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SOFTWARE DEVELOPMENT FOR FAULT PLANE SOLUTION (FPS) AND ISOSEISMIAL MAP

(With Special Emphasis on Seismological Characteristics of Muzaffarabad Earthquake, 2005)

By

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CERTIFICATE OF APPROVAL

This dissertation by **Mr. Faisal Shahzad** is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as the requirement for the award of M.Sc degree in Geophysics.

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Dedicated to my parents, Brothers and Sister

And to Ammar Ahmad Khan and Noor-e-Fatima.

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ABSTRACT

Focal Mechanism studies and Intensity Investigations have helped seismologists to have the better understanding and seismic zonation of the area under investigation. For Focal mechanism studies, Beach Ball Calculator (BBC ver 1.0), has been prepared using MATLAB 7.0.1. This is the first programmable software for Fault Plane solution, which can run on multiple operating systems. For intensity investigation a website (Geoquaidian's Earthquake Information Center - GEIC) has been prepared in present study.

A destructive earthquake of 7.6 Mw hit in the northern part of Pakistan on 8th October, 2005. This earthquake caused severe damages and loss of life. The United State Geological Survey (USGS) named it as the deadly earthquake of year 2005. In present study seismological characteristics of this event has been studied using BBC ver 1.0 and GEIC website. The area lies between longitude 71°E-74°E and latitude 33°30'N-35°N. This area covers almost all the terrain ranging from Main Mantle thrust (MMT) to Main Boundary Thrust (MBT). The geology and seismicity of the area is discussed in detail with special reference to Indus Kohistan Seismic Zone (IKSZ) identified by Seeber et al, 1979.

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CHAPTER NO 1

INTRODUCTION

Chapter No 1

INTRODUCTION

Earthquakes are well known to most of us as they have occurred since the earliest times and have caused extensive destruction and loss to life in the past. Earthquakes probably destroyed many great civilizations of the world. Pakistan lies in a region of high seismicity and possesses the history of large earthquake causing severe destruction to building and lives. A short description of those events is provided in the Table 1.1. In Pakistan, almost all of the earthquakes are being produced due to tectonic activity and are referred to as tectonic earthquakes.

The seismological studies are very much important for the prediction of the earthquakes in the area. Scientists are continuously working on development of the methods, which are helpful for the better understanding of earth's structure. At the same time, Earthquake Seismology is a very broad field, comprises of many techniques. The Fault Plane Solution (FPS) or Focal Mechanism Solutions (FMS) is one of them, with the help of which one may not only understand the structural setting of the area but on a broader scale the plate tectonic can also be integrated. There are different softwares available for the drawing of beach ball diagrams of FMS, but either too costly or difficult to handle. Therefore in the present work, an attempt has been made to prepare software in MATLAB, which may draw the beach ball diagrams frequently used in FMS.

In the present study, the preliminary seismological characteristics of the October 8, 2005 Muzaffarabad earthquake has also been investigated. For this purpose a website, GEIC (Geoquaidian's Earthquake Information Center) has been prepared and used. Details are provided in the forthcoming sections.

1.1. LOCATION OF THE AREA

The study has been carried out in the area surrounding Muzaffarabad in northern Pakistan bounded by latitude 33°40'N – 35°N and longitude 71°E – 74° E as shown in Figure 1.1. The area contains very beautiful geomorphologic features like

Neelum and Kaghan valleys, Tarbela Dam site and other beautiful places. Events included in the study are the aftershocks ($m_b \geq 3.0$) of the 8th October 2005 Muzaffarabad earthquake from 8th October 2005 to 1st March 2006.

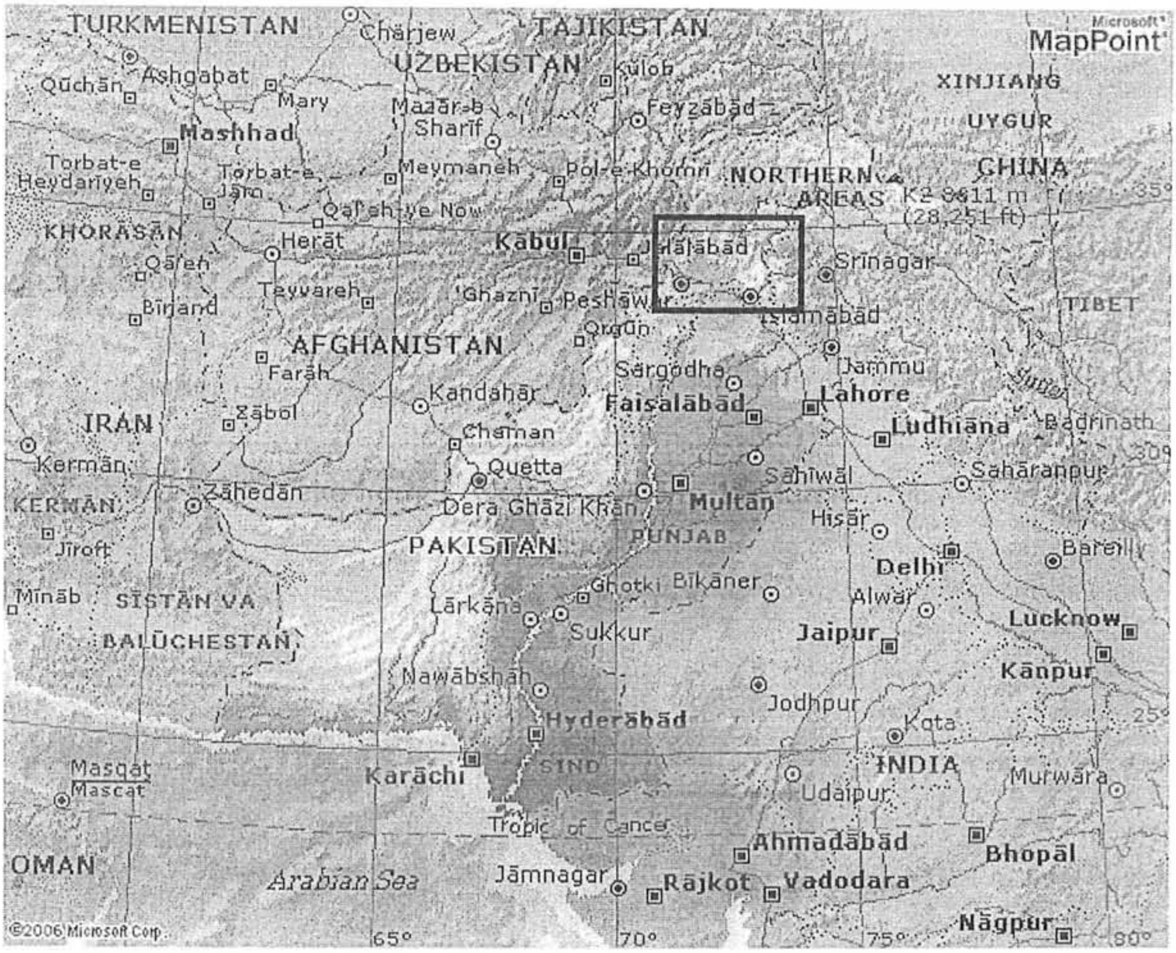


Figure 1.1. Map of Pakistan taken from Microsoft Map point (www.microsoft.com) on 15th June 2006, highlighting the study area by a rectangle.

1.2 MAIN OBJECTIVES AND PLAN/METHODOLOGY OF THE STUDY

As described earlier that the foremost objective of the present work is the development of a software in MATLAB for the determination of FMS. Along with this main objective, the preliminary investigations of October 8, 2005 Muzaffarabad earthquake i.e. the intensity map, seismicity map/pattern and etc has also been carried out.

earthquake i.e. the intensity map, seismicity map/pattern and etc has also been carried out.

The plan of the study is as follows.

- MonaLisa (2005) has prepared a structural map of the northern Pakistan using various published/unpublished works. This map (Figure 1.2) has been used as the base map for the study.
- On this base map, the main event and aftershock data of Muzaffarabad earthquake has been plotted. The seismicity map thus obtained exists in the following forms i.e.
    - General Seismicity map of the area (Figure 5.1)
    - Seismicity map of the area on basis of aftershocks magnitude (Figure 5.2a)
    - Seismicity map of the area on basis of aftershocks depth (Figure 5.3a)
- Along with the seismicity maps, the seismicity pattern has also been obtained in the form of graphs i.e.
    - Magnitude bar graph (Figure 5.2b)
    - Depth bar graph (Figure 5.3b)
    - Scatter plot of Magnitude and Depth (Figure 5.5)
    - Month wise frequency bar graph of aftershocks (Figure 5.4)
- Development of Beach Ball Calculator (BBC version 1.0) software using MATLAB for FPS (Chapter No 4)
- The comparison of the presently generated beach ball diagram of main event using BBC, with the one carried out by United States Geological Survey (USGS) as shown in Chapter 5.
- Preparation of website GEIC (Geoquaidian's Earthquake Information Center)
- Isoseismal map, Peak Ground Accelleration of different areas.

1.3 DATA SOURCES

The present work is based upon the seismological data compiled by USGS only. For the main event i.e. Muzaffarabad earthquake the source parameters i.e. location, depth and magnitude, however, has been taken from the local observatory.

This data was used to generate the beach ball diagram using BBC version 1.0. In this beach ball diagram T-axis (axis of maximum tensile stress), P-axis (axis of maximum compressive stress), slip vector their strikes and dips and types of faults are also determined. This beach ball diagram, along with the epicenters of aftershocks, is also plotted on the base map in order to find out a correlation between seismicity and structures present in the area.

Isoseismal map, Isoacceleration map and Isoforce map (in Modified Merculli i.e. MMI Scale) of the area was generated using MATLAB with the help of the damage and destruction information obtained from the following sources.

- Print and electronic media
- USGS website
- A website has been prepared to gather the data from the users. Users can access this website at www.geocities.com/fs_uol/geic.html

It should be noted that this work is of preliminary level and can be improved by the incorporation of seismological data from various sources instead of one source only i.e. USGS.

The chapters to follow deal with the general geology, theoretical aspects/methodology and finally the interpretation.

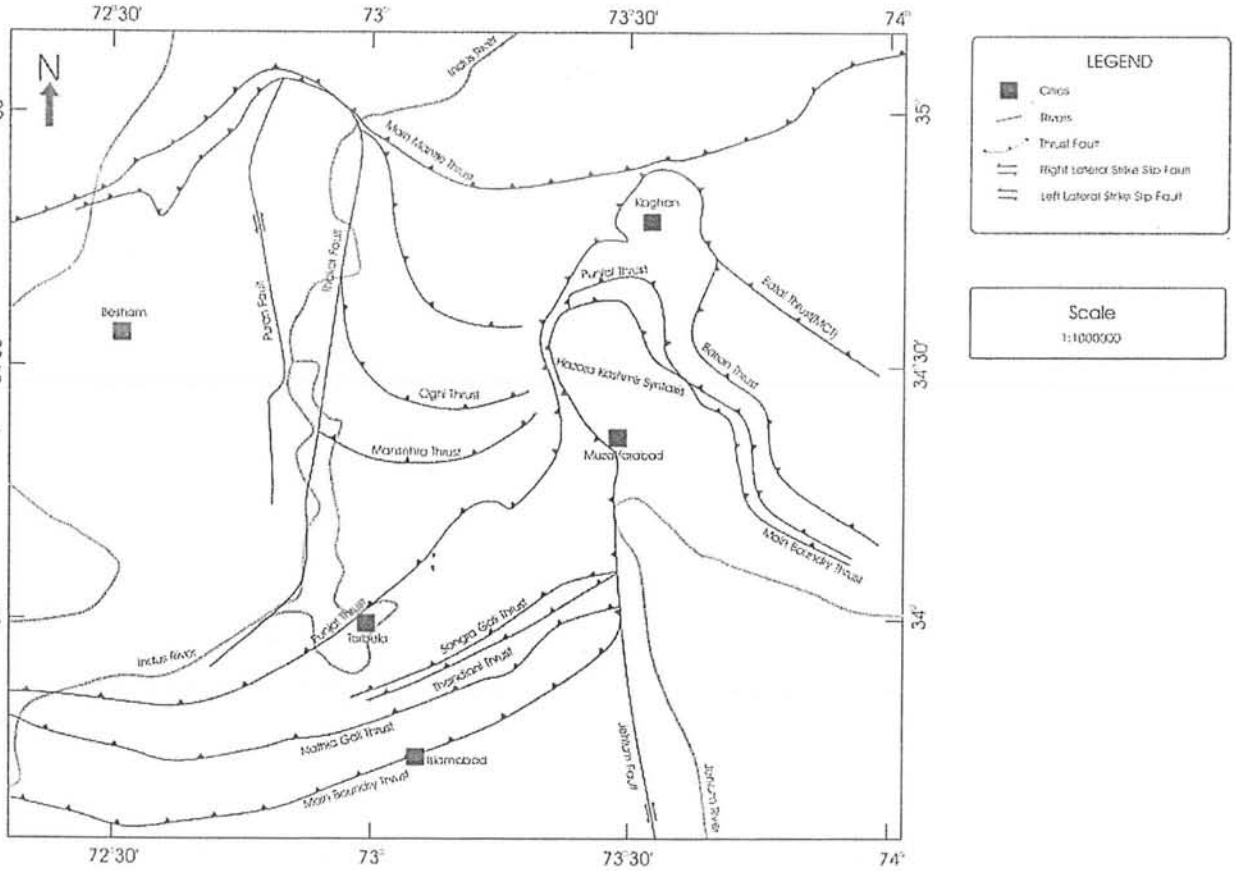


Figure No 1.2, Base Map of the area (adopted from Monalisa et al, 2005)

Sr. #	Date	Place	Magnitude	Destruction and Deaths toll
1.	1935	Quetta	7.5 m_b	Most of structures got collapsed and death toll reached 30,000.
2.	1945	Makran	8 Mw	Generation of Tsunamis and mud volcanoes and 4000 people died.
3.	28th December 1974	Pattan	6.0 m_b	Death tool about 6000.
4.	8th October, 2005	Kashmir	7.6 m_b	Structures collapse near the epicentral area, >100000 death

Table 1.1 Destructive Earthquakes of Pakistan (Prepared on the basis of Several resources)

CHAPTER NO 2

GENERAL GEOLOGY AND STRUCTURE OF THE AREA

Chapter No 2

General Geology and Structure of the Area

2.1 INTRODUCTION

Fold and Thrust belts are prominent features of continent-continent orogenic belts. The under thrusting of Indian Plate beneath the Eurasian Plate is producing compressional thin-skinned features since Eocene time on the northern and northwestern fringes of the Indian Plate. The continued underthrusting of the Indian Plate since Cretaceous produced the spectacular mountain ranges, which are Himalayas.

Thrusting in the Indian plate is certainly the accommodation method of shortening in the Himalayas. Fault plane solutions of the earthquakes give evidences that these are linked to the thrusts. However, in the Northwestern Himalayas complications arises, as the changed orientation of the Fault Plane solutions suggests that other accommodation features besides simple thrusting are occurring in the Northwestern Himalaya.

The study area includes a part of the Northwest Himalayan fold-and-thrust belt, one of the tectonic subdivision of Kazmi and Jan, 1997, which covers a 250 km wide and about 560 km long, irregularly shaped mountainous region stretching from the Afghan border near Parachinar up to the Kashmir Basin. The Hazara-Kashmir Syntaxis and Nanga Parbat Haramosh Massif form its eastern margin. It covers all the terrain between the Main Mantle Thrust (MMT) to the north and the Salt Range Thrust (SRT) to the south.

