SITE SPECIFIC SEISMIC HAZARAD ASSESMENT OF ISB/RWP REGION

A PARAMETRIC STUDY

Final Year Project (2016-17)

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This is to certify that

The Final Year Project titled

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Submitted by

The Team

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Under the Supervision of

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ABSTRACT

Pakistan is the 6th largest country by population and almost half of the population lives in earthquake prone areas. The country has experienced disastrous earthquakes including the 2005 Kashmir earthquake (7.6 magnitude), it is therefore imperative to perform an assessment of the hazards associated with the earthquakes. Islamabad, the capital of Pakistan, lies in the vicinity of the Margalla Hills. Incidentally, The Main Boundary Thrust also referred to as MBT, passes through these hills. Other faults that pose a danger to Islamabad are Jhelum fault, Murree fault, Hazara fault, Panjal fault and the Margalla fault. According to the study of Bhittai et al. (2011), the entire Islamabad region is prone to earthquakes rather than just a few sectors near the Margalla Hills. Islamabad being the capital city with foreign offices, high-level executive buildings and tall towers needs to be ready for any imminent seismic threat. According to Sajjad Ahmad (2009), the local site effects present a more serious threat to the Rawalpindi area; a major population center with a myriad of old buildings. A seismic hazard analysis of Islamabad and Rawalpindi has therefore been carried out through DSHA and PSHA in order to produce new parameters for the earthquake engineers and authorities like CDA in a bid to prevent and mitigate damage in the twin cities by using IBC and ASCE 7-10. Furthermore, we have formulated Microsoft Excel Spreadsheets for quick site specific analysis in the region.

DECLARATION

It is hereby solemnly and sincerely declared that the work referred to this thesis project has not been used by any other university or institute of learning as part of another qualification or degree. The research carried out and dissertation prepared was consistent with normal supervisory practice and all the external sources of information used have been acknowledged.

DEDICATION

We hereby dedicate this project to our parents and our teachers who have helped us achieve whatever we have so far and who stand by us no matter what.

ACKNOWLEDGMENT

Thanks to Almighty Allah who is the greatest of all, surely without His blessings and mercy nothing is possible. Thanks to our beloved parents who have been there in the times when we needed support and motivation and who have always helped us walk this journey of life. Without their blessings and prayers, we wouldn't have been able to do this.

Special thanks to our Thesis Supervisor; A/P Abdul Jabbar Khan who has been there to provide guidance, assistance and mentorship whenever we needed it. We dearly enjoyed working under his supervision and his positivity brought the best out of us. We also thank Mr. Sajid Iqbal and Mr. Asim Ayaz for their help that proved really important for the completion of this project.

Thanks to all the researchers who have contributed to this amazing field of geotechnical engineering, for we loved treading the path that they followed and we hope to create more avenues for the future.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement:

The 2005 earthquake was a reminder to how deadly and disastrous nature can be at times. Although Rawalpindi and Islamabad did not suffer major losses, yet the possibility of another event such as this looms over the region. The seismic hazard analysis that we have carried out is to find out how important it is to understand these threats. Following problems make our study necessary:

- Proximity to nearby faults; Main Boundary Thrust for example, just passes under the Margalla Hills.
- Lack of awareness among common people and professionals about the seismic threats to the region.
- Rapid growth and urbanization of the metropolis.
- Insufficient Ground Motion Parameters for application of modern building codes such as ASCE 7-10.

1.2 Objectives:

- Developing a Generalized Soil Profile of Islamabad/Rawalpindi
- Calculating Peak Ground Acceleration and Velocity using Deterministic Seismic Hazard Analysis (DSHA).
- Calculating Peak Ground Acceleration and Velocity using Probabilistic Seismic Hazard Analysis (PSHA).
- Formulating Excel Spreadsheets for our analyses
- Generating Design Spectrums and Seismic Hazard Curve

1.3 Background of the Region:

Islamabad is the capital city of Pakistan and it is located in the north east of the country on Potohar Plateau it ranges from 457 to 610 meters above the sea lever. Islamabad; the capital of the Islamic Republic of Pakistan is located at 33.43°N 73.04°E at the foot of the Margalla Hills in Islamabad Capital Territory. Islamabad lies near the ancient city of Rawalpindi and both are referred to as the twin cities. The city occupies an area of 906 sq. km.

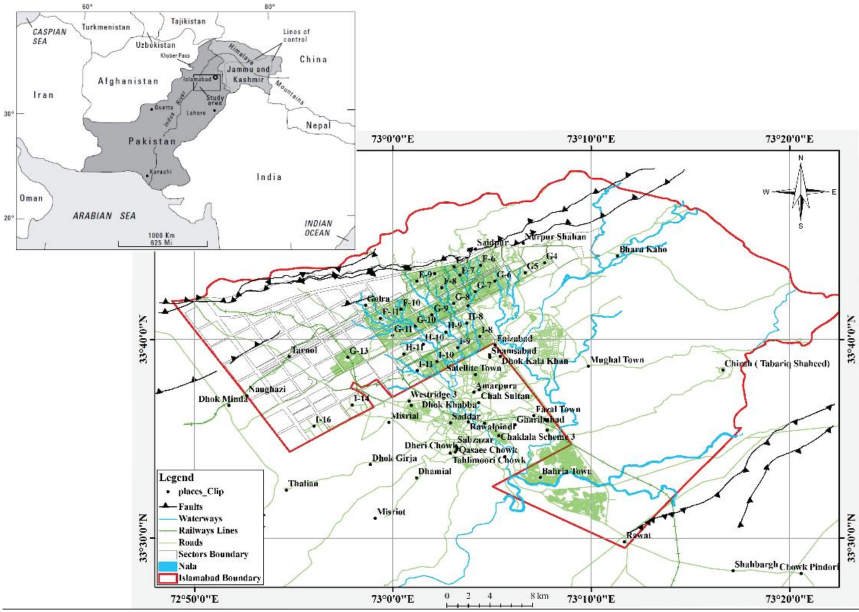


Figure 1: *The Area Studied for Computing Seismic Parameters, (Journal of Himalayan Earth Sciences Volume 48, No. 2, 2015 pp.101-107)*

Unlike other cities of the country it is a properly planned city. Site for Islamabad was selected in 1959 and the city was opened in 1963. Islamabad is consists of 505 km square of urban area and 401 km square of rural area. The city is located within the wider Islamabad capital territory which includes 906 km square of Islamabad and 3626 km square of specified area which includes Margalla Hills located in the north east which is part of the national park.

1.4 History and Importance of Islamabad:

Pakistan gained independence in 1947, Karachi was selected as the initial capital of the country but later on Islamabad was made the capital of the country for few reasons mentioned below.

Karachi was located on one end of the city towards the sea which makes it vulnerable to attacks from outside aggressors hence a capital was necessary to be made which is easily accessible from all parts of the country so Islamabad was selected as the site for new capital as it is closer to the headquarters in Rawalpindi and Kashmir which is a disputed area.

In 1958 commission was made to do studies and find the best site for new capital of the country keeping in mind the following attributes, a lot of emphasis was given to the location, climate logistics and defense requirements.

To prepare the master a Greek firm Konstantinos Apostolos Doxiadis of architects was hired to develop the master plan of the city is a grid plan with a triangular shape with its apex towards Margalla Hills.

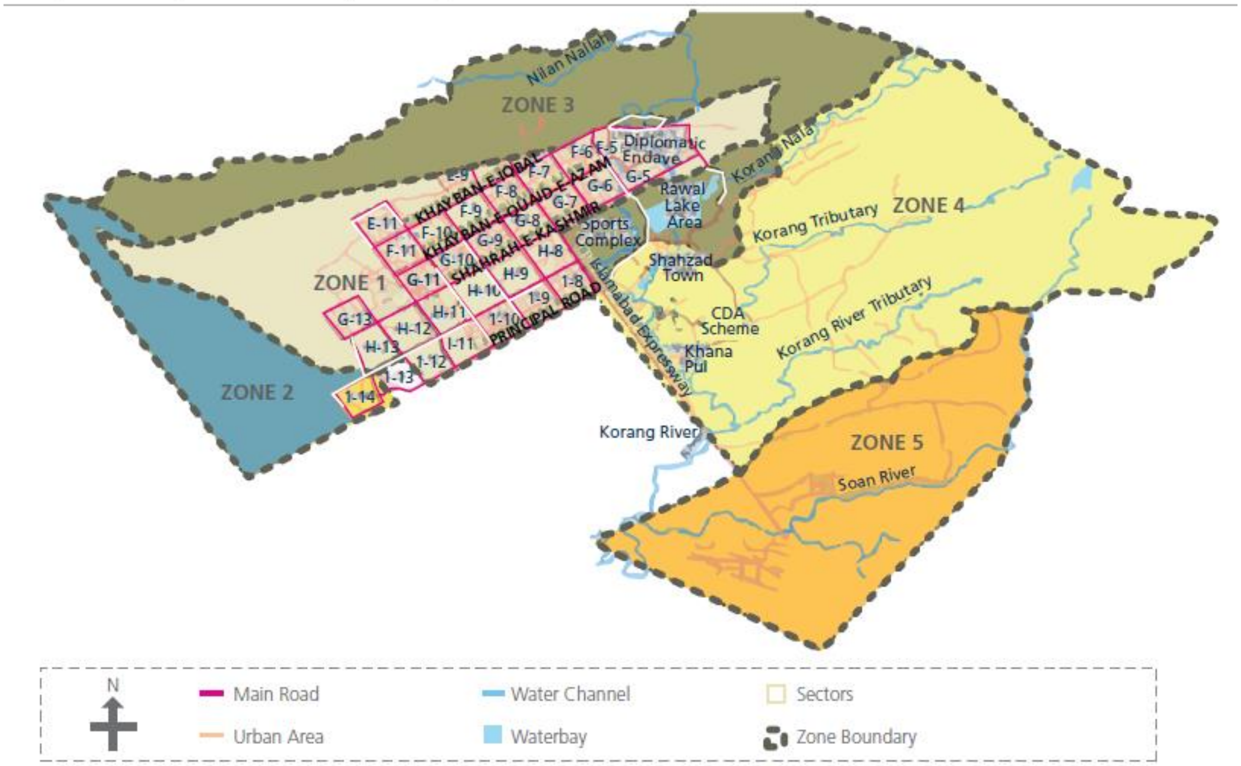
1.5 Master Plan:

For designing the master plan of the city, a Greek firm of architects Doxiadis Associates was hired. According to the plan the region was divided into following three zones as shown in the figure.

- Zone 1 consists of Islamabad
- Zone 2 consists of National park
- Zone 3 consists of Rawalpindi and its surroundings.

Margalla hills would act as a limit for the extension of the city towards the north. Islamabad was further divided in sectors which lie in Zone I. Each sector in Zone I is identified by a letter of the alphabet and a number and each sector covers an area of 4 km^2. Zone I cover an area of 222 km^2 and mainly consists of residential areas, Zone II consists of under developed residential areas having an area of 40 km^2. Zone III has an area of 204 km^2 and Zone IV covers an area of 283 km^2 and Zone V has an area of 158 km^2. Under the above master plan Islamabad was designed as a linear city with a grid arrangement of sectors, where each sector will be a humane community provided with self-sufficient utilities and amenities, it provided spaces for leisure and recreational activities.

Figure 1. Master plan of Islamabad Capital Territory



Source: UN-Habitat

Figure 2: *Master Plan of Islamabad*

1.6 Physiography of Islamabad:

Climate:

The city enjoys five seasons in a calendar year namely; winter, spring, summer, rainy monsoon and autumn. January is the coolest month of the year with temperatures dropping below zero in some hilly locations and meager snowfall. In June, temperatures rise above 40° making it the hottest month of the year followed by extreme rainfall in July. The temperature ranges from -3.9°C to 46.1°C from January through June.

The climate of Islamabad has hot and humid summers which are followed by monsoon and a cold winter. The weather of Islamabad varies considerable throughout the year. Winter is usually from December to march with small rainfall from December to February which are cold months temperature is around 4.5 C. Summer is from April to September with temperature varying around 35 C. Sometimes temperature rises as high as 46C. In summers the monsoon seasons begins it starts in June and ends in September winds are usually from southwest except in monsoon when the winds are from southwest. Average rainfall in this region is about 1150mm. About 65 percent of this rainfall occurs from June to September. Average humidity in this region is about 55 percent. From historical data and temperature, it is clear that his region has become warmer over the time. From studying the precipitation trends from 1961-2010 we see that precipitation has increased.

Topography & Terrain:

The geology of Potohar Plateau is made up of sedimentary rock which is made up of sand stone lime stone and shale. Soil in this region is shallow and is made up of clay. The agricultural productivity of soil in this region is low. Two rivers Kurang and Suan River pass through the outskirts of Rawalpindi and Islamabad. Margalla hills forms the foothill of Himalaya which is located within the in the Margalla hill National park which is in the north of Islamabad. It has an area of 12605 hectors. The hills are the part of Muree hill which has many valleys and high mountains. In addition, the Nullah Lai is an extensive stream system that flows through parts of Islamabad and Rawalpindi. The Nullah Lai has three tributaries (i.e. Saidpur Kas, Tenawali Kas and Bedarawali Kas) all of which originate in the Margalla Hills and pass through Islamabad to join the Nullah Lai. Below Khattarian Bridge, the Nullah Lai enters Rawalpindi and passes through the central city before joining the Soan River. Many drainage and sewerage channels also join the Nullah Lai as it passes through Rawalpindi.

1.7 Physiography of Rawalpindi:

Climate:

The climate of Rawalpindi is humid and subtropical, summers in this region are long and hot while winters are mild and wet. Though the climate of this region is classified similar to Islamabad but because of its geographical location and urbanization its climate is different from Islamabad, because of its closeness to Himalayas and Pir Panjal range the climate of this region shifts rather quickly, Average annual temperature of this region is

23.1 C and average annual rainfall is 1249mm most of which falls in monsoon the hottest month of the year for this region is June where temperature rises as high as 48 C and coldest month is January where temperature falls to -3.9 C.

