URBAN DEVELOPMENT DIRECTORATE (UDD)

Government of the People's Republic of Bangladesh

Geological Study and Seismic Hazard Assessment Under Preparation of Development Plan for Mirsharai Upazila, Chittagong District: Risk Sensitive Landuse Plan (MUDP)

Package No. 2 (Two)

Geophysical and Geotechnical investigations and Geophysical Test Report

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Submitted by

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1. INTRODUCTION

1.1. Background

Bangladesh can earn money in local and also in foreign exchange by opening a tourist resort at Mirsharai. The spot, if properly developed will become an excellent holiday resort and tourist center. The rowing facility can be arranged easily; fishing and hunting facilities are already there. The success of developing Mirsharai as a tourist center and Special Economic Zone depends much on good communication facilities and availability of modern amenities. Moreover, the proposed Special Economic Zone would generate many industries related new activities including huge vehicular traffic such as air, rail, road and water. This phenomenon would have both positive and negative impacts on the socioeconomic condition and existing land use pattern of the region. The proposed planning package would guide such probable changes in the socio-economic condition and land use pattern of the region, and would also address the adverse impact of such changes.

Landuse planning is an impotent component for a modern urban development. But practicing urban development using a proper landuse plan is not developed in Bangladesh. Prior to landuse planning it is very essential to access surface and subsurface geological conditions and the relevant geological hazard and risk in and around the site of future urban development. Therefore a rigorous geological and geotechnical site characterization, including a potential risk analysis need to carry out for a risk resilient urban development.

Urban development is being increasing very fast in Bangladesh. The government has planned to develop Mirsharai as a tourist center and Special Economic Zone. However, risk sensitive urban planning is very important in such a disaster prone country like Bangladesh for a risk resilient urban development in these cities and surrounding area. In those cities Mirsharai is most disaster prone area because of this city is located near one of the most seismo-tectonically active zones of the earth. So this area covers the assessment and management of earthquake, landslide, and hydrometorological hazards in pre-dominantly urban context. Considering the earthquake threat of the populated urban and rural areas of the project, UDD will have to be taken many initiatives for earthquake preparedness of the 16 (Sixteen) unions, including Ichhakhali, Wahedpur, Osmanpur, Karerhat, Katachhara, Khaiyachhara, Zorwarganj, Durgapur, Dhum, Maghadia, Mayani, Mithanala, Mirsharai, Saherkhali, Haitkandi and Hinguli Under Mirshari Upazila Development Plan (MUDP).

Slope stability assessment is very important for any development plan. While the study area is located near and/or in the hilly area, this assessment should be performed before any development plan. In this project our study area is along with hill track, slope stability assessment need to be conducted to protect slope failure and landslide. Geological, Geotechnical and DEM data should be compiled to accomplish this assessment.

Therefore the geological and geotechnical site characterization of the areas including potential seismic hazard and risk analysis is an important component for rick sensitive landuse planning of the populated urban and rural area. In here, Environmental & Geospatial Solutions (EGS) has been entrusted to conduct this project work.

1.2. Location and Accessibility

Mirsharai Upazila (CHITTAGONG DISTRICT) area 482.88 sqkm(BBS)/509.80sqkm, located in between 22°39' and 22°59' north latitudes and in between 91°27' and 91°39' east longitudes. It is bounded by TRIPURA state of India, CHHAGALNAIYA and FENI SADAR upazilas on the north, SITAKUNDA upazila and BAY OF BENGAL on the south, FATIKCHHARI upazila on the east, SONAGAZI and COMPANIGANJ (NOAKHALI) upazilas on the west.Mirsharai Thana was formed in 1901 and it was turned into an upazila in 1983. Mirsharai Upazila consists of 2 Municipality, 16 Union and 103 Mouza(Location of Project Area Figure1.1).

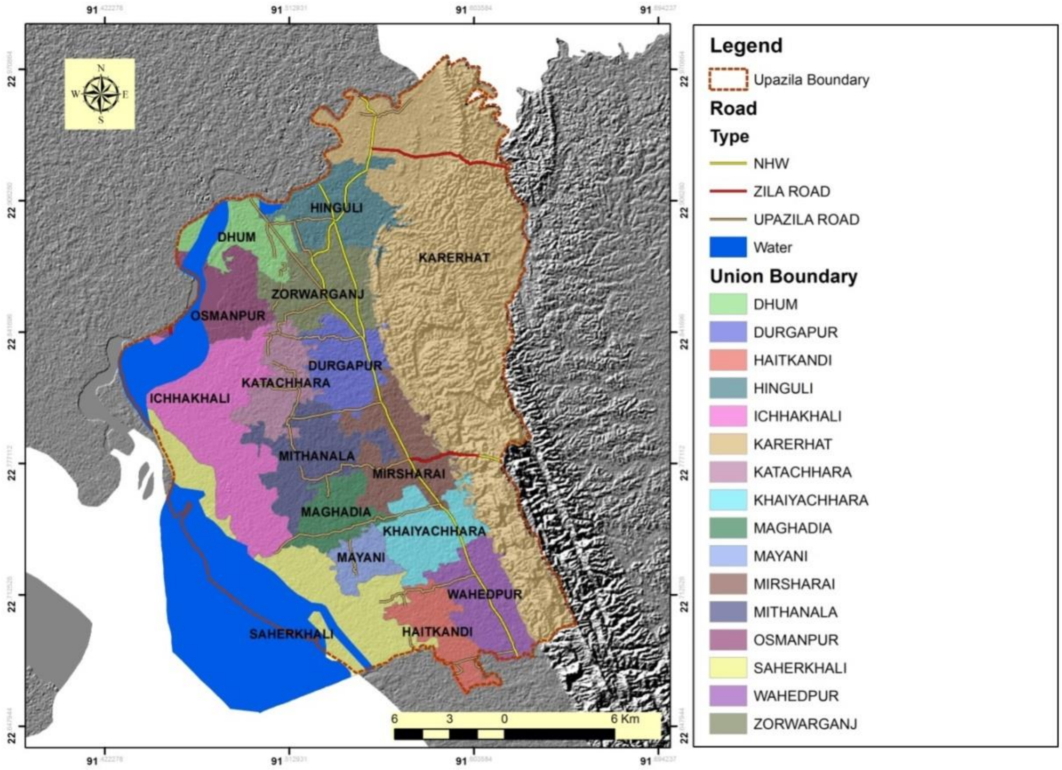


Figure 1.1 Location map of the project area

1.3. Aims and Objectives

The main objective of the research is to carry out a seismic hazard analysis of the 16 (Sixteen) unions, including Ichhakhali, Wahedpur, Osmanpur, Karerhat, Katachhara, Khaiyachhara, Zorwarganj, Durgapur, Dhum, Maghadia, Mayani, Mithanala, Mirsharai, Saherkhali, Haitkandi and Hinguli Under Mirshari Upazila Development Plan (MUDP). The main objective will be achieved through accomplishment of the following sub-objectives:

i. Geological and geomorphologic map of the study area

ii. Sub-surface lithological 3D model development

iii. Soil classification map using geophysical and geotechnical investigations

iv. Engineering geological map development based on AVS30

v. Foundation layers delineation and developing engineering properties of the sub-soil

vi. PGA, Sa (T) Maps of 0.2 and 1.0 second periods values of 10% exceedance probability during next 50 years for local site condition.

vii. Risk Sensitive Building Height

viii. Landslide vulnerable zones will be identified from the study.

ix. Liquefaction potential index (LPI) map will be constructed from study data.

x. Formulation of Policies and plans for mitigation of different types of hazards, minimizing the adverse impacts of climate change and recommend possible adaptation strategies for the region.

2. METHODOLOGY

2.1. Strategic Methodology

The methodology consists of both field and laboratory investigations. To conduct this project work, geomorphological, geotechnical and geophysical data of soil will be collected, analysed and interpreted. Geomorphological data will be collected from image of the study area to prepare a geomorphological map. Geotechnical data will be collected from field investigations *i.e.*, boring, standard penetration test (SPT), and laboratory investigations *i.e.*, soil physical properties test, consolidation test, direct shear test and triaxial test of undisturbed soil sample. Geophysical data will be collected from down-hole seismic test (PS logging) and Multi-channel analysis of surface wave (MASW) and Singles Microtremor survey. The total works will be conducted by the following methodology-

2.1.1. Geophysical Investigation

Field geophysical investigation is conducted to achieve the purpose of seismic risk and damage assessment. Seismic site characterization by analyzing seismic wave propagation velocity from acquired shallow seismic wave form data is the main objective. P-S logging, Multi Channel Analysis of Surface Wave (MASW) and Microtremor tools are involved in geophysical investigation.

General purposes of the geophysical survey:

- To estimate shear wave velocity and measure soil/rock properties (i.e. shear modulus, bulk modulus, compressibility, and Poisson's ratio)
- Engineering geological map development based on AVS30
- To Seismic site response study
- Risk Sensitive Building Height
- Characterization of strong motion sites
- Utilize this information for seismic hazard analysis

2.1.2. Geotechnical Investigation

Geotechnical investigations have become an essential component of every construction to ensure safety of human beings and materials. It includes a detailed investigation of the soil to determine the soil strength, composition, water content, and other important soil characteristics.

Geotechnical investigations are executed to acquire information regarding the physical characteristics of soil and rocks. The purpose of geotechnical investigations is to design earthworks and foundations for structures, and to execute earthwork repairs necessitated due to changes in the subsurface environment. A geotechnical examination includes surface and subsurface exploration, soil sampling, and laboratory analysis. Geotechnical investigations are also known as foundation analysis, soil analysis, soil testing, soil mechanics, and subsurface investigation. The samples are examined prior to the development of the location. Geotechnical investigations have acquired substantial importance in preventing human and material damage due to the earthquakes, foundation cracks, and other catastrophes.

Geotechnical investigations can be as simple as conducting only a visual assessment of the site or as detailed as a computer-aided study of the soil using laboratory tests.

General purposes of the geotechnical survey:

- Sub-surface lithological 3D model development
- Foundation layers delineation and developing engineering properties of the sub-soil
- Landslide vulnerable zones will be identified from the study
- Liquefaction susceptibility or Liquefaction potential index (LPI) map will be constructed from study data

Following investigations given in Table that have been conducted for the MUDP Project area:

Name of Union	Name of investigations			
	Borelog with SPT *(upto 30m)*	PS logging *(30m depth)*	MASW *(30m depth)*	Single Microtremor
Ichhakhali, Wahedpur, Osmanpur, Karerhat, Katachhara, Khaiyachhara, Zorwarganj, Durgapur, Dhum, Maghadia, Mayani, Mithanala, Mirsharai, Saherkhali, Haitkandi and Hinguli	85	15	20	30

2.2. Detail Procedures Of Survey/Testing

The methodology consists of both field and laboratory investigations. To conduct this project work, geomorphological, geotechnical and geophysical data of soil need to be collected, analysed and interpreted. Geomorphological data should be collected from satellite image of the study area to prepare a geomorphological map. Geotechnical data will be collected from field investigations i.e., boring, standard penetration test (SPT), and laboratory investigations i.e., soil physical properties test, unconfined test, direct shear test and triaxial test of undisturbed soil sample. Geophysical data will be collected from down-hole seismic test (PS logging) and Multi-channel analysis of surface wave (MASW) and Singles Microtremor survey. The total works will be conducted by the following methodology-

The method of testing/surveying, application, Instrumentation and previous works of Geophysical and Geotechnical investigation are given below-

2.2.1. Test Detail And Procedure Of Downhole Seismic Test (Ps Logging)

Seismic down hole test is a direct measurement method for obtaining the shear wave velocity profile of soil stratum. The seismic down hole test aims to measure the travelling time of elastic wave from the ground surface to some arbitrary depths beneath the ground. The seismic wave was generated by striking a wooden plank by a 7kg sledge hammer. The plank was placed on the ground surface at around 3 m in horizontal direction from the top of borehole. The plank was hit separately on both ends to generate shear wave energy in opposite directions and is polarized in the direction parallel to the plank.

The shear wave emanated from the plank is detected by a tri-axial geophone. The geophone was lowered to 1 m below ground surface and attached to the borehole wall by inflating an air bladder. Then, the measurements were taken at every 1 m interval until the geophone was lowered to 30 m below ground surface. For each elevation, 6 records were taken and then used to calculate the shear wave velocity. The first arrival time of an elastic wave from the source to the receivers at each testing depth can be obtained from the downhole seismic test.

Figure 2.1 Field Data Acquisition by PS logger

Two geophones are lowered in the hole by keeping them 1.5m apart. There exists two ways of moving geophone either upward or downward. Say, if the hole is 30m then the bottom geophone is kept at 30m and then the top geophone will be at 28.5m and then we bring these geophones upward by taking reading after each meter and for downward is vice versa. In

Downhole Seismic, an accelerometer mounted to a wooden plank source is used to trigger data collection.

Figure 2.2 Main Component of the Freedom Data PC

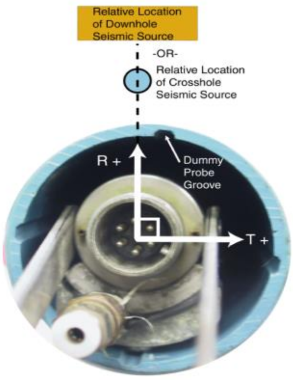


Figure 2.3 Receiver Orientation in Sinco casing

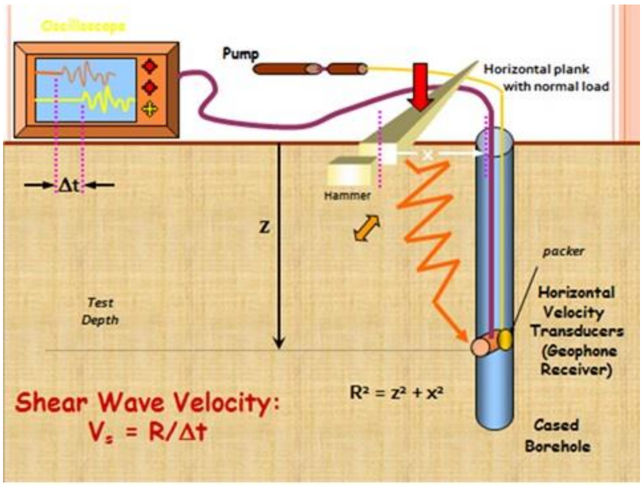


Figure 2.4 Calculation of Shear Wave Velocity by Down hole Seismic, where R_1=Distance between source to top geophone and R_2=Distance between source to bottom geophone

Figure 2.5 To set the wooden plank 1.0 meters from a borehole

Figure 2.6 To attach the trigger to a hammer.

Figure 2.7 To connect the air pump with a battery.

Figure 2.8 To connect the computer with cables which are connected to the geophone.

Figure 2.9 Make sure that the air bag at the geophone works. Then, put the geophone into the borehole and fix the safety rope with the holder

Figure 2.10 Hit the wooden plank in 3 directions which are on the left, right and vertical directions.

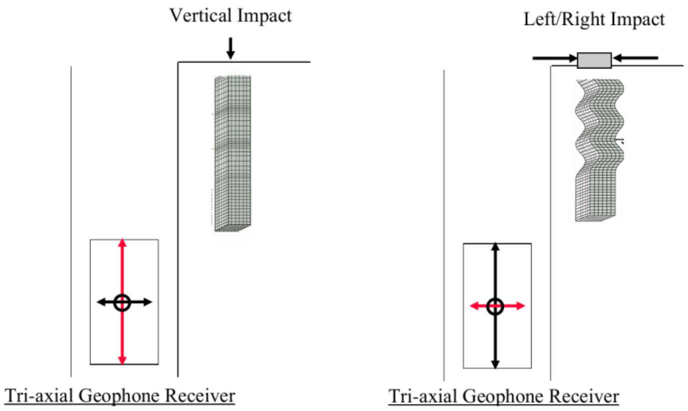


Figure 2.11 Triaxial geophone behavior.

Analysis and Calculation from PS Logging

P-wave travel time is calculated by the first arrival of either peak or trough in the seismic trace and P-wave is characterized by higher frequency and lower amplitude. On the other hand, shear wave is characterized by lower frequency but high amplitude.

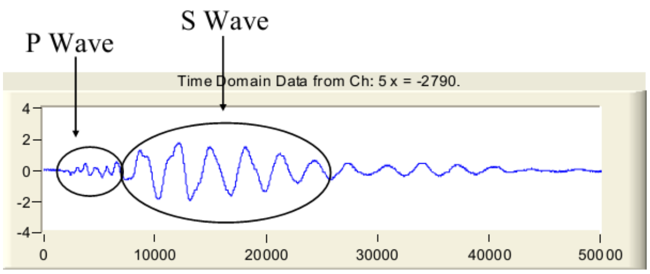


Figure 2.12 P wave and S wave in the Computer Window

S wave travel time is calculated from the first cross as we hit in both direction of the wooden plank so there generate opposite phase shear waves in radial and transverse direction and cross at some points.

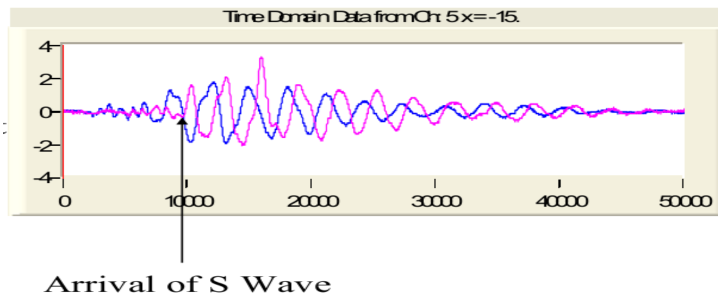


Figure 2.13 Arrival of S wave

Moreover, bounty of engineering geological parameters of soil can be determined whenever shear wave and compressional wave velocity is known. The Shear Modulus (G), Constrained Modulus (M) , Poisson Ratio (ν) and Young Modulus(E) of the soil profiles are calculated using the following formula:

$$G = \rho V_S^2$$
$$M = \rho V_P^2$$
$$\nu = [0.5(\frac{V_P}{V_S})^2 - 1]/[(\frac{V_P}{V_S})^2 - 1]$$
$$E = 2G(1+\nu)$$

Where, *p*is the local soil mass density (unit weight divided by gravity) obtained from the boring log information is taken 2 gm/cc for based on SPT results.

Besides, the average shear wave velocity upto 30 m depth has been determined using the following equation.

$$T_{30} = \sum \frac{Hi}{Vi}$$
$$AVS\ 30 = \frac{30}{T_{30}}$$

Where, Hi : Thickness of i th layer and $30 = \sum Hi$
Vi: S-wave velocity of i th layer

Instrument List

The PS logging test equipments are listed below-

1. One Freedom NDT PC
2. Two High Sensitive Tri-axial Geophones.
3. Two set Cable/Air lineSpool
4. Wooden Plank.
5. 7kg weight Hammer.

Figure 2.14 Freedom Data PC with P-SV Downhole Source and 1 Tri-axial Geophone Receiver used in Crosshole Seismic Investigations

Application of PS Logging Test

Downhole Seismic (PS Logging) system is useable for providing information on dynamic soil and rock properties for earthquake design analyses for structures, liquefaction potential studies, site development, and dynamic machine foundation design. The investigation determines shear and compressional wave depth versus velocity profiles. Other parameters, such as Poisson’s ratios and moduli, can be easily determined from the measured shear and compressional wave velocities. The PS Logging is a downhole method for the determination of material properties of soil and rock.

2.2.2. Test Detail And Procedure Of Multi-Channel Analysis Of Surface Wave (MASW)

MASW utilizes the frequency dependent property of surface wave velocity, or the dispersion property, for Vs profiling. It analyses frequency content in the data recorded from a geophone array deployed over a moderate distance.

The processing of MASW is schematically summarized in Figure 2.15. The principle MASW is to employ and arrange a number of sensors on the ground surface to capture propagating Rayleigh waves, which dominates two-thirds of the total seismic energy generated by impact sources. If the tested ground is not homogeneous, the observed waves will be dispersive, a phenomenon that waves propagate towards receivers with different phase velocities depending on their respective wavelength (see Figure 2.16).

From field observation, the data in space-time domain (for instance, the left plot in Figure 3.19) is transformed to frequency-velocity domain by slant-stack and Fast Fourier transform using

$$S(\omega,c)=\int e^{-i\frac{\omega}{c}x}U(x,\omega)\,dx$$

where $U(x,\omega)$ is the normalized complex spectrum obtained from the Fourier transform of $u(x,t)$, ω is the angular frequency, c is the testing-phase velocity and $S(\omega,c)$ is the slant-stack amplitude for each ω and c, which can be viewed as the coherency in linear arrival pattern along the offset range for that specific combination of ω and c. When c is equal to the true phase velocity of each frequency component, the $S(\omega,c)$ will show the maximum value. Calculating $S(\omega,c)$ over the frequency and phase-velocity range of interest generates the phase-velocity spectrum where dispersion curves can be identified as high-amplitude bands. The dispersion curve is, then, used in inversion process to determine the shear wave velocity profile of the ground.

In theory, a phase-velocity spectrum can be calculated for a known layer model **m** and the field setup geometry. This process is called forward modeling. The inversion process tries to adjust assumed layer model as much as possible through several iterations in order to make the calculated spectrum looks similar to the dispersion curve obtained from the field test. Once the algorithm can match the calculated with the measured one, the assumed model will be considered as the true profile.

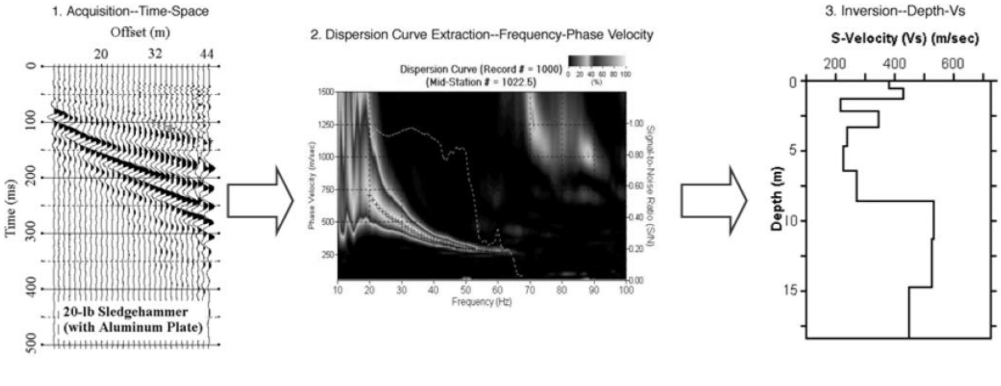


Figure 2.15 MASW data processing (Park et al., 1999)

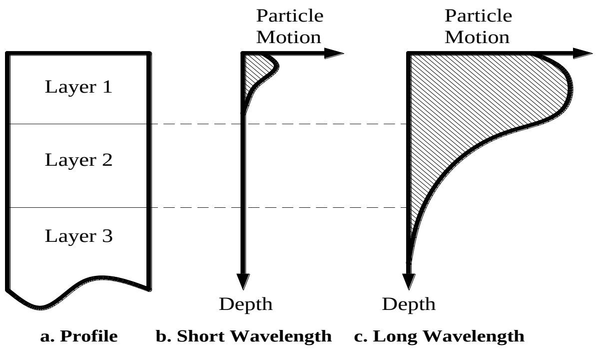


Figure 2.16 Rayleigh wave dispersion in layer media (Rix, 1988)

Active Source Data Acquisition

The active MASW method was introduced in GEOPHYSICS in 1999. This is the most common type of MASW survey that can produce a 2D VS profile. It adopts the conventional mode of survey using an active seismic source (e.g., a sledge hammer) and a linear receiver array, collecting data in a roll-along mode. It utilizes surface waves propagating horizontally along the surface of measurement directly from impact point to receivers. It gives this VS information in either 1D (depth) or 2D (depth and surface location) format in a cost-effective and time-efficient manner. The maximum depth of investigation (z max) is usually in the range of 10–30 m, but this can vary with the site and type of active source used.

Seismic energy for active source surface wave surveys can be created by various ways, but we used a sledgehammer to impact a striker plate on the ground since it is a low-cost, readily available item. To signal to the seismograph when the energy has been generated, a trigger switch is used as the interface between the hammer and the seismograph. When the sledgehammer hits the ground, a signal is sent to the seismograph to tell it to start recording.

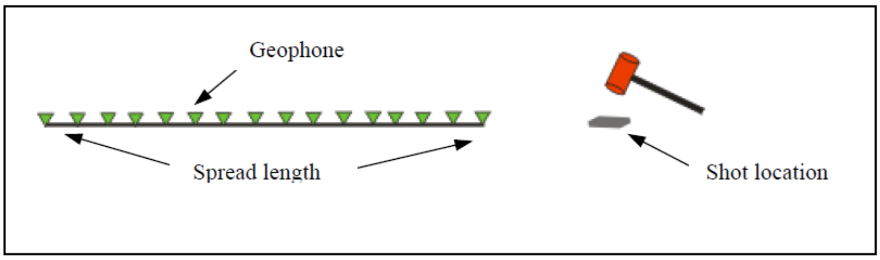
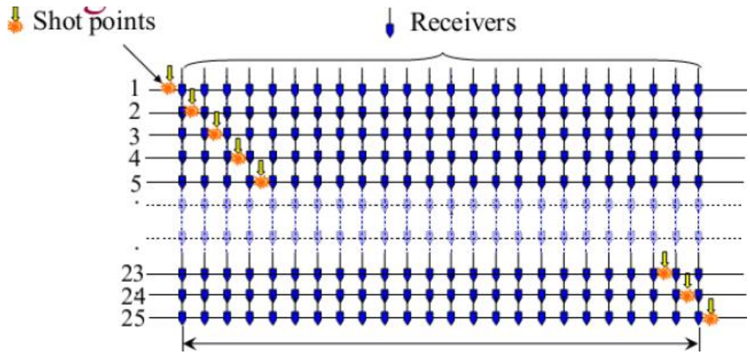


Figure 2.17 Schematic of linear active source spread configuration

During our field work we used 12 channels with 3m interval, 1.5 m source (sledge hammer) offset, 1 ms sample interval, 2 seconds record length and auto trigger option. Natural frequency of Geophone is 10 Hz. And the active source spread configuration for the station 20 was like below:



Survey Line Length

(Number of Sources= Number of Receivers + 1)

Figure 2.18 MASW Field Data Acquisition

At every station one data was acquired by stacking (3 times hammer hit) to enhance the data quality.

Analysis of MASW

In the phase velocity analysis, SPAC (Spatial Autocorrelation) method (Okada, 2003) is employed. Okada (2003) shows Spatial autocorrelation function $\rho(\omega,r)$ is expressed by Bessel function.

$$\rho(\omega, r) = J_0(\omega r / c(\omega)) \text{ -------------------(1)}$$

Where, r is the distance between receivers, ω is the angular frequency, c(ω) is the phase velocity of the waves, J_0 is the first kind of Bessel function. The phase velocity can be obtained at each frequency using equation (1). Figure 3-20 shows an example of dispersion curve of the survey, the frequency range between 15 and 50 Hz.

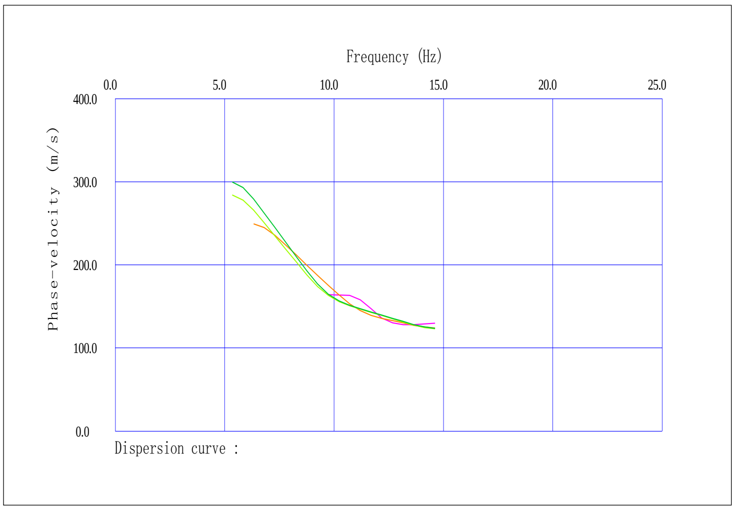


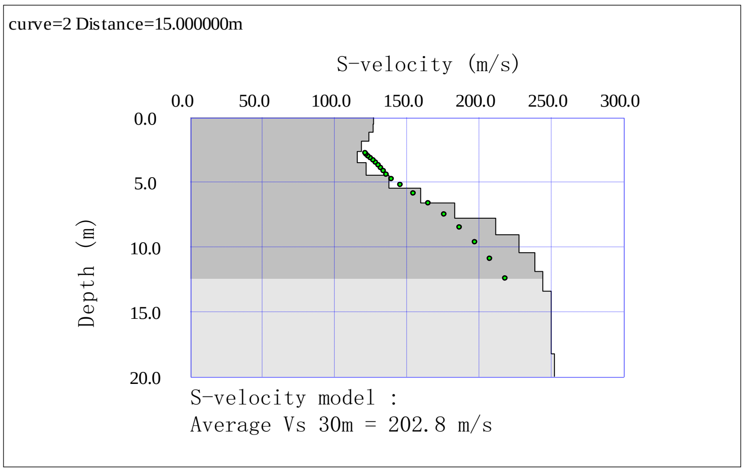
Figure 2.19 Dispersion Curve

A one-dimensional inversion using a non-linear least square method has been applied to the phase velocity curves. In the inversion, the following relationship between P-wave velocity (Vp) and Vs (Kitsunezaki et. Al.., 1990):

$$Vp = 1.29 + 1.11Vs \text{ ------------------------- (2)}$$

Where Vp and Vs are the P-wave velocity and S-wave velocity respectively in (km/sec).

These calculations are carried out along the measuring line, and the S-wave velocity distribution section was analyzed, then summarized to one dimensional structure; SeisImager software can also give a 2-D velocity model (for active), a sample of which is shown in Fig. 2.20.



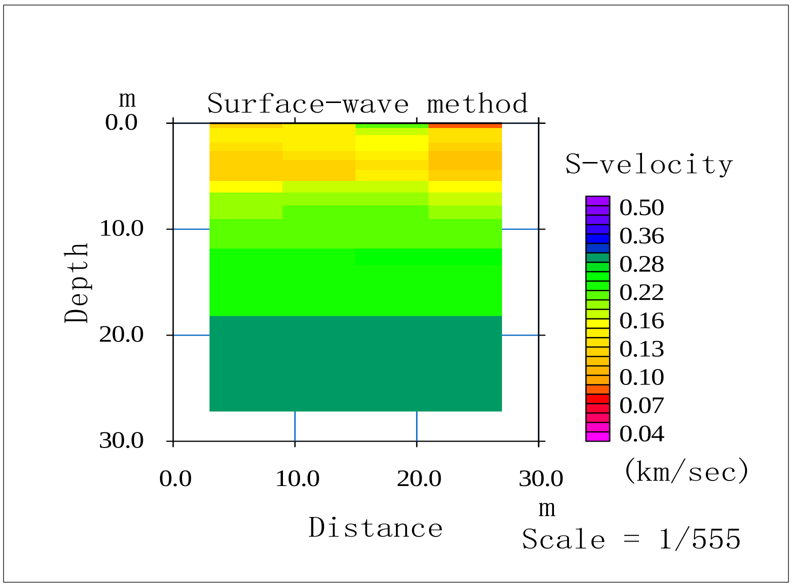


Figure 2.20 One dimensional Velocity Structure and 2 D velocity Model

Figure 2.21 shows an example of dispersion curve for passive MASW and phase velocity versus frequency as a sample. A one dimensional inversion using a non-linear least square method has been applied to the phase velocity curves and one dimensional S-wave velocity structures down (Figure 2.22).

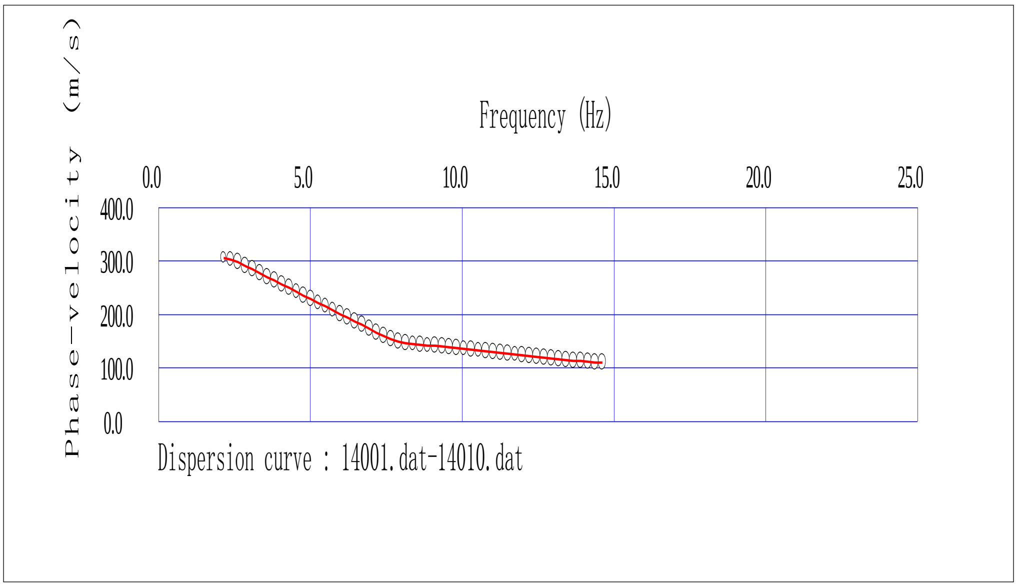


Figure 2.21 Dispersion Curve for MASW

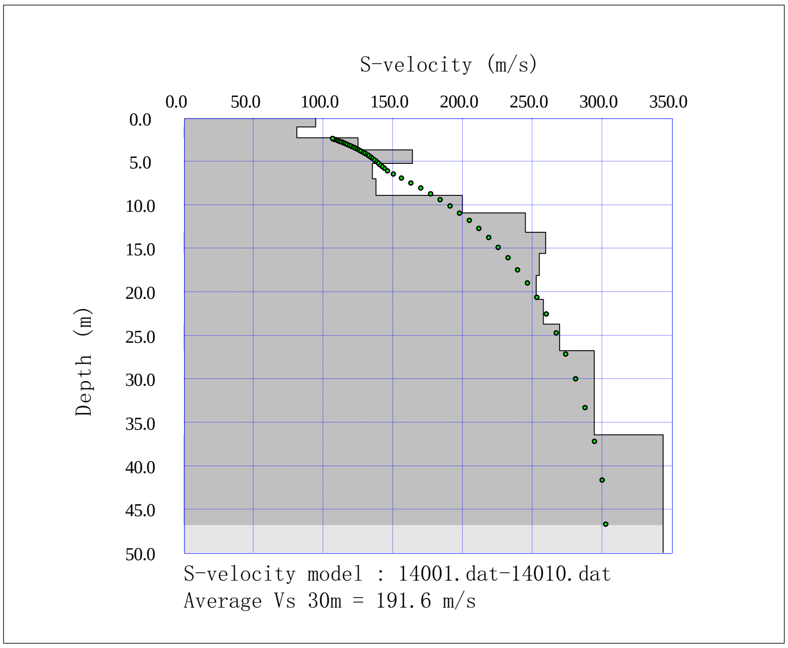


Figure 2.22 One dimensional velocity structure for MASW

Calculation of AVS 30

The AVS30 can be calculated as follows:

$T_{30} = \sum(Hi/Vi)$

AVS 30= $(30/ T_{30})$

Where, Hi= Thickness of the i th layer and $\sum$Hi= 30

Vi= S wave velocity of the I th layer

2.2.3. Test Detail And Procedure Of Microtremor Measurement (Single Microtremor)

Microtremor method is a practical and economical seismic survey since it has potential to explore deep soils without a borehole. Microtremors are the phenomenon of very small vibrations of the ground surface even during ordinary quiet time as a result of a complex stacking process of various waves propagating from remote man-made vibration sources caused by traffic systems or machineries in industrial plants and from natural vibrations caused by tidal and volcanic activities. Observation of microtremors can give useful information of dynamic properties of the site such as predominant period, amplitude, peak ground acceleration and shear wave velocity.

