

**SITE CLASSIFICATION OF F-9 PARK AND COMSATS
UNIVERSITY CRICKET GROUND BY CALCULATING
SHEAR WAVE VELOCITY USING MASW AND MAM
SURVEY**



BY

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**DEPARTMENT OF EARTH AND ENVIRONMENTAL
SCIENCES
BAHRIA UNIVERSITY, ISLAMABAD**

2023

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A thesis submitted to Bahria University, Islamabad in partial fulfillment of
the requirement for the degree of BS in Geophysics

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ABBREVIATIONS

MAM	Multichannel Analysis of Micro Tremors
MASW	Multichannel Analysis of Surface Waves
V _s 30	Shear wave velocity of first 30 meters
MBT	Main Boundary Thrust
NEHRP	National Earthquake Hazards Reduction Program
Ma	Million Years
SPPZ	Southern Potwar Platform Zone
NPDZ	Northern Potwar Deformed Zone
SAC	Seismic Analysis Code
SEG	Society of Exploration Geophysicists
ASCII	American Standard Code for Information Interchange
JPEG	Joint Photographic Experts Group

ABSTRACT

Seismic hazards and their damages have been substantially serious on unconsolidated or soft rocks then on rock sites even if they are very close to Earthquake epicenter. To find or characterize shallow subsurface soil by usage of shear wave velocity is important method in practice. Passive techniques based on recordings of ambient noise are very appealing instruments for estimating the velocity and thickness of soil layers. These methods are in fact very cheap and noninvasive exploration alternatives. For this thesis, methods of MAM (Multi array analysis of micro tremor) and MASW (Multi channel analysis of surface waves) were utilized to calculate shear wave velocity of F9 Park Islamabad. Three MASW and one MAM survey was conducted. Total of 72 geophones, 3 channels were used. Distance between two geophones were kept at 5 meter. After acquiring data, it was processed using Geopsy module. Dispersion curve was developed using F-K analysis and then inverted to calculate shear wave velocity. Velocity of shear waves is in between $277\text{-}356\text{ ms}^{-1}$. This range of velocity falls in D ground type according to NEHRP codes. This indicate in subsurface there is stiff soil or medium or dense deposits of sand. They can increase or amplify ground shaking during seismic hazards. Vs 30 curve of F9 Park was developed. Contour map of Islamabad was developed using data of F9 Park, Kachnar Park, COMSATS University and Jasmine Garden. From these study engineers can create building code based on shear wave velocity value and NEHRP code and can develop buildings, projects and structure based on these codes that can prevent any seismic hazard and can save many lives and can prevent financial losses.

ACKNOWLEDGMENT

We would like to express our deepest gratitude to our thesis supervisor Ms. Urooj Shakir, Senior Assistant Professor, Department of Earth and Environmental Sciences, Bahria University Islamabad for their valuable guidance, support, and encouragement throughout this project. Their expertise, enthusiasm and commitment to our success were crucial in assisting us in overcoming the numerous obstacles that we encountered.

Additionally, we would like to thank Mr. Shahid, Senior Geophysicist in Seismology section at PMDC Islamabad. He provided us with thorough supervision and resources required for our research, for which we are eternally grateful.

We are also thankful to Prof. Dr. Said Akbar Khan, Head of Department, Earth and Environmental Sciences, Bahria University Islamabad. Furthermore, we want to express our gratitude to our family and friends who have continuously provided us with love, encouragement, and inspiration during our academic career. Through the numerous ups and downs of this journey, we have been able to endure because to their constant support and understanding.

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Chapter 1

Introduction

1.1 General introduction

Active seismic zones are regions where there is movement of tectonic plates and are known to generate seismic activity. The stress that the moving tectonic plates impose on the Earth crust is released through seismic activity. Active seismic zones can have a big impact on a region. Buildings constructed there are more vulnerable to seismic dangers which include ground shaking, liquefaction, landslides, and fault rupture. These dangers have the potential to seriously impact buildings, infrastructure, and the environment, resulting in casualties and lost revenue (Kramer, 1996).

Seismic hazards and their damages have been substantially serious on unconsolidated or soft rocks than on rock sites even if they are very close to Earthquake epicenter. So the study of relation between sedimentary structures and basement rock have gained more attention and focus since past decade or so (Zor *et al.*, 2010). The geotechnical characterization for assessment of seismic hazard of soil is important task. Passive techniques based on recordings of ambient noise are very appealing instruments for estimating the velocity and thickness of soil layers. These methods are in fact very cheap and noninvasive exploration alternatives (Di Giulio *et al.*, 2006).

It is vital to assess the geotechnical features of the site in order to reduce the seismic risk associated with active seismic zones. Geophysical techniques like the multichannel analysis of surface waves (MASW) and the multichannel analysis of micro tremors (MAM) can be used to conduct site characterization surveys that can reveal important details about the sites subsurface structure, including the characteristics of the soil and rocks as well as the seismic velocity profile. This data can be used to assess the seismic risk at the location and construct secure buildings and infrastructure. MAM survey has penetration depth of about 100 meters, while MASW has penetration depth of ten of meters. Frequency range of MAM survey is 0.5-20 Hz, while MASW has 4-40 Hz range. (Subramaniam *et al.*, 2020).

The shear wave velocity of the soil or rock has an impact on how quickly surface waves travel through the subsurface as measured by the MASW method. The method is based on surface wave dispersion, in which wave velocity varies with frequency. The shear wave velocity profile can be calculated with depth by examining the surface waves' dispersion properties. MASW surveys can be used to define vast areas because they are quick and affordable. The ambient noise produced by natural sources including traffic, wind, and ocean waves is measured using MAM, a passive method. The method is based on the study of micro tremors, which are ground vibrations of small amplitude brought on by ambient noise. The frequency of the micro tremors is correlated with the soil or rock's shear wave velocity. The frequency composition of the micro tremors can be examined to estimate the depth of the shear wave velocity profile. MAM surveys can be carried out without the need for excavation and are non-invasive (Subramaniam et al., 2020).

Mostly, when doing a seismic survey and source used in survey generates compressional waves, more than two third of total seismic energy generated is transferred into Rayleigh waves, which are main components of Ground rolls. If we suppose change in vertical velocity a surface wave has a unique propagation velocity (referred to as the phase velocity, or C_f) for each frequency component (f). This different behavior results in unique wavelength (λ_f) for every frequency. We call this property Dispersion. In body wave survey ground rolls are consider as a noise, but we can use its dispersive properties to find out near surface elastic properties. By analyzing plain wave fundamental mode, we can make a profile of shear velocity (V_s). Usage of Rayleigh wave is most common way to find dispersive properties of surface waves. This analysis gives us the crucial parameter to evaluate near surface stiffness, which is an important property for many geotechnical studies (Park et al., 1999).

In ground water, engineering and environmental studies, elastic properties of near surface materials and their effect on movement of seismic waves are of main interest (Xia et al., 1999). The key to establish effective seismic-hazard mitigation techniques, such as assessment of seismic risk, preparation of emergency response, and land-use planning by taking into consideration of proposed and existing buildings, is the calculation of shear wave velocity profiles for sedimentary structures. For a thorough evaluation of seismic hazard and simulation of powerful ground motions, accurate determination of shear

velocity profiles on sedimentary structures, including the bedrock, is essential. Shallow shear velocity profiles, particularly to a depth of 30 m (V_{s30}), are necessary to assess and quantify local site conditions and effects that are used for building code (Zor et al., 2010).

1.2 Scope of work

In comparison to traditional high-resolution seismic methods, MASW is a recently created seismic technique that deals with comparatively lower frequencies and shallower study depth ranges. In a highly efficient manner, it offers shear-wave velocity (V_s) information on near-surface materials. It is becoming more and more well-liked among engineering communities due to the comparatively high value of this (V_s) information in the majority of geotechnical engineering projects as well as due to the generally straightforward in-field operation and data processing (Park et al., 2007).

Only a small number of field workers are required to complete the survey because of the system's greatly improved mobility, with one or two of them people operating the source and receivers while the other is responsible for managing data while in the field (Park et al., 2007).

The site classification survey's scope is fairly broad and incorporates a variety of various goals when employing the MASW and MAM methodologies. These techniques can be utilized in engineering applications including site selection, foundation design, and seismic hazard assessment to offer useful information on the subsurface structure of a site. Structures can be designed to be as safe and stable as possible using the knowledge gleaned from the site categorization study (Park et al., 1997)

Many research have employed site classification surveys using MASW and MAM techniques. At a site in Korea, MASW was utilized to calculate the shear wave velocity profile of the subsurface strata. They discovered that the shear wave velocity increased with depth and distinguished a number of separate soil and rock strata (Park et al., 1999).

MASW with deep boreholes had also been used to map the nuclear power plant site and for underground mine investigation in South Africa (Park, 2013).

1.3 Significance of work

There is need to establish methods and techniques and shallow mapping of subsurface and sedimentary features for earthquake hazard assessment and land use planning. For better society management and hazard assessment there is need to calculate

shear wave velocities that inflict most damage. Shallow shear velocity profiles, particularly to a depth of 30 meters (V_{s30}), are necessary to evaluate local site conditions and impacts utilized for building codes (Zor et al., 2010).

The seismic surface-wave approach known as multichannel analysis of surface waves (MASW) was created expressly for near-surface applications at depths typically less than a few tens of meters. Due to two factors, including the fact that it is simpler to use than other common seismic approaches (such as refraction, reflection, and surface-wave surveys) and provides the shear-wave velocity (VS) of ground materials, one of the most crucial geotechnical parameters in civil engineering, the technique has seen a rapid rise in use since it was first developed in the late 1990s (Park, 2013).

In site characterization, we will be utilizing Geophysical methods to develop a V_s 30 contour map of F9 Park and COMSATS University cricket ground. Since, Islamabad lies in active seismic zone and on the foothill of Margalla Mountains and reverse thrust fault known as MBT, The area is always at high risk for seismic hazard. Areas around the park have suffered damages in recent past due to seismic activities. When in such seismic hotspots, there is always danger of seismic activity and study using MASW and MAM methods will reduce the risk of any damages either financially or in terms of casualties. It will help to counter any seismic hazard and to for better planning and management of park and its surrounding areas.

The survey's findings can provide details about the soil and rock qualities, such as the shear wave velocity profile, which can be used to spot probable liquefaction or instability in the ground. The design of buildings, bridges, and other facilities inside and surrounding of the park can be improved with the use of this data.

The study can also give a baseline understanding of the park's underlying structure, which is useful for upcoming planning and development initiatives. The survey's findings can be used to pinpoint places that are favorable for particular kinds of development or those that should be avoided because of the possibility of rock or soil instability. It will give an understanding to keep the park and its surrounding safe from seismic hazards

1.4 Problem statement

In any active tectonic area, there is risk of seismic activities. Seismic waves cause damages in weak lithologies present in subsurface. This is due to response of earthquake on different sub surface lithologies. Mostly in soft rocks amplitude of seismic waves increases drastically and so does the destruction on surface of Earth. Thin alluvium causes amplification of seismic waves. (Wills et al., 2000). Earthquake in Istanbul of August 17, 1999 is a prime example. It was of magnitude 7.4. Although being 90 kilometers from the epicenter, Istanbul's Yeşilyurt area sustained heavy damage. Ground shaking was even stronger at Avcılar (20 km west of Yeşilyurt), where it led to significant damage and fatalities. (Bozdağ & Kocaoğlu, 2005).

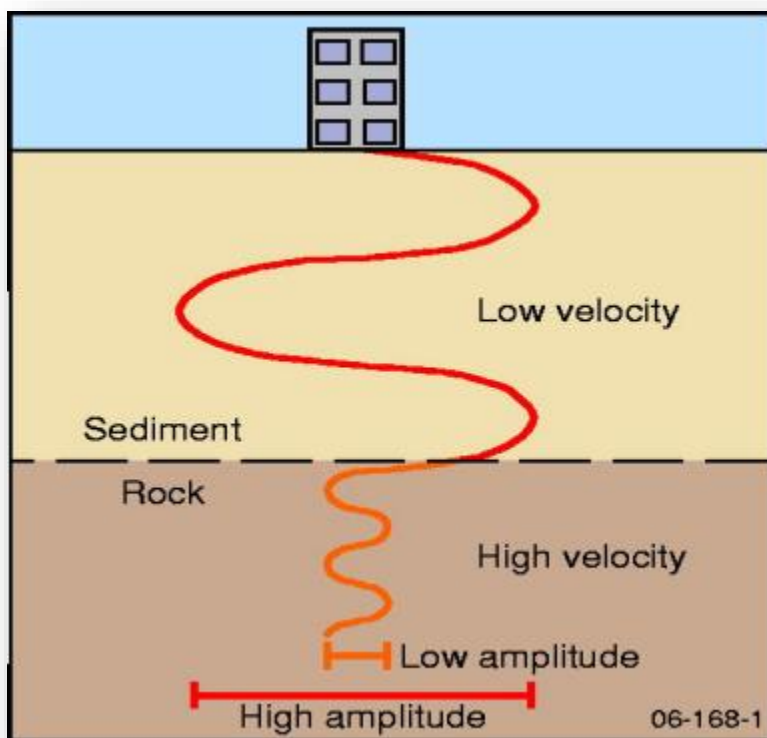


Figure 1.1. Effect of seismic waves on loose sediments where amplitude is maximum and velocity is low and on consolidated rocks where amplitude is low and velocity is high

There are many methods to identify subsurface structures and lithologies, Borehole method is used for this purpose. It identifies lithologies and on basis of that we can map

sub surface. But it has demerits. It is costly and requires labor and takes too much time. First there is sampling, then samples go to lab and then samples are analyzed making it a lengthy process taking up to months. There is a need of simpler, cheap and less time taking method that also doesn't require lot of labor force to develop a map or profile for subsurface.

MASW and MAM, they are those methods that can tick all the above boxes. They are simpler and can map subsurface. They aren't time taking processes. By using these shallow seismic methods, we can easily develop a soil profile by calculating shear wave velocity. Thus, making them useful for shallow imaging.

1.5 Objectives

- 1) Developing a dispersion curve by performing F-k analysis on data acquired on field.
- 2) Creating shear wave velocity curves by inverting all combined dispersion curves
- 3) Estimating Vs 30 value, creating soil profile by using NEHRP codes.

1.6 Location of study area

F 9 Park is located in Islamabad between residential sectors of F 8 and F 10. It is in center of city having latitude and longitude of 33.6057 and 73.1317. It was created as recreational park and to preserve green spaces in Islamabad. The second location for our survey was COMSATS University cricket ground. Temperature is usually pleasant but exceeds 35° in summers. We recorded one MAM readings and three MASW readings in park. And one MAM and MASW survey in COMSATS. Tectonically area is basically on foothills of MBT Main Boundary Thrust.

The subsurface structure of the park can be learned a lot through site categorization surveys utilizing the MASW and MAM techniques. The survey's findings can be utilized to assess the park's seismic risk and develop secure and reliable facilities and buildings. The survey's findings can be utilized to create appropriate mitigation strategies for potential risks.

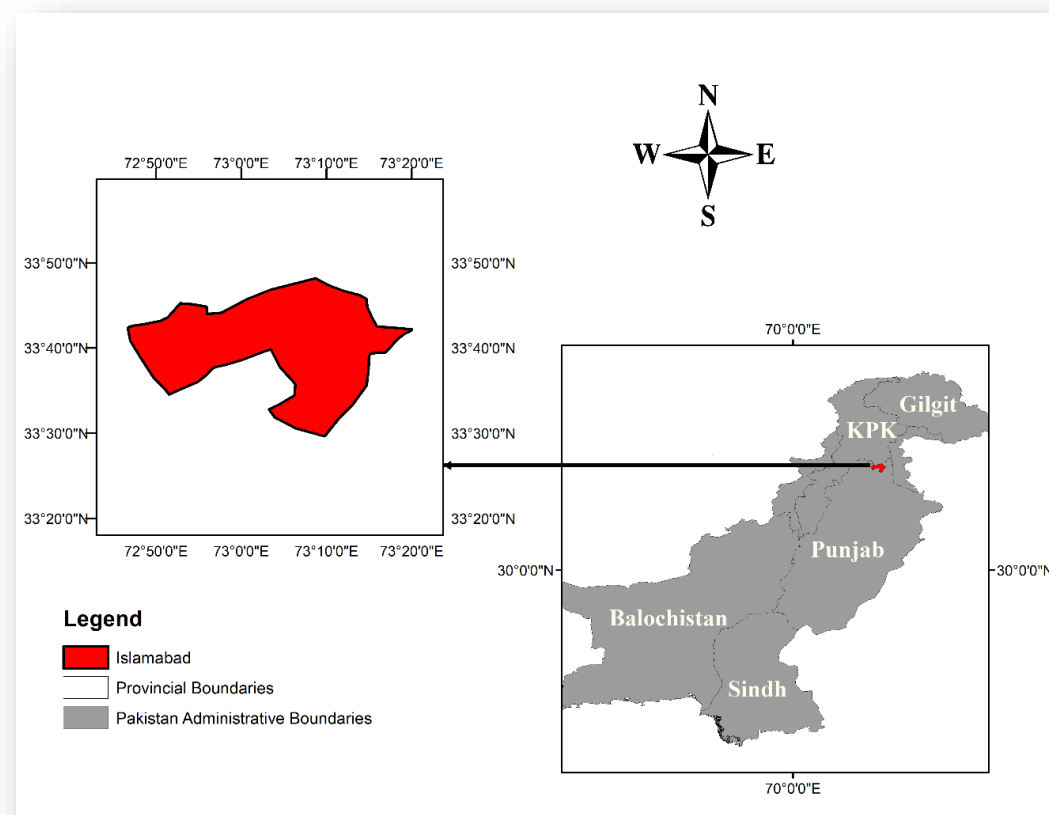


Figure 1.2. Map of Pakistan indicating our study area Islamabad which lies north of Punjab

1.7 Instruments and data set

For conducting MASW and MAM surveys, we require;

Table 1.1. Instruments used for Multichannel analysis surface waves (MASW) and Multichannel analysis of micro tremor (MAM) survey

Instruments	Software
3 Seismograph	Sysmatrack Software
72 sets of geophones (3 Array of 24 Geophone)	Geopsy software
6 Bundles of wire for connecting geophones	Surfer Software

3 laptops	
Triggering geophones	
3 Bundles of wire to connect triggering geophones	
Metal Plate	
Sledge Hammer	
3 USB cables	

1.8 Methodology

Methodology of survey starts with acquiring data in field. After acquisition of data, we process the data. We load data and then perform F-K analysis. We then make dispersion curve and invert it to make shear velocity profile.

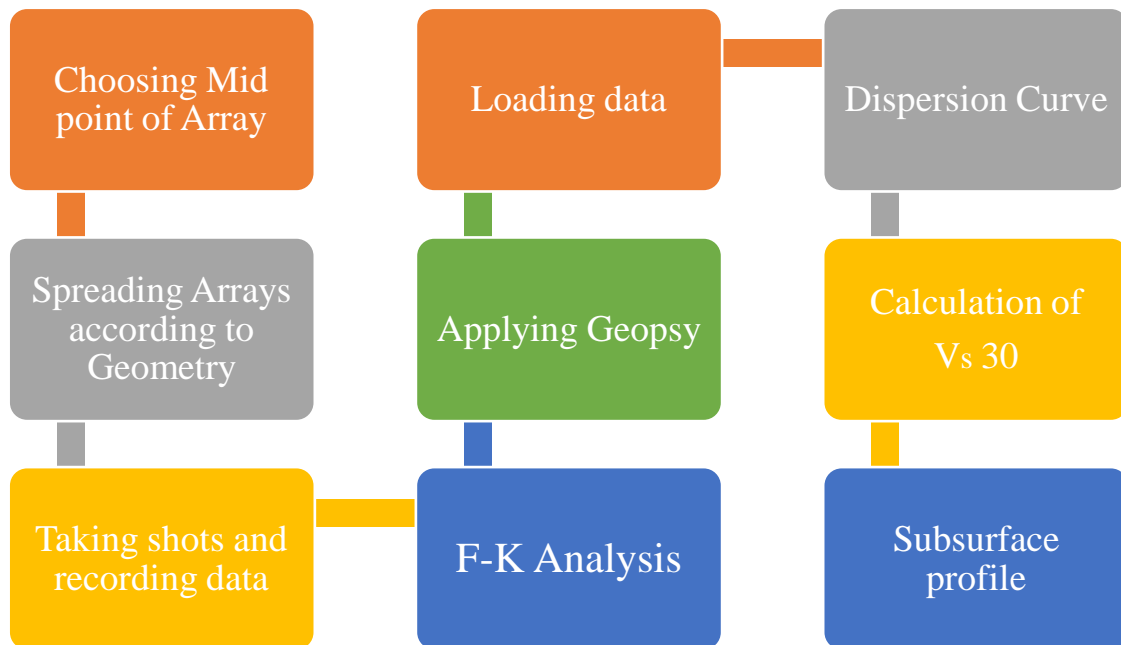


Figure 1.3. Workflow of Site Classification method using MASW and MAM survey which starts from data acquisition than data processing and finally calculating shear wave velocity and developing soil profile

Site classification method starts by selecting mid-point to spread arrays. When we established that mid-point we start to spread arrays according to our geometry, then place geophones. After placing geophones we connect seismograms with laptop and geophones. After this, we strike hammer with metal plates and record data. We take total of 15 shots for MAM and 3 shots at 4 points each for MASW. After recording data we load data in Geopsy module of Sesarray package. We first apply Geopsy and then perform F-K analysis. We develop Dispersion curve using F-K analysis. We invert V_s 30 to calculate shear velocity profile. We then use NEHRP codes to classify soil materials.

