**Government of the People's Republic of Bangladesh**

Ministry of Housing and Public Works

**Urban Development Directorate (UDD)**

**Preparation of Development Plan for Fourteen Upazilas**

**Package-04**

(Saghata Upazila, District: Gaibandha; Sariakandi Upazila and Sonatala Upazila, District: Bogra)

# FINAL SURVEY REPORT

## GEOLOGICAL SURVEY Of Sariakandi Upazila, Bogra

**June, 2017**

**Modern Engineers Planners & Consultants Ltd.**

# Letter of Transmittal

Ref No.: MEPC/UDD/2017/54 Date: 04.06.2017

To

The Project Director

"Preparation of Development Plan for Fourteen Upazilas" Project

Urban Development Directorate (UDD)

82 Segun Bagicha, Dhaka-1000.

**Subject: Submission of the Final Survey Report on Geological of Sariakandi Upazila, Bogra.**

Dear Sir,

I have the pleasure to submit herewith the Final Survey Report on Geological of Sariakandi Upazila, Bogra District under "**Preparation of Development Plan for Fourteen Upazilas Project**" Package No: 04 (Saghata Upazila, District- Gaibandha; Sonatala Upazila and Sariakandi Upazila, District- Bogra) for your kind information and further action.

Thanking you and assuring you of our best services.

Best Regards

……………………………………

**(Engr. A. Sobahan)**
Managing Director of MEPC

……………………………………

**(Shamim Mahabubul Haque)**
Team Leader, Package-4

# Executive Summary

An extensive geo-scientific investigation is one of the fundamental prerequisite for any sustainable infrastructural development initiative. In this context, a systematic study including geophysical, geotechnical as well as geological study has been done in the proposed project area. The study would be useful for planning, designing and future maintenance of the project area. Moreover, the current study would also be beneficial for the planners as well as the concerned authorities to take relevant decisions pertaining to disaster risk reduction and mitigation. This geological survey work has been carried out in the project area under the package-4 (covering Sariakandi Upazila of Bogra District) project titled 'Preparation of Development Plan for Fourteen Upazilas' a initiative of Urban Development Directorate (UDD).

The project area is located at Sariakandi Upazila of Bogra district in Rajshahi Division. The Upazila is about 30 km from Bogra main town. This area is located in between 24°44' and 25°04' north latitudes and in between 89°31' and 89°45' east longitudes. It is bounded by Saghata and Sonatala Upazilas on the north, Dhunat and Kazipur Upazilas on the south, Islampur, Madarganj and Marishabari Upazilas on the east, Gabtali upazila on the west. Sariakandi is an old aged Upazila of Bogra district. People living in the Char area migrated from the eastern part to western part of the Upazila affecting by river erosion and flood and looked for the permanent settlement in and around of the municipal area. The large portion of the settlement of this Upazila was taken place as a result of in-migration from nearly Jamalpur, Sirajganj and Gaibandha district.

To accomplish the project objective, a detail geotechnical and geophysical investigation have been carried out. As a part of geotechnical investigation a total of 11 boreholes were drilled to get a clear idea about physical and mechanical properties of the soil. A geophysical study was conducted by means of 3 nos down-hole seismic test (PS logging) and 5 nos. of Multi-channel Analysis of Surface Wave (MASW) Test to estimate the shear wave velocity Laboratory testing of soil samples such as Grain Size Analysis, Natural Moisture Content, Direct Shear Test, etc has been performing in the laboratory which will give more qualitative and quantitative information about the subsurface materials.

The upper soils of the study area are mostly alluvium Silt and alluvium Sand. Fine to Medium grained Sand has been found by increasing of depth. The SPT N value ranges of those Soils are varies from 5 to 50. From the Down hole seismic Test (PS Logging) the average shear wave velocity (AVS 30) up to 30 m are 165 to 169m/s. According to MASW test result, the velocities of the soil strata below 160 m/s upto depth 7.3m from existing ground level which indicate are

the soil upto this depth soft or loose in nature. But the velocities of all the test locations are gradually improved with increasing of depth.

Results will be integrated in a module by which it is possible to produce sub-surface litho-logical 3D model of different layers, engineering geological mapping based on AVS30, Seismic Hazard Assessment Map (risk sensitive micro-zonation maps), soil type map, seismic intensity map, Peak Ground Acceleration (PGA) and recommended building height maps for both high rise building and low rise building, liquefaction and Ground Failure Map etc.

Above test result would give a clear idea about the geo-hazard status of particular landscape where newly urban developing activities or any other mega infrastructure project is going on and this mentioned investigation also gives idea about the vulnerability of existing build up infrastructure of a particular area. Based on these results, proper management techniques as well as other necessary adaptation process could be addressed before or after the development activities in the studied area. It is to be mentioned that the long-term maintenance cost will be reduced and the developed structure will withstand against the potential natural hazards if the infrastructures are built following the risk informed physical land-use plan.

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# List of Abbreviations/Acronyms

| | | |
|---|---|---|
| ASTM | : | American Society for Testing and Materials |
| AVS30 | : | Average Shear Wave velocity of 30 meter depth |
| BH | : | Borehole |
| EGL | : | Existing Ground Level |
| GWL | : | Ground Water Level |
| MASW | : | Multi-Channel Analysis of Surface Wave |
| MEPC | : | Modern Engineers Planers & Consultants Ltd. |
| nos | : | numbers |
| N value | : | Soil resistance or compactness |
| PGA | : | Peak Ground Acceleration |
| PGV | : | Peak Ground Velocity |
| PS logging | : | Primary and Shear wave logging (Down-hole seismic test) |
| SA | : | Spectral Acceleration |
| SPAC | : | Spatial Autocorrelation |
| SPT | : | Standard Penetration Tests |
| UDD | : | Urban Development Directorate |

# CHAPTER ONE: INTRODUCTION

## 1.1 Background of the Study

With the increasing of population growth, economic growth and increasing life expectance of the peoples in Bangladesh, rapid urban expansion is the common phenomena right now. In this consequences, the present trend of planning practice is very much poor, mostly oriented towards planning of major cities and towns in Bangladesh but not in all other towns or growth centers because involves of huge amount of financial allocation/grants. Recent policy of Bangladesh Government, the Upazila has been recognized as the most significant tier of administration. So that these areas are need to be planned and developed to accommodate all social, economic, administrative, infrastructure services and service facilities for the region. The current government's intention is to reflect the national policy of bringing development administrative and service facilities to the door step of rural masses and to ensure better delivery of government services to the people. Realizing the fact and importance of formulating development plans for Upazilas, Urban Development Directorate has come up with a great initiative to plan those areas. At the first phase of this initiative UDD has decided to prepare development plan for 14 Upazilas all over Bangladesh into five different packages. For each package separate consultancy team has been appointed to carry out that job more fruitfully. Modern Engineers Planners and Consultants Ltd. (MEPC) have been selected for package-4 (Saghata Upazila of Gaibandha District and Sariakandi Upazila & Sonatala Upazila of Bogra District) by project evaluation committee of UDD.

Subsurface geological and geotechnical investigation has been considered in this study for a durable and sustainable urban environment. Initially this work is to determine subsurface soil condition of the project area up to 30 meter depth from ground surface and evaluating of natural geological and hydro-meteorological hazards such as earthquake, landslide and ground failure which integrate the consequence into the design of the infrastructure.

Following investigations and surveys activities has been carried out which are geo-morphological survey; drilling of boreholes and preparation of borehole logs; collection of undisturbed and disturbed soil sample as per standard guide line; conducting standard penetration tests (SPTs); drilling of boreholes and casing by PVC pipe for conducting Down-hole seismic test, conducting Down-hole seismic test and conducting Multi-Channel Analysis of Surface Wave (MASW). Geologic and geomorphologic conditions of the study area is not much complex, the area is mostly covered by loose sediments of floodplain deposits. Most of the area is plain in nature but some low or marshy land also occurred and almost everywhere soils are resent fluvial type of deposit which is much soft and thicker.

Following soil sample test such as Grain Size Analysis, Natural Moisture Content, Specific Gravity, and Direct Shear Test has been performing in the laboratory which will give more qualitative and quantitative information about the subsurface materials. These field and laboratory data will be analyzed and produce risk sensitive micro-zonation maps of the project area.

## 1.2 Scope of Work

The aim of this work is to determine subsurface soil condition of the project area and evaluating of natural geological and hydro-meterological hazards such as earthquake, liquefaction, ground failure and integrate the consequence into the design of the infrastructure. The main objective will be achieved through accomplishment of the following sub-objectives:

a) Preparation of Geological map of the study area;

b) Preparation of sub-surface lithological 3D model of different layers through geo-technical investigation;

c) Preparation of engineering geological mapping based on AVS30;

d) Determination of soil type in the project area;

e) Foundation layer identification;

f) Preparation of Seismic Hazard Map;

g) Finally intensity map is prepared for high rise and low rise building.

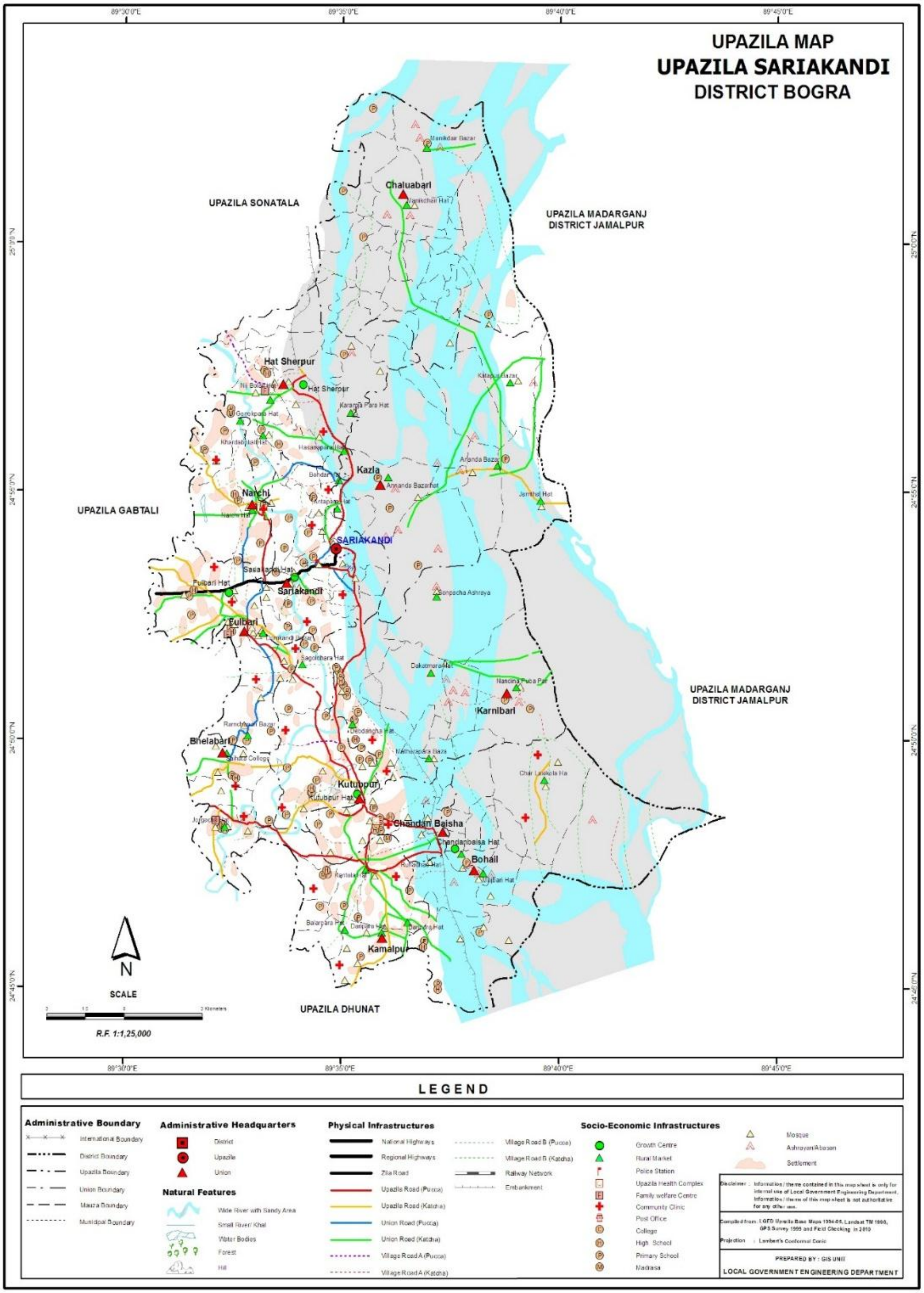
## 1.3 Brief Description of the Area

Sariakandi is an Upazila of Bogra district in the division of Rajshahi. Sariakandi is an old aged Upazila of Bogra district. People living in the Char area migrated from the eastern part to western part of the Upazila affecting by river erosion and flood and looked for the permanent settlement in and around of the municipal area. The large portion of the settlement of this Upazila was taken place as a result of in-migration from nearly Jamalpur, Sirajganj and Gaibandha district. The fertile land, available char area, communication facility over river way and excellent geography exerted a pull on people to live and conduct business here. Thus, settlement developed by the surrounding inhabitants and with the people of remote area as well.

Sariakandi Upazila is a flood prone area located at Bogra district under Rajshahi Division. The Upazila is adjacent to four others Upazila namely Madarganj Upazila (Jamalpur district) at east, Gabtali Upazila (Bogra district) at west, Sonatola Upazila (Bogra district) at north and Dhunat Upazila (Bogra District) at south. Most of the business, economic and administrative activities are based on the Sariakandi municipal area. The total area of Sariakandi Upazila is 408.5 square kilometer with a total population covering 270719 (Banglapedia, 2015). The whole Upazila is covered by 122 Mouzas and the number of village is 216. The major rivers of the area are Jamuna and Bangali. Jamuna River runs over the middle part of the Upazila adjoining to Kazla, Sariakandi, Karnibari, Chandan Baisha and Bohail Union from north to south. The Upazila has 4048.82 acre khas land. The sandy land area, homogeneous topography, Char area, moderate moisture etc. are the common geographical characteristics of the study area.