Single Microtremor observation

Method

1) The transfer function of surface layer

$$S_T = \frac{\text{Hor. spectrum at surface}}{\text{Hor. spectrum at base}} = \frac{S_{HS}}{S_{HB}}$$

2) Vertical component of MT is affected by Rayleigh wave at surface, but no effect at base and no amplification of vertical waves.
Define the effect of Rayleigh wave as;

$$E_S = \frac{\text{Ver. spectrum at surface}}{\text{Ver. spectrum at base}} = \frac{S_{VS}}{S_{VB}}$$

3) To eliminate the effect of Rayleigh wave, define new transfer function as;

$$S_{TT} = \frac{S_T}{E_S} = \left(\frac{S_{HS}}{S_{VS}}\right) x \left(\frac{S_{VB}}{S_{HB}}\right) = \left(\frac{S_{HS}}{S_{VS}}\right)$$

(1.0)

$$H / V spectrum = \frac{Hs}{Hv} = \frac{\sqrt{F_{NS} x F_{EW}}}{F_{UD}}$$

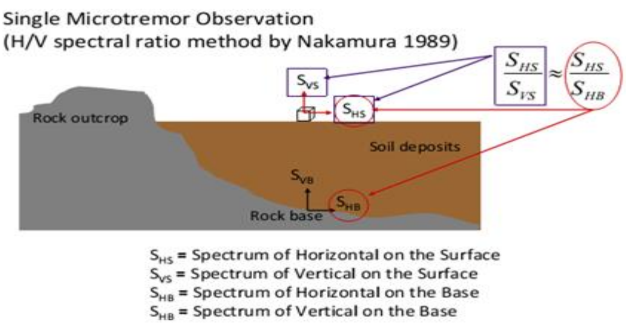


Figure 2.23 Fundamental of Single Microtremor observation

Field Data Acquisition System

Microtremor observations are performed using portable equipment, which is equipped with a super-sensitive sensor, a wire comprising a jack in one site and USB port in another site, and a laptop computer is also used. The microtremor equipment has been set on the free surface on the ground without any minor tilting of the equipment. The N-S and E-W directions are properly maintained following the directions arrowed on the body of the equipment. The sampling frequency for all equipments is set at 200Hz. The low-pass filter of 40Hz is set in the data acquisition unit. Like the seismometer or accelerometer, the velocity sensor used can measure three components of vibrations: two horizontal and one vertical. The natural period of the sensor is 2 sec. A global positioning system (GPS) is used for recording the coordinates of the observation the available frequency response range for the sensor is 0.5-20Hz. sites. The length of record for each observation was 10~20 min. In all fields of this project this data acquisition system has be applied.

Figure 2.24 Field data acquisition of Single microtremor

2.2.4. Standard Penetration Test (SPT) Method

The Standard Penetration test (SPT) is a common in situ testing method used to determine the geotechnical engineering properties of subsurface soils. The test procedure is described in the British Standard BS EN ISO 22476-3, ASTMD1586. A short procedure of SPT N-value test is described in the following paragraph.

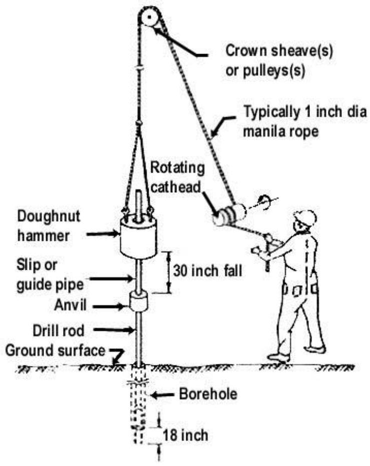


Figure 2.25 The SPT sampler in place in the boring with hammer, rope and cathead (Adapted from Kovacs, et al., 1981)

The test in our field uses a thick-walled sample tube, with an outside diameter of 50 mm and an inside diameter of 35 mm, and a length of around 650 mm. This is driven into the ground at the bottom of a borehole by blows from a slide hammer with a weight of 63.5 kg (140 lb) falling through a distance of 760 mm (30 in). The sample tube is driven 150 mm into the ground and then the number of blows needed for the tube to penetrate each 150 mm (6 in) up to a depth of 450 mm (18 in) is recorded. The sum of the number of blows required for the second and third 6 in. of penetration is termed the "standard penetration resistance" or the "N-value". In cases where 50 blows are insufficient to advance it through a 150 mm (6 in) interval the penetration after 50 blows is recorded. The blow count provides an indication of the density of the ground, and it is used in manyempirical geotechnical engineering formulae.

The main objective of SPT is as follows:

a) Boring and recording of soil stratification.
b) Sampling (both disturbed and undisturbed).
c) Recording of SPT N-value
d) Recording of ground water table.

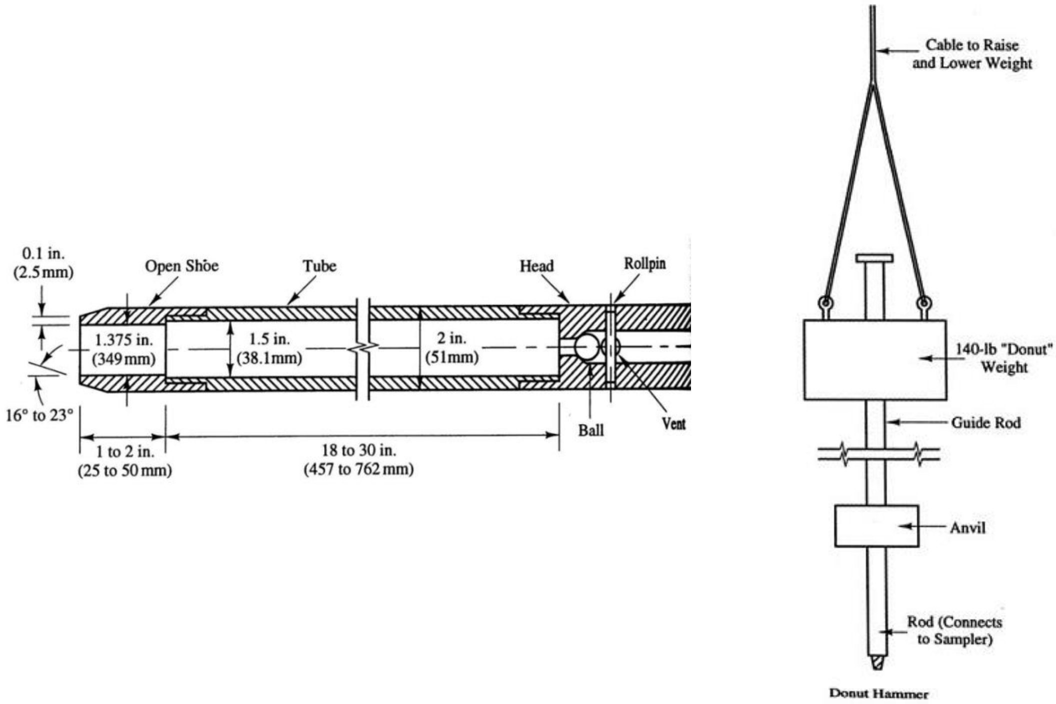


Figure 2.26 SPT Sampler and Donut Hammer

3. GEOPHYSICAL AND GEOTECHNICAL SURVEY

3.1. GEOPHYSICAL INVESTIGATIONS

The main objectives of these investigation to estimate local site effects against earthquakes and the task has been segregated by three-fold: 1) To determine shear wave velocity profile at various sites, 2) To classify soil conditions according to seismic design specifications and 3) To analyze soil amplifications in the area. Field measurements of shear wave velocities were conducted in Mirsharai Upazila and described in below.

Shear wave velocity profile (Vs profile) in the field were carried out by three geophysical exploration methods namely 1) downhole seismic test (PS logging), 2) Multichannel Analysis of Surface Wave (MASW) and 3) Single Microtremor.

Downhole seismic test is a direct measurement method for obtaining the shear wave velocity profile of soil stratum. Multichannel analysis of surface waves (MASW) is a non-invasive technique which can be used to determine the Vs profile at sites. Single Microtremor is used to determine predominant period and compare with Vs data. In this project, the downhole seismic, MASW and Single Microtremor tests were performed at 15, 20 and 30 locations respectively. Geophysical investigations activities and field data acquisition are shown in Figure-3.1.

MASW Field data acquisition

Down-Hole Seismic (PS Logging) Field data acquisition

Single Microtremor Field data acquisition

Figure 3.1 Geophysical investigations activities and field data acquisition

3.1.1. MASW Survey Result

To predict subsurface shear-wave interval velocities, multi-spectral analyses of surface waves (MASW) are popularly used. Shear wave velocities can also extract additional velocity-related information such as mechanical properties of soils and rocks. In general, MASW data compare favorably to other geophysical methods for predicting interval velocities. Furthermore, comparisons to vertical seismic profiles correlate well with MASW predicted shear wave interval velocities. In this perspective, MASW test has been completed at twenty (20) different locations at Mirsharai Upazilla by 15th February to 21st February and field raw data has been processed and also interpreted. Location of MASW tests are shown in Figure-3.2 and Table- 3.1. The investigation and results of the MASW test activities and result are enclosed in Appendix A at tabular and also graphical format.

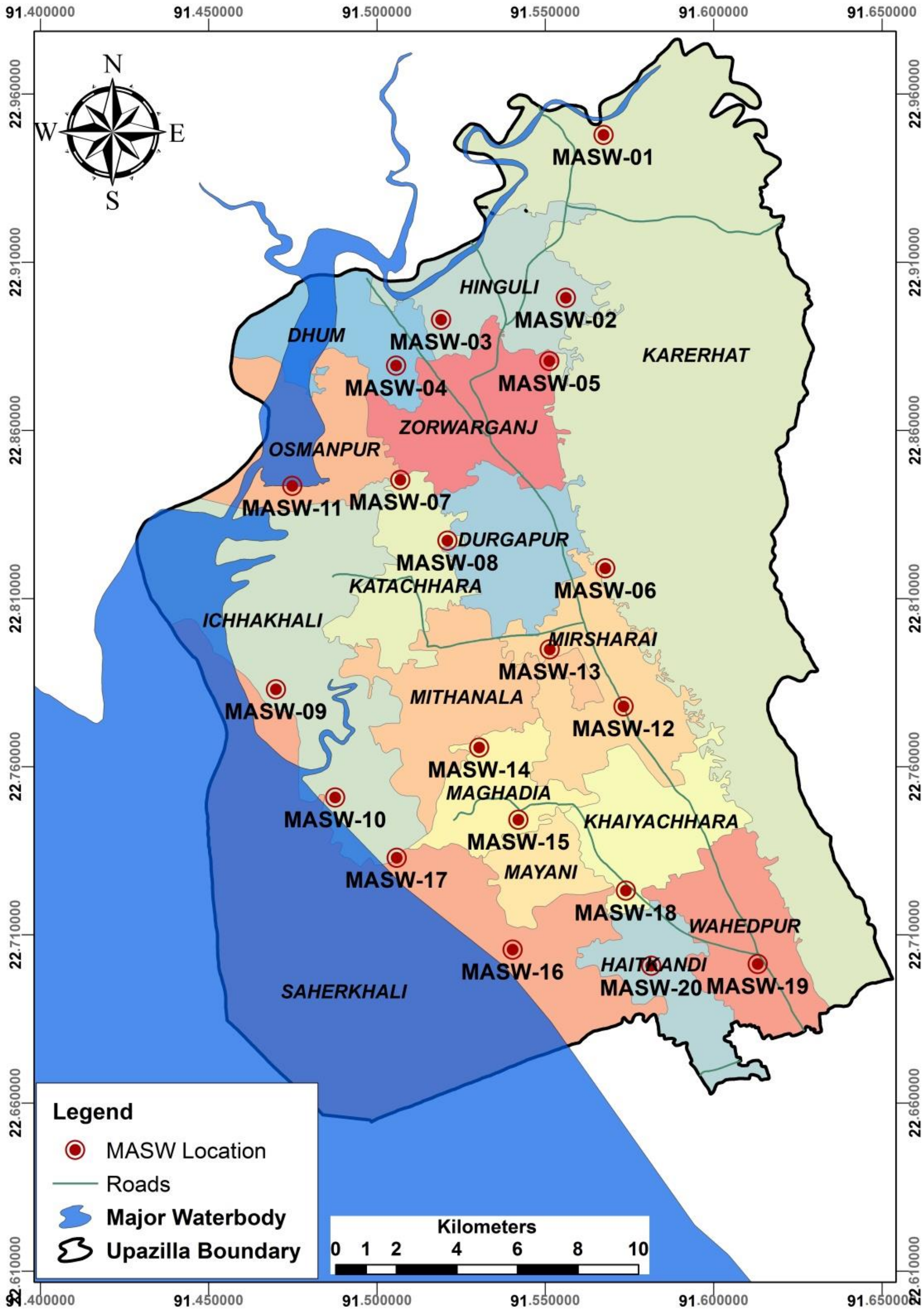


Figure 3.2 Location for MASW survey

Table-3.1 MASW survey location

MASW_ID	Location	Latitude	Longitude
MASW-01	Olinagar L.B. Adorsho High School	22.9479045	91.5673217
MASW-02	Middle Azomnogor, Hinguli	22.89947	91.55612
MASW-03	Jamalpur, Barayarhat Pourashava	22.892964	91.519036
MASW-04	Naherpur, Dhum Union	22.879295	91.505672
MASW-05	Khilmurali, Jorawargonj	22.880663	91.551181
MASW-06	Mohamaya Lake Gate, Mirshorai	22.819062	91.567814
MASW-07	Temohoni, Katachara Union	22.84534	91.506941
MASW-08	Uttav, Katachara Union	22.833622	91.519465
MASW-09	Veribadh, Ichakhali	22.783081	91.469953
MASW-10	BEZA, Ichakhali	22.75094	91.48756
MASW-11	Muhuri Project, Veribadh	22.843563	91.47481
MASW-12	Mirshorai College, Mirshorai	22.77799	91.57322
MASW-13	Bishwo Darbar, Amantola	22.794934	91.551293
MASW-14	Tegoria, Magadia	22.765763	91.530332
MASW-15	Moddhom Magadia Miabari, Magadia	22.74429	91.54198
MASW-16	Veribadh, Saherkhali	22.70568	91.5403
MASW-17	Bamansundar Khal, Shaherkhali, BEZA	22.733001	91.50586
MASW-18	N Hatkumli, Joberhazi Road, Haitkandi	22.72324	91.57393
MASW-19	Choto kamal Daho, Kankir hat bazar road, Wahedpur	22.70142	91.61302
MASW-20	Monir hut, East Hait Kandi	22.70559	91.58147

Table- 3.2 Summary of MASW Test Result

MASW-01		MASW-02		MASW-03		MASW-04		MASW-05	
Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)
0	161	0	158	0	137	0	109	0	138
1.7	163	1.7	187	1.7	149	1.7	121	1.7	156
3.8	164	3.8	209	3.8	160	3.8	129	3.8	178
6.3	166	6.3	221	6.3	185	6.3	171	6.3	212
9.2	176	9.2	244	9.2	216	9.2	201	9.2	240
12.5	186	12.5	269	12.5	241	12.5	224	12.5	261
16.3	194	16.3	288	16.3	262	16.3	238	16.3	278
20.4	200	20.4	301	20.4	274	20.4	250	20.4	289
25	205	25	317	25	290	25	270	25	296
30	205	30	317	30	290	30	270	30	296
AVS 30 - 183.8 m/s		AVS 30 - 250.7 m/s		AVS 30 - 217.6 m/s		AVS 30 - 191.9 m/s		AVS 30 - 232.6 m/s	

Table- 3.2 Summary of MASW Test Result (continue)

MASW-06		MASW-07		MASW-08		MASW-09		MASW-10	
Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)
0	119	0	117	0	123	0	110	0	132
1.7	122	1.7	127	1.7	125	1.7	122	1.7	138
3.8	155	3.8	130	3.8	142	3.8	131	3.8	132
6.3	207	6.3	144	6.3	175	6.3	154	6.3	149
9.2	244	9.2	165	9.2	201	9.2	177	9.2	172
12.5	266	12.5	197	12.5	219	12.5	195	12.5	199
16.3	289	16.3	221	16.3	234	16.3	212	16.3	219
20.4	312	20.4	244	20.4	241	20.4	226	20.4	237
25	326	25	262	25	248	25	234	25	263
30	326	30	262	30	248	30	234	30	263
AVS 30 - 225.2 m/s		AVS 30 - 181.1 m/s		AVS 30 - 194.1 m/s		AVS 30 - 177.2 m/s		AVS 30 - 186.1 m/s	

MASW-11		MASW-12		MASW-13		MASW-14		MASW-15	
Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)
0	134	0	156	0	113	0	130	0	151
1.7	141	1.7	159	1.7	122	1.7	136	1.7	154
3.8	144	3.8	160	3.8	125	3.8	159	3.8	168
6.3	149	6.3	176	6.3	159	6.3	183	6.3	189
9.2	161	9.2	211	9.2	192	9.2	210	9.2	212
12.5	175	12.5	238	12.5	214	12.5	230	12.5	233
16.3	187	16.3	265	16.3	236	16.3	242	16.3	251
20.4	194	20.4	286	20.4	257	20.4	249	20.4	265
25	210	25	318	25	287	25	254	25	281
30	210	30	318	30	287	30	254	30	281
AVS 30 - 170.9 m/s		AVS 30 - 222.7 m/s		AVS 30 - 190.6 m/s		AVS 30 - 204.2 m/s		AVS 30 - 217.2 m/s	

MASW-16		MASW-17		MASW-18		MASW-19		MASW-20	
Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)	Depth (m)	Velocity (m/s)
0	113	0	94	0	120	0	117	0	116
1.7	111	1.7	103	1.7	124	1.7	125	1.7	122
3.8	130	3.8	140	3.8	142	3.8	139	3.8	130
6.3	151	6.3	175	6.3	161	6.3	180	6.3	143
9.2	172	9.2	207	9.2	179	9.2	207	9.2	161
12.5	190	12.5	217	12.5	200	12.5	230	12.5	185
16.3	199	16.3	220	16.3	213	16.3	247	16.3	209
20.4	203	20.4	221	20.4	236	20.4	262	20.4	233
25	206	25	221	25	263	25	291	25	250
30	206	30	221	30	263	30	291	30	250
AVS 30 - 168.1 m/s		AVS 30 - 178.9 m/s		AVS 30 - 186.0 m/s		AVS 30 - 201.8 m/s		AVS 30 - 175.4 m/s	

- Velocity below 160 m/s
- Velocity 160 m/s to 200 m/s
- Velocity 201 m/s to 240 m/s
- Velocity 241 m/s to 280 m/s
- Velocity above 280 m/s

The shear wave velocity is a fundamental parameter required to definethe dynamic properties of soils. If the soil velocity is less then 180m/s, it can be say as loose or soft soil. Estimation of shear wave velocity (Vs) / average shear wave velocity (AVS) and mapping is a way to characterize varying site conditions, and it can also be used to model earthquake-related ground shaking (e.g., Petersen and others, 1997; 1999; Wills and others, 2000). Estimation of AVS aims to generate a map of estimated shear wave velocities for the upper 30m of the subsurface. Further this map can be used for seismic site response analysis i.e., to determine peak ground acceleration (PGA) and spectral acceleration (SA) values of both bedrock and ground surface.

According to MASW test results S-wave velocity more than 180 m/s varies from 6.3m to 12.5m depth, which is suitable for foundation (Table-3.2). Foundation depth should be varies from around 6m to 13m in overall Mirsharai Upazila.

3.1.2. Down-Hole Seismic (PS Logging) Test Results

As a fundamental parameter, shear wave velocity is required to define the dynamic properties of soils. If the soil velocity is less than 180m/s, it can be say as loose or soft soil. Estimation of shear wave velocity (Vs) / average shear wave velocity (AVS) and mapping is a way to characterize varying site conditions, and it can also be used to model earthquake-related ground shaking. Estimation of AVS aims to generate a map of estimated shear wave velocities for the upper 30m of the subsurface. Further this map can be used for seismic site response analysis i.e., to determine peak ground acceleration (PGA) and spectral acceleration (SA) values of both bedrock and ground surface. In this context, Downhole seismic test data acquisition has been completed at Mirsharai Upazilla in fifteen (15) different locations on date 19th February to 27th February 2018. Location of PS logging tests are shown in Figure-3.3 and Table-3.3. Field data has been processed, and the investigation of downhole seismic test is enclosed in Appendix B at tabular and also graphical format.

Downhole seismic (PS Logging) data shows S-wave velocity more than 180 m/s at different depth in different locations at Mirashari Upazila, which varies from 6 to 15m at different locations (Table 3.4).

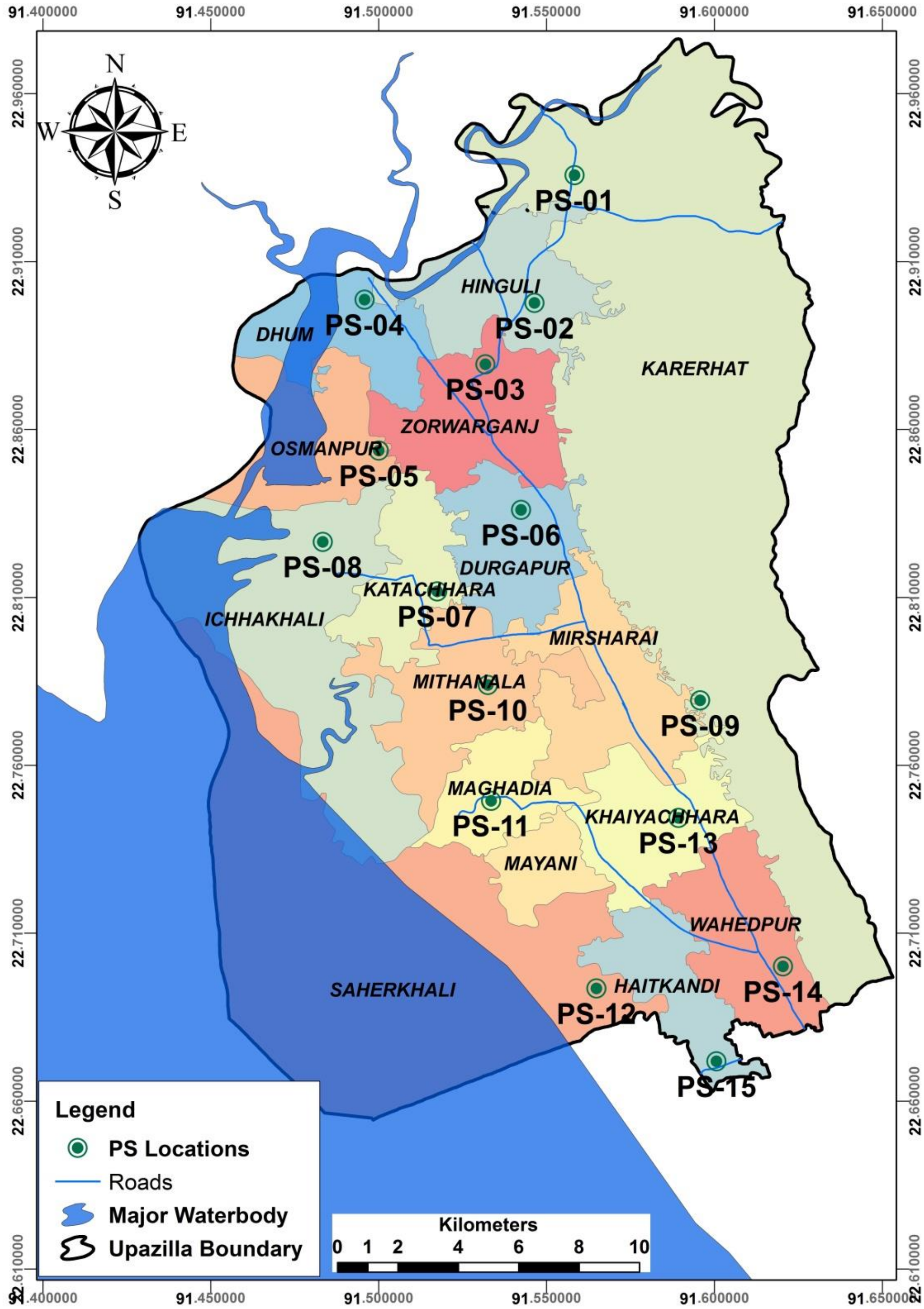


Figure 3.3 Location for PS Logging test

Table-3.3 Location of Downhole Seismic (PS logging) test

PS_ID	Borehole_ID	Location	Latitude	Longitude
PS-01	BHM02	Choturua, Ward-1, Korerhat	22.93579	91.55832
PS-02	BHM07	Khil hinguli Govt. Primary School	22.89774	91.5464
PS-03	BHM11	Imampur Titabot tola Furkania Madrasha	22.87949	91.53175
PS-04	BHM12	Bono Chowdhury Jame Mosque, Mobarokguna, Dhoom	22.89871	91.49581
PS-05	BHM20	39 no. East Shahedpur Govt. Primary School, Azampur	22.85378	91.50001
PS-06	BHM25	Jaforer Poultry Farm, Choitonner Hat, Durgapur	22.83615	91.54239
PS-07	BHM27	Abdus Sattar Bhuiyar Hat Govt. Primary school, Kata chora	22.81188	91.51746
PS-08	BHM35	Vanguni Bazar Baitunnur Jame Mmosque, Ichakhali	22.82661	91.48335
PS-09	BHM38	Ichakhali Economic Zone Office, Ichakhali	22.76242	91.46612
PS-10	BHM56	Hazi Badiul Alam Chowdhury Govt. Primary School, Mithanala	22.78397	91.53249
PS-11	BHM60	90 no. Maghadia NC Govt. Primary School, Maghadia	22.74951	91.53351
PS-12	BHM69	Dhoomkhali, Shaherkhali	22.69363	91.56484
PS-13	BHM72	Morjida Masima Taluk, Borotakia	22.74442	91.58926
PS-14	BHM79	West Wahedpur Molla para Mosque	22.7002	91.62035
PS-15	BHM84	South Baliadi Govt. Primary School	22.67191	91.60059

Table- 3.4 Summary of Downhole Seismic (PS Logging) Test Result

	PS01 (BH-M02)	PS02 (BH-M07)	PS03 (BH-M11)	PS04 (BH-M12)	PS05 (BH-M20)
Depth(m)	Velocity (m/s)	Velocity (m/s)	Velocity (m/s)	Velocity (m/s)	Velocity (m/s)
1.5	218.20	177.77	133.62	112.81	106.07
3	331.38	168.47	149.36	118.24	96.89
4.5	370.07	180.21	161.78	122.49	153.29
6	191.51	212.53	223.61	88.25	185.62
7.5	303.65	221.51	222.10	183.28	151.84
9	380.95	231.22	228.56	190.27	163.51
10.5	168.56	244.62	304.54	186.40	177.56
12	287.94	237.01	230.00	164.56	128.19
13.5	307.22	234.49	334.73	178.43	215.39
15	288.55	249.24	230.64	192.25	287.39
16.5	336.65	246.72	430.52	211.59	211.44
18	288.86	297.56	383.87	230.90	230.80
19.5	432.76	277.81	431.70	259.73	192.57
21	576.49	292.18	192.63	288.69	384.16
22.5	863.26	277.54	307.82	260.05	226.95
24	1151.69	256.41	165.17	144.70	575.91
25.5	577.60	249.64	288.83	308.19	861.95
27	577.95	249.92	576.73	289.20	576.49
28.5	865.44	264.83	385.03	241.03	
30		270.07	385.02	385.36	

Table- 3.4 Summary of Downhole Seismic (PS Logging) Test Result (continue)

	PS06 (BH-M25)	PS07 (BH-M27)	PS08 (BH-M35)	PS09 (BH-M48)	PS10 (BH-M56)
Depth(m)	Velocity (m/s)	Velocity (m/s)	Velocity (m/s)	Velocity (m/s)	Velocity (m/s)
1.5	126.97	166.16	90.25	177.72	118.34
3	120.13	135.32	95.98	272.26	116.54
4.5	161.38	135.58	123.12	378.50	157.67
6	126.93	136.90	125.60	390.89	156.78
7.5	153.25	187.51	206.10	377.53	277.39
9	128.01	253.95	143.36	380.55	150.03
10.5	146.32	236.31	209.85	273.34	202.70
12	164.71	239.92	229.45	287.76	118.57
13.5	286.95	243.96	197.44	307.03	223.46
15	287.78	252.88	144.40	230.82	168.71
16.5	230.90	262.14	211.53	259.62	349.49
18	384.07	243.30	383.36	288.47	296.69
19.5	288.68	233.23	240.50	231.00	287.76
21	288.89	226.92	192.72	384.49	375.30
22.5	231.39	222.26	211.93	288.67	249.48
24	289.11	242.41	288.86	288.72	178.13
25.5	433.17	240.38	212.06	307.94	215.34
27	231.57	238.21	289.02	288.79	398.42
28.5	308.52	249.91	481.14	231.11	361.03
30	385.75	246.42	577.25	288.83	221.66

Table- 3.4 Summary of Downhole Seismic (PS Logging) Test Result (continue)

	PS11 (BH-M60)	PS12 (BH-M69)	PS13 (BH-M72)	PS14 (BH-M79)	PS15 (BH-M84)
Depth(m)	Velocity (m/s)	Velocity (m/s)	Velocity (m/s)	Velocity (m/s)	Velocity (m/s)
1.5	95.82	119.45	69.50	112.96	78.35
3	184.71	146.61	100.65	166.44	199.44
4.5	140.38	125.42	144.21	169.63	157.09
6	113.89	113.97	183.79	126.76	140.67
7.5	220.13	175.49	243.16	158.47	174.99
9	127.61	190.19	281.87	283.31	226.95
10.5	190.90	256.53	177.60	210.14	153.72
12	164.30	285.91	144.13	191.69	562.21
13.5	197.06	154.33	168.15	187.07	333.34
15	381.64	191.97	164.93	287.39	164.65
16.5	197.51	146.51	226.50	197.66	187.21
18	192.19	230.43	144.57	164.93	164.80
19.5	240.11	226.41	430.84	197.84	230.53
21	192.34	192.33	384.23	192.43	192.29
22.5	192.38	230.73	231.25	216.41	192.36
24	288.30	192.42	384.92	288.42	192.37
25.5	274.63	168.42	371.03	480.06	288.38
27	288.46	164.99	385.12	288.67	230.83
28.5	178.77		385.33	259.87	288.51
30	384.47		192.99	192.60	384.48

3.1.3. Single Microtremor Test Results

Microtremor observations were performed using portable equipment, which is equipped with a ultra-sensitive sensor, a wire comprising a jack in one side and USB port in another side, and a laptop computer with GEODAS (Geophysical Data Acquisition System) made by Buttan Service Co. Japan, is used for the data acquisition.

The microtremor equipment has been set on the free surface on the ground without any minor tilting of the equipment. The N-S and E-W directions are properly maintained following the directions arrowed on the body of the equipment. The sampling frequency for all the measurements is set at 200 Hz. The low-pass filter of 50 Hz is set in the data acquisition unit. Like the seismometer or accelerometer, the velocity sensor used can measure three components of vibration: two horizontal and one vertical. The natural period of the sensor is 2 sec. The available frequency response range for the sensor is 0.5–20 Hz.

A global positioning system (GPS) is used for recording the coordinates of observation sites.

Three-components (NS, EW, and UD) of microtremors were observed during 10 minute.

Location of Microtremor tests are shown in Figure- 3.4 and Table- 3.5. Field data has been processed, and the investigation of microtremor tests are enclosed in Appendix C at tabular and also graphical format.

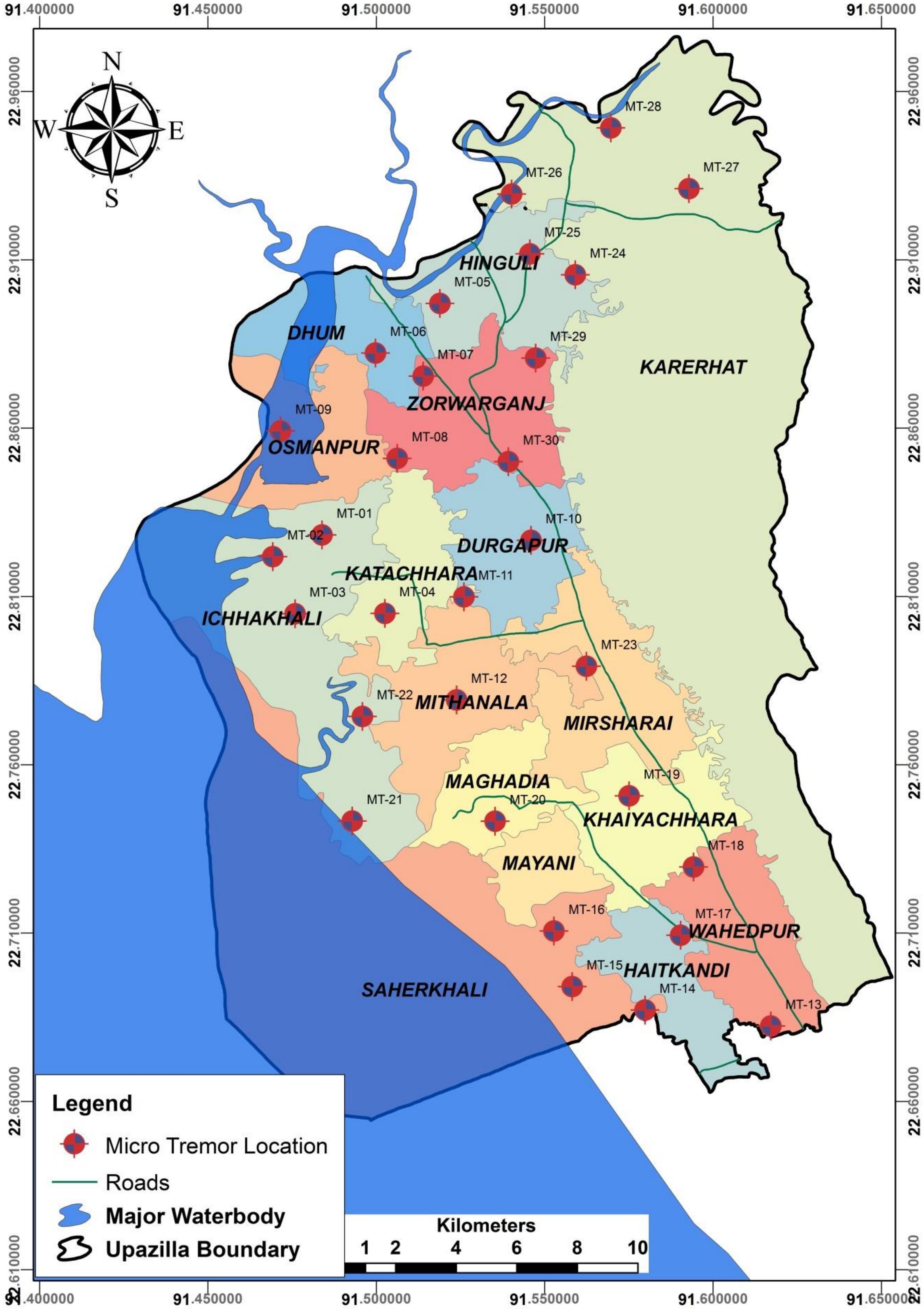


Figure 3.4 Location for single Microtremor survey

Table-3.5 Location of single Microtremor survey

MT_ID	Location	Lat	Long
MT-01	Ichakhali, Shahebjir Nagar	22.828280	91.483920
MT-02	Vaggoni, Ichakhai	22.821860	91.469320
MT-03	Susham Khal, Ichakhai	22.804900	91.475900
MT-04	Bariakhali, Katachhara	22.805010	91.502565
MT-05	Ganakchara, Dhum	22.897080	91.518910
MT-06	Moulavi bazaar, Dhum	22.882330	91.499810
MT-07	Naherpur, Dhum	22.875480	91.513950
MT-08	Shahedpur, Zorwarganj	22.851020	91.506260
MT-09	Azampur, Osmanpur	22.859180	91.471640
MT-10	Hariharpur, Durgapur	22.826680	91.546010
MT-11	Massapukur, Kattachara	22.809930	91.526050
MT-12	Middle Mithanala, Mithanala	22.779276	91.523874
MT-13	Mohalonga, Wahedpur	22.676150	91.614850
MT-14	Uttar bogachotor, Saherkhali	22.683210	91.578450
MT-15	Dhumkhali, Saherkhali	22.694140	91.558220
MT-16	Abdul Qaium Road, Shaherkhali	22.710640	91.552810
MT-17	Kaochua, Haitkandi	22.709420	91.590450
MT-18	Gasbaria, Khaiyachhara	22.729670	91.594240
MT-19	Sayedali, Khaiyachhara	22.750810	91.575130
MT-20	Jafrabad, Maghadia	22.743280	91.535330
MT-21	Chorsorod, Maghadia	22.743330	91.492900
MT-22	Rahmatabad, Ichhakhali	22.774370	91.495900
MT-23	Mirsharai	22.789326	91.562447
MT-24	Islampur, Hinguli	22.905580	91.559140
MT-25	Taltola, Hinguli	22.911810	91.545650
MT-26	Katagong, Karerhat	22.929550	91.540200
MT-27	Nolkho, Karerhat	22.931180	91.592860
MT-28	West Olinagar, Karerhat	22.949200	91.569680
MT-29	Khilmurali, Zorwargonj	22.880850	91.547340
MT-30	Mohanagar, Zorwargonj	22.850040	91.539260

To meet the project demand thirty Single Microtremor (MT) surveys were carried out throughout the project area to derive the fundamental/peak period. This information is crucial to avoid building resonance effect during an earthquake. It is found that the peak period ranges from 0.6 to 2.5 second. There exists a rule of thumb that the fundamental period of the buildings should not coincide with the peak period of the ground surface and building's fundamental period is (N/10), where N is number of storey. Therefore, each and every peak period value can be utilized for the corresponding building height. However, the unions located to the south of Mirsharai Upazila mostly characterized by high peak period value (Figure 3.5). Moreover, this information of peak period will be further correlated with the Spectral Acceleration value to be derived from Probabilistic Seismic Hazard Assessment to propose the suitable building height for the project area.

