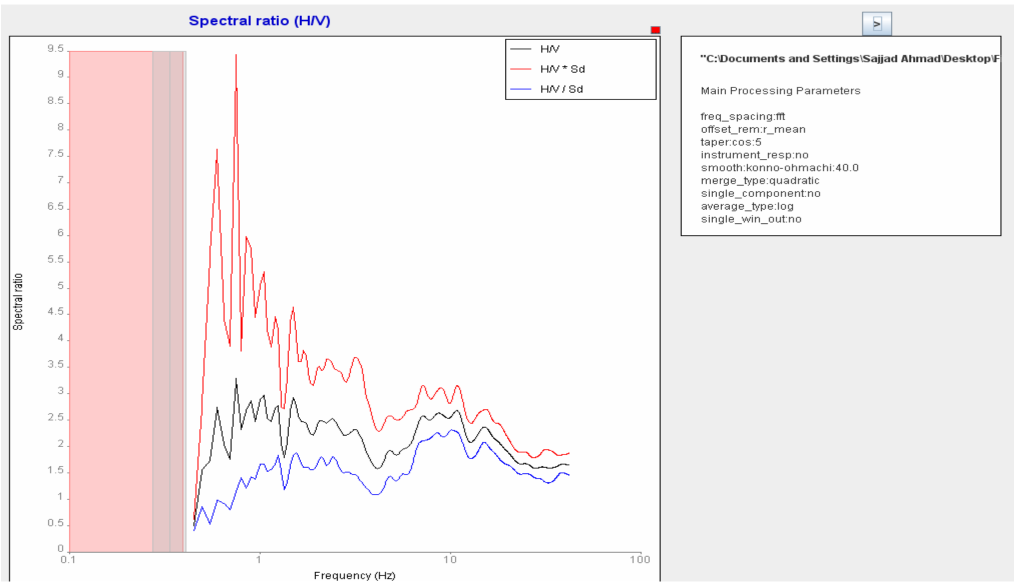

Figure 4.33:- Site response spectrum computed at site MZD090 showing complex shape and no clear peak can be recognized.

4.8 Discussion and Conclusions

Geological as well as topographic conditions of the two cities (Islamabad and Muzaffarabad) are substantially different. Islamabad site is plain and near to Margalla hills and as mentioned earlier sediment thickness is low according to previous environmental study. Its lithology is quite smooth which has also been indicated by the map of spatial distribution of the frequency obtained by using first peak observed in the area (figure 5.5). On the other hand Muzaffarabad city has quite different thickness as well as lithology as mentioned earlier (Chap. 2). This area is complex and deposits are coarse grained giving a high frequency as shown in figure 5.2, 5.3 & 5.4. Muzaffarabad is situated at the junction of rivers so the deposits are pebble and bolder type (Chap 2-figure 2.6 & 2.7).

4.8.1 Islamabad City (F-10 Sector)

Islamabad frequency map giving a consistent overview of the area except few spots of different frequency which are may be due to variation in the thickness of the sediments deposited in the area. In general it seems to be very clear that the frequency lies in range of 2 Hz. As the area is near Margalla hills (about 3 km). Thickness of the sediments is variable 30 to 100m (Sheikh et al.- Environmental study-Islamabad-Rawalpindi)

CDA hydrological test hole also shows that the depth of the water column also variable. As it is well known that saturated layer gives a dynamic response and extends duration of the wave.

Distribution of the sediments can decide about the site response because the response depends on the sediment layering and lithology.

The double peak indicate more than one uniform layer of thickness (different lithology)

Several layers give response having several peaks because of the response of the different material lying underneath site.

Buildings in Islamabad are modern and comparatively of good quality in construction as compared to Rawalpindi area. Rawalpindi is an old city and densely populated. The thickness of the sediments is higher as compared to the Islamabad area (Sheikh et al. Environmental study-Islamabad-Rawalpindi), so it is in more due to local site effects.

Site response study is also valid for Islamabad city. During Kashmir earthquake 2005 the multistory building collapsed has no connection with frequency response as the frequency response obtained is quite high in the area which does not corresponds to resonance frequency of such high rise building, so the failure may be due to poor construction.

Local site- As it has been observed that a short distance can produce change in the response because of the change in variable sediments thickness that is why it is logical to say it local site response.

