

Project No. EQD-6042/22-23

The Geotechnical Investigations for determining the Shear Strength Characteristics and Bearing Capacity of the Soil in the Joshimath Region

Sponsored by

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Govt. of Uttarakhand, Dehradun**

(Final Report)

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**Department of Earthquake Engineering
Indian Institute of Technology Roorkee
Roorkee 247667, Uttarakhand, INDIA**

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Preface

In general, whole of the Indian Himalayan region is very fragile and vulnerable to multi-hazards including Landslides, Earthquakes, Floods and Cloud-bursts. However, vulnerability in terms of landslides and earthquakes is greater for North-Western Himalaya including Uttarakhand. State of Uttarakhand lies in Seismic Zones IV and V (IS: 1893-1, 2016). Further, **whole of the Chamoli district falls in Seismic Zone V and mountains consist of very fragile-weathered rocks.** The district is also subjected to heavy rains particularly during Monsoons. This leads to frequent rainfall-induced and earthquake-induced landslides. Sometime, both precipitation and shaking may be the reason of landslides. And also there has been increase in anthropogenic activities related to construction of various infrastructures which has further aggravated the problem of slope instability in this region.

Joshimath is Tehsil headquarter, winter abode of Shri Badrinath Temple, and staging area for the forward posts along Sino-Indian border; hence has administrative, spiritual and strategic significance. Moreover located on Rishikesh-Badrinath National Highway (NH 7), Joshimath is an important stop over for the people visiting Badrinath, Auli, Valley of Flowers, Hemkund Sahib and other trekking routes, and hence visited by tourists, pilgrims and adventure lovers in large numbers. Joshimath is situated on an E-W running ridge to the SW of Vishnuprayag that is the confluence of the Dhaul Ganga and Alaknanda rivers. The ridge is traversed by SSE-NNW running streams with high gradient.

Rocks exposed in the area belong to the Higher Himalayan Crystallines represented dominantly by gneisses of Joshimath Formation that are observed to dip NE at moderate angles. **Proximity to Main Central Thrust (MCT)** that passes close to the south of Joshimath at Helang makes the rocks structurally weak and sheared. The area around Joshimath town is observed to be covered by **thick layer of overburden material.** Large boulders of gneisses and fragments of basic and schist rocks are observed to be embedded in gray coloured silty-sandy matrix. As also indicated by previous reports and publications Joshimath town is located over thick cover of landslide material. The region has been witnessing gradual sinking for a long time and the same has been formally reported first by Mishra Committee of 1976.

A multi-institutional team visited Joshimath in August 2022 and submitted a report in September 2022. Prof. B.K. Maheshwari was part of this team on behalf of IIT Roorkee. Some issues of cracks in buildings were observed by team and some remedial measures were suggested. In January 2023, there was significant increase in number of buildings developing cracks. In the first week of January 2023, there was a tremendous increase in the flow of sub-surface water in some of the areas of the town leading to ground subsidence at a faster rate. A multi-institutional committee led by Dr. Ranjit Sinha, the Secretary, Disaster Management, Govt. of Uttarakhand visited the town during Jan. 5-7, 2022 and submitted its report. Taking the cognizance of the report, Uttarakhand State Disaster Management Authority (USDMA) requested IIT Roorkee to carry out the Geotechnical studies to determine the shear strength characteristics of the soil in Joshimath region through its letter number 1656/USDMA (Admin)-61 (2021) dated January 7, 2023. A detailed proposal was submitted on Jan. 10, 2023 which was accepted by USDMA through its letter number 1746/USDMA-1093/2023 dated Jan. 16, 2023.

A team for field tests was departed from IIT Roorkee to Joshimath in the early morning of January 18, 2023. The field team was in Joshimath for about a month till February 14, 2023 for conducting various tests.