According to the upazila website there are 85 sq. km of river area situated here. Manash, Belai, Dakuria, Sukhdah, Bangali, Jamuna are the major river of this upazila. Besides this river there are Dubri beel, Dharaborsha Beel, Dewlir beel, Koier Beel, Molash Beel, Boro Morchar beel are famous of this area. According to the BBS of Bogra district there are 17.4 km of navigable water network round the year and 20 km navigable water network only for the monsoon.

## Map 1.1: Sariakandi Upazila Map




Source: LGED

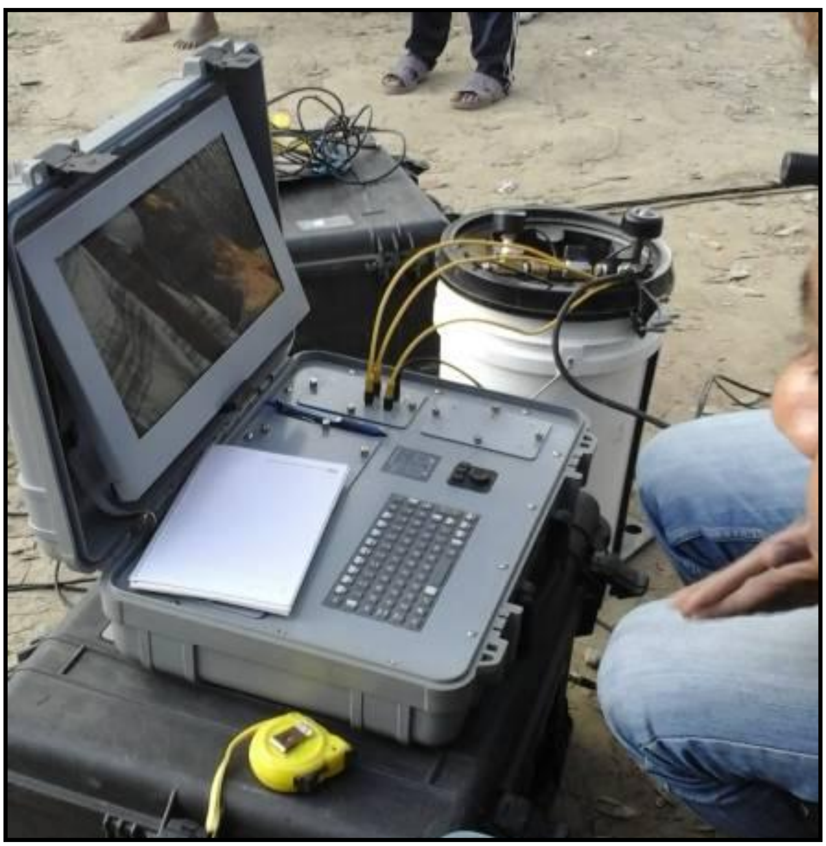
# CHAPTER TWO: METHODOLOGY

The methods and materials used to carry out of these activities have been described below:

## 2.1 Test Details and Procedure of Down-Hole Seismic Test (Ps Logging)

Main objectives of downhole seismic test 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 sledge hammer. The plank was placed on the ground surface at around 1 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, 3 records were taken and then used to calculate the shear wave velocity.



Source: Field Survey, 2016

**Plate-1: Downhole Seismic Test data logger**

### 2.1.1 Procedure of Field Work and Analysis

a) A wooden plank with an approximate dimension of 2 ft x 1 ft x 2 ft is fixed to the ground. The wooden plank is placed about 1m from the borehole as shown in Plate-2.

Source: Field Survey, 2016

**Plate-2: Wooden Plank as the Vibration Source**

b) Cables are wired from the geophone Plate 3 and the trigger to the data acquisition unit Plate 4. Signals in the vertical, radial and transverse directions are recorded by the data acquisition unit.

Source: Field Survey, 2016

**Plate-3: Geophone**

Source: Field Survey, 2016

**Plate-4: Data Acquisition Unit**

c) The geophone is lowered into the borehole as shown in Plate 5 Then, air is pumped into the air bag to fix the geophone to the casing (PVC pipe) at 1 m interval in depth basically.

Source: Field Survey, 2016

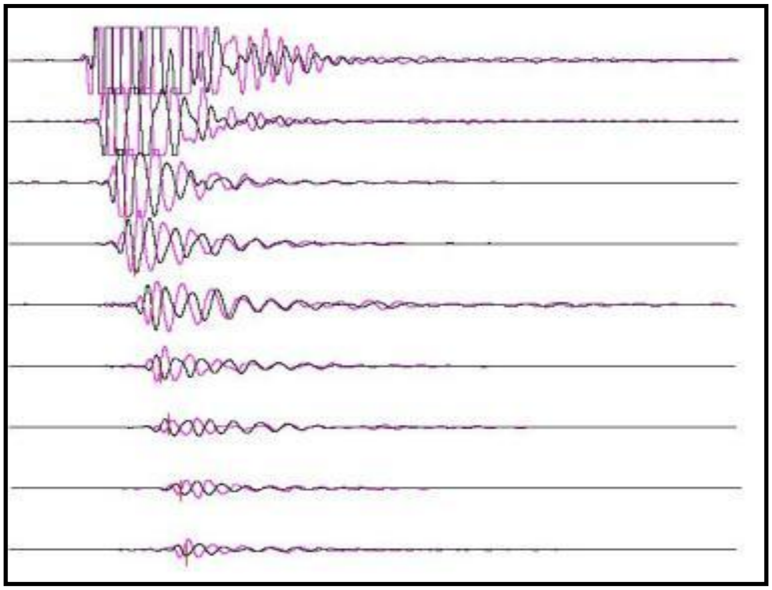
**Plate-5: Geophone Lowering In the Borehole**

d) Excitations are generated by hitting the wooden plank in three directions by the hammer.

Source: Field Survey, 2016

**Plate-6: Direction of Excitations**

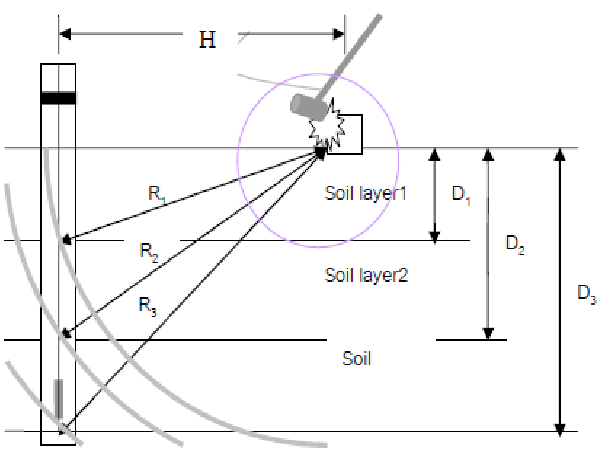
e) Data is recorded in the data acquisition unit. Figure 2.1 illustrates a typical dataset in obtaining the arrival time of S-wave. Hitting the wooden plank in opposite directions generates signals as shown in the figure. The time that two curves begin to separate is the arrival time of shear wave. By doing the same analysis for every depth, S-wave profiles are obtained throughout the depth of the borehole.



Source: Field Survey, 2016

**Figure 2.1: Determination of the Arrival Time of S-Wave**

f) Using the raw data of the test depth (D), the shortest pass (R) and the recorded arrival time of S-wave (t) in the inclined path is calculated to the travel time, $t_c$, in the vertical path as shown in Figure 2.2.




$$t_c = D\frac{t}{R}$$

Where

$t_c$ is the corrected travel time

$D$ is the testing depth from ground surface,

$t$ is the first arrival time from test

$R$ is the distance between the source an receiver

(Source: Auld 1977)

**Figure 2.2: Calculation of the Travel Time**

g) By plotting the corrected travel time versus depth, the velocity of every 1 m interval is calculated from (Auld 1977)

$$V_d = \frac{\Delta D}{\Delta t_c} \, [\mathit{Auld\ 1977}]$$

Where, $\Delta D$ is depth interval showing similar slope and $\Delta t_c$ is the corrected travel time difference of $\Delta D$.

## 2.2 Test Details and Procedure of Multi-Channel Analysis of Surface Wave (MASW)

Multichannel Analysis of Surface Wave (MASW) is recent and very popular method for computation of shear wave velocity. This method is widely used for seismic microzonation. A MASW is a seismic surface method, widely used for subsurface characterization and is increasingly being applied for seismic microzonation and site response studies (Anbazhagan and Sitharam, 2008). It is also used for the geotechnical characterization of near surface materials (Park and Miller, 1999; Xia et al., 1999; Miller et al., 1999; Anbazhagan and Sitharam, 2008). MASW is used to identify the subsurface material boundaries, spatial and depth variations of weathered and engineering rocks (Anbazhagan and Sitharam, 2009). We have used the MASW system consisting of 12 channels Geode seismograph with 12 vertical geophones of 10 Hz capacity.

The measuring procedure in this project is shown as follows:

i. To decide the measuring line
ii. To set receivers along the line at the ground surface. The intervals of each geophone are 3m.
iii. To set an acrylic board at a half interval outside the line
iv. To shoot it vertically. Then generated elastic waves are recorded by receivers.
v. To shift the acrylic board between second receiver and the third receiver, and shoot it vertically. Then generated elastic waves are recorded at receivers.
vi. To iterate this procedure up to setting the acrylic boards at a half interval outside the other side of the line.

The data acquisition parameters are given in Table 2.1.

**Table 2.1: MASW Data Acquisition Parameters**

| Seismic refraction | |
|---|---|
| Number of channels | 12 |
| Geophone spacing | 3m |
| Array length | 33m |
| Sampling rate | 1ms |
| Record length | 2 sec |
| Natural frequency of Geophone | 10 Hz |
| Source | 8 kg hammer |
| Shot number | 13 points, 11 between geophones and 2 outside of measuring line |

*Source: Park and Miller, 1999; Xia et al. 1999; Miller et al. 1999; Anbazhagan and Sitharam, 2008.*

### 2.2.1 Analysis of MASW

Data processing consists of two main steps: (i) Obtaining the dispersion curves of Rayleigh wave phase velocity from the records; (ii) Determining the V s profiles from which the Vs30 values are calculated (see Figure 2.3). In the phase velocity analysis, SPAC (Spatial Autocorrelation) method (Okada, 2003) is employed. Okada (2003) shows Spatial Autocorrelation function $\rho$ (ώ, r) is expressed by Bessel function.

$$\rho(\omega, r) = J_0(\omega r / c(\omega))$$ [*Okada, 2003*]

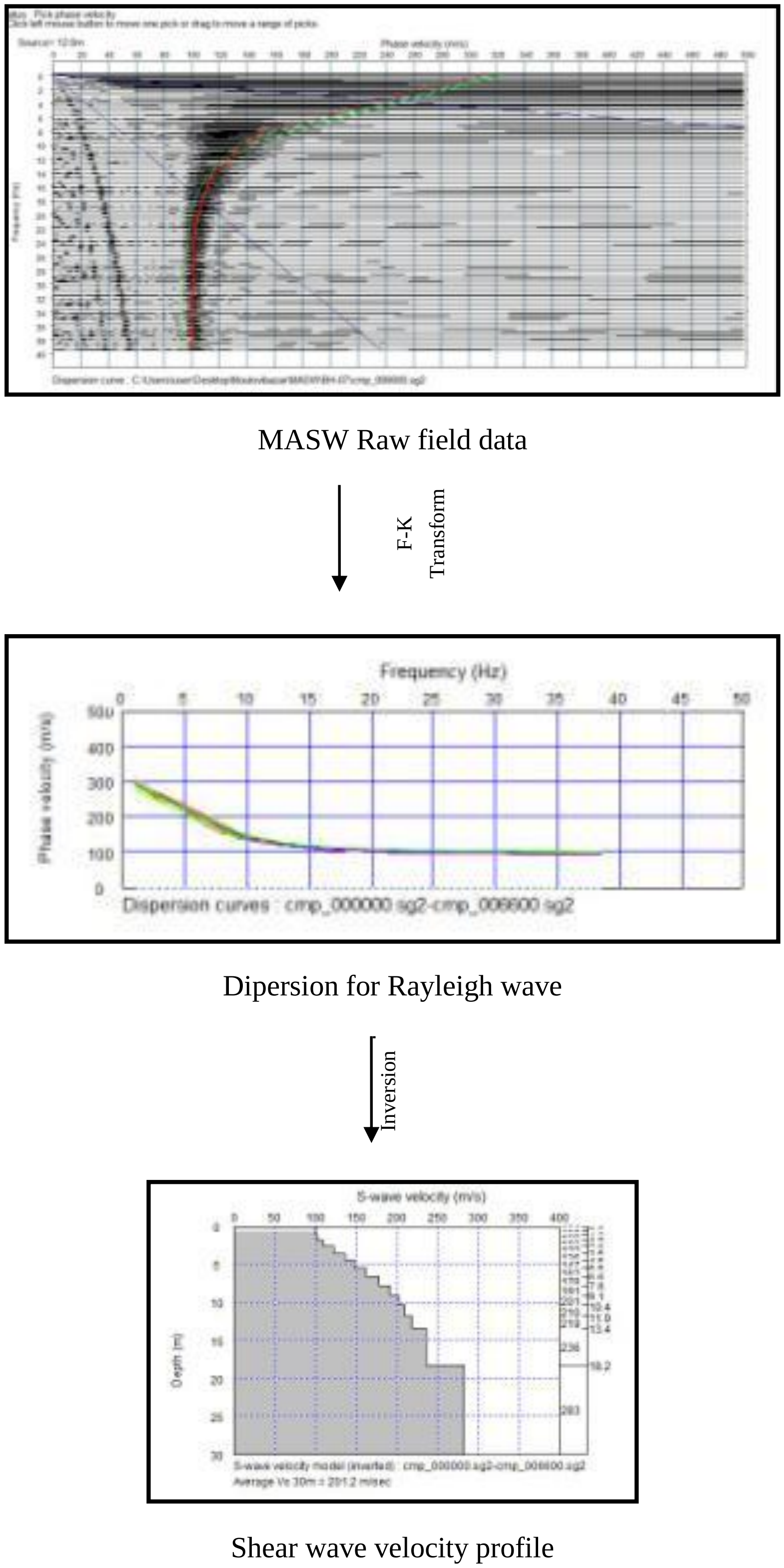
Where, r is the distance between receivers, ώ is the angular frequency, ***c (ώ)*** is phase velocity of waves, $J_0$ is the first kind of Bessel function. The phase velocity was obtained at each frequency using equation (2). A one dimensional inversion using a non-linear least square method has been applied to the phase velocity curves. In the inversion, the following relationship between P-wave velocity ($V_p$) and $V_s$ (Kitsunezaki et. al., 1990):

$$Vp = 1.29 + 1.11Vs$$ [*Kitsunezaki et. al., 1990*]

Where, $V_s$ is S-wave velocity (km/s), $V_p$ is P-wave velocity (km/s). In order to assume density $\rho$ (g/cm3) from S-wave velocity, the relationship of Ludwig et al. (1970) is used.

$$\rho = 1.2475 + 0.399Vp - 0.026Vp^2$$ [*Ludwig et al. (1970)]*

These calculations are carried out along the measuring line, and the S-wave velocity distribution section was analyzed.