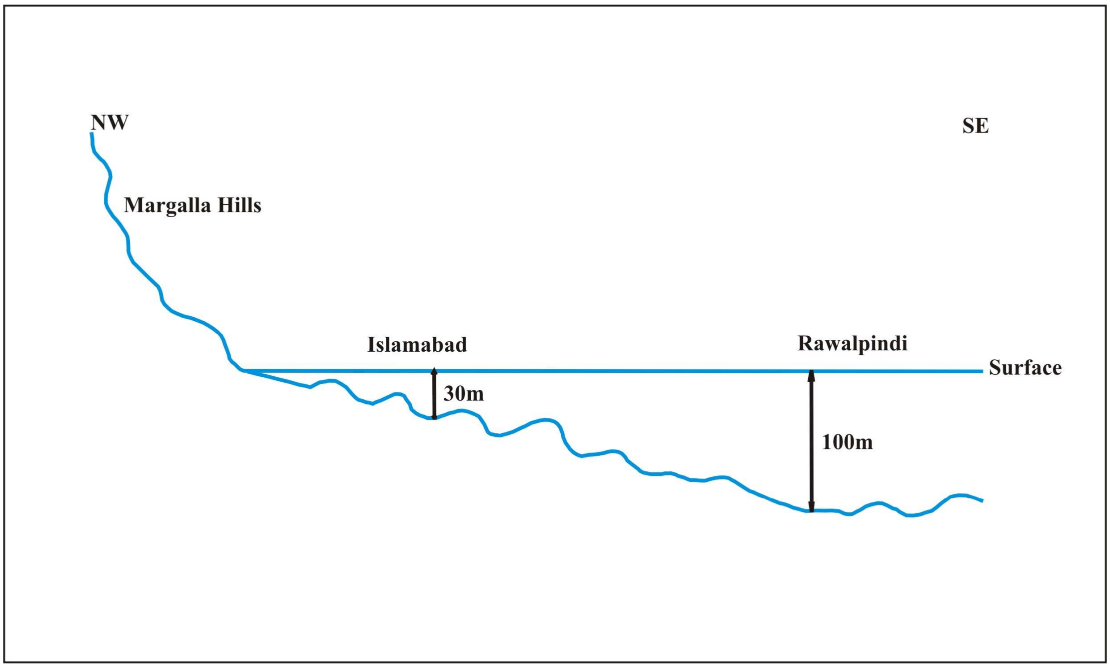

Figure 4.34:- Sketch of the sediment thickness in Islamabad-Rawalpindi areas (Rough sketch on the bases of previous study- Sheikh et al Environmental study- Islamabad-Rawalpindi).

(Scale used for surface line 1cm = 1km and incase of thickness line about 1 cm = 30 m)

It is general consensus in scientific society that amplification factor obtained by this method is not reliable. In case of Islamabad city the amplification factor obtained is quite stable over the entire region. It varies from 2-5 (figure 4.37). The reason for this smooth behavior of the amplification factor is not known. Based on that minimum factor of two should be considered in site response but not sure about as the method used is not sensitive regarding calculation of the amplification factor.