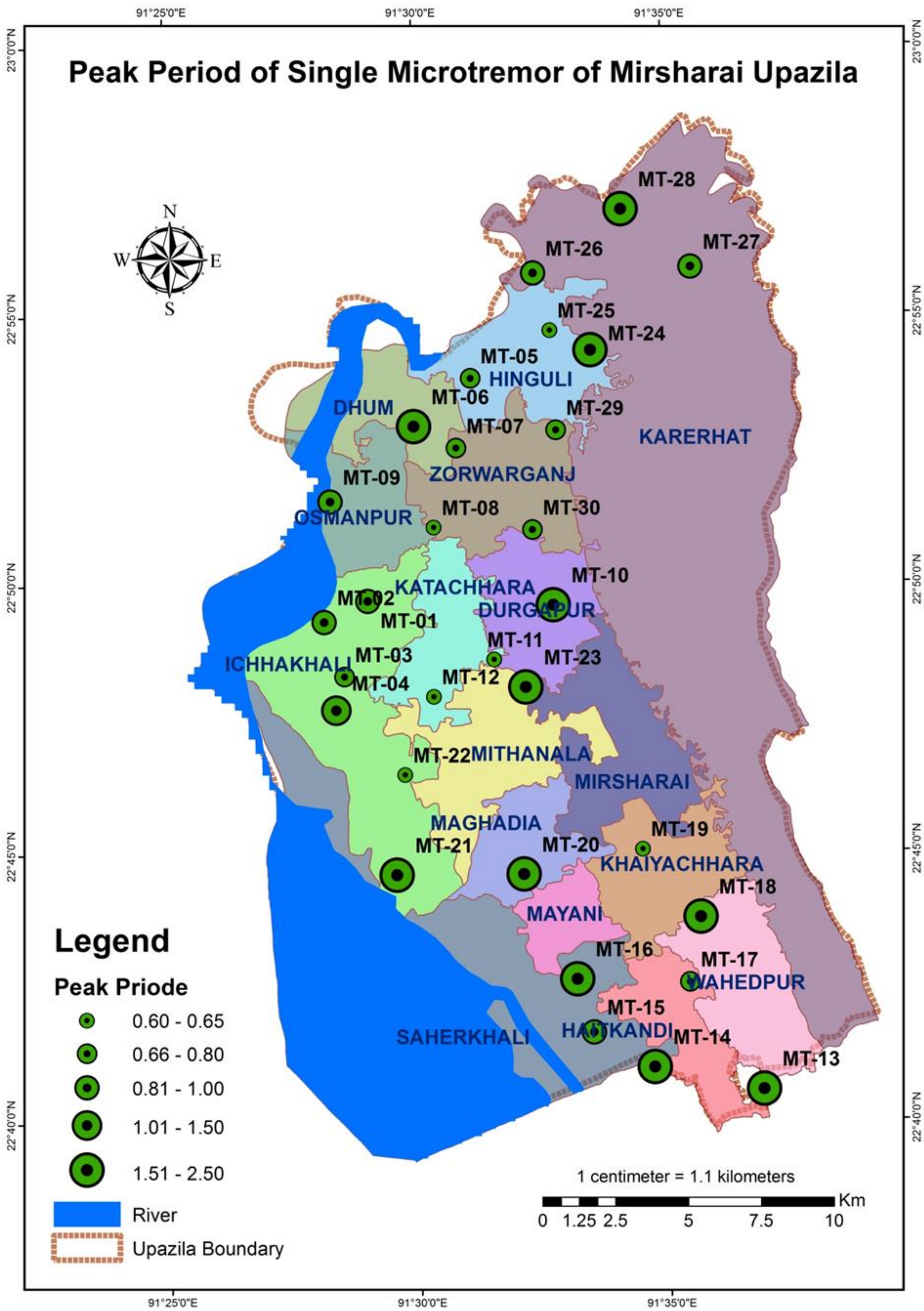


Figure 3.5 Peak Periods for Single Microtremor of Mirsharai Upazila

3.2. GEOTECHNICAL INVESTIGATIONS

To ensure safety of human beings and materials, geotechnical investigations have become an essential component of every construction, it includes a detailed investigation of soil strength, composition, water content, and other important soil characteristics. The standard penetration tests were conducted in order to know subsurface geological conditions. The borings with SPT were carried out at 85 points at Mirsharai Upazila Figure-3.6.

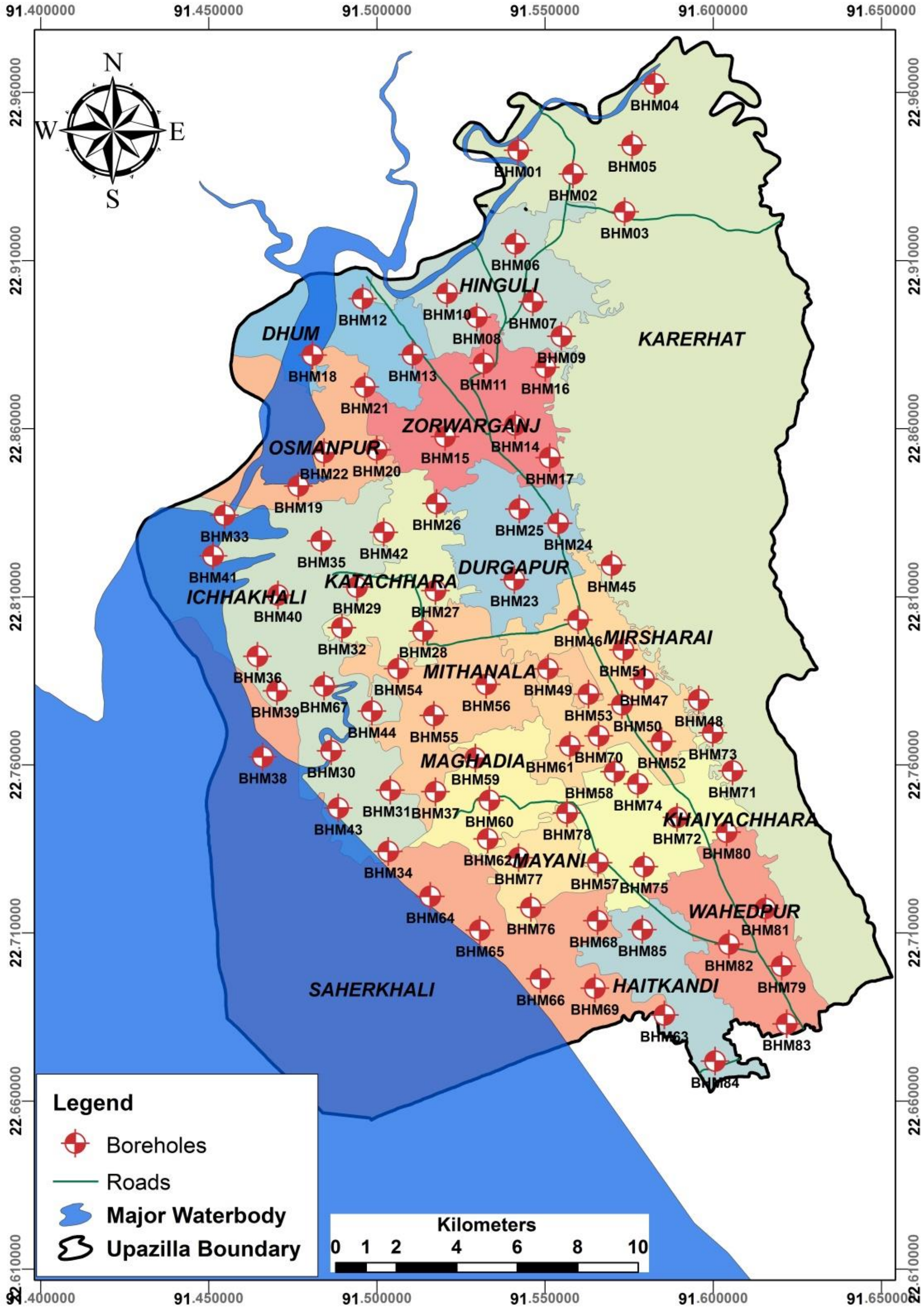


Figure 3.6 Borehole Location for SPT test

3.2.1. Standard Penetration Test (Spt) Log Analysis And Interpretation

SPT is a common in-situ testing method used to determine the geotechnical engineering properties of subsurface soils. It was developed in the late 1920s and has been used extremely in North and South America, the United Kingdom, Japan, and elsewhere. Because of this long record of experience, the SPT is well-established in engineering practice. It is performed inside exploratory boring using inexpensive and readily available equipment, and thus adds little cost to a site characterization program.

All the borings has to be conducted and preparation of field bore log by visual classification has to be done in the presence of the experienced technical personnel. The borehole records have to be taken that include soil type, nature of sample, soil moisture content and consistency, SPT blow counts (N Value), ground water observation and apparent origin (fill, alluvium, recent sediments, etc.) and daily field logs have been prepared. The bore locations are given in following table-3.6 and geotechnical investigations activities and lab data acquisition are shown in Figure-3.7.

SPT Field data acquisition

Lab data acquisition

Figure 3.7 Geotechnical investigations activities and lab data acquisition

Table-3.6 Location of Borehole for SPT test

Borehole_ID	Location	Latitude	Longitude
BHM01	West Joar Roshidia Govt. Primary School	22.94282	91.54206
BHM02	Choturua, Ward-1, Korerhat	22.93579	91.55832
BHM03	Giamara gram, Bagan road, Korerhat	22.92456	91.57372
BHM04	Bisshowtila Jame mosque, Olinogor, Korerhat	22.9626	91.58258
BHM05	Poshchim olinogor, Korerhat	22.94435	91.5759
BHM06	Ajomnogor Community Clinic, Hinguli	22.91506	91.54119
BHM07	Khil hinguli Govt. Primary School	22.89774	91.5464
BHM08	Jamalpur, Baraiarhat Pourashava	22.89317	91.5297
BHM09	East Mehedi Nagar (Forrest Office)	22.88751	91.55489
BHM10	West Hinguli, Gonokchora	22.90032	91.52085
BHM11	Imampur Titabot tola Furkania Madrasha	22.87949	91.53175
BHM12	Bono Chowdhury Jame Mosque, Mobarokguna, Dhoom	22.89871	91.49581
BHM13	Banglabazar, Shantor road, Dhoom	22.88204	91.51064
BHM14	163 no. Fayezullah master Govt. Primary School	22.86107	91.54115
BHM15	Alhaz Bodiul alam Chowdhury Govt. Primary School	22.85769	91.52032
BHM16	Khil murari, ward no. 5, Zorargonj	22.8783	91.55009
BHM17	Shonapahar, murari, Zorargonj	22.85143	91.55145
BHM18	Guccho gram M.A. Haider Primary School, Osmanpur	22.88176	91.4809
BHM19	Bashkhali, Veribadh, Muhuri Project, Osmanpur	22.84304	91.47659
BHM20	39 no. East Shahedpur Govt. Primary School, Azampur	22.85378	91.50001
BHM21	East Moregang Jame Mosque, Osmanpur	22.87252	91.49651
BHM22	Patacoat, Azampur, Osmanpur	22.85292	91.48433
BHM23	68 north durgapur Primary School, Varoddaj hat	22.81511	91.54094
BHM24	East Raypur Baitul Aman Jame Mosque, Durgapur	22.83193	91.55396
BHM25	Jaforer Poultry Farm, Choitonner Hat, Durgapur	22.83615	91.54239
BHM26	Tetuiana Nath Para, Durgapur	22.83779	91.51776

BHM27	Abdus Sattar Bhuiyar Hat Govt. Primary school, Kata chora	22.81188	91.51746
BHM28	Bamon Shundor Govt. Primary School, Kata Chora	22.79988	91.51379
BHM29	Ahmed Ali Miar Hat Govt Primary School, Kata Chora	22.81297	91.49413
BHM30	Gudammar tek, Ichakhali	22.76421	91.48643
BHM31	Char shorot Sharbojonin Charnatia Durga Mondir, Ichakhali	22.75251	91.50399
BHM32	Jobayeda Islam Nurani Islamia madrasha	22.80081	91.48951
BHM33	Muhuri Project, Sluice Gate, Ichakhali	22.83434	91.45464
BHM34	Bamonshundor Forrest Bit Office, Shaherkhali	22.7343	91.50339
BHM35	Vanguni Bazar Baitunnur Jame Mmosque, Ichakhali	22.82661	91.48335
BHM36	Chunumijar Tek, Ichakhali	22.79233	91.46452
BHM37	94 no. Hasim Nagar Govt. Primary School,	22.75204	91.51743
BHM38	Ichakhali Economic Zone Office, Ichakhali	22.76242	91.46612
BHM39	Lodiakhali, Ichakhali	22.78207	91.47032
BHM40	Sony Mijer tek, Tekerhat Bazar,Ichakhali	22.81053	91.47058
BHM41	Ichakhali Economic Zone, Ichakhali	22.82266	91.44786
BHM42	Kazigram govt. Primary School, Ichakhali	22.82931	91.50229
BHM43	Rajamiar Farm, Char Shorot, Ichakhali	22.74718	91.48854
BHM44	Rahmatabad, Ichakhali	22.77602	91.49851
BHM45	Mohamaya Eco Park, Durgapur	22.81944	91.56983
BHM46	Mithachora Bazar , Mirshorai	22.80319	91.5599
BHM47	South Talbaria, Mirshorai	22.78553	91.57944
BHM48	East Ambaria, Mirshorai	22.7794	91.59575
BHM49	Ora Kazi Mijibari Jame Mosque, Mirshorai	22.78863	91.55093
BHM50	Mirshorai Degree College, Mirsorai	22.77792	91.57289
BHM51	North Talbaria Govt. Primary School, Mirshorai	22.79426	91.57335
BHM52	Hamid Ali Jame Mosque, East Khoiachora	22.76701	91.58471
BHM53	Khankaye Latifia Madrasha, Mirshorai	22.7811	91.56298
BHM54	Rabiul Hossain Govt. Primary School	22.78867	91.50636
BHM55	Chairman Bari, West Muliyash	22.77471	91.51698
BHM56	Hazi Badiul Alam Chowdhury Govt. Primary School, Mithanala	22.78397	91.53249
BHM57	Mayani Bogla Kumar Primary School, Mayani	22.73095	91.56573
BHM58	West Khoiachora Munipara, Jame Mosque	22.758	91.57073
BHM59	3 Ghoriatola, Jame mosque, Maghadia	22.76206	91.5293
BHM60	90 no. Maghadia NC Govt. Primary School, Maghadia	22.74951	91.53351
BHM61	Sheker Taluk, Middle Maghadia	22.76571	91.55742
BHM62	Kazir Taluk Govt. Primary School, Maghadia	22.73803	91.53299
BHM63	Komor ali Union High School, Komor Ali Union Bazar	22.68562	91.58553
BHM64	Katakhali Beribadh, Shekerkhali	22.72091	91.51587
BHM65	Beri Badh, Shekerkhali	22.71091	91.53063
BHM66	North Dhoom Khali, Gazaria, Shekerkhali	22.69645	91.54869
BHM67	Ichakhali Khalpar,Ichakhali	22.78354	91.48431
BHM68	Shaherkhali High School, Shaherkhali	22.71369	91.56564
BHM69	Dhoomkhali, Shaherkhali	22.69363	91.56484
BHM70	West Gobania, Mirshorai	22.76866	91.56601

BHM71	Shonaichora, Khoiachora	22.75824	91.60582
BHM72	Morjida Masima Taluk, Borotakia	22.74442	91.58926
BHM73	Khoiachora Waterfall Road, Khoiachora	22.76957	91.59991
BHM74	Said Ali Govt. Primary School	22.75439	91.57765
BHM75	Majeda Huq High School, Mayani	22.72981	91.57939
BHM76	Shah Abdul Majid Govt. Primary School, West Mayani	22.7176	91.54582
BHM77	West Mayani Shahid Kamal Uddin Govt. Primary School	22.73242	91.54217
BHM78	13 no. Mayani Union Complex Building	22.7457	91.55657
BHM79	West Wahedpur Molla para Mosque	22.7002	91.62035
BHM80	Beltola, Wahedpur	22.74	91.604
BHM81	Sheker Taluk, Middle Maghadia	22.71732	91.61549
BHM82	Maizgao	22.70669	91.6047
BHM83	Jafrabad Govt. Primary School, Wahedpur	22.68304	91.62183
BHM84	South Baliadi Govt. Primary School	22.67191	91.60059
BHM85	Hait kandi High School	22.71106	91.57895

While boring and SPT testing, soil samples are being visually classified in the following way:

Sieve	**Soils**	**Designations**
+No 4 (4.76mm)	Gravel	
No.4 to No 10(2.00mm)	Coarse	Sand
No. 10 to No 40 (0.42mm)	Medium	Sand
No. 40 to No 200 (0.07mm)	Fine	Sand
No.200	Silt or Clay	

Some soil has one dominant lithology with minuscule amount of other soil type. In such cases, minor soil sample are written in the following manner with along with dominant soil type.

1. Trace 1 to 10%
2. Little 10 to 25%
3. With 25 to 35%

SPT- N value is also note down while SPT Testing. Then the collected soil samples are being cross checked with SPT-N values to ensure quality data collection.

Based on N-values, other very useful soil parameters may be obtained from the co-relation charts given by different research workers. Two such useful co-relations for cohesive and non-cohesive soils after K. Terzaghi are given below:

Table-3.7 Values of Relative Density (Dr.), Friction Angle and Unit Weight of Non- cohesive soil based on N-values

N-values	Condition	Relative Density	Angle of Internal friction (Degree)	Moist Unit Weight (Pcf)
0-4	Very Loose	0-15%	28^0	70-100
4-10	Loose	15-35%	28^0-30^0	95-125
10-30	Medium dense	35-65%	30^0-36^0	110-130
30-50	Dense	65-85%	36^0-41^0	110-140
Over 50	Very dense	85-100%	Over 41^0	> 130

Table-3.8 Values of Unconfined Compressive Strength based on N-values for Cohesive Soil (Approximate):

N-values	Condition	Unconfined Compressive Strength (Tsf)
Below 2	Very soft	Below 0.25
2-4	Soft	0.25-0.50
4-8	Medium stiff	0.50-1.00
8-16	Stiff	1.00-2.00
16-32	very stiff	2.00-4.00
Over 32	Hard	over 4.00

In the above table the shear strength of cohesive soil is equal to ½ of unconfined compressive strength and the angle of shearing resistance is equal to zero. It should be remembered that the co-relation for cohesive soil is not always much reliable.

3.2.2. Subsurface 3D model of different layers through Geotechnical investigation

According to 250m × 250m grid pattern, Standard penetration test locations are selected and drilling for identifying the geological characteristic of sub-surface soft sedimentary rocks. Description of different layer of the soil, its sedimentary characteristics, structure, and lithology are reflected in 3D model. Engineering properties of different soil layer: SPT value, soil strength and foundation layer etc are also being described. Computing all the results of soil properties and geotechnical properties preparation of 3D model for sub surface information of different layers of the area can be done by using GIS.

Lithological succession encountered in the boreholes reveals that geologically the study area is very complex as the eastern part is high terrace zone on the other hand western part is flat land area which finally ended up in bay of bangle. The borelogs encompasses eight distinct lithofacies, denoted as layers1 to layer8 and each layer has distinct lithological characteristics and standard penetration test blow counts (SPT-N) as described in Figure-3.8a.

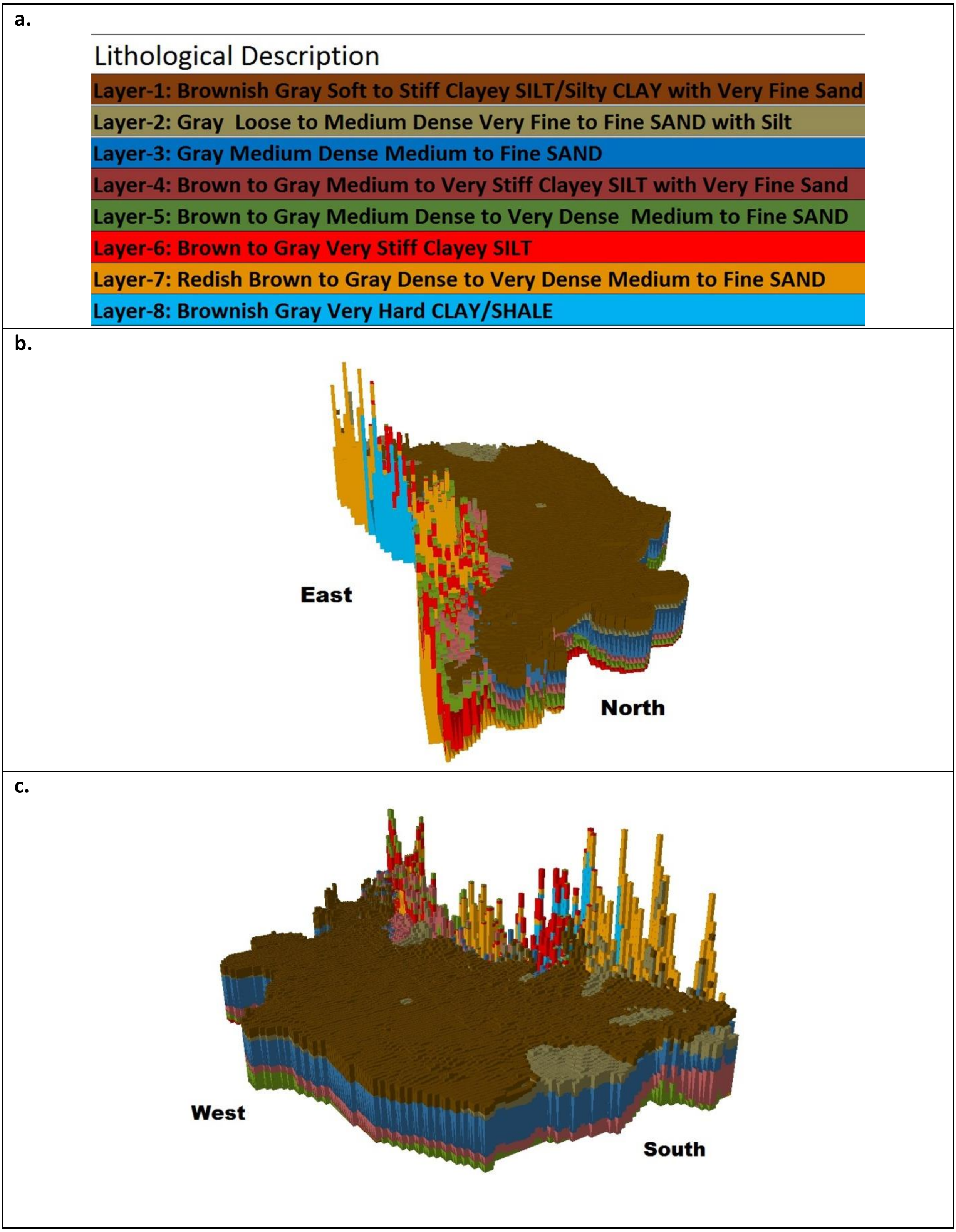


Figure 3.8 (a) Legend and Lithologic characteristic of subsurface of Mirsharai Upazila; (b) Subsurface 3-D model showing Northeastern part; (c) Subsurface 3-D model in Southwestern direction

Subsurface 3D model was prepared showing Northeastern part and along Southwestern direction using ArcGIS to elucidate the subsurface geological conditions of the study area as shown in Figure 3.8 b & c respectively. All 85 boreholes of 30m depth were carefully examined to delineate the spatial distribution of the subsurface lithological units of the area.

Among 8 layers; layer 1 to layer 5 is mostly present at the flat landed areas and layer 6 to layer 8 is mainly present at hilly regions of the study area. From the Figure 3.8 b & C, it can observe that Layer 1 is present at the top of the study area. However the layer is absent at the hilly regions and southern part of the flat lands of study area. A thin layer of layer 2 is present almost throughout the flat landed areas of the study area. Layer 3 which is considered as the foundation layer is the thickest layer within the flat land zone and thickness increases gradually toward southwestern part of the area. Thickness of Layer 4 gradually decreases toward western part of the study area. Layer 5 is also considered as foundation layer where layer 3 is absent especially at Karerhat Union. Thickness of the layer gradually increases toward north of the area. Layer 6 is discretely present within the area and thickness of the layer increases toward northeastern part of the area. Layer 7 and 8 mainly encountered at the eastern part of the area. Both the layers are present within the hilly regions of the study area and could not be encountered within the 30m depth zone of flat land regions. Thickness of layer 7 increases abruptly toward northeastern part of the area and the thickness of layer 8 increases abruptly toward eastern part of the area.

Based on N-value (soil resistance) layer 3 and layer 5 consider as a foundation layer. Among them layer 3 cover almost all area of Mirsharai Upazila. Only northern part of the Karerhat union and surrounding area reflect layer 5 as a foundation layer. Northern part of the Karerhat union, central part of Zorwarganj, South-eastern part of Durgapur and Wahedpur, Eastern part of Mirsharai and Khaihachhara and South-western part of Mithanala union reflect shallow foundation depth (3m), which need to be verified with allowable bearing capacity. Foundation depth of overall area of Mirsharai Upazila varies 3m to 10m (Figure-3.9). Very few areas consider their foundation depth more than 10m. This analysis might be updated while other test result will integrate.

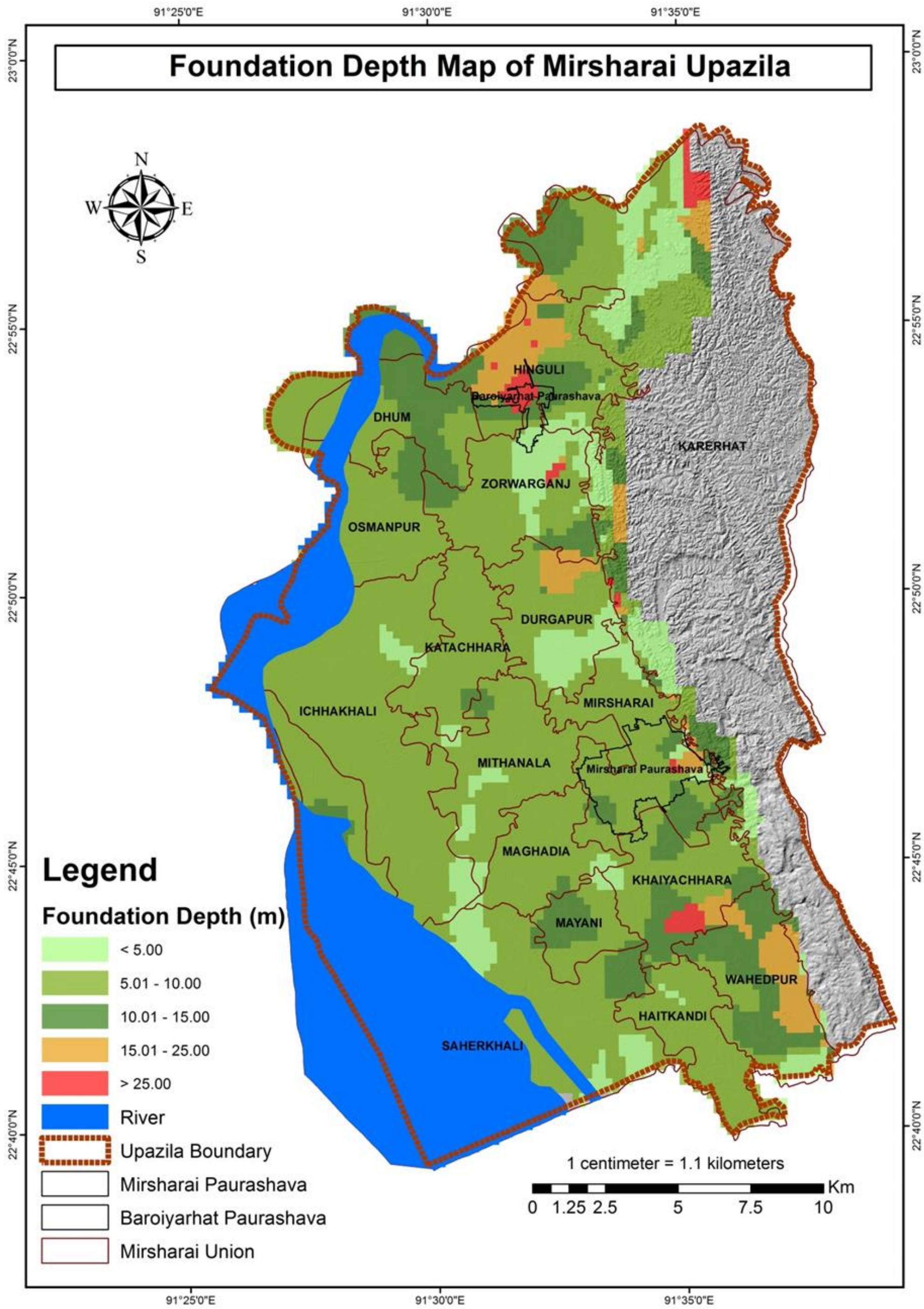


Figure 3.9 Foundation depth of Mirsharai Upazila

3.2.3. Subsurface Cross-Sections

Five cross-sections were prepared, two roughly in North-south direction, one East west, one North-east and one North-west direction. Each cross section covers several boreholes and many boreholes that are very close to the section line. There are 8 different facies assemblages encountered in this area by borehole, where most of the layers are inconsistent.

Cross-section A-A'

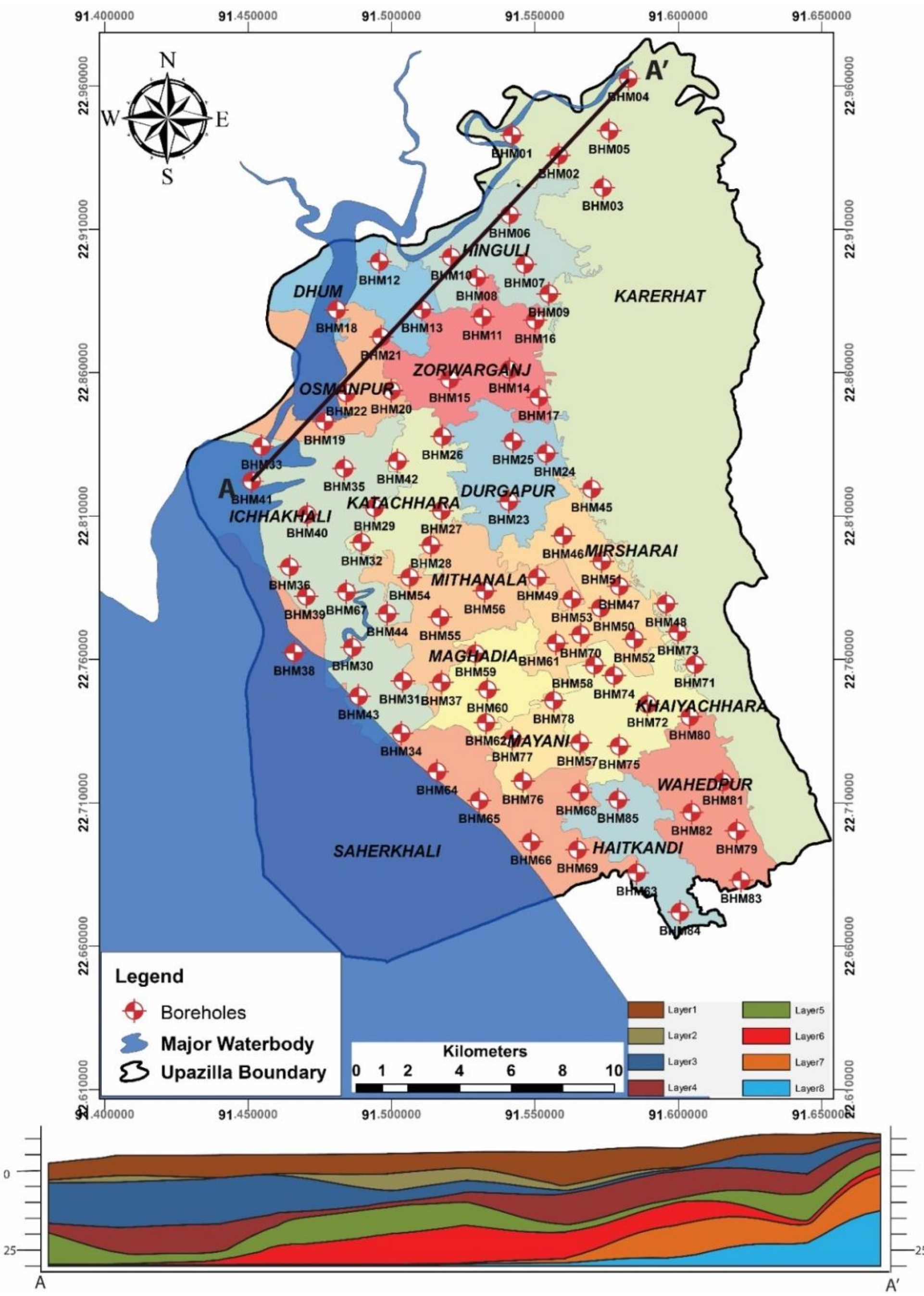


Figure 3.10 Cross-section A-A’

Cross-section A-A’ is drawn in northern portion of the studied area in N-W direction that cover approximately 20.766 km from BH_M41 to BH_M4. It encounters BH_M 21, BH_M 6, BH_M 2 and has a close proximity to BH_M33, BH_M19, BH_M13, BH_M10, BH_M5. In this section all layers was encounter but varies in thickness.

Cross-section B-B’

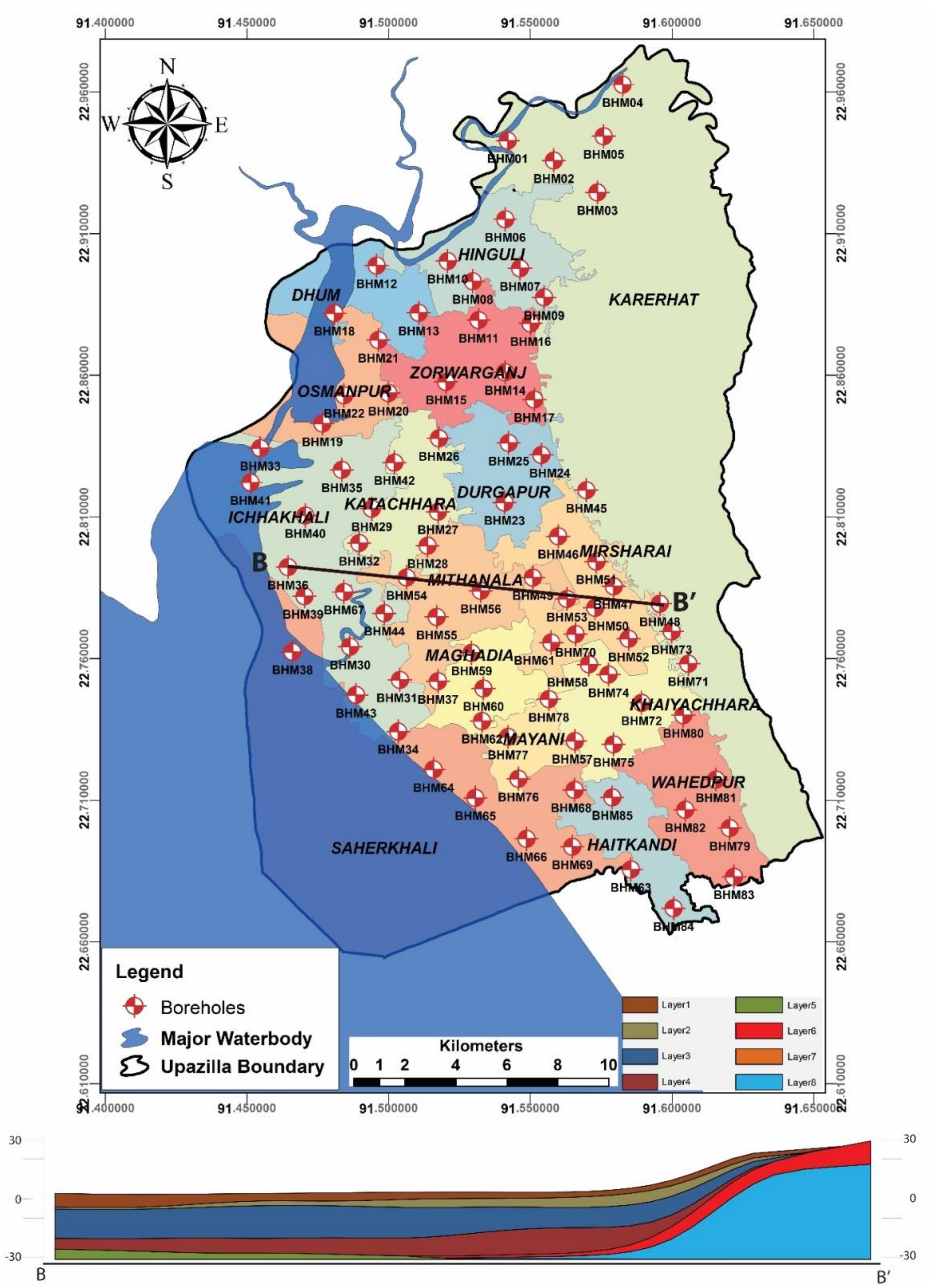


Figure 3.11 Cross-section B-B'

Cross section B-B' is drawn along the middle portion of the studied area that cover approximately 12.88 km from BH_M36 to BH_M48, where It encounters BH_M28 and BH_M53as well. Layer Thickness in almost uniform from 36 to 47, noticeably layer1 have 1to 5m, Layer2 have 1-4, Layer3 have 10-15m Layer 4 have 5-6m thickness. Layer 2 pinched out near 36 and Layer5 was found at the base of Layer4 but. It also pinched out near 48 along with other layers such as 1,2,3,4. Layer 7 was not encountered in any of this borehole. Highest thickness of the Layer 6 found in 48 and also Thickness of the Layer 8 at and near 48 was about 30m and its base was not found.