Source: Field Survey, 2016

**Figure 2.3: Main Step of the MASW Processing Technique**

## 2.3 Test Details and Procedure of Standard Penetration Test

The geotechnical boreholes have been constructed using wash boring method. In this investigation, 11 numbers of boreholes have been prepared at Sariakandi Upazila. The borehole logs are enclosed in the Appendix C. The boring method has been described in the following section.

### 2.3.1 Drilling

The bore holes are being drilled through mechanical percussion wash boring method at the locations previously decided. As 30 m boring is so complicated and time consuming moreover it has done continuously to the end to prevent the possibility of caving of the boring wall, is will been decided to send two sets of worker who will work in 8 hrs until desired depths will be achieved. In this manner the estimated time for boring execution will 12- shifts and 11- shifts are considered for mobilization, assemble and disassemble of the equipment, site cleanup and backfill the bore holes to their pre-existing condition.

### 2.3.2 Data Collection

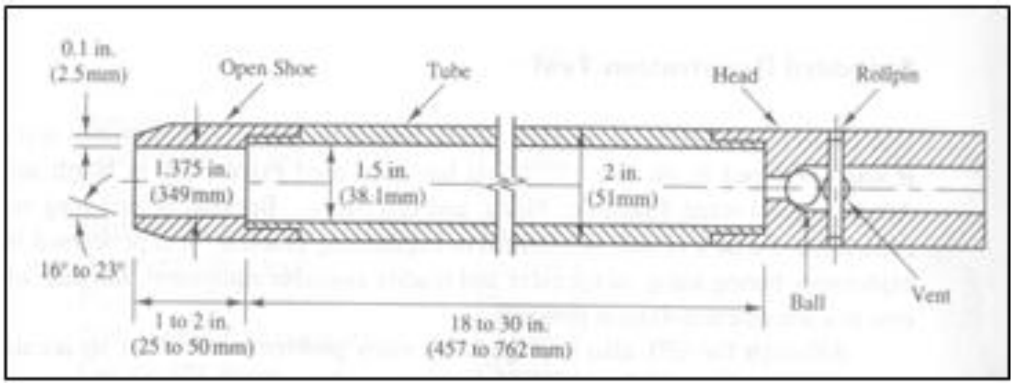
The field data are being collected according to the respective standard methods. First of all the location, areal coverage, topography, geomorphology of the test site are note down. The soil sample collection procedure is mentioned in the section 2.3.4. While SPT soil samples are collected. At the same time, the ground water table is note down.

### 2.3.3 SPT Execution

As it mentioned earlier, the geotechnical boreholes will be constructed using mechanical boring method. The depth of those boreholes is to 30m. In this method N values (standard Penetration Test) is counted and soil sample also be taken in every 1.5m depth interval. The subsequent procedure which has been followed during the field work is furnished as follows:

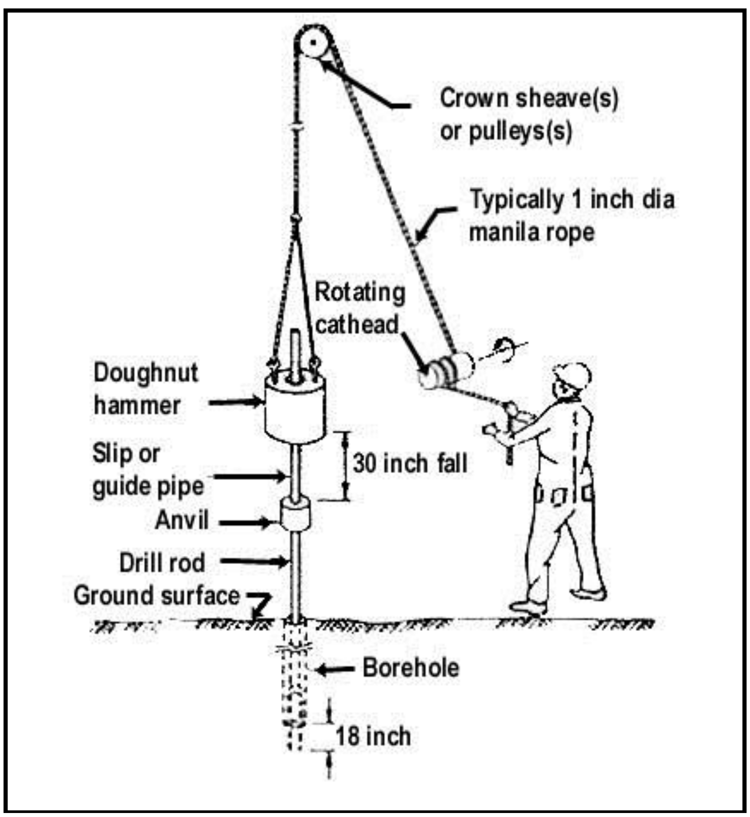
i. Drill a 100-200 mm (2.5-8 in) diameter exploratory boring to the depth of the first test.
ii. Insert the SPT sampler (also known as a Split-spoon Sampler) into the boring. The shape and dimensions of this sampler are shown in Figure 4. It is connected via steel rods to a 63.5 kg (140 lb) hammer, as shown in Figure 5.
iii. An automatic tripping mechanism (in case of rotary drilling used this technique in this investigation), raise the hammer a distance of 760 mm (30 in) and allow it to fall. This energy drives the sampler into the bottom of the boring. Repeat this process until the sampler has penetrated a distance of 450 mm (18 in), recording the number of hammer blows required for each 150 mm (6 in) interval.

iv. Compute the N-value by summing the blow counts for the last 300 mm (12 in) of penetration. The blow count for the first 150 mm (6 in) is retained for reference purposes, but not used to compute N because the bottom of the boring is likely to be disturbed by the drilling process and may be covered with loose soil that fell from the sides of the boring.
v. Extract the SPT sampler, then remove and save the soil sample (disturbed sample).
vi. Drill the boring to the depth of the next test and repeat steps 2 through 6 as required.




Source: http://eeg.geoscienceworld.org/content/gseegeosci/12/2/161/F2.large.jpg

**Figure 2.4: Split-spoon Sampler**




Source: http://www.valueerror.com/pennstate/ce_lab/wp-content/uploads/2014/05/download.jpeg

**Figure 2.5: The SPT Sampler in Place in the Boring with Hammer**

### 2.3.4 Soil Sampling

Two main categories of soil samples are collected, undisturbed and disturbed. Undisturbed samples, which are required mainly for shear strength and consolidation tests, are obtained by techniques which aim at preserving the in-situ structure and water content of the soil. In boreholes, undisturbed samples can be obtained by withdrawing the boring tools (except when hollow-stem continuous-flight augers are used) and driving or pushing a sample tube into the soil at the bottom of the hole. The sampler is normally attached to a length of boring rod which can be lowered and raised by the cable of the percussion rig. When the tube is brought to the surface, some soil is removed from each end and molten wax is applied, in thin layers, to form a seal approximately 25mm thick: the ends of the tube are then covered by protective caps. Undisturbed block samples can be cut by hand from the bottom or sides of a trial pit. During cutting, the samples must be protected from water, wind and sun to avoid any change in water content: the samples should be covered with molten wax immediately they have been brought to the surface. It is impossible to obtain a sample that is completely undisturbed, no matter how elaborate or careful the ground investigation and sampling technique might be. In the case of clays, for example, swelling will take place adjacent to the bottom of a borehole due to the reduction in total stresses when soil is removed and structural disturbance may be caused by the action of the boring tools; subsequently, when a sample is removed from the ground the total stresses are reduced to zero.

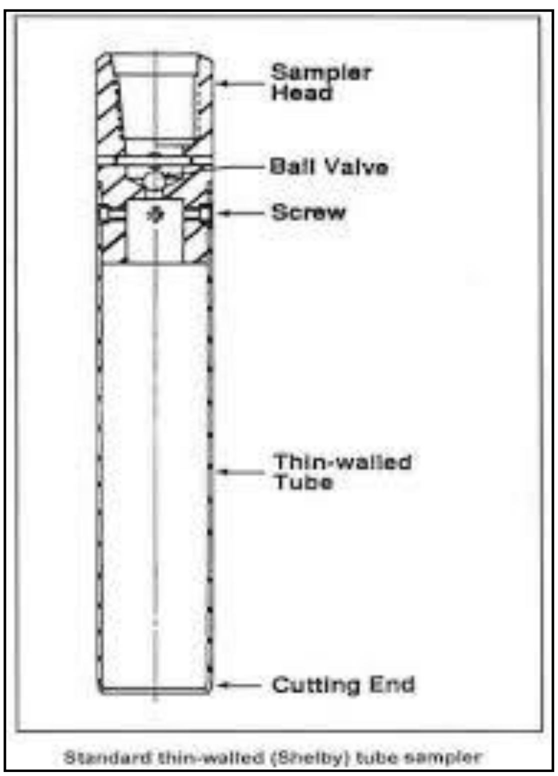
Soft clays are extremely sensitive to sampling disturbance, the effects being more pronounced in clays of low plasticity than in those of high plasticity. The central core of a soft clay sample will be relatively less disturbed than the outer zone adjacent to the sampling tube. Immediately after sampling, the pore water pressure in the relatively undisturbed core will be negative due to the release of the in-situ total stresses. Swelling of the relatively undisturbed core will gradually take place due to water being drawn from the more disturbed outer zone and resulting in the dissipation of the negative excess pore water pressure: the outer zone of soil will consolidate due to the redistribution of water within the sample. The dissipation of the negative excess pore water pressure is accompanied by a corresponding reduction in effective stresses. The soil structure of the sample will thus offer less resistance to shear and will be less rigid than the in-situ soil.

A disturbed sample is one having the same particle size distribution as the in-situ soil but in which the soil structure has been significantly damaged or completely destroyed; in addition, the water content may be different from that of the in-situ soil. Disturbed samples, which are used mainly for soil classification tests, visual classification and compaction tests, can be excavated from trial pits or obtained from the tools used to advance boreholes (e.g. from augers and the clay cutter). The soil recovered from the shell in percussion boring will be deficient in fines and will be unsuitable for use as a disturbed sample. Samples in which the natural water content has been preserved should be placed in airtight, non-corrosive containers: all containers should be completely filled so that there is negligible air space above the sample.

All samples should be clearly labeled to show the project name, date, location, borehole number, depth and method of sampling; in addition, each sample should be given a serial number. Special care is required in the handling, transportation and storage of samples (particularly undisturbed samples) prior to testing. The types of tube samplers used in this study are described below.

**Thin-walled Sampler**

Thin-walled samplers (Figure 2.6) have been used to collected undisturbed samples from boreholes. These samplers are used in soils which are sensitive to disturbance such as soft to firm clays and plastic silts. The sampler does not employ a separate cutting shoe, the lower end of the tube itself being machined to form a cutting edge. The internal diameter may range from 35 to 100 mm. The area ratio is approximately 10% and samples of first-class quality can be obtained provided the soil has not been disturbed in advancing the borehole. In trial pits and shallow boreholes the tube can often be driven manually.