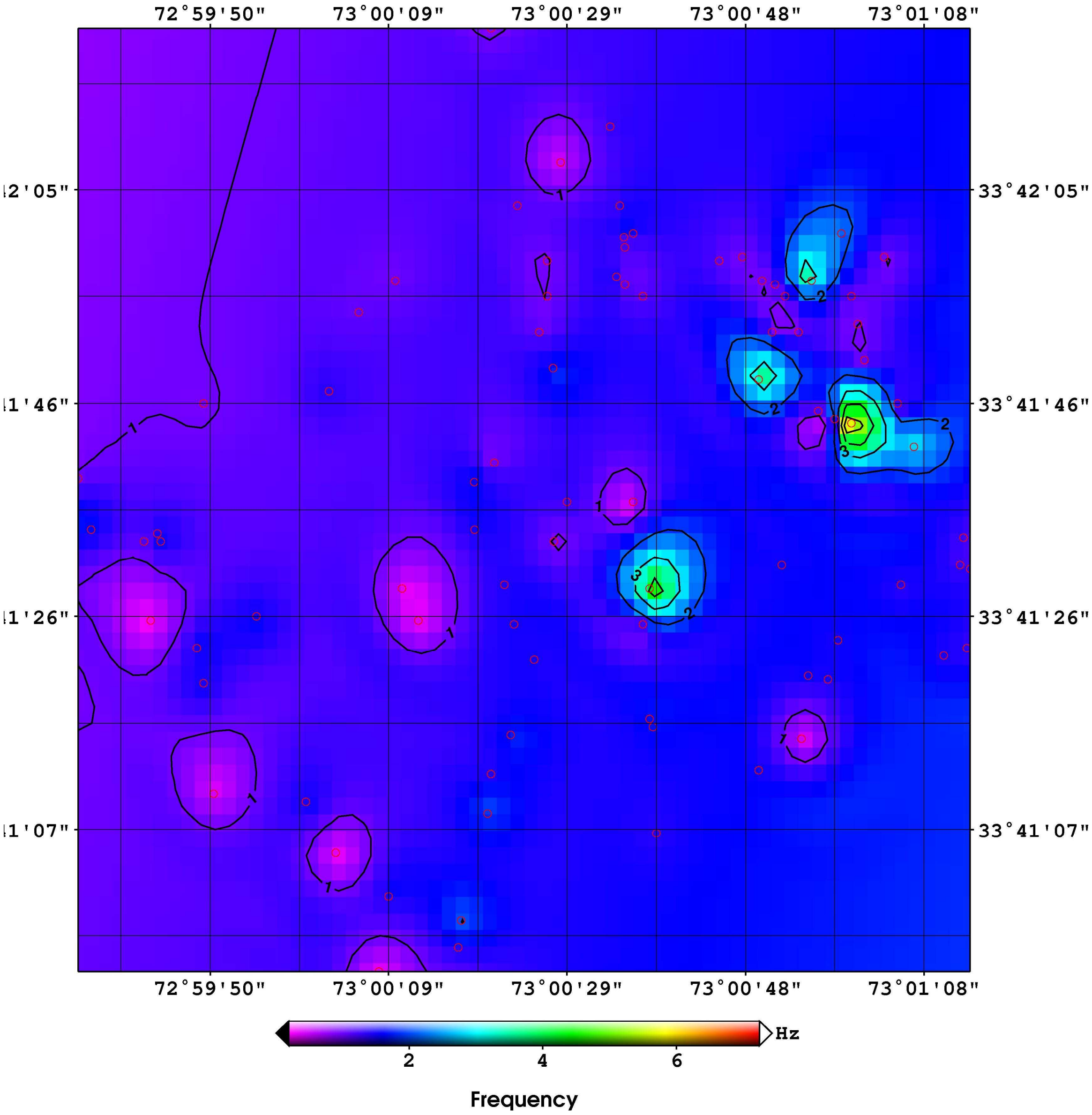

Figure 4.35:- Map of F-10 sector Islamabad city, showing the spatial distribution of the frequency of the site with first peak.