Cross-section C-C'

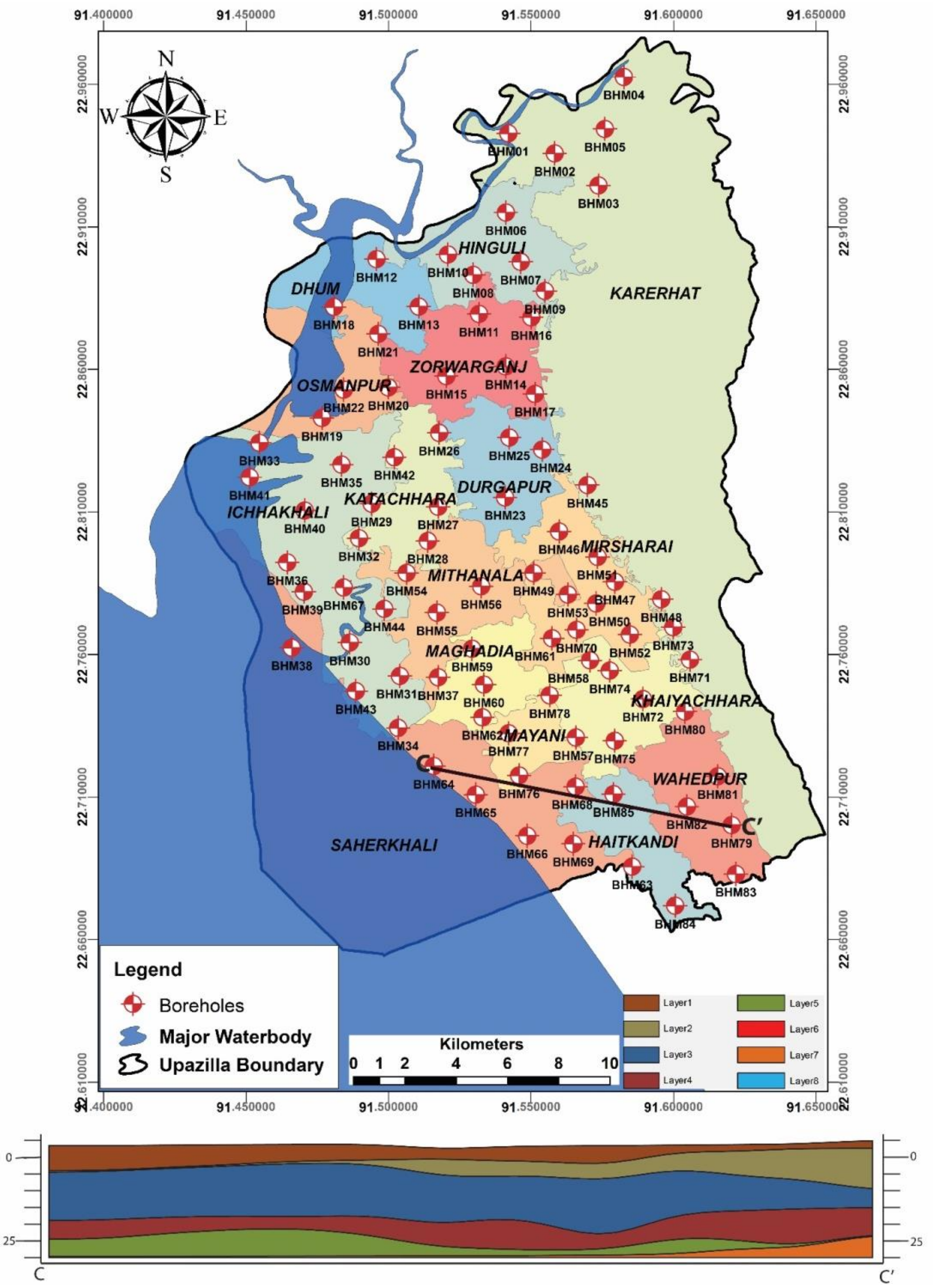


Figure 3.12 Cross-section C-C'

Cross section C-C' is drawn in the southern portion of the studied area in NWW direction that cover approximately 10.976 km from BH_M64 to BH_M79. It encounters BH76 68 85 82 . At 64 Layer1 is about 5 to 6 m , Layer 3 is 15-16m, Layer 4 is about 4-5m and Layer6 is abou 5 to 8 m in thickness.Layer 2 is absent here but near 76 its thickness is 2-3 m and it increased toward 79 and become 10-12m while layer1 become 1-2m in thickness. Layer 4 Varies from 4 to 8 m in thickness throughout the section. Layer 7 was found in bore 79 but it was very thin. Layer-8 was absent in this section.

Cross-section D-D'

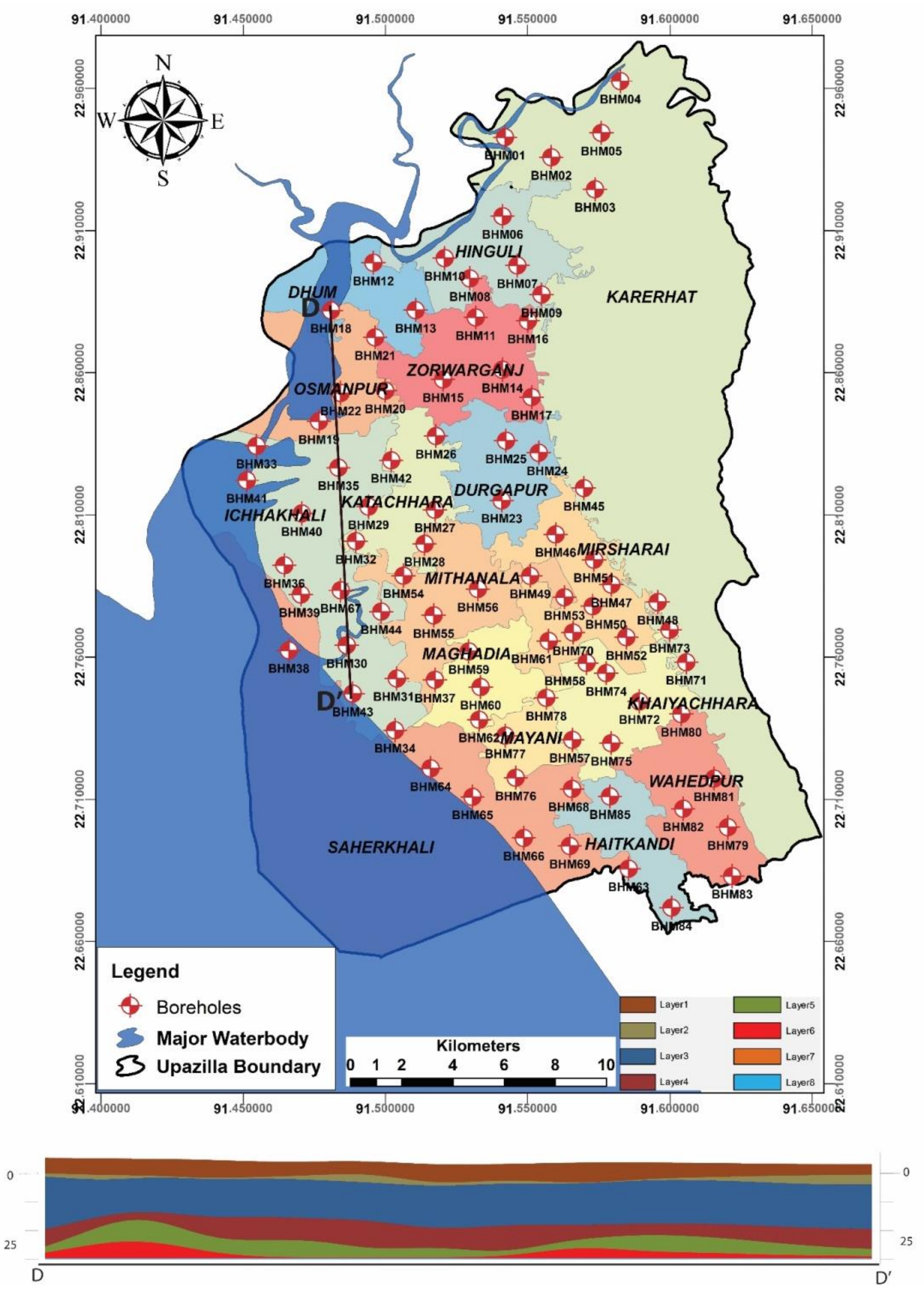


Figure 3.13 Cross-section D-D'

Cross section D-D' is drawn along the middle portion of the studied area that cover approximately 14.924 km from BH_M18 to BH_M43. It encounters BH_M 22, BH_M19 BH_M35 BH_M67 BH_M30. Layer 1 is 1-6m in thickness where layer 3 is 15-20m in thickness throughout the section. Layer 4 is about 8-10 m in thickness but decreased near 22 and 67. Layer5 is mostly thin in this section but have 5-8m thickness near 22. Layer 6 also has the same condition as the Layer5. Layer7 and Layer 8 are found in this section.

Cross-section E-E'

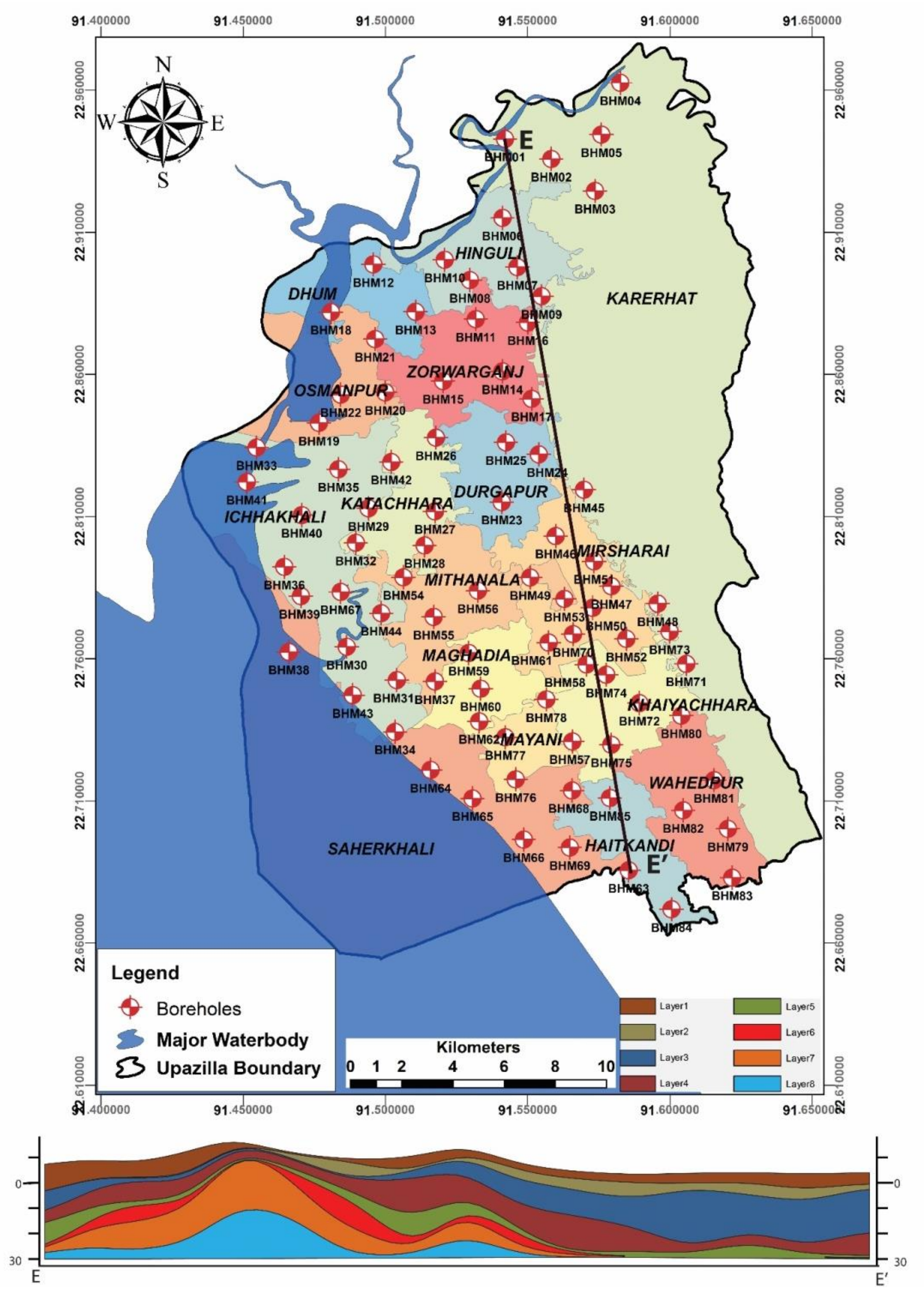


Figure 3.14 Cross-section E-E'

Cross section E-E' is drawn along the middle portion of the studied area that cover approximately 27.69km from BH_M1 to BH_M69. In the east portion layer 1,2,3,4 have average thickness of 5m, 3m, 20m, 10m respectively. Near the borehole No. BH_M 9 to BH_M 45 these layers pinched and layer 7 and 8 have thickness of about 15m each. In the southern part of the cross-section represents nearly 20 m thick layer 3.

4. CONCLUSION

Earthquakes are related to faulting and tectonic instability of an area. The overall tectonics of Bangladesh and adjoining region is conducive for the frequent and recurring earthquakes. The geo tectonic setting of the country is very active seismically. These are Himalayan Arc, Shillong Plateau and Dauki fault system in the North, Burmese arc and acrretionary wedges in the East, Naga-Disang-Haflong thrust zone in the Northeast. Threatened earthquake disaster inside Bangladesh may be expected from these active seismic zones outside the national boundary.

Seismically, Bangladesh is divided into three zones i.e. less risk zone (zone 1), moderate risk zone (zone2) and highly risk zone (zone3). Mirsharai Upazila at Chittagong district of Bangladesh is situated in zone 2. Besides these, this area is located between Arakan Megathrust and Sagaing fault. So, Mirsharai is moderately vulnerable to earthquake. To propitiate the risk of earthquake some initiatives have been taken by the concerned authorities. One of the projects works named "Geological Study And Seismic Hazard Assessment Under Preparation of Development Plan for Mirsharai Upazila, Chittagong District: Risk Sensitive Landuse Plan (MUDP)" which has been initiated by Urban Development Directorate.

In this project work, both the geophysical and geotechnical investigations have been conducted. The duration of the project is six months (19^{th} December, 2017 to 18^{th} June, 2018). In geotechnical survey 85 numbers of SPT boring (up to 30m) has been conducted in the field and the soil samples also collected from the field and laboratory tests are going on, which will complete with in few weeks. And in geophysical Survey, fifteen (15) PS Logging, twenty (20) MASW, and thirty (30) Microtremor (single array) have been investigated by using some sophisticated instruments. However, subsurface 3D model of different layers has been developed through Geotechnical investigation, which will be updated eventually by integrating other data set. Vs30 value has been determined from MASW and downhole seismic survey, which will compile with other test (velocity from N-value) values. Finally, by using these geotechnical and geophysical data, geological study and seismic hazard assessment will be prepared.

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6. APPENDICES

Appendix A: Multi-channel Analysis of Surface Wave (MASW) Test Results and Graphs

Appendix B: P-S Wave Velocity Logging Test Results and Graphs

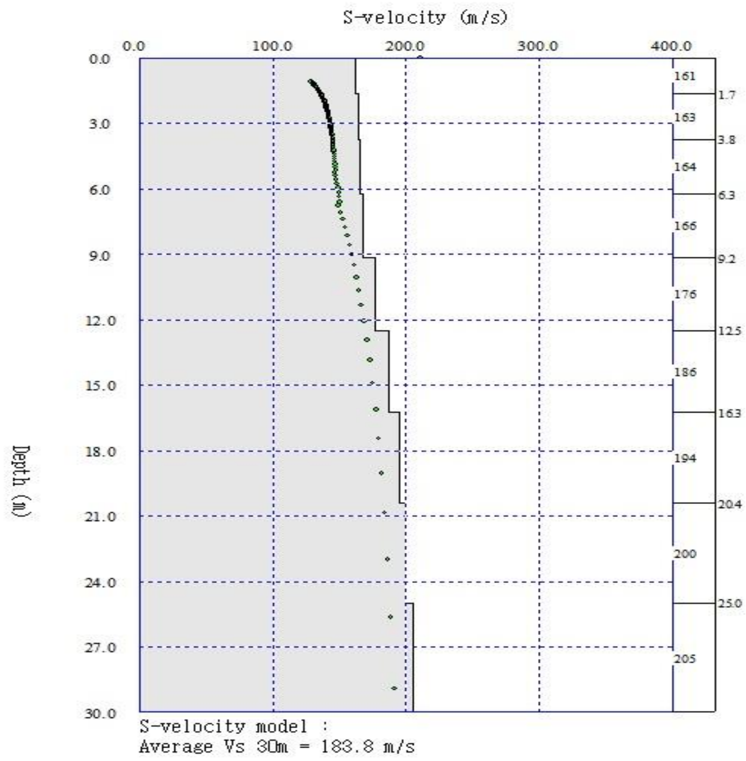
Appendix C: Microtremor Test Results and Graphs

APPENDIX A: MULTI-CHANNEL ANALYSIS OF SURFACE WAVE (MASW) TEST RESULTS AND GRAPHS

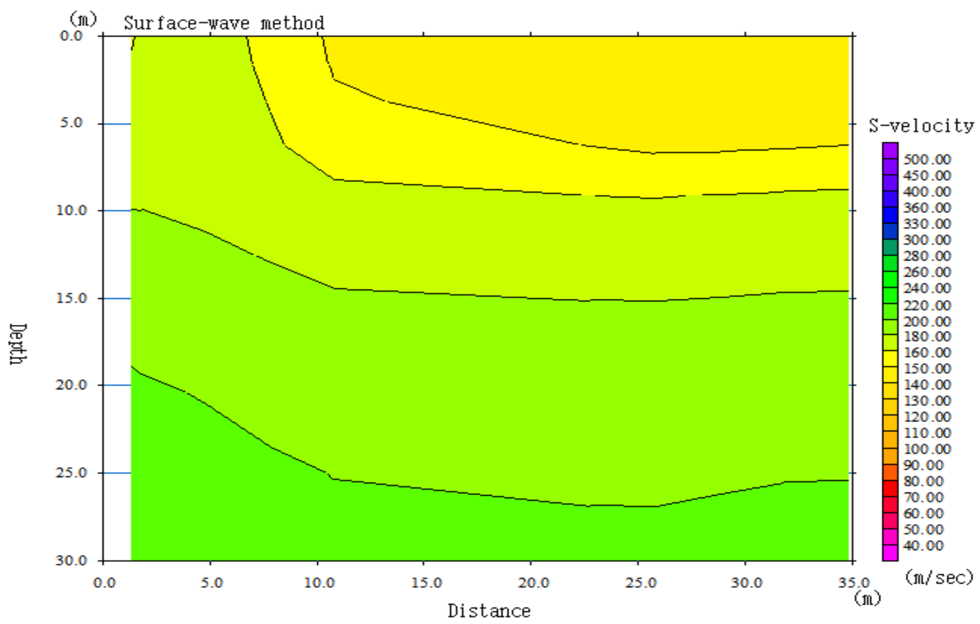
MASW Serial No.- MASW-01
Location: Karerhat
Coordinates: Lat- 22.9479045 Long- 91.5673217

Depth	S-Wave Velocity
0.0	161
1.7	163
3.8	164
6.3	166
9.2	176
12.5	186
16.3	194
20.4	200
25.0	205
30.0	205

1D Model



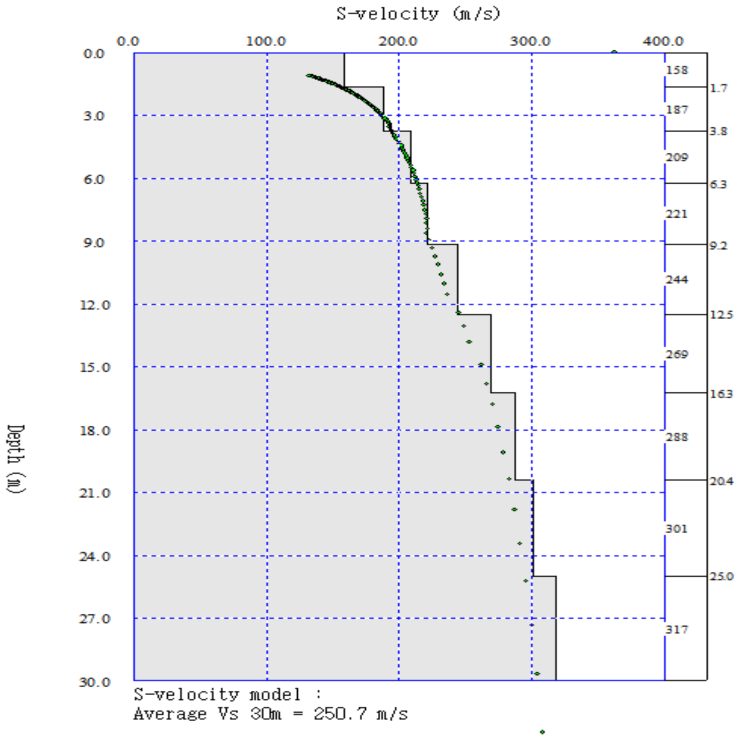
2D Model



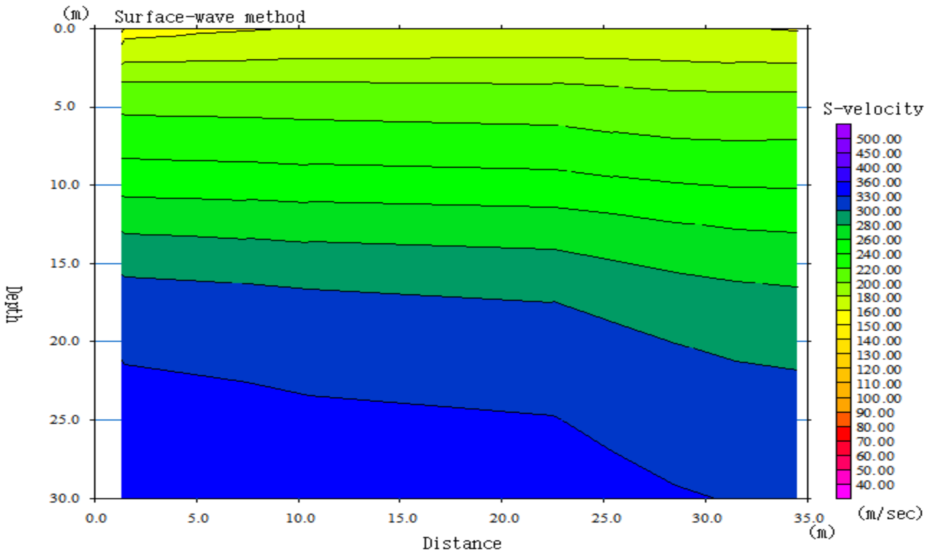
MASW Serial No.- MASW-02
Location: Middle Azomnogor, Hinguli
Coordinates: Lat-22.89947 Long- 91.55612

Depth	S-Wave Velocity
0.0	158
1.7	187
3.8	209
6.3	221
9.2	244
12.5	269
16.3	288
20.4	301
25.0	317
30.0	317

1D Model



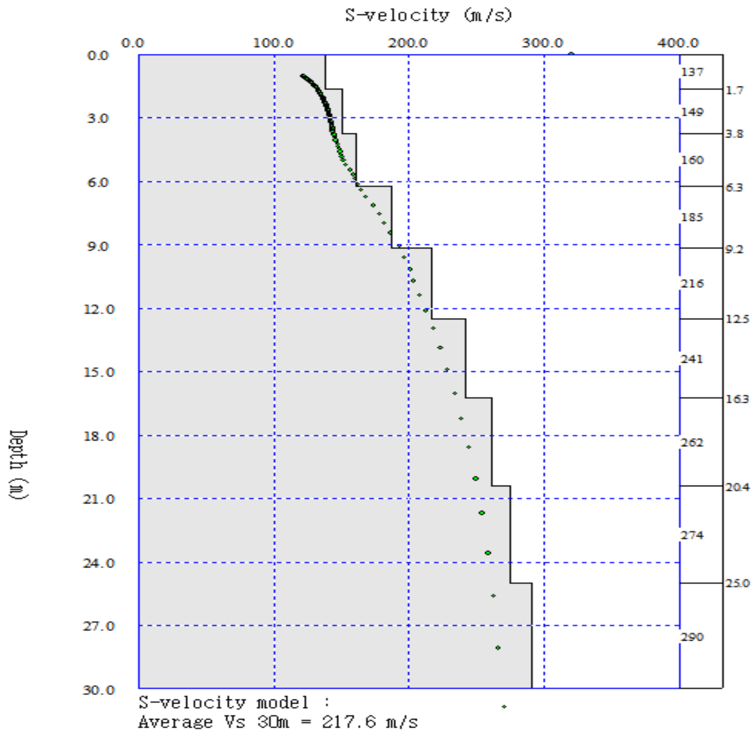
2D Model



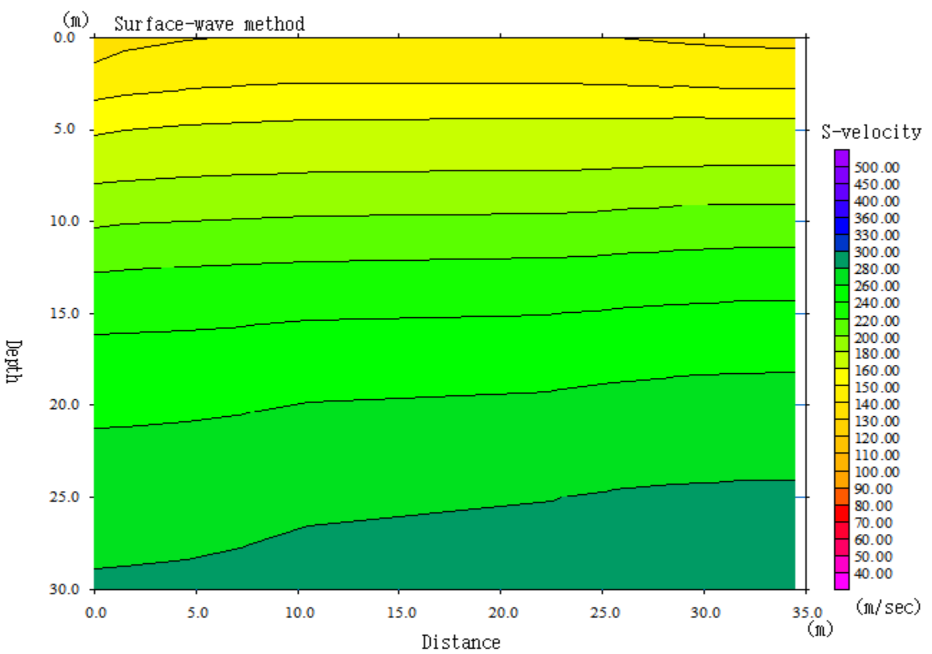
MASW Serial No.- MASW-03
Location: Jamalpur, Barayarhat Pourashava
Coordinates: Lat-22.892964 Long- 91.519036

Depth	S-Wave Velocity
0.0	137
1.7	149
3.8	160
6.3	185
9.2	216
12.5	241
16.3	262
20.4	274
25.0	290
30.0	290

1D Model



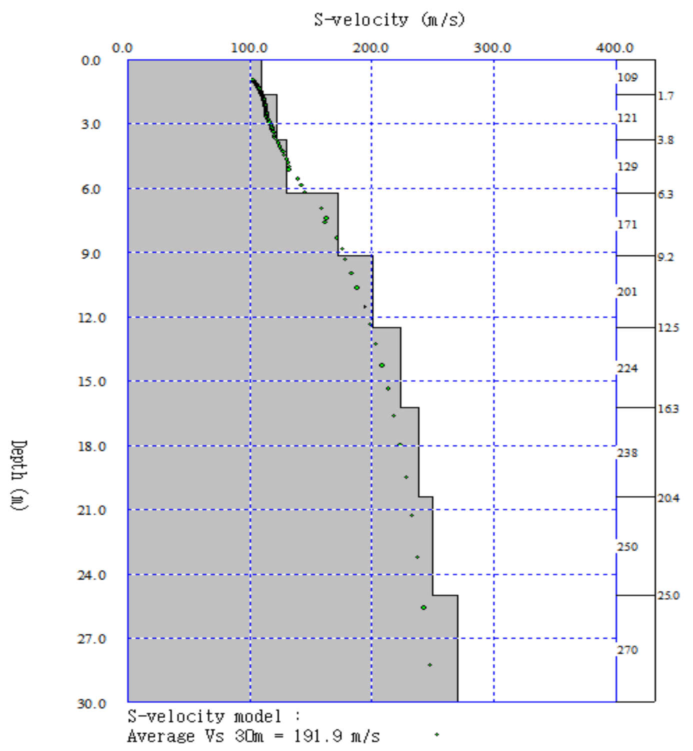
2D Model



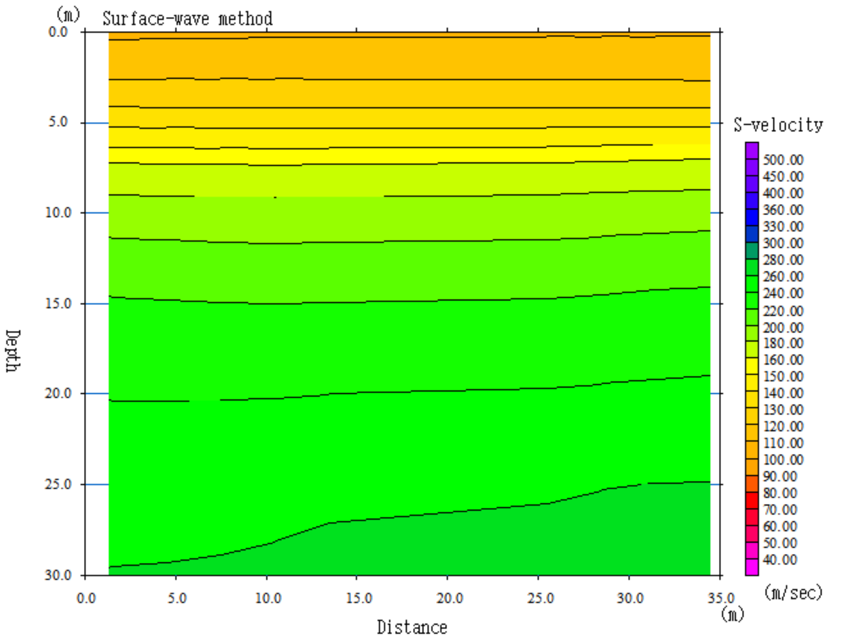
MASW Serial No.- MASW-04
Location: Naherpur, Dhum Union
Coordinates: Lat-22.879295 Long- 91.505672

Depth	S-Wave Velocity
0.0	109
1.7	121
3.8	129
6.3	171
9.2	201
12.5	224
16.3	238
20.4	250
25.0	270
30.0	270

1D Model



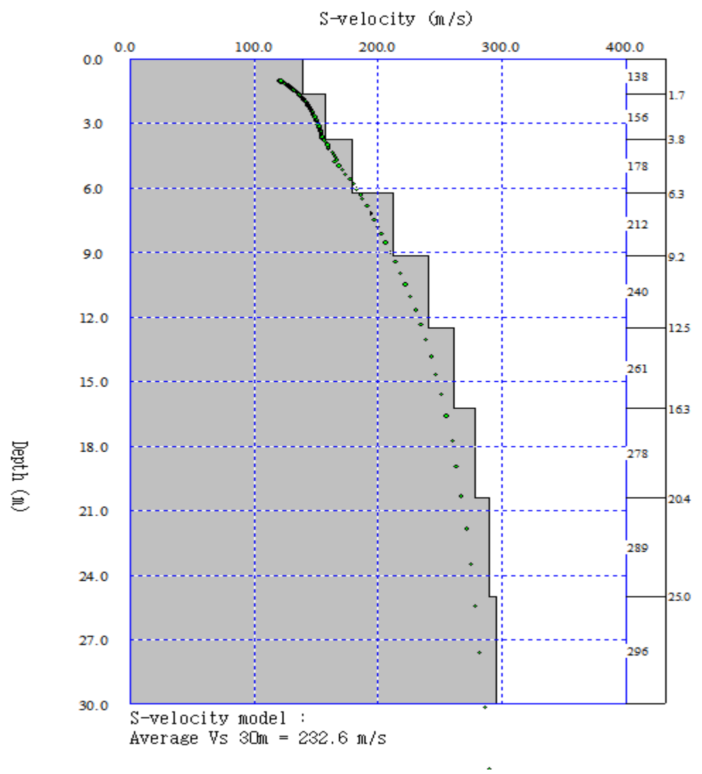
2D Model



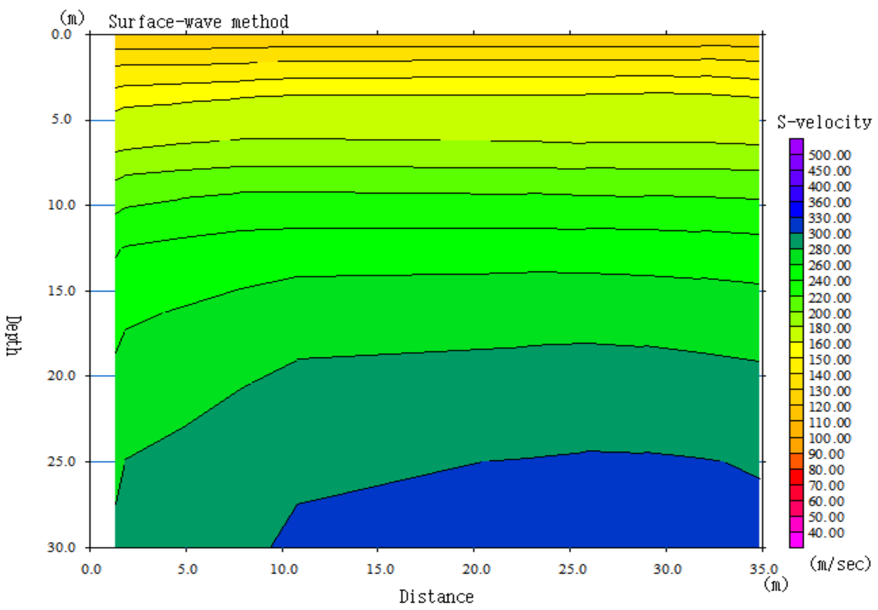
MASW Serial No.- MASW-05
Location: Khilmurali, Jorawargonj
Coordinates: Lat-22.8800096 Long- 91.552098256

Depth | S-Wave Velocity | 1D Model

Depth	S-Wave Velocity
0.0	138
1.7	156
3.8	178
6.3	212
9.2	240
12.5	261
16.3	278
20.4	289
25.0	296
30.0	296