2.2 REGIONAL TECTONIC SETTING OF THE AREA

The north-south convergence of the Indian and Eurasian plates results in compressional tectonics of the Himalaya, exhibited by thrusting along Himalayan arc (Fig.2.1). The western boundary of the Indian plate is obliquely convergent along the Kirthar-Suleiman Mountain Belts with the plates containing Afghanistan and Iran resulting in both strike slip motion along the Kirthar and Suleiman shear zones and the Chaman fault and thrusting along E-W trending features such as the Loralai Hills (Pennington, W. D, 1979).

According to Kazmi and Jan (1997), a major thrust fault, the Panjal-Khairabad Fault divides the NW Himalayan sequence into a deformed southern zone, often referred to as the external or foreland zone, and a deformed and crystalline northern zone, also known as the hinterland zone. The part of the hinterland zone comprises the Himalayan crystalline nappes, whereas the foreland zone is comprised of the Hazara-Kashmir Syntaxis, Hazara Lower Sedimentary Belt, and Northern Potwar Deformed Zone. In the present case the study area consists of the zone of crystalline nappes, a part of Khyber-Lower Hazara Sedimentary belt (hinterland zone) and Hazara Kashmir Syntaxis and Kurram-Cherat-Margalla fold and thrust belt (foreland zone). A brief description of these is given below.

2.2.1 Zone of Crystalline Nappes

This zone comprises the northwestern margin of the Indian Plate and forms a relatively narrow belt south of the MMT (Indus Suture Zone). It extends westward from Nanga Parbat Haramosh Massif to the Afghan border. It is comprised of a thick sequence of Proterozoic basement gneisses and schist unconformably overlain by variably metamorphosed Phanerozoic cover sediments. Subduction of the Indian plate has decoupled the sedimentary cover from the basement. This cover has been imbricated with and extensive series of thrust slices and crustal Nappes. In Hazara, thrust structures have developed in a large duplex with its floor at the Mansehara Thrust and roof at the MMT.

Collision and subduction have thickened the Indo-Pakistan plate margin through formation of a thick sequence of ductile mylonites and imbrications of cover and basement along north dipping crustal scale thrust stacks. Six major nappes have been identified in this region although the metamorphic and structural geometries suggest that a number of smaller slices were stacked with them. Each nappe is stratigraphically distinct from the one adjacent to it. The nappes are shown in Fig.2.2

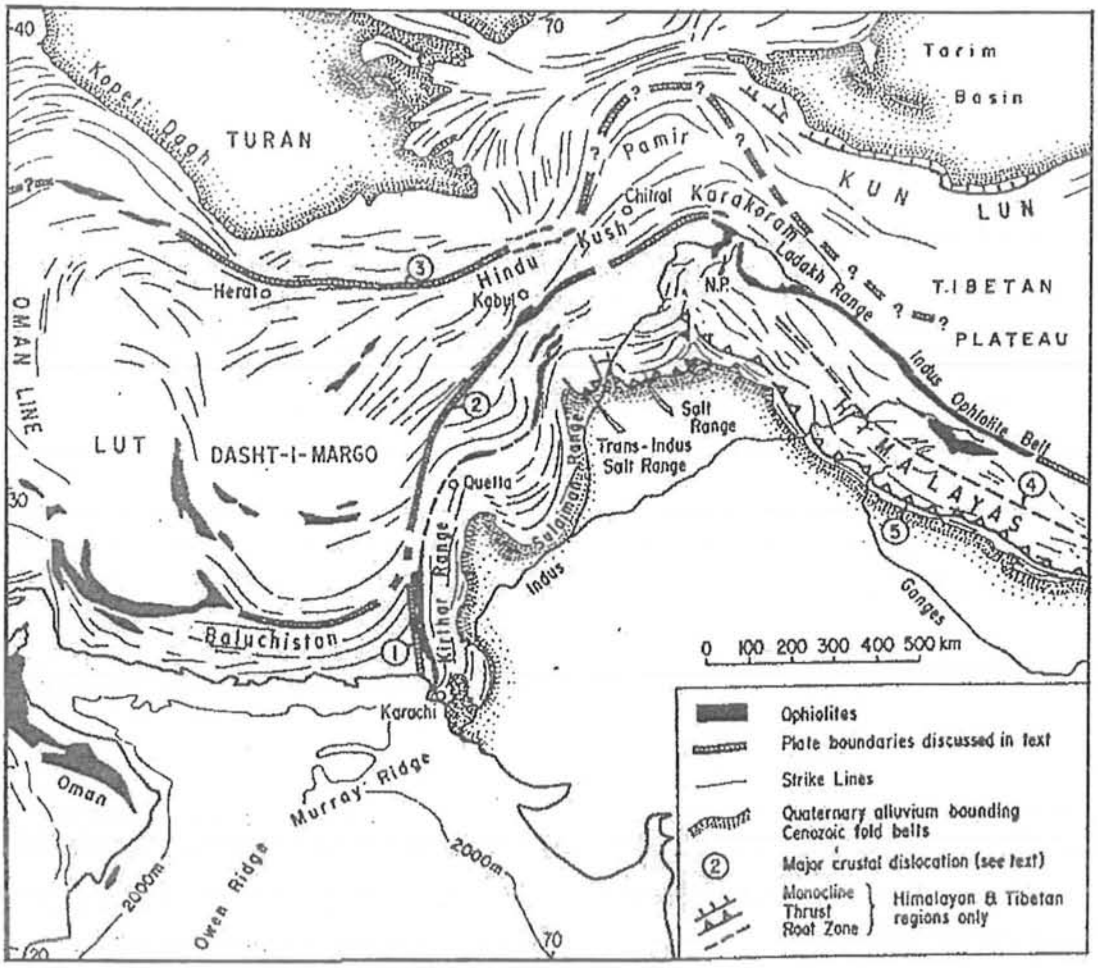


Figure 2.1 Tectonic Sketch Map of Pakistan and Adjacent region. The plate boundaries are clearly marked. (Adopted from Powell, C. M, 1979)

a. Besham Nappe

Along Alpurai Thrust, the Swat sequence overlies Late Archean to Late Proterozoic sequence of Besham Nappe. This nappe zone comprises an N-S oriented antiform at the apex of Indus Syntaxis. The core of antiform is comprised of quartzo-feldspathic basement gneisses, granites, metasediments and metavolcanics. These are imbricated with metasediments of younger cover sequence of the Karora Group. The cover rocks in the core of the anticline have been metamorphosed to chlorite grade whereas the tectonised cover slices towards the flanks are comprised of higher-grade granetiferous rocks. This feature gives an overall sense of metamorphic inversion. (Kazmi and Jan, 1997)

North of Besham, the Kohistan island arc sequence (Jijal Complex) has been thrusted over the Besham sequence along the MMT. The thrust zone is characterized by breccia with serpentine matrix and blastomylonites derived. Some authors have suggested that the Besham Nappe sequence underlies the Hazara Nappe and Swat Nappe sequence and that the Besham Nappe is apparently a tectonic window.

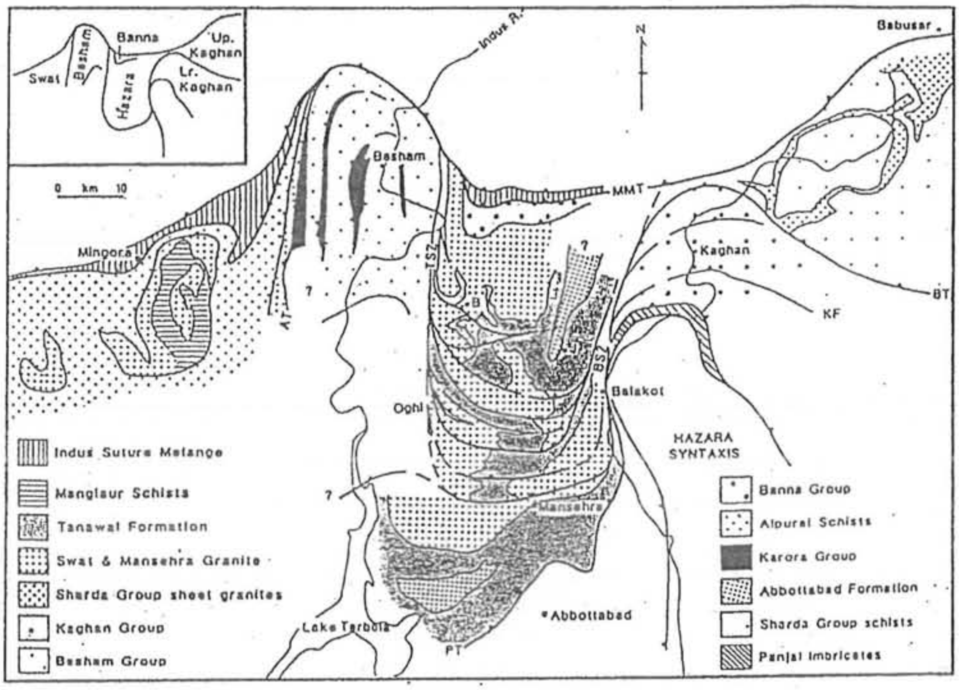


Figure 2.2 Map Showing different Nappe areas of NW Himalayan Fold and Thrust Belt (Adopted from, Kazmi and Jan, 1997)

b. Hazara Nappe

This nappe is 40 to 50 km and the Mansehra thrust forms its southern boundary. It extends northwards for about 75 km, up to the MMT and the Banna Thrust. The Balakot shear zone separates it form Hazara-Kashmir Syntaxis and the Kaghan Nappe.

One characteristic structural feature of the Hazara Nappe is the presence of number of north dipping, south-verging, curved thrust faults or shear zone which terminates northwards in the Thakot and Butgram shear zone. The latter shear zones are apparently crustal scale structures like a pair of lateral ramps to a thrust system. The other thrusts and shear zones as mentioned earlier, which internally imbricate the Hazara Nappe, are apparently hanging wall splays of the linked lateral ramp system. Each major N-dipping thrust has higher-grade rock in the hanging-wall than in foot-wall.

c. Banna Nappe

The Banna Nappe lies to the south of MMT and crops out in Alai Kohistan, along the northern margin of the Mansehra Granite. It comprises calcareous schist, slates, phyllites and marbles. The Banna thrust juxtaposes this group over the high grade Tnawal Formation of the Hazara Nappe. This thrust, however has a back thrust sense movement towards the northwest and it is characterized by brittle deformation.

d. Kaghan Nappe

The Kaghan Nappe forms the northern potion of Hazara-Kashmir Syntaxis. It lies between Panjal Thrust and the MMT. On the Western side, the Mansehra Thrust and Balakot shear zone separate it forms the Hazara Nappe. The Balakot Shear Zone forms a north verging loop, following the general trend of Hazara-Kashmir Syntaxis. Kaghan Nappe swings southeastward to join MCT. South of Naran, this shear zone has southeasterly trend and is called as Batal Thrust. This fault divided the Kaghan region into a northern Sharda zone and a southern Kaghan zone.

The granite gneisses of the Sharda Group have been described as mainly pretectonic. The Batal Fault, which has been referred to as MCT by Ghazanfar and Chaudhry (1986) and Greco (1991), separates the low metamorphic grade rock of Kaghan Group from High-grade sequence of Sharda Group.

2.2.2 Hazara Kashmir Syntaxis

The geological formations and broader geological structures of the Himalayas make an abrupt hairpin bend as if "they were bending round a pivotal point obstructing them". Different people studied this structural feature of the Himalayas and finally it was called as Hazara Kashmir Syntaxis. The Hazara Kashmir Syntaxis is a complex tectonic zone. It is difficult to define its outer limit, though its axial zone is well defined by a stack of thrust faults, which form a loop around its axis. This axial zone has NNW orientation and is largely covered by Murree Formation. The axial zone of the syntaxis with its Miocene molasses cover (Murree Formation) is in continuation of the Sub-Himalayan zone to the southeast. The Himalayan Frontal Thrust continues from the sub-Himalayan zone northwestward into the core of the Syntaxis and is terminated against the MBT (Kazmi and Rana 1982, Baig and Lawrence 1987).

North of Balakot, the axis of Hazara-Kashmir Syntaxis bends northeastward and continues into Kaghan and beyond into the Nanga Parbat Haramosh region. On western side of Hazara-Kashmir Syntaxis there are several arcuate, south verging thrust faults, which terminate in the Jehlum fault at an acute angle between Balakot and Kohala.

2.2.3 Khyber-Hazara Lower Sedimentary Belt

This metasedimentary fold and thrust belt lies to the north of Punjal Khairabad thrust and extends eastward from Khyber Pass region to Garhi Habibullah. The Peshawar Basin covers a large part of this belt. To the northeast among the Hazara Kashmir Syntaxis this belt is wedged in between the Panjal thrust and Balakot Shear zone. The Mansehra Thrust, which comprises a mylonitised shear zone, possibly an extension of Balakot Shear Zone (Baig and Lawrence 1987), separates the Khyber Hazara metasedimentary belt from Hazara Crystalline Napped Zone. Farther to the west, the north margin of this metasedimentary belt extends up to the Besham and Swat Crystalline Nappes (Kazmi and Jan, 1997).

This metasedimentary belt is largely composed of Precambrian to Early Mesozoic sediments. The Precambrian sequence is comprised of slates, phyllites with subordinate quartzites and marbles, which crop out in the southern part of the belt. The Precambrian section is largely in the form of thrust blocks with variation in metamorphic grade at some places. These rocks in Hazara region are exposed up to Tarbela.

The Khyber Hazara metasedimentary fold and thrust belt has been intruded by mafic dykes, sills and granitic rocks, in which the Ambela pluton is the most conspicuous. These intrusive rocks range in age from Late Paleozoic to Early Mesozoic. This metasedimentary belt is characterized by tight, asymmetrical or isoclinal folds, which are imbricated by several thrust faults. (Kazmi and Jan, 1997)

2.2.4 Kurram-Cherat-Margalla Fold and Thrust Belt

This arcuate and narrow (20 to 30 km wide) thrust belt lies to the north of Kohat-Potwar fold belt. From near Balakot (Hazara-Kashmir-Syntaxis), it extends southwestward through Margalla Hills, Attock Cherat and Kalachitta Ranges to the Sufaid Koh Range on Afghanistan border, a distance of about 350 km. it is an intensely deformed and tectonised belt with isoclinal folds and several south-verging thrust sheets. Eastward the Jehlum Fault has cut it. Southward it has been thrust over the Kohat-Potwar fold belt. The Panjal Thrust and its western continuation, the Khairabad Fault, define the northern limits Kurram–Cherat-Margalla thrust belt. Across the Panjal-Khairabad Thrust the metamorphic grade and stratigraphy differs significantly.

2.3 LOCAL TECTONIC SETTING

The local tectonics of the study area (location of main earthquake) is influenced by the formation of Hazara -Kashmir Syntaxis. Several active tectonic features like Jhelum Fault (Left Lateral strike slip), Main Boundary Thrust (MBT), Panjal Thrust, Himalayan Frontal Thrusts (Muzaffarabad Thrust of Baig and Lawrence, 1987, Kashmir Boundary Thrust, Riasi and Kotli Thrusts) are situated in or close vicinity of the main event location. Whereas the faults like Mansehra Thrust, Oghi Thrust, Thandiani Thrust, Sangragali Thrust and Nathiagali Thrust also exist in the adjacent areas making the study area seismically very active. Few of these features are shown in figure 1.2. A brief description of the some of the structural features existing in the study area is given below.

2.3.1 Main Mantle Thrust

The mega shear MMT, which is aligned with the Nanga Parbat Haramosh line on east, spans an area of about 400 km through Diamir, Kohistan, Swat, Dir and Bajaur before entering Afghanistan. The general trend of MMT is NE-SW and it is located along the contact of the mafic/calc alkaline meta-igneous rocks and the metasediments belonging to the Indo-Pakistan continental mass. Along this mega-thrust, the igneous rocks have over-thrust the metasediments to the south over a 10-15 km wide zone. This thrust is also manifests the broad high topography of Kohistan relative to Hazara, adjacent to the south.