Topography & Terrain:

Rawalpindi is a part of salt range and Potohar Plateau. Terrain of Rawalpindi is mostly rolling and hilly, with ravines and Nullah running out from hills. Highest parts are found towards northwestern and southwestern side with ground falling in elevation towards Nullah Lai in the west and Kurang river in the eastern side.

These streams usually overflow in the rainy season and cause a lot of damage. The drainage system designed for the city is usually flat sloping gently from Jabbar Miana village towards Soan River. The land of this area is fertile and vegetables & crops are usually grown in this area.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Earthquake is a natural phenomenon which can have negative impact on people and environment. The discipline of earthquake engineering deals with the effects earthquakes have on people and methods of reducing those effects. Earthquake Engineering is a relatively new discipline. Many of the developments in this field occurred in the past 30-40 years. Earthquake Engineering is a broad field it is mainly concerned with aspects of geology, geotechnical engineering, structural engineering, geology and geology, along with the knowledge of these fields the practice of earthquake engineering requires knowledge of social economic and political factors as well. The following passage explains the basic terminologies that need to be understood in order to fully comprehend this study.

2.2 Background:

The study of earthquake is an ancient one. Historical written records of earthquakes found in china are as old as 3000 years, Japanese and eastern Mediterranean records are about 1600 years old. In United States though the records of earth quake are only 350 years old, and on west coast of America which is a seismically active area record of earth quakes goes back to about 200 years only. The experience of humans with earthquake is short compared to the millions of years over which the earthquakes are taking place. Today a significant population of the earth lives under a constant threat of earthquake which can result in loss of lives and property and public infrastructure worth of billions of dollars is at the risk of damage due to earth quake. Earth quakes are a risk to many local, regional and national economies, these risks are not limited to one or two countries. Earthquake is a global phenomenon and a global problem. Earthquakes have occurred over millions of years and they will continue to occur in future as well. Earth quakes that will occur in remote underdeveloped areas will cause less damage and those occurring in densely populated urban areas where public dwelling and other infrastructure relies on ground motion will result in huge economic loss and loss of live

2.3 Seismic Hazards

Earth quakes along with tornados, hurricanes and floods is a natural phenomenon which can cause serious loss of lives and damage to properties. Each year these natural hazards cause tremendous loss damage throughout the world. Hazards which are associated with earth quake are known as seismic hazards.

2.3.1 Ground Shaking

When an earthquake takes place, seismic waves are produced which travel through the earth in the form of vibrations. When these waves travel through the ground in the form of vibrations they cause shaking of the ground which can last from a few seconds to minutes. The strength and duration of ground shaking depends upon the size and location of earthquake and on the characteristics of site. Sites which are in proximity to the source of large earthquakes will experience large ground shaking which result in loss of life and property, ground shaking is the most significant of all seismic hazards because all other hazards are caused by the ground shaking. Among all the seismic hazards ground shaking produces the most damage, sites where ground shaking is low other seismic hazards are also low. Characteristics of soil at site influence the ground shaking. Since soil characteristics can change over short distances hence ground shaking can also change over short distances.

2.3.2 Structural Hazards

Over the years structural damage has been the leading cause of death in both the rural areas where people live in unreinforced masonry buildings as well as the urban areas where people live in modern buildings. It is not necessary that the entire structure will collapse to cause death but the falling objects such as bricks facing and parapets on the outside of the structure or heavy picture and shelves within a building have caused loss of lives. Earthquakes also causes damage to the facilities provided inside the building such as piping, lighting and storage systems. Over the years advancements have been made in the earthquake resistant design of structure and the design requirements in building codes have also improved with time. With the passage of time earthquake resistant design has shifted from an emphasis on structural strength to the emphasis on both strength and ductility. The need for the prediction of accurate ground motion has also increased. In the current design practice a geotechnical engineer is responsible to provide the structural engineer with accurate ground motions.

2.3.3 Liquefaction

Liquefaction is a phenomenon which occurs due to dynamic loading such as earthquakes in saturated soils, in this phenomena soil loses all of its strength to the point where it can no longer supports the structures and hence the structures fall which results in economic loss of loss of lives as well, because liquefaction mostly occurs in saturated soils this phenomenon is observed near rivers bays and other bodies of water. Liquefaction is observed in sands where water is available nearby due to dynamic loading such as earthquake water level rises when it reaches the sand it saturates the sand due to which the sand loses all of it strength and behaves as a liquid almost this phenomenon is known as liquefaction.

2.3.4 Landslides

Earthquakes of large magnitude often causes landslides. Although majority of the landslides caused by the earthquake are small, some of the earthquakes have resulted in large landslides. There are a number of cases in history where landslides have buried entire villages and towns. Usually landslides induced by earthquakes causes damage to bridges and other man-made facilities such as roads and buildings.

Some of the landslides induced by earthquake are a result of liquefaction but some also represent such slopes which are only marginally stable under normal static conditions.

2.3.5 Retaining Structure Failures

Retaining structures are frequently damaged in earthquakes. Usually most of the damage takes place in water front areas such as ports and harbors. As these facilities are used for moving goods when these facilities are damaged it results in loss of business this loss can go beyond the cost of repair and reconstruction of these facilities.

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2.3.6 Lifeline Hazards

The networks that include transportation, telecommunication, water and sewage, oil and gas distribution and waste water systems are collectively known as lifelines. It may include transmission towers, power plants, roads, bridges, buried electrical cables, airports and water treatment facilities etc. Lifelines provide are the facilities that provide services to people which might be sometime taken for granted but are key to the business and day to day life of people. Failure of life lines not only results in huge economic losses but it can also have adverse effect on the environment. The economic losses and effects on business because of the failure of lifelines may be larger than the capital required to repair these facilities. Failure of life lines can also disrupt the emergency and rescue services which are required immediately after the earthquake. In 1906 damaged was caused by a fire which could not be fought properly because the broken water pipes. In 1989 after Loma pieta earthquake a fire broke because of the damaged gas pipe lines and again the firefighting activities were hampered by the broken pipelines.

2.3.7 Tsunami Hazards

If an earthquake results in a fracture in the bed of the sea then it can produce waves for a longer period of time which can result in tsunami. Tsunamis have great speeds in open sea but they are difficult to detect they usually have height of about 1m and wavelength of several kilometers. As tsunamis approach the shore line due to less depth their speed reduces and their height increases. In some areas due to the shape of the sea floor the wave may amplify producing a nearly vertical wall of water rushing towards the land resulting in huge economic loss and loss of life. The great Hoei Tokaido Nonhaido killed around 30000 people in japan in the year 1707. The Chile earthquake in 1960 produced a tsunami which killed 300 people in Chile, 61 people in Hawaii and 199 people in japan.

2.4 Significant Historical Earthquake

Earthquakes takes place almost daily throughout the world, most of the earthquakes are so small that they can’t be even felt only a small number of those earthquakes are noticeable and even a smaller number of those earthquakes are large enough to be considered as major earthquakes. Following table shows some of the major earthquakes that occurred in the history these earthquakes are considered as major earthquakes either because of their size or the damaged that they caused.

The following table contains some of the major earthquake that took place in history, year in which the earthquake event took place, location of the earthquake, number of deaths and description of earthquake.

Date	Location	Magnitude	Deaths	Comments
780 BC	China			It produced a lot of damage in Shaanxi Province
A.D 79	Italy			Sixteen years of continuous earthquakes which ended with the eruption of Mt. Vesuvius it buried the city of pompeii
893	India		180,000	It spread a lot of damage, many people died because of collapse of earthen homes
1556	China	8.0	530,000	It occurred in densely populated area, it triggered landslides which claimed lives of many people living near the mountains.
1755	Portugal	8.6	60,000	Lisbon earthquake, the first scientific description of earthquake
1783	Italy		50,000	Calabria earthquake: Fist scientific commission of earthquake investigation formed
1811-1812	Missouri	7.3,7.5,7.8	Several	Three large earthquakes within two month of new Madrid area felt all across united states.
1819	India		1500	Cutch earthquake: first well documented observation of faulting
1857	California	8.3	1	One of the largest earthquake known to be produced by San Andreas Earthquake
1872	California	8.5	27	Owens Valley earthquake it is one of the strangest earthquake to have occurred in United states
1886	South Carolina	7.0	110	It was a very strong earthquake that produced liquefaction
1906	California	7.9	700	It was the first large earthquake which strikes densely populated area in United States of America. Damage was caused by fire. It produced 21 ft. offsets in 270 miles rapture of San Andreas Fault
1923	Japan	7.9	99,000	Kanto Earthquake it causes damage in Tokyo Yokohama area because of fire in Tokyo and Tsunami in Coastal Areas it influenced the design practices in Japan.
1925	California	6.3	13	Santa Barbara Earthquake, it caused liquefaction and failure of Dam, it led to first ever provisions of earthquake resistance in US.

1933	California	6.3	120	It caused huge damage to buildings, many children were killed and many more were injured. It led to greater design code requirement in code.
1940	California	7.1	9	Large ground displacements along imperial fault were observed. First important accelerogram was recorded for engineering purposes.
1959	Montana	7.1	28	Faulting within the reservoir produced seiche which over toped the dam
1960	Chile	9.5	2,230	It is the largest earthquake ever recorded in history.
1964	Alaska	9.2	131	Known as the good Friday earthquake. It caused a lot of damage due to liquefaction and landslides.
1964	Japan	7.5	26	It caused widespread liquefaction which caused damage to roads bridges and port facilities
1967	Venezuela	6.5	266	It caused the collapse of new buildings in Caracas.
1971	California	6.6	65	It caused the collapse of many buildings, bridges many structural lessons were learnt. Particularly the need for spiral reinforcement for concrete columns.
1975	China	7.3	1300	Successful prediction was made, and evacuation was done which save a lot of people.
1976	China	7.8	700,000	It is thought to be the deadliest earthquake in history it destroyed the city of Tangshan.
1985	Mexico	8.1	9500	It caused a lot of damage to buildings and roads and bridges many lessons were learnt in regards to effect of soil on seismic waves.
1989	California	7.1	63	It caused a lot of liquefaction in the san Francisco bay area
1994	California	6.8	61	North Ridge Earthquake, occurred on previously unknown fault beneath a very populated area, buildings bridges and lifelines were destroyed.
1995	Japan	6.9	5300	Hyogo-ken Nenbu earthquake, caused damage to Kobe japan, it produced widespread liquefaction.

2.5 Faults

A fault is a fracture along which the blocks of crusts move. Length fault can vary from several meters to hundreds of kilometers and it could be several kilometers deep. Sometimes these faults are easy to identify and at other times they may be hard to locate. Just the presence of the fault does not mean that earthquake will occur at the fault, the fault might be in active on the other hand if a fault is not observable on the surface does not mean that earthquake will not occur in fact in most earthquakes the rapture of fault does not reach the ground surface. A fault consists of foot wall and hanging wall, depending upon how these walls move relative to one another faults are classified into following three types.

1. Normal Fault
2. Reverse Fault
3. Strike Slip Fault

Footwall

Foot wall is the block of crust that lies under the fault plane.

Hanging wall

Hanging wall is the block of crust that lies above the fault plane.

Normal Fault

If the hanging wall moves down relative to the foot wall then the fault is known as normal fault

Reverse Fault

If the hanging wall move up relative to the foot wall then the resulting fault is known as reverse fault.

Strike Slip Fault

If the blocks of crust move parallel to one another then the resulting fault is known as strike slip fault.

When the crust is pulled apart it results in normal faulting in this case the over laying block moves down with respect to the lower fault. When the crust is being compressed it results in reverse fault where the over laying block moves up with respect to the lower fault. It is possible that the blocks of crusts might move parallel to one another resulting in strike slip fault in this case the fault is nearly vertical. An oblique slip involves combination of these movements:

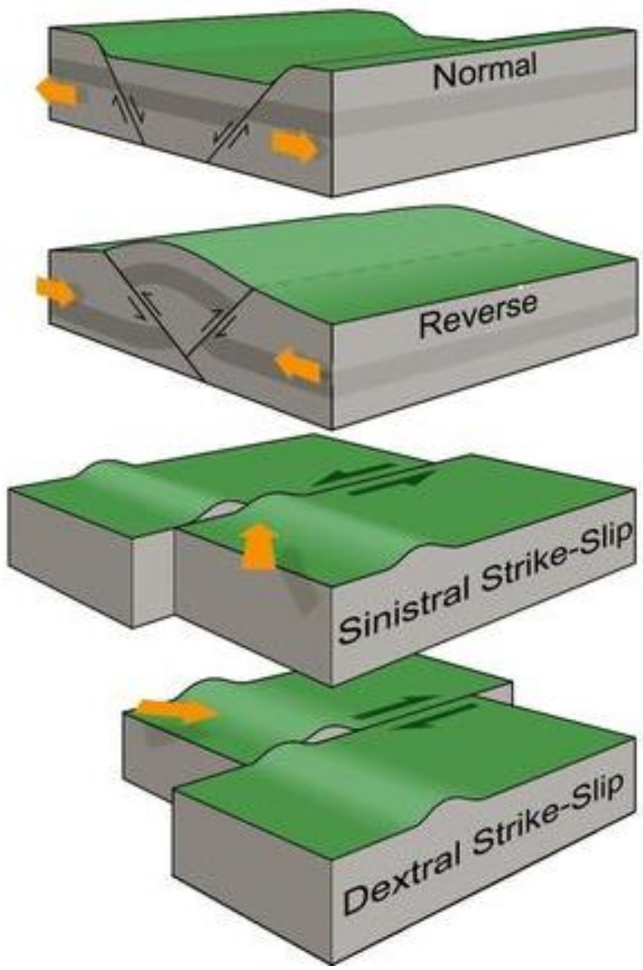


Figure 3: Types of Faults

Earthquake is a natural phenomenon which has negative impacts on people and environment. The humane experience with earthquakes is a short one compared to the time from which these earthquakes are taking place. In regards to earthquakes Tiwari wrote in his paper. 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 of dollars. These losses are more in developing countries because of high population density and poor constructions in terms of earthquakes (Tiwari, 2000)