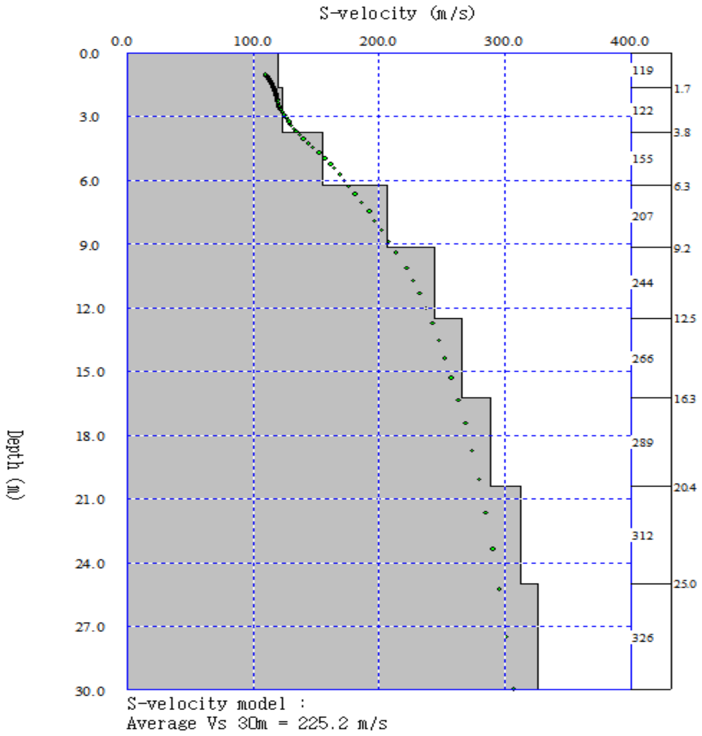
2D Model



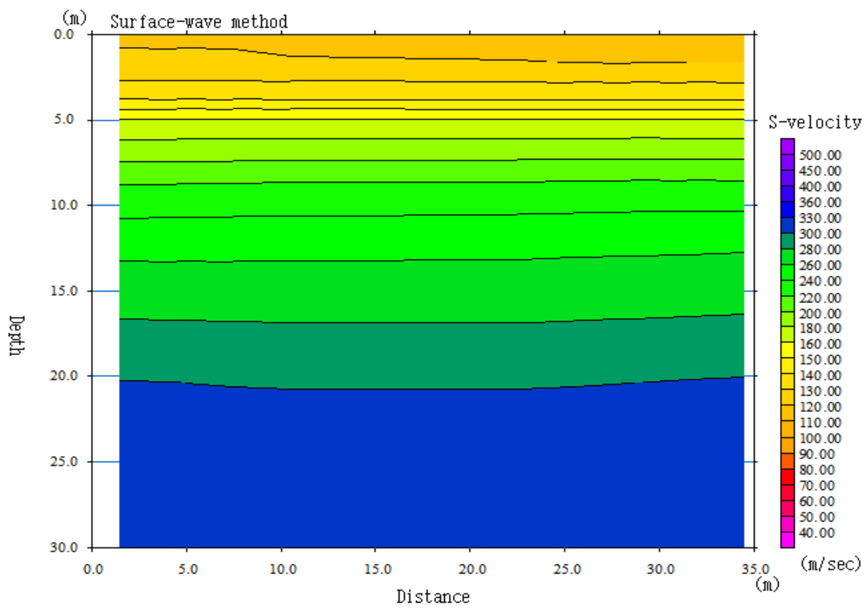
MASW Serial No.- MASW-06
Location: Mohamaya Lake Gate, Mirshorai
Coordinates: Lat-22.819062 Long- 91.567814

Depth	S-Wave Velocity
0.0	119
1.7	122
3.8	155
6.3	207
9.2	244
12.5	266
16.3	289
20.4	312
25.0	326
30.0	326

1D Model



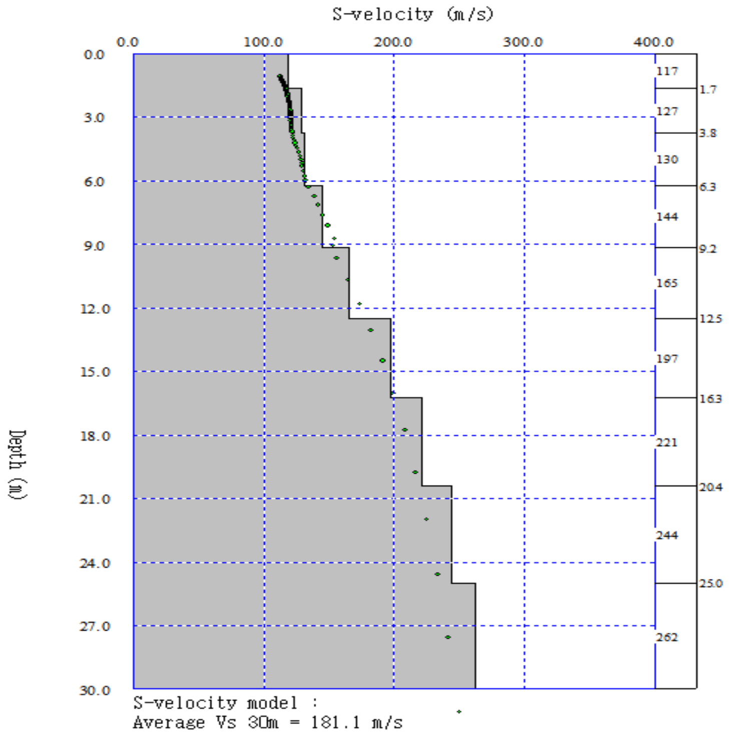
2D Model



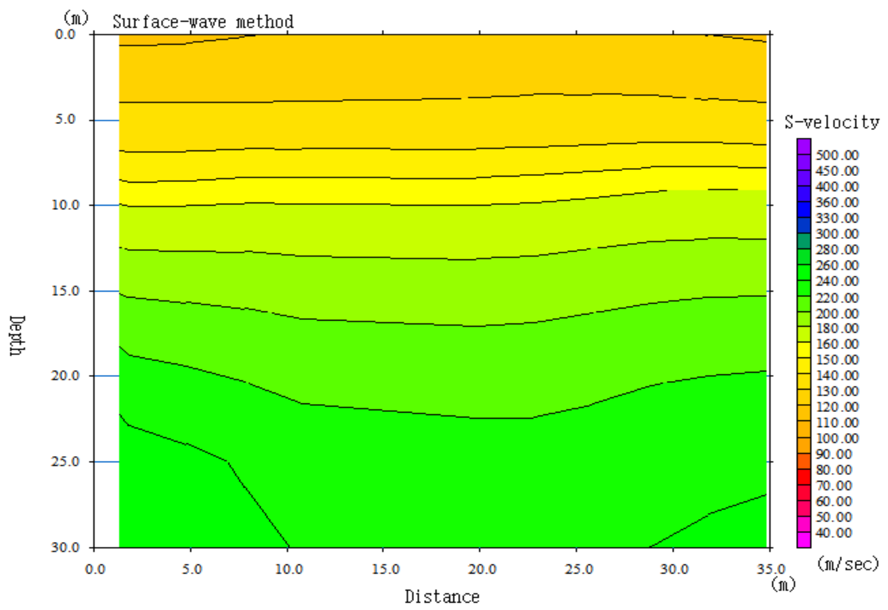
MASW Serial No.- MASW-07
Location: Temohoni, Katachara Union
Coordinates: Lat-22.84534 Long- 91.506941

Depth	S-Wave Velocity
0.0	117
1.7	127
3.8	130
6.3	144
9.2	165
12.5	197
16.3	221
20.4	244
25.0	262
30.0	262

1D Model



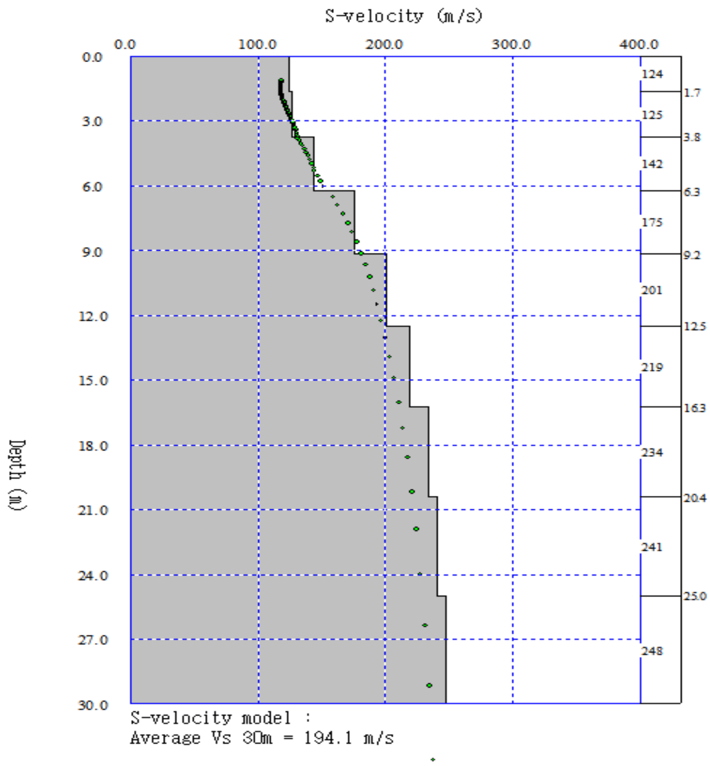
2D Model



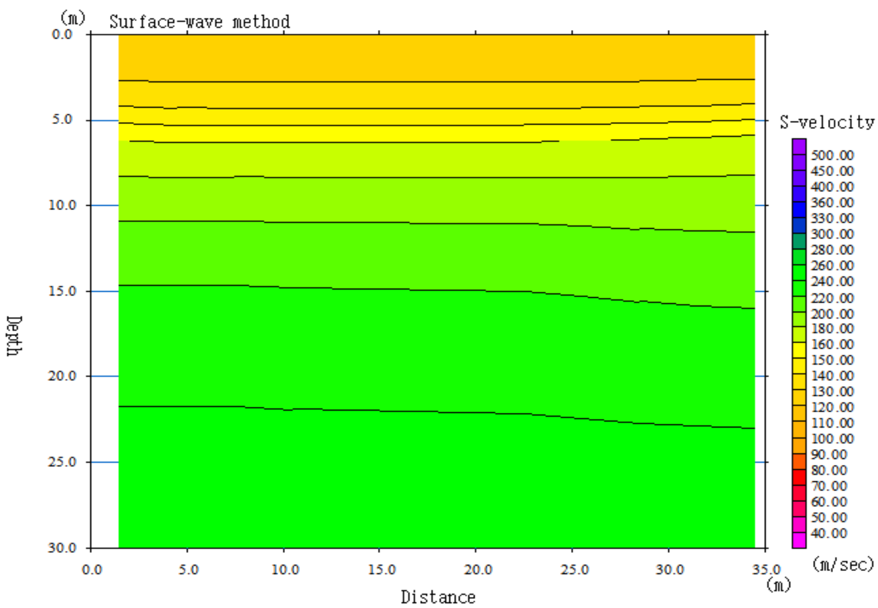
MASW Serial No.- MASW-08
Location: UttarKatachara Union
Coordinates: Lat-22.82728021Long- 91.520913551

Depth	S-Wave Velocity
0.0	123
1.7	125
3.8	142
6.3	175
9.2	201
12.5	219
16.3	234
20.4	241
25.0	248
30.0	248

1D Model



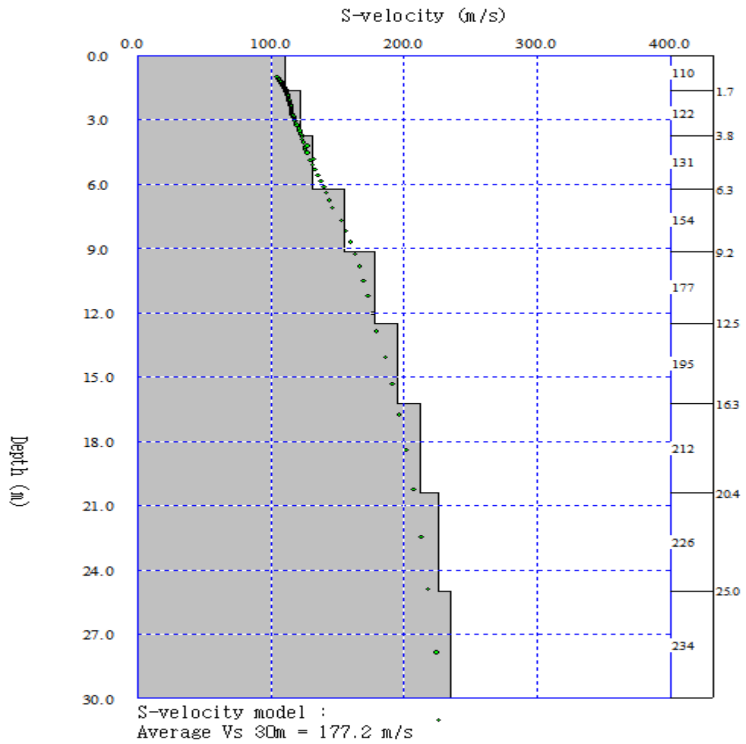
2D Model



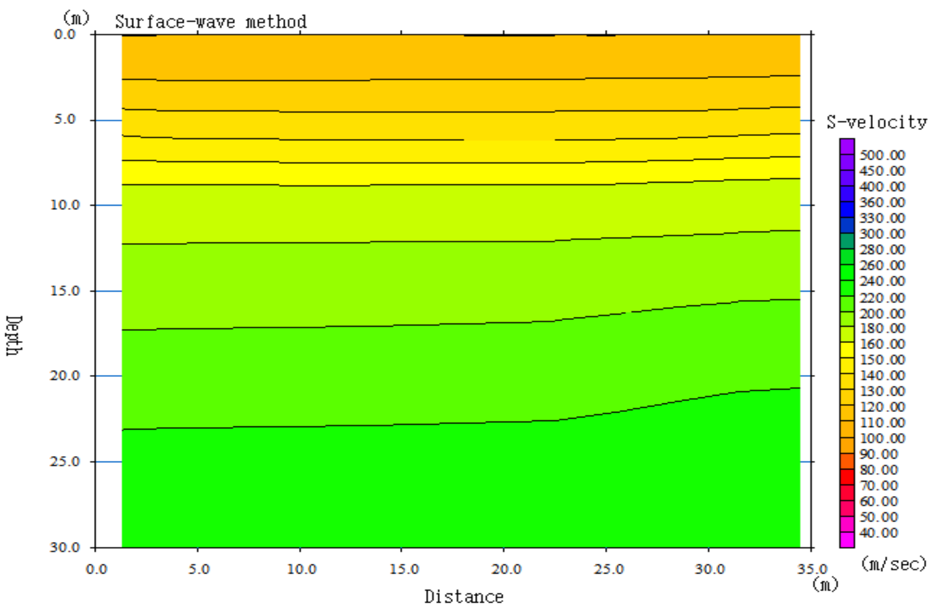
MASW Serial No.- MASW-09
Location: Veribadh, Ichakhali
Coordinates: Lat-22.783081 Long- 91.469953

Depth	S-Wave Velocity
0.0	110
1.7	122
3.8	131
6.3	154
9.2	177
12.5	195
16.3	212
20.4	226
25.0	234
30.0	234

1D Model



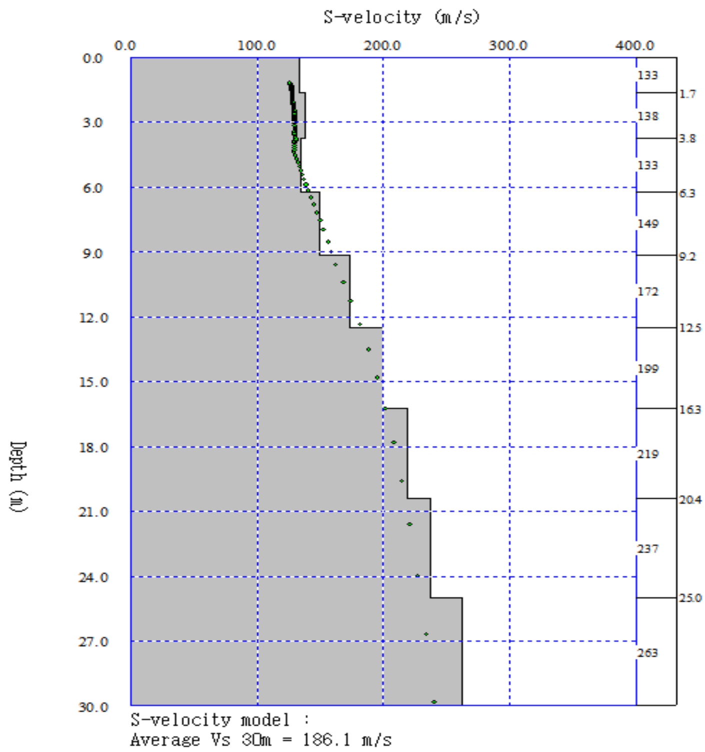
2D Model



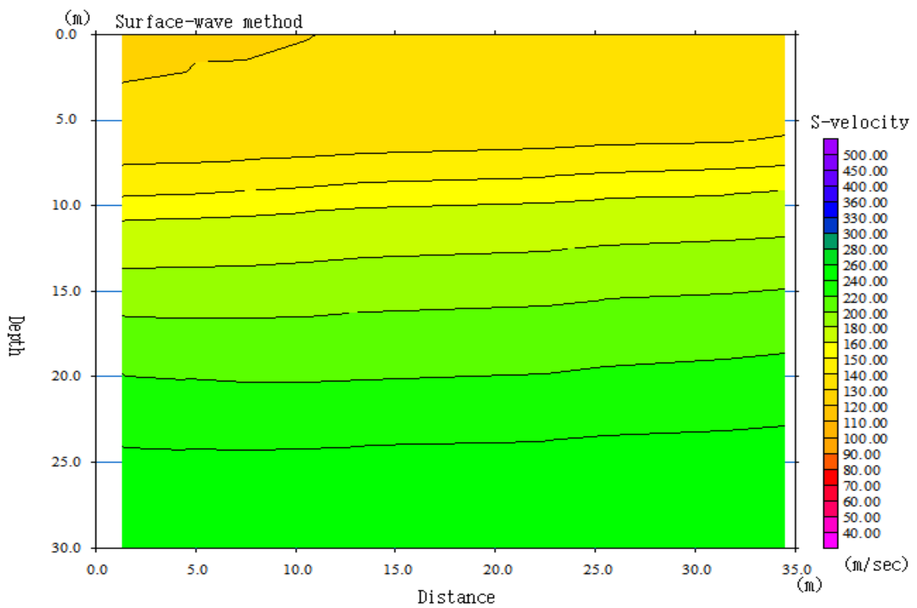
MASW Serial No.- MASW-10
Location: BEZA, Ichakhali
Coordinates: Lat-22.75094 Long- 91.48756

Depth	S-Wave Velocity
0.0	132
1.7	138
3.8	132
6.3	149
9.2	172
12.5	199
16.3	219
20.4	237
25.0	263
30.0	263

1D Model



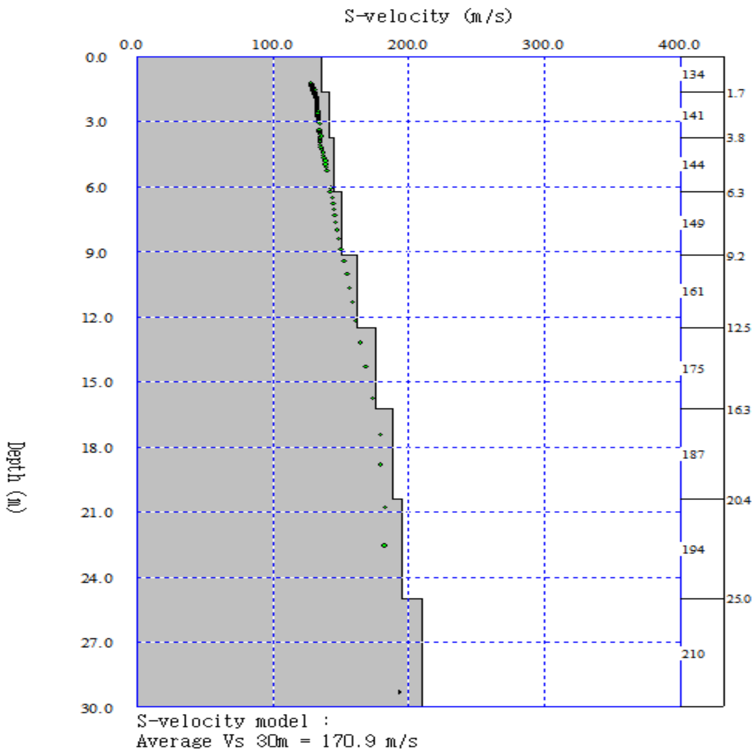
2D Model



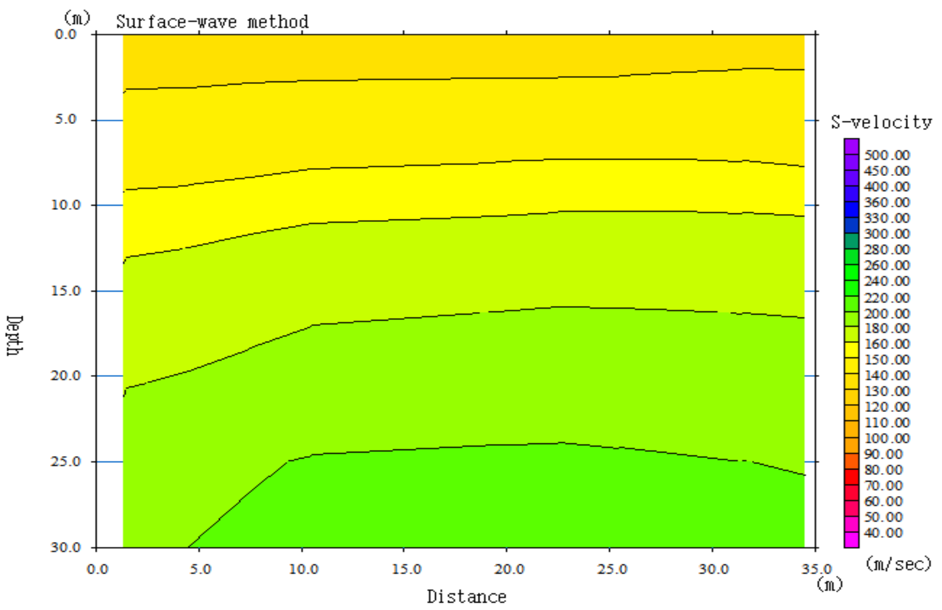
MASW Serial No.- MASW-11
Location: Muhuri Project, Veribadh
Coordinates: Lat-22.843563 Long- 91.47481

Depth	S-Wave Velocity
0.0	134
1.7	141
3.8	144
6.3	149
9.2	161
12.5	175
16.3	187
20.4	194
25.0	210
30.0	210

1D Model



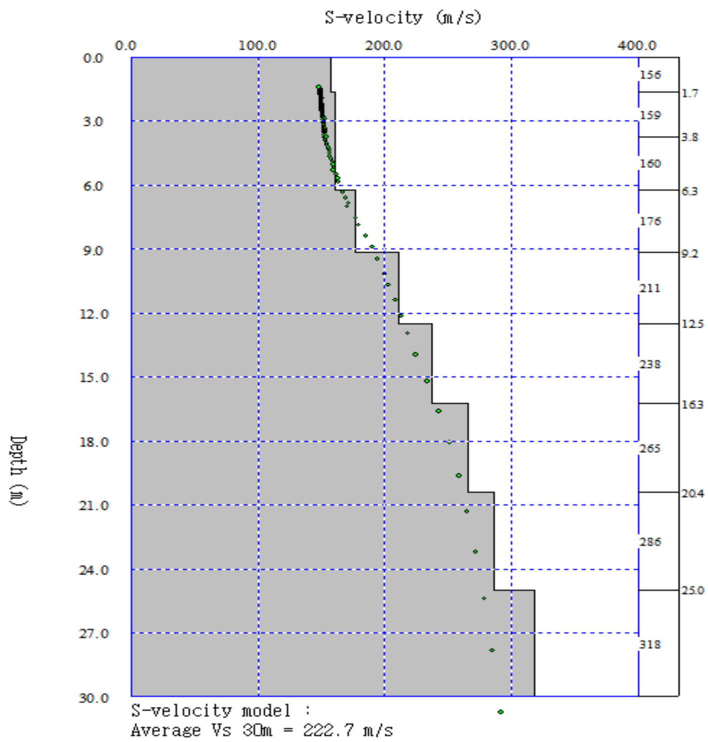
2D Model



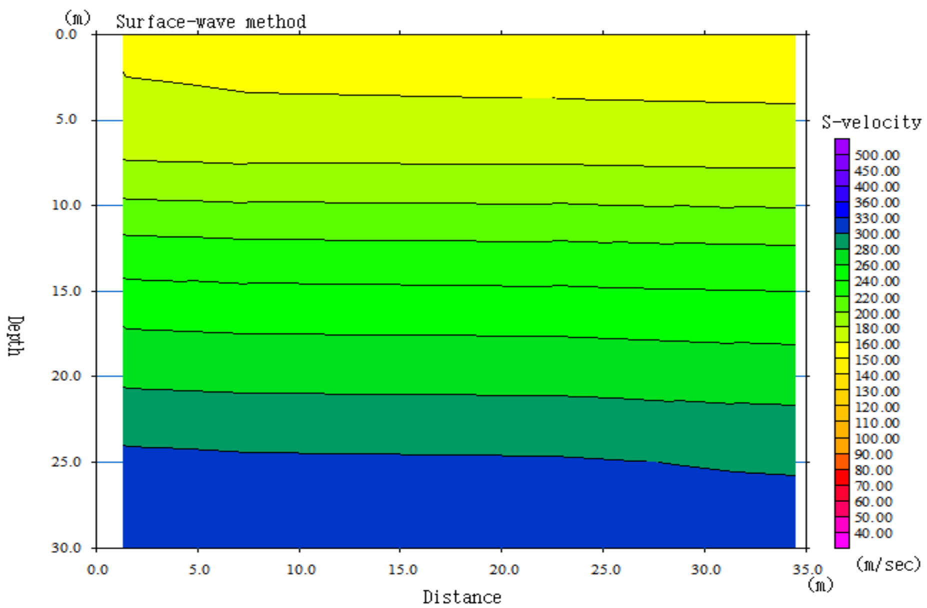
MASW Serial No.- MASW-12
Location: Mirshorai College, Mirshorai
Coordinates: Lat-22.77799 Long- 91.57322

Depth	S-Wave Velocity
0.0	156
1.7	159
3.8	160
6.3	176
9.2	211
12.5	238
16.3	265
20.4	286
25.0	318
30.0	318

1D Model



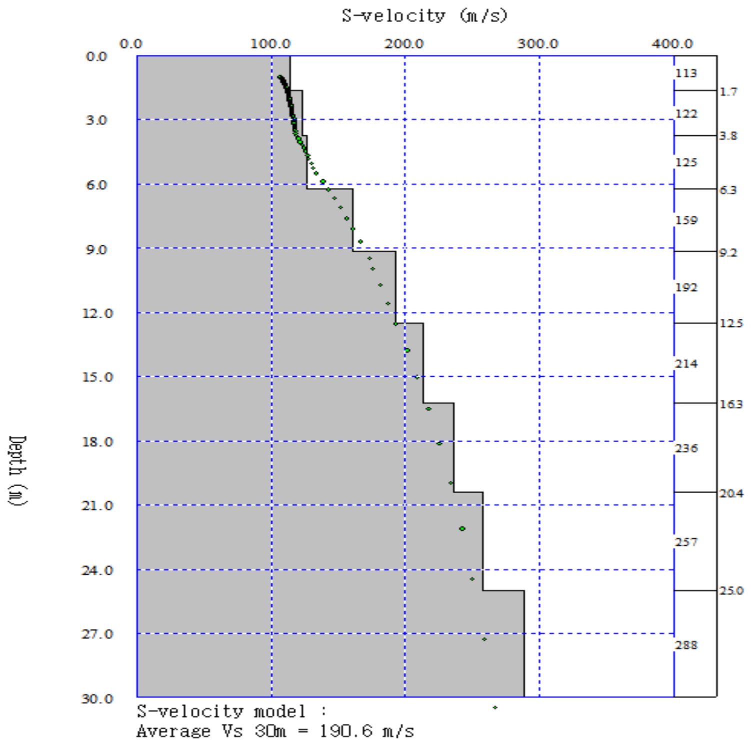
2D Model



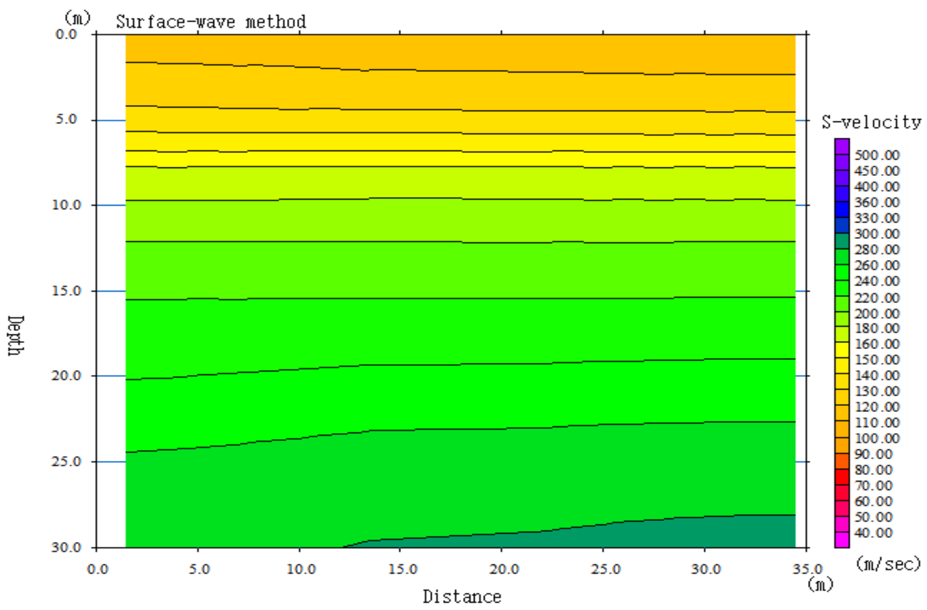
MASW Serial No.- MASW-13
Location: BishwoDarbar, Amantola
Coordinates: Lat-22.794934 Long- 91.551293

Depth	S-Wave Velocity
0.0	113
1.7	122
3.8	125
6.3	159
9.2	192
12.5	214
16.3	236
20.4	257
25.0	287
30.0	287

1D Model



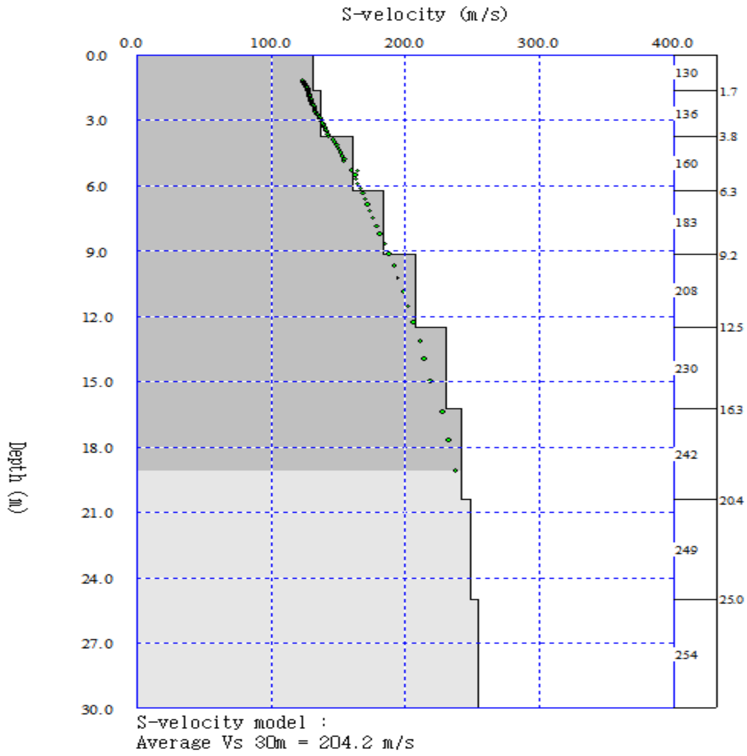
2D Model



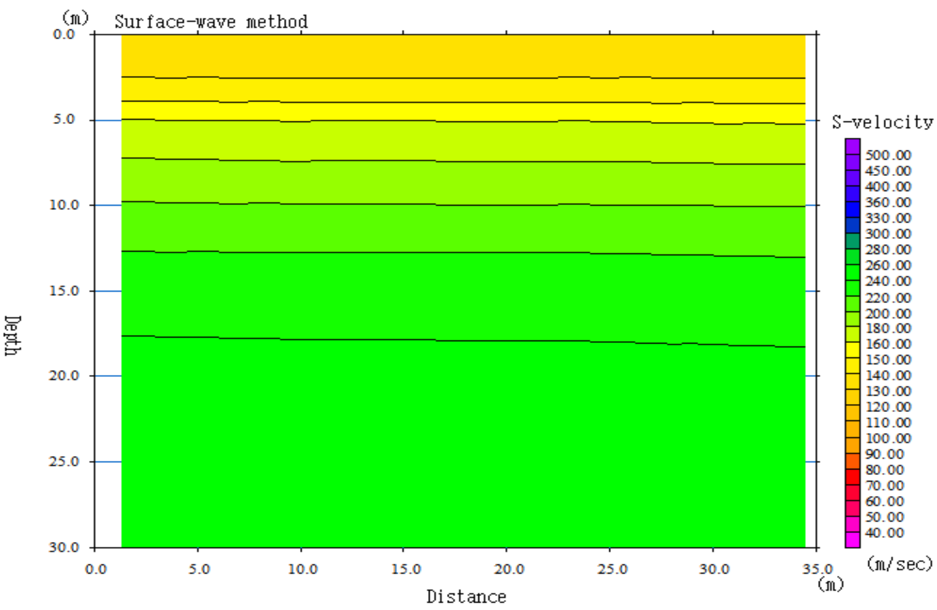
MASW Serial No.- MASW-14
Location: Tegoria, Magadia
Coordinates: Lat-22.765763 Long- 91.530332

Depth	S-Wave Velocity
0.0	130
1.7	136
3.8	159
6.3	183
9.2	210
12.5	230
16.3	242
20.4	249
25.0	254
30.0	254

1D Model



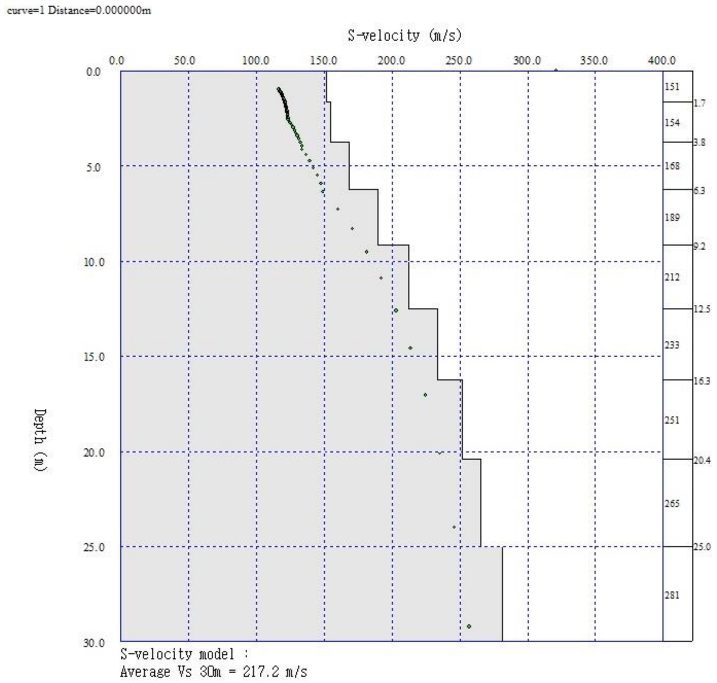
2D Model



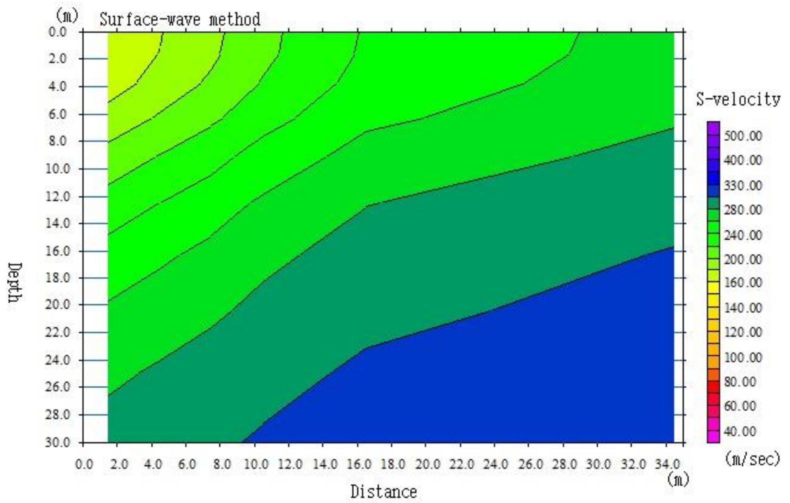
MASW Serial No.- MASW-15
Location: Moddhom Magadia Miabari, Magadia
Coordinates: Lat-22.74429 Long- 91.54198