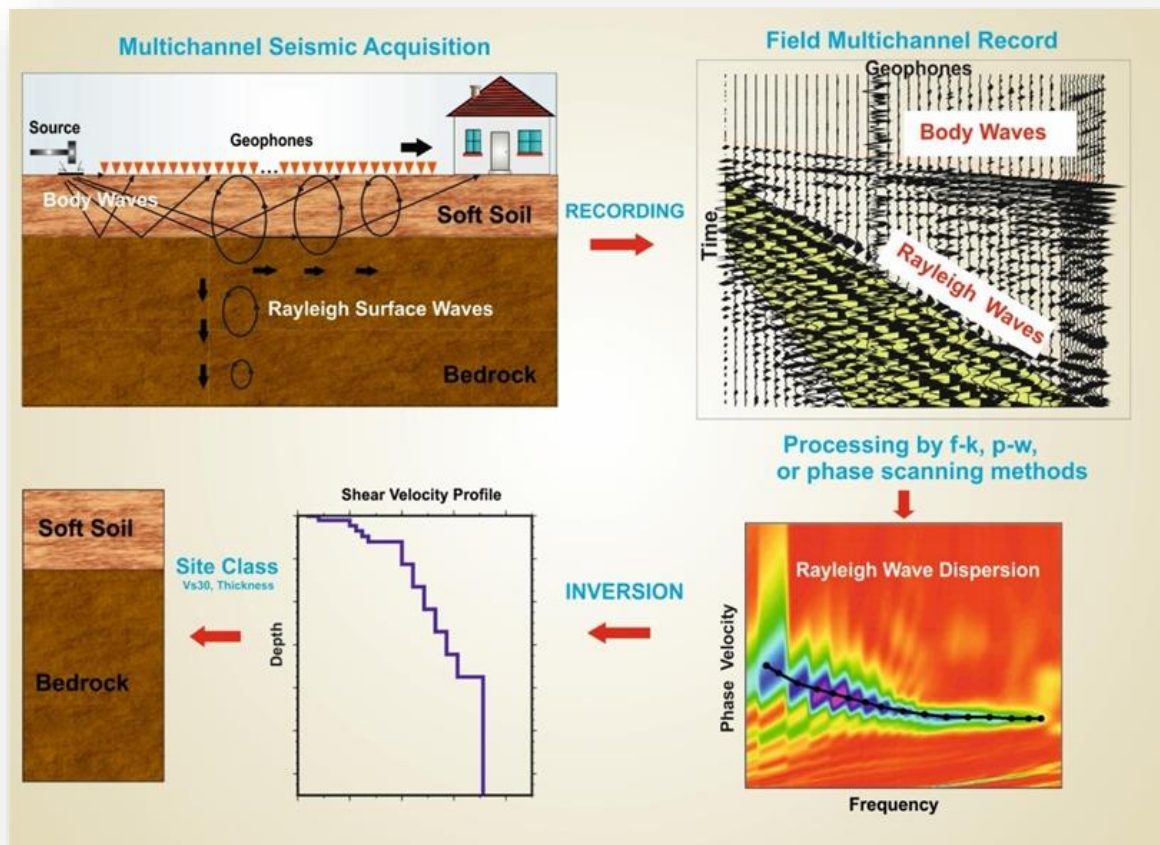


Figure 1.4. Graphical representation of MAM and MASW survey which shows acquisition of data and its recording from which dispersion curve is generated after processing and shear velocity curve is formed after process of inversion and then soil profile is developed.

Chapter 2

Geology and Stratigraphy

2.1 Introduction

Pakistan is located on the boundary between the Eurasian and Indian plates, where the Indian plate is sliding towards the north with respect to the Eurasian plate. The Himalayan mountain range and Tibetan plateau were created as a result of the collision of the Eurasian and Indian plates. The collision, which began about 55 Ma ago and is still active to this day, causes ongoing erosion, uplifting, and sediment deposition (Kazmi & Jan, 1997).

2.2 Sedimentary basins

A sedimentary basin is a low area or depression in the crust of the planet that develops as a result of plate tectonic movement and contains preserved deposits. Their sizes range from 100 meters to vast ocean basins. Sedimentary basins frequently contain hydrocarbons. The Indus basin and the Baluchistan basin are the two major sedimentary basins in Pakistan in terms of geology and origin history (Bender & Raza, 1995).

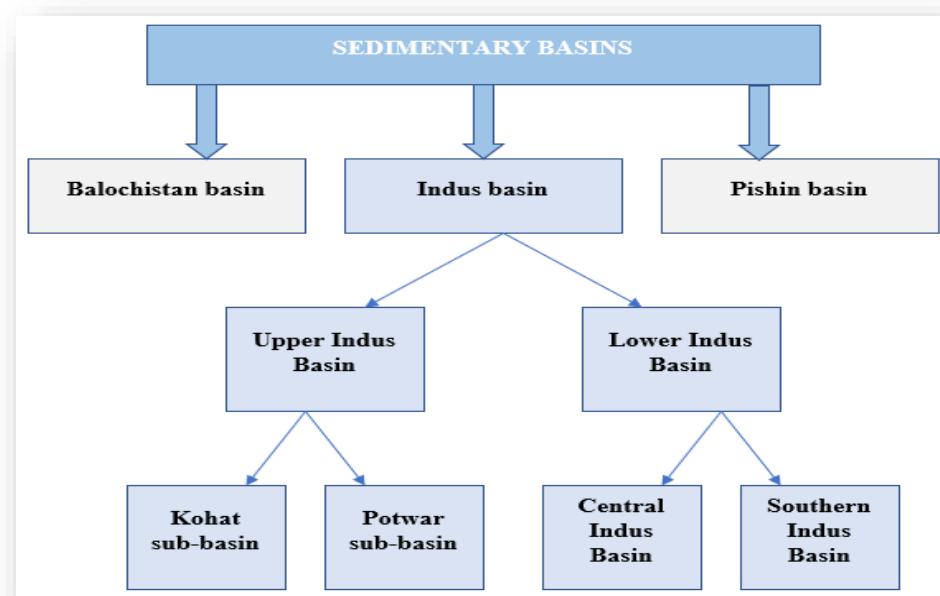


Figure 2.1. Sedimentary basins of Pakistan in which Indus basin is divided into two basins which are further sub divided into two basins and our study areas lies Potowar basin which is sub division of upper Indus basin

2.3 Upper Indus basin

The largest Pakistani basin, the Indus, stretches from eastern Pakistan to the western half of India. It has a total size of 1.12 million km², with Pakistan making up over 47% of that amount. Upper, middle, and lower Indus basins are further divided by the Sargodha and Mari-Kandhot structural highs (Kadri, 1995).

Upper Indus basin is further subdivided into Potwar and Kohat basins. The Potwar-Sub Basin, which is in Pakistan's Lesser Himalayas, contains sediments extending from the Pre-Cambrian to the Quaternary. It stretches for around 130 km in the north from the Main Boundary Thrust (MBT) to the Salt Range Thrust. There are major unconformities in the Potwar and Kohat sub-basins between the Permian and Cambrian age. The Soan Syncline structurally separates the Potwar basin into the less deformed Southern Potwar Platform Zone (SPPZ) and the more deformed Northern Potwar Deformed Zone (NPDZ) (Abid et al., 2019). Islamabad lies in Northern Potwar Deformed zone. It is at south or on foothill of Thrust fault known as MBT Main boundary thrust. The area of Islamabad is nearly about 906.50 square kilometers (Kadri, 1995).

2.4 Geology and stratigraphy of Islamabad

The convergence of the Eurasian Plate tectonics with the Pakistan-India Plate is the main factor influencing Islamabad's geology. Three structural zones can be identified in the region:

- 1) Jurassic through Eocene limestone and shale are folded in a complicated manner in the Northern Margalla Hills. Major topographic barriers have been created by the uplifts.
- 2) Sandstone and shale from the Rawalpindi group underlie a southward-sloping piedmont that lies south of mountains.
- 3) Soan River flows along the Soan syncline at the southernmost portion.

The plains and mountains that make up the geography of research area have a combined elevation difference of more than 1,175 m. Each of the three major physiographic zones tends east-northeast. The northern area of the region may contain a portion of the lower and outer Himalayas, which also contain the Hazara and Kala Chitta

Mountains. These mountains are known as the Margalla Hills. The Margalla hills, which reach a height of 1,600 m not far from Islamabad, are composed of limestone and shale ridges that age from the Jurassic through the Eocene and are intricately crushed, folded, and largely overturned. A south-dipping piedmont bench made primarily of folded sandstone and shale from the Miocene Rawalpindi group is found south of the Margalla hills. Sandstone ridges that have been buried are typically covered with interbedded sand and limestone gravel that can reach 200 metres in some places (Warwick, 2007).

The sedimentary rocks that are exposed in the Islamabad record 150 million years (Middle Jurassic to Quaternary) of mild geologic fluctuations and slow deposition during the Indian tectonic plates drift northward across the Indian Ocean. Since 1.9 Ma, there has been intense tectonic activity, extensive erosion, and localized deposition of coarse clastic continental sediment. The 150 to 24 Ma period was characterized by slow, primarily marine deposition and little tectonic activity. The 24 to 1.9 Ma period was marked by rapid, voluminous, continental deposition and slow subsidence (Williams et al., 1999).

The oldest formation exposed is of Jurassic age Samana Suk formation. Just roughly 675 m of mostly marine sedimentary rocks from the Samana Suk Formation (Middle Jurassic) to the start of the Murree Formation's deposition (lower Miocene) are preserved, although more than 7,572 m of continental sedimentary rock from the last 20 million years is preserved. Since last 1.5 years, the only sediments left are thin, discontinuous masses of alluvium and Aeolian silt because erosion has outpaced deposition during the structural deformation (Sheikh et al. 2008).

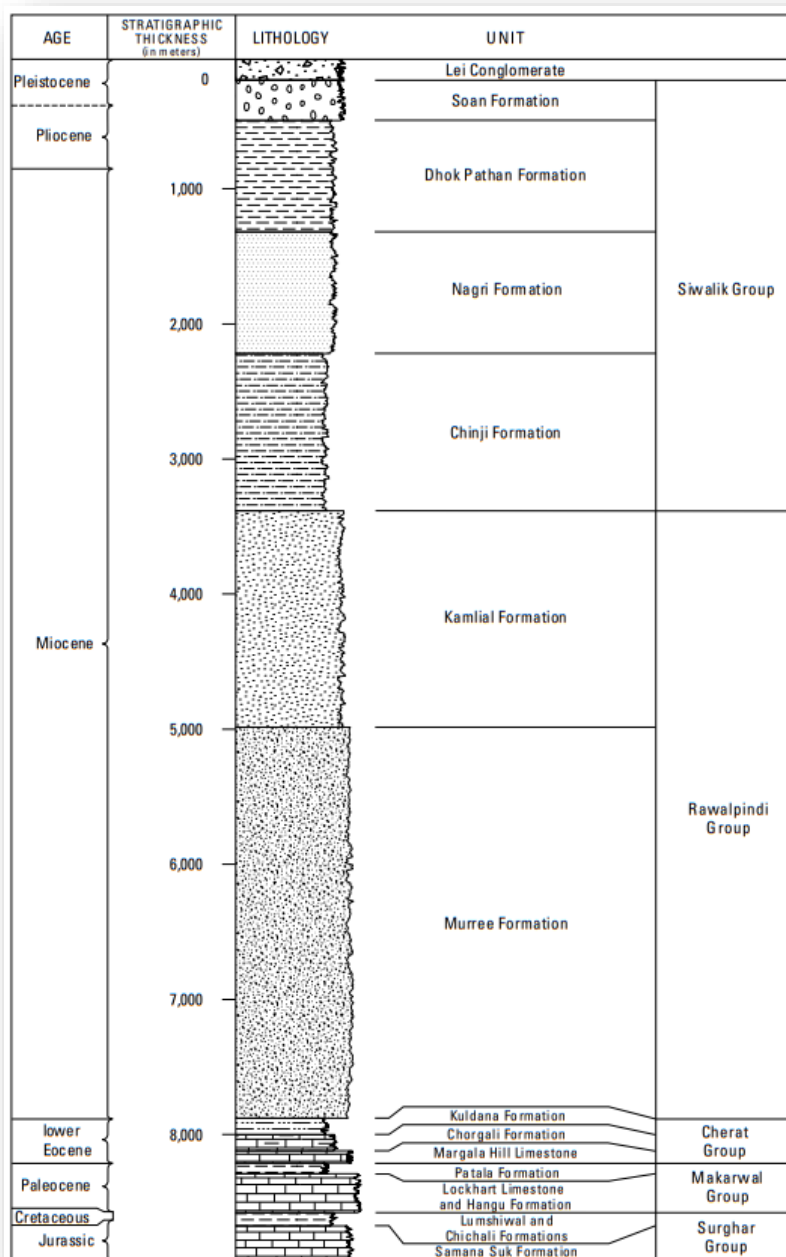


Figure 2.2. Stratigraphy of Potowar basin from Jurassic to Pleistocene age whereas in our study area Islamabad mostly Rawalpindi group is exposed

Chapter 3

Seismic Acquisition

3.1 Introduction

Geophysics is the science that studies the Earth by using the laws of physics. Geophysical research into the Earth's interior involve measurements made at or near the Earth's surface that are influenced by the internal distribution of physical properties. Geophysical methods can be used for a wide range of inquiries by operating at various scales, from studies of the entire Earth to exploration of a specific area of the upper crust for engineering or other objectives. Geophysical exploration methods, also known as geophysical surveying, use measurements made in geographically constrained locations to ascertain the distributions of physical attributes at depths that correspond to the regional underlying geology. Of course, drilling boreholes is another option for examining subsurface geology, but these are expensive and only provide data at specific areas. Geophysical surveying offers a reasonably quick and affordable method of obtaining widely dispersed information about subsurface geology, but occasionally being susceptible to significant ambiguities or uncertainties of interpretation. The seismic methods are able to identify and define regional features of possible importance in the search for subsurface resources that no feasible drilling program could find. Drilling is still necessary, but with good application, geophysical surveying can optimize exploration operations by increasing the rate of ground covering and reducing the necessity for drilling (Rice et al., 2013)

Active methods are those which use a source like sledge hammer to generate surface waves. They have high frequency and less depth up to few meters. Passive methods are those in which through cultural noise like traffic noise surface waves are produced. They have low frequency and have high depth going up to few hundred.

MASW and MAM techniques are form of shallow seismic survey where we have utilized hammer and metal plates as a source. After acquiring data, we utilize Geopsy module to process data and develop dispersion curve. By using dispersion curve, we calculate shear wave velocity and develop soil profile (Park et al., 2007).

3.2 Selection of site

A crucial stage in the entire survey is choosing a suitable location for a MASW and MAM survey. The site must be accurate in representing the region of interest and free from any barriers or interference that might hinder the collection of data. The length of one complete array comprising of 24 geophones that are placed in single straight line is 120 meter. So, the ideal site must be at least 120 meter long and wide. We selected two places to carry out survey F-9 Park and COMSATS University cricket ground.

3.3 F-9 Park

F-9 Park in Islamabad was chosen as the study site for our thesis in order to carry out the MASW and MAM survey. F-9 Park is situated right in the middle of the city. The park, which has an area of around 759 acres. The park is located on a plot of ground that is mostly level, and there is absence of any obstructions that can cause hindrances while placing geophones and spreading arrays making it an ideal place for our survey.

In F-9 Park, we conducted 3 MASW surveys and 1 MAM survey.

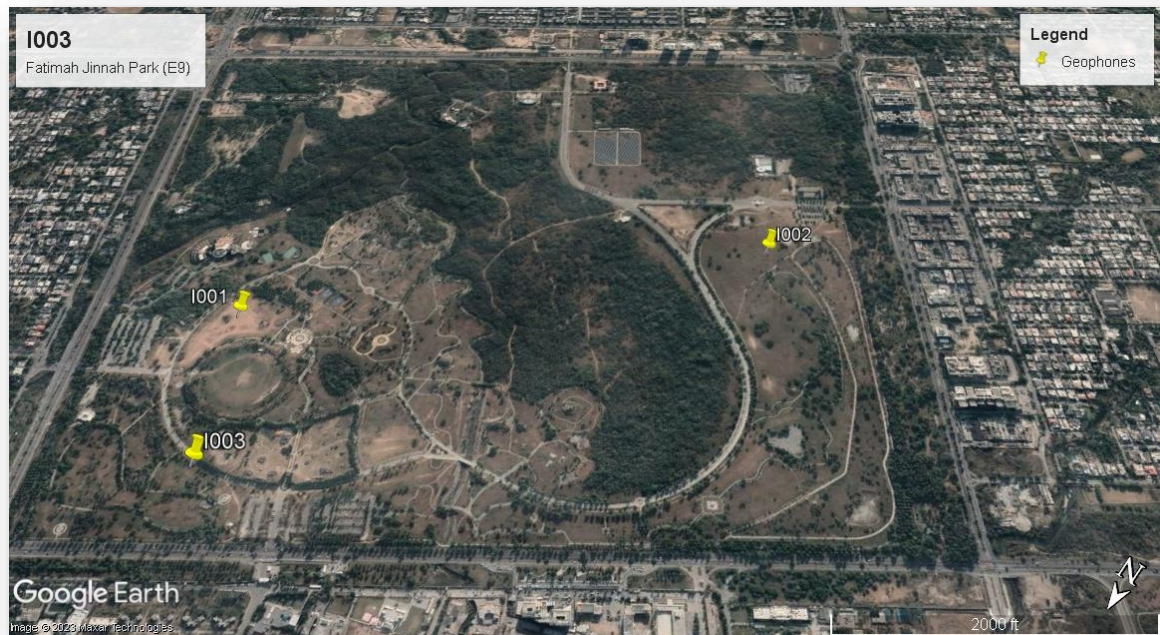


Figure 3.1. Aerial view of our study area F-9 Park, where we performed one MAM and 3 MASW surveys respectively in three location



Figure 3.2. Aerial view of our study area F-9 Park, showing locations of our survey points where we have performed MAM and MASW surveys.

Table 3.1. Locations of survey in which one MAM and MASW survey was performed at site one and other two MASW survey were performed at site two and three respectively

Site	Survey
Site 1	One MAM and one MASW survey
Site 2	One MASW survey
Site 3	One MASW survey

3.4 Instruments

For data acquisition we used 3 seismographs of SysmaTrack with 24 bit integrated battery. It can be expandable up to 24 channels.



Figure 3.3. Setting up instruments in field in which two seismographs have been connected with two channels while triggering geophone is been connected with seismogram

Seismographs are equipped with 24 bit resolution acquisition board and is available in 12 channels version expandable to 24 channels. It has 2 poles of each 12 channel and 12 volt battery and a USB interface to connect it with notebook or laptop. It stores recorded files in connected Laptop in Seg-2 format. To connect with seismograph, we use 3 Dell laptops having 4 GB of RAM Intel Core i5 processor 11th Generation. To manage Seismographs SysmaTrack software was used. It was installed in all 3 laptops. We also had 2 back up laptops just as a precaution. We also used total of 6 strings meaning 72 Geophones in total. Geophones have frequency range of 4.5-40 Hz and 3 triggering geophones as well of same frequency. We used metal plate and hammer as a seismic source.

3.5 MAM Survey

3.5.1 Arrays

To conduct MAM survey, we first marked our mid-point. From that mid-point, in all four directions and in diagonal directions (45° angle from mid points) we spread our arrays. We first spread the wires in straight lines. We marked distance of 2.5 meter from measuring tape in all directions of array and placed the first geophone in all direction. Then in all direction we placed the other geophones corresponding to line with distance of 5 meter. So, the distance kept between 2 consecutive geophones was at 5 meters. After all the Geophones are placed we connected positive and negative terminals of geophones with connecting wires. We connected all geophones with their respective connecting wire and then connected those wires with seismograph. Coordinates of all six channels we connected for MAM survey are described in Table 3

Table 3.2. Latitude and Longitudes of all six channels and center point of MAM survey and their respective elevations

Channel no.	Latitude	Longitude	Elevation (m)
Centre	33.69885	73.01719	583
M1- Channel 01	33,6991	73.01765	556
M1- Channel 24	33.69843	73.01651	566

M2- Channel 01	33.69835	73.01748	564
M2- Channel 24	33.69931	73.01671	564
M3- Channel 01	33.69861	73.017639	560
M3- Channel 24	33.699294	73.017180	565



Figure 3.4. Connecting positive and negative terminal of geophones with connecting wire which is then connected into seismogram in the field

We spread 3 arrays, each array has 2 channels each of 12 geophones. We named these arrays as M1, M2 and M3. We also placed 3 triggering geophones close to middle-point we marked. We connected all three of them with their connecting wire and connected these wires to three seismographs.