There are a number of cases in history where earthquake has caused liquefaction of soil, this results in loss of strength of soil due to which buildings might fall and it can also trigger landslides J.N Malik investigates the liquefaction caused by 8th October 2005 earthquake. In this paper, they reported the farthest liquefaction that occurred which is located at a distance of about 220-240Km away from the epicenter of the earthquake in the area of Jammu as a result of the earthquake that occurred in October 2008. This earthquake resulted in minor damages to the homes, minor cracks were observed in walls in this area. Due to the earthquake, the water table in this area rose it rose to about 1ft below the ground normally it used to be 20ft below the ground (J.N Malik et.al. ,2006)

Similarly, Saroh carried out a study which presents the results based on the field tests which are performed to assess how susceptible the soil of the costal belt of the city of Karachi is to liquefaction in the event of an earthquake and the study shows that this area is highly susceptible to liquefaction in the event of an earthquake (Sarosh h. Lodi et.al. 2015)

There is a threat of seismic hazard to Islamabad because it is laying close to an active fault such as Main boundary thrust, there are other faults near Islamabad having the potential for producing earthquakes. In this study, they did the evaluation of the seismic parameters using the seismic data over an area of about 300 km radius around Islamabad. This study suggests that seismic hazard in this area is not uniform it varies from 0.30-0.32g for a return period of 475 years and 0.2-0.25g for a return period of 2500 years. This study shows that these values do not confirm the present seismic zone 2B. This study showed that as the values of spectral acceleration varies from point to point there is a need for other criteria and the entire city of Islamabad is prone to earthquake hazard. (Sarfraz khan et.al.,2015)

This study gives an insight in to the seismology of the region and seismic hazard to this region. It gave useful details about the major earthquakes that took place in this region and the surrounding areas like kangra earthquake 1905, pattan earthquake 1974 and Muzaffarabad earthquake of 2005. This study also provided useful information regarding the history of earthquakes in the past century with the exact locations of the epicenters of the earthquake and the magnitude of the earthquake. (Northern Area Report 2006)

It is the collapse of building in earthquakes which has been a cause of deaths that is why it is imperative that the construction practice of buildings be improved and improvements need to be done to seismic resistant design of buildings. This study analyses the destructions, especially to buildings and dwellings it gives information on the type of construction, causes of failure due to earthquake, potential seismic resistant interventions during reconstruction phase and solutions for winter shelters. This study gives details on the factors for such high cause of loss of life and properties, risk reduction measure to be included in long and short-term recovery programs and gives suggestions on the approaches adopted for reconstruction and rehabilitation programs (Mr. N.M.S.I. Arambepola 2005)

In order to determine the class of site, shear wave velocity tests need to be performed in this study Krishna this study describes measurement of shear wave velocity on site by explaining the principles of the down hole and cross hole tests. Velocities of compressional waves and shear waves are determined using cross hole tests. For a known distance time of a wave traveling from the source to the receivers is measured. The shear wave velocity is determined using the following equations $V_s=(R_2-R_1)/(T_2-T_1)$, R_1^2=Z_1^2+x^2, R_2^2=Z_2^2+x^2 where Z_1 and Z_2 gives the vertical depth of the 2 receivers from the hammer and plate which is the source of waves and x is the horizontal distance of receivers from the hammer. A plot between time and depth is drawn and the slope of line obtained gives the velocity of the waves. (Krishna)

This study provides assistance in determining Vs for top 30m soil profile. When exploration of soil is not possible and when data specific to the site is not available, following the recommendation given in this paper it gives an estimation of Vs30 within 30% actual value. If the sites are rocky then Vs30 is measured on the basis of Vs measurements at the site, Vs30 can also be obtained from the published data. For sites having soil recommendations are given to estimate Vs based on the geotechnical properties, recommendations in regards to equations are given. Sites which have both rock and soil are intermediate sites for such sites shear wave velocity is calculated separately for rock and soil. If data for rocky strata is unavailable Vs30 can be calculated from the published data using correlations provided. (J.P Castanga et.al)

Shear wave velocities could also be used for the determination of soil properties. This study describes measurements of shear wave and primary wave on top soil. This study gives the equations for determining different soil properties like the bulk density: poisons ration: K/G the ratio of incompressibility and rigidity, E/G the ration of elasticity and rigidity. (Usman Uyanik 2010)

Similarly dynamic geotechnical properties of soil/rock are can be determined by various in-situ test methods. Dynamic problems are related to liquefaction, ground response, Slope Stability, Vibrations, pile driving and dynamic compaction. Traffic vibrations also cause dynamic problems in a great extent, earthquake can cause dynamic problems. Engineering interest is mostly concerned on those methods that can measure dynamic properties of soil and rock in order to design the site specific problems (Campanella 1994)

In order to determine seismic hazard for an area Deterministic and Probabilistic Hazard analysis needs to be carried out Saeed Zaman presents probabilistic seismic hazard analysis carried out using three models of seismic sources i.e.

specially smoothed gridded seismicity (2 BG seismicity in which one includes three depth interval of seismicity and the other only shallow depth in area of faults which are mapped), crustal fault models which are thirteen in number and subduction source model and earthquake catalogue. Epicentric uncertainties are taken into account by using CE and GR magnitude frequency models, $M_{max,}$ Crustal fault slip rates, three NGA, two intermediate depths and three subduction GMPE's. With the new improvements, the maps in this paper represents the seismic hazard of Pakistan. Using the data available and most recent computerized data interpretation the seismic hazard of Pakistan has been updated. However, there is a need for further studies like paleo seismic investigation of crustal faults to verify the assumed characteristics of crustal faults. Record of strong ground motion for earthquake is also necessary to make a more prudent choice of GMPE's. In short, the seismic hazard maps presented in this paper will change in the future when more data is available. (Saeed Zaman)

Rasheed Ullah and Irshad Ahmad carried out an important study for the region of Islamabad in which they determined Peak ground acceleration along with other parameters they performed both the deterministic hazard Analysis and probabilistic hazard analysis. In deterministic seismic hazard analysis Islamabad was taken as a center and a circle of about 100km was drawn and all faults laying inside the circle or just touching the circle were considered. The deterministic seismic hazard analysis shows main boundary thrust to be the most critical fault for Islamabad and its vicinity. This fault can generate an earthquake with moment magnitude (Mw=8.1) and peak ground acceleration values of 0.49g, following are the two reasons for this:

This fault passes at a nearest of about 2km from Islamabad. It is one of the largest faults of Pakistan that can generate earthquakes of greater magnitudes.

In the probabilistic Seismic hazard analysis and within 100 km radius circle of Islamabad 4 areal source zones are selected and their recurrence relationships have been developed. Among these source zones the Potwar salt range and Himalaya zones show low b values 0.95 and 0.83 respectively, these zones can be termed Hazardous. The Hazara and Banu zones show high b values of 1.23 and 1.11 and are seismically sable zones. In this study, for the city of Islamabad, peak ground acceleration of 0.28g was obtained at bedrock for 10% probability of exceedance in 50 years with return period of 475 years. From probabilistic seismic hazard analysis, it is clear that the city of Islamabad should be placed in zone-III of Uniform building code and building code of Pakistan. Peak ground acceleration of deterministic seismic hazard analysis is 0.49g and for probabilistic seismic hazard analysis it is 0.28g which are drastically different from one another. The reason for this is that deterministic seismic hazard analysis takes into account the direct contribution of Main Boundary Thrust (MBT) which is just at a distance of 2km from Islamabad. Whereas in probabilistic seismic hazard analysis areal seismic source zones are considered in which seismicity is spread over the seismic source zones. Therefore, it is recommended for Islamabad (which is an important city) procedure defined by US geological survey for developing US seismic hazard maps should be adopted but this procedure requires precise information regarding geometry and seismicity of individual faults which is currently unavailable. Research should be conducted to characterize the faults of Pakistan. (Rasheed Ullah et.al 2010)

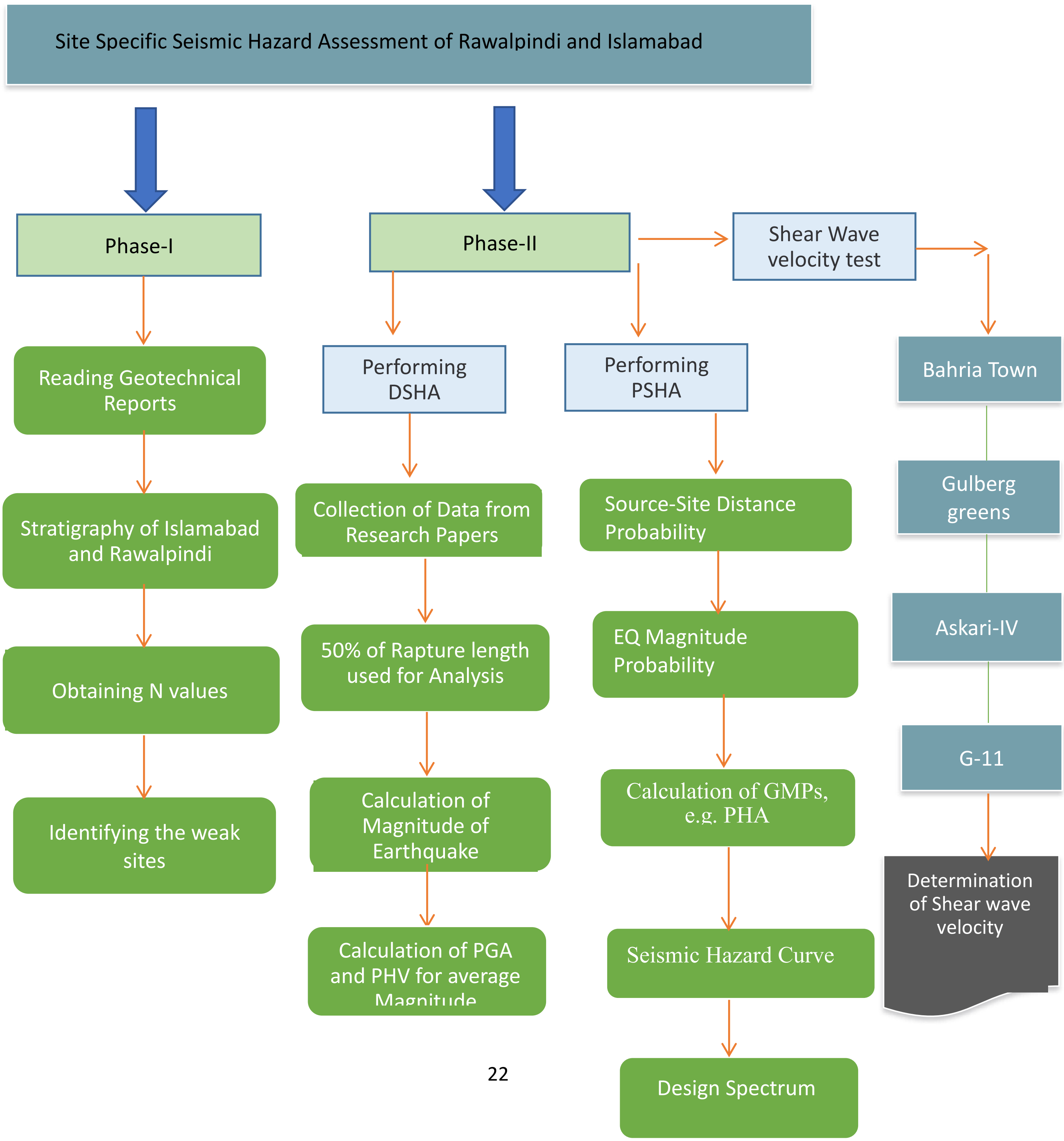
Study of Abdul Qadir Bhatti is an important study as for a as seismic hazard analysis of Islamabad is concerned. This study shows that the seismic hazard in Islamabad is not uniform as it varies from sector to sector with a PGA varying from $1.35 m/s^2$ to $2.54 m/s^2$. This study shows that the F series of sector is most prone to seismic hazard with F-11 sector most prone to the seismic hazard. It was found that an earthquake M_w =6.2 at a distance of 20 to 30 km is likely to strike Islamabad. Building Code of Pakistan has placed Islamabad in seismic zone 2B indicating a 500-years of return period with PGA of 0.16-0.25g. Similarly, NESPAK suggested a PGA of 0.3g for a return period of 2500 years. The peak ground acceleration (PGA) for this return period in this study ranges from 0.24g to 0.37g. The peak ground acceleration calculated in this study falls in this rage. This study shown peak ground acceleration for a grid of 1km by 1km therefore micro zonation is built into IBC 2006 criteria. S_s which is spectral acceleration at0.2 seconds at a return period of 2500 years) S_1 Which is spectral acceleration at 1 seconds at a return period of 2500 years will allow structural engineers to define seismic load in terms of IBC 2006 and ASCE 7-05 criteria. Authors have established in this study that 90% of the earthquakes in this region are caused by thrust fault mechanism and are shallow earthquakes where even a small magnitude could be disastrous, (Abdul Qadir Bhatti et.al 2011)

CHAPTER 3

METHODOLOGY

3.1 Methodology:

The following flow chart shows you the steps involved in our study:



1) Development of the soil profile:

Knowing the soil profile is of key importance in Civil Engineering. Knowing the kind of soil, they are dealing with provides a lot of ease to engineering who are working on the design of the foundations of all kinds of structures. It can give them a hint about the bearing capacity of the soil the type of failure that can occur etc. It can give them a general idea about the kind of soil they are going to deal with without going through the process of digging bore holes.