The project proposal from IIT Roorkee covered following points:

(A) Objectives

1. To determine the shear strength characteristics of the soil (mixed with boulders) in best possible way
2. To determine the bearing capacity of the soil (mixed with boulders) from field tests
3. Based on the above to suggest type of foundation and buildings / structures which can be constructed on the soil strata in the Joshimath region. Thus, advice general retrofitting measures for vulnerable foundations of existing buildings, if required

Above objectives are for long-term solution

(B) Team Members: (from Dept. of Earthquake Engineering, IIT Roorkee)

1. Dr. B.K. Maheshwari, Professor
2. Dr. R.S. Jakka, Associate Professor
3. Mr. Sukanta Das, Research Scholar (Final Year)
4. Mr. Shantanu Saraswat, Research Scholar (Second Year)

(C) Field tests to be conducted

by IIT Roorkee

1. MASW Tests (at 10 locations): Multi-channel Analysis of Surface Waves along with HVSR. This test will provide shear wave velocity profile of the ground up to a depth of 30 to 50 m.

by an External Agency under the supervision of IIT Roorkee

2. Bore-holes using Earth Augers (10 in numbers): Upto a depth of 10 m or till refusal is arrived (whichever met earlier), soil sampling at 1.5m depth interval. These samples will be tested in the laboratory for index properties.
3. Dynamic Cone Penetration Test (DCPT) 10 in numbers: Up to 10 m depth or till refusal is arrived (whichever met earlier).
4. Plate Load Tests (10 in numbers): on a plate of size 300mm×300mm in a pit of size 1.5m×1.5m at a depth of 1.5m, up to a loading intensity of 60t/sqm.
5. Direct Shear Test (DST): 5 tests on a box of 300mm×300 mm, 2 tests on a box of size 700mm×700 mm up to a depth of 2m.

Joshimath has 9 wards and it was decided to conduct at least 1 test in each ward (except DST). Above tests are feasible in the present situation. However, will not yield any soil samples for lab testing except the second one. Standard Penetration Test (SPT) though provides soil samples for testing in the laboratory but collecting useful soil samples in a boulder strata is not feasible.

The outcome of this work indicates that the Joshimath ground consist of a mixture of boulders and gravels, and it was very difficult to conduct the field tests in this strata. Final outcome indicates that more than 50% of the Joshimath lies in a very high risk zone.

Acknowledgement

The investigators will like to thankfully acknowledge the support of following members for this project work:

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2. Shri Savin Bansal, Add. Chief Executive Officer (Admin.), USDMA, Dehradun
3. Dr. Shantanu Sarkar, Director, UK Landslide Mitigation Center, Dehradun
4. Ms. Kumkum Joshi, SDM, Joshimath
5. Mr. N.K. Joshi, DDO, Joshimath
6. Mr. N.P. Aterkar, Director, Soilex Pvt. Ltd., Roorkee

IIT Roorkee

1. The Director
2. Dean, SRIC
3. Registrar
4. Head, Dept. of Earthquake Engineering

Final Report for Joshimath Geotechnical Investigations

Ward-wise map of Joshimath is shown in **Fig. 1**. On January 19, 2023 and later, the team members visited different parts of the Joshimath and finalized following locations to conduct the field tests:

1. Gandhinagar (GN): Near Govt. P.G College, (Ward 1)
2. Marwadi (MW): Near gate of Jaypee Colony (Ward 2)
3. Lower Bazar (LB): Near Narsingh Mandir (Ward 3)
4. Singhdhar (SD1): Near Panchvati Inn (Ward 4)
5. Singhdhar (SD2): Near Parking Plot (Ward 4)
6. Manoharbagh (MB1): Near Ropeway Tower No. 1 (Ward 5)
7. Manoharbagh (MB1): Near PWD Guest House (Ward 5)
8. Manoharbagh (MB3): Near CPWD Office (Ward 5)
9. Upper Bazar (UB): Near Nagarpalika (Ward 6)
10. Sunil (SN): Near Shivalik Cottage (Ward 7)
11. Parsari (PS): Near AT Nala (Ward 8)
12. Ravigram (RG): Near Helipad in Front of NTPC Gate (Ward 9)