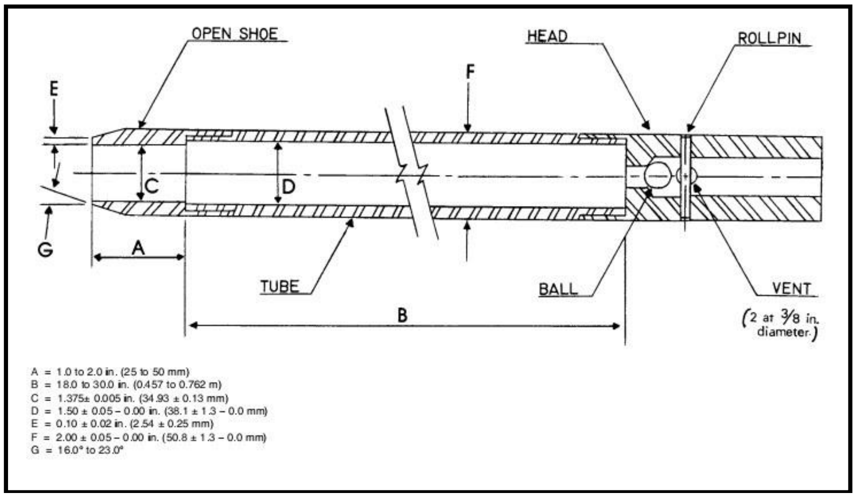



Source: http://foundationeng.blogspot.com/

**Figure 2.6: Thin-Walled (Shelby Tube) Sampler**

### Split-spoon sampler

Split-spoon samplers (Figure 2.7) have been to collect disturb samples. It consists of a tube which is split longitudinally into two halves: a shoe and a sampler head incorporating air-release holes are screwed onto the ends. The two halves of the tube can be separated when the shoe and head are detached to allow the sample to be removed. The internal and external diameters are 35 and 50 mm, respectively, the area ratio being approximately 100%, with the result that there is considerable disturbance of the sample. This sampler is used mainly in sands, being the tool specified in the standard penetration test (SPT).




Source: http://foundationeng.blogspot.com/

**Figure 2.7: Undisturbed (Split-Spoon) Sampler**

### 2.3.5 Carrying out Different Engineering Tests on Soil Sample

A wide variety of laboratory tests is performing on soils to measure number of soil parameters. Some soil properties are intrinsic to the composition of the soil matrix and are not affected by sample disturbance, while other properties depend on the structure of the soil as well as its composition, and can only be effectively tested on relatively undisturbed samples. Some soil tests measure the direct properties of the soil, while others measure "index properties" which provide useful information about the soil without directly measuring the property desired.

The test types and standard which have been following given in the following section. Before explaining each of the engineering tests, the standard followed in each test is mentioned here:

- ✓ **Natural Moisture Content Tests** are performing on selected samples according to ASTM D420-69.
- ✓ **Specific Gravity** Tests is performing on selected soil Samples, according to ASTM D854-83.

- ✓ **Grain size Analysis Tests** is conducting on available representative disturbed & undisturbed soil samples, collected from different strata according to ASTM D421-38 & D422-63.

**Natural Moisture Content Tests**

Moisture content was determined from selected samples according to ASTM D420-69. The water content of a soil sample is the ratio of the weight of the water in the sample to its dry weight it is usually expressed as a percentage. The soil sample is weighed both in natural state and in oven dry state and the moisture content is calculated by dividing the loss of weight of the sample by its dry weight.

**Specific Gravity Test**

Specific gravity of soil particles ($G_s$) is defined as the ratio of the mass of given volume of soil particles to the mass of an equal volume' of water at $4^0$c. 1 he specific gravity for most natural soils falls in general range of 2.60 to 2.80. To determine the specific gravity of soil sample, 25 gm of oven dried soil sample is thorough pulverized and is placed in a calibrated pyenometer. Water is poured inside the pyenometer until its top is slightly below the calibrated mark. The mixture is then boiled thoroughly in order in eliminate all the air bubbles. More water is then added to the mixture till it over-night. The temperature is then recorded and the bottle is weighed.

The specific gravity $G_s$ is given by:

$$G_s = \frac{G_s \text{ x } W_s}{W_s - W_1 + W_2}$$

Where

$G_t$ = Specific gravity of water

$W_s$ = the weight of oven dry soil (25gnis)

$W_1$ Weight of flask + soil + water

$W_2$ = Weight of flask + water

**Grain size Analysis Test-**

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. This test is carried out ASTM D421-38 & D422-63.

**Sieve Analysis**

1. Write down the weight of each sieve as well as the bottom pan to be used in the analysis.
2. Record the weight of the given dry soil sample.
3. Make sure that all the sieves are clean, and assemble them in the ascending order of sieve numbers (#4 sieves at top and #200 sieve at bottom). Place the pan below #200 sieve. Carefully pour the soil sample into the top sieve and place the cap over it.
4. Place the sieve stack in the mechanical shaker and shake for 10 minutes.
5. Remove the stack from the shaker and carefully weighs and record the weight of each sieve with its retained soil. In addition, remember to weigh and record the weight of the bottom pan with its retained fine soil.

**Hydrometer Analysis Test**

For hydrometer analysis, 50gms of the oven dry sample is taken and 125 mL of the dispersing agent (sodium hexameta phosphate (40 g/L)) solution has been added and the mixture is stirred until the soil is thoroughly wet. The soil has been left to soak for at least ten minutes. While the soil is soaking, 125mL of dispersing agent into the control cylinder has been added and the cylinder is filled by distilled water to the mark of 1000 cc. the reading at the top of the meniscus formed by the hydrometer stem is taken. A reading less than zero is recorded as a negative (-) correction and a reading between zero and sixty is recorded as a positive (+) correction. This reading is called the zero correction. The meniscus correction is the difference between the top of the meniscus and the level of the solution in the control jar (Usually about +1). The control cylinder is shaken in such a way that the contents are mixed thoroughly. The hydrometer and thermometer are inserted into the control cylinder and the zero correction and temperature have been noted respectively. the soil slurry into a mixer by adding more distilled water are transferred, if necessary, until mixing cup is at least half full. Then the solution for a period of two minutes has been mixed. Immediately the soil slurry into the empty sedimentation cylinder has been transferred. Distilled water up to the mark has been added. After an elapsed time of one minute and forty seconds, very slowly and carefully the hydrometer has been inserted for the first reading. The reading is taken by observing the top of the meniscus formed by the suspension and the hydrometer stem. Hydrometer readings after elapsed time of 2 and 5, 8, 15, 30, 60 minutes and 24 hours have recorded. For hydrometer analysis, meniscus correction to the actual hydrometer reading has been applied and corrected hydrometer reading has been calculated. From those corrected hydrometer reading percent finer is calculated and the grain size curve diameter versus the adjusted percent finer are plotted on the semi-logarithmic sheet.

**Direct Shear Tests**

To determine shear characteristics, direct shear tests on 60 mm x 60 mm x 20 mm thick specimens prepared from selected disturbed and undisturbed samples were performed according to ASTM D3080-72. The results of a direct shear test on a cohesion less and cohesive soil can be presented in a summary table & by stress-strain curve. A stress-strain curve normally consists of shear stress; various shear displacement for both the undisturbed and the remolded tests under a specified normal load. The normal load usually varies from 1/3kg/cm$^2$ to 1 kg/cm$^2$. Another curve of normal stress verses shearing stress will give angle of internal friction and cohesion for cohesive soil.

# CHAPTER THREE: SURVEY RESULT AT SARIAKANDI UPAZILA

## 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 Sariakandi Upazila and described in below.

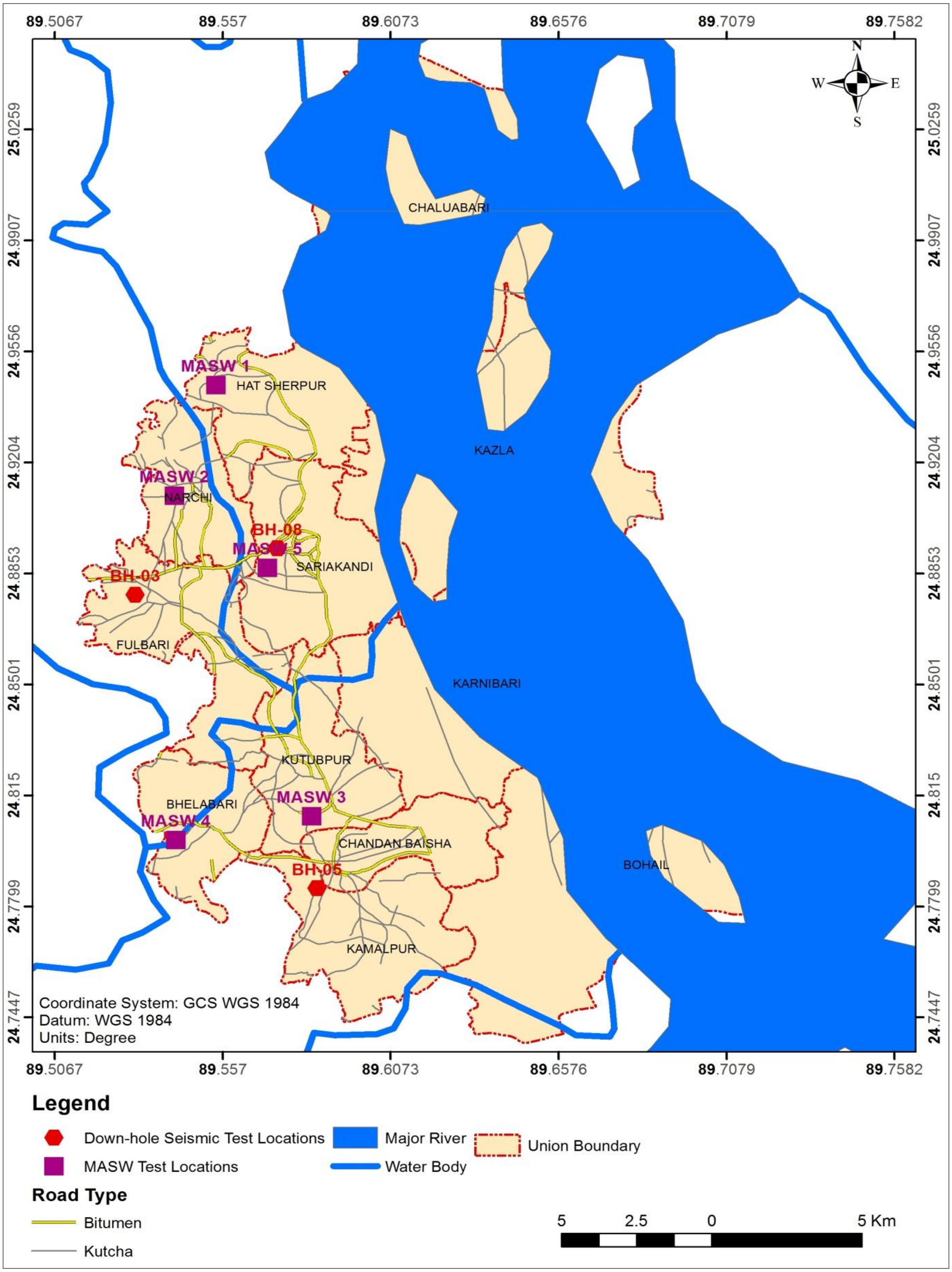
Shear wave velocity profile (Vs profile) in the field were carried out by two geophysical exploration methods namely 1) seismic downhole test and 2) Multichannel Analysis of Surface Wave (MASW).

Seismic downhole test is a direct measurement method for obtaining the shear wave velocity profile of soil stratum. However, the test requires borehole which is not time and cost effective for the project. Multichannel analysis of surface waves (MASW) is a non-invasive technique which can be used to determine the Vs profile at sites. In this project, the seismic downhole and MASW tests were performed at 3 and 5 locations respectively. Locations of seismic downhole test and MASW tests are shown in Map 3.1. The GPS coordinate of the test locations are showing in Table 3.1.

Source: Field Survey, 2016

**Plate-7: Investigation of the Geological Field Work**

**Map 3.1: Locations Map of the Geophysical Tests at Sariakandi Upazila**




Source: MEPC

## Table 3.1: Down-hole Seismic Test (PS logging) and MASW Test Locations

| Upazila Name | Test/ Survey Name | ID | Location Name | Coordinate | | Data Acquisition Data |
|---|---|---|---|---|---|---|
| | | | | Latitude | Longitude | |
| Sariakandi | Downhole Seismic Test (PS Logging) | BH-08 | Sariakandi Upozila Porishod, Sariakandi sadar | 24.89326 | 89.57335 | 2/9/2016 |
| | | BH-05 | Koroytola Govt. Primary School, Kamalpur union | 24.78558 | 89.58518 | 2/9/2016 |
| | | BH-03 | Gomir uddin Bhumukhi School and College, Hat Fulbari union | 24.87858 | 89.53075 | 2/9/2016 |
| | Multi-channel analysis of surface waves (MASW) | MASW 1 | Nizbolail High School Field, Hat Sherpur Union | 24.94502 | 89.5549 | 1/9/2016 |
| | | MASW 2 | Majada Rahaman High School Field, Narchi Union | 24.90995 | 89.54247 | 2/9/2016 |
| | | MASW 3 | Kutubpur Govt. Primary School Field, Kutubpur Union | 24.80849 | 89.58361 | 2/9/2016 |
| | | MASW 4 | Jorgacha Fazil Madrasha, Jorgacha Bazar, Bhelabari Union | 24.80098 | 89.54293 | 2/9/2016 |
| | | MASW 5 | Sariakandi Govt. High School Field, Sariakandi Sadar | 24.88711 | 89.57037 | 2/9/2016 |

Source: Field Survey, 2016

MASW 1: Nizbolail High School Field, Hat Sherpur Union

MASW 2: Majada Rahaman High School Field, Narchi Union

MASW 3: Kutubpur Govt. Primary School Field, Kutubpur Union

MASW 4: Jorgacha Fazil Madrasha, Jorgacha Bazar, Bhelabari Union

MASW 5: Sariakandi Govt. High School Field, Sariakandi Sadar

Source: Field Survey, 2016

**Plate-8: Investigation of the Geological Field Work**

### 3.1.1 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 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. 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 Sariakandi Upazila in three different locations on date 2$^{nd}$ September 2016.

The average shear wave velocity (AVS) of each PS logging test are tabulated in Table 3.2. Work plan of the test depth was 30m, however, in some locations did not reach the geophone to the 30 m in depth due to adverse conditions of PVC.