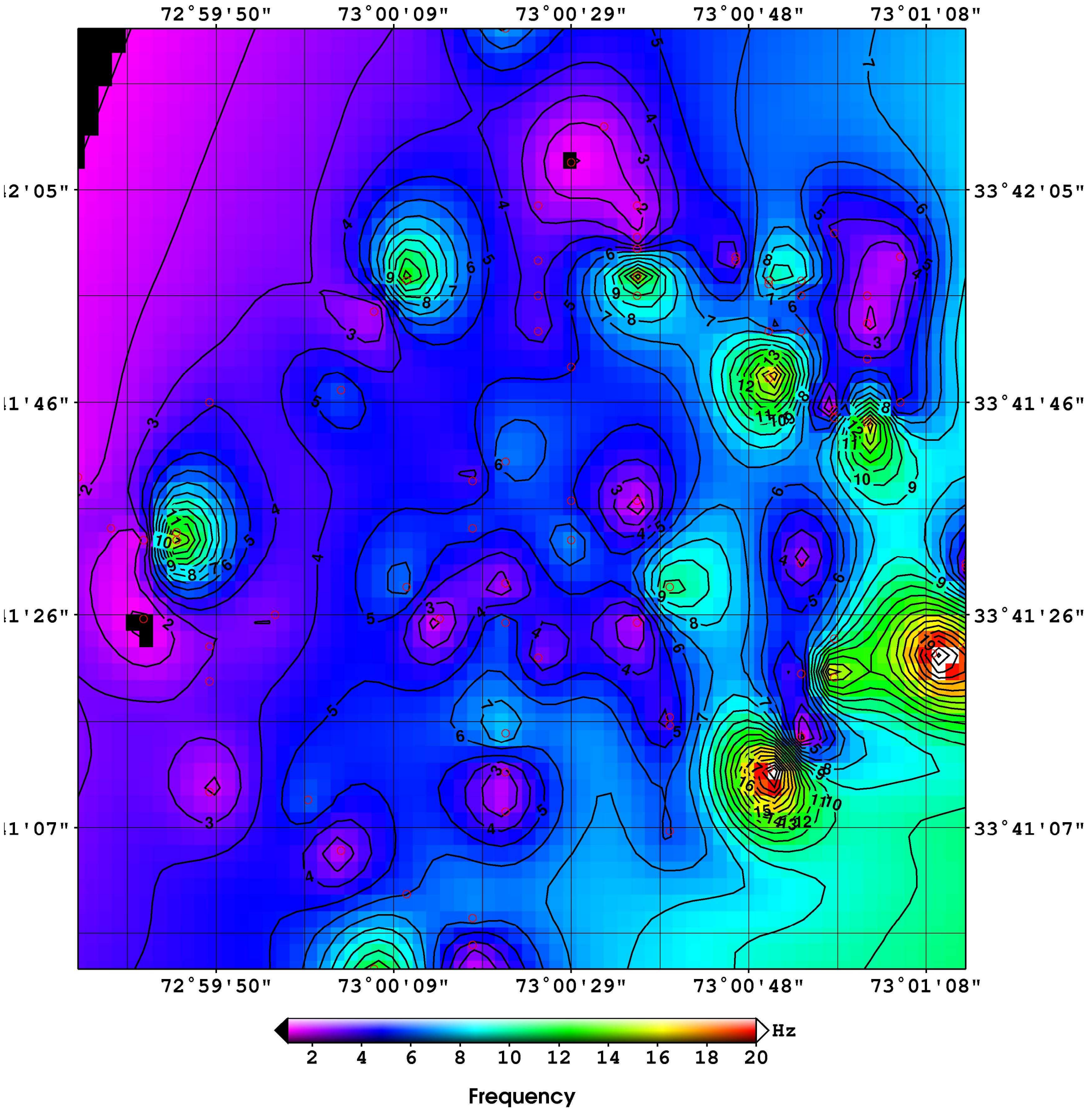

Figure 4.36:-Map of F-10 sector Islamabad city, showing the spatial distribution of the frequency of the second peak.

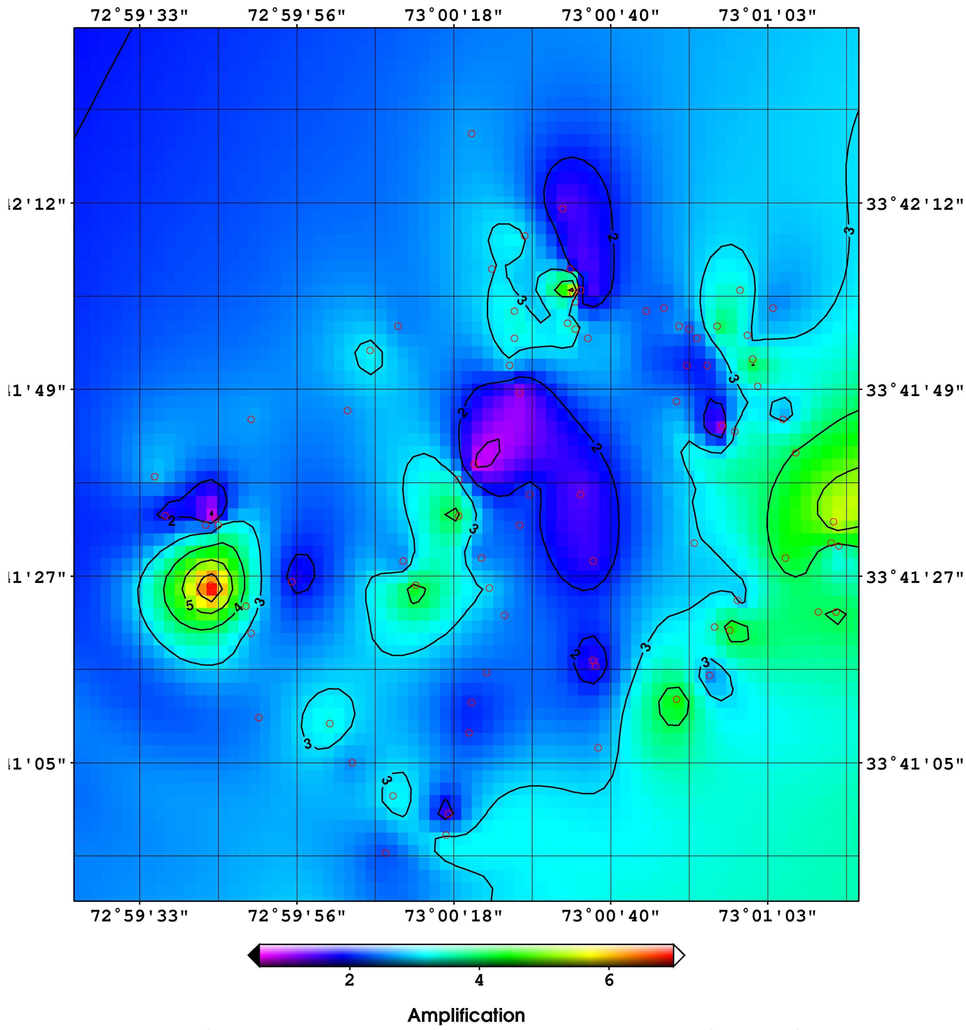

Figure 4.37:- Map of F-10 sector Islamabad city, showing the Amplification factor distribution.