One of the advantages of developing soil profile would be that it will allow us to classify this region as far as seismic zonation is concerned.

Soil profile for the region of Islamabad and Rawalpindi is not available. One of the objective of our study is to prepare a soil profile for the region We read about 20 geotechnical reports for different sites in the region of Rawalpindi and Islamabad and for each sector or area we had on average 5 reports using those reports we draw the soil profile for that area and then we merged the profile obtained from those 5 bore holes data to obtain a single profile for the area we repeated this process for about 20 sites and investigated the soil profile beneath the ground. According to the building code of Pakistan this region is classified as rocky but our study reveals that not all the region is laying over the rock there are weak regions too. All of this process was hand written later on we used Auto Cad to plot the data figure shows you the profile that we obtained.

Another benefit of developing soil profile of this region is that all those people who will be doing construction in these areas will have a general idea of the kind of soil they are dealing with without having to dig bore holes.

Following are the sites which were selected for the study of the region of Rawalpindi and Islamabad:

Site	Site	Site
Sector F-16	Sector-H12	Sector-G11
F9 Park	NARC	Park Enclave Society
Gulberg Greens	Bahria Town Rawalpindi	DHA phase IV
Morgah	Safari Villas	Askari IV
Askari-X	Mareer Chowk	Ratta Amral Bridge
H-13	NUST Site 1	NUST site 2
Bahria Town Phase IIV	Naval Anchorage	…………………..

Figure 4: *Tagged Locations of Isb/Rwp*

Rawalpindi:

Following is the sub surface soil profile of Rawalpindi that we developed using borehole data.

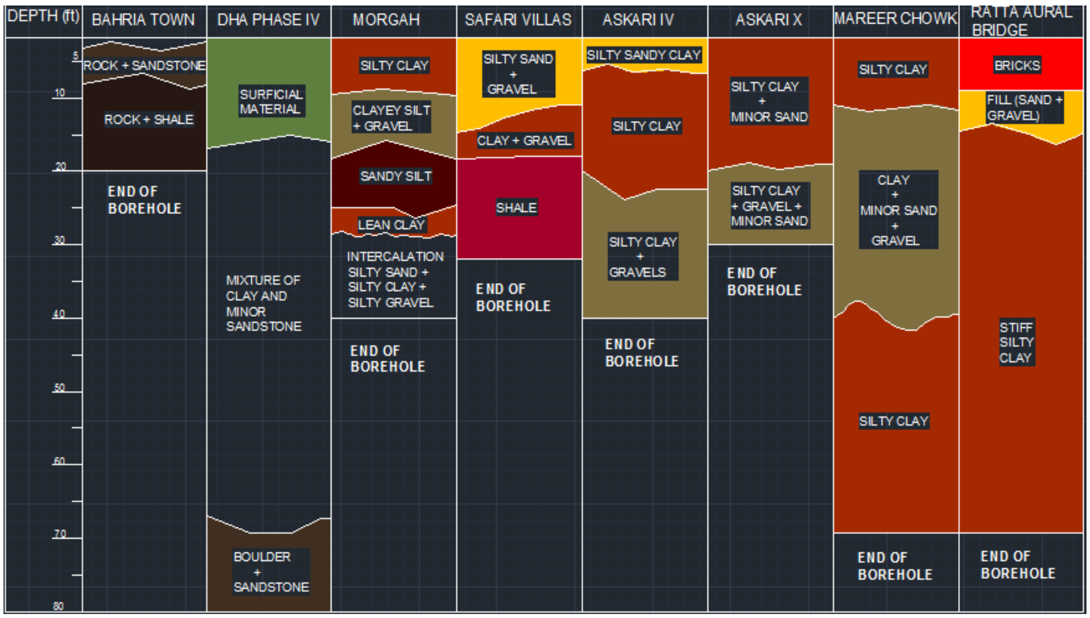


***Figure 5:** Soil Profile of Rawalpindi*

Islamabad:

Following is the sub surface soil profile that we developed for Islamabad using borehole data.

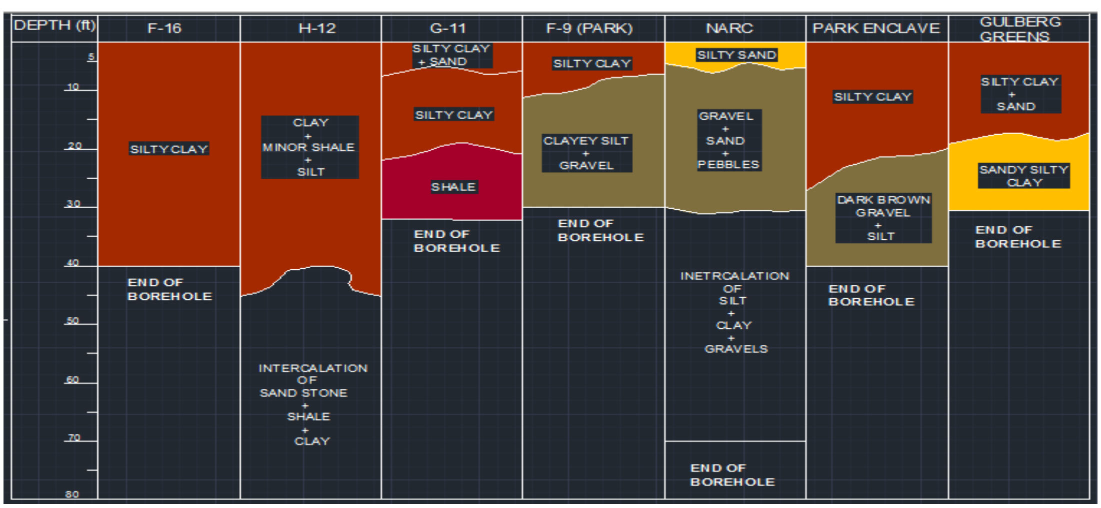


***Figure 6:** Soil Profile of Islamabad*

2) Shear Wave Velocity Test:

We also obtained SPT-N values from the bore hole data from these values we could get an indication of the weak sites i.e. the sites having less than 10 N value, the sites having less n value meant that those sites are weak or the soil is not stiff hence it means when the earth quake waves will pass through it these soils will be prone to damage. So, we marked those sites and we performed shear wave test on those sites the instrument we used was Seistronix RAS 24:

The figure below explains how we performed shear wave velocity. First, we inserted the channels in the ground (these channels come with Seistronix RAS 24 device), using a sledge hammer we produced shear waves in the ground these waves propagated through the ground and reached the channels where these waves are detected by the device and a seismograph is plotted on the screen of the laptop attached. This seismograph can be read for interpretation.

24-Channel Setup

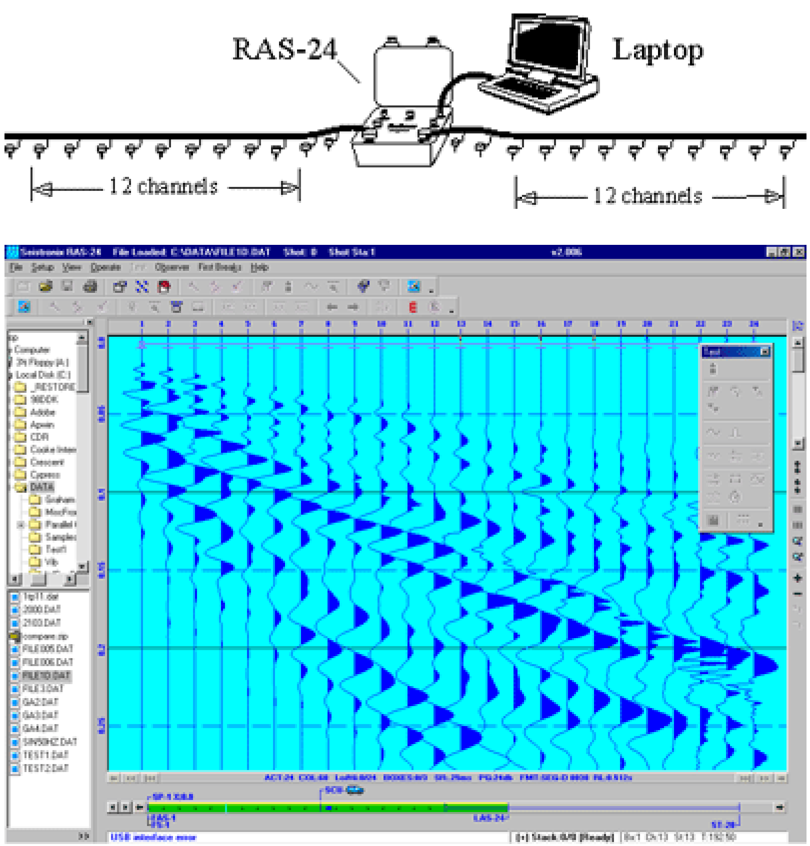


Figure 7: *Interface & Functioning of Seistronix RAS-24*

Seistronix RAS-24:

Seistronix RAS-24 is the device we used for the shear wave testing. This device is used for small refraction and reflection surveys. It is less costly and easy to use. Other applications include shallow refraction and reflection exploration, ground water surveys location of faults, depth to bed rock and other general geotechnical surveys. It is a user-friendly device the data could be seen easily and interpreted and manipulated with ease. It also offers geophone resistance, geophone similarity, geophone pulse and cable leakage tests to detect problems before they can affect the data in anyway. It continuously records the data and sends it to laptop for permanent storage. The data could be seen in the form of graphs.

Figure 8: *Seistronix RAS-24*

3) Use of seismic waves to obtain dynamic properties of soil and Rock:

We used the values of seismic velocities to obtain properties of soils using various equations. Following chart shows the parameters that could be obtained using seismic waves and against them are written the equations that could be used to obtain those parameters.

Following are some of the values that could be obtained using value of velocity of shear and primary waves.

The benefit is that you can obtain these values at a much less cost without putting much effort and without disturbing the natural condition of soil.

Values	Equations	Reference
K is the bulk Modulus ρ is the density U is the elastic Moduli Alpha is elastic poison's ration G is the shear modulus E is the elastic Modulus	V_p=1.16Vs+1.36 V_p=[(k+0.75U)/ ρ)]^0.5 V_s=(U/ ρ)^0.5 Alpha=[1-2(V_s/V_p)^2]/[2-2(V_s/V_p)^2] G= ρV_s^2 E=2(1+a)G M=$P_x$$V_p$^2	Rosli Saad and Edy Tonnizm Mohamad et.al
Rock densities using shear wave velocity Allowable bearing capacity Allowable bearing capacity Ultimate bearing capacity	ρ=aV_p^Alpha a=0.31, Alpha=0.25 q_a=(G/V_p) G=PV_s^2 q_a=(ρV_s^2/100V_p) q_a=q_{ult}/F. S	Ali K EÇELİ et.al (2012)
Poisson's ratio Shear modulus Bulk modulus Young modulus Ration of incompressibility and rigidity Ratio of elasticity and rigidity Bulk density	K = 2G [(1+u)/3(1-2u)], E = 2G [1+u] U=[(V_p/V_s)^2-2]/[2(V_p/V_s)^2-2] K/G=[(V_p/V_s)^2-(4/2)] E/G=3[(V_p/V_s)^2(4/3)]/[(V_p/V_s)^2-1] P=16+0.002V_p G=ρV_s^2	Usama Uyanik et.al (2010)
Undrained shear strength using seismic waves	V_s=23Su^0.475 For Cohesive soils	Guidelines for estimation of shear wave velocity

It is also possible to determine values of shear wave velocity for all soils using N values that we obtained from geotechnical reports, there are a number of equations. There are equations for all soils, silts, clays and for sands. (University of California Los Angeles page 5 or 6)

Dynamic Geotechnical properties of soil/rock are determined by various in-situ test methods. Dynamic problems are related to liquefaction, ground response, Slope Stability, Vibrations, pile driving and dynamic compaction. Traffic vibrations also cause dynamic problems in a great extent, earthquake can cause dynamic problems. Engineering interest is mostly concerned on those methods that can measure dynamic properties of soil and rock in order to design the site-specific problems (Campanella 1994)

The In-situ test which are performed in laboratory depends upon the accuracy with which the tests are performed and the extent to which the sample is disturbed. Field tests will cause minimum disturbance to the soil sample and in case of shear wave tests the sample is not disturbed at all so highly accurate results are obtained and the cost and effort required is minimum.

4) Investigation:

Using seismic waves or shear waves we can perform the following investigations:

We can investigate

- Altering zones in sub-surface soil
- Cavities present in soil
- The occurrence and location of discontinuities in the soil
- Stability analysis of the ground
- Mechanical properties of soil and rock.

Only 3 properties are required to describe mechanical properties of a system which are, k (bulk modulus), E (young Modulus), G (shear Modulus). For poison's ratio, we have the correspondence between the ratio K/G (the ratio of incompressibility and rigidity) and velocity ratio V_p/V_s.

There is correspondence of ratio E/G (the ratio of elasticity and rigidity) and velocity ration V_p/V_s. there are universal equation for K and G which are listed below.

$K = 2G [(1+u)/3(1-2u)]$,

$E = 2G [1+u]$

I n terms of the ratio of seismic waves we have the equation for poisons ratio which is as follows

$U = [(V_p/V_s)^2-2]/[2(V_p/V_s)^2-2]$

Combining the above three equation we obtain the following equations

$K/G = [(V_p/V_s)^2-(4/2)]$

$E/G = 3[(V_p/V_s)^2(4/3)]/[(V_p/V_s)^2-1]$

Now how can we use the seismographs to obtain numerical values of these properties is also explained in the paper.