In addition numerous auxiliary fractures are developed along and across the thrust; frequent brecciation and mylonitization are also observed along the contact. To distinguish the mega shear from the other thrust such as MBT and MCT in the outer and central Himalayas, this thrust has been named the Main Mantle thrust to signify its association with the high density mantle derived rocks.

2.3.2 Panjal Thrust

The Panjal Thrust runs parallel to MBT on the eastern limb of the Syntaxis. The two faults curve around the apex of the Syntaxis then bend southward. The two faults join about 5 km north of Balakot. However, according to Baig and Lawrence (1987) a separate left lateral strike slip fault (Jhelum Fault) truncates the Panjal Thrust and MBT north of Balakot. The Panjal Thrust probably separates from MBT about 6 km south of Balakot and continues beneath Kunhar valley alluvium up to Garhi Habibullah. It then swings southwestward and is clearly exposed. From the point of bifurcation, the MBT takes a southeastward course up to Muzarffarabad and then southward to Kohala.

2.3.3 Main Boundary Thrust (MBT)

Main Boundary Thrust (MBT) is the southern front of Himalayas and displays the younger but major lineament along which pre-collisional rocks are thrust over the post-collisional Murree Formation of mid-Oligocene to Miocene age. This boundary received different name: in the west of Himalayans or Hazara-Kashmir Syntaxis it was defined as Murree Thrust and in western most sections as Kohat Thrust, however researchers have proved the extension of

MBT which dips towards north at an angle less than 15°. The significance of the boundary in Himalayan tectonic is concerned with the following aspects:

i. It provides place for the accommodation of continued convergence of Indian-Eurasian collision.
ii. Although it bends surficially around the Hazara-Kashmir Syntaxis to join westerly-extended Hazara Thrust system, the seismicity pattern related tot the basement shows its extension towards North West in the form of Indus-Kohistan Seismic Zone (ISKZ) as discussed above.
iii. It represents Paleozoic or Panjal suture.
iv. It show an anomalous behavior as the rocks involved in the east (India) are Precambrian and Paleozoic, whereas in the west (Pakistan) are Mesozoic.

Those points are very critical and debatable in the understanding and formulation of a tectonic model for MBT and regions and further north.

2.3.4 Jehlum Fault

Kazmi (1977b) pointed out that the fault along the western margin of the axial zone of the Syntaxis was a left lateral strike slip fault and he named it, the Jehlum Fault. Baig and Lawrence (1987) reported that along this fault Muree, Abbotabad and Hazara Formations are highly deformed between Balakot and Muzaffarabad. Blocks of Panjal Volcanics and Triassic limestone have been dragged several kilometers southward, the rock are brittlely deformed and a left lateral offset of about 31 km is indicated n the western limb of the Syntaxis. Then Jehlum fault apparently dislocates the MBT and terminates the eastward continuation of some of the structures of NW Himalayan fold and thrust belt, which shows that it is the youngest major tectonic features in the syntaxial zone. A number of east west trending fault join the Jhelum fault at an acute angle pointed northward, indicating a relative left-lateral strike slip movement.

2.4. SUBSURFACE TECTONIC FEATURES

Seeber and Armbruster (1979), based upon the seismological data of Tarbela Seismological Network identified two subsurface active seismic zones in the northern parts of Pakistan and named them Indus Kohistan Seismic Zone (IKSZ) and Hazara Lower Seismic Zone (HLSZ). These are described below.

2.4.1 Indus Kohistan Seismic Zone (IKSZ)

Most of the seismicity associated with the IKSZ is occurring in a horizontally elongated wedge-shaped structure pointing toward the southwest. The lower limb of this wedge dips toward the northeast and the upper limn is horizontal about 11 km depth. Several fault-plane solutions consistently indicated thrust faulting on either f two conjugate planes with similar dips towards the northeast and southwest. Both conjugate planes are represented by seismic alignments within the wedge and their configuration suggests that this wedge is the front of a slab moving toward the southwest with respect to the rock layers above and below it.

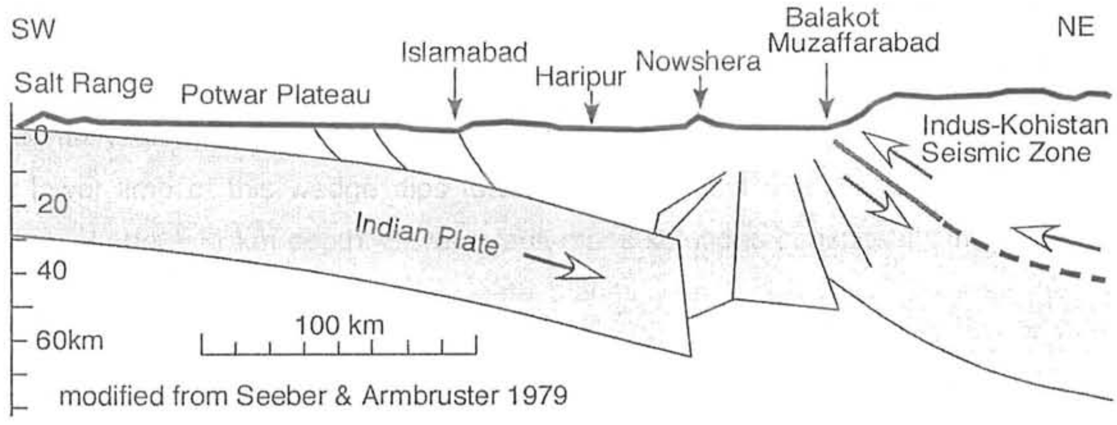


Figure. 2.3 N-S Cross-Section Showing IKSZ and HLSZ (Taken from Billham, 2005).

The Surface features associated with the IKSZ are consistent with flake tectonics. The decoupling of the "sedimentary" layer from the basement explains the absence of a geological expression of the basement faulting at the surface along the IKSZ. The high topography northeast of the IKSZ, where the thrusting thickens the crust, is qualitatively consistent with both an isostaitcally compensated environment and with the underthrusting of a rigid slab. The deep and scattered crustal seismicity in the subducting basement slab is probably due to the bending of this slab at the subduction front and not directly related to the flaking or thrusting itself. If the convergence rate at the IKSZ is of the order of 1 cm/year (Molnar et al, 1977), the residence time of the stress field associate with being at any point in the crust is relatively short, perhaps a few million year and this short term stress field may not have time to develop extensive fault zones, a broad zone of scattered seismicity is then expected (Seeber et al, 1980).

2.4.2 Hazara Lower Seismic Zone (HLSZ)

The Hazara seismotectonic province encompasses mostly eastward trending fold and faults of Hazara region in northern Pakistan. The deformation within this zone is primarily the result of thrusting and deep crustal development process associated with the collision between the Indo-Pakistan and Eurasian plates.

Modern teleseismicty within this zone has occurred at a moderate to high level. There have not, however, been any moderate to large magnitude even in modern times. Historical data on the other hand, indicate a number of moderate to large events in the past causing significant damages.

Seismically defined faults within the Hazara region have been identified using microseimsicity data. Armbuster and others (1978) has shown that shallow seismicity within the Hazara region occurs on perpendicular and steeply dipping fault, characterized by reverse and strike slip faulting. The microseimsicity data suggest that the Hazara thrust fault may be related to a décollement surface identified at depth. Telesiemically located events, however, do not align within any of the mapped surface faults or microseismically defined faults. As the mapped faults are dominantly thrust faults, a narrow alignment of epicenters along them is not to be expected. Furthermore, some activity may be associated with faults that are located below the possible décollement surface and that don't have any surface expression. The broad band of activity following the dominant structural tends, however, suggests that at least some of these earthquakes may be related to the major mapped structures (Quittmeyer et al., 1979).

CHAPTER NO 3

THEORATICAL BACKGROUND OF METHODS APPLIED

Chapter No 3

THEORETICAL BACKGROUND OF METHODS APPLIED

An earthquake is essentially a sudden and transient motion or series of motions of the earth's surface originating in a limited underground region, due to disturbance of the elastic equilibrium of the rock mass and spreading from there in all directions. The source of the elastic energy, i.e. the focal region, is generally an extended volume of rock mass of irregular shape. The centroid of this volume is the focus. The center of the vertical projection of this volume of rock mass on the earth's surface is called the epicenter of the earthquake. Thus, the epicenter is a geographical point with a given latitude and longitude fixing on the earth's surface of the location of the earthquake under reference. The distance of the epicenter from the place of the observation or recording center is called the epicentral distance, as seen in Figure 3.1. We are visualizing our self not on a plane or a level surface but more realistically on the curved surface of the planet Earth, which is 6,730 km in radius. The epicentral distance is represented in terms of degrees, as the distances involved on the earth surfaces are very large and one degree latitude or longitude is roughly equal to 111km.

The earth is in a state of continuous vibrations of low amplitude which are generally not felt. Earthquake vibrations differ from these low amplitude continuous vibrations by their abrupt and distinct beginning. Also earthquake vibrations last for a relatively short duration. In the similar passion, the vibrations are produced in underground blasts produced by human beings and are also termed as earthquakes. These vibrations travel to the different parts of the earth away from the focus, in the form of seismic waves. Study of these seismic waves is termed as **earthquake seismology**. Two most important are Focal Mechanism studies and Intensity studies, which will be explained in the next sections.

3.1 SEISMIC WAVES

Seismic waves are the waves of energy caused by the sudden breaking of a rock within the earth or an explosion. They are the energy that travels though the earth and are recorded in seismographs.

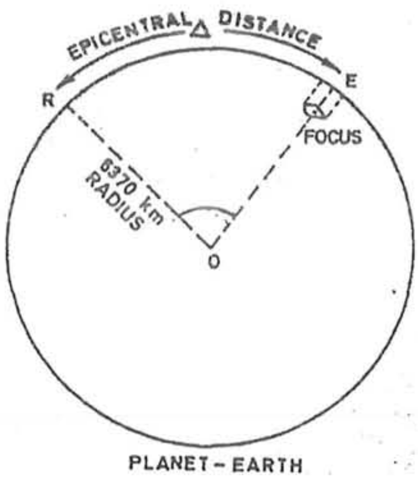


Figure 3.1. Diagrammatic representation of a recording station 'R' and an earthquake: focus 'F', epicenter 'E' and epicentral distance 'Δ' (Agarwal, 1991)

3.2 TYPES OF SEISMIC WAVES

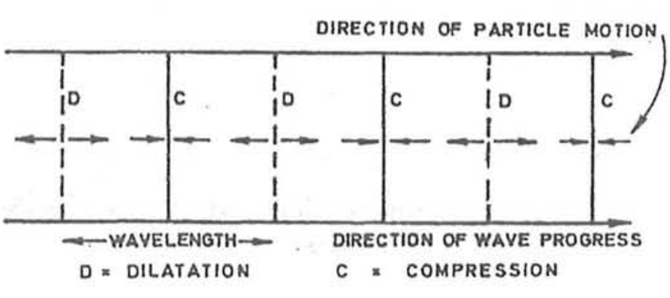
There are several different kinds of seismic waves and they all move in different ways. The two main types of waves are **body waves** and **surface waves**.

3.2.1 Body Waves

It is a type of seismic wave that travels through the interior of the earth with a propagation mode that does not depend on any boundary surface.

3.2.1.1 Longitudinal (Primary / Compressional) Waves

In longitudinal waves the direction of particle motion is in the same of opposite to the direction of the wave propagation, as shown in the Figure 3.2. The velocity of the longitudinal waves is related to the elastic contestants and density as follow:



$$\alpha = \sqrt{\frac{\lambda + 2\mu}{\rho}} = \sqrt{\frac{E}{\rho} \cdot \frac{(1-\sigma)}{(1-2\sigma)(1+\sigma)}} \quad \text{................ (3.1)}$$

Where ρ is the density, μ and λ are the lames constants, E is the modulus of elasticity and σ is Poisson's ratio. Since σ is generally about 0.25 and also the density doesn't vary significantly in the earth materials, variations in the longitudinal wave velocity are due to variation in the modulus of elasticity E.

3.2.1.2 Transverse (Secondary / Shear) Waves

In transverse waves the particle motion within the transmitting medium is at right angles to the direction of wave propagation, as shown in Figure 3.3. The transverse wave velocity is related to the elastic constants and density as follows:

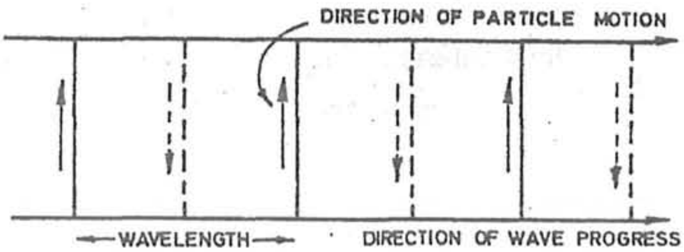


Figure. 3.3: Diagrammatic representation of transverse wave.

$$\beta = \sqrt{\frac{\mu}{\rho}} = \sqrt{\frac{E}{\rho} \cdot \frac{1}{2(1+\sigma)}} \quad \text{................ (3.2)}$$

Let us look at the ratio of the longitudinal and transverse wave velocities on the basis of the foregoing expression.

$$\frac{\alpha}{\beta} = \sqrt{\frac{(1-\sigma)}{(1/2-\sigma)}} = \sqrt{3} \text{ (For Poisson's Ration = 1/4)}$$

Since, Poisson's ratio is always less than half; the longitudinal wave velocity is always higher than the transverse wave velocity in any given medium. Thus, the longitudinal waves always arrived ahead of the transverse waves and the two are usually referred to as primary and secondary waves respectively.

If during the passage of a transverse wave the particle motion is confined to a particular plane only, then it is said to b e a polarized transverse wave, a

If during the passage of a transverse wave the particle motion is confined to a particular plane only, then it is said to b e a polarized transverse wave, a horizontally traveling wave so polarize that the particle motion is only in horizontal plane is called SH wave. Similarly, if the polarization is in the vertical plane, the name given is SV wave.

3.2.2 Surface Waves

The elastic energy, due to earthquakes, traveling within the earth has to emerge and travel along the earth's free surface and through its various layers. The waves, which transmit elastic energy in the close vicinity of free surface and interfaces between different elastic media, are called surface waves. Rayleigh and Love waves are the two surface waves commonly observed on earthquake record and are briefly explained here.

3.2.2.1 Rayleigh Waves

Rayleigh waves were predicted by Lord Rayleigh in 1885 and were the first surface waves to be recognized. The earth has a free surface and the elastic energy generated during an earthquake has an opportunity to travel along this free surface. The particle motion is always in vertical plane and is elliptical and retrograde with respect to the direction of wave propagation, as shown in figure 3.4. If we take 0.25 for Poisson's ratio then

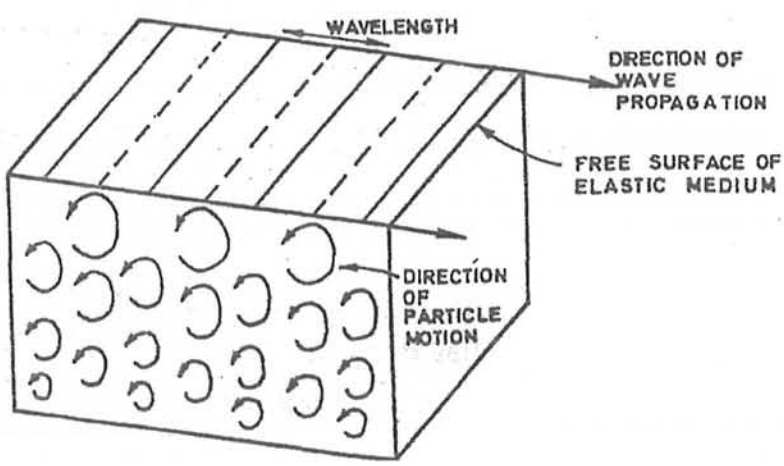


Figure 3.4: Diagrammatic representation of Rayleigh waves.

$$c = 0.9194\,\beta \quad \ldots\ldots\ldots\ldots\ldots\ (3.3)$$

Where c is the velocity of rayleigh wave and is approximately nine-tenths of the transverse wave velocity.