4.8.2 Muzaffarabad City

Muzaffarabad is situated at the junction of the rivers as mentioned earlier, so the sediments deposited are high energetic (pebble, bolder) it is also indicated by the results obtained from the first peak spectrum of the observations taken in Muzaffarabad. Site response gives high and variable frequency.

Distribution of the observation points is not uniform. Reasons for not having good distribution of observation points are that there were few reasonable point available (due to have construction in progress, traffic and other unavoidable). Some of the planned places in the city where it was not possible to take observation like public place or very inclined place where it was difficult to keep equipment for observation.

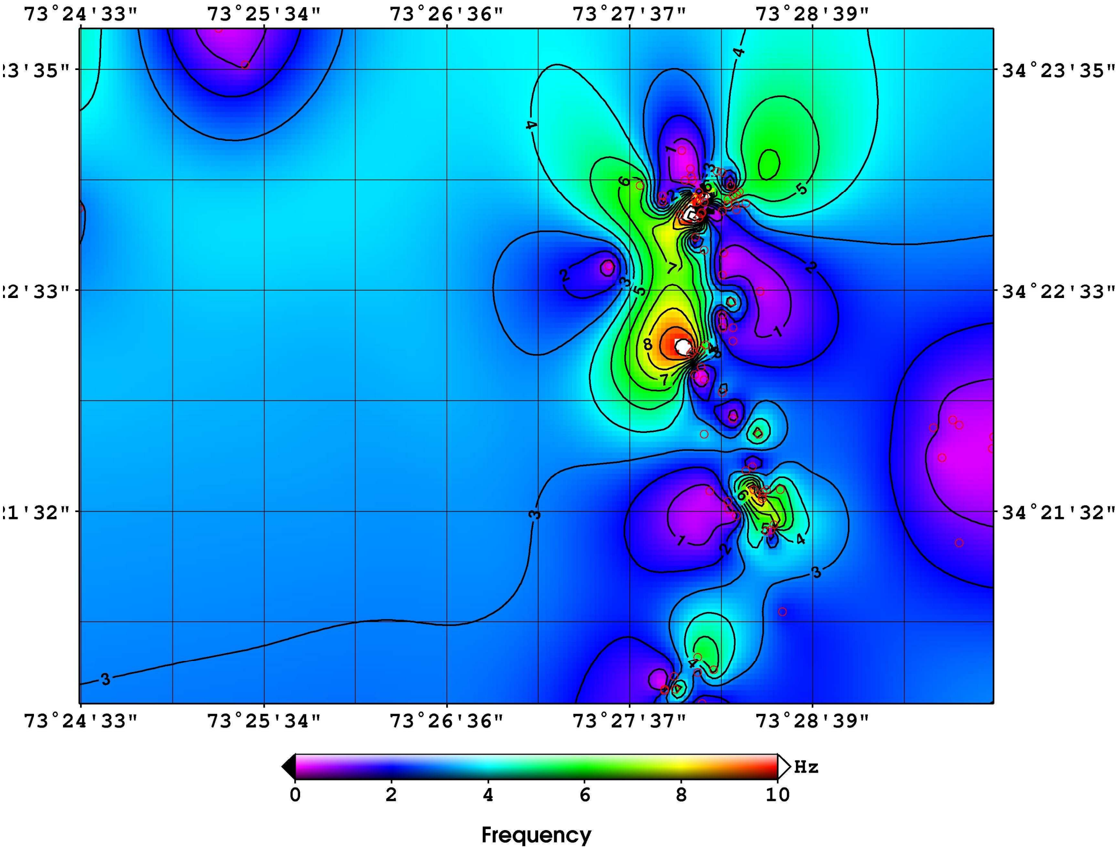

Figure 4.38:- Map of Muzaffarabad city, showing the spatial distribution of the fundamental frequency of the site ranges 0-10 Hz.