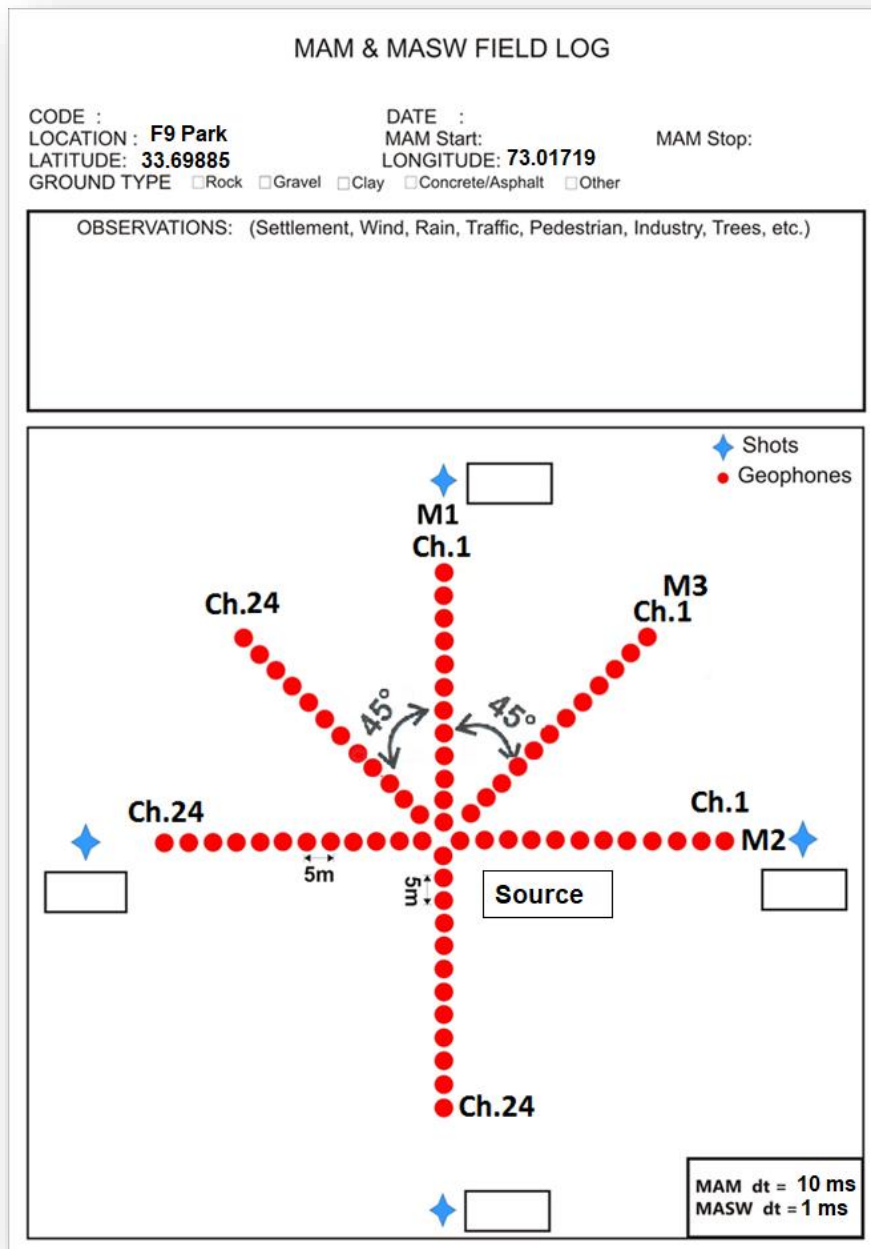


Figure 3.5. Field log of MAM survey which shows geometry and position of geophone and spacing in between and position of source



Figure 3.6. Ariel view of geometry of MAM survey in which position of first and last geophones of all three arrays are displayed

3.5.2 Seismograph connection

We connect Channel 1 and 2 of M1 array into 1st seismograph and same with M2 into 2nd seismograph and 2 channels of M3 into 3rd seismograph.



Figure 3.7. Connecting wire of first channel with seismogram similarly second channel will be connected to seismogram and then connecting wire of triggering geophone will be connected to seismogram

Then we connect these seismograph with laptops through a USB port and cables. After this, we run the software in all three laptops.

3.5.3 Geophone test

First thing, we did was to check all geophones. Either all geophones were connected or not.



Figure 3.8. Running Geophone Test in Field before survey to make sure all geophones are properly connected and working properly and recording the traces

This is done if any geophone is not active, we can reconnect it and then check seismic traces of all geophones. This tells us either all geophones were properly recording or not.

3.5.4 Parameters of recording

Once, we are done with geophone testing, we then set the parameters of recordings. We set sampling interval to 10 milliseconds and Gain to High Gain. We also set sampling rate to 100. Recording length of one shot is 3.63 seconds and we took 15 shots making the total recording time to 55 minutes.



Figure 3.9. Measuring distance using measuring tape between two geophones to keep spacing between two geophone to 5 meter

3.5.5 Recording

After setting all parameters, we start acquisition. We take the first shot in the center on 33.69885 latitude and 73.01719 longitude and wait for 3.63 seconds which is recording time. After recording is done, we save the file and then take the second shot and record second reading. We continued this till 15 readings.



Figure 3.10. Taking shots by striking hammer with metal plate for MASW survey

3.5.6 Field observations

While recording data, we were also recording surrounding observations. Anything that might add unnecessary noise or causes hindrances in recording good quality of data.

While recording data, there was noise of Grass mower that added noise in data. It was about 200 meters away from channel 1 of M1 array. Pedestrian noise was also added occasionally into it.

3.6 MASW survey

After recording of MAM survey, we moved towards MASW. With penetration depth of tens of meter it require 3 shots at 4 points each. So, we started the setup of MASW and recorded its data.

3.6.1 Array arrangement

We first changed the geometry of array. We removed the M3 array, because we only need 2 arrays in this survey. We needed cross shaped geometry for MASW survey. Also out of those 2 array, one array is disconnected and only one array records the data. MASW survey records the data of one single straight array or to be more precise it records data one straight line.

After removing M3 array, we removed the M2 connector from seismograph. For time being, we also closed down the other two laptops as well to preserve battery. Now only one seismograph is connected with one M1 array. We now removed all 3 Triggering geophones as well.

After this, we take our metal plate and hammer and moved to channel 1 of M1 array. We using measuring tape measured 5 meter distance and placed Triggering geophone there. We connected this Triggering geophone with its connecting wire and plugged wire into the seismograph. Next to that we placed metal plate.

3.6.2 Recording parameters

Now we again change parameters of recording. We changed sampling interval to 1 milliseconds. We selected Gain to Low Gain. We also set sampling rate to 1000. Recording time of each shot was 30 seconds and we took 3 shots at this point making the recording time up to minute and half.

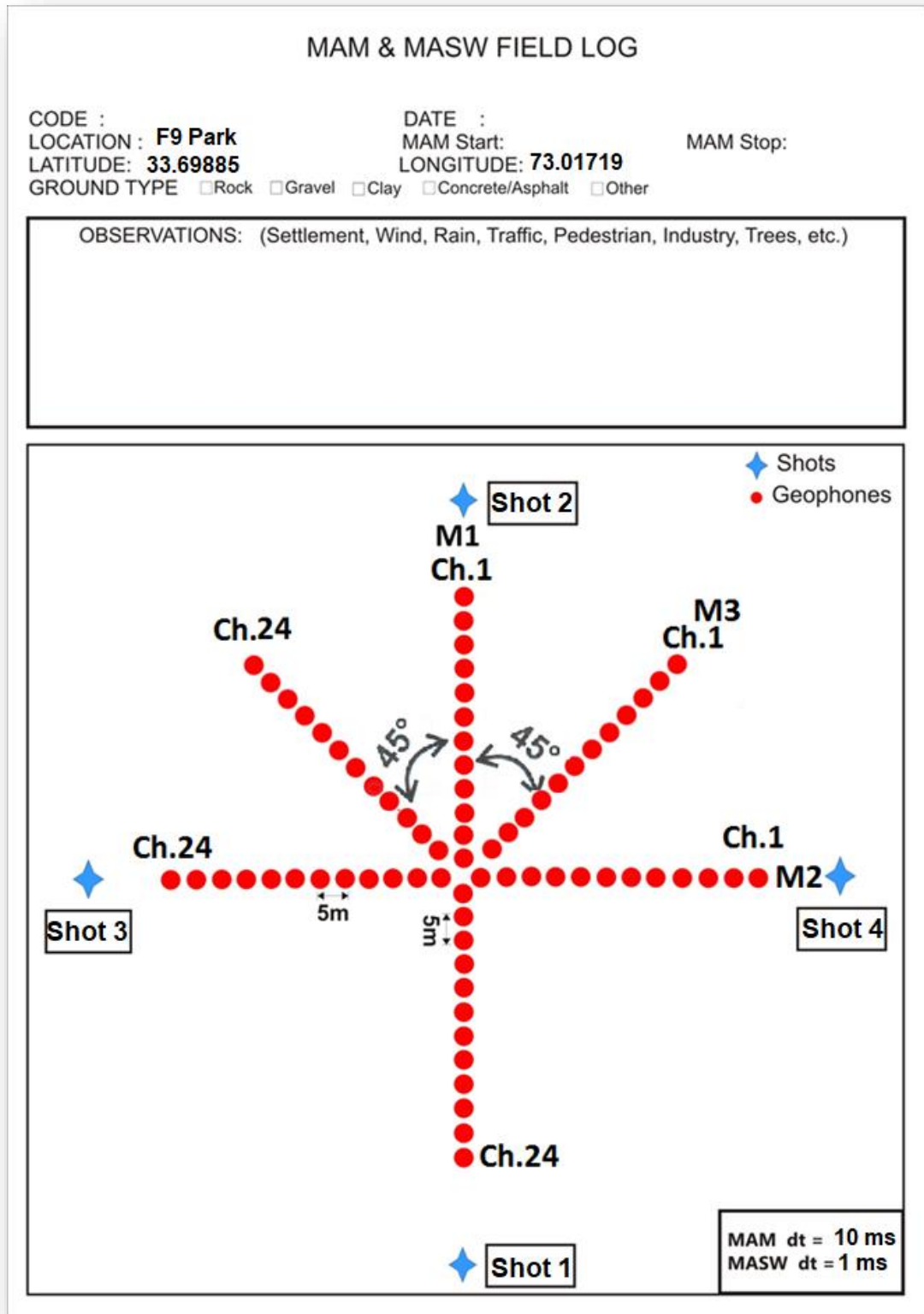


Figure 3.11. Field log for MASW survey showing geometry for survey and all four shot Points of MASW Survey

3.6.3 Recording

Now for time being, within 20 – 30 meters of our array, we stopped all the movements and any unnecessary noise that can hamper the recording.

We then took 3 shots meaning struck the hammer thrice on metal plate with pause of about 5-7 seconds. After recording data, we saved the file which was in Seg-2 format.

After being done by recording at first channel, we moved to second channel of M1 array and spread the connecting wire, placed Triggering geophone connected it with wire 5 meters away from 24th geophone. We kept metal plate at near distance from Triggering geophone. We again stopped any noise or any type of movement within 20 – 30 meter radius. After this, we took 3 shots with small pause and then waited for recording to finish. After completion of recording we saved the file. Then unplugged the Triggering Geophone.

After recording on both channels of M1 array, we moved to 2nd array which was M2. We unplugged the M1 array connectors from seismograph and plugged connectors of both channels of M2 in seismograph.

We moved to 24th geophone or second channel of M2 array, placed our Triggering geophone connected it with wire 5 meters away and setup the parameters of MASW survey in software of 2nd laptop. We then stopped all unnecessary movements and noises and took shots thrice on metal plate with hammer. We then waited for data to be recorded then stored the file.

After this we unplugged the Triggering geophones from wire and moved to 1st channel and placed Triggering geophone connected it wire 5 meter away from 1st geophone of M2. We then struck the plate three times and waited for data to be recorded. After data is recorded and file is stored, we removed the other two arrays as well. We removed geophones closed laptops and seismograph and packed all our things ready to be transported. We then moved to our 2nd site of F9 Park and recorded the MASW survey.



Figure 3.12. After performing MAM and MASW survey at site 1 packing all instruments to move towards site 2 to perform MASW survey

3.7 MASW survey at site 2

After survey at first site had completed we transported all equipment to 2nd site. Here we only performed one MASW survey in single array or single line. We only took

shots at two points. We only used one seismograph and one laptop and one array or only 24 geophones.

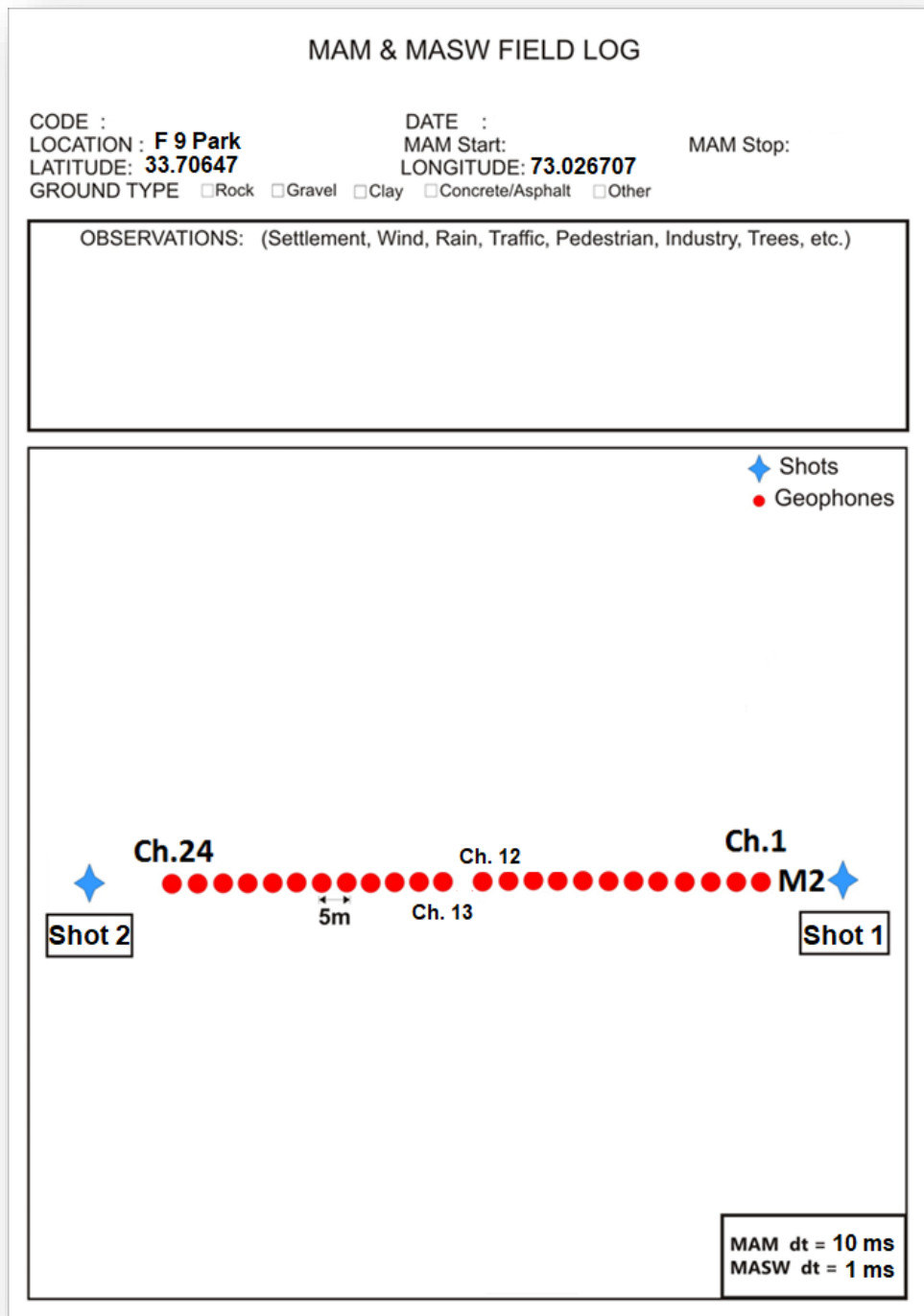


Figure 3.13. Field log of MASW survey showing geometry and channels and points where shots are being taken at site 2

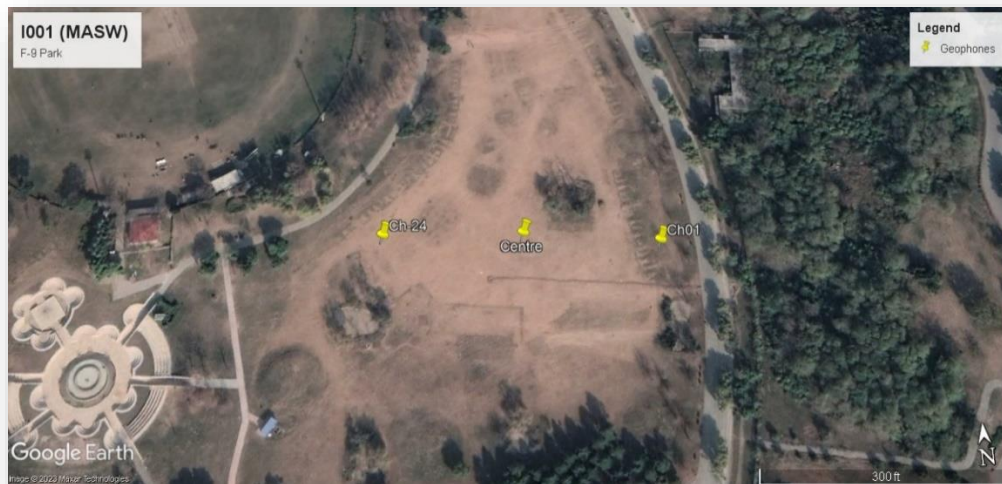


Figure 3.14. Ariel photograph of geometry and positions of first and last geophone of channel of MASW survey at site 2

3.7.1 Array

So we started to unwrap our equipment and afterwards we set our geometry. We first marked our mid-point which was at 33.706467, 73.026707 latitude and longitudes and since we only need one array for this survey, we rolled out connecting wires of geophones in both sides.

We then on both perpendicular sides marked 2.5 meter from mid-point we marked and placed geophones there. Afterwards we placed geophones in both sides parallel to connecting wire at 5 meter distance from each other. We then connected positive and negative terminals with wire. We then plugged wires of both channels in seismograph. Then we plugged one end of connecting wire of Triggering geophone with seismograph and rolled out other end towards first channel. We placed Triggering geophone 5 meter from first geophone and connected it with connecting wire.

3.7.2 Setting parameters

After rolling out geometry of MASW survey, we connected laptop with seismograph and run the software. We first performed Geophone test to check all geophones are connected or not. We then checked traces of geophones to see if they are recording properly or not.

Once we were confirmed that all geophones were properly working, we then set up parameters of MASW. We kept sampling interval to 1 milliseconds. We selected Gain to

Low Gain. We also set sampling rate to 1000. Once parameters are set we then moved to data recording.



Figure 3.15. Spreading Array and setting up geophones for MASW survey at site 2 after which their positive and negative terminals are connected with connecting wire which is then connected into seismogram

3.7.3 Acquisition

We took our first shots at channel 1. On 33.706385 latitude and 73.027265 longitude, we struck the hammer thrice with pause of 5 – 7 seconds. We then waited for data to be recorded and saved the recording file. We then unplugged the Triggering geophone and rolled out connecting wire to second channel.



Figure 3.16. Setting up connecting wire for triggering geophone for MASW survey at 2nd site, its one end is connected with triggering geophone and other end with seismogram

On second channel 5 meters away from 24th geophone we placed triggering geophone connected it to wire and then took our second shots. Coordinates of second shots were 33.706519, 73.026068 latitude and longitudes. We saved the file. We then removed the geophones, wrapped the connecting wires into their bundles, closed the laptop and seismograph. After we packed our instrument we moved to our third and last site to perform MASW survey.

3.8 MASW survey at site 3

We went to our third site. There we marked our middle-point at 33.709681, 73.024157 latitude and longitude.