Depth	S-Wave Velocity
0.0	151
1.7	154
3.8	168
6.3	189
9.2	212
12.5	233
16.3	251
20.4	265
25.0	281
30.0	281

1D Model



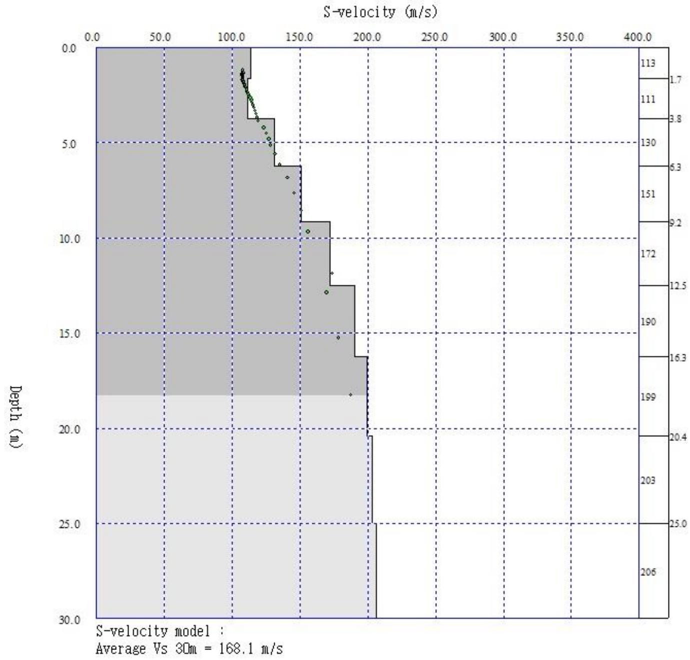
2D Model



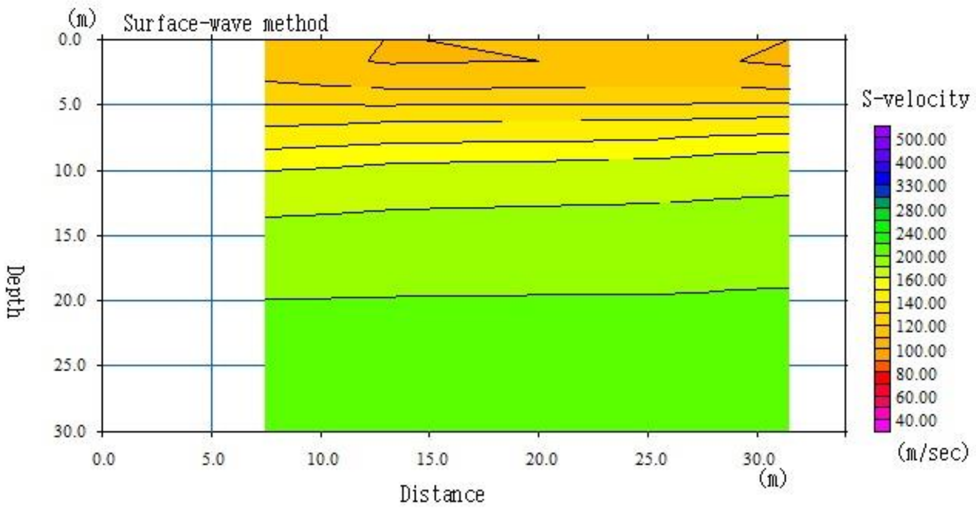
MASW Serial No.- MASW-16
Location: Veribadh, Saherkhali
Coordinates: Lat-22.70568 Long- 91.5403

Depth	S-Wave Velocity
0.0	113
1.7	111
3.8	130
6.3	151
9.2	172
12.5	190
16.3	199
20.4	203
25.0	206
30.0	206

1D Model



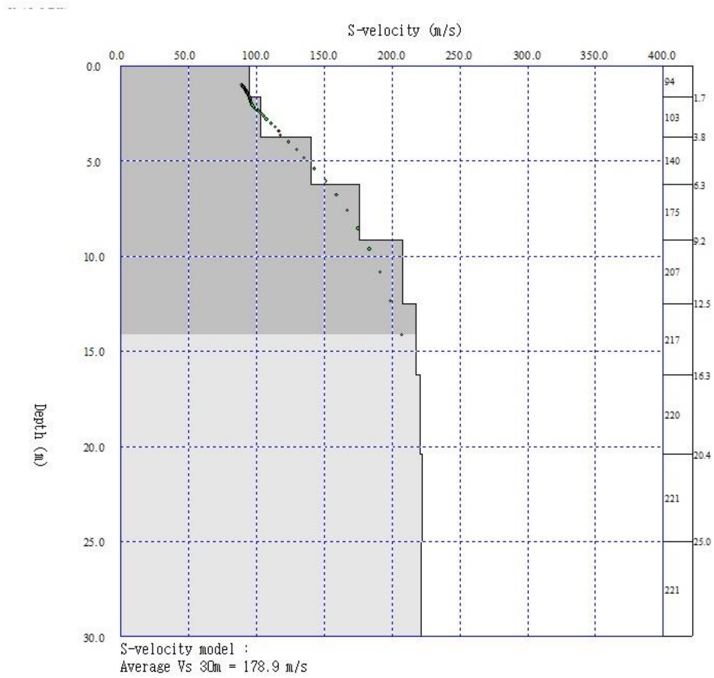
2D Model



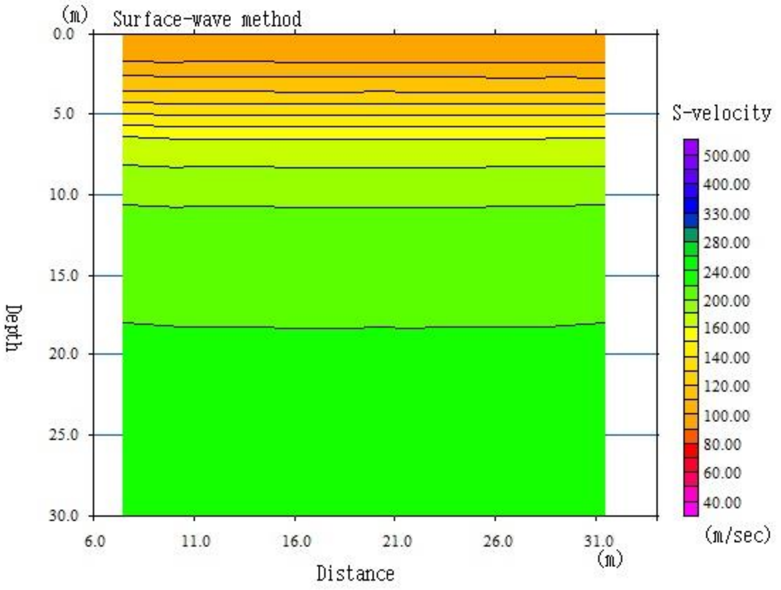
MASW Serial No.- MASW-17
Location: BamansundarKhal, Shaherkhali, BEZA
Coordinates: Lat-22.733001 Long- 91.50586

Depth	S-Wave Velocity
0.0	94
1.7	103
3.8	140
6.3	175
9.2	207
12.5	217
16.3	220
20.4	221
25.0	221
30.0	221

1D Model



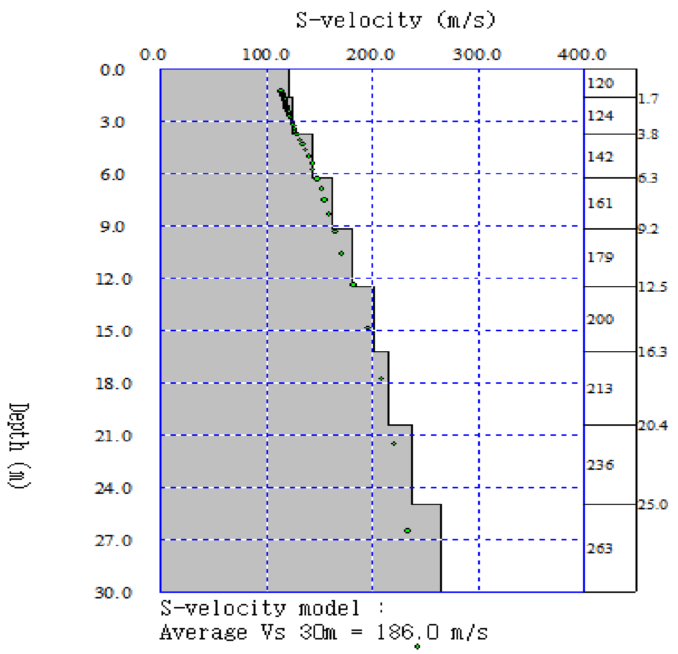
2D Model



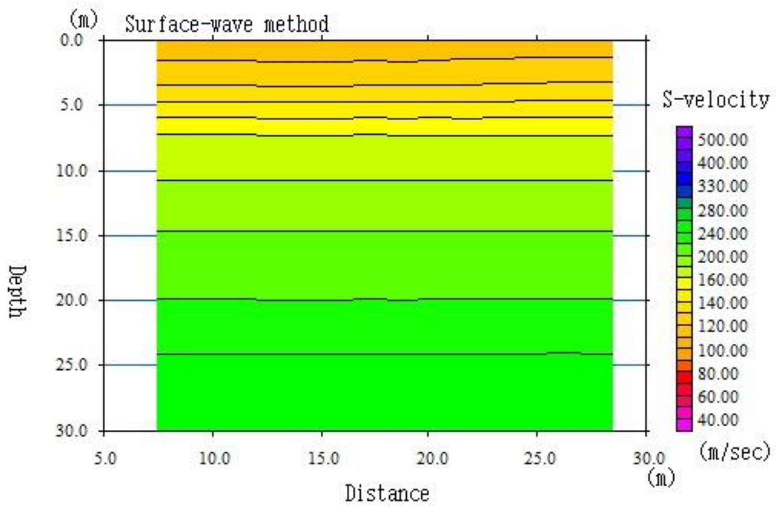
MASW Serial No.- MASW-18
Location: N Hatkumli, Joberhazi Road, Haitkandi
Coordinates: Lat-22.72324 Long- 91.57393

Depth	S-Wave Velocity
0.0	120
1.7	124
3.8	142
6.3	161
9.2	179
12.5	200
16.3	213
20.4	236
25.0	263
30.0	263

1D Model



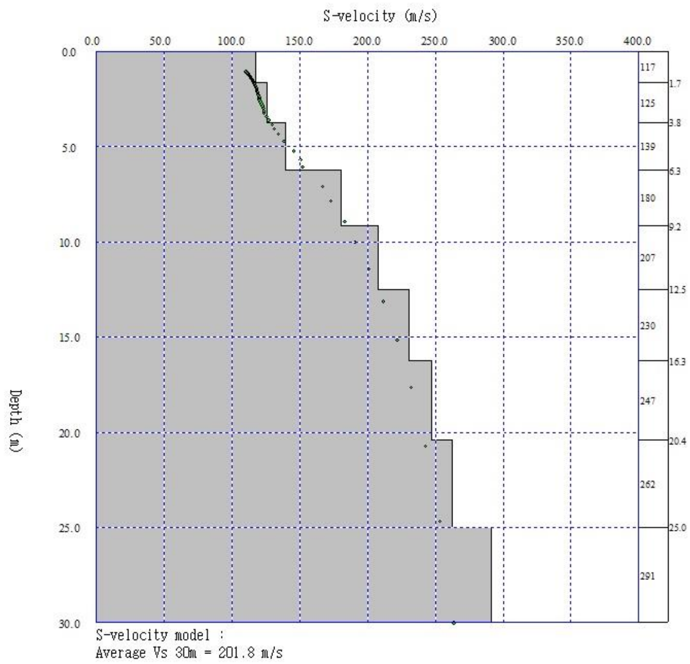
2D Model



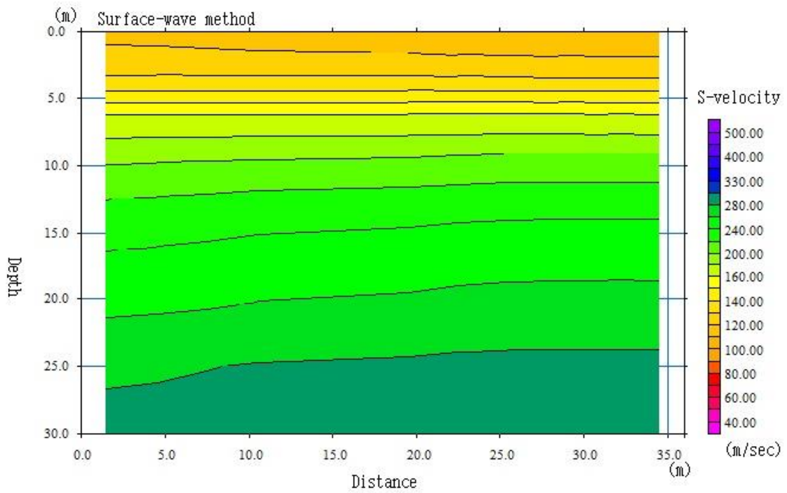
MASW Serial No.- MASW-19
Location: ChotokamalDaho, Kankir hat bazar road, Wahedpur
Coordinates: Lat-22.70142 Long- 91.61302

Depth	S-Wave Velocity
0.0	117
1.7	125
3.8	139
6.3	180
9.2	207
12.5	230
16.3	247
20.4	262
25.0	291
30.0	291

1D Model



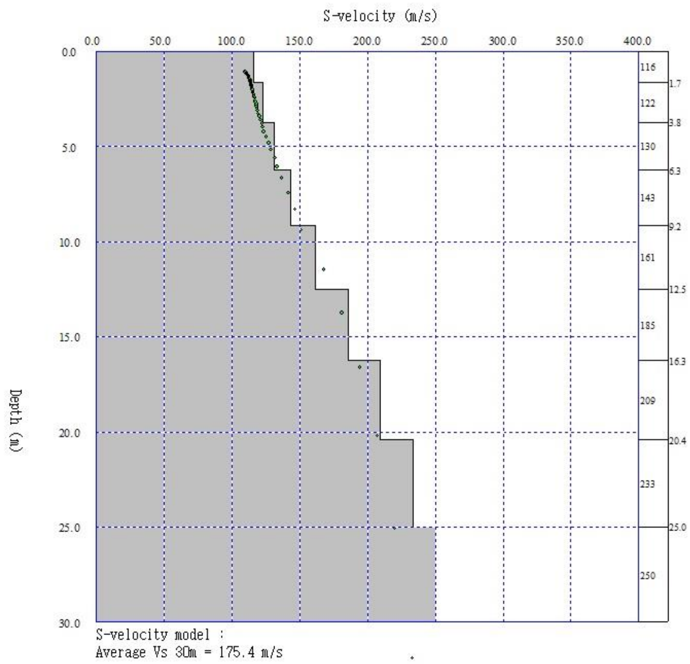
2D Model



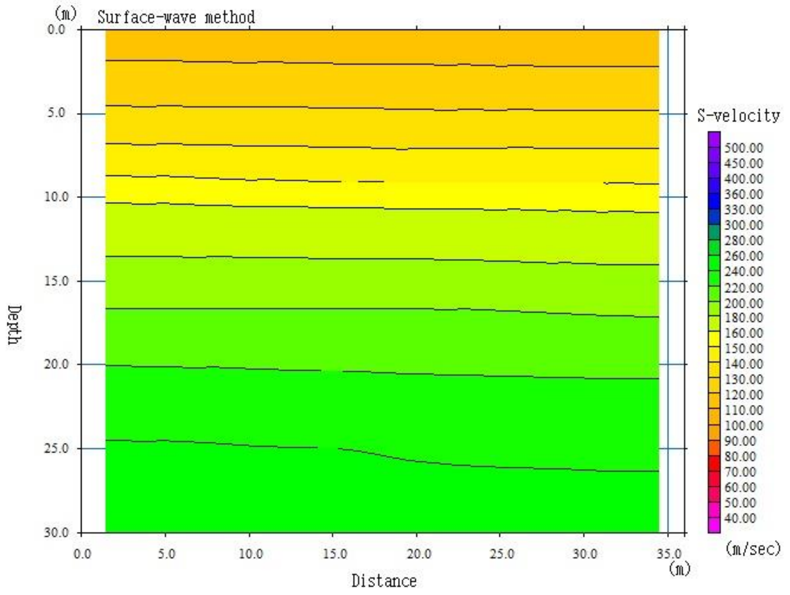
MASW Serial No.- MASW-20
Location: Monir hut, East HaitKandi
Coordinates: Lat-22.70559 Long- 91.58147

Depth	S-Wave Velocity
0.0	116
1.7	122
3.8	130
6.3	143
9.2	161
12.5	185
16.3	209
20.4	233
25.0	250
30.0	250

1D Model



2D Model



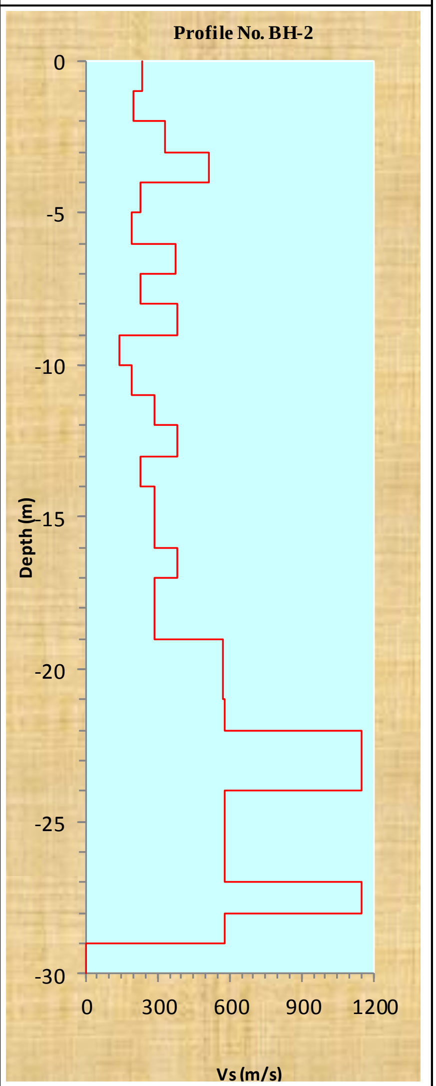
APPENDIX B: P-S WAVE VELOCITY TEST RESULTS AND GRAPHS

SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 25/02/2018	Source : 7kg Sledge Hammer
Location : Choturua, Ward-1, Korerhat	Downhole Receiver : Tri-axial Geophone
PS Id : 01/BH-2	Recording Equipment: Freedom Data PC
Coordinate Lat- 22.93579 Long- 91.55832	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Compretional Wave, tc=D*t/R (s)	Interval Time,ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.005997	-1	1.41	0.0042	0.0042	236	AVS 5 269
0.010315	-2	2.24	0.0092	0.0050	201	
0.012906	-3	3.16	0.0122	0.0030	331	
0.014633	-4	4.12	0.0142	0.0020	512	
0.018951	-5	5.10	0.0186	0.0044	228	
0.024133	-6	6.08	0.0238	0.0052	192	AVS 10 248
0.026724	-7	7.07	0.0265	0.0027	377	
0.031042	-8	8.06	0.0308	0.0043	230	
0.033633	-9	9.06	0.0334	0.0026	381	
0.040542	-10	10.05	0.0403	0.0069	145	
0.045724	-11	11.05	0.0455	0.0052	192	AVS 15 252
0.049179	-12	12.04	0.0490	0.0035	288	
0.051770	-13	13.04	0.0516	0.0026	383	
0.056088	-14	14.04	0.0559	0.0043	231	
0.059543	-15	15.03	0.0594	0.0035	289	
0.062997	-16	16.03	0.0629	0.0035	289	AVS 20 270
0.065588	-17	17.03	0.0655	0.0026	385	
0.069043	-18	18.03	0.0689	0.0035	289	
0.072497	-19	19.03	0.0724	0.0035	289	
0.074224	-20	20.02	0.0741	0.0017	577	
0.075952	-21	21.02	0.0759	0.0017	576	AVS 25 308
0.077679	-22	22.02	0.0776	0.0017	577	
0.078543	-23	23.02	0.0785	0.0009	1149	
0.079406	-24	24.02	0.0793	0.0009	1152	
0.081134	-25	25.02	0.0811	0.0017	577	
0.082861	-26	26.02	0.0828	0.0017	578	AVS 29 333
0.084588	-27	27.02	0.0845	0.0017	578	
0.085452	-28	28.02	0.0854	0.0009	1153	
0.087179	-29	29.02	0.0871	0.0017	578	

Graphical Representation of Vs

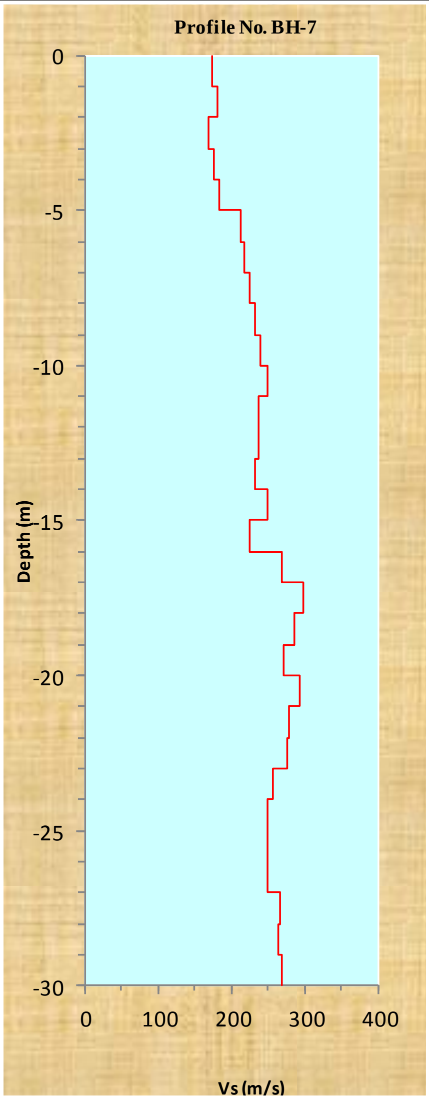


SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 25/02/2018	Source : 7kg Sledge Hammer
Location : Khil hinguli Govt. Primary School	Downhole Receiver : Tri-axial Geophone
PS Id : BH-7	Recording Equipment: Freedom Data PC
Coordinate Lat- 22.89774 Long- 91.5464	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Comprentional Wave, tc=D*t/R (s)	Interval Time, ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.008153	-1	1.41	0.0058	0.0058	173	**AVS 5** **177**
0.012586	-2	2.24	0.0113	0.0055	182	
0.018123	-3	3.16	0.0172	0.0059	168	
0.023557	-4	4.12	0.0229	0.0057	177	
0.028856	-5	5.10	0.0283	0.0054	184	
0.033456	-6	6.08	0.0330	0.0047	213	**AVS 10** **198**
0.037967	-7	7.07	0.0376	0.0046	218	
0.042359	-8	8.06	0.0420	0.0044	225	
0.046642	-9	9.06	0.0464	0.0043	231	
0.050781	-10	10.05	0.0505	0.0042	240	
0.054761	-11	11.05	0.0545	0.0040	250	**AVS 15** **210**
0.058959	-12	12.04	0.0588	0.0042	237	
0.063158	-13	13.04	0.0630	0.0042	237	
0.067457	-14	14.04	0.0673	0.0043	232	
0.071456	-15	15.03	0.0713	0.0040	249	
0.075891	-16	16.03	0.0757	0.0044	225	**AVS 20** **222**
0.079605	-17	17.03	0.0795	0.0037	268	
0.082956	-18	18.03	0.0828	0.0034	298	
0.086454	-19	19.03	0.0863	0.0035	285	
0.090145	-20	20.02	0.0900	0.0037	270	
0.093561	-21	21.02	0.0935	0.0034	292	**AVS 25** **230**
0.097152	-22	22.02	0.0971	0.0036	278	
0.100756	-23	23.02	0.1007	0.0036	277	
0.104652	-24	24.02	0.1046	0.0039	256	
0.108656	-25	25.02	0.1086	0.0040	250	
0.112656	-26	26.02	0.1126	0.0040	250	**AVS 30** **235**
0.116654	-27	27.02	0.1166	0.0040	250	
0.120415	-28	28.02	0.1203	0.0038	266	
0.124200	-29	29.02	0.1241	0.0038	264	
0.127900	-30	30.02	0.1278	0.0037	270	

Graphical Representation of Vs



SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 23/02/2018

Location : Imampur Titabot tola Furkania Madrasha

PS Id : 3/BH-11

Coordinate Lat- 22.87949 Long- 91.53175

Operator : The Olson Instruments Downhole Seismic system

Source : 7kg Sledge Hammer

Downhole Receiver : Tri-axial Geophone

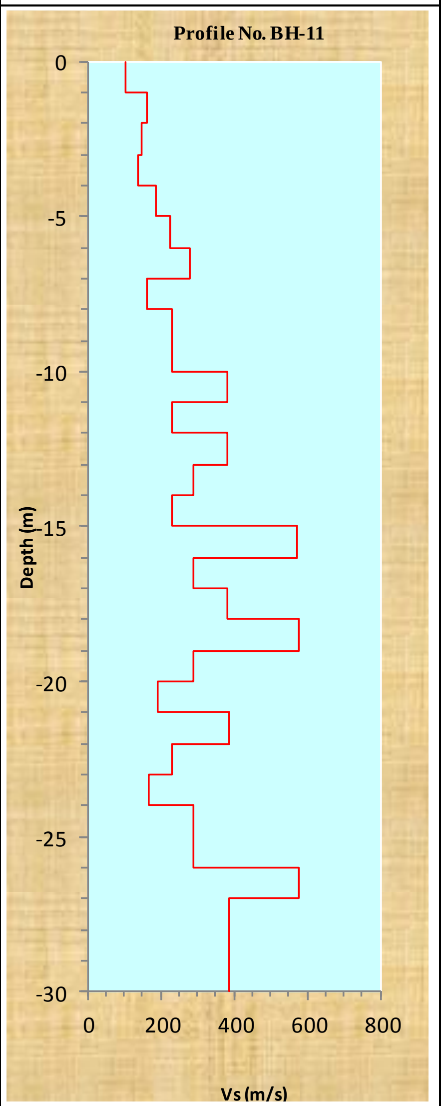
Recording Equipment: Freedom Data PC

Borehole Information : Grouted Cased

Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Comprentional Wave, tc=D*t/R (s)	Interval Time, ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.013600	-1	1.41	0.0096	0.0096	104	AVS 5: 143
0.017600	-2	2.24	0.0157	0.0061	163	
0.023651	-3	3.16	0.0224	0.0067	149	
0.030567	-4	4.12	0.0297	0.0072	139	
0.035754	-5	5.10	0.0351	0.0054	185	
0.040077	-6	6.08	0.0395	0.0045	224	AVS 10: 173
0.043535	-7	7.07	0.0431	0.0036	280	
0.049587	-8	8.06	0.0492	0.0061	164	
0.053909	-9	9.06	0.0536	0.0044	229	
0.058232	-10	10.05	0.0579	0.0044	229	
0.060825	-11	11.05	0.0606	0.0026	380	AVS 15: 199
0.065148	-12	12.04	0.0649	0.0043	230	
0.067741	-13	13.04	0.0675	0.0026	382	
0.071200	-14	14.04	0.0710	0.0035	288	
0.075522	-15	15.03	0.0754	0.0043	231	
0.077251	-16	16.03	0.0771	0.0017	573	AVS 20: 226
0.080709	-17	17.03	0.0806	0.0035	288	
0.083303	-18	18.03	0.0832	0.0026	384	
0.085032	-19	19.03	0.0849	0.0017	575	
0.088490	-20	20.02	0.0884	0.0035	289	
0.093677	-21	21.02	0.0936	0.0052	193	AVS 25: 227
0.096271	-22	22.02	0.0962	0.0026	385	
0.100593	-23	23.02	0.1005	0.0043	231	
0.106645	-24	24.02	0.1066	0.0061	165	
0.110103	-25	25.02	0.1100	0.0035	289	
0.113561	-26	26.02	0.1135	0.0035	289	AVS 30: 244
0.115290	-27	27.02	0.1152	0.0017	577	
0.117883	-28	28.02	0.1178	0.0026	385	
0.120477	-29	29.02	0.1204	0.0026	385	
0.123071	-30	30.02	0.1230	0.0026	385	

Graphical Representation of Vs

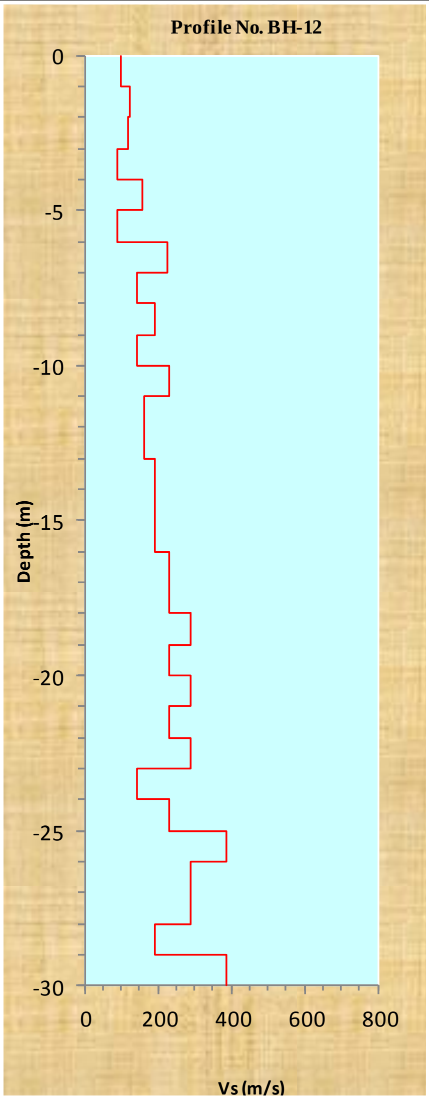


SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 22/02/2018	Source : 7kg Sledge Hammer
Location : Bono Chowdhury Jame Mosque, Mobarokguna, Dhoom	Downhole Receiver : Tri-axial Geophone
PS Id : 4/BH-12	Recording Equipment: Freedom Data PC
Coordinate Lat- 22.89871 Long- 91.49581	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Compretional Wave, tc=D*t/R (s)	Interval Time,ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.013996	-1	1.41	0.0099	0.0099	101	AVS 5 113
0.020039	-2	2.24	0.0179	0.0080	125	
0.027808	-3	3.16	0.0264	0.0085	118	
0.039030	-4	4.12	0.0379	0.0115	87	
0.045073	-5	5.10	0.0442	0.0063	158	
0.056295	-6	6.08	0.0555	0.0113	88	AVS 10 126
0.060611	-7	7.07	0.0600	0.0045	224	
0.067517	-8	8.06	0.0670	0.0070	143	
0.072696	-9	9.06	0.0723	0.0053	190	
0.079602	-10	10.05	0.0792	0.0070	144	
0.083918	-11	11.05	0.0836	0.0044	229	AVS 15 141
0.089961	-12	12.04	0.0897	0.0061	165	
0.096004	-13	13.04	0.0957	0.0061	165	
0.101183	-14	14.04	0.1009	0.0052	192	
0.106363	-15	15.03	0.1061	0.0052	192	
0.111542	-16	16.03	0.1113	0.0052	192	AVS 20 157
0.115858	-17	17.03	0.1157	0.0043	231	
0.120174	-18	18.03	0.1200	0.0043	231	
0.123627	-19	19.03	0.1235	0.0035	288	
0.127944	-20	20.02	0.1278	0.0043	231	
0.131397	-21	21.02	0.1312	0.0035	289	AVS 25 166
0.135713	-22	22.02	0.1356	0.0043	231	
0.139166	-23	23.02	0.1390	0.0035	289	
0.146072	-24	24.02	0.1459	0.0069	145	
0.150388	-25	25.02	0.1503	0.0043	231	
0.152978	-26	26.02	0.1529	0.0026	385	AVS 30 179
0.156430	-27	27.02	0.1563	0.0035	289	
0.159883	-28	28.02	0.1598	0.0035	289	
0.165063	-29	29.02	0.1650	0.0052	193	
0.167653	-30	30.02	0.1676	0.0026	385	

Graphical Representation of Vs

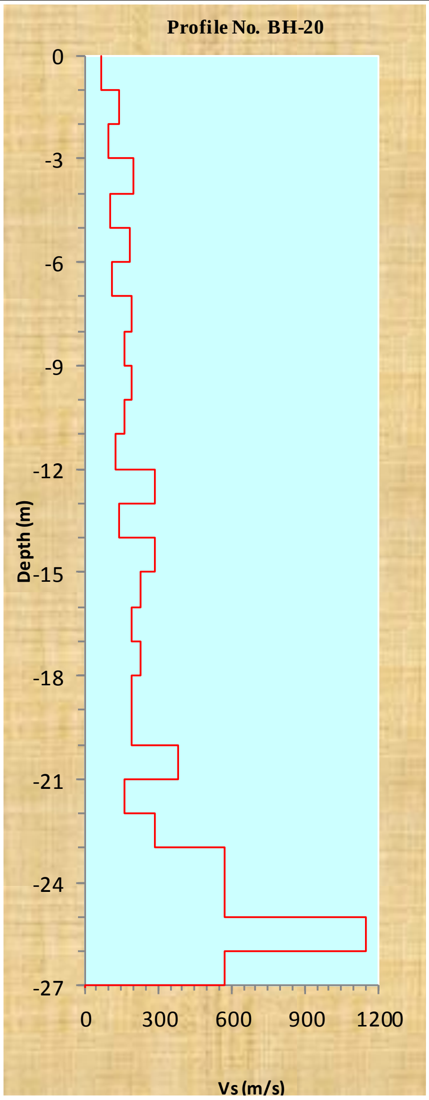


SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 22/02/2018	Source : 7kg Sledge Hammer
Location : 39 no. East Shahedpur Govt. Primary School, Azampur	Downhole Receiver : Tri-axial Geophone
PS Id : 5/BH-20	Recording Equipment: Freedom Data PC
Coordinate Lat- 22.85378 Long- 91.50001	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Compretional Wave, tc=D*t/R (s)	Interval Time, ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.020659	-1	1.41	0.0146	0.0146	68	AVS 5 107
0.024114	-2	2.24	0.0216	0.0070	144	
0.033614	-3	3.16	0.0319	0.0103	97	
0.037933	-4	4.12	0.0368	0.0049	204	
0.047433	-5	5.10	0.0465	0.0097	103	
0.052615	-6	6.08	0.0519	0.0054	186	AVS 10 129
0.061252	-7	7.07	0.0606	0.0087	114	
0.066434	-8	8.06	0.0659	0.0053	189	
0.072480	-9	9.06	0.0720	0.0061	164	
0.077662	-10	10.05	0.0773	0.0052	191	
0.083708	-11	11.05	0.0834	0.0061	164	AVS 15 143
0.091481	-12	12.04	0.0912	0.0078	128	
0.094935	-13	13.04	0.0947	0.0035	287	
0.101845	-14	14.04	0.1016	0.0069	144	
0.105299	-15	15.03	0.1051	0.0035	287	
0.109618	-16	16.03	0.1094	0.0043	230	AVS 20 155
0.114800	-17	17.03	0.1146	0.0052	192	
0.119118	-18	18.03	0.1189	0.0043	231	
0.124300	-19	19.03	0.1241	0.0052	193	
0.129482	-20	20.02	0.1293	0.0052	193	
0.132073	-21	21.02	0.1319	0.0026	384	AVS 25 173
0.138119	-22	22.02	0.1380	0.0061	165	
0.141574	-23	23.02	0.1414	0.0035	289	
0.143301	-24	24.02	0.1432	0.0017	576	
0.145029	-25	25.02	0.1449	0.0017	576	
0.145892	-26	26.02	0.1458	0.0009	1148	AVS 27 183
0.147620	-27	27.02	0.1475	0.0017	576	