According the frequency profile shown in the plot of with second peak (figure 4.39-4.40). It gives more energetic impression. Frequency is higher and variable in this case too. Therefore, it can be concluded that the damages in this city are also not due to site response, the other reason may be topography, ground shaking or poor construction material during Kashmir earthquake 2005. As it is mentioned earlier that cities situated at hill on hill tops experienced more damage than the cities situated on the foot hills. Surface to surface topography influences the amplitude and frequency contents of the motion. The focusing and defocusing of the incoming seismic waves may be due to particular topographic features of the area of interest (Bard, 1994; Lacave, 1999).

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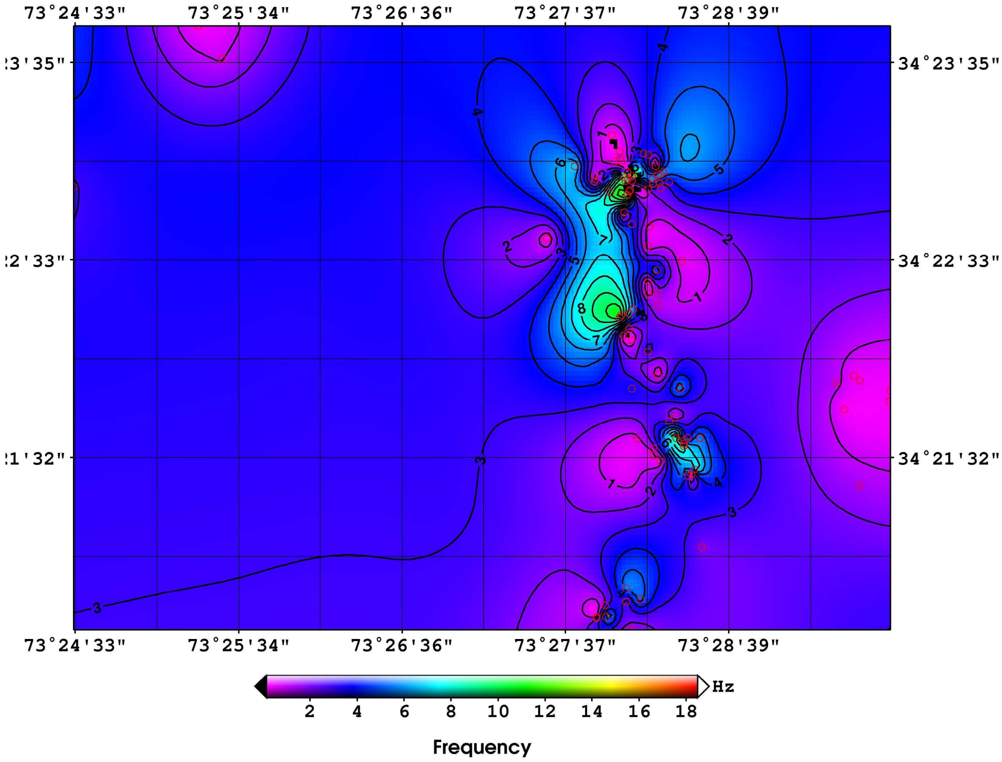

Figure 4.39:- Map of Muzaffarabad city, showing the spatial distribution of the frequency of the site with second peak ranges 0-18 Hz.