3.2 Seismic Hazard Analysis:

After completing phase 1 of the project that involved weak site identification and then conducting shear wave velocity tests on those sites, we moved on to phase 2 of the project. The phase 2 is the core part of our project and involves detailed seismic analysis of the region of our consideration.

There are two approaches available to conduct seismic hazard analyses and both are good in certain situations and both have certain drawbacks as well. The two approaches are listed below:

1. Deterministic
2. Probabilistic

For our particular project, we have used both of these approaches to carry out the seismic hazard analyses of Islamabad and Rawalpindi. Not only that but we also formulated excel spreadsheets that enable us to calculate site specific seismic parameters thus enabling us to provide site specific results.

We started off with the Deterministic Seismic Hazard Analysis first and then moved on to the second approach. The Deterministic Seismic Hazard Analysis was then formulated on Microsoft Excel.

In order to perform both the analyses certain papers published in journals have helped us and we have referenced them in the end of the thesis under Bibliography.

3.3 Deterministic SHA:

The Deterministic SHA is an approach of SHA that is a subset of the probabilistic approach. This approach is based on a particular scenario for which the analysis is performed. The scenario is usually the worst-case scenario.

In order to get the worst-case scenario, the following two factors are to be checked:

1. That the source-to-site distance is minimum
2. Maximum possible magnitude is considered

The detailed and step by step procedure that we employed is explained below:

3.3.1 Fault Selection:

Fault selection is a very crucial step since it is the starting point and governs the effects of earthquake on any site. The fault selection is also a very difficult step since you have to consult the fault maps and geo hazards of the region and the data has to be collected from multiple sources.

Therefore, we used data from existing research of multiple researchers from their researches. The works done by them are pertinent to the geology of the area and were not of main significance for us to repeat them again.

Hence, we collected the data about the various faults in the vicinity of the region and then used them for our own analysis. We have selected 14 faults that are of significance to our study. The faults of significance are those that are within a radius of 100 km from our site. Outside this 100-km radius, the ground shaking due to an earthquake is usually not so disastrous and thus not very significant.

These faults include large faults such as the Main Boundary Thrust, the Himalayan Frontal Thrust and the Main Mantle Thrust as well as some smaller faults.

We have classified the faults based on the type of faults. There were three different classifications that we used:

- All types
- Reverse type
- Strike Slip type

Fault Name	Fault Length (km)	Rupture Length (km)
Main Mantle Thrust	339	170
Batal Fault	71	35
Riasi Fault	200	100
Pir Panjal	98	48
Main Boundary Thrust	353	176
Himalaya Frontal Thrust	225	112
Hissartang	160	80
Khair-e-Murad	164	82
Khairabad	205	103
Nathia Gali	70	35
Soan Back Thrust	103	52
Puran	99	49
Thakot	85	42
Chaman	850	425

All the faults that were important to the study and have been used in the analysis are listed in the table above. In the second column, we have the lengths of the faults. The third column has the rupture length of the faults. We have used 50% of the total fault length as the rupture length of the fault. The reason is that above 50% of rupture at a single event is unprecedented and produces unrealistically large magnitudes.

As seen from the table, Main Mantle Thrust has a fault length of 339 km while Main Boundary Thrust has a fault length of 353 km and is the longest. One important thing here is that Chaman fault has also been considered for the sake of the fact that it is the largest fault in Pakistan and is located in the province of Baluchistan. We wanted to check the hazard posed by the largest fault of Pakistan to the region of Islamabad and Rawalpindi. Small faults like Puran, Thakot, Batal Pir Panjal and Nathia galli Thrust have been included because the places where these faults are will experience large ground shaking irrespective of the fault lengths. It is very important to consider all the faults in an area to perform a comprehensive analysis.

3.3.2 Magnitude Computation:

Calculation of Moment Magnitudes is the second important step after having identified the faults. Moment Magnitude of an earthquake is a measure of the energy released during an earthquake event.

To calculate the moment magnitudes, we have used five different regression models developed by different researchers. Some of these are magnitude length relationships while others are magnitude area relationships. The applicability of these regression models depends on the earthquake sources and catalogues that have been used to prepare the regression models.

The regression models that we have used are all applicable in our region since all have been formulated using worldwide data. The models are:

- Wells and Coppersmith (1994)
- Bonilla et. Al. (1984)
- Ellsworth B Relationships
- Wyss (1979)
- Somerville et. Al. (1999)

After calculating the magnitudes from all these five different models, we calculated their mean to get the least possible error in potential Moment Magnitudes that can be generated from all the faults.

The regression models have been shown below:

Ellsworth-B:

Mw = logA + 4.2

A=fault area (km2)

Bonilla et. Al. 1984:

Mw=6.04 + 0.708LogL All types of faults (45 events used)

Mw=5.71 + 0.916LogL Reverse and reverse-oblique faults (12 events used)

Mw=6.24 + 0.619LogL Strike-slip (23 events used)

Somerville et. Al. 1999:

Mw = log A + 3.95

A=rupture area (km2)

Wells and Coppersmith 1994:

Mw = 4.07 + 0.98LogA All slip types (148 events used)

Mw = 3.98 + 1.02LogA Strike-slip faults (83 events used)

Mw = 4.33 + 0.90LogA Reverse faults (43 events used)

Mw = 3.93 + 1.02LogA Normal faults (22 events used)

Wyss 1979:

Mw=logA + 4.15

All these relationships were checked for applicability from multiple reports like the 'Magnitude Scaling Relationships by M.W. Stirling and T. Goded.'

The results and calculations of the magnitudes are shown in the table below:

Deterministic Seismic Hazard Analysis									
ALL FAULTS									
Fault	**Fault Length (km)**	**Rupture Length (km)**	**Wells & Coppersmith**	**Bonilla**	**Rupture Area W&C (km^2)**	**Ellsworth**	**Wyss**	**Somerville**	**Avg. M_w**
Main Mantle Thurst	339	170	7.67	7.62	3088.16	7.69	7.64	7.44	7.61
Batal Fault	71	35	6.87	7.13	577.70	6.96	6.91	6.71	6.92
Riasi Fault	200	100	7.40	7.46	1753.88	7.44	7.39	7.19	7.38
REVERSE FAULTS									
Pir Panjal	98	48	7.05	7.25	829.85	7.12	7.07	6.87	7.07
Main Boundary Thrust	353	176	7.74	7.77	3937.31	7.80	7.75	7.55	7.72
Himalaya Frontal Thrust	225	112	7.50	7.59	2290.87	7.56	7.51	7.31	7.49
Hissartang	160	80	7.32	7.45	1526.16	7.38	7.33	7.13	7.32
Khair-e-Murad	164	82	7.33	7.46	1560.99	7.39	7.34	7.14	7.33
Khairabad	205	103	7.46	7.55	2093.15	7.52	7.47	7.27	7.45
Nathia Gali	70	35	6.88	7.12	565.46	6.95	6.90	6.70	6.91
Soan Back Thrust	103	52	7.09	7.28	908.24	7.16	7.11	6.91	7.11
STRIKE SLIP									
Puran	99	49	7.05	7.33	841.40	7.13	7.08	6.88	7.09
Thakot	85	42	6.98	7.28	727.78	7.06	7.01	6.81	7.03
Chaman	850	425	8.10	7.91	7413.10	8.07	8.02	7.82	7.98

As is evident from the table above, Chaman Fault can produce an earthquake of magnitude 7.98. Main Boundary Thrust can produce a 7.72 magnitude earthquake while the Main Mantle Thrust can produce an earthquake of 7.61 in case 50% of the fault ruptures.

These magnitudes are the moment magnitudes and they represent the amount of energy released.

3.3.3 Site Selected:

Although we have formulated spreadsheets to calculate site specific ground motion parameters but the first part was to perform analysis for a site in Islamabad. We selected Islamabad Stock Exchange as our site because all the fault distances from ISE to the faults that we have considered for our study are available. Whenever we have to perform analysis for any other site, we just need to change the source-to-site distance as the input parameter and the results will be just fine with our excel spreadsheets as well as quick.

3.3.4 Computations of Peak Ground Acceleration:

To calculate the Peak Ground Acceleration, we have used the Attenuation Relationship proposed by Boore, Joyner and Fumal (1993) because of emphasis by Kramer in his book, Geotechnical Earthquake Engineering. This particular relationship was selected because of three particular reasons:

There were no Pakistan specific attenuation relationships available for seismic hazard analysis of the region.

To compute PGA values at Mangla Dam, a revision of Boore 1993 was used.

According to Jain (2005), this particular relationship is suitable for Central Himalayas as established through his regression model.

The attenuation relationship is as follows:

In the use of this expression, a site is classified into one of four categories (A, B, C, and D) depending on the average shear-wave velocities of the upper 30m of geologic material. Classes A, B, C, and D include sites where the average shear-wave velocity are:

greater than 750 m/s;
between 360 m/s and 750 m/s;
between 180 m/s and 360 m/s;
and less than 180 m/s, respectively.

As a result of lack of data presently available for site class D, Boore, Joyner, and Fumal excluded it from their analysis.

When the constants derived for estimating the peak acceleration for the larger of two horizontal components are substituted, the above equation reduces to:

$$G_B = \begin{cases} 0 & \text{for site class A} \\ 1 & \text{for site class B} \\ 0 & \text{for site class C} \end{cases} \qquad G_C = \begin{cases} 0 & \text{for site class A} \\ 0 & \text{for site class B} \\ 1 & \text{for site class C} \end{cases}$$

$$\log_{10}(Y) = -0.038 + 0.216(M - 6) - 0.777 \log_{10}(R^2 + 30.03)^{1/2} + 0.158G_B + 0.254G_C$$

As can be seen, the relationship accounts for the various site classes that are categorized on the basis of shear wave velocity. Once through refraction survey and other methods you have identified the site class, you can use the appropriate values for the various coefficients to calculate the PGA values. Since we were conducting the analysis for the entire region of Islamabad, and it wasn't possible to classify the sites on the basis of shear wave velocities, we calculated the results at the bedrock;

thus, Site Class A. However, since our results were generated through Microsoft Excel Spreadsheets, we calculated the PGA values for all the site classes.

Using the attenuation relationship, we calculated the PGA values generated by all the 14 faults in the vicinity of Islamabad and for all the site classes as well thus giving very comprehensive results.

The table below shows the PGA values calculated for the faults around Islamabad:

Distance			PHA					
All Faults	**Avg. M_w**	**Source to Site Distance (Km)**	**R (PHA)**	**Site Class A**	**Site Class B**	**Site Class C**	**R (PHV)**	**Peak Velocity LOG(PHV) (cm/sec)**
Main Mantle Thurst	7.610							
Batal Fault	6.920							
Riasi Fault	7.380	66.430	66.656	0.069	0.100	0.125	66.550	1.0200
Reverse Fault								
Pir Panjal	7.070	36.060	36.474	0.095	0.136	0.170	36.281	1.2103
Main Boundary Thrust	7.720	1.980	5.827	0.428	0.616	0.769	4.463	2.5216
Himalaya Frontal Thrust	7.490	72.120	72.328	0.069	0.099	0.124	72.231	1.0236
Hissartang	7.320	24.670	25.271	0.141	0.203	0.253	24.992	1.5240
Khair-e-Murad	7.330	26.570	27.129	0.135	0.194	0.241	26.869	1.4926
Khairabad	7.450	43.650	43.993	0.099	0.142	0.178	43.833	1.2947
Nathia Gali	6.910	20.880	21.587	0.129	0.186	0.232	21.260	1.4031
Soan Back Thrust	7.110	26.570	27.129	0.121	0.173	0.216	26.869	1.3848
Strike Slip								
Puran	7.090	83.510	83.690	0.050	0.073	0.091	83.606	0.7345
Thakot	7.030	81.610	81.794	0.050	0.072	0.089	81.708	0.7200
Chaman	7.98							

3.3.5 Computations of Peak Horizontal Velocity:

Even though Peak Ground Acceleration is enough for design against seismic forces yet to get a more reliable behavioral pattern of ground shaking at a site, Peak Horizontal Velocity is also very useful.

The vertical component is not of significance because of the fact that buildings are designed against vertical forces and the vertical acceleration or velocity can be dealt with by the structure itself normally.

The attenuation relationship used to compute PHV was of Boore (1988). This once again closely fits the behavior of our region of Islamabad due to the same reasons as for PGA computation.

The attenuation relationship is shown below:

$$\log \text{PHV(cm/sec)} = j_1 + j_2(M-6) + j_3(M-6)^2 + j_4 \log R + j_5 R + j_6 \qquad (3.29)$$

$$R = \sqrt{r_0^2 + j_7^2}$$

Table 3-7 Coeffecients for Joyner and Boore (1988) Peak Horizontal Velocity Attenuation Relationship

Component	j_1	j_2	j_3	j_4	j_5	j_6	j_7	$\sigma_{\log PHV}$
Random	2.09	0.49	0.0	−1.0	−0.0026	0.17	4.0	0.33
Larger	2.17	0.49	0.0	−1.0	−0.0026	0.17	4.0	0.33

The relationship gives PHV in cm/sec and we have computed the values for all the faults.

The computations are shown in the table below:

All Faults	Avg. M_w	Source to Site Distance (Km)	Peak Velocity LOG(PHV) (cm/sec)
Main Mantle Thurst	7.610		
Batal Fault	6.920		
Riasi Fault	7.380	66.430	1.0200
Reverse Fault			
Pir Panjal	7.070	36.060	1.2103
Main Boundary Thrust	7.720	1.980	2.5216
Himalaya Frontal Thrust	7.490	72.120	1.0236
Hissartang	7.320	24.670	1.5240
Khair-e-Murad	7.330	26.570	1.4926
Khairabad	7.450	43.650	1.2947
Nathia Gali	6.910	20.880	1.4031
Soan Back Thrust	7.110	26.570	1.3848
Strike Slip			
Puran	7.090	83.510	0.7345
Thakot	7.030	81.610	0.7200
Chaman	7.98		

As seen in the table, the PGA produced at ISE from MBT is 0.428g, it is a very large value compared to all other faults in the vicinity of ISE. The reason is that ISE lies extremely close to the Main Boundary Thrust, just 1.98 km away.