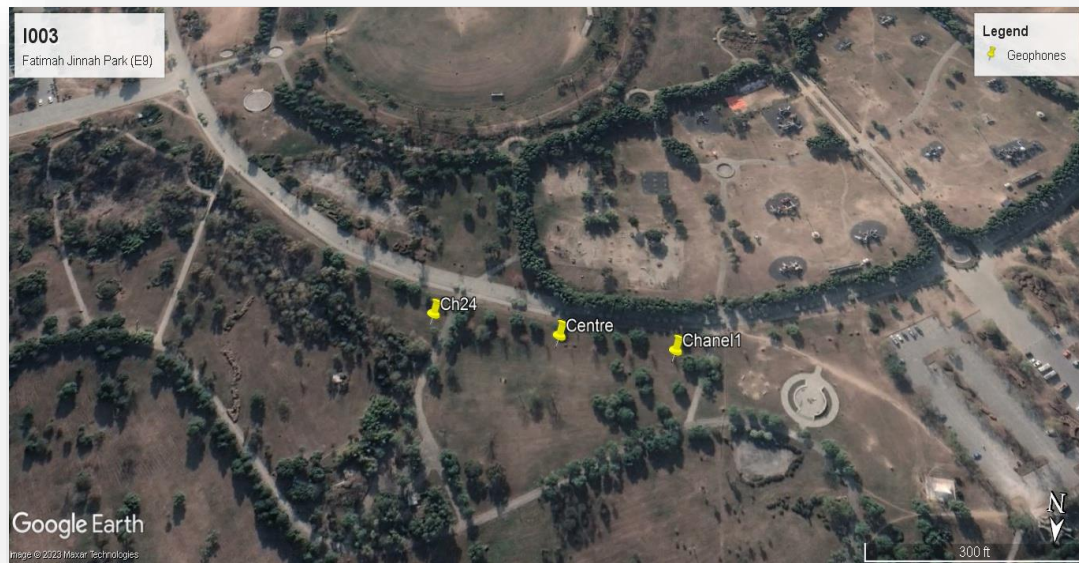


Figure 3.17. Ariel photograph of site 2 showing geometry and first and last geophone of channel and center position for MASW survey

We repeated same procedure as previous survey. We then rolled out our connecting wires of geophone on both sides, and placed our first geophones from 2.5 meters of mid-point on both sides. We then placed remaining geophone of an array with 5 meter distance and plugged them with connecting wire. We then rolled out connecting wire of triggering geophone and connected it with triggering geophone at one end 5 meters from first geophone and second end to seismograph.

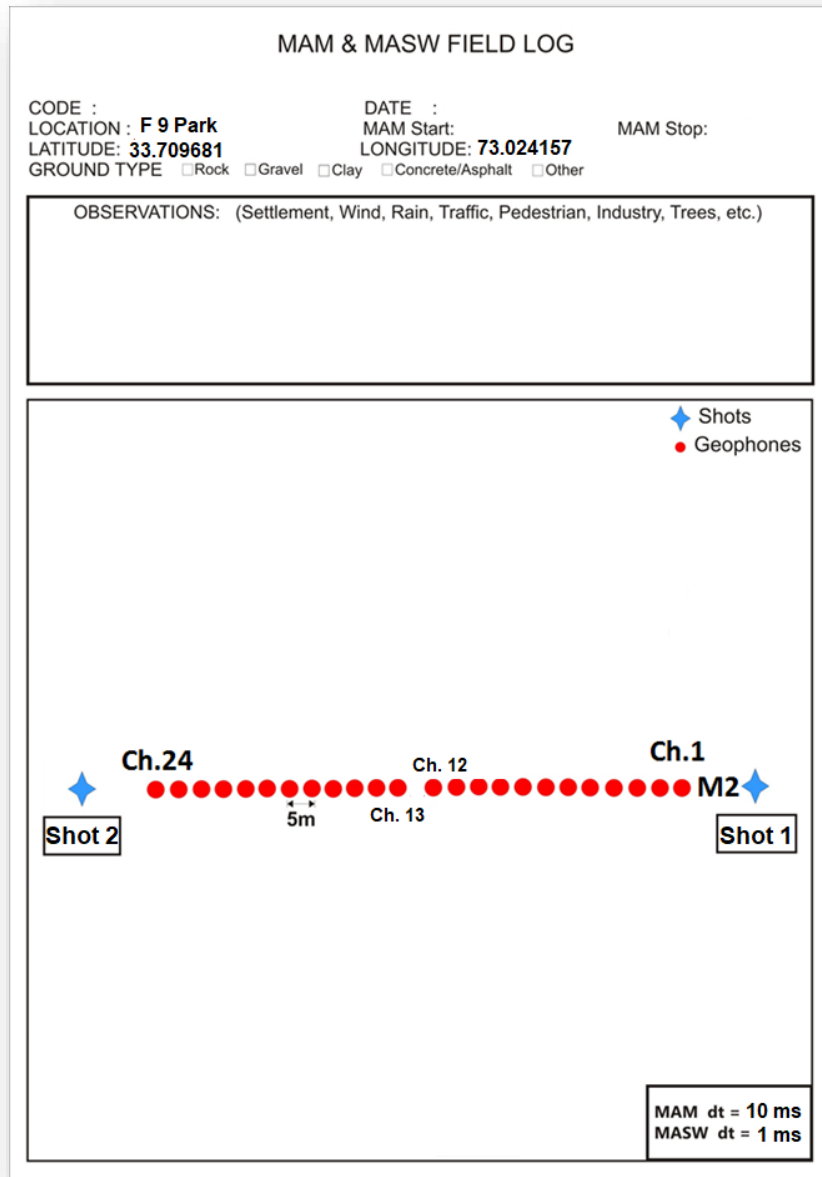


Figure 3.18. Field log of MASW survey showing geometry and channels and points where shots are being taken at site 3

3.8.1 Geophone test and recording

We connected seismograph with laptop and performed geophone test. There was problem with one geophone of second channel which was not properly connected. So, we reconnected it, checked the traces of all geophones and then moved to setting parameters of MASW survey. We kept parameters same as previous survey.

Then we moved to acquiring data and took our first shots at 33.709695 latitude and 73.023557 longitude. After recording and saving the file, we then moved towards second channel.



Figure 3.19. After setting geophones connecting positive and negative terminals of geophones with connecting wire

We then set the Triggering geophone on second channel and at 33.709638, 73.024828 latitude and longitude, we struck hammer on metal plate thrice and recorded data. After acquiring, we packed our all instruments. We acquired data on 3 sites and 4 surveys in total.

3.9 COMSATS University cricket ground

3.9.1 Array

We performed one MAM and one MASW survey in COMSATS University cricket ground. We used two channels and total of 48 geophones, two seismogram and two triggering geophones along with two laptops. We kept the same parameters of acquisition here as they were in F-9 Park.

3.10 Survey

For MAM and MASW survey, we laid out geometry in plus shape. We were using only two channels. We first calibrated geophones by running geophone test and then recorded data. We took 16 shots and recorded data of 56 minutes. For MASW survey, we took 3 shots at 4 points each and recorded data.



Figure 3.20. Location of channels in COMSATS University cricket ground for MASW and MAM survey

Table 3.3. Latitude and Longitudes of all six channels and center point of MAM survey and their respective elevations

Channel no.	Latitude	Longitude	Elevation (m)
Centre	33.646818	73.156992	430

M1- Channel 01	33.646335	73.157183	420
M1- Channel 24	33.647328	73.156824	425
M2- Channel 01	33.646697	73.156350	425
M2- Channel 24	33.646200	73.157605	430

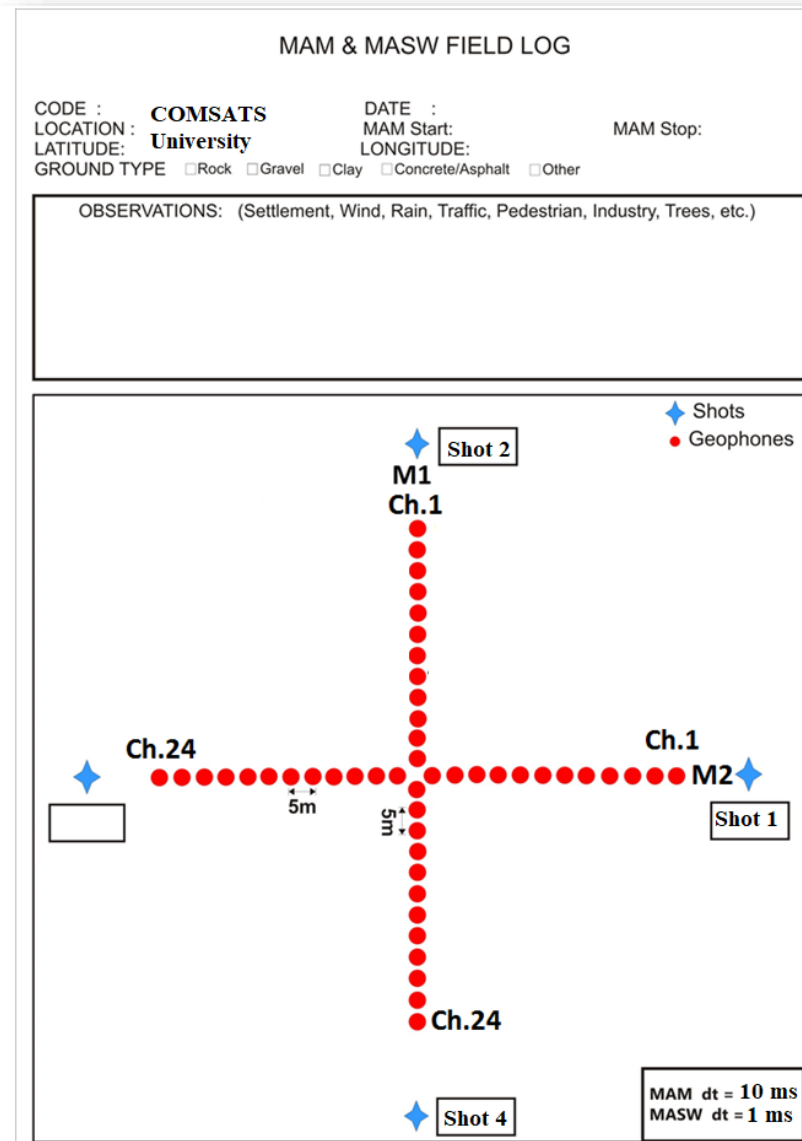


Figure 3.21. Field log of MASW and MAM survey showing geometry and channels and points where shots are being taken

Chapter 4

Processing of Data

For every seismic method, the step after acquiring data is processing. Processed data contains noises and main purpose of processing is to eliminate those noises and improve quality of traces (Milsom & Eriksen, 2013)

We perform processing separately for MASW and MAM, with steps almost the same and develop Vs 30 curves. We utilize Geopsy module of Sesarray package.

4.1 MAM survey

We performed processing for MAM survey first. We first loaded data files and then performed F-K analysis. This process is time taking and takes time up to 12 to 14 hours. After F-K, we developed a dispersion curve and then inverted it to establish Vs 30 curve.

4.1.1 Data loading

First step was to load all data files in Geopsy. The recorded files are in Seg-2 format of **.dat** files. These files do not contain any source or receiver information. To perform Fk analysis in Geopsy, we needed file format to be in **SAC** format.

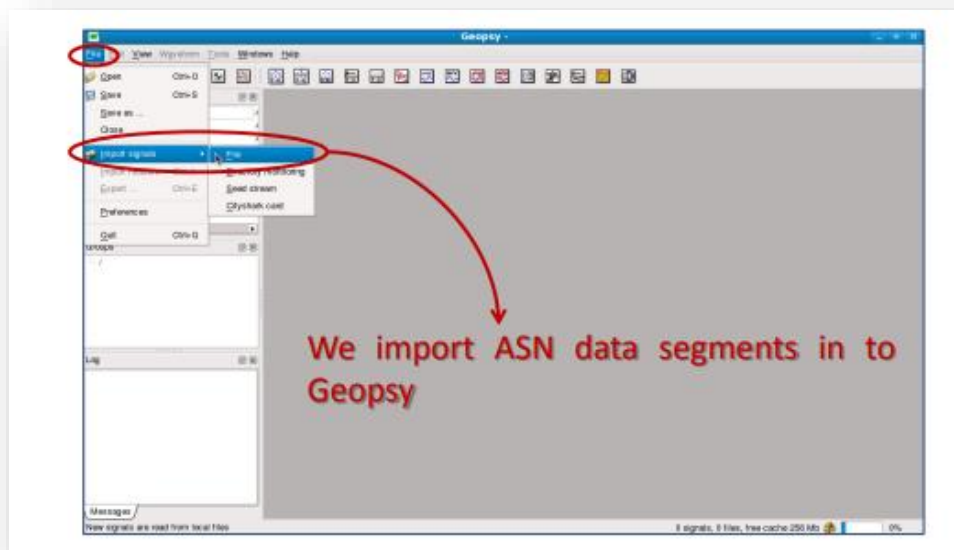


Figure 4.1. To start processing in Geopsy software we first import files in which we recorded data in field which was in seg-2 format

We first imported all the files in .dat format in software. After importing all the files, we opened them in Geopsy and check their waveforms. Since, we cannot directly convert Seg-2 format into SAC, we first converted them into ASCII format.

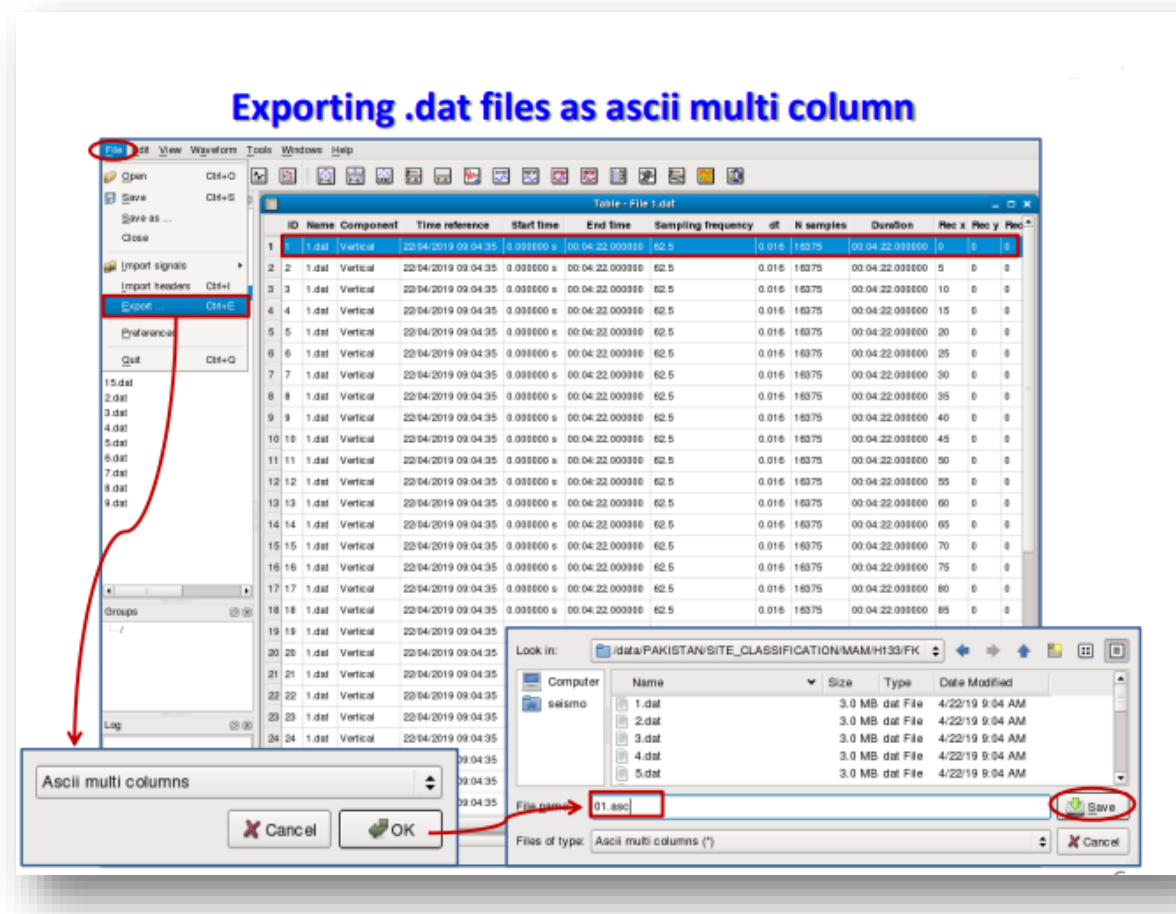


Figure 4.2. Since we can't process data in seg-2 format in Geopsy as it doesn't support that format we convert seg-2 format into ASCII format

We converted all Seg-2 files one by one into ASCII. We clicked on export option and selected ASCII multiple columns. After all 15 Seg-2 files were converted into ASCII files, we merged these 15 files into 1 file called *sall*. We merged these files using *cat* command. *Cat* command allows us to create multiple or single file and allows us to view the contents of the file. We wrote command *cat *.asc > sall* to merge files into one *sall* file.

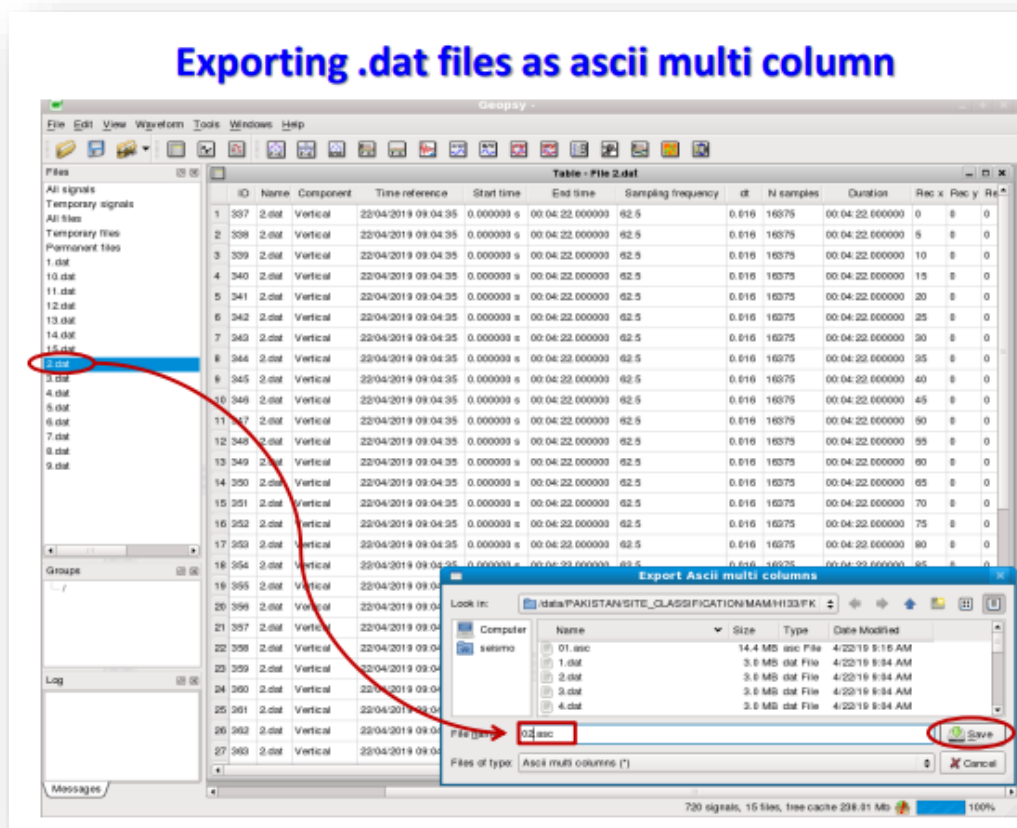


Figure 4.3. Converting all seg-2 files of MAM survey into ASCII format one by one after which ASCII will be converted into SAC format on which F-k analysis will be performed

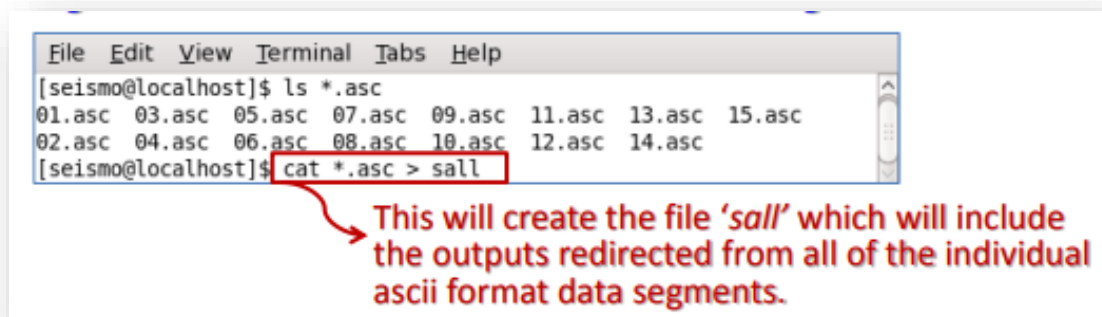


Figure 4.4. Command we write in Geopsy which will convert ASCII files into single Sall file which is then converted into SAC format

After this, we converted this sall file into SAC format. For this, we used command script of *convert2sac.csh*. It will convert all recording into SAC files. We will get total of 72 channel SAC files.