**Table 3.2: Summary of PS Logging Test Result**

| Depth from Existing Ground Level | AVS 5 | | | AVS 10 | | | AVS 15 | | | AVS 20 | | | AVS 25 | | | AVS 28 to AVS 30 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BH-03 | BH-05 | BH-08 | BH-03 | BH-05 | BH-08 | BH-03 | BH-05 | BH-08 | BH-03 | BH-05 | BH-08 | BH-03 | BH-05 | BH-08 | BH-03 | BH-05 | BH-08 |
| 5m | 95 m/s | 79 m/s | 92m/s | | | | | | | | | | | | | | | |
| 10m | | | | 120 m/s | 110 m/s | 123 m/s | | | | | | | | | | | | |
| 15m | | | | | | | 134 m/s | 131 m/s | 138 m/s | | | | | | | | | |
| 20m | | | | | | | | | | 138 m/s | 144 m/s | 151 m/s | | | | | | |
| 25m | | | | | | | | | | | | | 155 m/s | 160 m/s | 160 m/s | | | |
| 30m | | | | | | | | | | | | | | | | 165 m/s | 166 m/s | 169 m/s |

Source: Field survey, 2016

According to down hole seismic test results, the average shear wave velocities upto depth 30 are 165ms to 169m/s. It is indicate the soil of this area is soft or loose in nature. But actual soil condition (soil type, engineering properties and seismic behavior of soil) will be known when all the field data (SPT and soil laboratory test result, down hole seismic test result and MASW test result) has been integrated in a module to produces different type of maps including micro-zonation map of the project area.

The shear wave velocities at every 1m interval of each site are given in Appendix 1 at tabular and also graphical format.

### 3.1.2 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 five different locations at Sariakandi Upazila by 2nd September 2016 and field raw data has been processed and also interpreted. The results of the MASW test are enclosed in Appendix B at tabular and also graphical format.

According to MASW test result, the velocities of the soil strata below 160 m/s upto depth 7.3m from existing ground level which indicate are the soil upto this depth soft or loose in nature. But the velocities of all the test locations are gradually improved with increasing of depth. At MASW 5 which is located at Sariakandi Govt. High School Field, Sariakandi Sadar is show velocity above 300m/s at 24.3 m depth. The average shear wave velocities upto depth 30 m from 177.3 to 210.7m/s of the area. The detail MASW survey results are shown in Table 3.3.

**Table 3.3: Summary of MASW Test Results**

| MASW 1 | | MASW 2 | | MASW 3 | | MASW 4 | | MASW 5 | |
|---|---|---|---|---|---|---|---|---|---|
| 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) |
| 0.0 | 122 | 0.0 | 117 | 0.0 | 137 | 0.0 | 135 | 0.0 | 133 |
| 0.7 | 118 | 0.7 | 118 | 0.7 | 135 | 0.7 | 134 | 0.7 | 134 |
| 1.5 | 117 | 1.5 | 117 | 1.5 | 133 | 1.5 | 133 | 1.5 | 133 |
| 2.5 | 121 | 2.5 | 121 | 2.5 | 134 | 2.5 | 135 | 2.5 | 136 |
| 3.5 | 132 | 3.5 | 131 | 3.5 | 139 | 3.5 | 143 | 3.5 | 145 |
| 4.7 | 142 | 4.7 | 144 | 4.7 | 150 | 4.7 | 153 | 4.7 | 159 |
| 5.9 | 153 | 5.9 | 158 | 5.9 | 163 | 5.9 | 163 | 5.9 | 173 |
| 7.3 | 162 | 7.3 | 170 | 7.3 | 174 | 7.3 | 173 | 7.3 | 187 |
| 8.8 | 173 | 8.8 | 184 | 8.8 | 187 | 8.8 | 183 | 8.8 | 200 |
| 10.4 | 183 | 10.4 | 198 | 10.4 | 198 | 10.4 | 193 | 10.4 | 212 |
| 12.1 | 194 | 12.1 | 213 | 12.1 | 209 | 12.1 | 207 | 12.1 | 223 |
| 13.9 | 202 | 13.9 | 227 | 13.9 | 223 | 13.9 | 224 | 13.9 | 234 |
| 15.8 | 208 | 15.8 | 244 | 15.8 | 237 | 15.8 | 238 | 15.8 | 244 |
| 17.9 | 212 | 17.9 | 257 | 17.9 | 244 | 17.9 | 247 | 17.9 | 257 |
| 24.3 | 215 | 24.3 | 266 | 24.3 | 252 | 24.3 | 256 | 24.3 | 305 |
| *AVS 30- 177.3m/s* | | *AVS 30- 195.1m/s* | | *AVS 30- 197.6m/s* | | *AVS 30- 197.2m/s* | | *AVS 30- 210.7m/s* | |

*Velocity below 160m/s*
*Velocity 160m/s to 200m/s*
*Velocity 200m/s to 240m/s*
*Velocity 240m/s to 280m/s*
*Velocity above 280m/s*

Source: Field survey, 2016

## 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. Investigation borings with standard penetration test were conducted in order to know vertical geological conditions. The borings with SPT were carried out at 14 points at Sariakandi Upazila.

### 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. Although the SPT also is plagued by many problems that affect its accuracy and reproducibility, it probably will continue to be used for the foreseeable future, primarily because of its low cost. However, it is partially being replaced by other test methods, especially on larger and more critical projects.

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 3.4 and the geotechnical borehole log are enclosed in the below section.

**Table 3.4: Bore Hole Information Summary at Sariakandi Upazila**

| BH ID | Location | Coordinate | |
|---|---|---|---|
| | | Latitude | Longitude |
| BH-01 | Antapara Govt. School | 24.913839 | 89.572267 |
| BH-02 | Sariakandi Dak Banglaw | 24.894658 | 89.580200 |
| BH-03 | Hat Fulbari | 24.964400 | 89.541950 |
| BH-04 | Bandar Hat | 24.927764 | 89.577597 |
| BH-05 | Kuritala | 24.847028 | 89.580222 |
| BH-06 | Kutubpur | 24.810708 | 89.593622 |
| BH-07 | Norchi | 24.915833 | 89.542461 |
| BH-08 | Sariakandi Upazila Parishad | 24.902744 | 89.582042 |
| BH-09 | Gonaipara Hat | 24.944608 | 89.542000 |
| BH-10 | Bhelabari | 24.829278 | 89.538833 |
| BH-11 | Hindukandi Jamatul Ferdouse | 24.896000 | 89.572611 |

Source: Field survey, 2016

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 3.5: 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 |

Source: K. Terzaghi

**Table 3.6: 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 |

| N-values | Condition | Unconfined Compressive Strength (Tsf) |
|---|---|---|
| 8-16 | Stiff | 1.00-2.00 |
| 16-32 | very stiff | 2.00-4.00 |
| Over 32 | Hard | over 4.00 |

Source: K. Terzaghi

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.

*The lithology is already written down in a standard format and has been attached in the Appendix 3.*

# CHAPTER FOUR: CONCLUSION

Sariakandi Upazila and its adjoining areas is mostly comprises by monotonous flood plain area except few depression. Soil quality of the project area is is varying as morphological difference, that's why geological, geotechnical and geophysical investigations has been carried out such a pattern to cover all morphological unit. In this consequences, 11 boreholes with SPT, 3 downhole seismic tests and 5 MASW program has been completed in the field as a part of this survey investigation. During this survey, soil samples (disturbed and undisturbed) are also collected for further laboratory test which will give idea about the soil engineering properties. This investigation data will be analyzed and integrated in a module from which it can possible to generate geomorphologic map, sub-surface litho-logical 3D model of different layers, engineering geological mapping based on AVS30, Seismic Hazard Assessment Map (risk sensitive micro-zonation maps), soil type map, seismic intensity map, Peak Ground Acceleration (PGA) and recommended building height maps for both high rise building and low rise building etc.

Above investigation and outcomes would give a clear idea about the geo-hazard status of particular landscape where newly urban developing activities or any other mega infrastructure project is going on and this mentioned investigation also gives idea about the vulnerability of existing build up infrastructure of a particular area. Based on these results, proper management techniques as well as other necessary adaptation process could be addressed before or after the development activities in the studied area. It is to be mentioned that the long-term maintenance cost will be reduced and the developed structure will withstand against the potential natural hazards if the infrastructures are built following the risk informed physical land-use plan.

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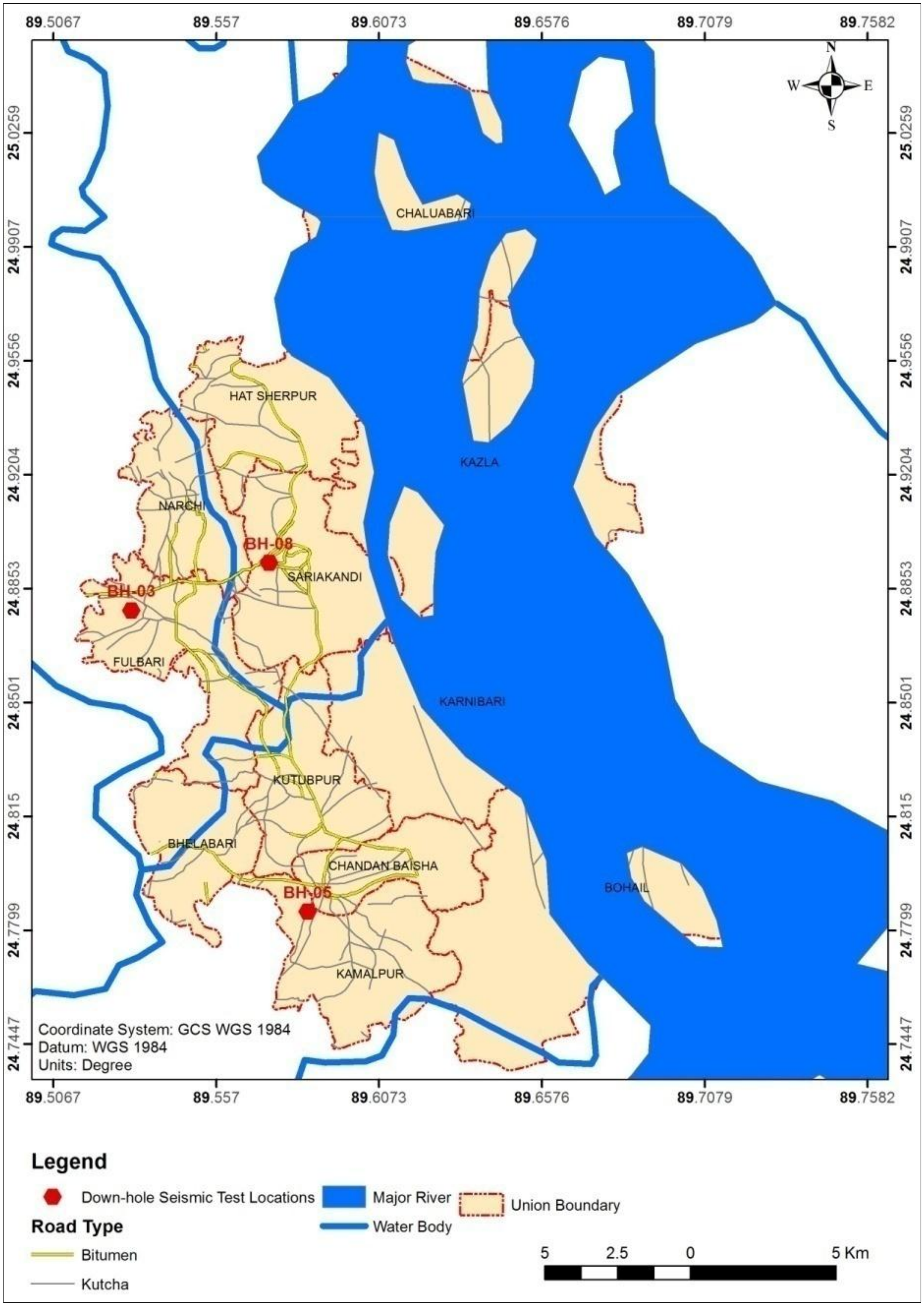
# APPENDICES