In case we had to calculate PGA values for a site other than ISE, say someplace in SOAN, most probably the Soan Back thrust would produce the controlling PGAs.

3.3.6 Controlling Earthquake:

The controlling earthquake comes out to be the Main Boundary Thrust, capable of producing a magnitude of 7.7 (Mw), and can yield PGA up to 0.428g at bedrock. This fault MBT will be used as a line source and I will be performing the Probabilistic Seismic Hazard analysis for this region under study.

Furthermore, we will also be making Microsoft Excel spreadsheets for this procedure to let us calculate site specific ground motion parameters.

3.4 Probabilistic SHA:

Probabilistic approach is used most commonly now a day since it is more useful in predicting the ground shaking as well. The deterministic approach has a few shortcomings as will be discussed.

In the Deterministic approach, we take the worst-case scenario for a particular site. The worst-case scenario however is not expected to usually occur very frequently. Thus, if you design the facility required against the worst-case scenario, the scenario might not actually occur during the service life of the facility. This will yield unnecessary expenses and higher cost.

There are multiple uncertainties that are therefore imperative we calculate them. Some of them are:

- Source to Site Distance Uncertainty
- Magnitude Uncertainty
- Uncertainty in GMPs

All of these uncertainties are calculated as the probabilities of occurrence, meaning by that we calculate the chance of certain cases of these happening in percentages. For the sake of keeping it easy, we will proceed in the order of:

- Distance Uncertainty
- Magnitude Uncertainty
- Uncertainty in GMPs

The first uncertainty is the Source to Site Distance Uncertainty. This involves a very simple procedure that will be explained below:

3.4.1 Source to Site Distance Uncertainty:

The first and foremost uncertainty that must be calculated is the source to site distance uncertainty.

We employed the following steps:

- Calculated the min. source to site distance.
- Traced that distance from site to source.
- Traced a distance of 100 km from site to the fault source.
- Calculated the horizontal distance of the right-angled triangle.

Before we move on to the further steps one thing is important to be explained here. The min. distance is mostly the perpendicular distance from the site to the fault source. The maximum distance taken, that is 100 km is due to the fact that anything happening outside the 100-km radius is not going to cause any significant damage to our site.

We used the Pythagoras theorem to calculate the base of the thus formed right angled triangle thus giving us the fault length.

Further steps are listed below:

Divided the entire fault length into five different intervals using the following formula:

$$Interval = \frac{r_{\max} - r_{min}}{5}$$

Each successive source to site distance was calculated using the above interval distance being added into the previous source to site distance.

We calculated the entire combination of source to site distances in this manner through our Microsoft Excel Spreadsheets.

The following picture gives an idea:

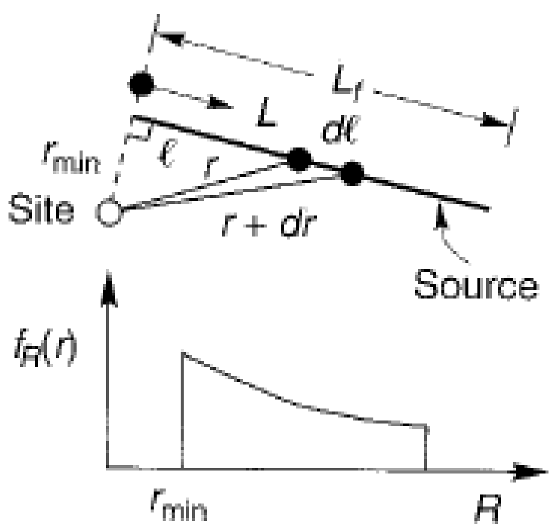


Figure 9: Source to Site Distance

The source to site distance sample computations for Askari X (site) are shown:

Site Name	Roots (Askari 10)
R_{max} (km)	100
R_{min} (km)	18.09
Interval	16.382

Source to Site Distance Probability				
Interval	R	Interval Distance (km)	Source to Site Distance (km)	Probability P[R=r]
X1	18.09	29.344	26.281	0.298
X2	34.472	18.184	42.663	0.185
X3	50.854	17.229	59.045	0.175
X4	67.236	16.881	75.427	0.172
X5	83.618	16.712	91.809	0.170
	100	98.350		

As is evident from the table, as the distance along the fault for an interval increases so does the probability.

The inherent assumption here is that the earthquake has a uniform probability of occurrence anywhere along the fault. Thus, probability is solely the function of the length of a particular interval.

3.4.2 Magnitude Uncertainty:

In the deterministic approach, we simulated the worst-case scenario. And we also established that the worst-case scenario should simulate the maximum potential magnitude of earthquake from a particular fault. But such a high magnitude is usually not expected to occur in short span of time. So, calculating the probability of occurrence of different earthquake magnitudes can give a valuable information for designing facilities.

In order to calculate the uncertainties, we need to set a maximum and a minimum earthquake magnitude. We set the following boundaries:

$$M_{max} = 8.5$$

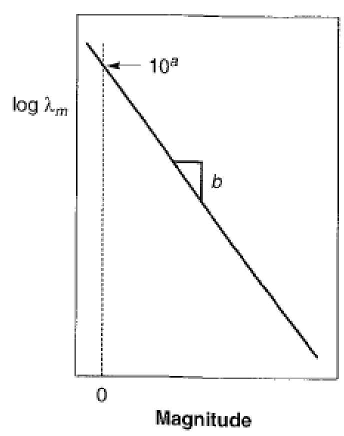
$$M_{min} = 5.0$$

We took the threshold magnitude as 5.0 because of the fact that earthquakes smaller than 5.0 do not release as much energy and consequently do not cause damage or collapse of facilities and structures.

The maximum magnitude was selected as 8.5 since the attenuation relationship of Boore (1993) has an inherent shortcoming that it cannot accurately calculate ground motion for magnitudes above 8.5. Also, the maximum potential earthquake that we have calculated for MBT is 7.7, so above 8.0 becomes really far-fetched and unrealistic.

To calculate the probabilities of magnitudes, we have used Guttenberg-Richter Law and some of its simplified equations for probability calculations. The relationship is shown below:

$$\log \lambda_m = a - bm$$



The equation above has mean annual rate of exceedance of a particular magnitude represented by ‘m’. The coefficients a and b represent the seismicity of a particular source zone.

‘a’ represents the frequency of earthquake occurrence in a particular source zone.
‘b’ represents the distribution of smaller and larger earthquakes.
The meaning of ‘a’ and ‘b’ has been shown in the figure above.

3.4.3 Seismicity of the Source Zone:

The seismicity of a source zone is defined by the coefficients of the Guttenberg-Richter Law, ‘a’ and ‘b’. We took the seismicity of the Himalayan Zone from the research of Rashidullah, Irshad Ahmad J. eng. & appl. sci. Vol. 29 No. 2 July - December 2010. The MBT lies in the Himalayan Zone so we took the seismicity characteristics of the said zone. Even though it would be more accurate if we had the seismicity characteristics of the fault itself but Himalayan Zone gave us reasonably fine results when compared with other studies.

So, we selected:

$$a = 4.39$$

$$b = 0.83$$

When these seismicity characteristics are multiplied by ln (10), we get the following:

$$\alpha = \ln(10) \times a$$

$$\beta = \ln(10) \times b$$

These coefficients are then used in the following equation:

$$F_M(m) = P[M < m | M > m_0] = \frac{\lambda_{m_0} - \lambda_m}{\lambda_{m_0}} = 1 - e^{-\beta(m - m_0)}$$

$$F_M(m) = P[M < m | m_0 \leq m \leq m_{\max}] = \frac{1 - \exp[-\beta(m - m_0)]}{1 - \exp[-\beta(m_{\max} - m_0)]}$$

This equation is used to calculate probability of occurrence at various magnitudes. The detailed steps to computing the we followed are below:

- Selected the threshold and the maximum magnitudes.
- Divided into an interval of 0.5 each.
- Used the equation to calculate probabilities for each upper bound and each lower bound.
- The difference of PM(U) and PM(L) gave the probability of the interval.

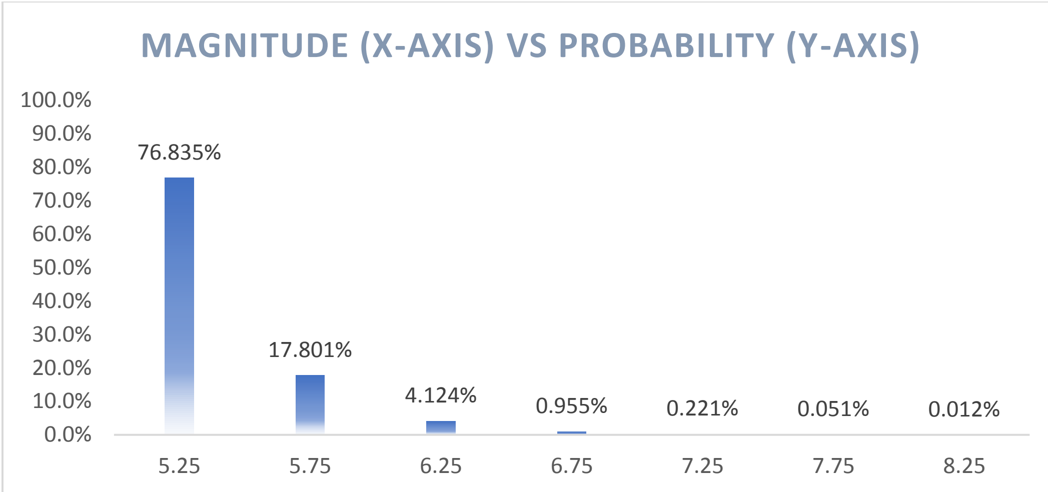
The computations are shown:

M_{max}	8.5
M_{min}	5
Interval	0.5
a	4.39
b	0.83

The above parameters were used to get the following computations:

Magnitude Probability						
Lower Bound Magnitude M(l)	Upper Bound Magnitude M(u)	Average Magnitude m	P[M(l)]	P[M(u)]	P[l<M<u]	P[M=m]
5	5.5	5.25	0.00000	0.61624	0.61624	61.6240%
5.5	6	5.75	0.61624	0.85320	0.23696	23.6960%
6	6.5	6.25	0.85320	0.94432	0.09112	9.1117%
6.5	7	6.75	0.94432	0.97935	0.03504	3.5037%
7	7.5	7.25	0.97935	0.99283	0.01347	1.3473%
7.5	8	7.75	0.99283	0.99801	0.00518	0.5181%
8	8.5	8.25	0.99801	1.00000	0.00199	0.1992%

As can be seen from the table, the probability of occurrence of earthquakes with smaller magnitudes in much higher as compared to the larger ones.



The chart above shows how much larger earthquakes occur less frequently compared to the smaller ones.

3.4.4 Calculations of Peak Ground Acceleration:

To calculate the Peak Ground Acceleration, we have used the Attenuation Relationship proposed by Boore, Joyner and Fumal (1993) because of emphasis by Kramer in his book, Geotechnical Earthquake Engineering. This particular relationship was selected because of three particular reasons:

There were no Pakistan specific attenuation relationships available for seismic hazard analysis of the region.

To compute PGA values at Mangla Dam, a revision of Boore 1993 was used.

According to Jain (2005), this particular relationship is suitable for Central Himalayas as established through his regression model.

The attenuation relationship is as follows:

In the use of this expression, a site is classified into one of four categories (A, B, C, and D) depending on the average shear-wave velocities of the upper 30m of geologic material. Classes A, B, C, and D include sites where the average shear-wave velocity are:

greater than 750 m/s;
between 360 m/s and 750 m/s;
between 180 m/s and 360 m/s;
and less than 180 m/s, respectively.

As a result of lack of data presently available for site class D, Boore, Joyner, and Fumal excluded it from their analysis.
When the constants derived for estimating the peak acceleration for the larger of two horizontal components are substituted, the above equation reduces to:

$$G_B = \begin{cases} 0 & \text{for site class A} \\ 1 & \text{for site class B} \\ 0 & \text{for site class C} \end{cases} \qquad G_C = \begin{cases} 0 & \text{for site class A} \\ 0 & \text{for site class B} \\ 1 & \text{for site class C} \end{cases}$$

$$\log_{10}(Y) = -0.038 + 0.216(M - 6) - 0.777 \log_{10}(R^2 + 30.03)^{1/2} + 0.158G_B + 0.254G_C$$

As can be seen, the relationship accounts for the various site classes that are categorized on the basis of shear wave velocity. Once through refraction survey and other methods you have identified the site class, you can use the appropriate values for the various coefficients to calculate the PGA values. Since we were conducting the analysis for the entire region of Islamabad, and it wasn't possible to classify the sites on the basis of shear wave velocities, we calculated the results at the bedrock; thus, Site Class A. However, since our results were generated through Microsoft Excel Spreadsheets, we calculated the PGA values for all the site classes.

Using the attenuation relationship, we calculated the PGA values generated by all the 14 faults in the vicinity of Islamabad and for all the site classes as well thus giving very comprehensive results.

As opposed to the DSHA, the PGA values calculated using the PSHA have incorporated all the possible combinations of magnitudes and the source to site distances. A total of 42 different combinations were simulated for all the three site classes A, B and C.

The steps that we followed are as below:

- Selected the source to site distance and the magnitude.
- Identified the probabilities from earlier calculations.

- Used Boore (1993) attenuation equations and used the larger coefficients.
- Repeat the steps for all possible combinations of magnitude and source to site distance.