Now, we will import all 72 SAC files in Geopsy and open them and perform F-K analysis on it.

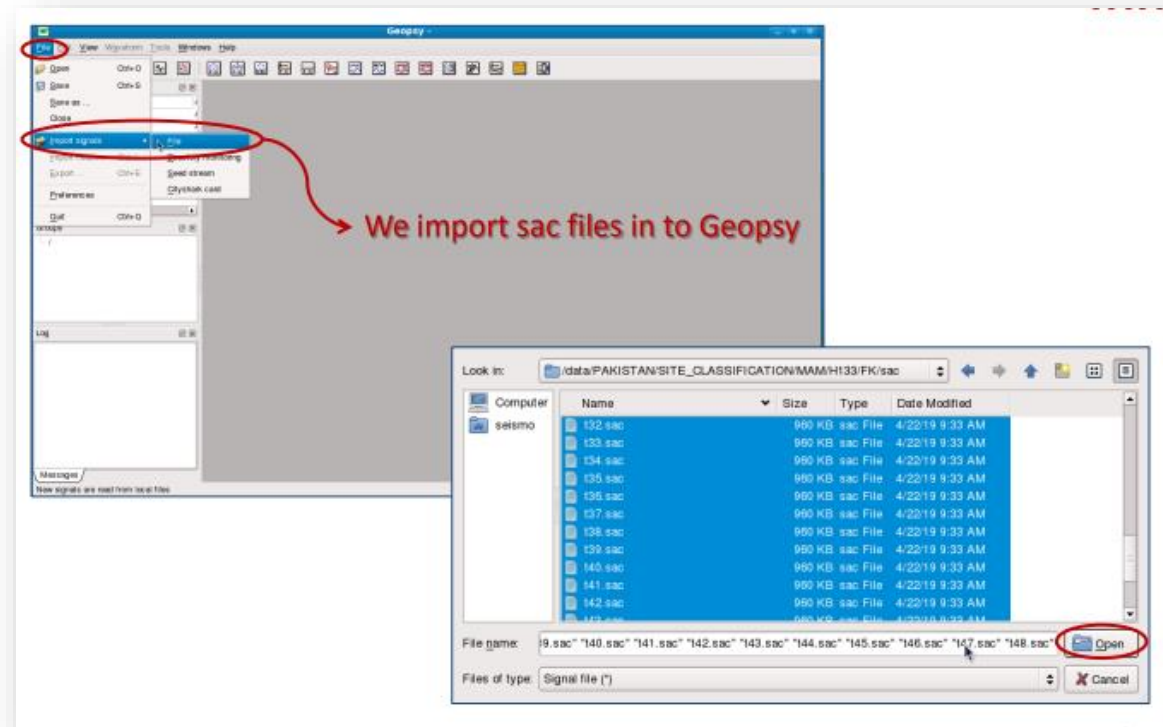


Figure 4.5. After converting seg-2 formats into SAC format by first converting them into ASCII format and sall file, we import SAC files in Geopsy

4.1.2 F-K analysis

Wave field transformation techniques are increasingly in demand for dispersion analysis, primarily because to their capacity to distinguish between various seismic occurrences and to identify a variety of Rayleigh wave propagation modes. The fundamental idea behind these methods is to translate the experimental time-domain data into a new domain where spectral maxima are used to identify the surface wave propagation properties. The majority of techniques employ the Fourier transformation, which divides a signal's various frequency components and converts it to the frequency domain. By using

numerical transformation methods, time domain data are typically translated to the frequency wavenumber domain, also known as the f-k domain. The field data is subjected to the Fourier transformation in both time and space, and as a result, it is turned into an image of energy space as a function of frequency and wavenumber (Dey).

Now, after importing files in Geopsy we set up parameters of F-K analysis. We kept:

- Number of Samples: 100
- Velocity: 50-1000 ms^{-1}
- Frequency: 4-20 Hz

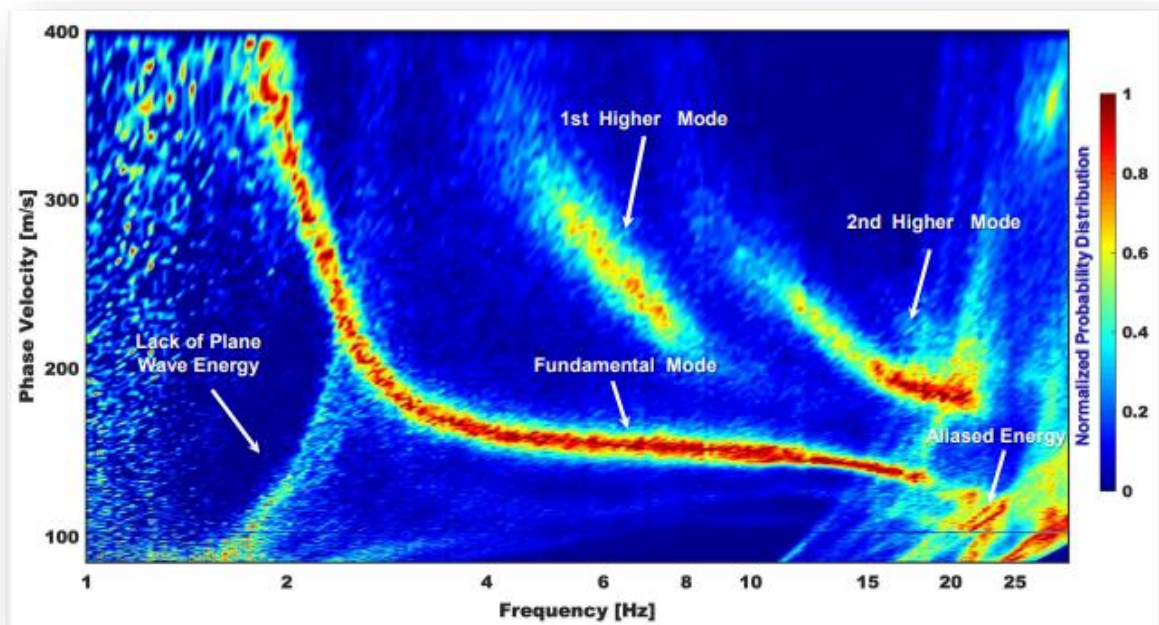


Figure 4.6. Image of dispersion curve showing amplitude and types of mods which are fundamental mod and higher order mod

It takes up to 10-14 hours for F-K analysis. It makes graph between frequency and velocity. After it is completed, we saved the file in **.max** format. To view, F-K analysis in real time we can use command **max2curve**.

After this we performed pick order and select points with maximum amplitude and saved the file. We can export image into JPEG format.

4.2 MASW survey

For MASW survey, process of F-K analysis is somehow similar to MAM survey. We loaded all data files and then perform F-K analysis. We set source and receiver array distances. We kept:

- Number of Samples: 1000
- Velocity: 50-1000 ms^{-1}
- Frequency: 4-25 Hz

After F-K analysis, we picked highest amplitudes and saved the file with same procedure as done in MAM survey.

4.2.1 Combining dispersion curve

After F-K analysis, we run Dinver tool to combine dispersion curve. We performed two MASW surveys and one MAM along with MASW. For MAM and MASW survey performed together, we added all curves of MAM and MASW survey and combined them.

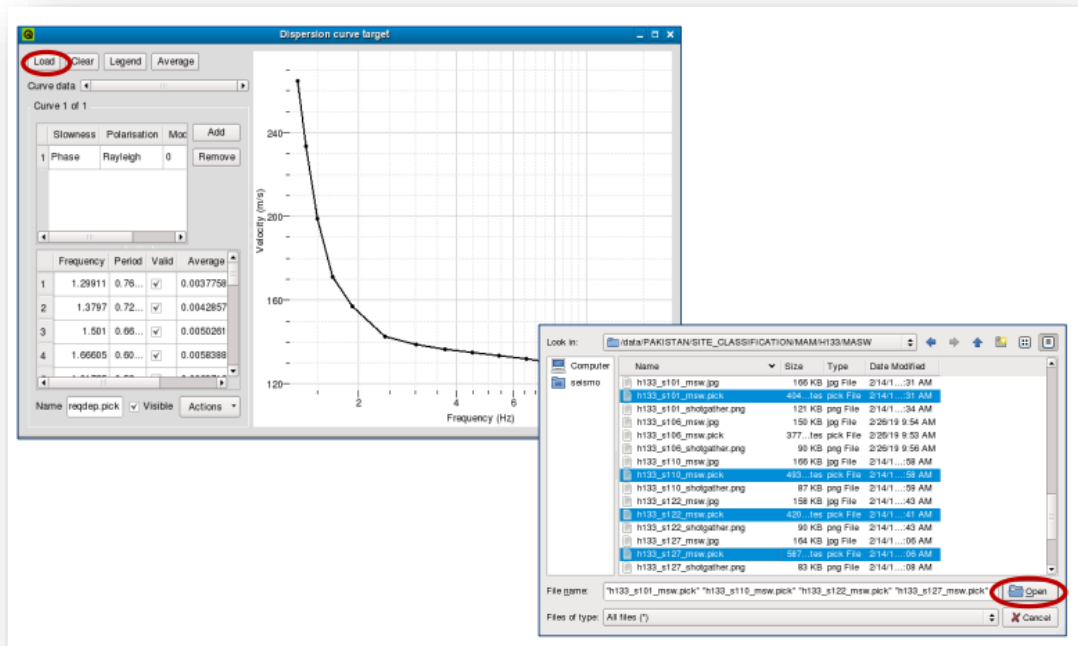


Figure 4.7. After dispersion curves are created, we combine these dispersion curves and make one curve using Dinver tool which is further used to calculate shear wave velocity curve

After wards, we calculate theoretical dispersion curve using different algorithms and see the difference between calculated and observed dispersion curve. We already have thousands of models of soil profile and shear wave velocity curves, we run them and see the least misfit. By performing this inversion process we calculate shear velocity curves. For other two MASW surveys, we performed same procedure.

4.2.2 Calculation of Vs 30

After combining the curves through Dinver tool, we and obtain curve of shear wave velocity. From that curve using equation (1), we calculate value of Vs 30. We then used it to compare it with NEHRP building codes and classified the site. Vs 30 is calculated by formulae.

$$V_s 30 = \frac{30}{\sum_{i=1}^n h_i / V_{si}} \quad (1)$$

Whereas, $\sum_{i=1}^n n$ represents sum of number of layers in first 30 meter of subsurface, h_i represents thickness of layers in first 30 meter of subsurface and V_{si} shows shear wave velocity and to normalize the result up to 30 meter we divide it by 30.

Chapter 5

Results and Discussion

5.1 Results of MASW and MAM survey of F-9 Park

5.1.1 Dispersion curve at site 1

After F-K analysis, we get dispersion curve. Dispersion curve is a relationship between frequency and phase velocity. It gives us amplitude and is helpful in calculating shear wave velocity. Whereas, phase velocity is speed at which crest or trough of wave move.

In dispersion curve, we get two types of mods. Fundamental mod which has high amplitude but has low frequency. From fundamental mod, we pick high amplitude. It has low noise and has high energy content. Higher mods are dip in dispersion curve having high frequency and low amplitude. They have high noise and low energy content (Xia et al., 1999).

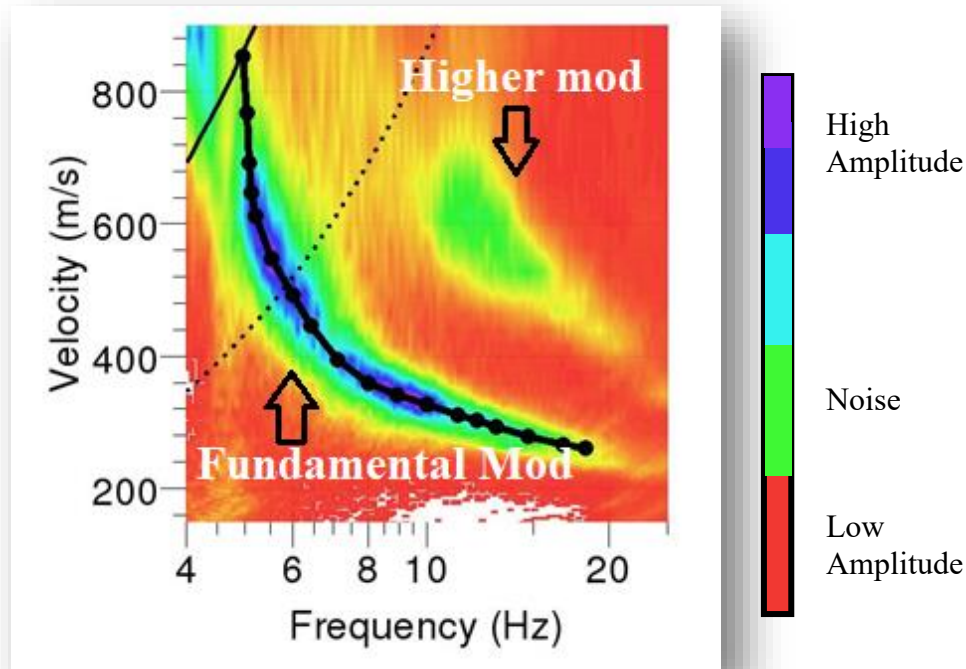


Figure 5.1. Dispersion curve of MAM survey obtained after performing F-k analysis, from curve we pick highest amplitude, it also shows fundamental and higher mod from which fundamental mod represents highest amplitude, while higher mode represents noise

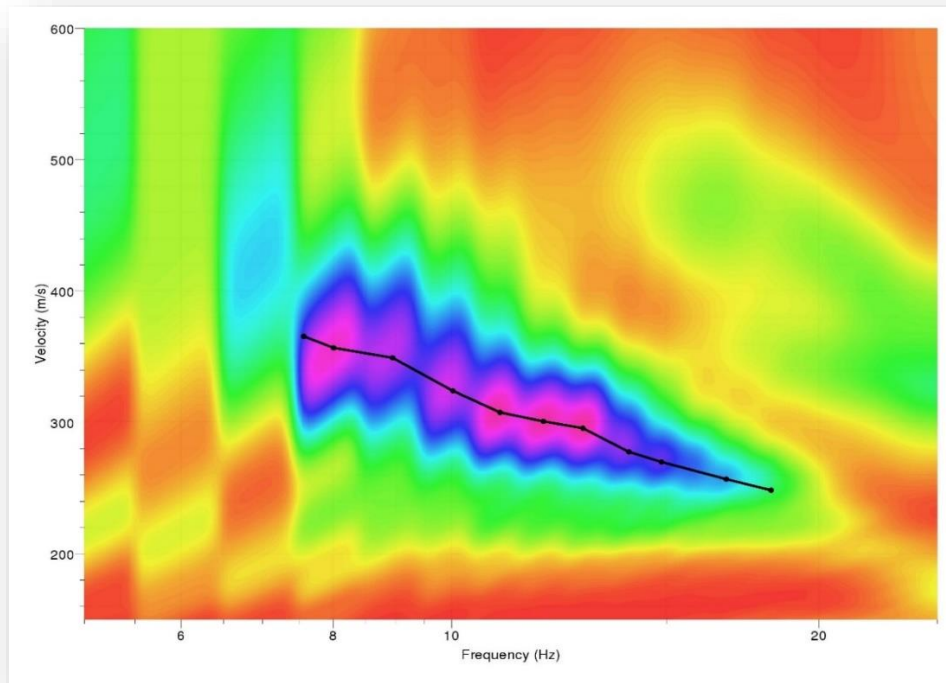


Figure 5.2. Dispersion curve of shot 1 of MASW survey at site 1 which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

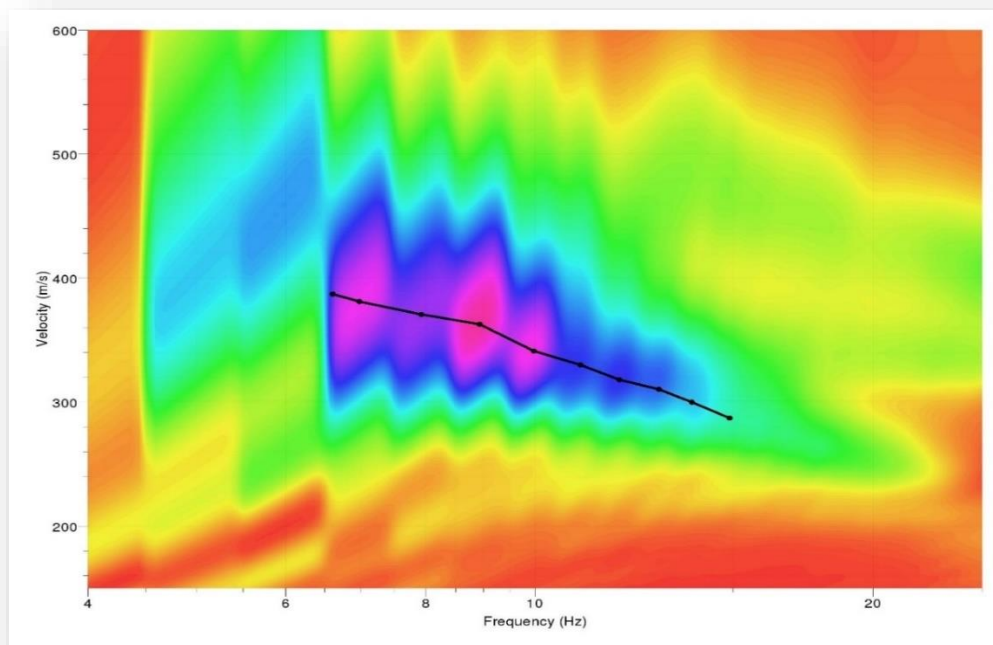


Figure 5.3. Dispersion curve of shot 2 of MASW survey at site 1 which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

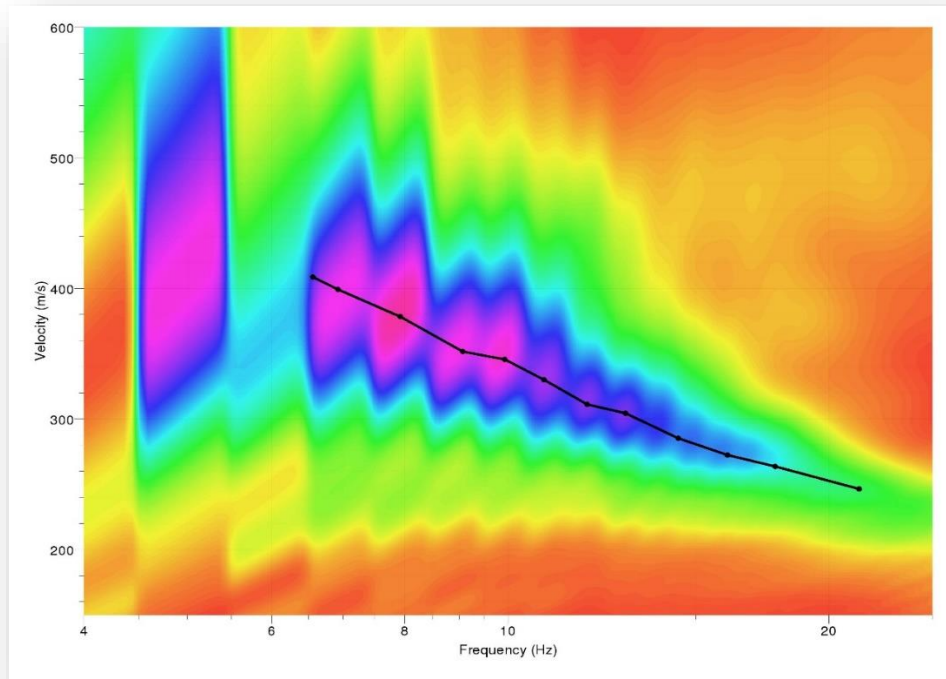


Figure 5.4. Dispersion curve of shot 3 of MASW survey at site 1 which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

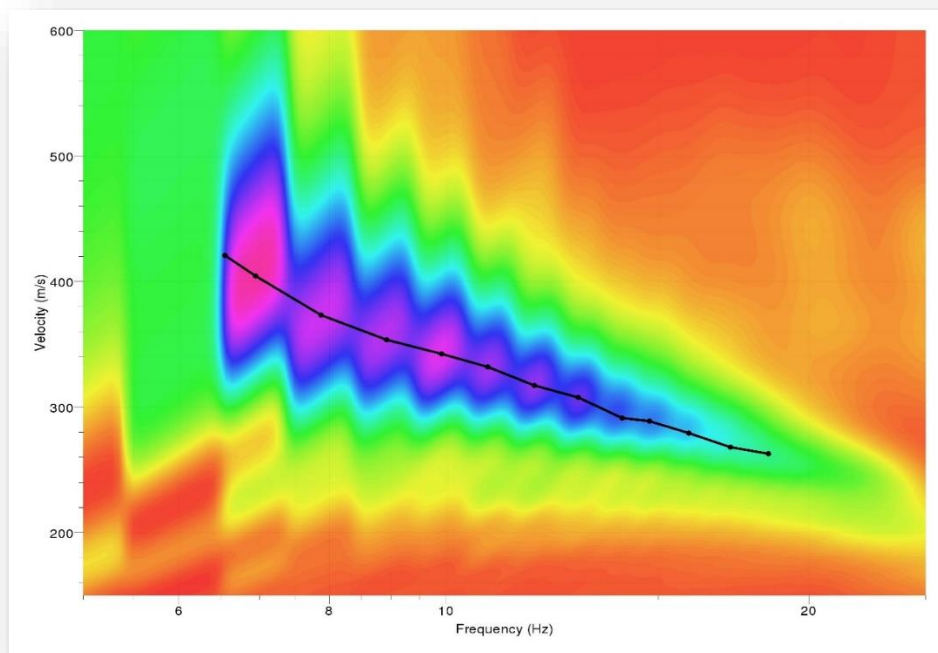


Figure 5.5. Dispersion curve of shot 4 of MASW survey at site 1 which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

From those curves, we get maximum amplitudes. We get 1 dispersion curve from MAM survey and for MASW survey performed with MAM, we get 4 curves because of 4 shot points and for other 2 MASW survey we get 2 from each because of 2 shot points making total of 9 dispersion curve.