3.2.2.2 Love Waves

A mathematician with the name LOVE demonstrated the existence of Love waves. In these types of waves particle motion occurs only in the horizontal plane and is transverse to its direction of propagation, as shown in figure 3.5 and hence is only recorded on horizontal component records. The love wave velocity depends upon wavelength, the thinness of the upper layer and the elastic properties of the two media. Thus all love waves are dispersive. Love wave velocity for short and long wavelengths, compared to layer thickness, equals the shear wave velocity in the upper and lower medium respectively. Thus, these waves travel faster than the Rayleigh waves and are the fist to appear among the surface waves group.

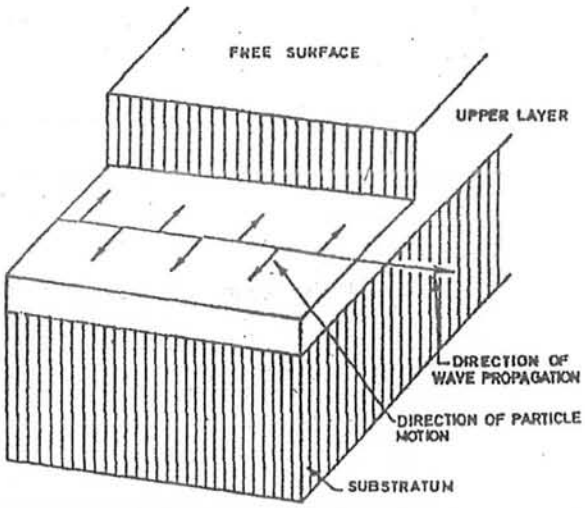


Figure 3.5: Diagrammatic representation of Love wave.

3.3 STRUCTURE OF THE EARTH'S INTERIOR

Seismic body waves provide a unique means of investigating the nature of the earth's interior below the depth from which samples cannot be obtained. Body waves from large earthquakes can be detected all over the earth and their paths and travel times through the earth allow geoscientist to deduce such properties as the density and physical sate of materials at depth. With the help of refracted waves studies, Moho and Guttenberg discontinuities have been marked between Crust/Mantle and Mantle/Core respectively.

3.4 FOCAL MECHANISM STUDIES

The Seismic waves generated by earthquakes when recorded at the seismic stations around the world can be used to determine the nature of faulting associated with the earthquakes, orientation of the fault planes and important information about the state of stress of the lithosphere. The result of such analysis is called focal mechanism solution of fault plane solution (Kearey and Vine; 1990).

3.5 ELASTIC REBOUND THEORY

It is now generally agreed that several slow processes acting over a very long period of time gradually allow storage of elastic strain energy in the earth's crust, which is finally released at the time of earthquake. The most convincing observation was made by an American geologist H.F. Reid, on the basis of results obtained by the California earthquake commission for San Francisco earthquake, 1906. Through the repeat surface triangulation, it was found that the straight rows of trees planted in the region across the San Andreas Fault had gradually become curved. Finally, when faulting occurred during the 1906 earthquake, each row of trees split into two. This is shown in figure 3.7. These observation led to the formation of elastic rebound theory of earthquake by H. F. Reid. According to him

- There are blocks of the earth's crust that slide past each other along the fractures in the earth crust.
- As long as the blocks on either side of the fault are free to slide slippage will be continuous and smooth. If, however, the walls of opposite sides of the fault become locked together because of irregularities along the fault surface, then also slippage will occur.
- Long time spans during which no movement occurs would be followed by short movement of rapid motion.

Reid concluded that during the times when the walls ere locked together the rocks adjacent to the fault would be progressively bend and would accumulated elastic strain energy. When the crust failed and rapid movement occurred, the strained rocks would snap back (rebound) and an earthquake would occur. The larger the amount of strain energy release, the stronger will be the earthquake. This is illustrated by the figure 3.8.

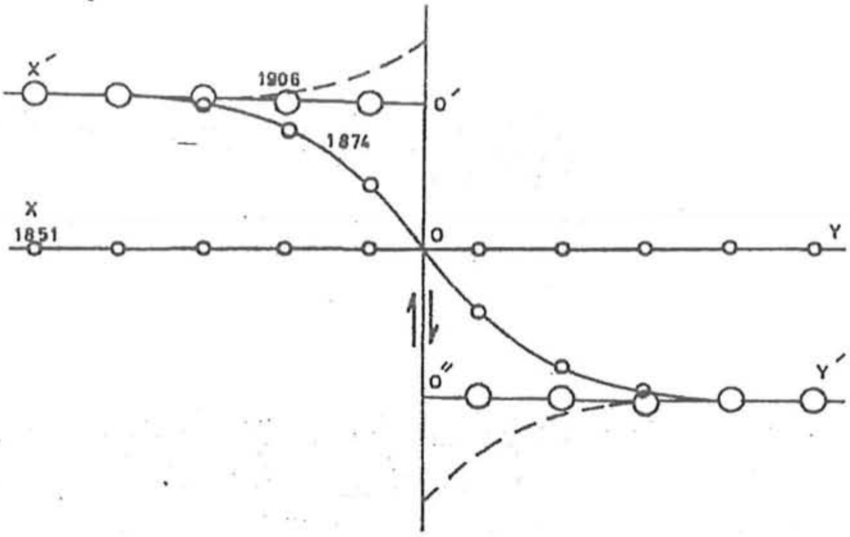


Figure 3.6: Displacement of a straight row of trees XY across San Andreas Fault and its rapture X'O - O Y' during the 1906 California earthquake, showing elastic deformations of the Earth's crust X'O Y.

3.6 FAULT PLANE SOLUTIONS

A focal mechanism solution (FMS) is the result of an analysis of waveforms generated by an earthquake and recorded by a number of seismographs. It usually takes at least 10 records to produce a reasonable FMS, and then only if the seismograph stations are well distributed geographically around the epicenter. The complete characterization of an earthquake's focal mechanism provides important information, including the origin time, epicenter location, focal depth, seismic moment (a direct measure of the energy radiated by an earthquake), and the magnitude and spatial orientation of the 9 components of the moment tensor. And from the moment tensor, we can ultimately resolve the orientation and sense of slip of the fault.

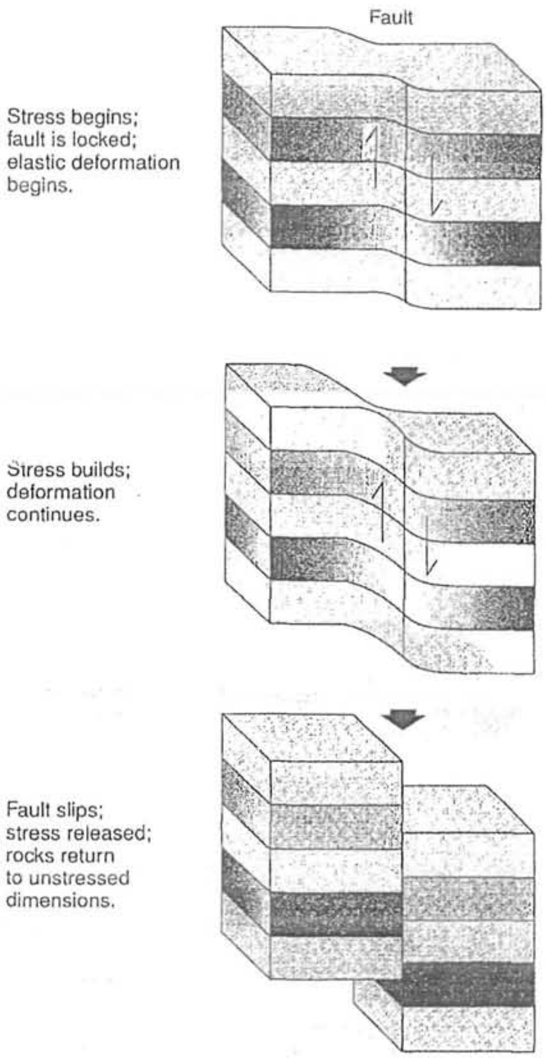


Figure 3.7. The phenomenon of elastic rebound along fault zones, the rocks deform elastically under stress until failure and then snap back to their original, undeformed condition after the earthquake.

The radiation pattern of energy emitted by a crustal earthquake can be modeled to the first order using a simpler process that does not explicitly involve a fault discontinuity, the double force couple or simply the double couple. The double couple is mathematically described in 3 dimensions by a symmetrical tensor with 9 components, known as the moment tensor. Like the stress and strain tensors, the moment tensor can be described in terms of three orthogonal axes: P (for pressure; a compressive axis), T (for tension) and N (for null). The orientation and magnitude of these axes for a given earthquake can be resolved using data recorded by several seismographs that are distributed around the epicenter. The orientation of the axes of a moment tensor is of interest to a structural geologist because the fault surface along which the earthquake was generated is 45° from the P and T axes, and contains the N axis. Bu the problem is that for any moment tensor, there are two possible planes that meet those criteria. The two planes are called the nodal planes, and they are at right angles to one another and intersect along the N axis. One of the planes is the fault surface, and the other is called the auxiliary plane and has no structural significance. All a seismologist can say with reference to the moment tensor alone is that the earthquake was generated on one or the other of the nodal planes. It takes geological input to differentiate between the two possible fault-plane solutions. Assuming that the fault plane can be differentiated from the auxiliary plane, the FMS can provide us with the orientation of the fault plane, the direction of hanging-wall slip, and hence the type of fault involved in the earthquake: strike-slip, reverse, normal, oblique and all of this information can be obtained within seconds if we know how to interpret a graphic depiction of the FMS, known as a "beachball" diagram. Analysis of several FMS in a main shock-aftershock sequence allows us to map the patch along the fault that slipped, and evaluate whether more than one fault generated earthquakes during the sequence. More sophisticated quantitative analysis of the earthquake source mechanics can sometimes identify the direction of fault propagation.

The beachball diagram can also be obtained by graphic techniques from a study of P-wave first motions. However, the graphic technique does not provide enough information to define the moment tensor for the earthquake. The basic techniques for using P-wave first motions recorded by an array of seismographs to define a FMS beachball diagram were developed before the advent of the microcomputer, and it is still useful to have at least a crude understanding of how to make the diagram manually (description after Kasahara, 1981, p. 38-44). From the preliminary determination of the epicenter, we know the location and origin time of the earthquake. Let us say that 14 geographically separate seismograph stations recorded the event. From the well-known locations of those stations, we compute the distance between each station and the epicenter. Then we use a standard seismic-velocity model of Earth to define the exact time (t) that the P-wave of the earthquake should have arrived at each station. Consulting the seismogram recording the vertical component at each station, we evaluate whether the first motion detected at that station was an "up" motion, a "down" motion, or no apparent signal at the expected time.

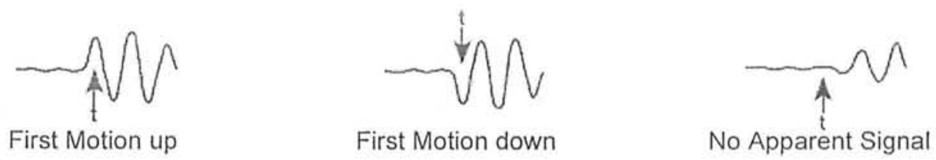


Figure. 3.8 Showing different types of First phase arrivals

The portion of the energy received by each seismograph, that left the earthquake focus in the form of a Compressional P-wave, can be thought of as having raveled along a *ray path* from the focus to the seismograph. Two things are important about that ray for each station: the ***azimuth*** along which it traveled from the earthquake focus to the station, and its ***take-off angle*** (also known as angle of emergence). The take-off angle is the angle between the ray as it just emerges from the focus and an imaginary vertical line extending through the focus. In routine work, the take-off angle is interpreted from a table that relates take-off angle to distance between the focus and the

$$\beta = \sin^{-1}\left(\frac{pV_h}{R_h}\right) \qquad (3.4)$$

where,

p = slpoe of the travel time curve

V_h = Velocity of Source Layer

R_h = Distance between the focus and Center of the earth

Following method has been applied in the present study for calculating the fault plane solution i.e BBC ver 1.0

The first method is developed in present study and discussed in next chapter where as second technique is discussed in this chapter. PMAN adopt the following procedure.

1) Prepare a data file that contains information about the hypocenter parameters (latitude, longitude and depth of hypocenter), the number of station that record the event (N), Station code and Polarity of the data.
2) Calculate the azimuthal angle and takeoff angle using this software. First the software computes the epicentral distance and azimuthal angel for each station and then obtains the takeoff angle corresponding to the epicentral distance of the focal depth.
3) Plot the polarity data and draw nodal lines using a program of FPS. Using the files created in (2) the software plots the data on the mechanism diagram applying equal area projection. After plotting data, draw the nodal lines with the help of PC mouse. In the end, the software actually gives us the Rake, T-axis and P-axis. The flow charts of data are given in figure 3.9 and 3.10.
4) The final step is the interpretation of the focal mechanism diagram. Type of the fault can be determined with the help of beach-ball diagram. If the dilations are surrounded by the compression within the circle with only a tiny portion of dilations touching the circumference, then normal faulting is indicated. Opposite case is true fro reverse faulting i.e. compressions are surrounded by dilatations. In case of strike slip faulting, the compression and dilatations from quadrants which are equally or nearly equally distributed along the circumference.(Figure No 3.9)

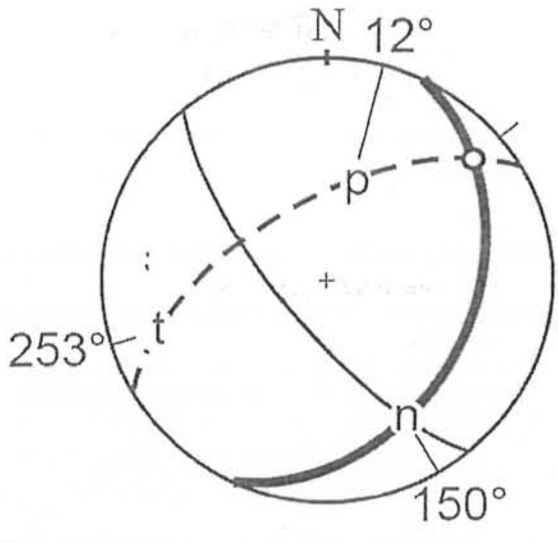


Figure 3.9. Final beach Ball Diagram

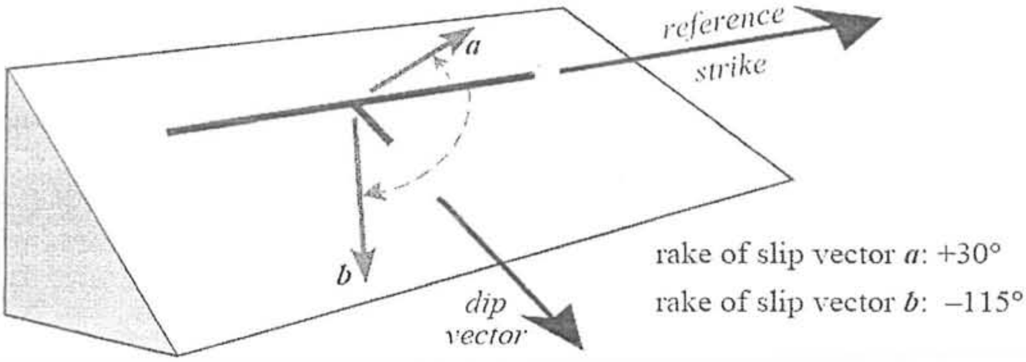


Figure No 3.10, Schematic Representation of a Fault Plane

3.7 DAMAGE OBSERVATION AND EARTHQUAKE INTENSITY

It is commonly known and understood that the major earthquakes have resulted in large-scale destruction whereas many others have caused limited damage. The damage potential of different earthquakes is varying and reduces with increasing distance for every earthquake. It has therefore been found useful to systematically study the damage during past earthquakes even when no scientific earthquake studies were undertaken and no instrumental data were obtained. It is to be emphasized here that the importance of earthquake observations has not diminished with the availability of sophisticated instrumental data and earthquake effects are studied even now.