# Appendix-1

## Downhole Seismic Test (PS Logging) Results and Graphs

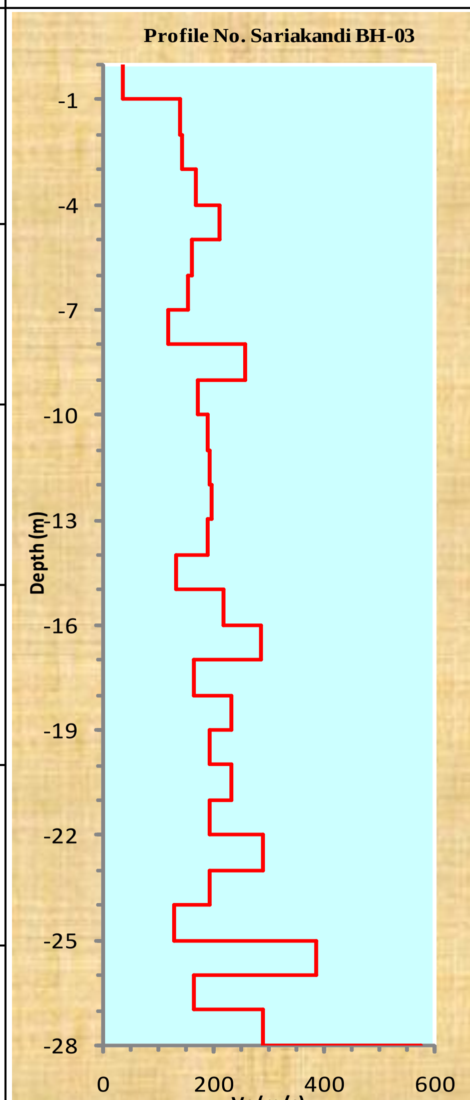


## SHEAR WAVE VELOCITY MEASURMENTS FROM DOWNHOLE SEISMIC TEST (PS LOGGING)

| | |
|---|---|
| Tested Date(dd/mm/yyyy) : 02/09/2016 | Source : 7kg Sledge Hammer |
| Location : Gomir uddin Bhumukhi School and College, Hat Fulbari union, Sariakandi Upazila | Downhole Receiver : Tri-axial Geophone |
| PS Id : BH-03 | Recording Equipment: Freedom Data PC |
| Coordinate : Lat-24.87858 Long-89.53075 | 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* | | | | | | |
| 0.038808 | -1 | 1.41 | 0.0274 | 0.0274 | 36 | AVS 5 95 |
| 0.038808 | -2 | 2.24 | 0.0347 | 0.0073 | 138 | |
| 0.043990 | -3 | 3.16 | 0.0417 | 0.0070 | 142 | |
| 0.049191 | -4 | 4.12 | 0.0477 | 0.0060 | 167 | |
| 0.053517 | -5 | 5.10 | 0.0525 | 0.0048 | 210 | |
| 0.059574 | -6 | 6.08 | 0.0588 | 0.0063 | 159 | AVS 10 120 |
| 0.065956 | -7 | 7.07 | 0.0653 | 0.0065 | 153 | |
| 0.074284 | -8 | 8.06 | 0.0737 | 0.0084 | 119 | |
| 0.078069 | -9 | 9.06 | 0.0776 | 0.0039 | 258 | |
| 0.083802 | -10 | 10.05 | 0.0834 | 0.0058 | 173 | |
| 0.088994 | -11 | 11.05 | 0.0886 | 0.0052 | 191 | AVS 15 134 |
| 0.094185 | -12 | 12.04 | 0.0939 | 0.0052 | 191 | |
| 0.099269 | -13 | 13.04 | 0.0990 | 0.0051 | 195 | |
| 0.104569 | -14 | 14.04 | 0.1043 | 0.0053 | 188 | |
| 0.112140 | -15 | 15.03 | 0.1119 | 0.0076 | 132 | |
| 0.116682 | -16 | 16.03 | 0.1165 | 0.0046 | 219 | AVS 20 148 |
| 0.120143 | -17 | 17.03 | 0.1199 | 0.0035 | 287 | |
| 0.126200 | -18 | 18.03 | 0.1260 | 0.0061 | 165 | |
| 0.130527 | -19 | 19.03 | 0.1303 | 0.0043 | 230 | |
| 0.135718 | -20 | 20.02 | 0.1355 | 0.0052 | 192 | |
| 0.140045 | -21 | 21.02 | 0.1399 | 0.0043 | 231 | AVS 25 155 |
| 0.145236 | -22 | 22.02 | 0.1451 | 0.0052 | 192 | |
| 0.148698 | -23 | 23.02 | 0.1486 | 0.0035 | 288 | |
| 0.153889 | -24 | 24.02 | 0.1538 | 0.0052 | 192 | |
| 0.161677 | -25 | 25.02 | 0.1615 | 0.0078 | 128 | |
| 0.164273 | -26 | 26.02 | 0.1642 | 0.0026 | 384 | AVS 29 165 |
| 0.170329 | -27 | 27.02 | 0.1702 | 0.0061 | 165 | |
| 0.173791 | -28 | 28.02 | 0.1737 | 0.0035 | 288 | |
| 0.175521 | -29 | 29.02 | 0.1754 | 0.0017 | 576 | |

**Graphical Representation of Vs**

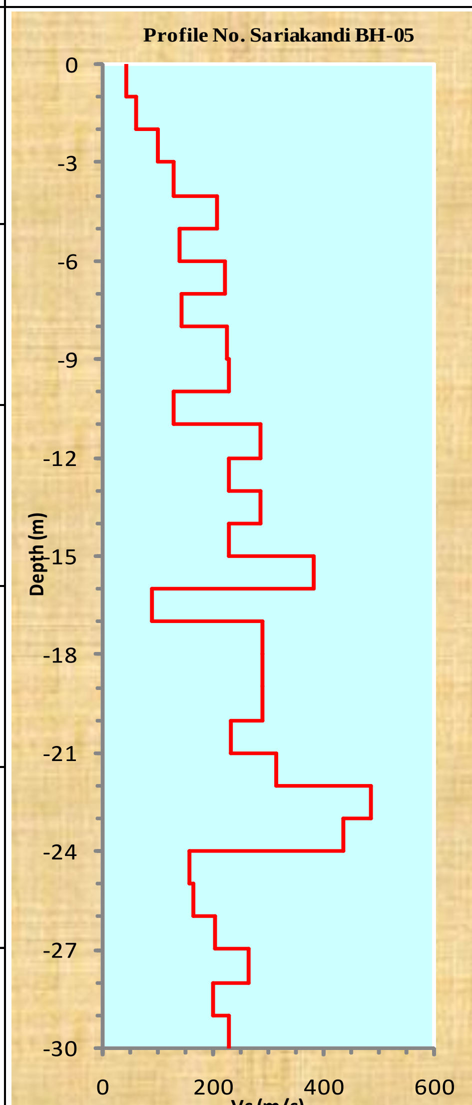


## SHEAR WAVE VELOCITY MEASURMENTS FROM DOWNHOLE SEISMIC TEST (PS LOGGING)

| | |
|---|---|
| Tested Date(dd/mm/yyyy) : 02/09/2016 | Source : 7kg Sledge Hammer |
| Location : Koroytola Govt. Primary School, Kamalpur union, Sariakandi Upazila | Downhole Receiver : Tri-axial Geophone |
| PS Id : BH-05 | Recording Equipment: Freedom Data PC |
| Coordinate : Lat-24.78558 Long-89.58518 | Borehole Information : Grouted Cased |
| Operator : The Olson Instruments Downhole Seismic system | Casing Diameter : 75mm PVC Casing |

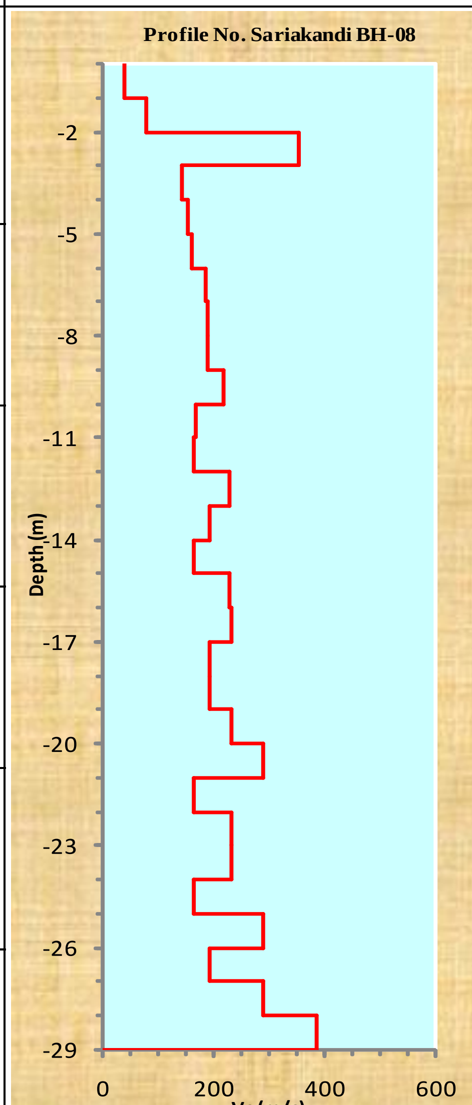
| Time arrival (s) | Recorded Geophone Depth from Existing Ground Level (m) | Source Saint Distance (m), R | Corrected Travel Time for Compretional Wave, tc=D*t/R (s) | Interval Time, ΔTs | Shear Wave Velocity Vs, Vs=D/tc (m/s) | Average Shear Wave Velocity (m/s) |
|---|---|---|---|---|---|---|
| *Existing Ground Level* | | | | | | |
| 0.034099 | -1 | 1.41 | 0.0241 | 0.0241 | 41 | AVS 5 79 |
| 0.045336 | -2 | 2.24 | 0.0405 | 0.0164 | 61 | |
| 0.053115 | -3 | 3.16 | 0.0504 | 0.0098 | 102 | |
| 0.060030 | -4 | 4.12 | 0.0582 | 0.0078 | 127 | |
| 0.064352 | -5 | 5.10 | 0.0631 | 0.0049 | 206 | |
| 0.071267 | -6 | 6.08 | 0.0703 | 0.0072 | 139 | AVS 10 110 |
| 0.075589 | -7 | 7.07 | 0.0748 | 0.0045 | 221 | |
| 0.082504 | -8 | 8.06 | 0.0819 | 0.0070 | 142 | |
| 0.086826 | -9 | 9.06 | 0.0863 | 0.0044 | 226 | |
| 0.091148 | -10 | 10.05 | 0.0907 | 0.0044 | 227 | |
| 0.098927 | -11 | 11.05 | 0.0985 | 0.0078 | 128 | AVS 15 131 |
| 0.102385 | -12 | 12.04 | 0.1020 | 0.0035 | 285 | |
| 0.106707 | -13 | 13.04 | 0.1064 | 0.0044 | 229 | |
| 0.110164 | -14 | 14.04 | 0.1099 | 0.0035 | 286 | |
| 0.114486 | -15 | 15.03 | 0.1142 | 0.0043 | 230 | |
| 0.117079 | -16 | 16.03 | 0.1169 | 0.0026 | 382 | AVS 20 144 |
| 0.128316 | -17 | 17.03 | 0.1281 | 0.0112 | 89 | |
| 0.131774 | -18 | 18.03 | 0.1316 | 0.0035 | 288 | |
| 0.135231 | -19 | 19.03 | 0.1350 | 0.0035 | 288 | |
| 0.138686 | -20 | 20.02 | 0.1385 | 0.0035 | 288 | |
| 0.143011 | -21 | 21.02 | 0.1428 | 0.0043 | 231 | AVS 25 160 |
| 0.146168 | -22 | 22.02 | 0.1460 | 0.0032 | 316 | |
| 0.148218 | -23 | 23.02 | 0.1481 | 0.0021 | 485 | |
| 0.150500 | -24 | 24.02 | 0.1504 | 0.0023 | 436 | |
| 0.156861 | -25 | 25.02 | 0.1567 | 0.0064 | 157 | |
| 0.162911 | -26 | 26.02 | 0.1628 | 0.0061 | 165 | AVS 30 166 |
| 0.167826 | -27 | 27.02 | 0.1677 | 0.0049 | 203 | |
| 0.171605 | -28 | 28.02 | 0.1715 | 0.0038 | 264 | |
| 0.176605 | -29 | 29.02 | 0.1765 | 0.0050 | 200 | |
| 0.181008 | -30 | 30.02 | 0.1809 | 0.0044 | 227 | |

**Graphical Representation of Vs**



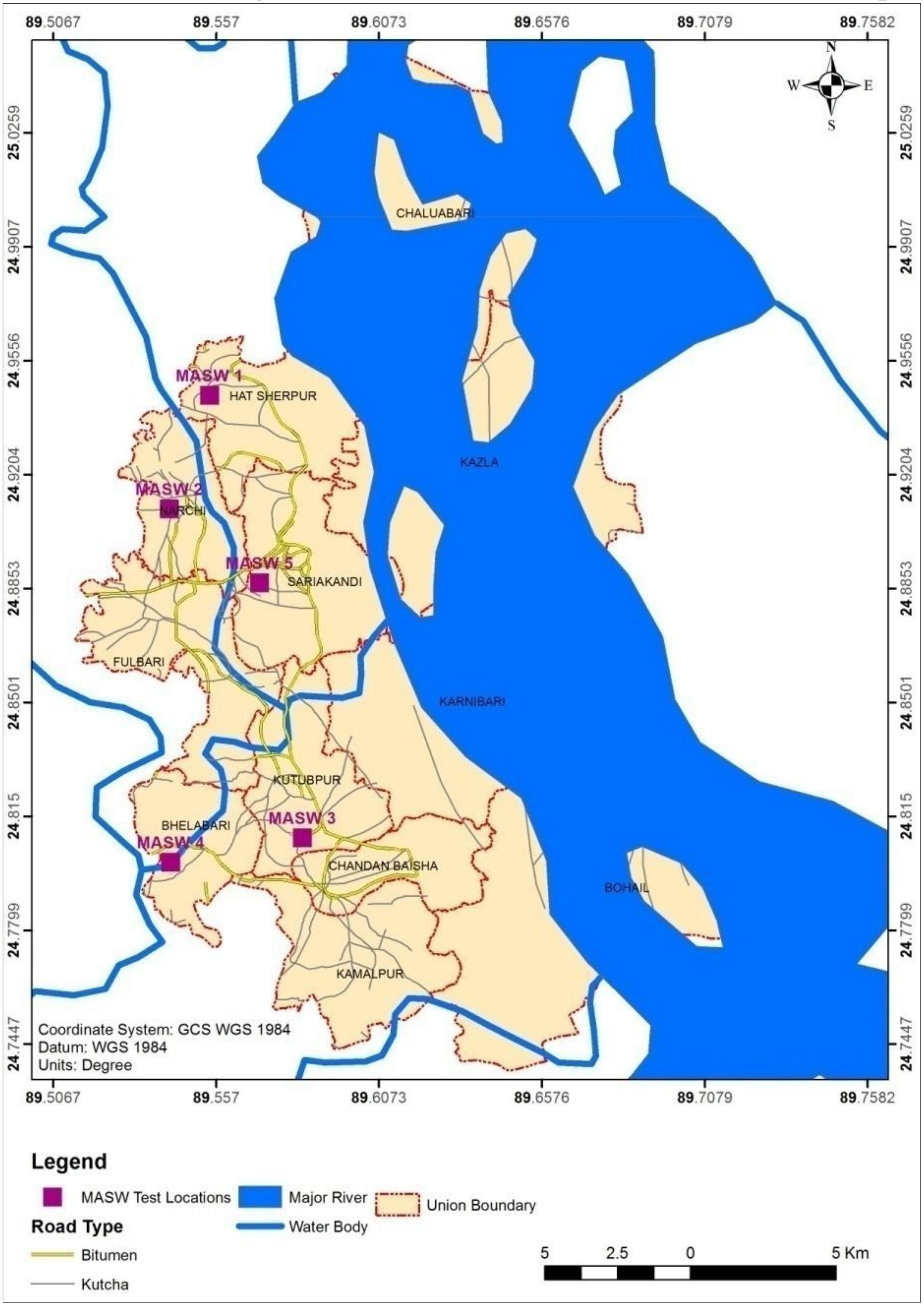
## SHEAR WAVE VELOCITY MEASURMENTS FROM DOWNHOLE SEISMIC TEST (PS LOGGING)