Dispersion curve is calculated by following formulae

$$V = \frac{2\pi f}{k} \quad (2)$$

Whereas V is phase velocity and k is wave number.

5.1.2 Combination of dispersion curve

After dispersion curve, we pick maximum amplitudes and then we combine all the curves of dispersion curves. The more the curves overlap, more reliable is the data.

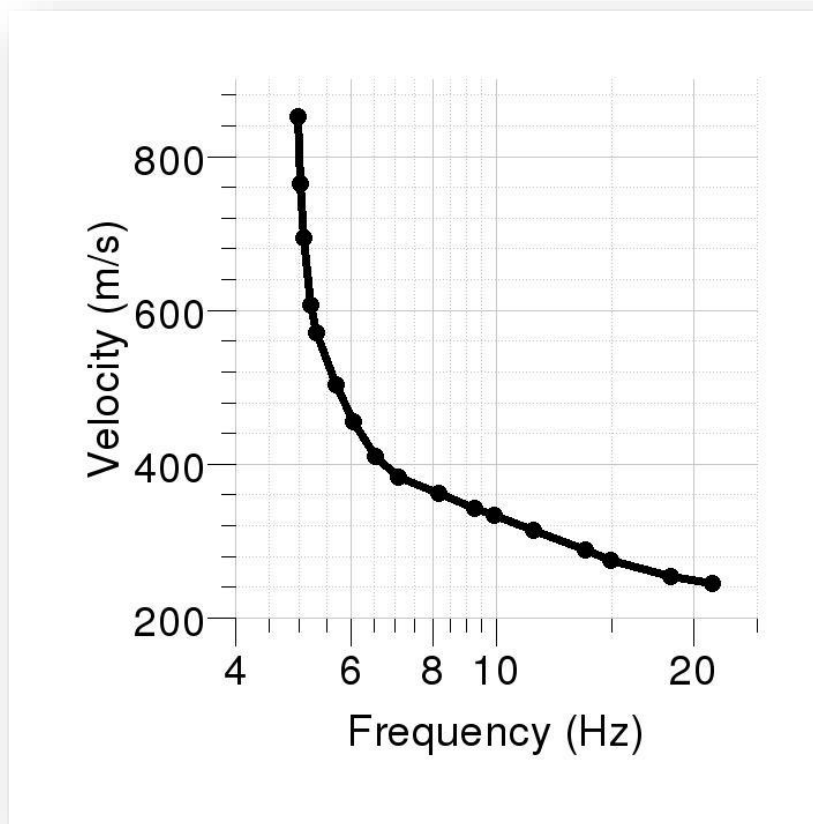


Figure 5.6. After picking maximum amplitudes from dispersion curves, we combine them and make another curve using Dinver tool. This curve is then utilized to make shear wave velocity curve

After combining all dispersion curve, we calculate theoretical dispersion curve and by running misfit model we calculated shear wave velocity curve.

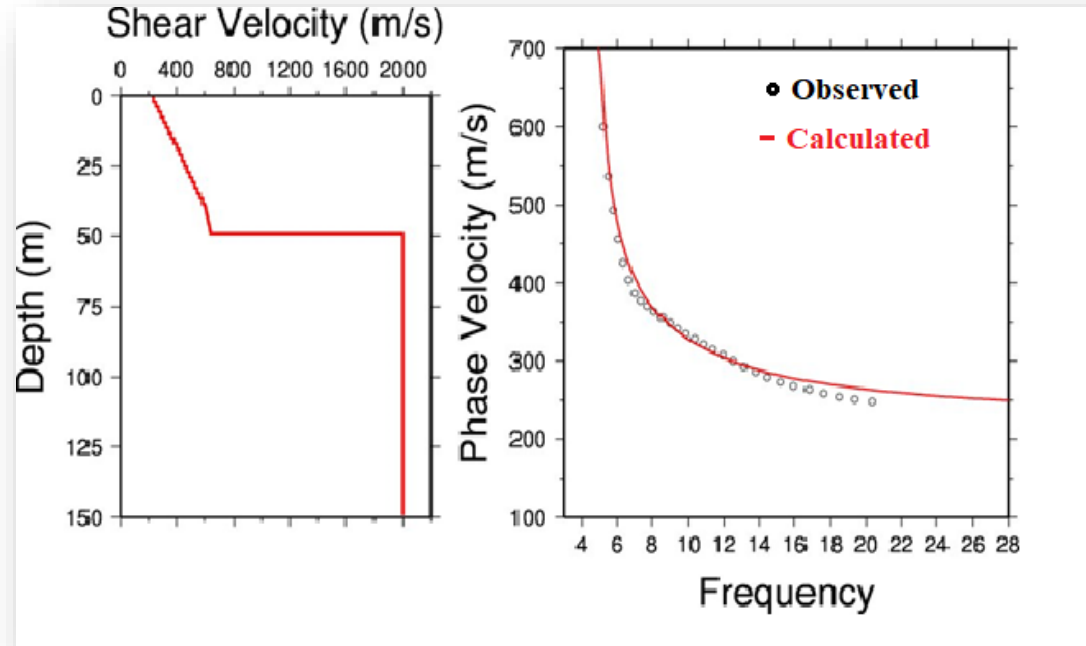


Figure 5.7. Shear wave velocity curve of site 1 showing shear wave velocity with depth, while the curve on right represents observed curve which is obtained from dispersion curve while the other is calculated using mathematical formulae

V_s 30 calculated at 1st site at 33.69885 latitude and 73.01719 is $356.83908 \text{ ms}^{-1}$.

According to NEHRP code we get building codes of D.

Therefore, it indicates there is a stiff soil, or deposits of medium dense sand, gravel, or stiff clay. After 50 meters, we get jump in shear wave velocity increasing up to almost 2000 ms^{-1} . It indicates presence of very hard rock after 50 meter. C40 velocity is $351.22714 \text{ ms}^{-1}$.

5.2 Results of MASW survey at site 2

5.2.1 Dispersion curve

We get 2 dispersion curves of MASW survey because of 2 shot points after F-k analysis.

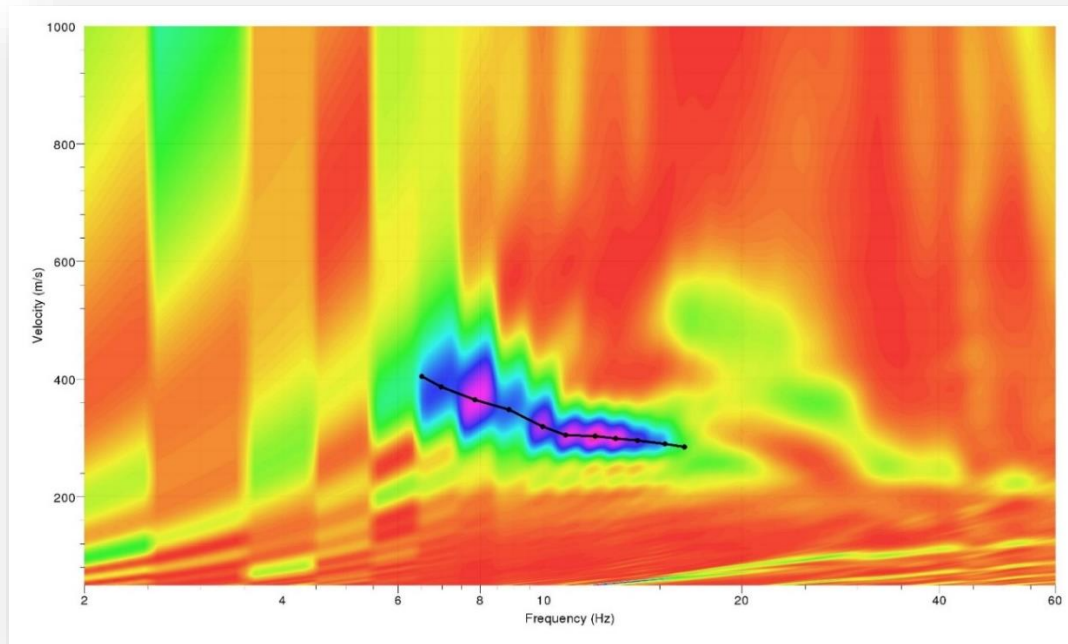


Figure 5.8. Dispersion curve of shot 1 of MASW survey at site 2 which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

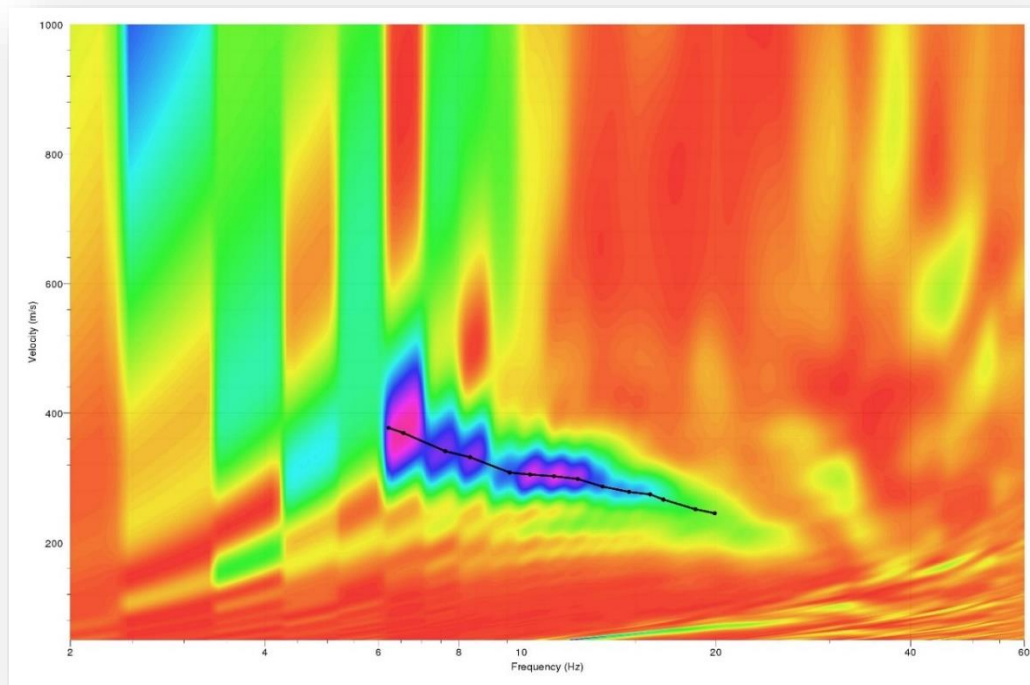


Figure 5.9. Dispersion curve of shot 2 of MASW survey at site 2 which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

5.2.2 Combination of dispersion curve

After dispersion curve, we pick maximum amplitudes and then combine all curves. For this, we use Dinver tool.

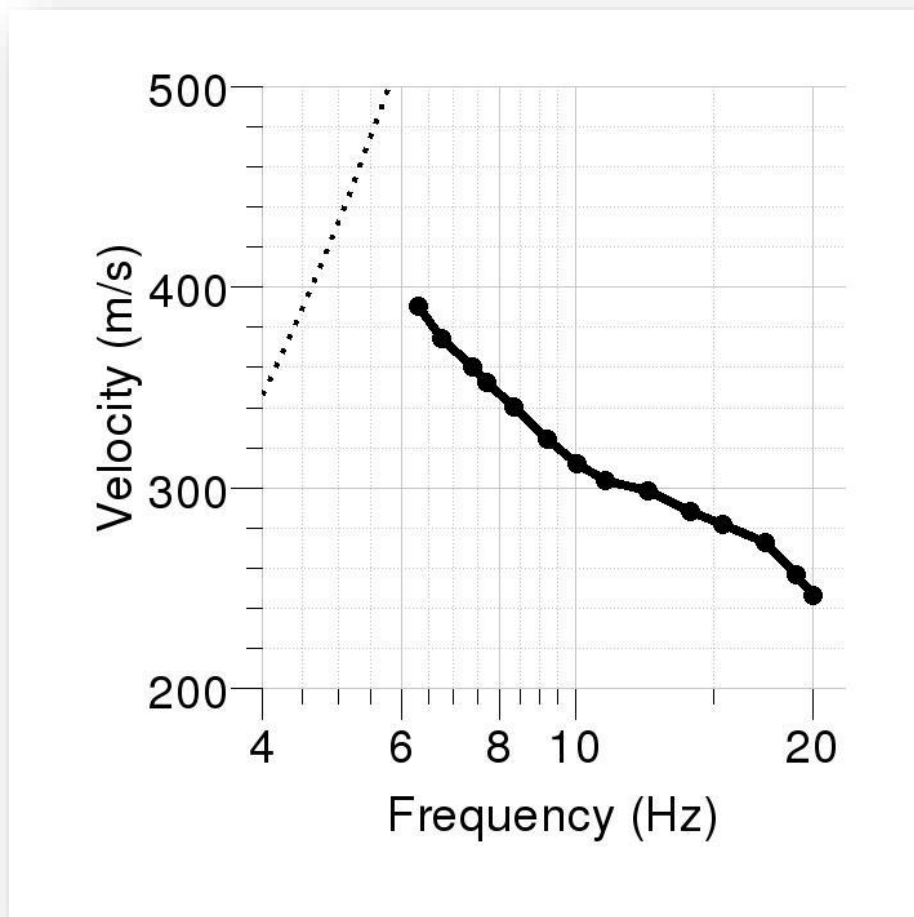


Figure 41. After picking maximum amplitudes from dispersion curves from site 2, we combine them and make another curve using Dinver tool. This curve is then utilized to make shear wave velocity curve

After this, we calculate theoretical dispersion curve and by running misfit model we calculated shear wave velocity curve

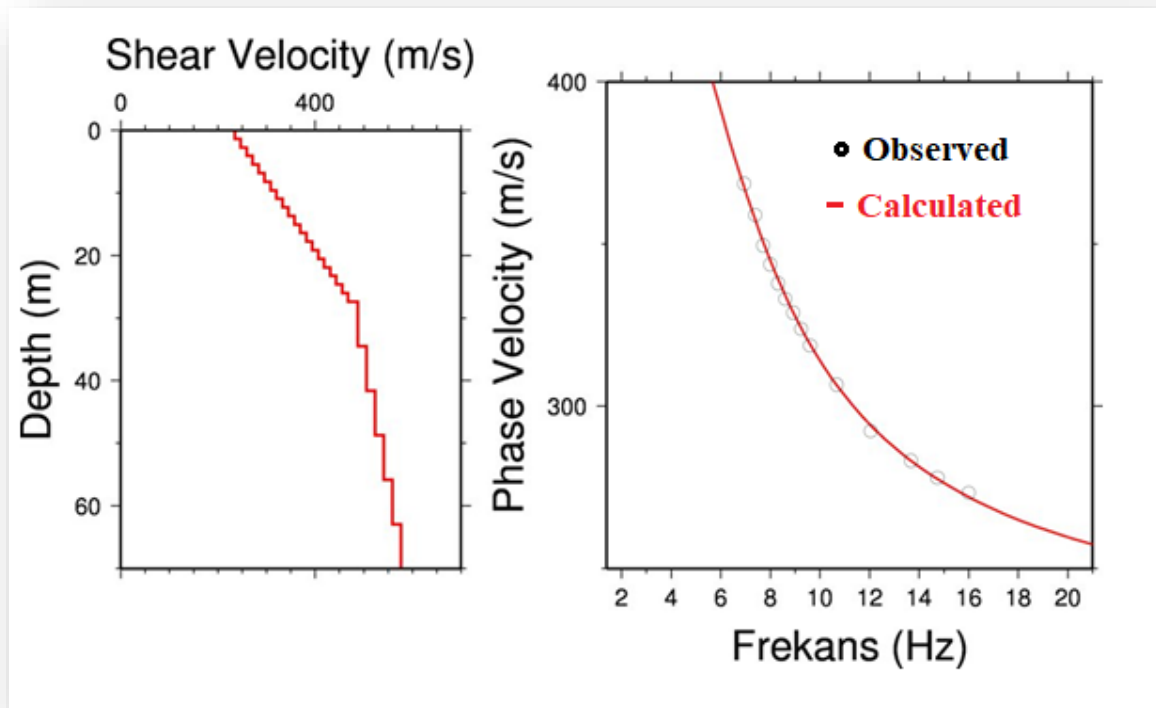


Figure 5.10. Shear wave velocity curve of site 2 showing shear wave velocity with depth, while the curve on right represents observed curve which is obtained from dispersion curve while the other is calculated using mathematical formulae

V_s 30 calculated at 2nd site at 33.33.706467 latitude and 73.026707 is 343.14331 ms^{-1} . According to NEHRP code we get building codes of D.

It has less shear velocity than site 1 but same building codes implying stiff soil and dense deposits of sand, or higher sized sediments such as gravel. Its graph is different from 1st site. There is gradual increase in shear wave velocity and there is no sudden increase in velocity after 50 meters indicating there is no hard rock present below subsurface at site 2. C40 velocity is 331.86136 ms^{-1} .

5.3 Results of MASW survey at site 3

5.3.1 Dispersion curve

We took 2 shots at site 3, so we get 2 dispersion curves after F-K analysis.