Graphical Representation of Vs



SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 23/02/2018

Location : Jaforer Poultry Farm, Choitonner Hat, Durgapur

PS Id : 6/BH-25

Coordinate Lat- 22.83615 Long- 91.54239

Operator : The Olson Instruments Downhole Seismic system

Source : 7kg Sledge Hammer

Downhole Receiver : Tri-axial Geophone

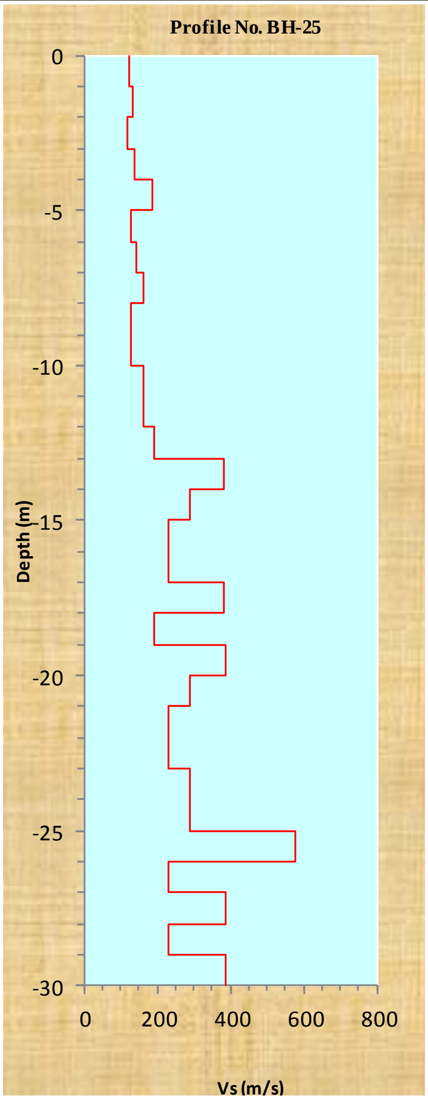
Recording Equipment: Freedom Data PC

Borehole Information : Grouted Cased

Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Comprehensional Wave, tc=D*t/R (s)	Interval Time, ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.011599	-1	1.41	0.0082	0.0082	122	AVS 5 136
0.017639	-2	2.24	0.0158	0.0076	132	
0.025405	-3	3.16	0.0241	0.0083	120	
0.032308	-4	4.12	0.0313	0.0072	138	
0.037486	-5	5.10	0.0368	0.0054	185	
0.045252	-6	6.08	0.0446	0.0079	127	AVS 10 136
0.052155	-7	7.07	0.0516	0.0070	143	
0.058195	-8	8.06	0.0577	0.0061	164	
0.065961	-9	9.06	0.0656	0.0078	128	
0.073727	-10	10.05	0.0734	0.0078	128	
0.079768	-11	11.05	0.0794	0.0061	164	AVS 15 155
0.085808	-12	12.04	0.0855	0.0061	165	
0.090985	-13	13.04	0.0907	0.0052	192	
0.093574	-14	14.04	0.0933	0.0026	382	
0.097026	-15	15.03	0.0968	0.0035	288	
0.101340	-16	16.03	0.1011	0.0043	231	AVS 20 173
0.105655	-17	17.03	0.1055	0.0043	231	
0.108243	-18	18.03	0.1081	0.0026	384	
0.113421	-19	19.03	0.1133	0.0052	193	
0.116009	-20	20.02	0.1159	0.0026	385	
0.119461	-21	21.02	0.1193	0.0035	289	AVS 25 185
0.123776	-22	22.02	0.1236	0.0043	231	
0.128090	-23	23.02	0.1280	0.0043	231	
0.131542	-24	24.02	0.1314	0.0035	289	
0.134993	-25	25.02	0.1349	0.0035	289	
0.136719	-26	26.02	0.1366	0.0017	577	AVS 30 199
0.141033	-27	27.02	0.1409	0.0043	232	
0.143622	-28	28.02	0.1435	0.0026	385	
0.147937	-29	29.02	0.1478	0.0043	232	
0.150525	-30	30.02	0.1504	0.0026	386	

Graphical Representation of Vs

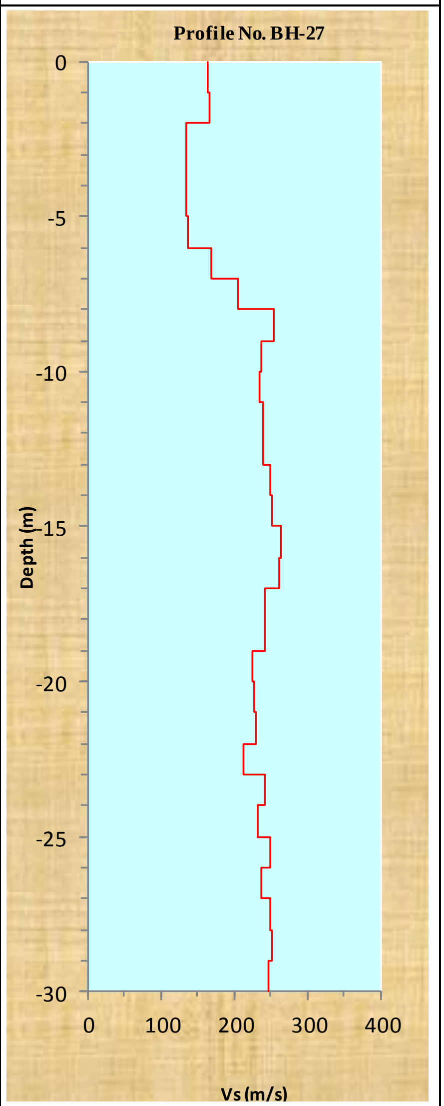


SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 24/02/2018	Source : 7kg Sledge Hammer
Location : Abdus Sattar Bhuiyar Hat Govt. Primary school, Kata chora	Downhole Receiver : Tri-axial Geophone
PS Id : BH-27	Recording Equipment: Freedom Data PC
Coordinate Lat- 22.81188 Long- 91.51746	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Comprettional Wave, tc=D*t/R (s)	Interval Time, ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.008564	-1	1.41	0.0061	0.0061	165	AVS 5 146
0.013458	-2	2.24	0.0120	0.0060	167	
0.020478	-3	3.16	0.0194	0.0074	135	
0.027656	-4	4.12	0.0268	0.0074	135	
0.034856	-5	5.10	0.0342	0.0073	136	
0.042056	-6	6.08	0.0415	0.0073	137	AVS 10 166
0.047859	-7	7.07	0.0474	0.0059	170	
0.052654	-8	8.06	0.0522	0.0049	205	
0.056531	-9	9.06	0.0562	0.0039	254	
0.060682	-10	10.05	0.0604	0.0042	238	
0.064916	-11	11.05	0.0646	0.0043	234	AVS 15 185
0.069056	-12	12.04	0.0688	0.0042	240	
0.073216	-13	13.04	0.0730	0.0042	239	
0.077215	-14	14.04	0.0770	0.0040	249	
0.081153	-15	15.03	0.0810	0.0040	253	
0.084936	-16	16.03	0.0848	0.0038	263	AVS 20 197
0.088756	-17	17.03	0.0886	0.0038	261	
0.092856	-18	18.03	0.0927	0.0041	243	
0.096985	-19	19.03	0.0969	0.0041	242	
0.101426	-20	20.02	0.1013	0.0044	225	
0.105826	-21	21.02	0.1057	0.0044	227	AVS 25 203
0.110156	-22	22.02	0.1100	0.0043	231	
0.114826	-23	23.02	0.1147	0.0047	214	
0.118946	-24	24.02	0.1188	0.0041	242	
0.123249	-25	25.02	0.1232	0.0043	232	
0.127267	-26	26.02	0.1272	0.0040	249	AVS 30 209
0.131461	-27	27.02	0.1314	0.0042	238	
0.135482	-28	28.02	0.1354	0.0040	248	
0.139457	-29	29.02	0.1394	0.0040	251	
0.143512	-30	30.02	0.1434	0.0041	246	

Graphical Representation of Vs

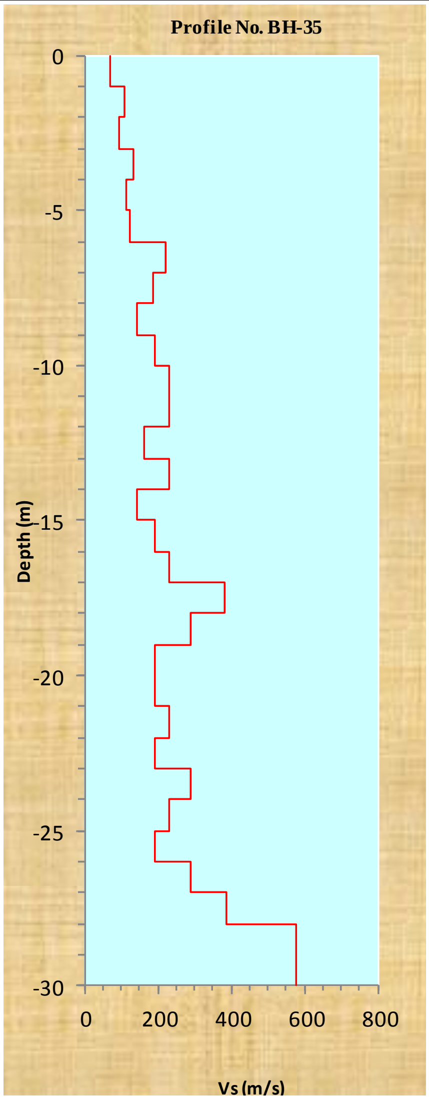


SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 22/02/2018	Source : 7kg Sledge Hammer
Location : Vanguni Bazar Baitunnur Jame Mmosque, Ichakhali	Downhole Receiver : Tri-axial Geophone
PS Id : 8/BH-35	Recording Equipment: Freedom Data PC
Coordinate Lat- 22.82661 Long- 91.48335	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Comprentional Wave, tc=D*t/R (s)	Interval Time, ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.019908	-1	1.41	0.0141	0.0141	71	AVS 5 100
0.025952	-2	2.24	0.0232	0.0091	109	
0.035450	-3	3.16	0.0336	0.0104	96	
0.042358	-4	4.12	0.0411	0.0075	134	
0.050993	-5	5.10	0.0500	0.0089	112	
0.058764	-6	6.08	0.0580	0.0080	126	AVS 10 125
0.063081	-7	7.07	0.0624	0.0045	223	
0.068262	-8	8.06	0.0677	0.0053	189	
0.075170	-9	9.06	0.0747	0.0070	143	
0.080351	-10	10.05	0.0800	0.0052	191	
0.084668	-11	11.05	0.0843	0.0044	229	AVS 15 141
0.088986	-12	12.04	0.0887	0.0044	229	
0.095030	-13	13.04	0.0948	0.0061	165	
0.099347	-14	14.04	0.0991	0.0043	230	
0.106255	-15	15.03	0.1060	0.0069	144	
0.111436	-16	16.03	0.1112	0.0052	192	AVS 20 158
0.115753	-17	17.03	0.1156	0.0043	231	
0.118344	-18	18.03	0.1182	0.0026	383	
0.121798	-19	19.03	0.1216	0.0035	288	
0.126979	-20	20.02	0.1268	0.0052	193	
0.132159	-21	21.02	0.1320	0.0052	193	AVS 25 167
0.136477	-22	22.02	0.1363	0.0043	231	
0.141658	-23	23.02	0.1415	0.0052	193	
0.145112	-24	24.02	0.1450	0.0035	289	
0.149429	-25	25.02	0.1493	0.0043	231	
0.154610	-26	26.02	0.1545	0.0052	193	AVS 30 183
0.158064	-27	27.02	0.1580	0.0035	289	
0.160654	-28	28.02	0.1606	0.0026	385	
0.162381	-29	29.02	0.1623	0.0017	577	
0.164108	-30	30.02	0.1640	0.0017	577	

Graphical Representation of Vs



SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 28/02/2018
Location : East Ambaria, Mirsharai

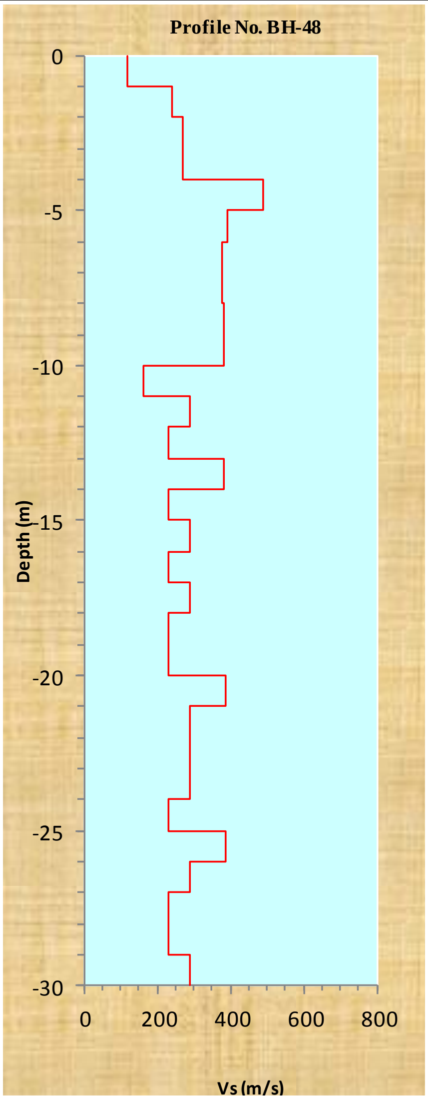
PS Id : 9/BH-48
Coordinate Lat- 22.7794 Long- 91.59575
Operator : The Olson Instruments Downhole Seismic system

Source : 7kg Sledge Hammer
Downhole Receiver : Tri-axial Geophone

Recording Equipment: Freedom Data PC
Borehole Information : Grouted Cased
Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Comprețional Wave, tc=D*t/R (s)	Interval Time, ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.012144	-1	1.41	0.0086	0.0086	116	AVS 5 225
0.014279	-2	2.24	0.0128	0.0042	239	
0.017334	-3	3.16	0.0164	0.0037	272	
0.020794	-4	4.12	0.0202	0.0037	268	
0.022659	-5	5.10	0.0222	0.0020	489	
0.025119	-6	6.08	0.0248	0.0026	391	AVS 10 283
0.027714	-7	7.07	0.0274	0.0027	376	
0.030309	-8	8.06	0.0301	0.0026	379	
0.032904	-9	9.06	0.0327	0.0026	381	
0.035499	-10	10.05	0.0353	0.0026	382	
0.041554	-11	11.05	0.0414	0.0061	165	AVS 15 267
0.045014	-12	12.04	0.0449	0.0035	288	
0.049339	-13	13.04	0.0492	0.0043	231	
0.051934	-14	14.04	0.0518	0.0026	383	
0.056259	-15	15.03	0.0561	0.0043	231	
0.059719	-16	16.03	0.0596	0.0035	288	AVS 20 263
0.064044	-17	17.03	0.0639	0.0043	231	
0.067504	-18	18.03	0.0674	0.0035	288	
0.071828	-19	19.03	0.0717	0.0043	231	
0.076153	-20	20.02	0.0761	0.0043	231	
0.078748	-21	21.02	0.0787	0.0026	384	AVS 25 268
0.082208	-22	22.02	0.0821	0.0035	289	
0.085668	-23	23.02	0.0856	0.0035	289	
0.089128	-24	24.02	0.0891	0.0035	289	
0.093453	-25	25.02	0.0934	0.0043	231	
0.096048	-26	26.02	0.0960	0.0026	385	AVS 30 269
0.099508	-27	27.02	0.0994	0.0035	289	
0.103833	-28	28.02	0.1038	0.0043	231	
0.108158	-29	29.02	0.1081	0.0043	231	
0.111618	-30	30.02	0.1116	0.0035	289	

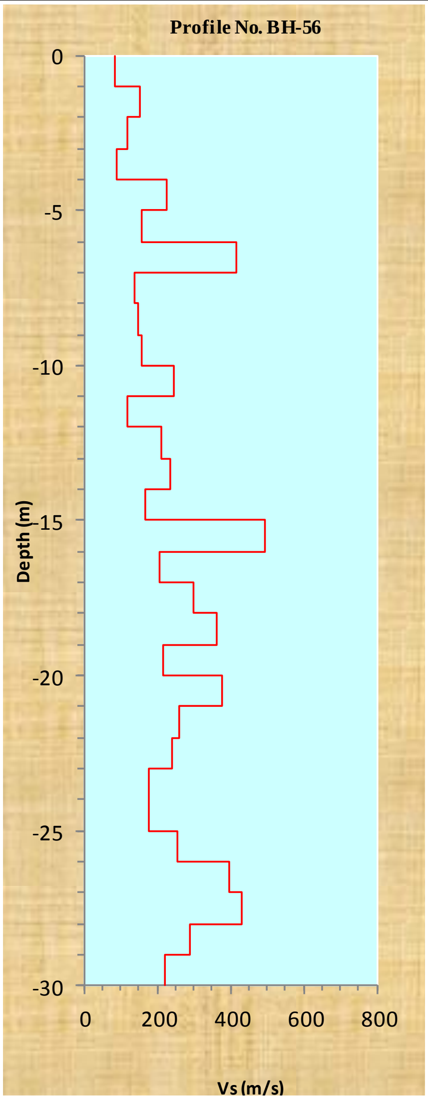
Graphical Representation of Vs



SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 24/02/2018	Source : 7kg Sledge Hammer
Location : Hazi Badiul Alam Chowdhury Govt. Primary School, Mithanala	Downhole Receiver : Tri-axial Geophone
PS Id : 10/BH-56	Recording Equipment: Freedom Data PC
Coordinate Lat- 22.78397 Long- 91.53249	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Comprational Wave, tc=D*t/R (s)	Interval Time,ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)	Graphical Representation of Vs
Existing Ground Level							
0.016927	-1	1.41	0.0120	0.0120	84	AVS 5 117	
0.020683	-2	2.24	0.0185	0.0065	153		
0.028545	-3	3.16	0.0271	0.0086	117		
0.039363	-4	4.12	0.0382	0.0111	90		
0.043470	-5	5.10	0.0426	0.0044	225		
0.049680	-6	6.08	0.0490	0.0064	157	AVS 10 140	
0.051933	-7	7.07	0.0514	0.0024	415		
0.059044	-8	8.06	0.0586	0.0072	139		
0.065655	-9	9.06	0.0653	0.0067	150		
0.071915	-10	10.05	0.0716	0.0063	159		
0.075922	-11	11.05	0.0756	0.0041	247	AVS 15 152	
0.084335	-12	12.04	0.0840	0.0084	119		
0.088992	-13	13.04	0.0887	0.0047	213		
0.093249	-14	14.04	0.0930	0.0043	234		
0.099159	-15	15.03	0.0989	0.0059	169		
0.101162	-16	16.03	0.1010	0.0020	494	AVS 20 171	
0.106019	-17	17.03	0.1058	0.0049	205		
0.109375	-18	18.03	0.1092	0.0034	297		
0.112130	-19	19.03	0.1120	0.0028	361		
0.116787	-20	20.02	0.1166	0.0047	214		
0.119441	-21	21.02	0.1193	0.0027	375	AVS 25 180	
0.123297	-22	22.02	0.1232	0.0039	259		
0.127454	-23	23.02	0.1273	0.0042	240		
0.133063	-24	24.02	0.1329	0.0056	178		
0.138772	-25	25.02	0.1387	0.0057	175		
0.142678	-26	26.02	0.1426	0.0039	256	AVS 30 193	
0.145182	-27	27.02	0.1451	0.0025	398		
0.147486	-28	28.02	0.1474	0.0023	433		
0.150941	-29	29.02	0.1509	0.0035	289		
0.155449	-30	30.02	0.1554	0.0045	222		

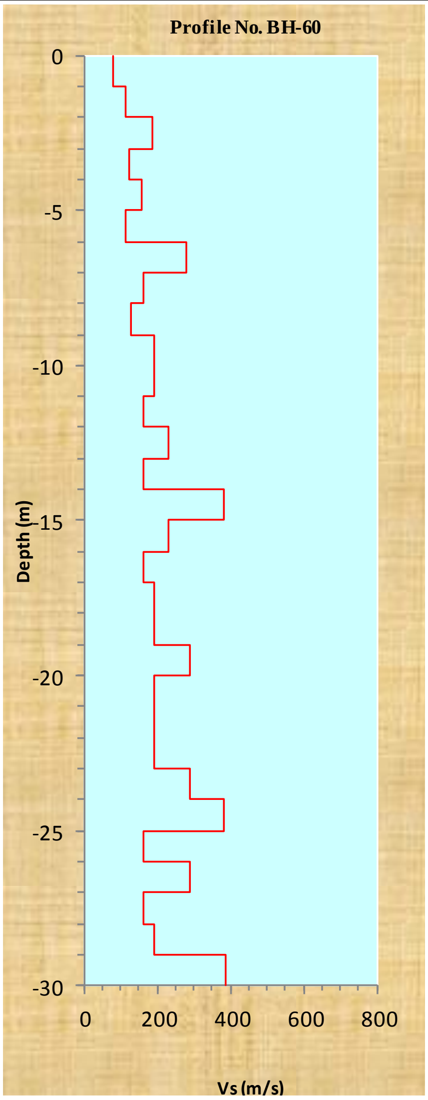


SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 26/02/2018	Source : 7kg Sledge Hammer
Location : 90 no. Maghadia NC Govt. Primary School, Maghadia	Downhole Receiver : Tri-axial Geophone
PS Id : 11/BH-60	Recording Equipment: Freedom Data PC
Coordinate Lat- 22.74951 Long- 91.53351	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Compretional Wave, tc=D*t/R (s)	Interval Time,ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.018103	-1	1.41	0.0128	0.0128	78	AVS 5 120
0.024160	-2	2.24	0.0216	0.0088	114	
0.028485	-3	3.16	0.0270	0.0054	185	
0.036272	-4	4.12	0.0352	0.0082	122	
0.042328	-5	5.10	0.0415	0.0063	158	
0.050980	-6	6.08	0.0503	0.0088	114	AVS 10 137
0.054440	-7	7.07	0.0539	0.0036	277	
0.060496	-8	8.06	0.0600	0.0061	163	
0.068283	-9	9.06	0.0679	0.0078	128	
0.073474	-10	10.05	0.0731	0.0052	191	
0.078665	-11	11.05	0.0783	0.0052	191	AVS 15 154
0.084721	-12	12.04	0.0844	0.0061	164	
0.089047	-13	13.04	0.0888	0.0044	230	
0.095103	-14	14.04	0.0949	0.0061	165	
0.097698	-15	15.03	0.0975	0.0026	382	
0.102024	-16	16.03	0.1018	0.0043	230	AVS 20 164
0.108080	-17	17.03	0.1079	0.0061	165	
0.113271	-18	18.03	0.1131	0.0052	192	
0.118462	-19	19.03	0.1183	0.0052	192	
0.121923	-20	20.02	0.1218	0.0035	288	
0.127114	-21	21.02	0.1270	0.0052	192	AVS 25 174
0.132305	-22	22.02	0.1322	0.0052	192	
0.137496	-23	23.02	0.1374	0.0052	192	
0.140957	-24	24.02	0.1408	0.0035	288	
0.143552	-25	25.02	0.1434	0.0026	384	
0.149608	-26	26.02	0.1495	0.0061	165	AVS 30 180
0.153069	-27	27.02	0.1530	0.0035	288	
0.159125	-28	28.02	0.1590	0.0061	165	
0.164316	-29	29.02	0.1642	0.0052	193	
0.166912	-30	30.02	0.1668	0.0026	384	

Graphical Representation of Vs

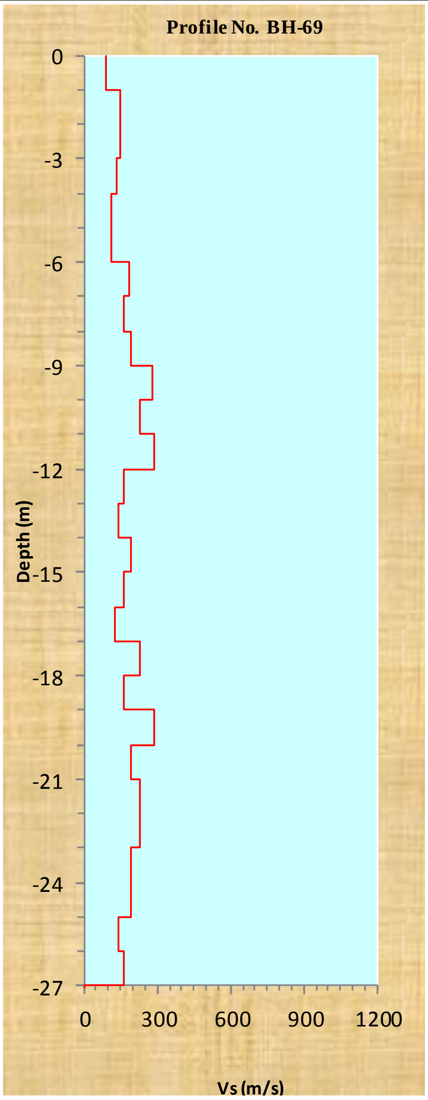


SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 26/02/2018	Source : 7kg Sledge Hammer
Location : Dhoomkhali, Shaherkhali	Downhole Receiver : Tri-axial Geophone
PS Id : 12/BH-69	Recording Equipment: Freedom Data PC
Coordinate Dhoomkhali, Shaherkhali	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Comprational Wave, tc=D*t/R (s)	Interval Time,ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.015498	-1	1.41	0.0110	0.0110	91	AVS 5 123
0.019824	-2	2.24	0.0177	0.0068	148	
0.025880	-3	3.16	0.0246	0.0068	147	
0.032802	-4	4.12	0.0318	0.0073	138	
0.041454	-5	5.10	0.0406	0.0088	113	
0.050105	-6	6.08	0.0494	0.0088	114	AVS 10 144
0.055296	-7	7.07	0.0547	0.0053	188	
0.061353	-8	8.06	0.0609	0.0061	163	
0.066544	-9	9.06	0.0661	0.0053	190	
0.070004	-10	10.05	0.0697	0.0035	284	
0.074330	-11	11.05	0.0740	0.0044	229	AVS 15 157
0.077791	-12	12.04	0.0775	0.0035	286	
0.083847	-13	13.04	0.0836	0.0061	165	
0.090769	-14	14.04	0.0905	0.0069	144	
0.095960	-15	15.03	0.0957	0.0052	192	
0.102016	-16	16.03	0.1018	0.0061	165	AVS 20 162
0.109803	-17	17.03	0.1096	0.0078	128	
0.114129	-18	18.03	0.1140	0.0043	230	
0.120185	-19	19.03	0.1200	0.0061	165	
0.123646	-20	20.02	0.1235	0.0035	288	
0.128837	-21	21.02	0.1287	0.0052	192	AVS 25 169
0.133163	-22	22.02	0.1330	0.0043	231	
0.137489	-23	23.02	0.1374	0.0043	231	
0.142680	-24	24.02	0.1426	0.0052	192	
0.147871	-25	25.02	0.1478	0.0052	192	
0.154792	-26	26.02	0.1547	0.0069	144	AVS 27 168
0.160849	-27	27.02	0.1607	0.0061	165	

Graphical Representation of Vs

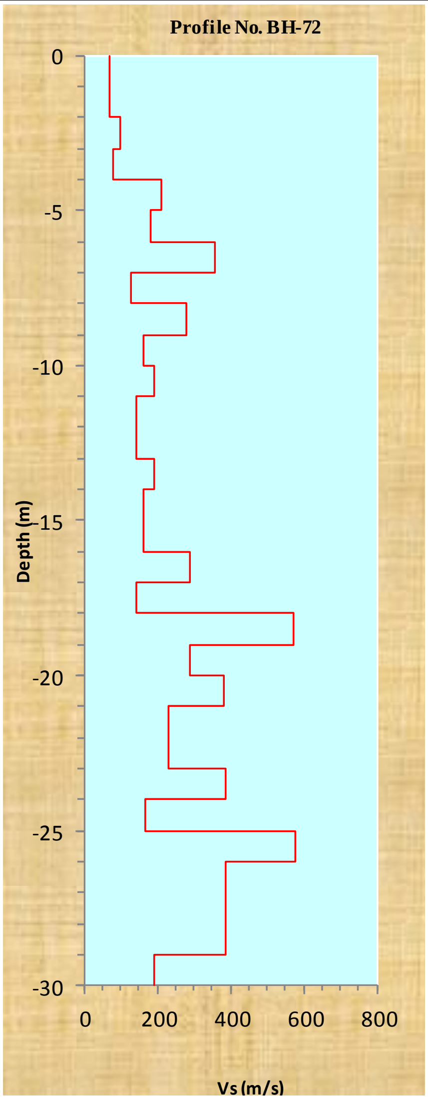


SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 28/02/2018	Source : 7kg Sledge Hammer
Location : Morjida Masima Taluk, Borotakia	Downhole Receiver : Tri-axial Geophone
PS Id : 13/BH-72	Recording Equipment: Freedom Data PC
Coordinate Lat- 22.74442 Long- 91.58926	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Compretional Wave, tc=D*t/R (s)	Interval Time,ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.020098	-1	1.41	0.0142	0.0142	70	AVS 5 89
0.032181	-2	2.24	0.0288	0.0146	69	
0.040813	-3	3.16	0.0387	0.0099	101	
0.052897	-4	4.12	0.0513	0.0126	79	
0.057212	-5	5.10	0.0561	0.0048	209	
0.062391	-6	6.08	0.0615	0.0054	184	AVS 10 122
0.064980	-7	7.07	0.0643	0.0028	359	
0.072749	-8	8.06	0.0722	0.0079	127	
0.076201	-9	9.06	0.0757	0.0035	282	
0.082243	-10	10.05	0.0818	0.0061	164	
0.087422	-11	11.05	0.0871	0.0052	191	AVS 15 134
0.094327	-12	12.04	0.0940	0.0069	144	
0.101232	-13	13.04	0.1009	0.0069	144	
0.106411	-14	14.04	0.1061	0.0052	192	
0.112453	-15	15.03	0.1122	0.0061	165	
0.118495	-16	16.03	0.1183	0.0061	165	AVS 20 149
0.121947	-17	17.03	0.1217	0.0035	288	
0.128852	-18	18.03	0.1287	0.0069	145	
0.130579	-19	19.03	0.1304	0.0017	573	
0.134031	-20	20.02	0.1339	0.0035	289	
0.136621	-21	21.02	0.1365	0.0026	384	AVS 25 163
0.140936	-22	22.02	0.1408	0.0043	231	
0.145252	-23	23.02	0.1451	0.0043	231	
0.147841	-24	24.02	0.1477	0.0026	385	
0.153883	-25	25.02	0.1538	0.0060	165	
0.155609	-26	26.02	0.1555	0.0017	577	AVS 30 178
0.158199	-27	27.02	0.1581	0.0026	385	
0.160788	-28	28.02	0.1607	0.0026	385	
0.163378	-29	29.02	0.1633	0.0026	385	
0.168556	-30	30.02	0.1685	0.0052	193	

Graphical Representation of Vs

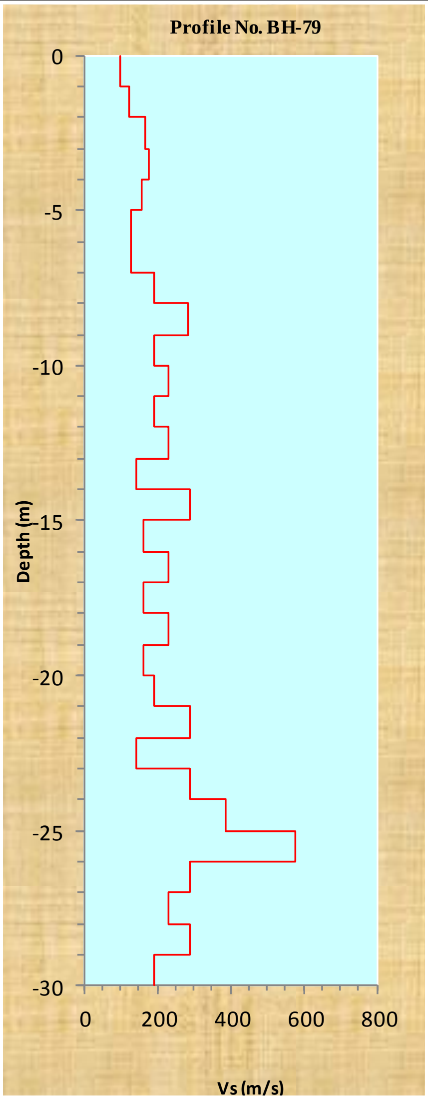


SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 28/02/2018	Source : 7kg Sledge Hammer
Location : West Wahedpur Molla para Mosque	Downhole Receiver : Tri-axial Geophone
PS Id : 14/BH-79	Recording Equipment: Freedom Data PC
Coordinate Lat- 22.7002 Long- 91.62035	Borehole Information : Grouted Cased
Operator : The Olson Instruments Downhole Seismic system	Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Comprehensional Wave, tc=D*t/R (s)	Interval Time, ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.013952	-1	1.41	0.0099	0.0099	101	AVS 5 140
0.020006	-2	2.24	0.0179	0.0080	125	
0.025195	-3	3.16	0.0239	0.0060	166	
0.030385	-4	4.12	0.0295	0.0056	179	
0.036439	-5	5.10	0.0357	0.0063	160	
0.044222	-6	6.08	0.0436	0.0079	127	AVS 10 153
0.052006	-7	7.07	0.0515	0.0079	127	
0.057195	-8	8.06	0.0568	0.0053	190	
0.060654	-9	9.06	0.0603	0.0035	283	
0.065844	-10	10.05	0.0655	0.0052	191	
0.070168	-11	11.05	0.0699	0.0044	229	AVS 15 167
0.075357	-12	12.04	0.0751	0.0052	192	
0.079681	-13	13.04	0.0794	0.0043	230	
0.086600	-14	14.04	0.0864	0.0069	144	
0.090059	-15	15.03	0.0899	0.0035	287	
0.096113	-16	16.03	0.0959	0.0061	165	AVS 20 171
0.100438	-17	17.03	0.1003	0.0043	230	
0.106492	-18	18.03	0.1063	0.0061	165	
0.110816	-19	19.03	0.1107	0.0043	231	
0.116870	-20	20.02	0.1167	0.0061	165	
0.122059	-21	21.02	0.1219	0.0052	192	AVS 25 181
0.125518	-22	22.02	0.1254	0.0035	288	
0.132437	-23	23.02	0.1323	0.0069	144	
0.135897	-24	24.02	0.1358	0.0035	288	
0.138491	-25	25.02	0.1384	0.0026	384	
0.140221	-26	26.02	0.1401	0.0017	576	AVS 30 192
0.143680	-27	27.02	0.1436	0.0035	289	
0.148005	-28	28.02	0.1479	0.0043	231	
0.151464	-29	29.02	0.1514	0.0035	289	
0.156653	-30	30.02	0.1566	0.0052	193	

Graphical Representation of Vs



SHEAR WAVE VELOCITY MEASURMENTS DOWNHOLE SEISMIC TEST (PS LOGGING)