| | |
|---|---|
| Tested Date(dd/mm/yyyy) : 02/09/2016 | Source : 7kg Sledge Hammer |
| Location : Shariakandi Upozila Porishod, Shariakandi sadar | Downhole Receiver : Tri-axial Geophone |
| PS Id : BH-08 | Recording Equipment: Freedom Data PC |
| Coordinate : Lat-24.89326 Long-89.57335 | 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) | Graphical Representation of Vs |
|---|---|---|---|---|---|---|---|
| *Existing Ground Level* | | | | | | | |
| 0.035441 | -1 | 1.41 | 0.0251 | 0.0251 | 40 | AVS 5 92 |  |
| 0.042362 | -2 | 2.24 | 0.0379 | 0.0128 | 78 | | |
| 0.042922 | -3 | 3.16 | 0.0407 | 0.0028 | 353 | | |
| 0.049283 | -4 | 4.12 | 0.0478 | 0.0071 | 141 | | |
| 0.055338 | -5 | 5.10 | 0.0543 | 0.0065 | 155 | | |
| 0.061394 | -6 | 6.08 | 0.0606 | 0.0063 | 159 | AVS 10 123 | |
| 0.066585 | -7 | 7.07 | 0.0659 | 0.0054 | 187 | | |
| 0.071775 | -8 | 8.06 | 0.0712 | 0.0053 | 189 | | |
| 0.076966 | -9 | 9.06 | 0.0765 | 0.0053 | 190 | | |
| 0.081463 | -10 | 10.05 | 0.0811 | 0.0046 | 219 | | |
| 0.087347 | -11 | 11.05 | 0.0870 | 0.0059 | 169 | AVS 15 138 | |
| 0.093403 | -12 | 12.04 | 0.0931 | 0.0061 | 164 | | |
| 0.097728 | -13 | 13.04 | 0.0974 | 0.0044 | 229 | | |
| 0.102919 | -14 | 14.04 | 0.1027 | 0.0052 | 192 | | |
| 0.108975 | -15 | 15.03 | 0.1087 | 0.0061 | 165 | | |
| 0.113300 | -16 | 16.03 | 0.1131 | 0.0043 | 230 | AVS 20 151 | |
| 0.117626 | -17 | 17.03 | 0.1174 | 0.0043 | 230 | | |
| 0.122816 | -18 | 18.03 | 0.1226 | 0.0052 | 192 | | |
| 0.128007 | -19 | 19.03 | 0.1278 | 0.0052 | 192 | | |
| 0.132332 | -20 | 20.02 | 0.1322 | 0.0043 | 231 | | |
| 0.135793 | -21 | 21.02 | 0.1356 | 0.0035 | 288 | AVS 25 160 | |
| 0.141848 | -22 | 22.02 | 0.1417 | 0.0061 | 165 | | |
| 0.146174 | -23 | 23.02 | 0.1460 | 0.0043 | 231 | | |
| 0.150499 | -24 | 24.02 | 0.1504 | 0.0043 | 231 | | |
| 0.156555 | -25 | 25.02 | 0.1564 | 0.0061 | 165 | | |
| 0.160015 | -26 | 26.02 | 0.1599 | 0.0035 | 288 | AVS 29 169 | |
| 0.165206 | -27 | 27.02 | 0.1651 | 0.0052 | 192 | | |
| 0.168666 | -28 | 28.02 | 0.1686 | 0.0035 | 289 | | |
| 0.171261 | -29 | 29.02 | 0.1712 | 0.0026 | 385 | | |

# Appendix-2

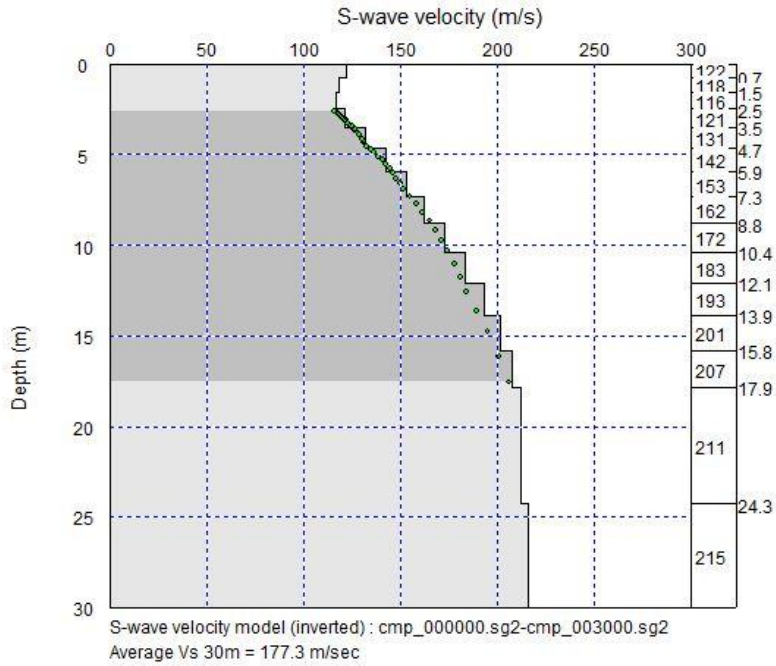
## Multi-channel Analysis of Surface Wave (MASW) Results and Graphs



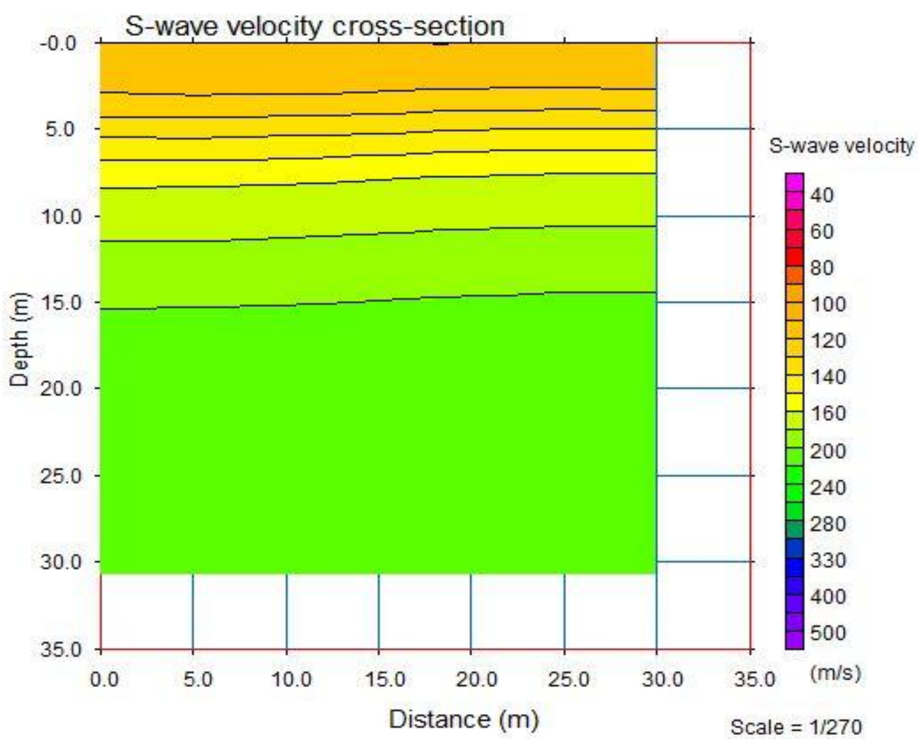
MASW ID:MASW-1 Data Acquisition Date: 01.09.2016
Coordinate : Lat- 24.94502 Long- 89.5549
Location: Nizbolail High School Field, Hat Sherpur Union, Sariakandi Upazila

| Depth | S-Wave Velocity (m/s) |
|---|---|
| 0.0 | 122 |
| 0.7 | 118 |
| 1.5 | 117 |
| 2.5 | 121 |
| 3.5 | 132 |
| 4.7 | 142 |
| 5.9 | 153 |
| 7.3 | 162 |
| 8.8 | 173 |
| 10.4 | 183 |
| 12.1 | 194 |
| 13.9 | 202 |
| 15.8 | 208 |
| 17.9 | 212 |
| 24.3 | 215 |

**1D Model**



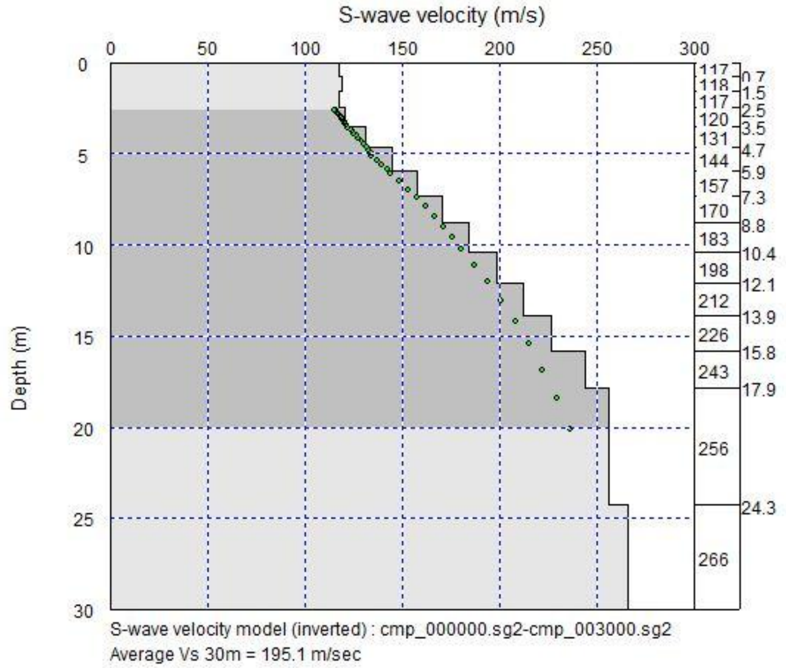

2D Model



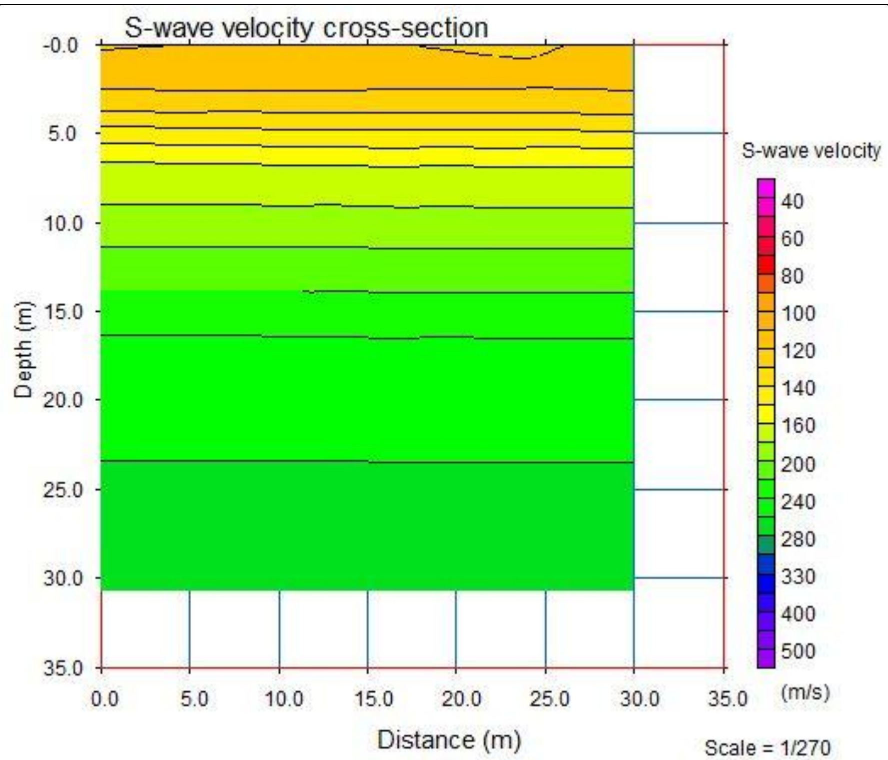
MASW ID: MASW-2  Data Acquisition Date: 02.09.2016
Coordinate : Lat- 24.90995  Long- 89.54247
Location: Majada Rahaman High School Field, Narchi Union, Sariakandi Upazila

| **Depth** | **S-Wave Velocity (m/s)** |
|---|---|
| 0.0 | 117 |
| 0.7 | 118 |
| 1.5 | 117 |
| 2.5 | 121 |
| 3.5 | 131 |
| 4.7 | 144 |
| 5.9 | 158 |
| 7.3 | 170 |
| 8.8 | 184 |
| 10.4 | 198 |
| 12.1 | 213 |
| 13.9 | 227 |
| 15.8 | 244 |
| 17.9 | 257 |
| 24.3 | 266 |