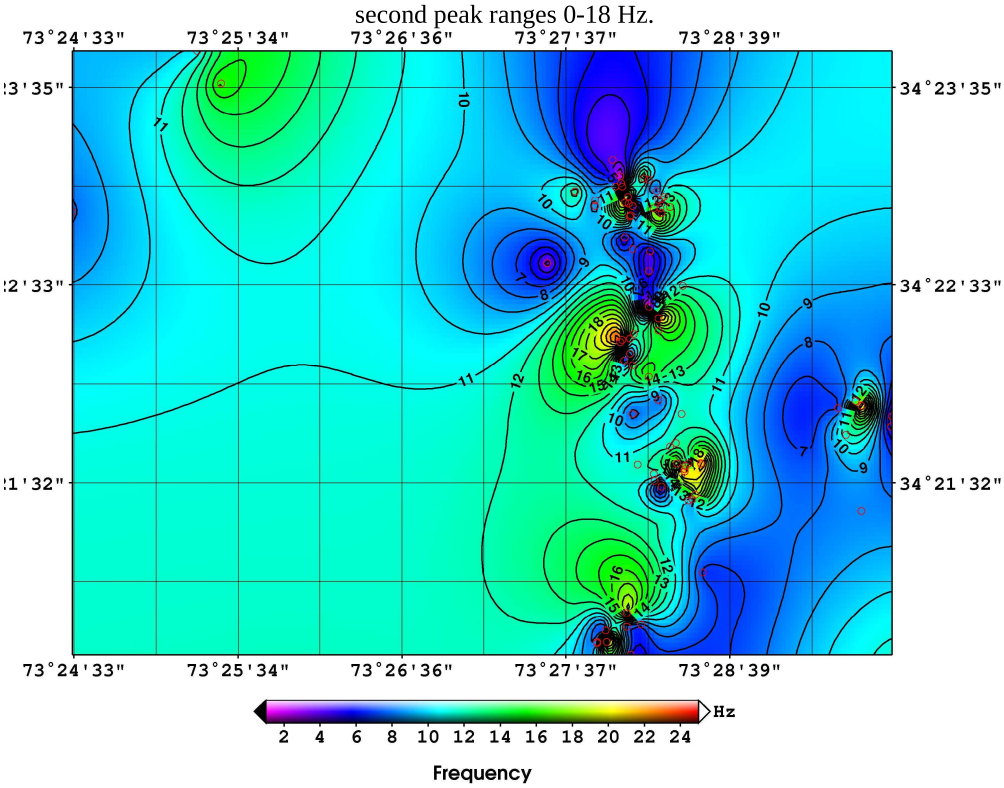

Figure 4.40:- Map of Muzaffarabad city, showing the spatial distribution of frequency of the site with second peak ranges 1-25 Hz.

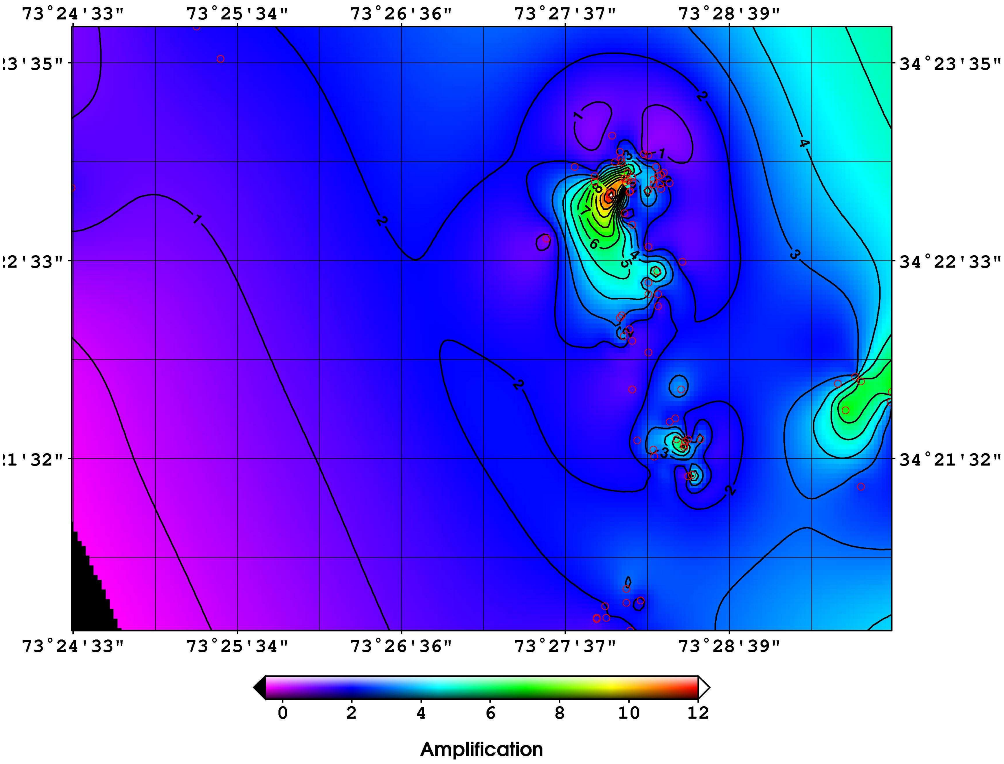

Figure 4.41:- Map of Muzaffarabad city, showing the Amplification factor distribution.

Amplification factor obtained in case of Muzaffarabad city is variable (figure 4.41). It has the variation in the entire city. The reason may be the result is extrapolated by the program used as the distribution of the points is not even. Keeping in view the results obtained minimum factor of 3 should be considered in site response again it is not sure as the method used is not sensitive to calculate amplification factor.

4.8.3 Comparison of the two cities

Results obtained from the two cities are expected. Muzaffarabad is situated at the high energetic bed while Islamabad's sediments are quite settled and fine compared to Muzaffarabad. The sediments show the smoothness in Islamabad indicated by the frequency response maps (figure 4.35-4.36) obtained while in case of Muzaffarabad high variation has been seen (figure 4.38-4.39-4.40). In case of Muzaffarabad the observation sites are not well distributed as compared to Islamabad. Still the frequency maps are showing high as well as variable frequency which is an indication of variation in thickness of the sediments lying underneath the study area which is in agreement with the existing condition shown in figures 2.6-2.8.