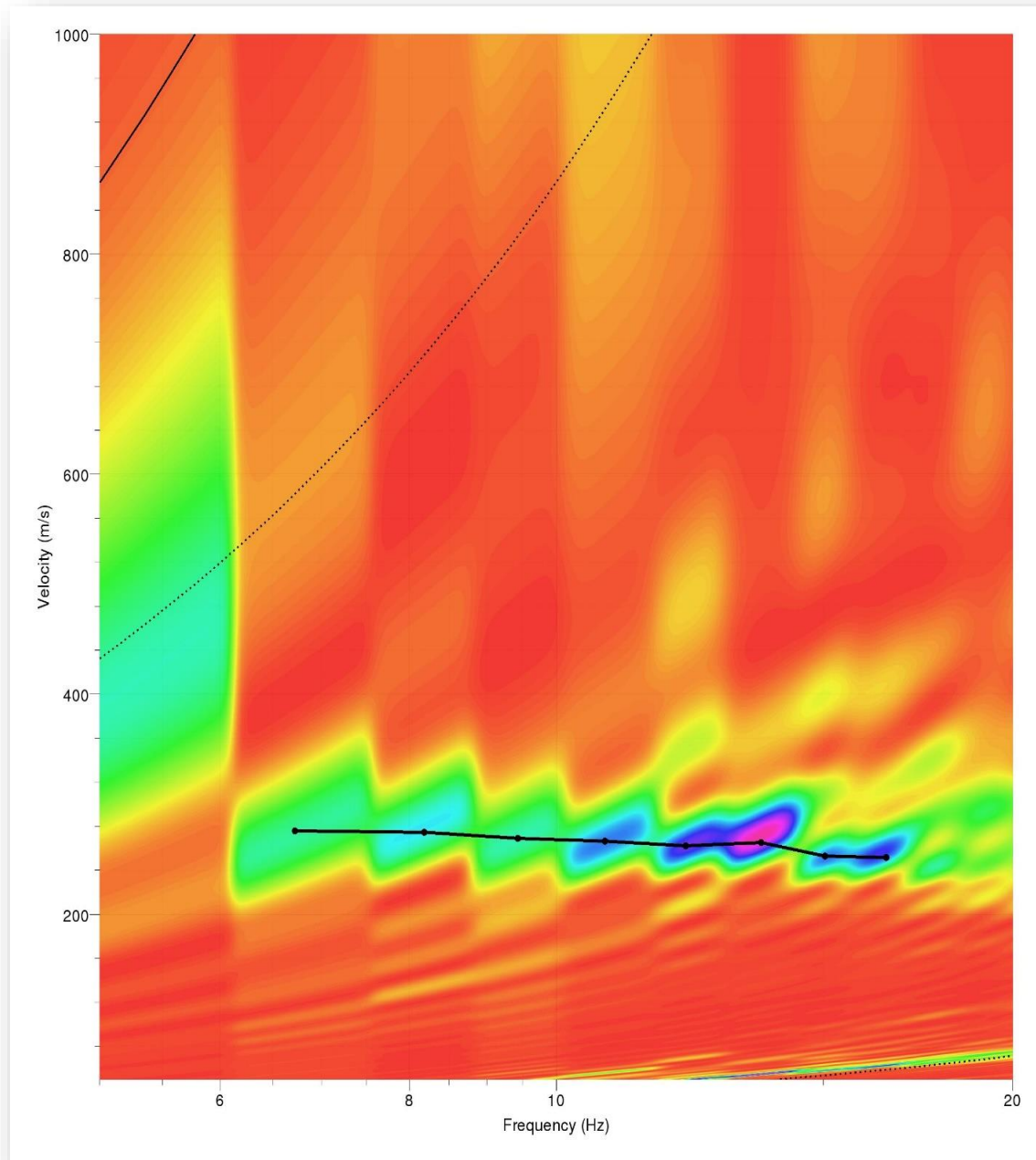


Figure 5.11. Dispersion curve of shot 1 of MASW survey at site 3 which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

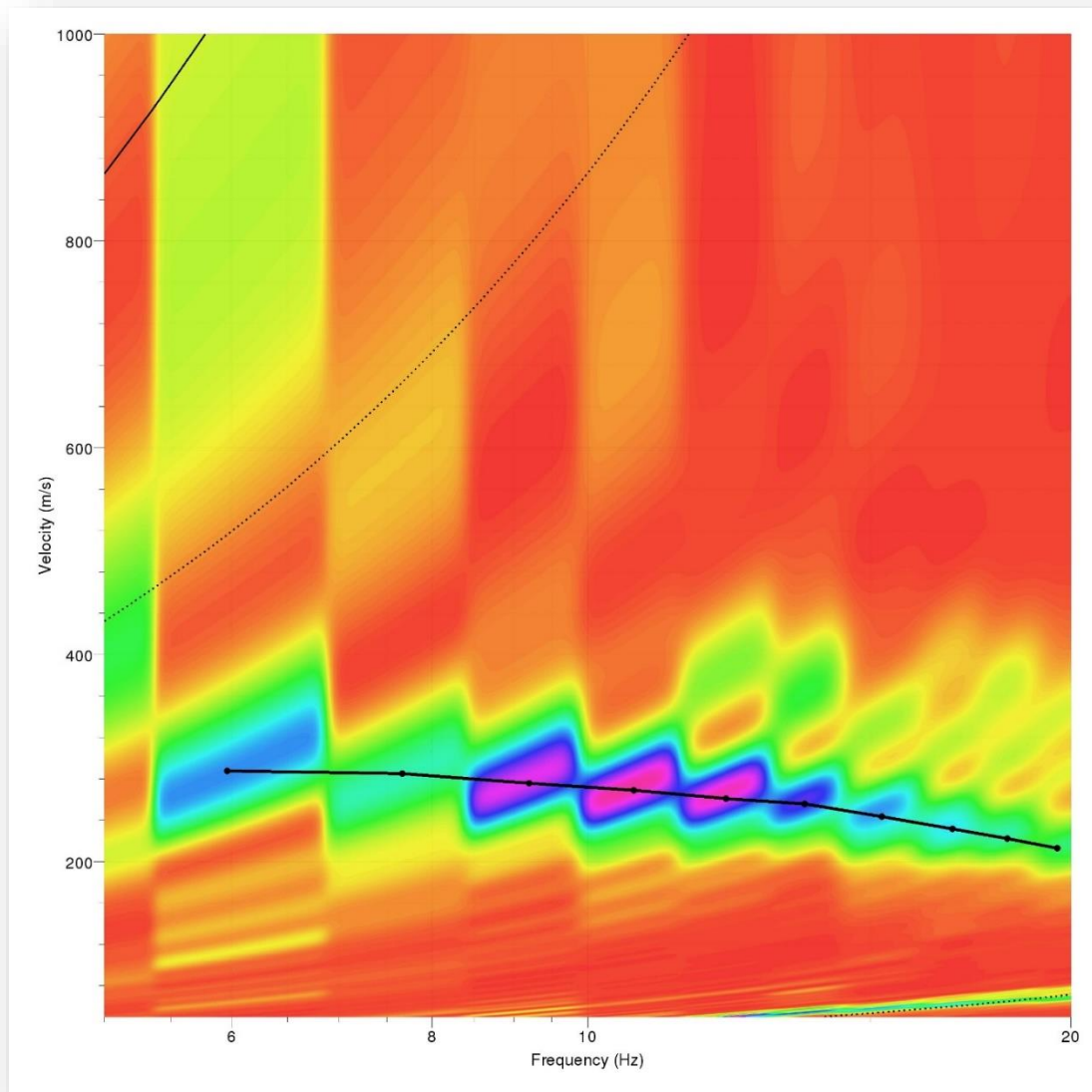


Figure 5.12. Dispersion curve of shot 2 of MASW survey at site 3 which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

5.3.2 Combination of dispersion curve

We choose the highest amplitudes after the dispersion curve, and then we combine all those curves using Dinver tool.

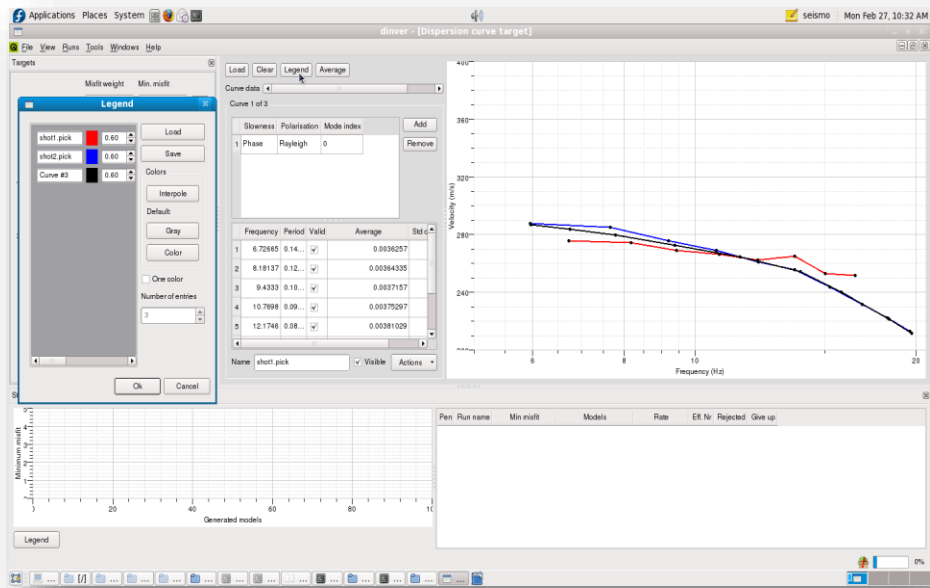


Figure 5.13. Combining maximum amplitude of dispersion curves using Dinver tool, the more these curves overlap each other more the reliable are results of survey

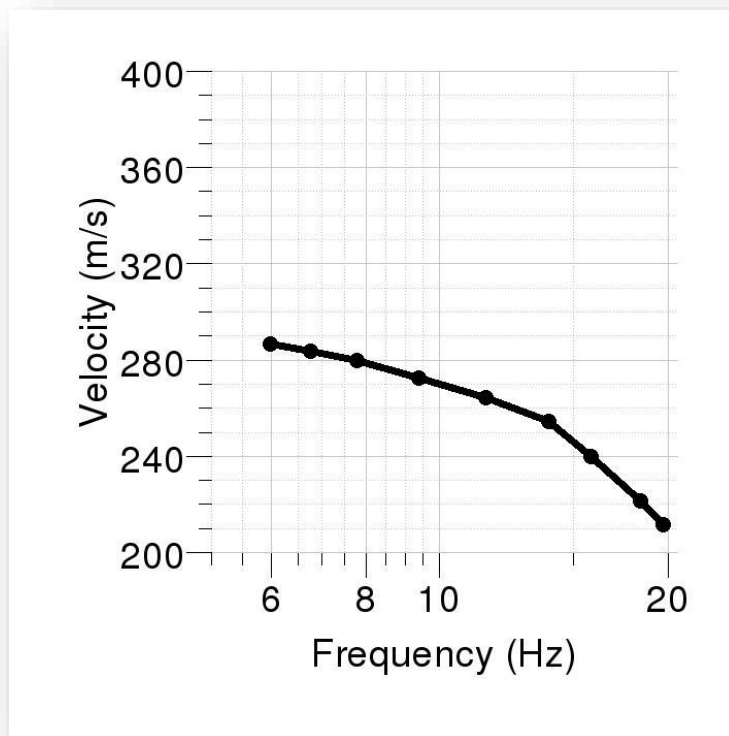


Figure 5.14. After running Dinver tool, we get the final combined curve which is then used to make graph of shear wave velocity

We calculate theoretical dispersion curves and by running misfit model, we calculate shear wave velocity curve.

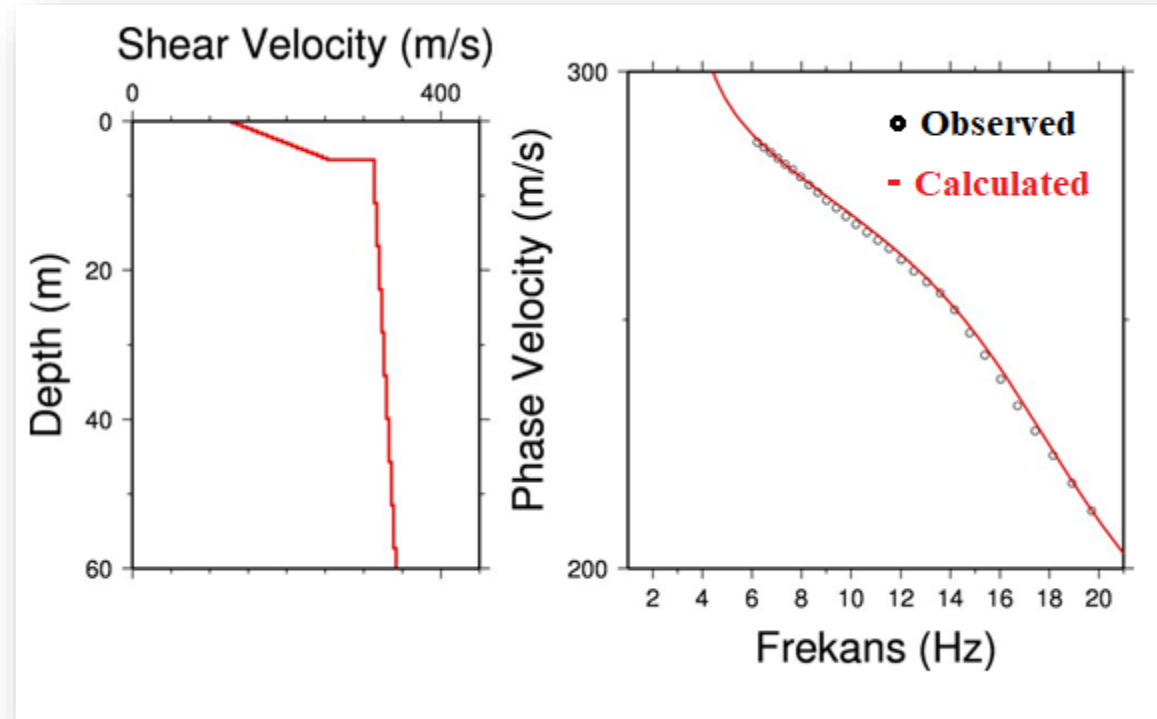


Figure 46. Shear wave velocity curve of site 3 showing shear wave velocity with depth, while the curve on right represents observed curve which is obtained from dispersion curve while the other is calculated using mathematical formulae

V_s 30 calculated at 3rd site at 33.709681 latitude and 73.024167 is $277.58026 \text{ ms}^{-1}$. According to NEHRP code we get building codes of D.

It has least value of V_s 30 of all three sites. It also falls in category of D in NEHRP. It also accounts for stiff soil with dense sand or stiff clay. Unlike 1st site there is no sudden increase in shear wave velocity. Up till 60 meters there are almost same velocity indicating stiff soil in subsurface and not hard rocks as in 1st site. C40 velocity is $282.46317 \text{ ms}^{-1}$. It is also least of all 3 sites. It can be calculated by frekans curve.

5.4 NEHRP codes

NEHRP building codes are American standard. American geology resembles with Pakistani geology, so we follow NEHRP building codes.

NEHRP Site Classification

NEHRP SITE CLASS	SOIL PROFILE	Vs30 (m/sec)
A	Hard Rock	> 1500
B	Rock	760 – 1500
C	Very dense soil and soft rock	360 - 760
D	Stiff soil	180 – 360
E	Soft soil	< 180
F	Special study requiring soils (e.g., liquefiable soils, sensitive clays, organic soils, soft clays > 36 m thick)	

**Vs30 = 168 m/s
Site Class E**

Figure 5.15. NEHRP building codes which are American standard and shows type of soil according to value of shear wave velocity

5.5 Shear wave velocity of all sites of F9 Park

Shear wave velocity of all 3 sites are presented in form of table.

Table 5.1. Vs 30 values of all three sites F9 Park along with latitude and longitudes

Site	Latitude	Longitude	Vs 30	NEHRP code
Site 1	33.69885	73.01719	356.83908	D
Site 2	33.706467	73.026707	343.14331	D
Site 3	33.709681	73.024167	277.58026	D

5.6 Soil profile

By using graph of shear wave velocity, we created soil profile of F-9 park indicating soil using NEHRP codes. The soil classification is based on NEHRP codes. This displays subsurface soil type in F-9 Park at all three site.

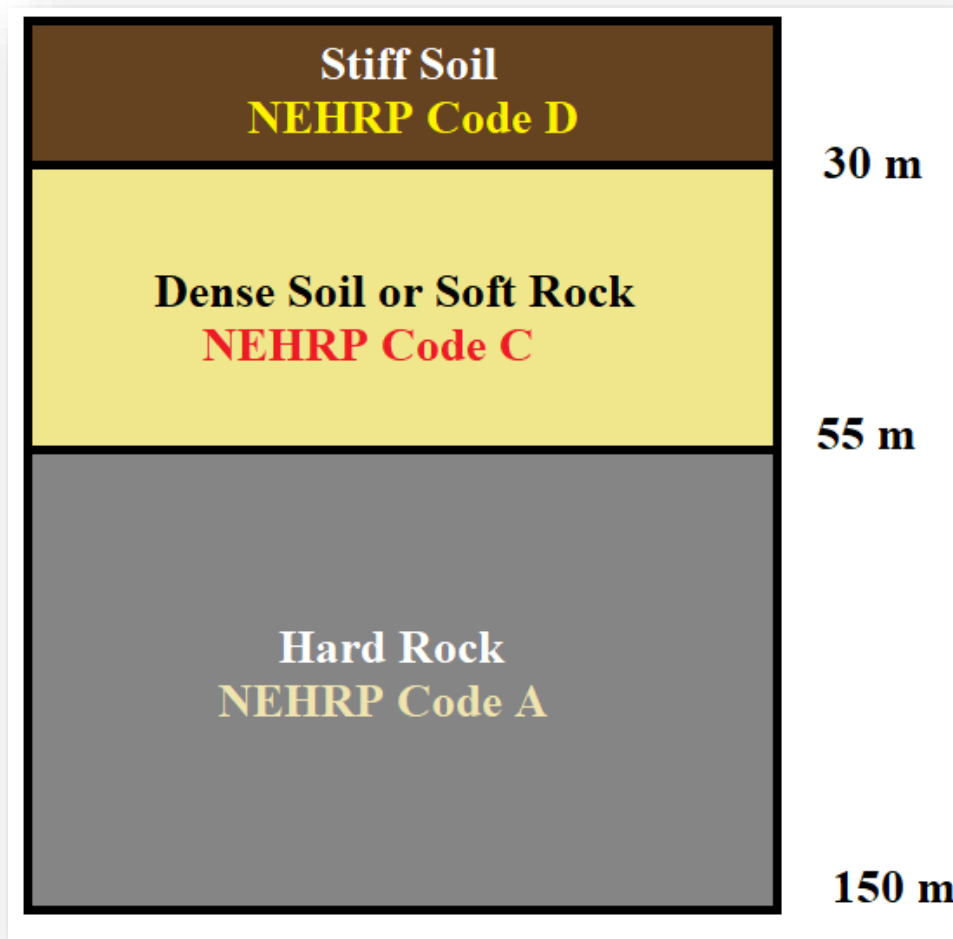


Figure 5.16. Soil profile at site 1 of F-9 Park developed by calculating shear wave velocity using MASW and MAM survey and comparing it with NEHRP codes

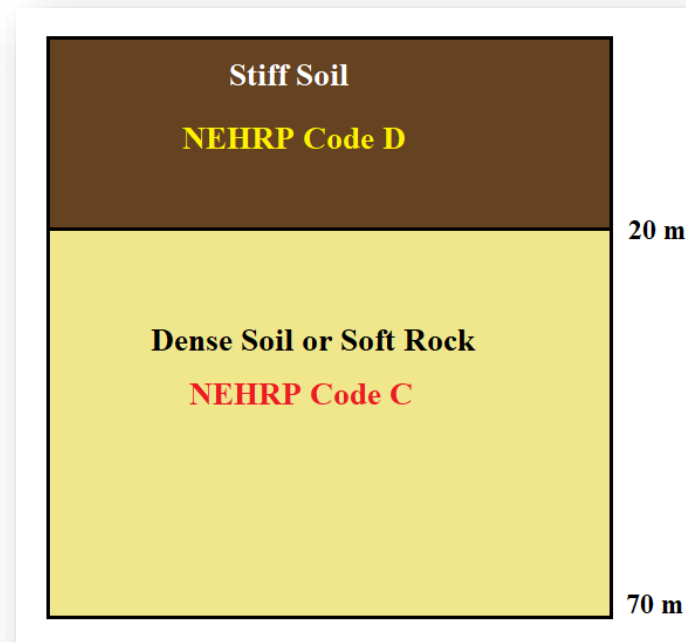


Figure 5.17. Soil profile at site 2 of F9 Park developed by calculating shear wave velocity using MASW survey and comparing it with NEHRP codes

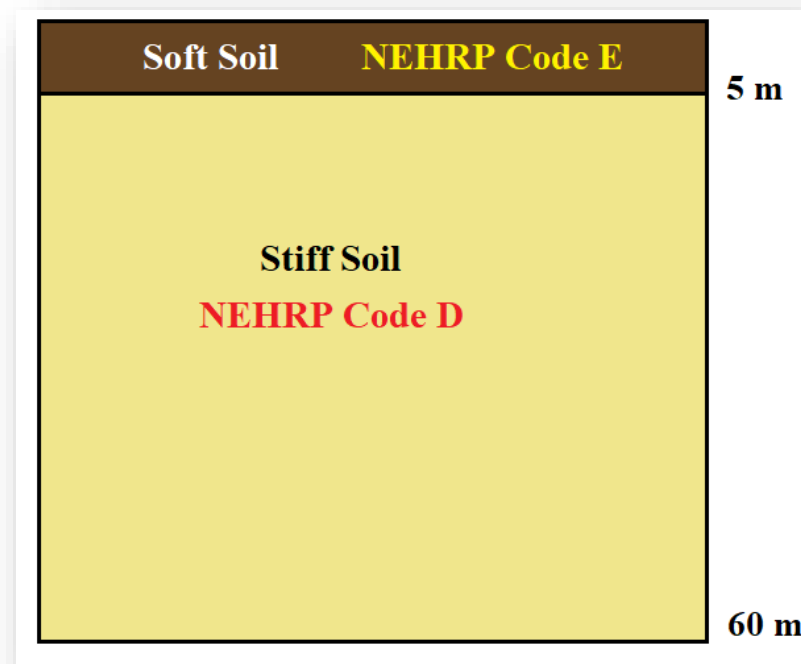


Figure 50. Soil profile at site 3 of F9 Park developed by calculating shear wave velocity using MASW survey and comparing it with NEHRP codes

In F9 Park, shear wave velocity range from 277-356 ms^{-1} , which fall in D category of NEHRP code. So, in subsurface there is stiff soil present or medium or dense sand or stiff clay present. It means the site will face strong ground shaking in event of seismic shaking. Structures that are present on such site will experience stronger shaking. So any project or building build on this site will require seismic retrofiting. The structures must be carefully designed by keeping seismic hazards in view. So proper designing is vital for any project or structure build in this site.