**1D Model**



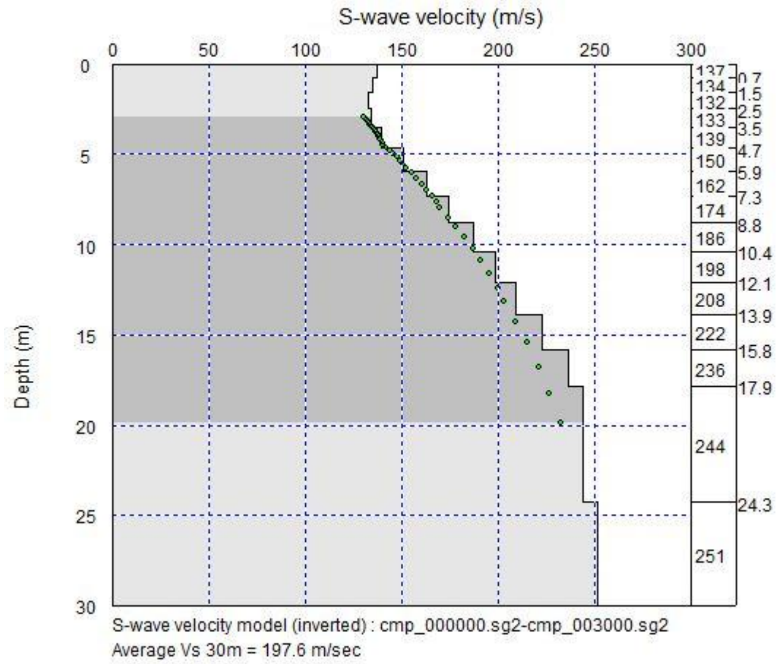

2D Model



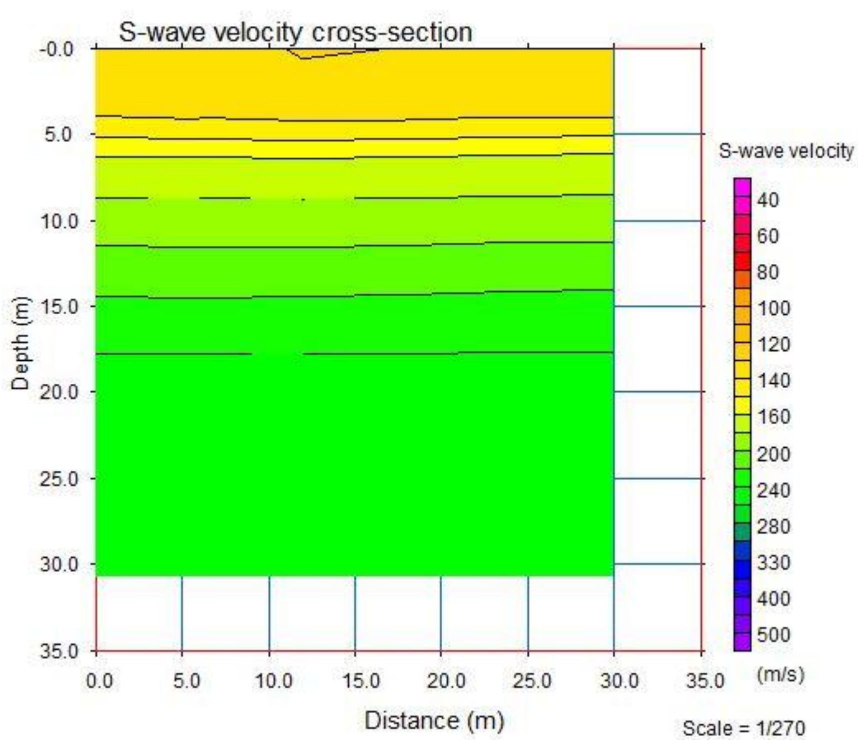
MASW ID: MASW-3 Data Acquisition Date: 02.09.2016
Coordinate : Lat- 24.80849 Long- 89.58361
Location: Kutubpur Govt. Primary School Field, Kutubpur Union, Sariakandi Upazila

| Depth | S-Wave Velocity (m/s) |
|---|---|
| 0.0 | 137 |
| 0.7 | 135 |
| 1.5 | 133 |
| 2.5 | 134 |
| 3.5 | 139 |
| 4.7 | 150 |
| 5.9 | 163 |
| 7.3 | 174 |
| 8.8 | 187 |
| 10.4 | 198 |
| 12.1 | 209 |
| 13.9 | 223 |
| 15.8 | 237 |
| 17.9 | 244 |
| 24.3 | 252 |

**1D Model**



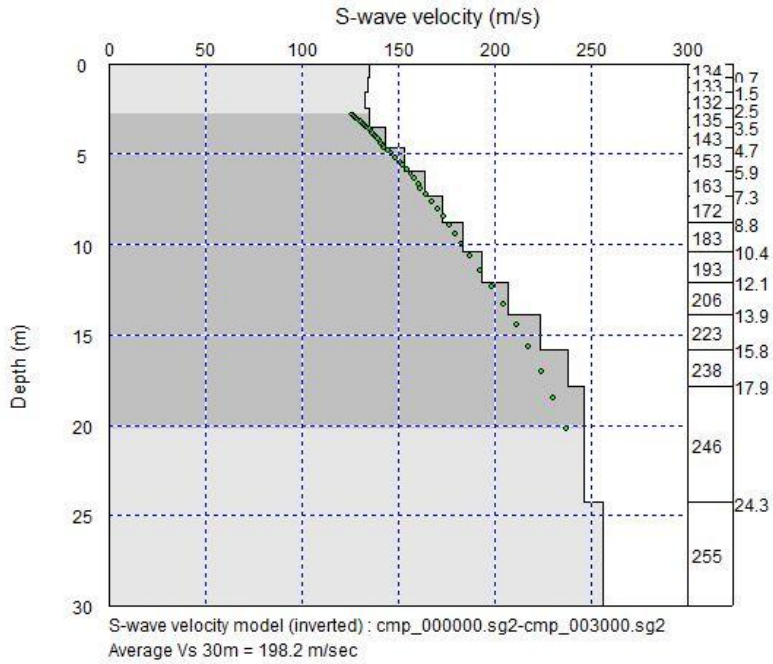

2D Model



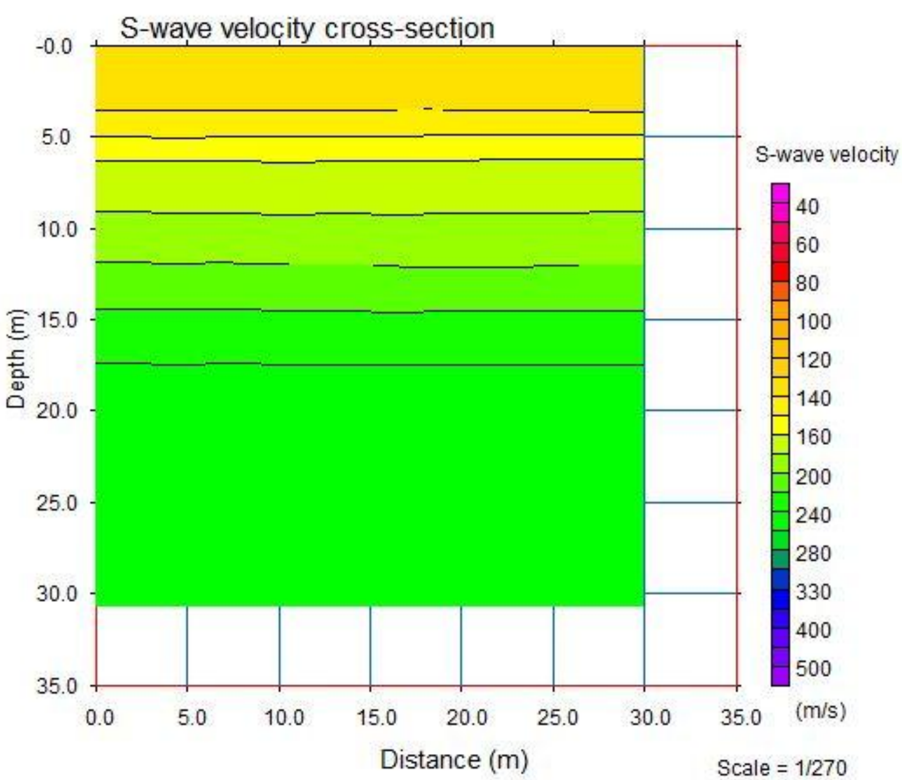
MASW ID: MASW-4 Data Acquisition Date: 02.09.2016
Coordinate : Lat- 24.80098 Long- 89.54293
Location: Jorgacha Fazil Madrasha, Jorgacha Bazar, Bhelabari Union, Sariakandi Upazila

| Depth | S-Wave Velocity (m/s) |
|---|---|
| 0.0 | 135 |
| 0.7 | 134 |
| 1.5 | 133 |
| 2.5 | 135 |
| 3.5 | 143 |
| 4.7 | 153 |
| 5.9 | 163 |
| 7.3 | 173 |
| 8.8 | 183 |
| 10.4 | 193 |
| 12.1 | 207 |
| 13.9 | 224 |
| 15.8 | 238 |
| 17.9 | 247 |
| 24.3 | 256 |

**1D Model**



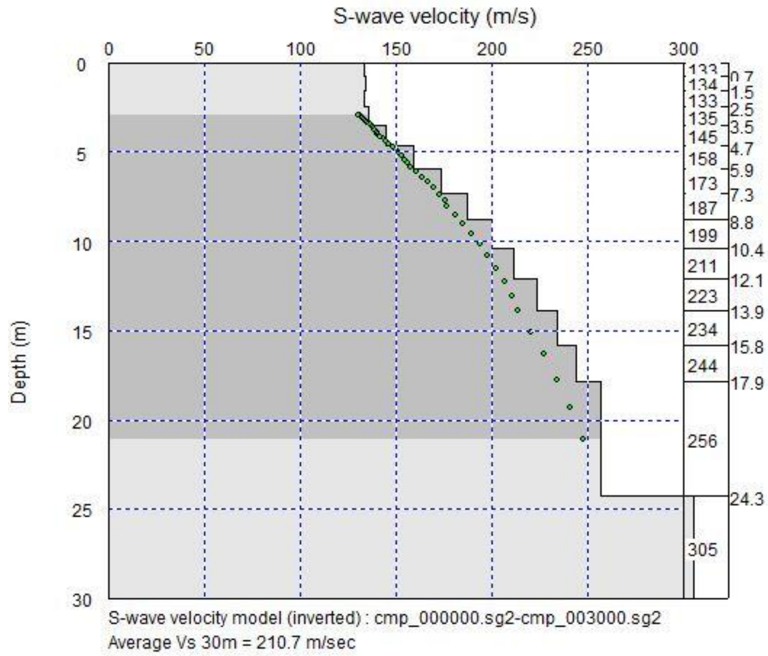

2D Model



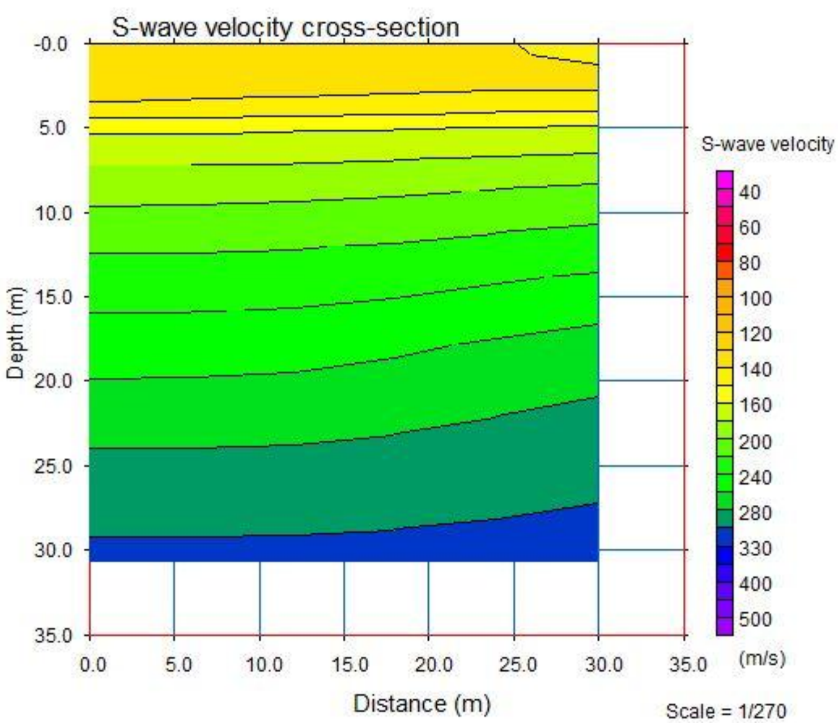
MASW ID: MASW-5 Data Acquisition Date: 02.09.2016
Coordinate : Lat- 24.88711 Long- 89.57037
Location: Sariakandi Govt. High School Field, Sariakandi Sadar, Sariakandi Upazila

| Depth | S-Wave Velocity (m/s) |
|---|---|
| 0.0 | 133 |
| 0.7 | 134 |
| 1.5 | 133 |
| 2.5 | 136 |
| 3.5 | 145 |
| 4.7 | 159 |
| 5.9 | 173 |
| 7.3 | 187 |
| 8.8 | 200 |
| 10.4 | 212 |
| 12.1 | 223 |
| 13.9 | 234 |
| 15.8 | 244 |
| 17.9 | 257 |
| 24.3 | 305 |

**1D Model**




2D Model



# Appendix-3

## Geotechnical Logs and Laboratory Test Results and Graphs