SITE CLASS A							
Magnitudes	**Mean Annual Rate of Exceedance λ_m**	**Return Period (Years)**	**P[M=m]**	**Distances**	**P[R=r]**	**R (PHA)**	**Peak Horizontal Acceleration (PHA)**
5.25	1.0777053	0.9279	0.6162	26.2810	0.2984	26.8463	0.0482
				42.6630	0.1849	43.0135	0.0337
				59.0450	0.1752	59.2988	0.0264
				75.4270	0.1716	75.6258	0.0218
				91.8090	0.1699	91.9724	0.0188
5.75	0.4144766	2.4127	0.2370	26.2810	0.2984	26.8463	0.0618
				42.6630	0.1849	43.0135	0.0432
				59.0450	0.1752	59.2988	0.0338
				75.4270	0.1716	75.6258	0.0280
				91.8090	0.1699	91.9724	0.0241
6.25	0.1594043	6.2734	0.0911	26.2810	0.2984	26.8463	0.0792
				42.6630	0.1849	43.0135	0.0555
				59.0450	0.1752	59.2988	0.0433
				75.4270	0.1716	75.6258	0.0359
				91.8090	0.1699	91.9724	0.0309
6.75	0.0613056	16.3117	0.0350	26.2810	0.2984	26.8463	0.1016
				42.6630	0.1849	43.0135	0.0711
				59.0450	0.1752	59.2988	0.0556
				75.4270	0.1716	75.6258	0.0461
				91.8090	0.1699	91.9724	0.0396
7.25	0.0235776	42.4131	0.0135	26.2810	0.2984	26.8463	0.1303
				42.6630	0.1849	43.0135	0.0912
				59.0450	0.1752	59.2988	0.0713
				75.4270	0.1716	75.6258	0.0591
				91.8090	0.1699	91.9724	0.0508
7.75	0.0090678	110.2808	0.0052	26.2810	0.2984	26.8463	0.1671
				42.6630	0.1849	43.0135	0.1169
				59.0450	0.1752	59.2988	0.0914
				75.4270	0.1716	75.6258	0.0758
				91.8090	0.1699	91.9724	0.0651
8.25	0.0034874	286.7477	0.0020	26.2810	0.2984	26.8463	0.2142
				42.6630	0.1849	43.0135	0.1500
				59.0450	0.1752	59.2988	0.1172
				75.4270	0.1716	75.6258	0.0971
				91.8090	0.1699	91.9724	0.0835

In the figures above, we have computations for PGA values in the last column for every combination of magnitude and source to site distance.

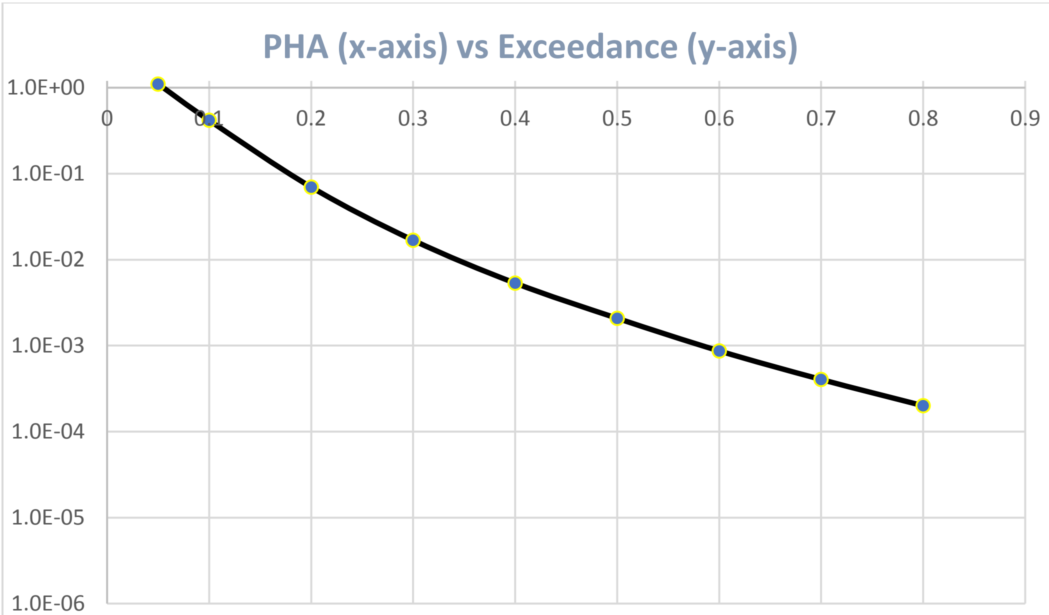
In the second column, we have the mean annual rates of exceedance, we calculated those using the following steps:

- Selected 0.05g as a benchmark PGA to check exceedance against.
- Chose Standard Normal Distribution to calculate probability of exceedance of 0.05g.
- Read Table C-1 from Geotechnical Earthquake Engineering to get P(PHA>0.05g).
- Used the following equation:
- $\nu = 10^{a-b(m.)}$
- Calculated the mean annual rate of exceedance of PGA of 0.05g through the following equation:
- Mean Annual Rate of Exceedance = $\nu \times P[PHA > 0.05g] \times [P(M)] \times [P(r)]$

3.4.5 Seismic Hazard Curve:

In the last topic, we detailed the steps to calculate the mean annual rate of exceedance of a PHA of 0.05 g.

We repeated the steps to calculate the exceedances at PHA of 0.1g, 0.2g, 0.3 g etc. to get a curve. That curve is called a seismic hazard curve and is very important to calculate the exceedances at any particular value.



On the y-axis, we have the values of exceedances. On the x-axis, we have the different PGA/PHA values. The curve is very useful for quick and easy calculation. We generated this curve on Microsoft Excel.

3.4.6 Return Periods of PGA/PHA:

The reciprocal of the mean annual rate of exceedance is the return period. We also calculated the return periods of the different PGA values.

3.4.7 Return Periods of Magnitudes:

After calculating the annual rate of exceedance of magnitudes using the Guttenberg-Richter Relationship, we calculated their return periods and the results are listed in the following table:

Magnitudes	Mean Annual Rate of Exceedance λ_m	Return Period (Years)
5.25	1.0777053	0.9279
5.75	0.4144766	2.4127
6.25	0.1594043	6.2734
6.75	0.0613056	16.3117
7.25	0.0235776	42.4131
7.75	0.0090678	110.2808
8.25	0.0034874	286.7477

As can be seen in the table, the return period of larger magnitudes is very large as compared to the smaller ones. A magnitude 8.25 earthquake will be generated around every 300 years from MBT. It should be noted that earthquakes with magnitudes around 6 occur after quite a small number of years on a regular basis.

3.5 Design Spectrum:

A design spectrum is a smoothed-out response spectrum that is of importance to the structural engineers for design of buildings. We formulated design spectrums for our sites:

- Gulberg Greens
- Askari X and IV
- Bahria Town

All these sites belonged to Site Class C according to building code of Pakistan and Site Class E according to ASCE 7-10.

We followed the following steps to formulate the design spectrum:

- Using the equations below we calculated the spectral acceleration parameters:

$$Ss/PGA = 0.3386\ PGA + 2.1696$$

$$S1/PGA = 0.5776\ PGA + 0.5967$$

- Calculated Maximum Considered Earthquake Spectral Response Parameters using the following equations:

$$SMS = FaSs$$

$$SM1 = FvS1$$

- Calculated Fa and Fv depending on the site classes and interpolated if necessary from the following table extracted from ASCE 7-10:

Table 11.4-1 Site Coefficient, F_a

	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at Short Period				
Site Class	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of S_S.

Table 11.4-2 Site Coefficient, F_v

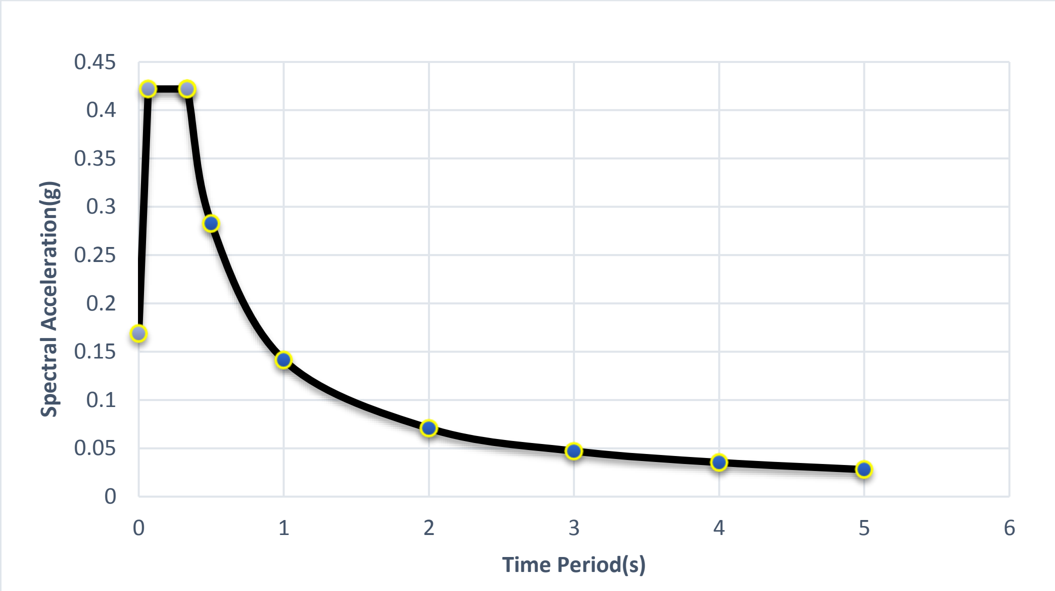
	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at 1-s Period				
Site Class	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of S_1.

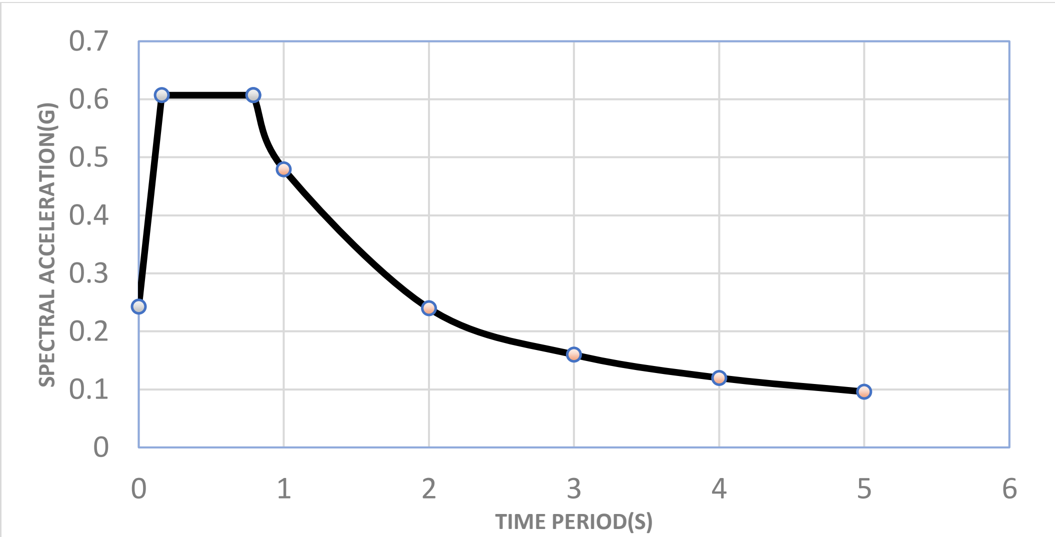
- Calculated Design Spectral Acceleration Parameters:

$$Sds = 2/3\ Sms \quad ; \quad Sd1 = 2/3\ Sm1$$

The Design Spectrum for Site Class A is shown below:



The design Spectrum for Site Class E is shown below:



3.6 Excel Spreadsheet Results:

All the calculations were performed on Microsoft Excel by generating formulas and making sure that nothing went wrong. We have cross checked all the results with hand calculations to remove any possibility of errors.