Tested Date(dd/mm/yyyy) : 26/02/2018

Location : South Baliadi Govt. Primary School

PS Id : 15/BH-84

Coordinate Lat- 22.67191 Long- 91.60059

Operator : The Olson Instruments Downhole Seismic system

Source : 7kg Sledge Hammer

Downhole Receiver : Tri-axial Geophone

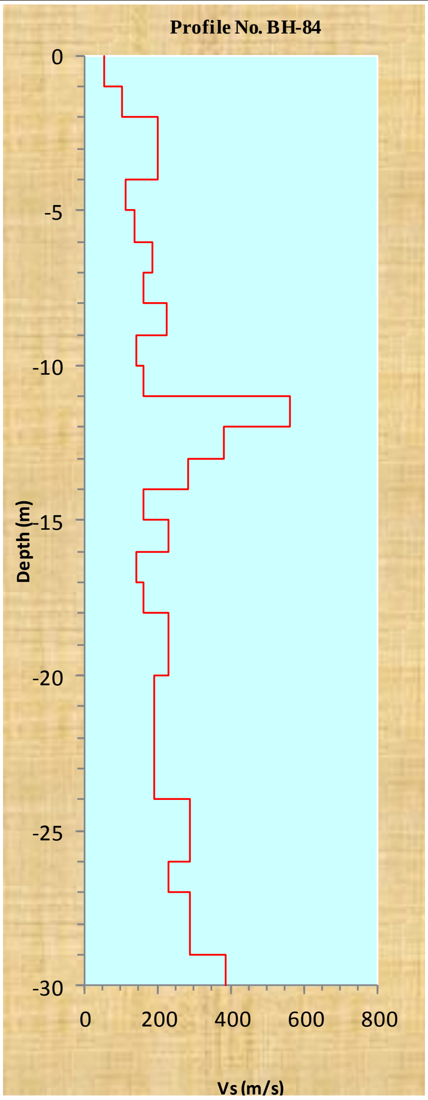
Recording Equipment: Freedom Data PC

Borehole Information : Grouted Cased

Casing Diameter : 75mm PVC Casing

Time arrival (s)	Recorded Geophone Depth from Existing Ground Level (m)	Source Saint Distance (m), R	Corrected Travel Time for Comprentional Wave, tc=D*t/R (s)	Interval Time,ΔTs	Shear Wave Velocity Vs, Vs=D/tc (m/s)	Average Shear Wave Velocity (m/s)
Existing Ground Level						
0.026687	-1	1.41	0.0189	0.0189	53	AVS 5: 106
0.031878	-2	2.24	0.0285	0.0096	104	
0.035340	-3	3.16	0.0335	0.0050	199	
0.039666	-4	4.12	0.0385	0.0050	202	
0.048319	-5	5.10	0.0474	0.0089	112	
0.055241	-6	6.08	0.0545	0.0071	141	AVS 10: 129
0.060433	-7	7.07	0.0598	0.0053	187	
0.066490	-8	8.06	0.0660	0.0062	163	
0.070816	-9	9.06	0.0704	0.0044	227	
0.077739	-10	10.05	0.0774	0.0070	143	
0.083796	-11	11.05	0.0835	0.0061	164	AVS 15: 154
0.085526	-12	12.04	0.0852	0.0018	562	
0.088122	-13	13.04	0.0879	0.0026	380	
0.091583	-14	14.04	0.0914	0.0035	287	
0.097640	-15	15.03	0.0974	0.0061	165	
0.101967	-16	16.03	0.1018	0.0043	230	AVS 20: 162
0.108889	-17	17.03	0.1087	0.0069	144	
0.114946	-18	18.03	0.1148	0.0061	165	
0.119273	-19	19.03	0.1191	0.0043	230	
0.123599	-20	20.02	0.1234	0.0043	231	
0.128791	-21	21.02	0.1286	0.0052	192	AVS 25: 169
0.133982	-22	22.02	0.1338	0.0052	192	
0.139174	-23	23.02	0.1390	0.0052	192	
0.144366	-24	24.02	0.1442	0.0052	192	
0.147827	-25	25.02	0.1477	0.0035	288	
0.151288	-26	26.02	0.1512	0.0035	288	AVS 30: 182
0.155615	-27	27.02	0.1555	0.0043	231	
0.159076	-28	28.02	0.1590	0.0035	288	
0.162537	-29	29.02	0.1624	0.0035	289	
0.165133	-30	30.02	0.1650	0.0026	384	

Graphical Representation of Vs



APPENDIX C: SINGLE MICROTREMOR TEST RESULTS AND GRAPHS

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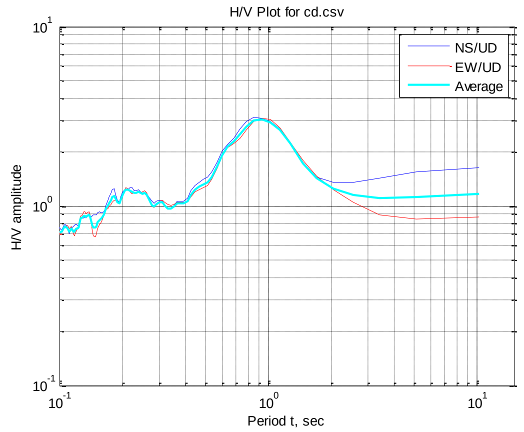
<tr><td>File: C2211050.TXT</td><td colspan="2" rowspan="3">
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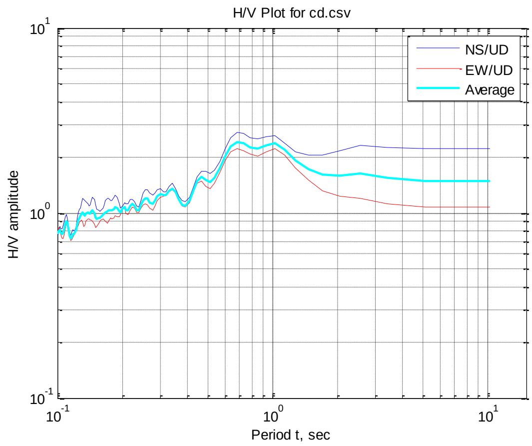
<tr><td>Location</td></tr>
<tr><td>MT Serial No.- MT-01
Location: Ichakhali, Shahebjir Nagar</td></tr>
<tr><td>Lat - 22.82828</td><td>Peak Period</td><td>0.90sec</td></tr>
<tr><td>Long - 91.48392</td><td>Peak Amplitude</td><td>3.0</td></tr>
<tr><td>File: C2211333.TXT</td><td colspan="2" rowspan="3">
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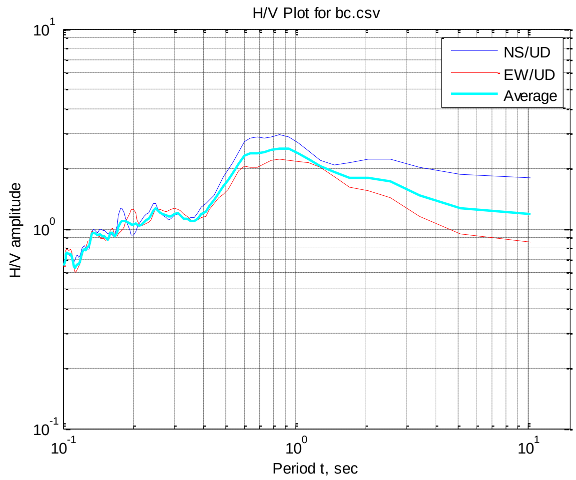
<tr><td>MT Serial No.- MT-02
Location: Ichakhai</td></tr>
<tr><td>Lat - 22.82186</td><td>Peak Period</td><td>1.0 sec</td></tr>
<tr><td>Long - 91.46932</td><td>Peak Amplitude</td><td>2.3</td></tr>
<tr><td>File: C2211527.TXT</td><td colspan="2" rowspan="3">
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<tr><td>Location</td></tr>
<tr><td>MT Serial No.- MT-03
Location: Ichakhai</td></tr>
<tr><td>Lat - 22.8049</td><td>Peak Period</td><td>0.8sec</td></tr>
<tr><td>Long - 91.4759</td><td>Peak Amplitude</td><td>2.5</td></tr>
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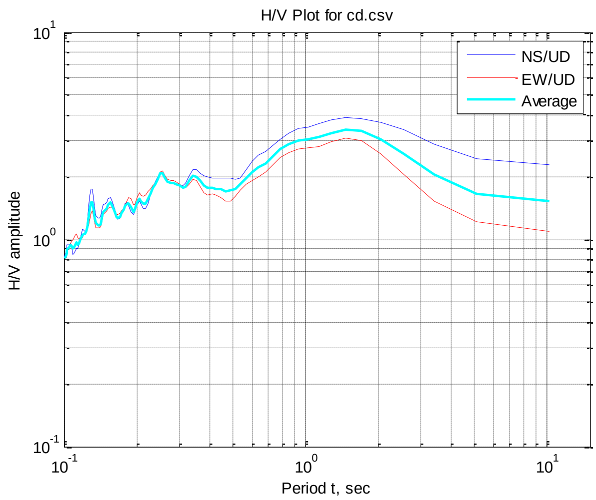
<tr><td>File: C2211601.TXT</td><td rowspan="3">
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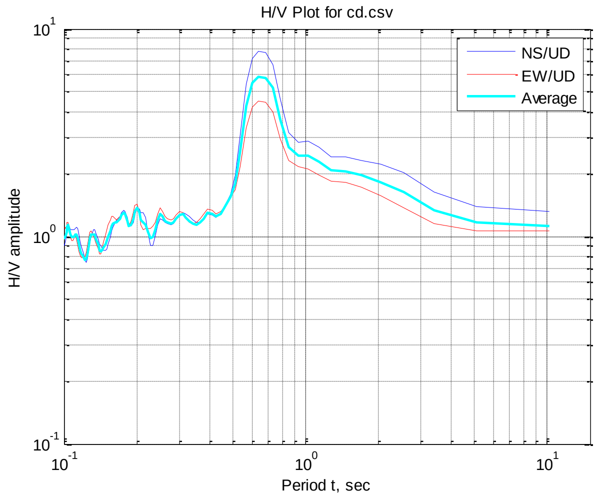
<tr><td>Location</td></tr>
<tr><td>MT Serial No.- MT-04
Location: Bariakhali</td></tr>
<tr><td>Lat - 22.79454</td><td>Peak Period 1.5sec</td></tr>
<tr><td>Long - 91.47306</td><td>Peak Amplitude 3.2</td></tr>
<tr><td>File: C2220957.TXT</td><td rowspan="3">
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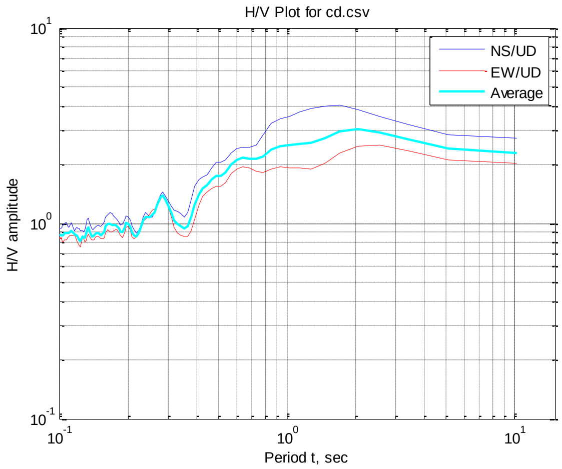
<tr><td>Location</td></tr>
<tr><td>MT Serial No.- MT-05
Location: Ganakchara</td></tr>
<tr><td>Lat - 22.89708</td><td>Peak Period 0.7 sec</td></tr>
<tr><td>Long - 91.51891</td><td>Peak Amplitude</td></tr>
<tr><td>File: C2221050.TXT</td><td rowspan="3">
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<tr><td>MT Serial No.- MT-06
Location: Dhoom</td></tr>
<tr><td>Lat - 22.88233</td><td>Peak Period 2.0sec</td></tr>
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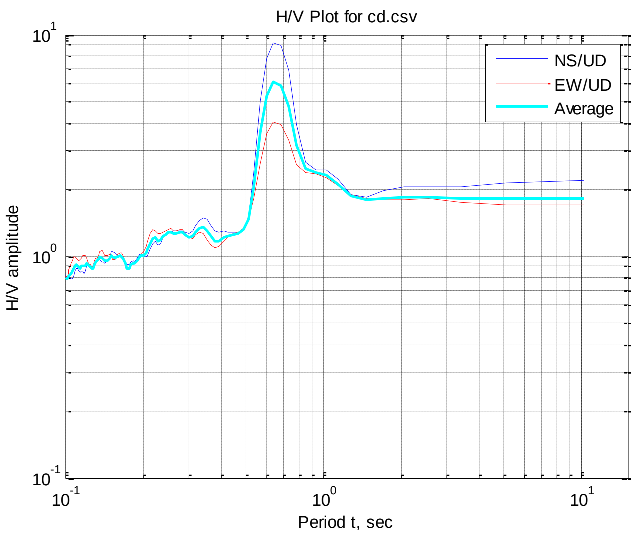
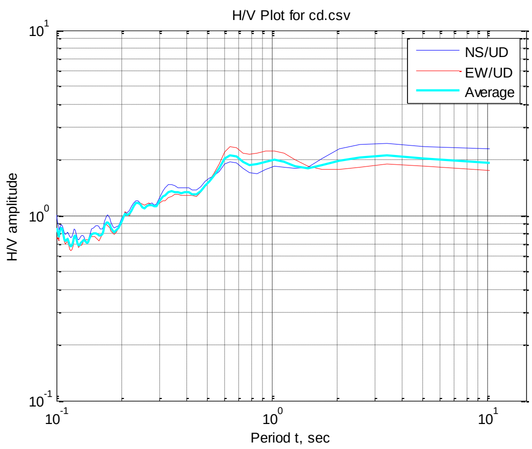
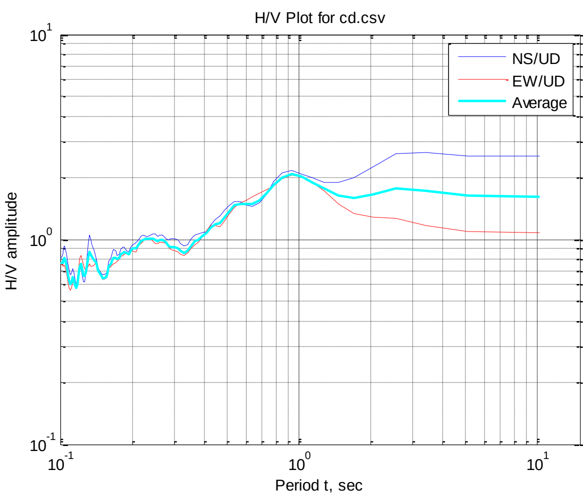
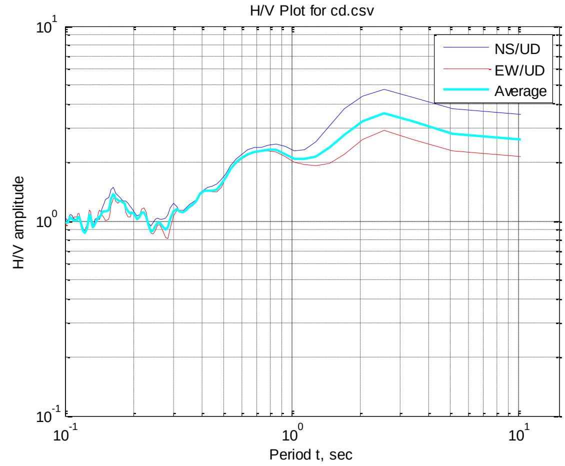
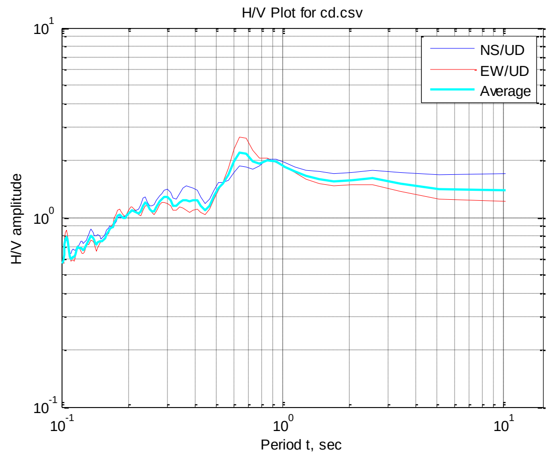
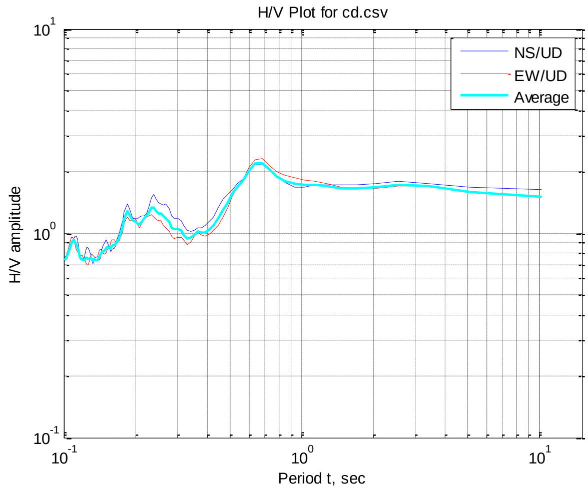
File: C2221130.TXT		
Location		
MT Serial No.- MT-07 Location: Naherpur, Dhum Union		
Lat - 22.87548	Peak Period	0.7sec
Long - 91.51395	Peak Amplitude	
File: C2221210.TXT		
Location		
MT Serial No.- MT-08 Location: Shahedpur		
Lat - 22.85102	Peak Period	0.6 sec
Long - 91.50626	Peak Amplitude	2.0
File: C2221255.TXT		
Location		
MT Serial No.- MT-09 Location: Azampur		
Lat - 22.85918	Peak Period	1.0sec
Long - 91.47164	Peak Amplitude	2.0

File: C2221359.TXT		
Location		
MT Serial No.- MT-10 Location: Hariharpur		
Lat - 22.82668	Peak Period	2.5sec
Long - 91.54601	Peak Amplitude	3.5
File: C2221441.TXT		
Location		
MT Serial No.- MT-11 Location: Massapukur, Kattachara Union		
Lat - 22.80993	Peak Period	0.65 sec
Long - 91.52605	Peak Amplitude	2.1
File: C2221518.TXT		
Location		
MT Serial No.- MT-12 Location: Middle Mithanala		
Lat - 22.79855	Peak Period	0.65sec
Long - 91.50579	Peak Amplitude	2.1

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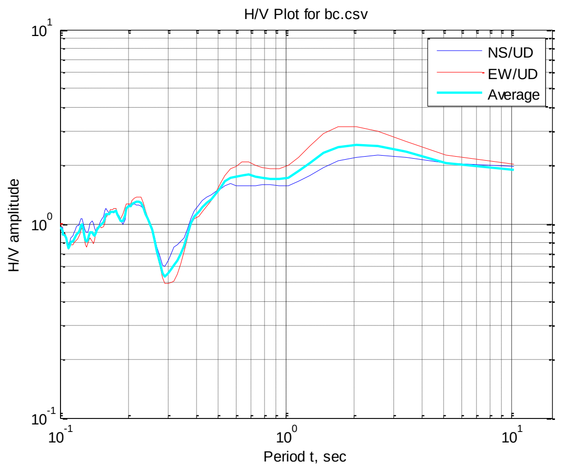
<tr><td>File: 12230925.TXT</td><td rowspan="3">
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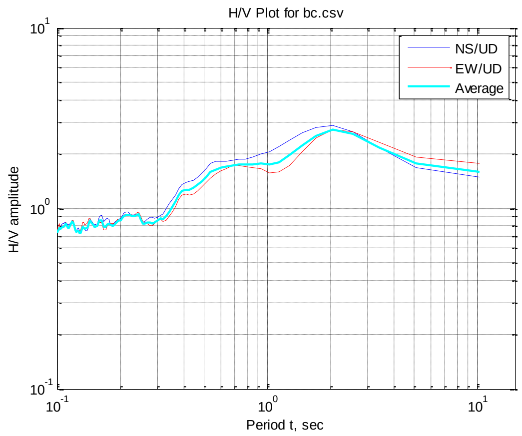
Location: Mohalonga</td></tr>
<tr><td>Lat- 22.67615</td><td>Peak Period 2sec</td></tr>
<tr><td>Long- 91.61485</td><td>Peak Amplitude 2.5</td></tr>
<tr><td>File: 12231016.TXT</td><td rowspan="3">
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Location: Uttar bogachotor</td></tr>
<tr><td>Lat- 22.68321</td><td>Peak Period 2sec</td></tr>
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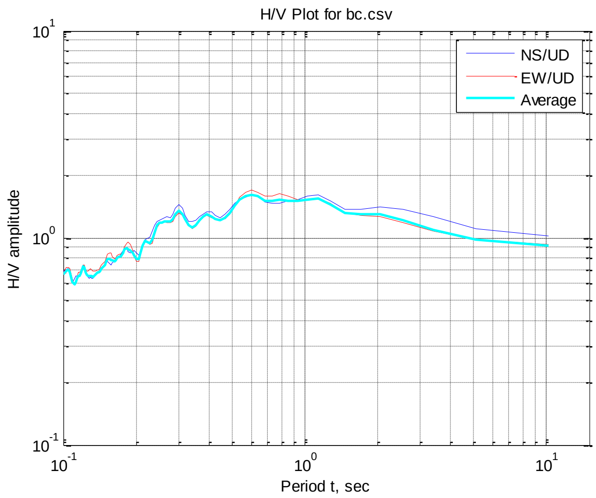
<tr><td>File: 12231059.TXT</td><td rowspan="3">
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Location: Dhumkhali</td></tr>
<tr><td>Lat- 22.69414</td><td>Peak Period 1sec</td></tr>
<tr><td>Long- 91.55822</td><td>Peak Amplitude 1.5</td></tr>
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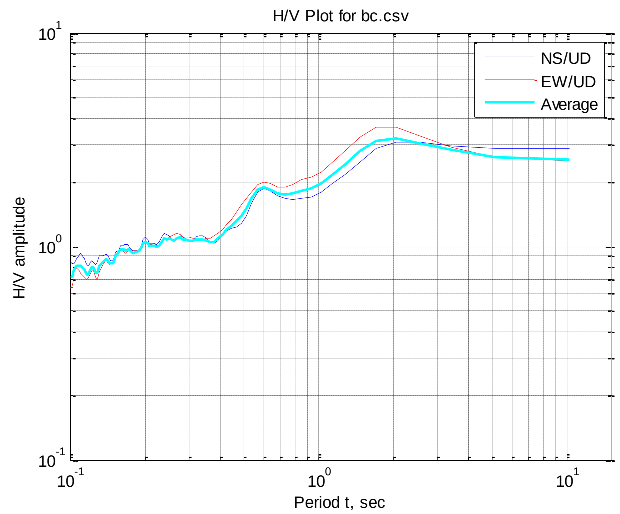
<tr><td>File: 12231154.TXT</td><td rowspan="3">
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<tr><td>MT Serial No.- MT-16
Location: Shaherkhali</td></tr>
<tr><td>Lat- 22.71064</td><td>Peak Period 2sec</td></tr>
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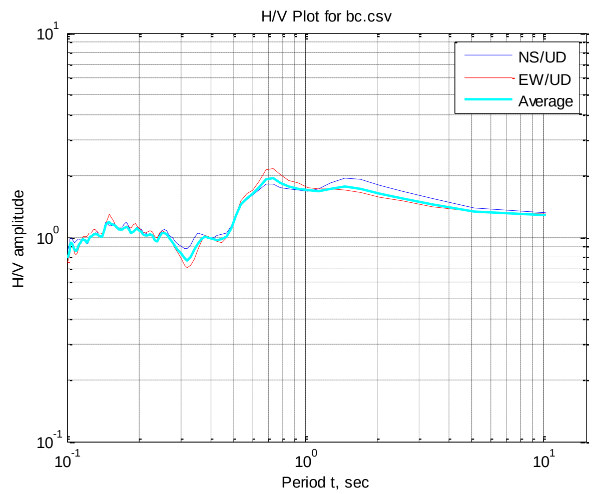
<tr><td>12231239.TXT</td><td rowspan="3">
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Location: Kaochua</td></tr>
<tr><td>Lat- 22.70942</td><td>Peak Period 0.7sec</td></tr>
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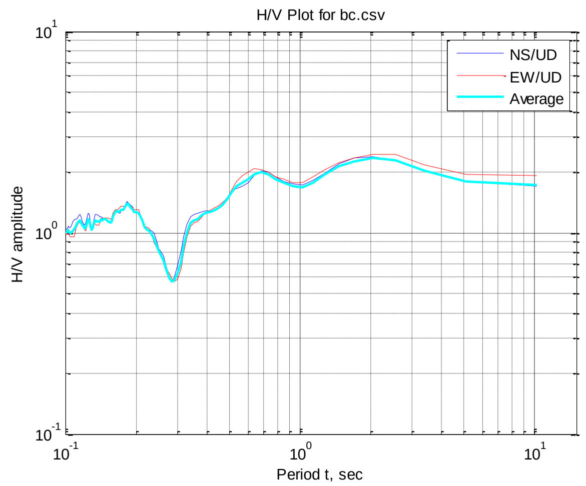
<tr><td>12231352.TXT</td><td rowspan="3">
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<tr><td>MT Serial No.- MT-18
Location: Gasbaria</td></tr>
<tr><td>Lat- 22.72967</td><td>Peak Period 2sec</td></tr>
<tr><td>Long - 91.59424</td><td>Peak Amplitude 2.3</td></tr>
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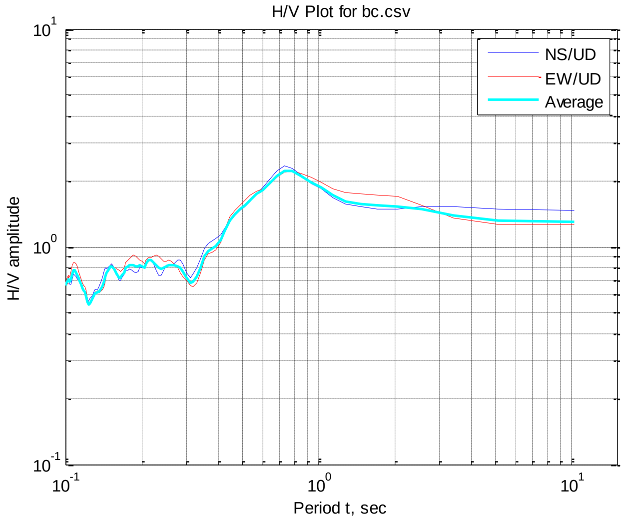
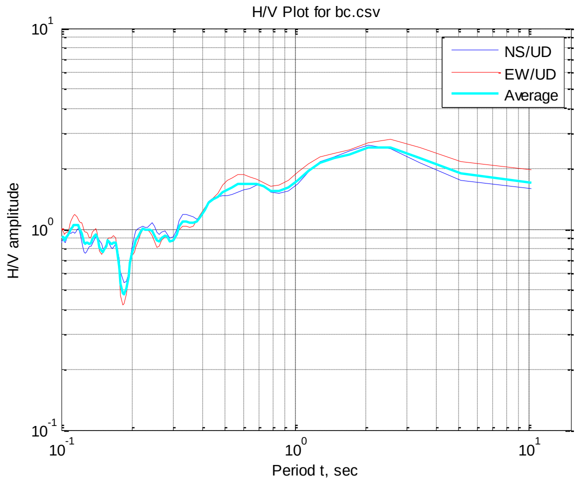
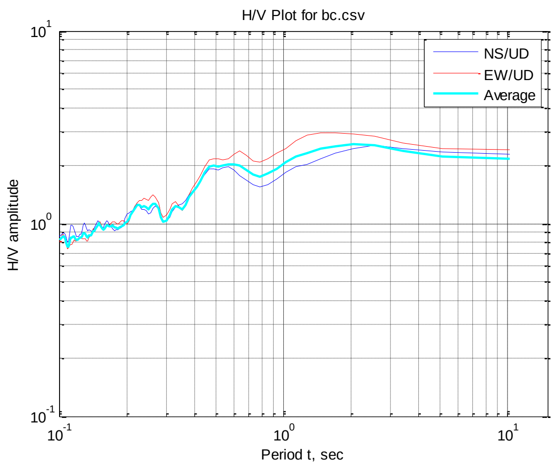
Location	
MT Serial No.- MT-19 **Location: Sayed ali**	



Lat - 22.75081	Peak Period 0.65sec
Long - 91.57513	Peak Amplitude 2.2
File: 12231521.TXT	
Location	
MT Serial No.- MT-20 **Location: Jafrabad**	



Lat - 22.74328	Peak Period 2sec
Long - 91.53533	Peak Amplitude 2.5
File: 12231607.TXT	
Location	
MT Serial No.- MT-21 **Location: Chorsorod**	



Lat - 22.74333	Peak Period 2.0sec
Long - 91.4929	Peak Amplitude 2.5

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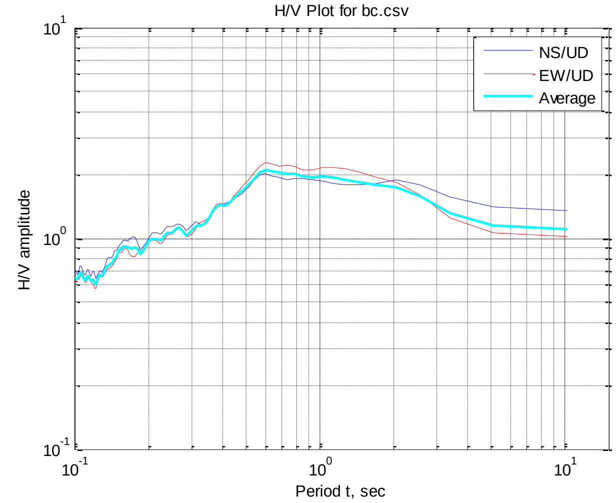
<tr><td>File: 12231704.TXT</td><td rowspan="3">
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Location: Rahmatabad</td></tr>
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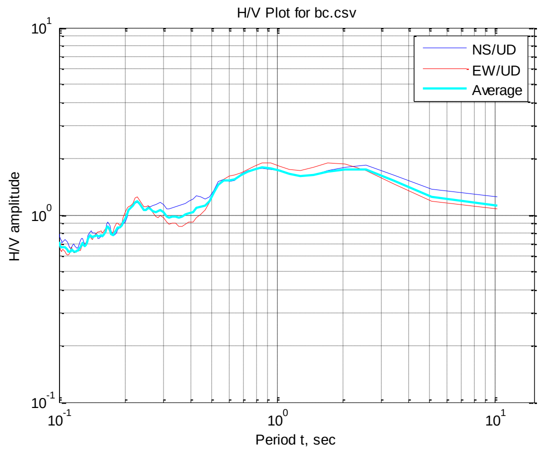
<tr><td>File: 12231746.TXT</td><td rowspan="3">
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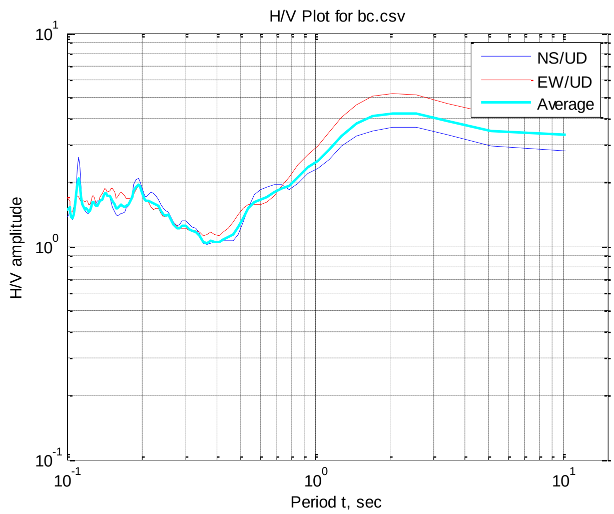
<tr><td>MT Serial No.- MT-23
Location: Mirsharai</td></tr>
<tr><td>Lat - 22.80128</td><td>Peak Period 2sec</td></tr>
<tr><td>Long - 91.53653</td><td>Peak Amplitude 1.8</td></tr>
<tr><td>File: 12240905.TXT</td><td rowspan="3">
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<tr><td>MT Serial No.- MT-24
Location: Islampur</td></tr>
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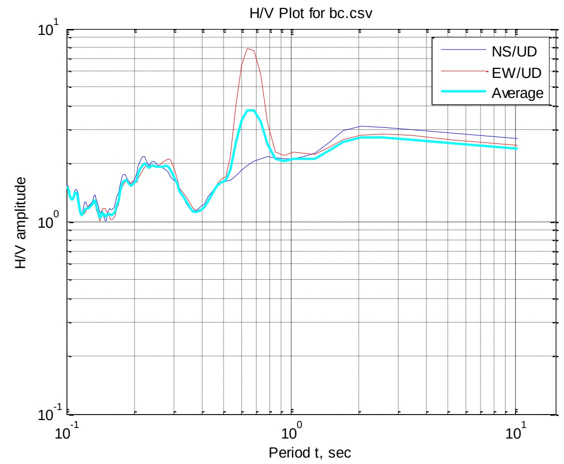
Location: Taltola</td><td>
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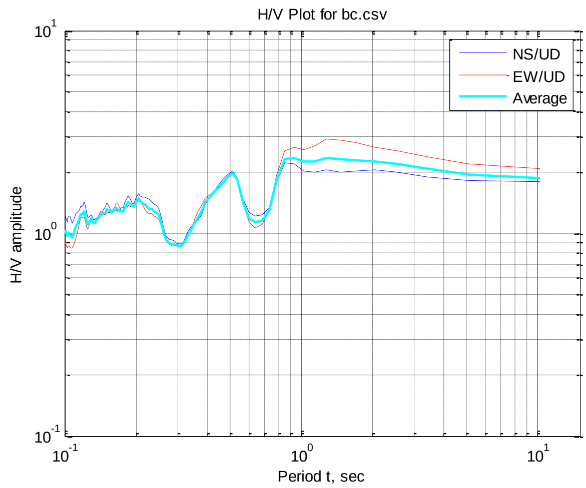
Location: Katagong</td><td>
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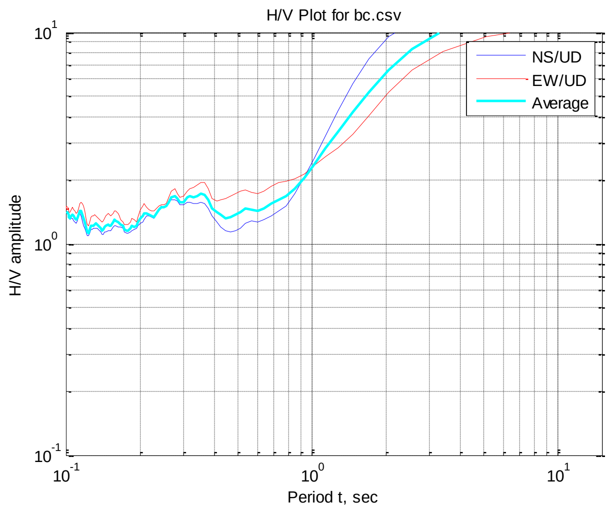
Location: Nolkho</td><td>
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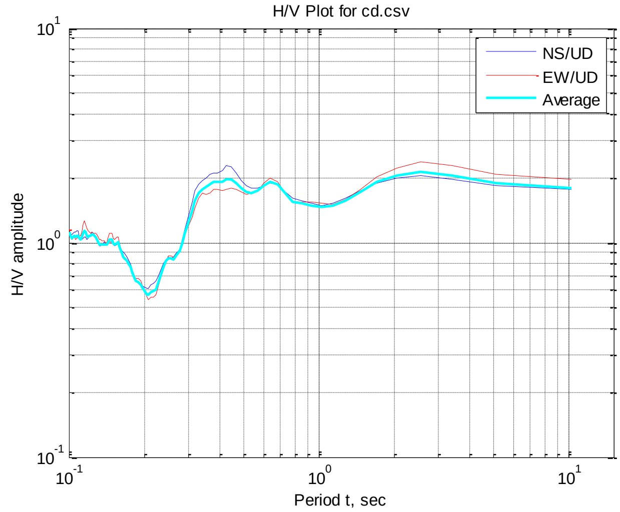
<tr><td>File: 12241214.TXT</td><td rowspan="3">
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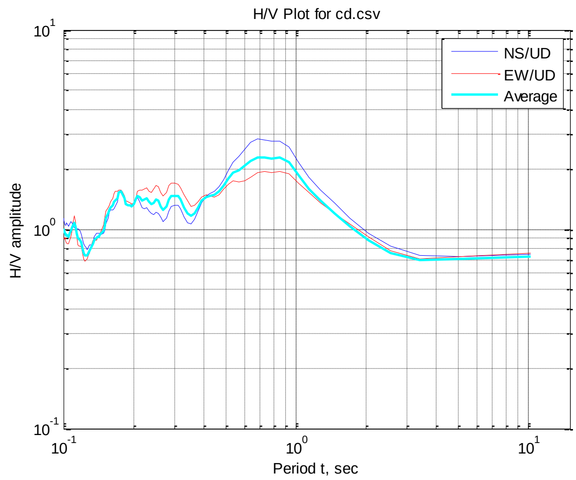
Location: West Olinagar</td></tr>
<tr><td>Lat - 22.9492</td><td>Peak Period 2.0sec</td></tr>
<tr><td>Long - 91.56968</td><td>Peak Amplitude 2.0sec</td></tr>
<tr><td>File: 12241312.TXT</td><td rowspan="3">
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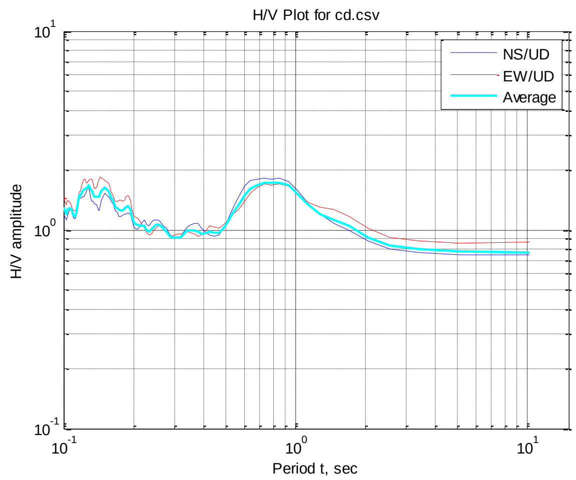
<tr><td>File: 12241404.TXT</td><td rowspan="3">
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