The violence of an earthquake felt in a particular locality is called its **intensity**. The violence of shaking, i.e., intensity of an earthquake, is assessed in terms of the associated effects which could systematically be used to represent its increase or decrease in different places. A comparison of intensity observations also helps to identify the relative size of an earthquake since bigger ones tend to be associated with higher intensities in general. However, while making such comparisons it has to be borne in mind that the intensity generally decreases with increasing distance from the earthquake epicenter. (Agarwal, 1991)

Different Intensity and damage observation scales exists for example Rossi-Forel scale, Mercalli Scale and Modified Mercalli scale (MMI). Modified Mercalli scale has undergone minor changes by UNESCO working group in 1964 (Krishna, 1964) whereby the terms used have been fully defined.

I. Not noticeable

The intensity of the vibration is below the limit of sensibility; the tremor is detected and recorded by seismographs only.

II. Scarcely noticeable (very slight)

Vibration is felt only by individual people at lest in houses, especially on the upper floors of buildings.

III. Weak, only partially observed

The earthquake is felt indoors by a few people, outdoors only in favorable circumstances. The vibration is similar to the passing of a light truck. Attentive observers not ice a slight swinging of hanging objects, somewhat more intense on the upper floors.

IV. Largely observed

The earthquake is felt indoor by many people and outdoor by a few. Here and there people wake up, but no one is frightened. The vibration is similar to the passing of a heavily loaded truck. Windows, doors and dishes rattle. Floors and walls creak. Furniture begins to shake. Hanging objects swing slightly. Liquids in open vessels arc slightly disturbed. The shock is noticeable in standing motorcars.

V. Awakening

a) The earthquake is felt indoors by all, outdoors by many. Many sleeping people wake up. A few run outdoors. Animals become uneasy. Buildings tremble through out. Hanging objects swing considerably. Pictures knock against walls or swing out of place. Occasionally, pendulum clock stop. Unstable objects may be overturned or shifted. Open doors and windows are thrust open and slam back again. Liquids spill in small amounts from well-filled open containers. The sensation of vibration is similar to the falling of a heavy object inside the building.

b) Slight damages in buildings of type A are possible.

c) Sometimes a change in the flow of springs occurs.

VI. Frightening

a) Felt by most indoors and outdoors. Many people in buildings are frightened and run outdoors. A few persons lose their balance. Domestic animals run Out of their stalls. In a few instances dishes and glassware may break and books fall down. Heavy furniture may possibly move and small steeple bells may ring.

b) Damage of grade I is sustained in single buildings of type B and in many of type A. Damage in a few but type A is of grade 2.

c) In a few cases comes up to 1cm in width arc possible in wet ground; occasional landslips in mountains, change in the flow of springs and in the water level of wells is observed.

VII. Damage to buildings

a) Most people arc frightened and run outdoors. Many find it difficult to stand. The vibration is noticed by persons driving motorcars. Large bells ring.

b) In many buildings of type C damage of grade I is caused; in many buildings of type B damage is of grade 2. Most buildings of type A suffer damage of grade 3, a few of grade 4. In single instances landslips of roadway on steep slopes, cracks in roads, seam of pipelines damaged; cracks in stonewalls.

VIII. Destruction of buildings

a) Fright and panic. Also persons driving motors cars are disturbed. Here and there branches of trees break off. Even heavy furniture move and partly overturns. Hanging lamps are damaged in part.

b) Most buildings of type C suffer damage of grade 2, and a few ofgrsde3. Most buildings of type B suffer damage of grade 3, and most buildings of type A suffer damage of grade 4. Many buildings of type C suffer damage of grade 4. Occasional breaking of pipe seams. Memorials and monuments move and twist Tombstones overturn. Stonewalls collapse.

c) Small landslips in hollows and unbanked roads on steep slopes; cracks in ground up to widths of several centimeters. Water in lakes becomes turbid. New reservoirs come into existence. Dry wells refill and existing wells become dry. In many cases change in the flow and level of water occurs.

IX. General damage to buildings

a) General panic. Considerable damage to furniture. Animals run to and fro in confusion and vocalise.

b) Many buildings of typeC suffer damage of grade3, a few of grade4. Many buildings of type B show damage of grade 4; a few of grade 5. Many buildings of type A suffer damage of grade 5. Monuments and columns fall. Considerable damage to reservoirs; underground pipes partly broken. In individual cases railway lines are bent and roadways damaged.

c) Over flow of water on flat land, sand and mud is often observed. Ground cracks to widths of up to 10cm; on slopes and river banks more than 10cm; furthermore a large number of slight cracks in ground; fall of rock, many landslides and earth flows; large waves in water. Dry wells renew their flow and existing wells dry up.

X. General destruction of buildings

a) Many buildings of type C suffer damage of grade 4, a few of grade 5. Many buildings of type B show damage of grade 5; most of type A have destruction of grade5; critical damage to dams and dikes and severe damage to bridges. Railway lines are bent slightly. Underground pipes broken or bent. Road paving and asphalt show waves

b) In ground, cracks up to a width of several cm, sometimes up to 1 meter. Broad fissures appear parallel to water courses. Loose ground slides from sleep slopes Considerable landslides are possible near river banks and steep coasts. In coastal areas displacement of sand and mud; change of water level in wells; water from canals, lakes, river etc. thrown on land. New lakes appear.

XI. Destruction

a) Severe damage to well-built buildings, bridges, water dams and railway lines; highways become useless; underground pipes destroyed.

b) Ground considerably distorted by broad cracks and fissures, as well as by movement in horizontal and vertical directions; numerous landslips and falls of rock. The intensity of the earthquake requires special investigation.

XII. Landscape change

a) Practically all structures above and below ground are greatly damaged or destroyed.

b) The surface of the ground Is radically changed. Considerable ground cracks with extensive vertical and horizontal movements are observed. Falls of rock and slumping of riverbanks over wide areas; lakes are dammed; waterfalls appear, and rivers are deflected. The intensity of the earthquake requires special investigation.

Section Quaid-i-Azam University

3.8 ISOSEISMAL LINES

It is customary to plot on a map the intensities assigned to various localities, where an earthquake has been felt. The lines drawn to join places of equal intensities for an earthquake are called isoseismal lines end are labeled by a corresponding intensity value. The map showing isoseismal lines will contain regions of graded Intensity and is called an isoseismal map. The higher value isoseismals lie towards the centre and the lower value isoseismals gradually enclose a larger area,

If the ground surrounding the earthquake source was isotropic and homogeneous in all directions and the energy radiation was equal in all directions, the isoseismal lines will form circles. This is seldom the case and usually they are elongated, elliptical in form and those with higher values may even be more irregular in shape. The following explains why this is so:

1) The intensity of an earthquake is the degree to which it is felt and is observed in terms of damage and is not the measure of its size. The damage will naturally depend upon the density of population, number of houses, type of construction, etc. which will not be generally uniform in the area of survey and its effect cannot be easily eliminated from the observations.

2) The energy radiation at source may not be uniform in all directions.

3) The source of energy is ordinarily a linear zone and not a spherical one.

4) All rocks do not transmit energy with equal efficiency; compact rocks are better energy carriers than loose materials. The rocks between places of observations and source will generally possess some azimuthal variations.

5) Presence of several buildings with natural period of vibration equal to the period of earthquake waves may enhance the damage due to resonance.

6) Presence of special geologic structural features in the path of the earthquake waves may act as barriers and reduce the damage in some localities.

In spite of all the foregoing limitations, an isoseismal map allows quantification of intensity attenuation with distance in various directions around an earthquake.

3.9 PREPARATION OF ISOSEISMAL MAP

Let us briefly consider the practical details of assessing, plotting and labeling equal intensity lines representing each successive grade i.e. preparation of an isoseismal map. The field data will be an assortment of various intensities scattered in different localities. The intensity variation within the same grade is substantial. The resolution of the data obtained on the basis of intensity scales does not allow tracing the variation within each grade. Ordinarily, a wide zone instead of lines will be covered by localities of the same intensity ranges. There are two distinct practices for handling this problem.

In the **first approach** positive (+ive) and negative (-ive) subscripts are attached to all intensity ratings for various localities to denote the intensity variation within the same grade. The isoseismal of a given value is made to enclose all the localities of that intensity rating, to pass close to the negative subscripted values and is labeled with that value of intensity. Thus, the isoseismal of a particular value is the outer boundary of the region or that intensity. This practice allows one to stop at any intensity level as might be commensurate with the actual observation and the extent of survey. Also, the map will allow unambiguous determination of the distance versus intensity measurements to determine the intensity attenuation characteristics.

The **second approach** in preparing isoseismal maps, which is followed by most American workers, is to show boundaries between regions of successive intensities. For intensity attenuation with distance a conservative approximation of distance of isoseismal of selected intensity, say 'VI', will still be the outer boundary of the zone representing intensity 'VI'. For fuller utilization of data such maps cannot leave any region unbounded until the limit of detectability or intensity 'I' is shown. Thus, alt American isoseismal maps without exception go down to intensity 'I'. Naturally, the approach becomes impracticable when the survey does not extend up to intensity 'I'. On the other hand, estimates of intensities 'I' to III/IV are ordinarily not reliable and their representation on a map does not serve much purpose. The inadequacy of these estimates is clearly borne out by the closer spacing of zones 'I to IV' compared to the higher ones and cannot be explained if each grade represents an approximately equal intensity decrement.

It is thus concluded that irrespective of whether the isoseismals are drawn to represent a specific grade or to mark boundaries between different grades, the situation largely remains the same. However, the first approach does not demand obtaining and representing estimates for low intensity zones, which are expected to be unreliable in any case.

3.10 INTENSITY VERSUS GROUND ACCELERATION

Ground shaking may cause sliding of objects if the horizontal component of ground acceleration is able to exert a force larger than the inertia of the object. Generally, the inertial force itself may reduce due to a temporary reduction in the value of the acceleration due to gravity on account of the upward component of ground acceleration. If the centre of gravity of the object is at a sufficient height compared to its base, the moment of the horizontal component of inertial force around a possible point of overturning on the base rim of the object may also equal o the stabilizing moment, depending on the violence of shaking. Under such collisions the object may overturn after rocking on the base rim. Observations on rocking and overturning with measurements of dimensions of the object, its weight and friction, could allow a quantitative estimate of the ground acceleration. This would be particularly useful in regions where instrumental data on ground acceleration arc not recorded.

With the availability of instrumental data on ground acceleration in regions of different intensities for numerous earthquakes, empirical relations between intensity and ground acceleration have been developed. One such relationship is:

$$\log a = \frac{I}{3} - \frac{1}{2} \quad \text{......................... 3.4}$$

Where a is the acceleration in cm/sec and I is the intensity in the Modified Mercalli scale. Thus the seismic intensity VII to VIII will approximately represent a ground acceleration of 10% g. Through such estimates it is possible to convert isoseismal maps into isoacceleration and isoforce maps for engineering applications.

The intensity is not a parameter directly representing the size of an earthquake. The difference will become clearer when we describe the parameter representing the size of an earthquake, i.e., the magnitude.

CHAPTER NO 4

SOFTWARE DEVELOPMENT

Chapter No 4:

Software Development

4.1 INTRODUCTION

This chapter deals with the software development, which has been done, in the present study these are

- **Beach Ball Calculator**

It is basically a software package that is developed for generation of fault plane solution. It is the unique of its type because of the fact that it is windows based software and is programmable. Few software packages are already available but they are operating system specific. The development phase has been carried out in **MATLAB**. This software can run on all the platforms supported by MATLAB. Later on after development this software has undergone the most important phase of software development life cycle (SDLC), which is testing. Testing was done by a geoscientist Mr. Asim Fraeed Jadoon working in software testing department of LMKR.

- **Geoquaidians Earthquake Information Center**

This is a unique website, developed first time in Pakistan. This website is dedicated to work wholly as e-earthquake information center. This website aims in providing ease especially to the students and to the general public who wants to get in contacts with the updates of the earthquakes in Pakistan. Any person can come on this website and can register him/herself for the earthquakes updates. These updates will be sending to their e-mail address as well as to their cellular as a **sms**. Currently this website has been configured to Mobilink and ufone users and will be updated for others as well.

4.2 OBJECTIVES AND SCOPE OF THE PROJECT

Objectives and scope of both BBC and Website is diversified in different dimensions and they can be upgraded under the changed requirements. Especially change in the website objectives and scope, we can change it easily.

Following are the main aspects of the **Beach Ball Calculator (BBC),**

- User input data (It takes input in .dat format)
- View data sets and select one desired from the list
- Can generate the Stereo net
- Plot the data with just one command
- Mark the fault plane and auxiliary plane
- Mark the nodal axis and plane
- Mark P and T axis
- Can send the data to printer for print
- Can save the softcopy in any graphics format

Following are the main aspects of the **Geoquaidians Earthquake Information Center website,**

- Dynamic Website
- User registration
- Seismology information
- Scientific data from different resources
- Intensity investigation survey of any earthquake
- Searching facilities

4.3 EXISTING SYSTEM

For both i.e. Fault Plane Solution and Intensity data acquisition there exists traditional methods In Pakistan, which can be divided in to two types

1. Fault Plane Solution
    1. Tracing Sheet Method
    2. PC Based Method
2. Intensity data acquisition
    1. Traditional method
    2. Questionnaire method

4.3.1.1 Tracing Sheet Method

This is the basic method in which we use tracing sheet and put it on a stereographic projection and by separating out the maximum dilatation from the compression we try to for four coordinates. On the basis of this we try to interpret the results.

4.3.1.2 PC Based Method

PC based methods are also available in the market. In this we input the data to the software and by the help of the mouse we can find out the four coordinates and try to identify the fault surface.

4.3.2.1 Traditional method

In tradition data gathering method we use a plain paper and write down the interview detail of the person and try to identify the intensity at that place using MMI scale.

4.3.2.2 Questionnaire method

In this method we develop a questionnaire and gave it to the effected people they fill the form and we calculate the intensity at that place.

4.3.3 Drawbacks Of Existing Systems

There are many problems in the existing system; which varies from data inaccuracy, laborious work and etc. The main drawbacks are as follow.

- Inaccuracy of the data
- Laborious work
- Should be expert
- Simple methods may lead to other sides
- Time consuming

4.4 PROPOSED SYSTEM

Something that has changed over the past decades is that the telephone rings less often. This is not a symptom or sign of inactivity, but reflects the fact that our activities are now built around the computer and Internet. In web base data acquisition there will be less time consumed and numerous users can access your website. As this thing will lead us to the environment, where there is minimum use of paper. Also the different costs on investigating agency can be reduced e.g. traveling. Keeping in view the above-defined benefits, it will make a platform for the users from all communities, where they can contact each other immediately. Similarly in case of BBC the developed package can be run on any platform supported by MATLAB and is easily programmable. This is quite unique because usually other programming languages are platform dependent and cannot be programmed later.