5.7 Results of MASW and MAM survey of COMSATS University

5.7.1 Dispersion curve

After performing F-k analysis, we obtained 5 dispersion curves.

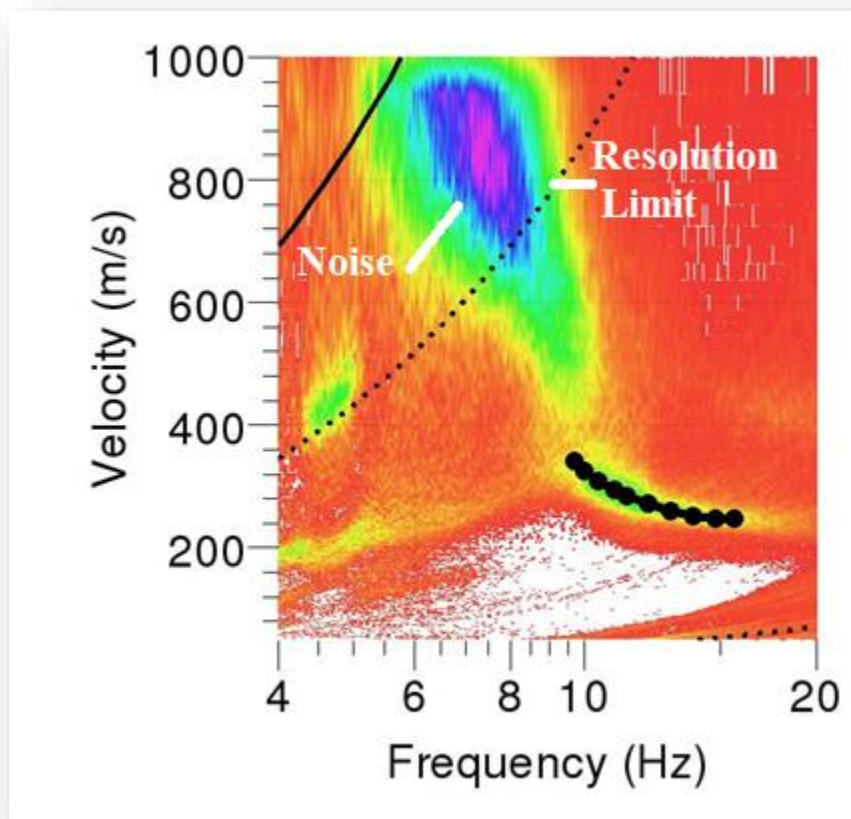


Figure 5.18. Dispersion curve of MAM survey obtained after performing F-k analysis, from curve we pick highest amplitude and below resolution limit, we get noise

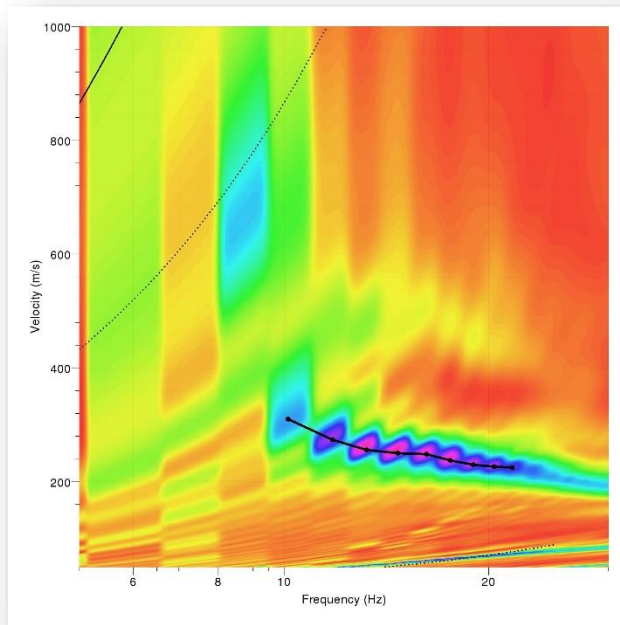


Figure 5.19. Dispersion curve of shot 1 of MASW survey which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

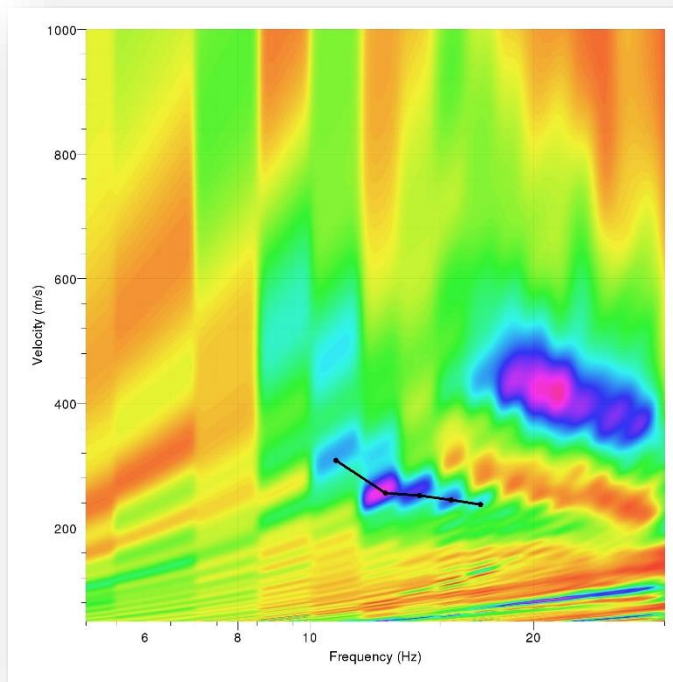


Figure 5.20. Dispersion curve of shot 2 of MASW survey which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

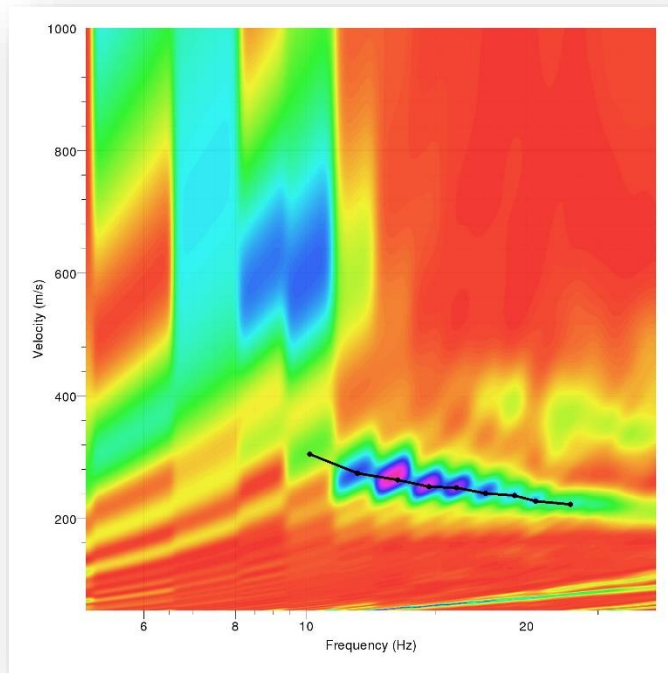


Figure 5.21. Dispersion curve of shot 3 of MASW survey which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

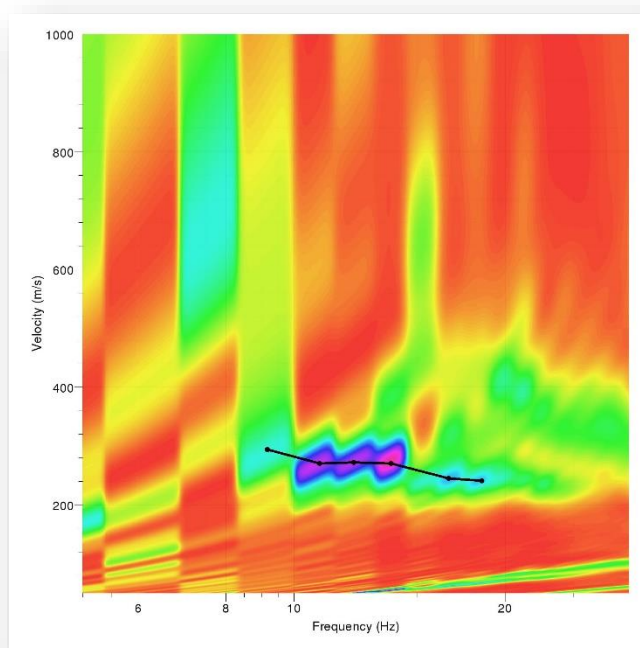


Figure 5.22. Dispersion curve of shot 4 of MASW survey which shows highest amplitude in magenta color, we pick this highest amplitude and make a curve

5.7.2 Combination of dispersion curve

We choose the highest amplitudes after the dispersion curve, and then we combine all those curves using Dinver tool. After that we calculate theoretical dispersion curve and by running misfit model we calculated shear wave velocity curve.

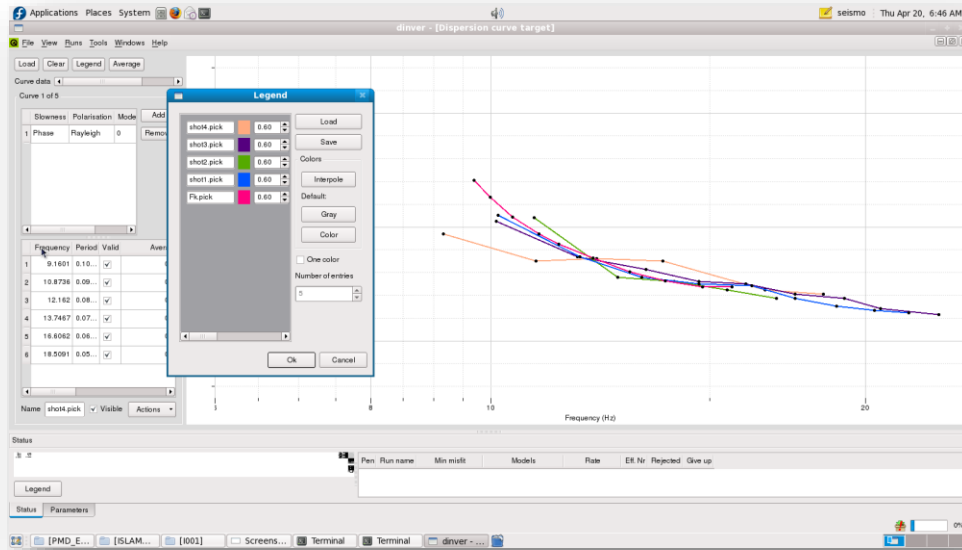


Figure 5.23. After picking maximum amplitudes from dispersion curves from site 2, we combine them and make another curve using Dinver tool. This curve is then utilized to make shear wave velocity curve

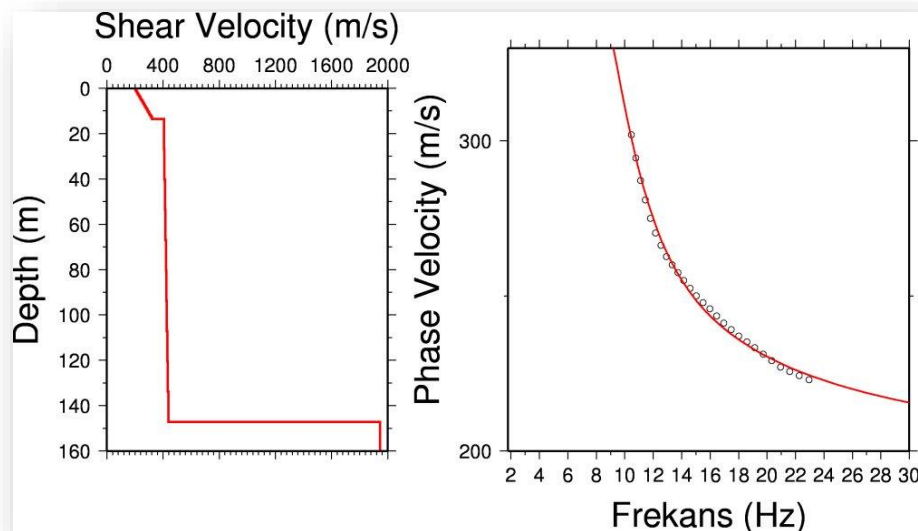


Figure 5.24. Shear wave velocity curve of showing shear wave velocity with depth, while the curve on right represents observed curve which is obtained from dispersion curve while the other is calculated using mathematical formulae

$V_s 30$ calculated at COMSATS University Cricket ground is 320 ms^{-1} . According to NEHRP code we get building codes of D.

It has less shear velocity than F-9 Park but NEHRP codes are same implying stiff soil and dense deposits of sand. C40 velocity is 354.90 ms^{-1} .

5.8 Soil Profile of COMSATS University

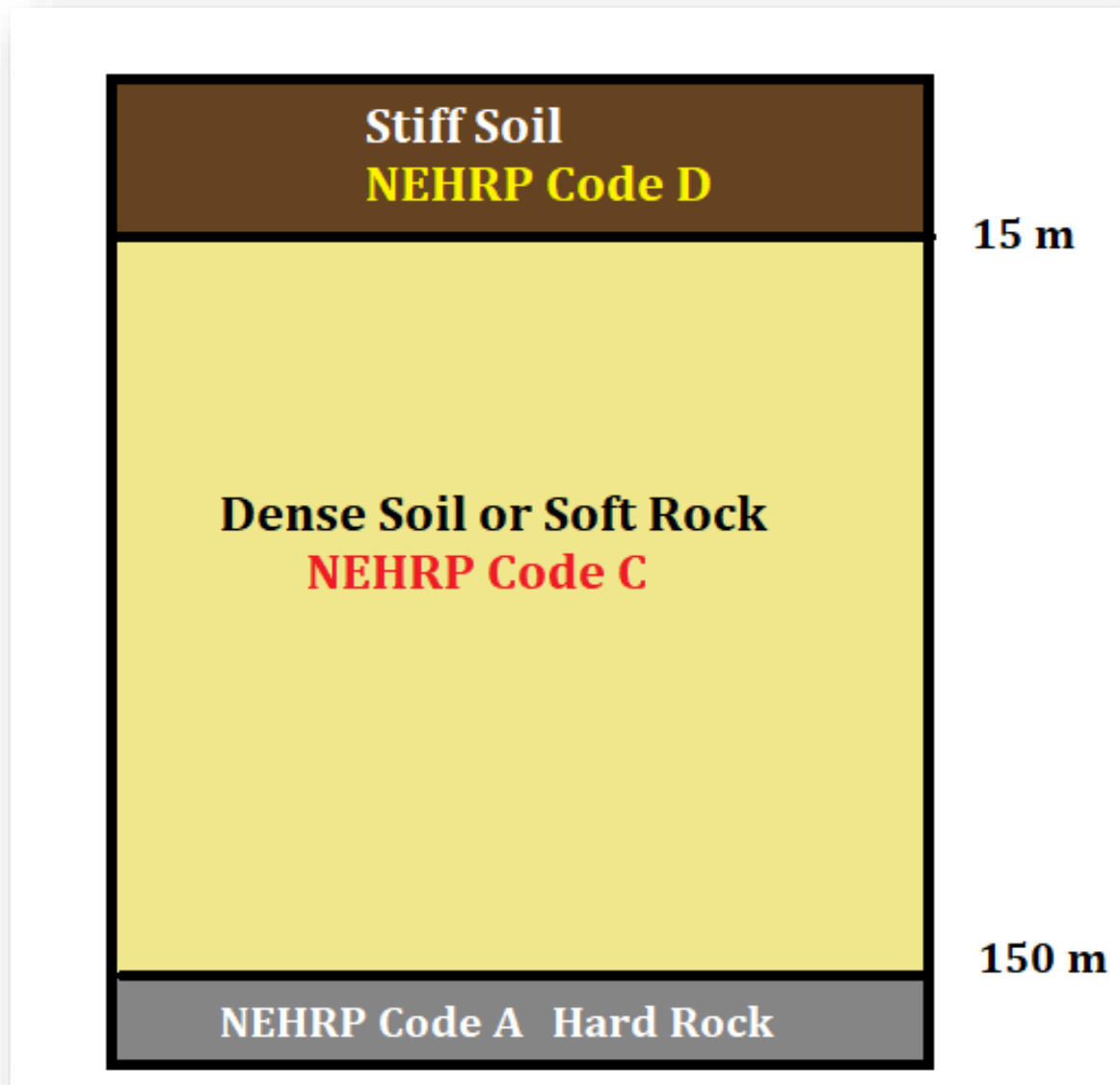


Figure 5.25: Soil profile of COMSATS University cricket ground developed by calculating shear wave velocity using MASW survey and comparing it with NEHRP codes

5.9 Contour map of Islamabad

It is contour map of Islamabad displaying $V_s 30$ values. The values of $V_s 30$ are from F9 Park, Kachnar Park, Jasmine Garden and COMSATS University. It visualizes shear wave velocities. From F9 Park, Kachnar Park, Jasmine Garden we have three values of $V_s 30$ from three different sites and one value from one site from COMSATS University.

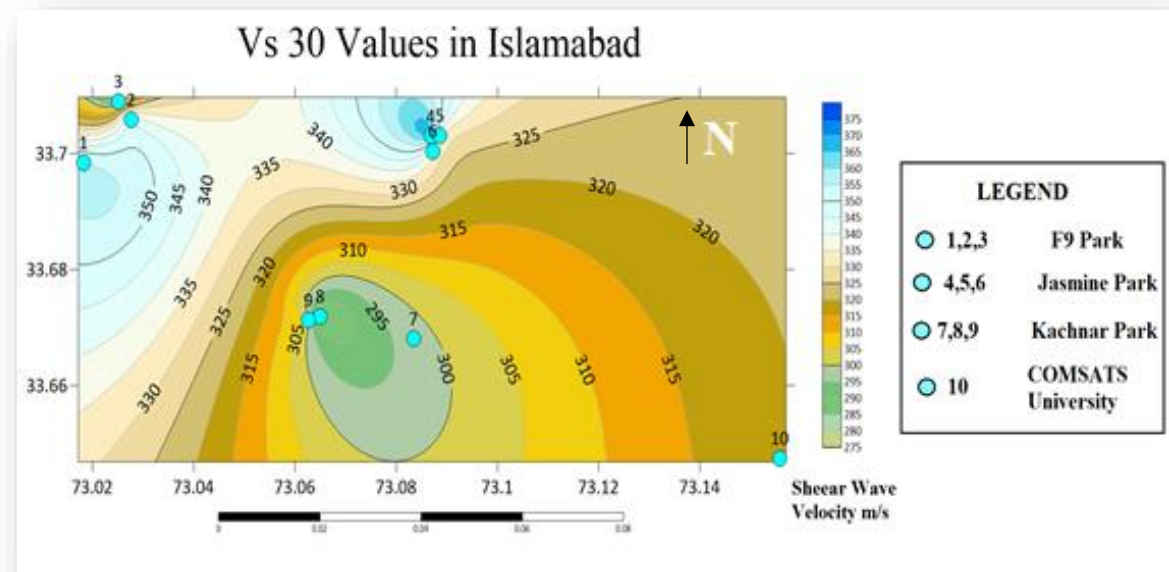


Figure 5.26. Contour map of Islamabad showing shear wave velocities from F9 Park, Kachnar Park, Jasmine Garden and COMSATS University.

Values of F9 and Jasmine Park are slightly higher than Kachnar Park and COMSATS University as those two places are closer to Margalla hills as generally places close to mountain have more $V_s 30$ values because basement rocks are more exposed, but they all fall in same D category of NEHRP codes meaning all structures do require seismic retrofitting and careful planning to protect them from seismic hazards.

CONCLUSION

- 1) By Performing F-K analysis, we developed Dispersion curves for both MAM and MASW survey at all sites which classified amplitude Behavior along with variations of frequency and velocity.
- 2) Shear wave velocity curve was generated by inverting combined Dispersion curves which helped in classifying soil using NEHRP codes.
- 3) Estimated value of V_s 30, categorized possible feasible sites for construction. All sites of F-9 Park and COMSATS University falls in D category according to NEHRP codes

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