The field tests were conducted at 12 sites. This is the final report based on the test results of following 12 sites:

1. Gandhinagar: Near Govt. P.G College: 30°33'24.2"N 79°34'19.1"E, 1800m
2. Marwadi: Near gate of Jaypee Colony: 30°33'50.7"N 79°33'23.6"E, 1520m
3. Lower Bazar: Near Narsingh Mandir: 30°33'21.2"N 79°33'54.9"E, 1850m
4. Singhdhar: Near Panchvati Inn: 30°33'26.8"N 79°33'32.6"E, 1820m
5. Singhdhar: Near Parking Plot: 30°33'27.8"N 79°33'18.6"E, 1820m
6. Manoharbagh: Near Ropeway Tower No. 1: 30°33'17.1"N 79°33'26.6"E, 1950m
7. Manoharbagh: Near PWD Guest House: 30°33'23.3"N 79°33'29.0"E, 1880m
8. Manoharbagh: Near CPWD Office: 30°33'23.6"N 79°33'15.2"E, 1900m
9. Upper Bazar: Near Nagarpalika: 30°33'20.8"N 79°33'42.9"E, 1900m
10. Sunil: Near Shivalik Cottage: 30°32'48.3"N 79°33'34.3"E, 2250m
11. Parsari: Near AT Nala: 30°32'04.8"N 79°35'17.4"E, 2120m
12. Ravigram: Near Helipad in Front of NTPC Gate: 30°32'56.4"N 79°34'36.3"E, 1940m

The testing sites are so selected such there is sufficient space available for carrying out various tests, while it also represents typical conditions existing in the ward considered and situated near to some damaged building / structure.