4.4.1 Hardware and Software Requirements

- **Server Side**

We will be using the QAU server for the posting of this website. So no extra hardware or software charges will be required for the server.

- **Client Side**

Following are the hardware and software required for client side.

Hardware:

- Pentium IV 1.7 GHz Processor
- Ram 256 MB or Greater
- Other hardware.

Software:

- Microsoft Windows 2000 Server or later
- Internet Explorer 6 recommended

4.4.2 Tools and Technology

In this project we will use the following tools:

- MATLAB ver 7
- Visual Studio.net
- Adobe Photoshop 6.0
- Microsoft FrontPage
- Macromedia Flash 6.0
- SQL Server 2000
- Microsoft Visio 2003
- Microsoft Project 2003

4.5 ANALYSIS

This is one of the most important phases of software development. It has been done accordingly.

4.5.1 Work Breakdown Structure Graphical

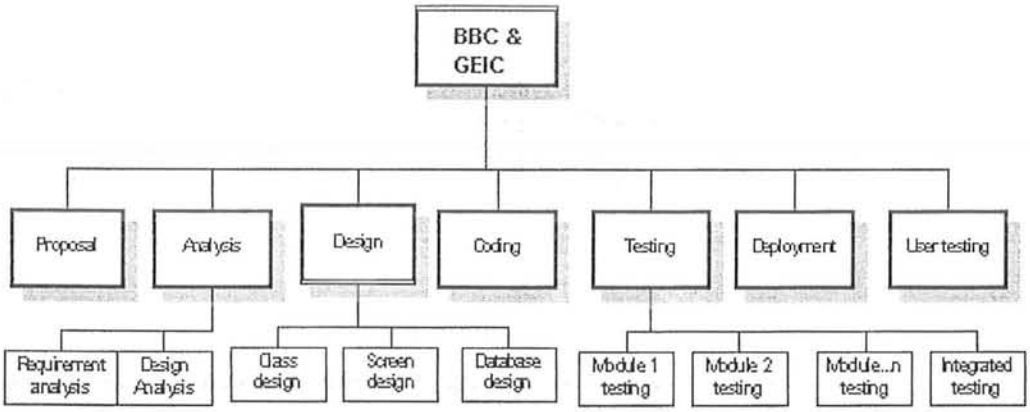


Figure 4.1. Work break down structure for BBC & GEIC

4.5.2 Work Breakdown Structure Tabulated

TASK ID	NAME	LEVEL	DURATION
1	Proposal	0	3 days
2	Analysis	1	2 days
2.1	Requirement analysis	2	1 days
2.2	Design Analysis	2	3 days
3	Design	1	5 days
3.1	Class design	2	1 days
3.2	Screen design	2	1 days
3.3	Database design	2	1 days
4	Coding	1	15 days
5	Testing	1	5 days
5.1	Module 1 testing	2	1 days
5.2	Module...n testing	2	1 days
5.4	Integrated testing	2	1 days
6	Deployment	1	2 days
7	User testing	1	3 days

4.5.3 Object oriented analysis and design

A combination of data and processes or functions or methods or procedures or modules in to single entity is called object. An entity is a thing that can be uniquely identified. A collection of objects is called a class. For the purpose of object oriented analysis and design (OOAD) unified modeling language (UML) is used. Rational Rose, Microsoft Visio are the popular CASE tools to draw UML. There are many types of techniques to draw UML diagrams but most popular are as follow.

- USE CASE
- CLASS
- STATE
- SEQUENCE

Use cases represents the all major processes or functions required by the customer as cases. Use cases have been defined for both BBC and GEIC as discussed below.

4.5.3.1 Beach Ball Calculator

There area different use cases in creating a beach ball calculator. These are

- User input
- Data view
- Schmidt equal area net creation
- Auxiliary, Fault and Null Planes marking
- P and T axis marking

4.5.3.2 Geoquaidians Earthquake Information Center (GEIC)

Following are the use cases which are consider when the design confirm

- General Access
- Scientific Data
- Intensity marking
- Searching data
- Registration

4.6 INTERACTIVE INPUT AND OUTPUT

4.6.1.1 Beach Ball Calculator

There are different steps through which Beach Ball Diagram can be prepared. It allows us to travel through some screens these are: -

1. This screen is displayed when the software runs.

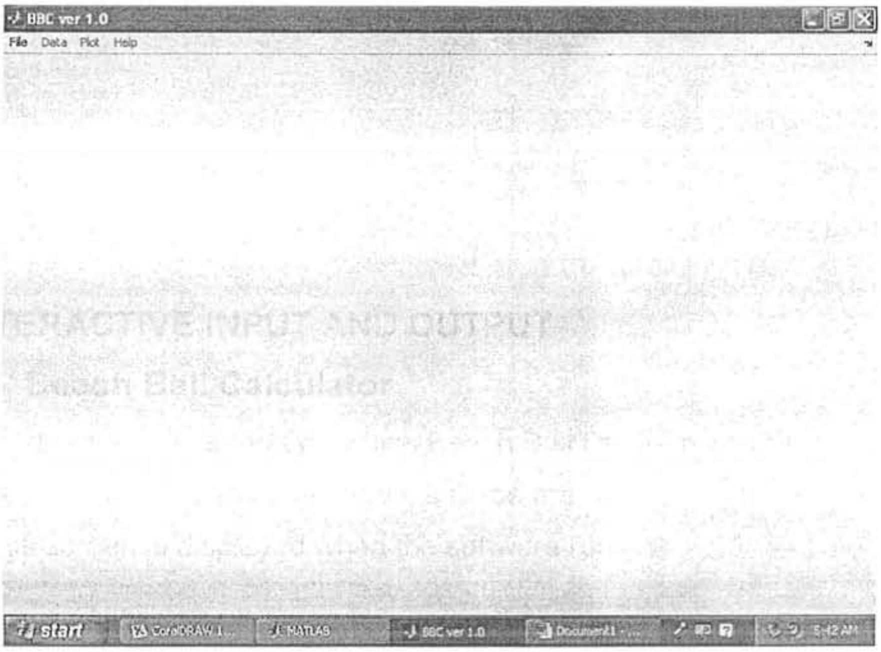


Figure 4.2 Start Screen of BBC ver 1.0

2. This screen is displayed by selecting open from file menu

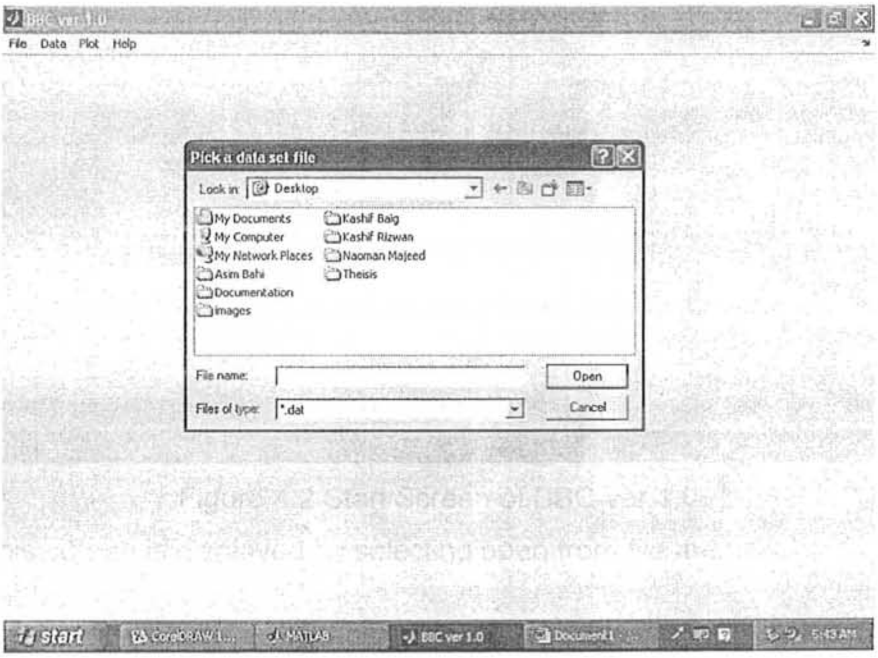


Figure 4.3 Data input screen of BBC ver 1.0

2. This screen is displayed by selecting data sets from data menu. User can select the active data sets.

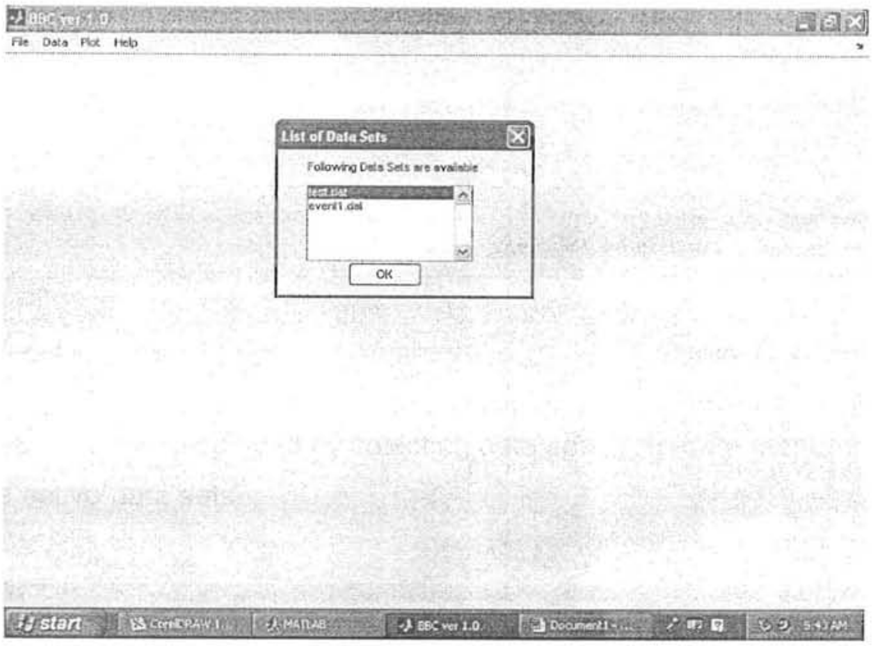


Figure 4.3 Select data set screen of BBC ver 1.0

2. This screen is displayed by selecting nodal planes by the help of mouse. In the end software automatically marks P and T axis.

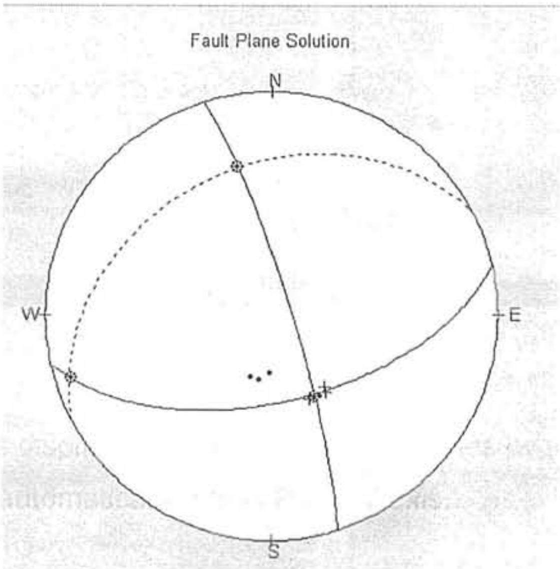


Figure 4.4 Prepared beach ball diagram using BBC ver 1.0

4.6.1.2 Geoquaidians Earthquake Information Center (GEIC)

This website has been developed to represent the Geoquaidian's activity about seismology in the international community and as well as to the local community. Same web site is used as the intensity investigation survey.

4.6.1.2.1 Welcome Screen

This is the welcome or start screen when any user open the website.

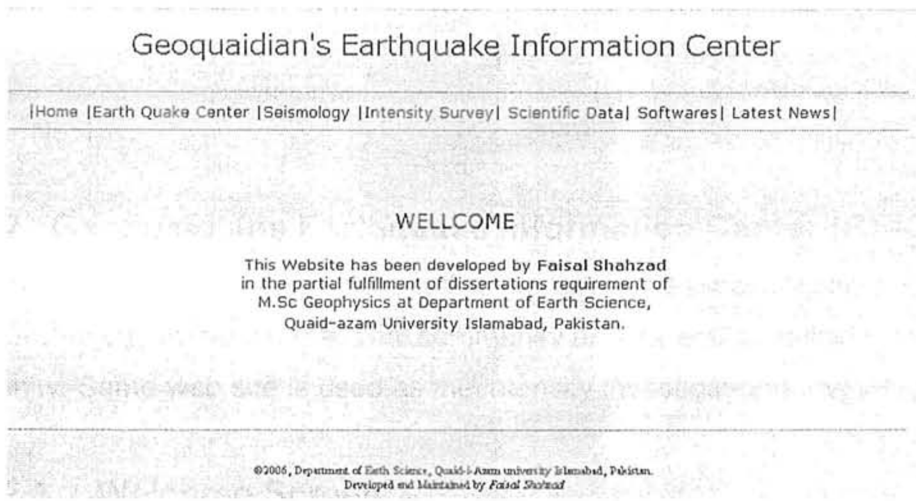


Figure 4.2 Welcome screen of GEIC

4.6.1.2.2 Intensity survey screen

These portions takes input from the users.

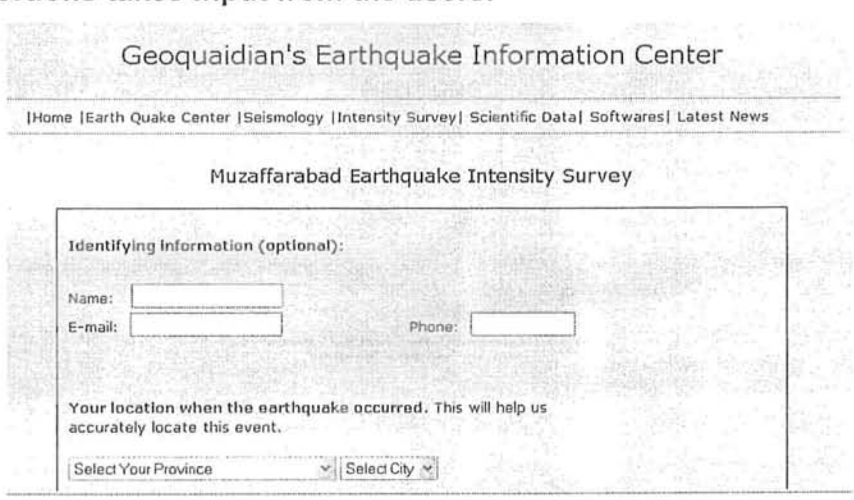
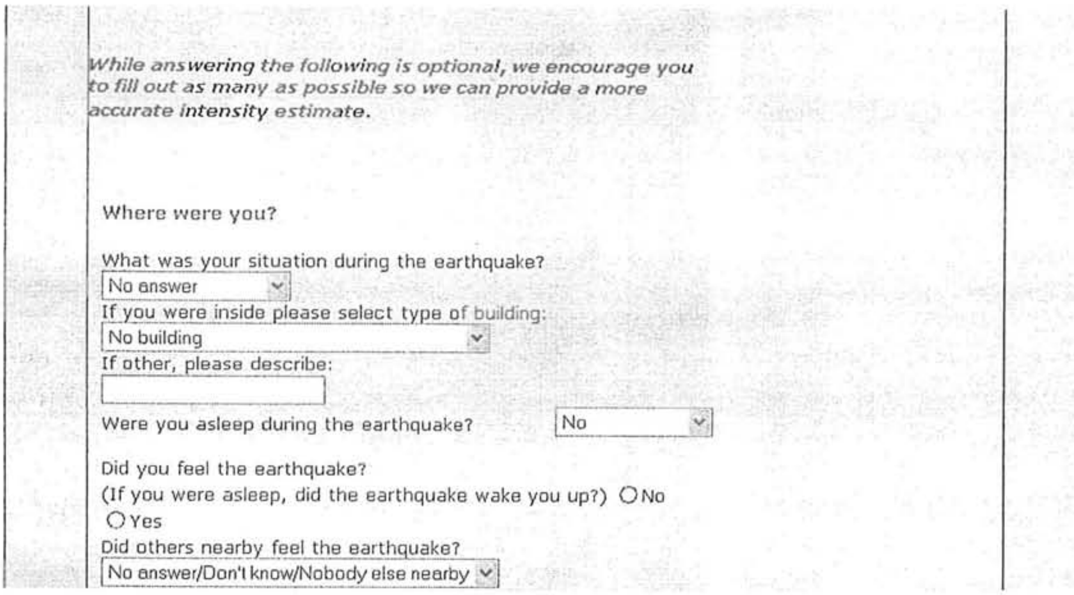


Figure 4.2a Intensity survey screen-I



While answering the following is optional, we encourage you to fill out as many as possible so we can provide a more accurate intensity estimate.