3.6.1 Deterministic SHA:

Magnitudes:

Deterministic Seismic Hazard Analysis									
ALL FAULTS									
Fault	**Fault Length (km)**	**Rupture Length (km)**	**Wells & Coppersmith**	**Bonilla**	**Rupture Area W&C (km^2)**	**Ellsworth**	**Wyss**	**Somerville**	**Avg. M_w**
Main Mantle Thurst	339	170	7.67	7.62	3088.16	7.69	7.64	7.44	7.61
Batal Fault	71	35	6.87	7.13	577.70	6.96	6.91	6.71	6.92
Riasi Fault	200	100	7.40	7.46	1753.88	7.44	7.39	7.19	7.38
REVERSE FAULTS									
Pir Panjal	98	48	7.05	7.25	829.85	7.12	7.07	6.87	7.07
Main Boundary Thrust	353	176	7.74	7.77	3937.31	7.80	7.75	7.55	7.72
Himalaya Frontal Thrust	225	112	7.50	7.59	2290.87	7.56	7.51	7.31	7.49
Hissartang	160	80	7.32	7.45	1526.16	7.38	7.33	7.13	7.32
Khair-e-Murad	164	82	7.33	7.46	1560.99	7.39	7.34	7.14	7.33
Khairabad	205	103	7.46	7.55	2093.15	7.52	7.47	7.27	7.45
Nathia Gali	70	35	6.88	7.12	565.46	6.95	6.90	6.70	6.91
Soan Back Thrust	103	52	7.09	7.28	908.24	7.16	7.11	6.91	7.11
STRIKE SLIP									
Puran	99	49	7.05	7.33	841.40	7.13	7.08	6.88	7.09
Thakot	85	42	6.98	7.28	727.78	7.06	7.01	6.81	7.03
Chaman	850	425	8.10	7.91	7413.10	8.07	8.02	7.82	7.98

GMPs:

Distance			PHA					
All Faults	**Avg. M_w**	**Source to Site Distance (Km)**	**R (PHA)**	**Site Class A**	**Site Class B**	**Site Class C**	**R (PHV)**	**Peak Velocity LOG(PHV) (cm/sec)**
Main Mantle Thurst	7.610							
Batal Fault	6.920							
Riasi Fault	7.380	66.430	66.656	0.069	0.100	0.125	66.550	1.0200
Reverse Fault								
Pir Panjal	7.070	36.060	36.474	0.095	0.136	0.170	36.281	1.2103
Main Boundary Thrust	7.720	1.980	5.827	0.428	0.616	0.769	4.463	2.5216
Himalaya Frontal Thrust	7.490	72.120	72.328	0.069	0.099	0.124	72.231	1.0236
Hissartang	7.320	24.670	25.271	0.141	0.203	0.253	24.992	1.5240
Khair-e-Murad	7.330	26.570	27.129	0.135	0.194	0.241	26.869	1.4926
Khairabad	7.450	43.650	43.993	0.099	0.142	0.178	43.833	1.2947
Nathia Gali	6.910	20.880	21.587	0.129	0.186	0.232	21.260	1.4031
Soan Back Thrust	7.110	26.570	27.129	0.121	0.173	0.216	26.869	1.3848
Strike Slip								
Puran	7.090	83.510	83.690	0.050	0.073	0.091	83.606	0.7345
Thakot	7.030	81.610	81.794	0.050	0.072	0.089	81.708	0.7200
Chaman	7.98							

3.6.2 Probabilistic SHA:

Source to Site Distance Probability:

Site Name	ISE
R_{max} (km)	100
R_{min} (km)	1.98
Interval	19.604

Source to Site Distance Probability				
Interval	R	Interval Distance	Source to Site Distance	Probability P[R=r]
X1	1.98	21.493	11.782	0.215
X2	21.584	19.647	31.386	0.197
X3	41.188	19.619	50.990	0.196
X4	60.792	19.612	70.594	0.196
X5	80.396	19.609	90.198	0.196
	100	99.980		

Magnitude Uncertainty:

M_{max}	8.5
M_{min}	5
Interval	0.5
a	4.39
b	0.83

Magnitude Probability						
Lower Bound Magnitude M(l)	Upper Bound Magnitude M(u)	Average Magnitude m	P[M(l)]	P[M(u)]	P[l<M<u]	P[M=m]
5	5.5	5.25	0.00000	0.61624	0.61624	61.6240%
5.5	6	5.75	0.61624	0.85320	0.23696	23.6960%
6	6.5	6.25	0.85320	0.94432	0.09112	9.1117%
6.5	7	6.75	0.94432	0.97935	0.03504	3.5037%
7	7.5	7.25	0.97935	0.99283	0.01347	1.3473%
7.5	8	7.75	0.99283	0.99801	0.00518	0.5181%
8	8.5	8.25	0.99801	1.00000	0.00199	0.1992%

GMPs and Annual Rates of Exceedances:

SITE CLASS A							
Magnitudes	Mean Annual Rate of Exceedance λ_m	Return Period (Years)	P[M=m]	Distances	P[R=r]	R (PHA)	Peak Horizontal Acceleration (PHA)
5.25	1.0777053	0.9279	0.6162	26.2810	0.2984	26.8463	0.0482
				42.6630	0.1849	43.0135	0.0337
				59.0450	0.1752	59.2988	0.0264
				75.4270	0.1716	75.6258	0.0218
				91.8090	0.1699	91.9724	0.0188
5.75	0.4144766	2.4127	0.2370	26.2810	0.2984	26.8463	0.0618
				42.6630	0.1849	43.0135	0.0432
				59.0450	0.1752	59.2988	0.0338
				75.4270	0.1716	75.6258	0.0280
				91.8090	0.1699	91.9724	0.0241
6.25	0.1594043	6.2734	0.0911	26.2810	0.2984	26.8463	0.0792
				42.6630	0.1849	43.0135	0.0555
				59.0450	0.1752	59.2988	0.0433
				75.4270	0.1716	75.6258	0.0359
				91.8090	0.1699	91.9724	0.0309
6.75	0.0613056	16.3117	0.0350	26.2810	0.2984	26.8463	0.1016
				42.6630	0.1849	43.0135	0.0711
				59.0450	0.1752	59.2988	0.0556
				75.4270	0.1716	75.6258	0.0461
				91.8090	0.1699	91.9724	0.0396
7.25	0.0235776	42.4131	0.0135	26.2810	0.2984	26.8463	0.1303
				42.6630	0.1849	43.0135	0.0912
				59.0450	0.1752	59.2988	0.0713
				75.4270	0.1716	75.6258	0.0591
				91.8090	0.1699	91.9724	0.0508
7.75	0.0090678	110.2808	0.0052	26.2810	0.2984	26.8463	0.1671
				42.6630	0.1849	43.0135	0.1169
				59.0450	0.1752	59.2988	0.0914
				75.4270	0.1716	75.6258	0.0758
				91.8090	0.1699	91.9724	0.0651
8.25	0.0034874	286.7477	0.0020	26.2810	0.2984	26.8463	0.2142
				42.6630	0.1849	43.0135	0.1500
				59.0450	0.1752	59.2988	0.1172
				75.4270	0.1716	75.6258	0.0971
				91.8090	0.1699	91.9724	0.0835

SITE CLASS B						
Magnitudes	Mean Annual Rate of Exceedance λ_m	Return Period (Years)	P[M=m]	Distances	P[R=r]	Peak Horizontal Acceleration (PHA)
5.25	1.077705	0.9279	0.6162	26.2810	0.2984	0.0704
				42.6630	0.1849	0.0488
				59.0450	0.1752	0.0380
				75.4270	0.1716	0.0315
				91.8090	0.1699	0.0271
5.75	0.414477	2.4127	0.2370	26.2810	0.2984	0.0903
				42.6630	0.1849	0.0626
				59.0450	0.1752	0.0488
				75.4270	0.1716	0.0404
				91.8090	0.1699	0.0347
6.25	0.159404	6.2734	0.0911	26.2810	0.2984	0.1158
				42.6630	0.1849	0.0803
				59.0450	0.1752	0.0626
				75.4270	0.1716	0.0518
				91.8090	0.1699	0.0445
6.75	0.061306	16.3117	0.0350	26.2810	0.2984	0.1485
				42.6630	0.1849	0.1030
				59.0450	0.1752	0.0802
				75.4270	0.1716	0.0664
				91.8090	0.1699	0.0570
7.25	0.023578	42.4131	0.0135	26.2810	0.2984	0.1904
				42.6630	0.1849	0.1320
				59.0450	0.1752	0.1029
				75.4270	0.1716	0.0852
				91.8090	0.1699	0.0732
7.75	0.009068	110.2808	0.0052	26.2810	0.2984	0.2442
				42.6630	0.1849	0.1693
				59.0450	0.1752	0.1319
				75.4270	0.1716	0.1092
				91.8090	0.1699	0.0938
8.25	0.003487	286.7477	0.0020	26.2810	0.2984	0.3132
				42.6630	0.1849	0.2171
				59.0450	0.1752	0.1692
				75.4270	0.1716	0.1400
				91.8090	0.1699	0.1203

SITE CLASS C						
Magnitudes	Mean Annual Rate of Exceedance λ_m	Return Period (Years)	P[M=m]	Distances	P[R=r]	Peak Horizontal Acceleration (PHA)
5.25	1.0777053	0.9279	0.6162	26.2810	0.2984	0.0879
				42.6630	0.1849	0.0609
				59.0450	0.1752	0.0475
				75.4270	0.1716	0.0393
				91.8090	0.1699	0.0337
5.75	0.4144766	2.4127	0.2370	26.2810	0.2984	0.1127
				42.6630	0.1849	0.0781
				59.0450	0.1752	0.0609
				75.4270	0.1716	0.0504
				91.8090	0.1699	0.0433
6.25	0.1594043	6.2734	0.0911	26.2810	0.2984	0.1445
				42.6630	0.1849	0.1002
				59.0450	0.1752	0.0780
				75.4270	0.1716	0.0646
				91.8090	0.1699	0.0555
6.75	0.0613056	16.3117	0.0350	26.2810	0.2984	0.1852
				42.6630	0.1849	0.1284
				59.0450	0.1752	0.1001
				75.4270	0.1716	0.0828
				91.8090	0.1699	0.0712
7.25	0.0235776	42.4131	0.0135	26.2810	0.2984	0.2376
				42.6630	0.1849	0.1647
				59.0450	0.1752	0.1283
				75.4270	0.1716	0.1062
				91.8090	0.1699	0.0913
7.75	0.0090678	110.2808	0.0052	26.2810	0.2984	0.3046
				42.6630	0.1849	0.2112
				59.0450	0.1752	0.1646
				75.4270	0.1716	0.1362
				91.8090	0.1699	0.1170
8.25	0.0034874	286.7477	0.0020	26.2810	0.2984	0.3906
				42.6630	0.1849	0.2708
				59.0450	0.1752	0.2110
				75.4270	0.1716	0.1747
				91.8090	0.1699	0.1501

CHAPTER 4

RECOMMENDATIONS

4.1 Recommendations:

1. The ground should be improved before construction of any building because weak grounds are vulnerable to liquefaction in an event of an earthquake resulting in damage to the building. The soil should go through series of soil testing and suitable method should be selected for that site based on the test results and site geology. The ground should be improved by imparting improvement techniques like rapid impact compaction, reinforced soil-cement raft, driven timber poles, low mobility grout, horizontal soil mixed beams etc. These techniques will make crust of the ground more rigid and reduces the chance of differential settlement which will subsequently enhance the performance of the building in an event of the earthquake.

2. Our results show that PGA=0.428g using DSHA and PGA=0.28g using PSHA which contradicts to the provision of BCP-07 for Isb/Rwp. Islamabad has been placed in Zone II-B which means that it should have PGA between 0.16-0.24g but our results shows that it should be placed in

Table 2.1 - Seismic Zones

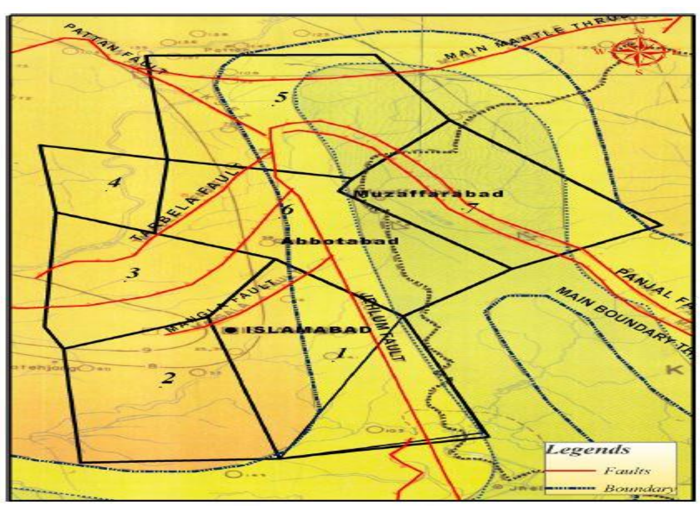
Seismic Zone	Peak Horizontal Ground Acceleration
1	0.05 to 0.08g
2A	0.08 to 0.16g
2B	0.16 to 0.24g
3	0.24 to 0.32g
4	> 0.32g

Where "g" is the acceleration due to gravity.
The acceleration values are for rock site condition with shear wave velocity (v_s) of 760 m/sec (Soil profile type S_B).
For seismic zone factors, refer Table 5.9.

Seismic Zonation of Pakistan, BCP-07

Zone III (Based on PSHA results because it accounts for all the uncertainties). Not only it has been proved by our results but Bhatti et al. & Mona Lisa et al. results also conform to our analysis as well. Although our results are little amateur because we have incorporated only few sites but it can be verified by increasing the number of sites all along the vicinity of Islamabad. Buildings based on BCP-07 seismic zonation provision are unsafe and they need to be reconsidered.

3. Public should be aware of the threats posed by the frequent earthquakes occurring in the region of Islamabad. They should be made aware of the fact that Islamabad lies in the 2nd most seismic hazardous zone so their buildings need to be better engineered against earthquakes to prevent any human & financial loss. They should make sure that seismic design will be incorporated in their buildings before construction. CDA should make sure that urbanization along the foot of Margalla hills should be immediately stopped as Main Boundary Thrust which is one the largest and most active fault passes right under these hills and it can cause a major earthquake anytime which can cause huge destruction in these areas. Also, CDA should make sure that seismic design will be incorporated in all the structures that are going to be building in Islamabad.



Faults of Islamabad & Surroundings

4. Pakistan specific attenuation relationships should be made which incorporates the earthquake data of Pakistan so that in future analysis should be based on them instead of global relationships. It is a shame that we are trying to find the best fit relation to conduct our analysis because of the unavailability of Pakistan specific attenuation relationship. Although Jain et al. [2000] concluded that their regression analysis for Central Himalayas closely fits the equation of Boore et al. [1997] and use of this equation has been precedent for the calculation of PGA at the Mangla Dam [NESPAK report, 2003] but still we need an attenuation equation of our own which solely uses the data of Pakistan. Efforts should be made at government level so that this can be done at the earliest possible.
5. Software like EQHAZ, CRSIS etc. must be used to calculate the ground motion parameters for sensitive buildings because they are very sensitive and it accounts for all the uncertainties in all the parameters. Although we have prepared the manual spreadsheets which are enough to calculate GMPs for residential and small scale commercial buildings and it can be calculated for any site in Islamabad by iterating the site-specific parameters but for sensitive structures and high-rise buildings this software must be taken into account for the calculations of GMPs.

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