In case of Islamabad as mentioned earlier study area is near Margalla hills. According to the previous environmental study the thickness of the sediments ranges 30-100 m. Lithology given by the CDA hydrological logs also shows that sediments are more or less same (shales, clay+shales or sandstone). Thickness of the sediments increases in the area which is farther away from the study area (NW-SE) see figure 4.34. In this direction an other thickly populated city Rawalpindi is situated. Site response is valuable for both of the cities (Islamabad+Rawalpindi). Comparatively Rawalpindi is in more danger because of poor construction, densely populated and high sediments thickness (Sheikh et al. Environmental study of Islamabad-Rawalpindi area).

High energy can be produced due to relatively big size of the sediments (pebble, bolder) As the distance from the mountain increases the grain size also becomes fine and fine like in Islamabad where fine grained deposited shown by the hydrological test holes (sand, shales+clay) on the other hand Muzaffarabad sediments deposited are very course, thin sand distributed unevenly due to seasonal floods. Major difference fits well in both cities Islamabad and Muzaffarabad in the context of frequency spectra computed.

5 Concluding Remarks

Pakistan region has history of facing several disastrous earthquakes. Recent Kashmir earthquake 2005 was the largest disaster in the region resulting in a large loss of lives and significant economical loss. Future planning is needed to minimize the losses due to earthquake by better understanding the tectonic processes and associated earthquakes threat in the region. In this regard Pakistan Meteorological Department (PMD) is in the process of improving the seismic monitoring by the installation of 20 Broad Band, 50 Short period and 50 strong motion stations. The PMD network is now in completion stage, which will help in providing useful local data to address the research problems in the future.

In this study with limited PMD seismic network data a test processing has been done and compared with international data from PDE. The epicenter locations of earthquakes calculated by the PMD data and PDE are not in good agreement. The magnitude comparison of local network and PDE suggests that local magnitude is quite close to PDE magnitude as compared to coda magnitude calculated by the PMD data. Therefore, it is recommend that local magnitude may be used until the development of own magnitude formula.

Secondly, a local site effect problem has been addressed in two cities (Islamabad-Muzaffarabad). The spectral ratios of horizontal to that of the vertical component of ambient noise readings reveal more consistent results than in terms of Islamabad when compared to Muzaffarabad. A Previous study regarding the environmental geology of Islamabad-Rawalpindi area, Northern Pakistan, provided some clues about the type and thickness of the sediments in Islamabad. The distribution of fundamental frequencies in Islamabad is in accordance with the expected behaviour of the sediments. In addition hydrological test holes made in Islamabad and Rawalpindi areas, show that thickness of the sediments seems to be shallow in Islamabad as compared to Rawalpindi. In this sense the local site effects are likely to pose more serious problems in Rawalpindi area, especially when the relatively old building stock is taken into consideration.

Future studies in this region should focus on improving the monitoring earthquakes and understanding the seismic hazard especially with regard to the local site effects in major population centers, such as Rawalpindi.

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8 Useful Internet Sources

Name	Internet address
SESAME project	http://sesame-fp5.obs.ujf-grenoble.fr/
Informtion about Muzaffrabad area	http://www.cybercity-online.net/Pakistan/muzaffarabad.html
	http://www.geo.uib.no/Seismologi/software/seislog/seislogCE.html
History made every day	http://www.history.com/this-day-in-history.do?action=Article&id=50842
SEISAN software 8.2.1 and manual	http://www.geo.uib.no/seismo/software/seisan/seisan.html
British Broad casting	(http://news.bbc.co.uk/onthisday/hi/dates/stories/september/19/newsid_4252000/4252078.stm
Geological survey of Pakistan	(http://www.gsp.gov.pk/paksitan/tectonics_zones.html
PMD	http://www.pakmet.com.pk/
International seismological Center	http://www.isc.ac.uk
United States geological survey	http://earthquake.usgs.gov/regional/world/pakistan/seismicity.php
The Tsunami page	http://www.drgeorgepc.com/Tsunami1945Pakistan.html
Google earth	www.earth.google.com
J- SESAME software	http://www.geo.uib.no/seismo/software/jsesame/jsesame.html
Environmental geology of Islamabad-Rawalpindi	http://pubs.usgs.gov/bul/2078/B2078_chapter_G.pdf