Where were you?

What was your situation during the earthquake?
No answer

If you were inside please select type of building:
No building

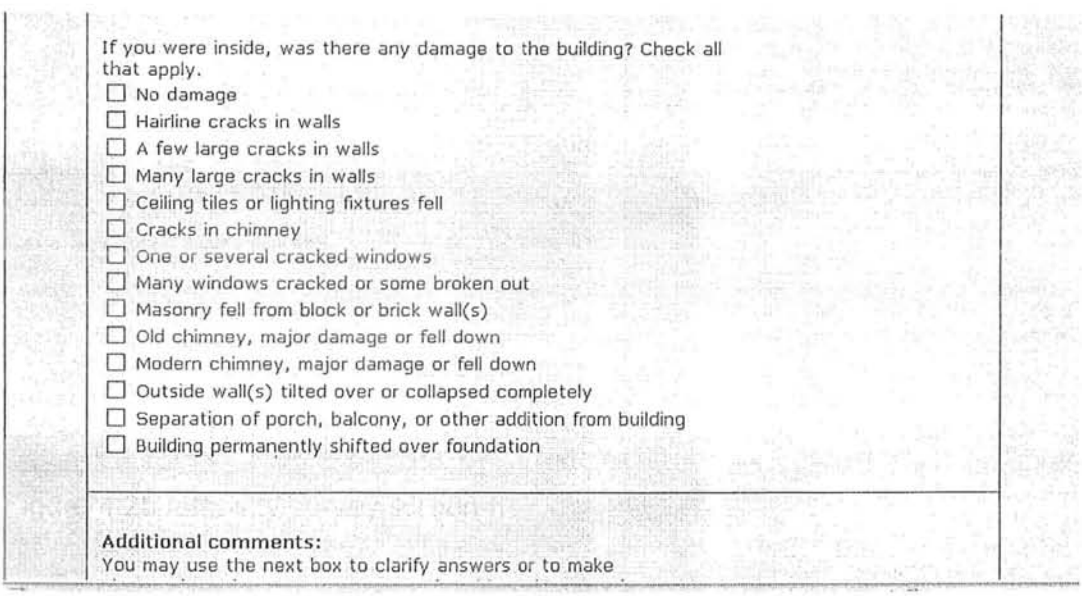
If other, please describe:

Were you asleep during the earthquake? No

Did you feel the earthquake?
(If you were asleep, did the earthquake wake you up?) ○ No ○ Yes

Did others nearby feel the earthquake?
No answer/Don't know/Nobody else nearby

Figure 4.2b Intensity survey screen-II



If you were inside, was there any damage to the building? Check all that apply.

- ☐ No damage
- ☐ Hairline cracks in walls
- ☐ A few large cracks in walls
- ☐ Many large cracks in walls
- ☐ Ceiling tiles or lighting fixtures fell
- ☐ Cracks in chimney
- ☐ One or several cracked windows
- ☐ Many windows cracked or some broken out
- ☐ Masonry fell from block or brick wall(s)
- ☐ Old chimney, major damage or fell down
- ☐ Modern chimney, major damage or fell down
- ☐ Outside wall(s) tilted over or collapsed completely
- ☐ Separation of porch, balcony, or other addition from building
- ☐ Building permanently shifted over foundation

Additional comments:
You may use the next box to clarify answers or to make

Figure 4.2c Intensity survey screen-III

CHAPTER NO 5

RESULTS AND CONCLUSIONS

Chapter No 5

RESULTS AND CONCLUSIONS

5.1. INTRODUCTION

As described in chapter; one that the main objective of the present work is the development of software in MATLAB for the Focal Mechanism Solution (FMS). Along with this major aim there were some minor but important work relevant to the seismological characteristics of October 8, 2005 Muzaffarabad earthquake has also been carried out. This includes the seismicity pattern on the basis of aftershock distribution (epicentral location, magnitude, depth) and the detailed intensity survey of the affected area.

In the present chapter, all these main and minor objectives of the present work have been discussed. Further the conclusions drawn from the present work and the future recommendations, if any, are also highlighted. The work is discussed in the following manner.

- Seismicity pattern
- Software Development
- Detailed Intensity Analysis

5.2. SEISMCIITY PATTERN

Seismicity of the area surrounding the Muzaffarabad area (the main event of October 8, 2005 earthquake) has been interpreted in terms of three different ways i.e. the epicentral location, magnitude and depth. For this purpose three different maps characterizing these parameters have been prepared (Figures 5.1, 5.2 and 5.3). Along with these three maps, the bar graph showing the seismicity pattern in terms of depth, magnitude, magnitude and depth, and frequency of earthquakes with respect to magnitude. It should be noted that the data used for these maps and graphs preparation consists of the data of international network (USGS only) and it ranges for the period of October 8th 2005 to March 1st 2006. A total of 628 aftershock data has been utilized for the purpose. All these maps and graphs are discussed below.

5.2.1 Seismicity Pattern on the Basis of Epicentral Location

Figure 5.1 show the map prepared using the epicentral location of the aftershocks. This figure clearly indicates that the majority of the aftershocks are moving away from the main event location i.e. in the NW-SE direction. There are few which are also present within the core of the Hazara Kashmir Syntaxis (HKS), a well-known tectonic feature in the area. Main event location is quite close to MBT. Overall the epicentral distribution is following a distinct surface pattern of NW-SE direction.

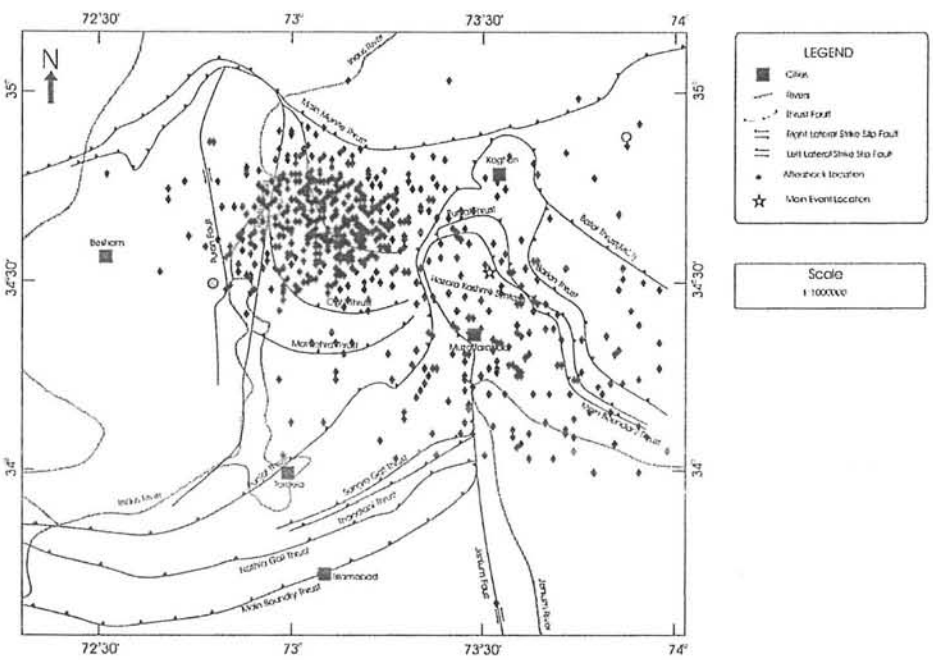


Figure 5.1. Seismicity Map of the area in terms of epicentral distribution

5.2.2 Seismicity Pattern on the Basis of Magnitude

Figure 5.2a. Show the seismicity pattern in terms of magnitude (body wave only). A very interesting picture in terms of magnitude appears. Majority of aftershocks (roughly 80%) are of the range of 3-5 mb followed by the earthquakes with magnitude 5 (Figure 5.2b). There is only one event with magnitude 6. The major concentration of these 3-5 mb events is along the nappe zone of Kazmi and Jan, 1997, known as the Hazara nappe zone and Banna nappe zone. These nappe zones are surrounded by the surface faults like Thakot

Fault in the west, Oghi and Mansehra Thrusts in the south and MMT in the north.

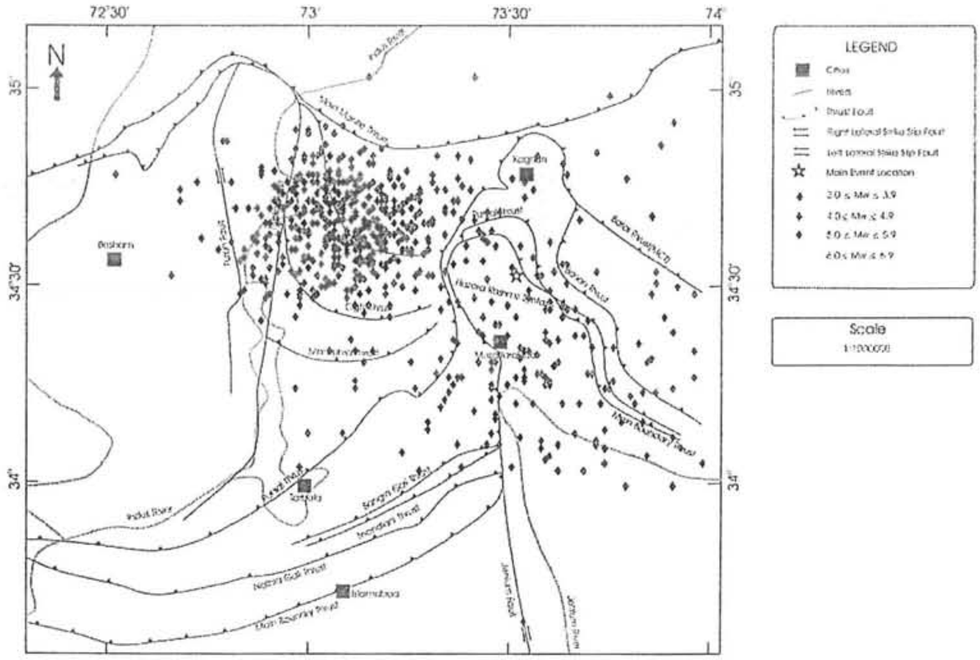


Figure 5.2a. Seismicity of the area with respect to magnitude

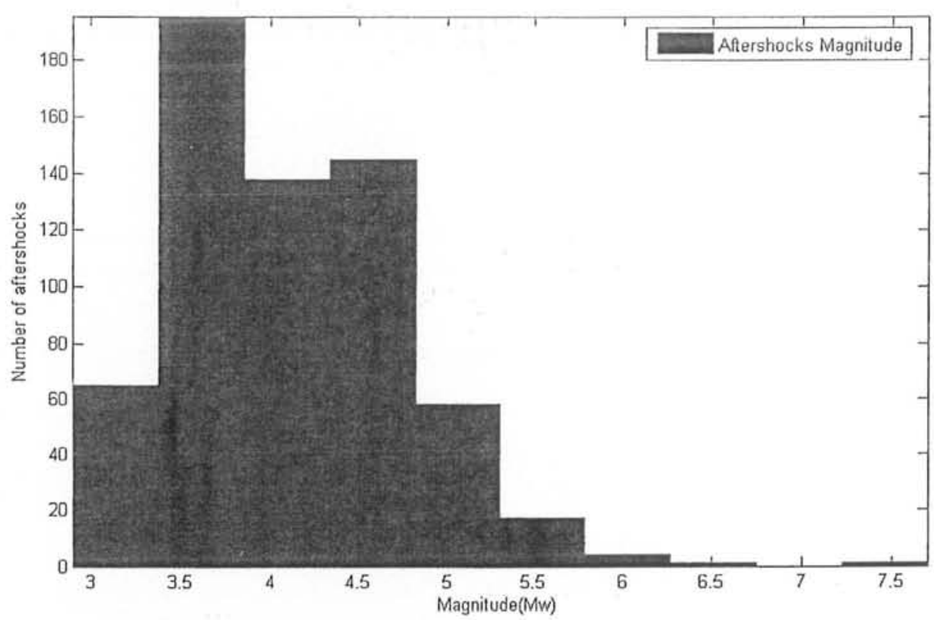


Figure 5.2b. Magnitude Bar graph of the aftershocks

Balakot Shear zone is on the east. Overall this is very active zone of collision. The pattern in terms of magnitude is therefore more prominent in terms of 3-5mb with the concentration in these nappe zones. Hazara Kashmir Syntaxis (HKS) shows less activity during this period of October 8th 2005 to March 1st 2006.

5.2.3 Seismicity Pattern on the Basis of Depth

Seismicity pattern in terms of the depth can also be interpreted in terms of depth of aftershocks (Figure 5.3a). This figure and the bar graph (Figure 5.3b) is the clear indicative of the fact that majority of the aftershocks are of the depth range of 5-10 km (green color dots). There is quite a few numbers of earthquakes having depth greater than 10 km (black dots). Seeber et al., 1979, as mentioned in chapter 2 has indicated the presence of a NW-SE directed a wedge shape thrust zone at the depth of 10-12 km, known as IKSZ. Seismicity pattern in terms of depth and concentration of earthquakes having the depth of 10 km is the clear indication of the presence of the IKSZ. However more data is required to confirm this fact.

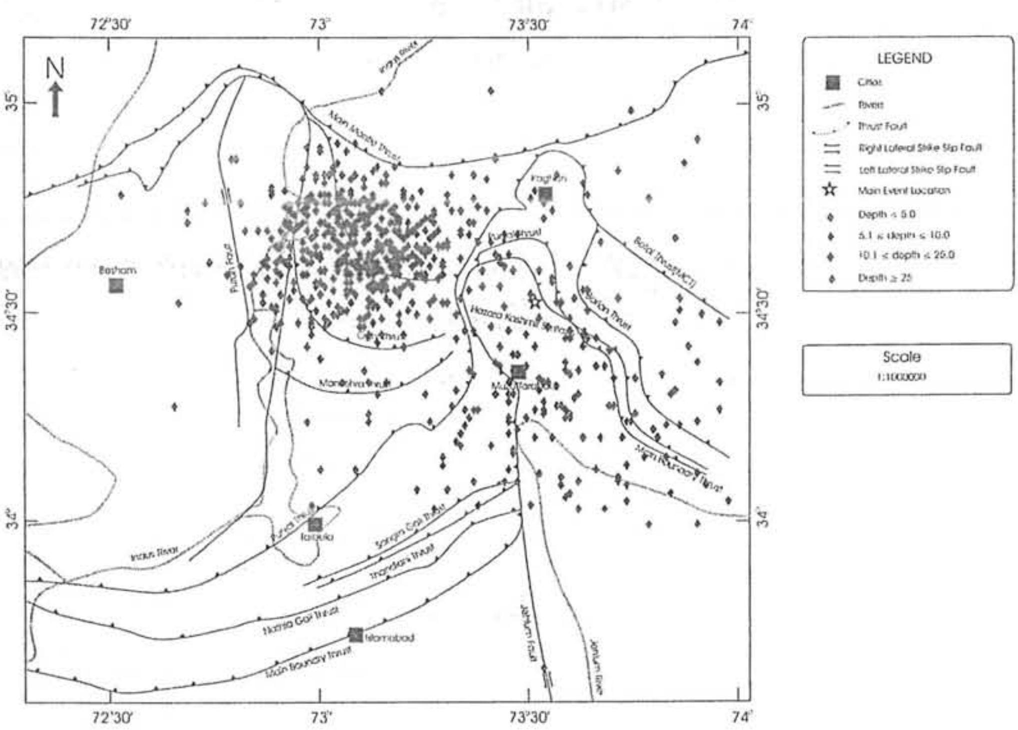


Figure 5.3a. Seismicity pattern in terms of depth

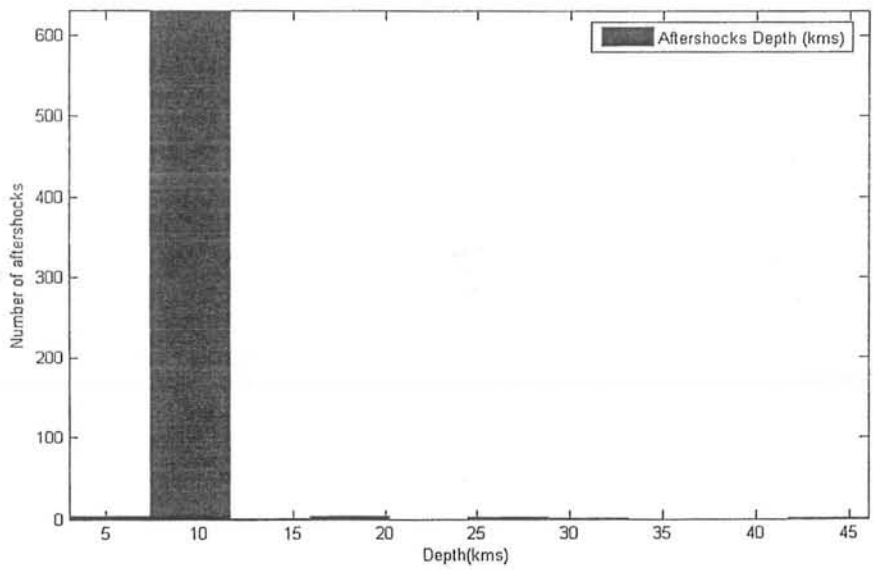


Figure 5.3b. Depth Bar graph of the aftershocks

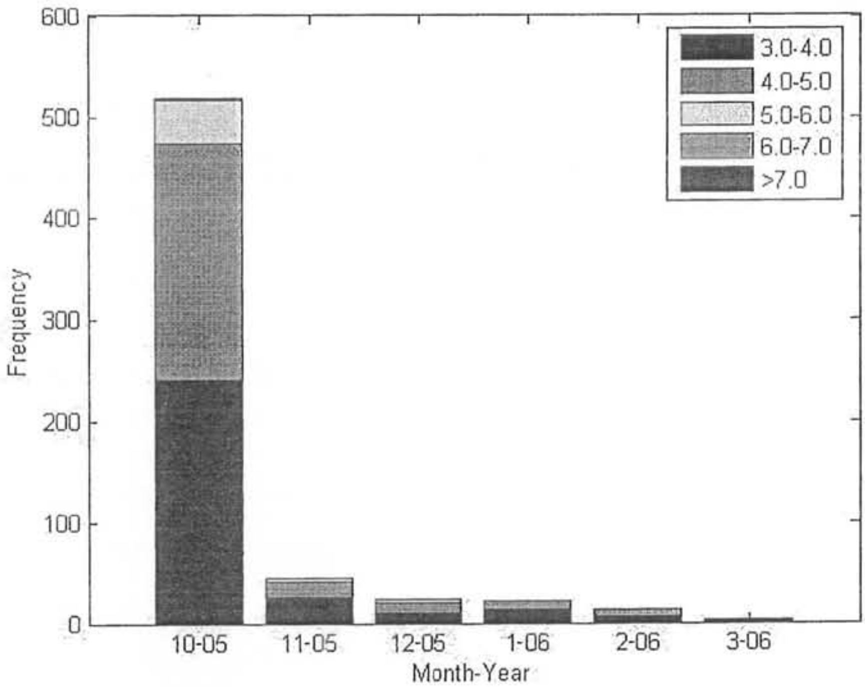


Figure 5.4. Month wise bar graph of the aftershocks with respect to magnitude

5.2.4 Seismicity Pattern on the Basis of Frequency of Earthquakes

A graph (Figure 5.4) has been prepared for the frequency of occurrences of earthquakes for the period ranging from October 8th 2005 to March 1st 2006. This graph shows that the frequency of occurrence of earthquakes is decreasing with the passage of time. Along with the frequency the magnitude of the aftershocks is also decreasing notably.

5.2.5 Seismicity Pattern on the Basis of Correlation between magnitude and depth of aftershocks

In order to have clearer picture of the area from seismological point of view, a scatter diagram was constructed (Figure 5.5). This scatter diagram shows the correlation between the magnitude and depth of aftershocks. This scatter diagram shows that the aftershocks with the magnitude range of 3-6 mb are occurring at the depth of 10 km mostly, which shows that the seismicity is prevailing at this depth level. This can be considered as another indicative of the presence/activation of IKSZ.

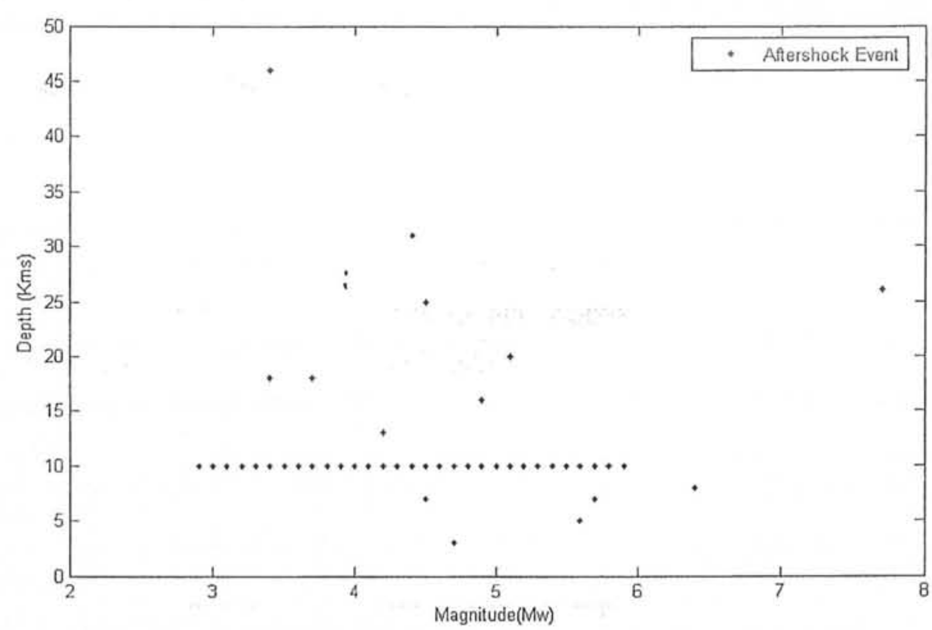


Figure 5.5. Scatter Plot of the magnitude and depth of the aftershocks

5.3. SOFTWARE DEVELOPMENT

The foremost objective of the present work is the development of software that can be served for

- The construction of beach ball diagram (use in FMS)
- The generation of a website containing some information regarding the field of seismology including the intensity questionnaire (arbitrarily named as Geoquaidians Earthquake Information Centre)

The explanation is given below.

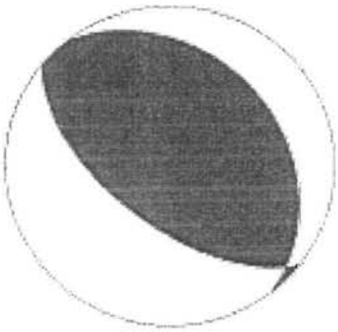
5.3.1 Construction of Beach Ball Calculator (BBC) use in FMS

The detailed procedure adopted for the generation of Beach Ball Calculator i.e. BBC has already been described in detail in the previous chapter. In this section only brief information regarding the comparison with the FMS carried out by USGS for the October 8, 2005 Muzaffarabad earthquake is provided.

The main advantage of this software is that it is open for comparison to any other already available software in market. The comparison is beneficial in a sense that one can check the accuracy/consistency involved in the construction of beach ball diagrams.

Other important thing is that there are number of commercial/non-commercial softwares available in the market that can be used for the generation of FMS. But either they are too costly or difficult to handle. Thus presently developed software can be used easily, especially for teaching and research purposes.

In the present work the FMS carried out by BBC for October 8,2005 Muzaffarabad earthquake and also by USGS has been compared(Figure 5.6 a,b). This comparison has been done in order to check the differences between the two. This comparison can be used to modify the BBC for future versions. It should be noted that this is the preliminary version of BBC, which can be used as the trial basis and will be modified more in future.

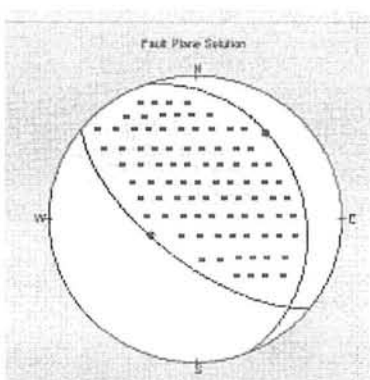


Nodal Plane 1
Strike: 121.4
Dip: 60.6

Nodal Plane 2
Strike: 322.3
Dip: 31.0

Depth:26 km

Figure 5.6a. Fault Plane Solution By USGS(Source www.usgs.gov)



Nodal Plane 1
Strike: 122
Dip: 62

Nodal Plane 1
Strike: 325
Dip: 29

Consistent Data: 6

Figure 5.6b. Fault Plane Solution By BBC ver 1.0

The above figures show that both solutions are nearly same. There is a slight different between both results which is due to the lake of data availability if the data is more approximately greater than 15 then the results will be better.

5.3.2 Construction of web site (Geoquaidians Earthquake Information Centre GEIC)

A web portal has been developed, which contains the following information. Which is the first ever Pakistan based website about earthquake.

- Earth Quake Center
- Seismology
- Intensity Survey
- Scientific Data
- Software

By taking the input about the scientific data it keeps the register user up to data with the help of sending them an email or by sms or by both as selected by the users. This feature makes it unique even sms facility is not available in USGS website.

5.4 INTENSITY ANALYSIS AND ISOSEISMAL MAP

Along with the seismicity pattern based upon magnitude, depth etc, and the intensity is considered to be another important parameter used for the description of the seismicity of an area. It is an observational parameter and various workers for the intensity have developed various scales. One of them is the Modified Merculli Scale (MMI). This is a very simple scale and can be employed anywhere. In the present work, using the information from the print and electronic media, an intensity map (Figure. 5.6) has been prepared in MMI scale. A total of 31 sites have been considered for the generation of the intensity isoseismal map.

From this map it is quite clear that the maximum intensity of **XI** has been observed near the main epicentral location, whereas when we move away from the main event location it is decreasing. The lowest intensity of **I** has been obtained for the site of Gwadar.

This intensity map can be improved further if the observations from the field studies are incorporated also.

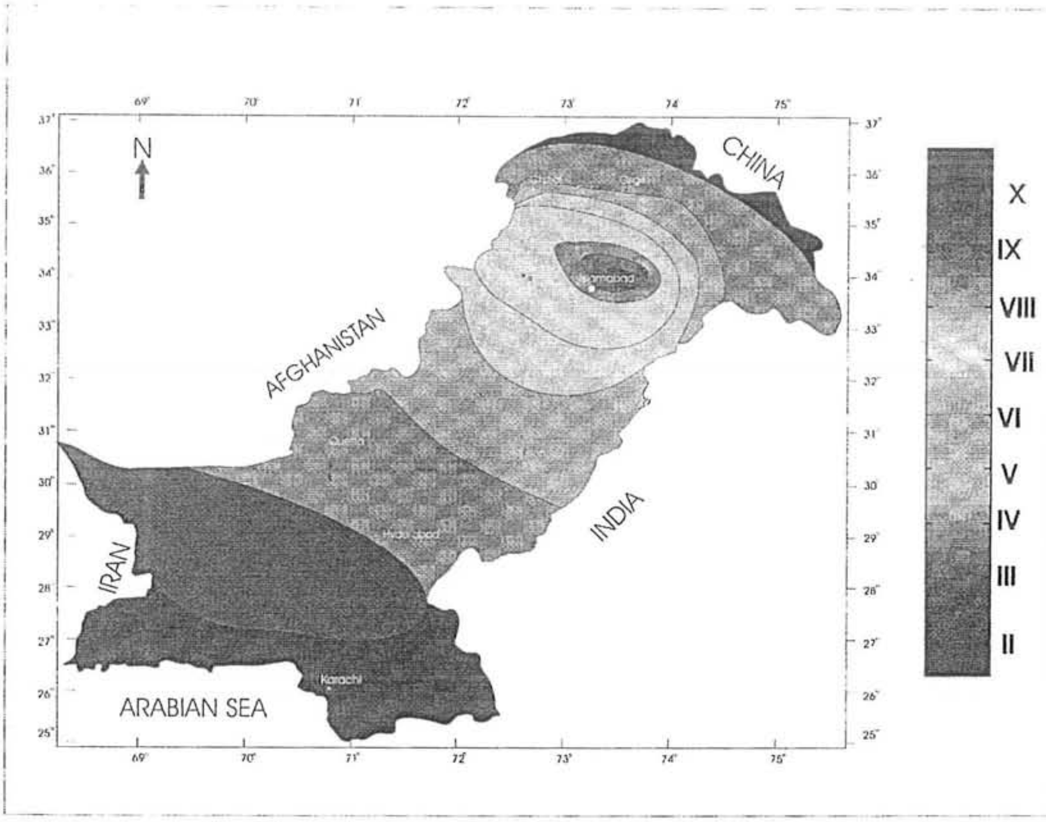


Figure 5.7 Intensity map of the October 8, 2005 Muzaffarabad Earthquake

5.5. CONCLUSIONS

- The most important conclusion drawn from the study is that seismically the area is very active.
- On the basis of the magnitude, the area is active up to magnitude range of 3-5 mb.
- On the basis of the depth, the area is active up to depth of 10-12 km.
- It is also noted that the frequency magnitude content of the aftershocks is decreasing with the passage of time.
- Scatter plot of magnitude and depth shows that the events of 3-5mb are concentrated around the depth of 10km.
- Above conclusions indicates the presence of Indus Kohistan Seismic Zone.

- Beach Ball Calculator ver 1.0 is a preliminary version and can be used for Focal Mechanism Studies (FMS).
- BBC is easy to handle with the unique opportunity of being programmable. Earlier software developed does not provide this functionality.
- The compared results with the USGS shows that BBC and USGS beach balls are approximately same with slight difference because of lake of availability of data.
- Web site developed is the first Pakistan based website which contains the information about the earthquake studies especially intensity data acquisition in present work.
- Intensity map prepared shows elliptical behavior as in the case of bigger events. Maximum intensity XI was observed near the epicenter where all the things got destroyed and minimum i.e. I in southern parts of Pakistan.
- As mentioned earlier that the present work has been done only on the data available from USGS. A better work can be done if the data is available from international centers and from some local centers.
- The second important factor is time factor. Time was very short because in earthquake studies data gathering is very much important. This is the main reason for only using the USGS data.

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