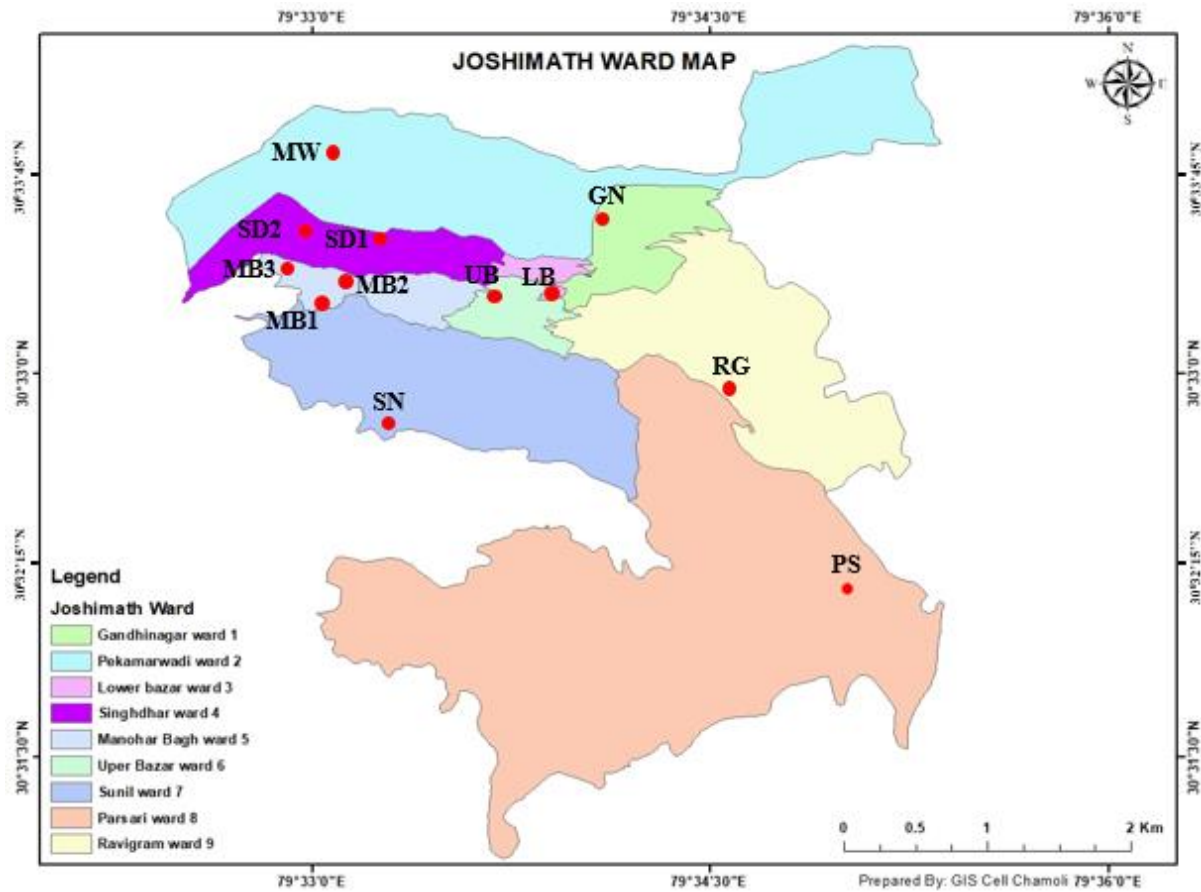


Fig. 1: Location of sites for geotechnical investigations in all 9 wards of Joshimath

This report contains the details of following six tests:

6. Plate Load Tests (PLT)
7. Dynamic Cone Penetration Test (DCPT).
8. Direct Shear Test (DST) in field
9. MASW Tests: Multi-channel Analysis of Surface Waves along with HVSr.
10. Natural Moisture Contents (NMC) Tests
11. Grain Size Distribution (GSD) Analysis

In next sections, a brief detail about above six tests are given, followed by the tests results for all the 12 sites. Next, summary and conclusions based on the results of field tests are discussed. At the end in Appendix, photographs of field tests in Joshimath are included.

1. PLATE LOAD TEST (IS 1888: 1982)

For designing shallow foundations, it is necessary to know the bearing capacity of soil at the desired depth. The plate load test (PLT) is performed on-site to determine the ultimate bearing capacity of soil at the desired depth. Data from the plate load test is helpful to confirm the design assumptions made from soil tests or can be used as a design parameter. *The plate load test* is a field test, which is performed to determine the ultimate bearing capacity of the soil and the probable settlement under a given load. This test is very popular for the selection and design of the shallow foundation.

For performing this test, the plate is placed at the desired depth, then the load is applied gradually and the settlement for each increment of the load is recorded. At one point settlement occurs at a rapid rate, the total load up to that point is calculated and divided by the area of the plate to determine the **ultimate bearing capacity** of soil at that depth. The ultimate bearing capacity is then divided by a safety factor (typically 2.5~3) to determine the **safe bearing capacity**.

Procedure

A semi-direct method of determining bearing capacity in the field is by conducting a plate bearing test according to the procedure laid down by IS:1888-1982. The method of performing the test is as follows:

- (i). The test is performed on a rough mild steel plates of 300 mm size, square in shape.
- (ii). A pit of dimension not less than five times the width of plate is excavated up to the anticipated depth of foundation. If water table is above the level of foundation, pump out the water carefully and it should be kept just at the level of foundation. The ground should be levelled and the test plate is seated over the ground at the centre of the pit.
- (iii). The load on the plate is applied either by gravity loading or reaction loading. The settlement of the plate is measured by a set of four dial gauges placed near each corner of plate. The dial gauges are fixed to independent supports which do not get disturbed during the test. A typical set-up of plate load test is shown in **Fig. 2**.
- (iv). A seating load of 7 kN/m^2 is first applied and released after some time. Loads are applied on the test plate in increments of one-fifth of the estimated safe load up to failure or at least until a settlement of 25 mm, whichever is earlier. The readings of the settlement dial gauges for each increment of the load are recorded after these become sensibly constant. An average of these three readings is taken as the settlement of plate for applied load.

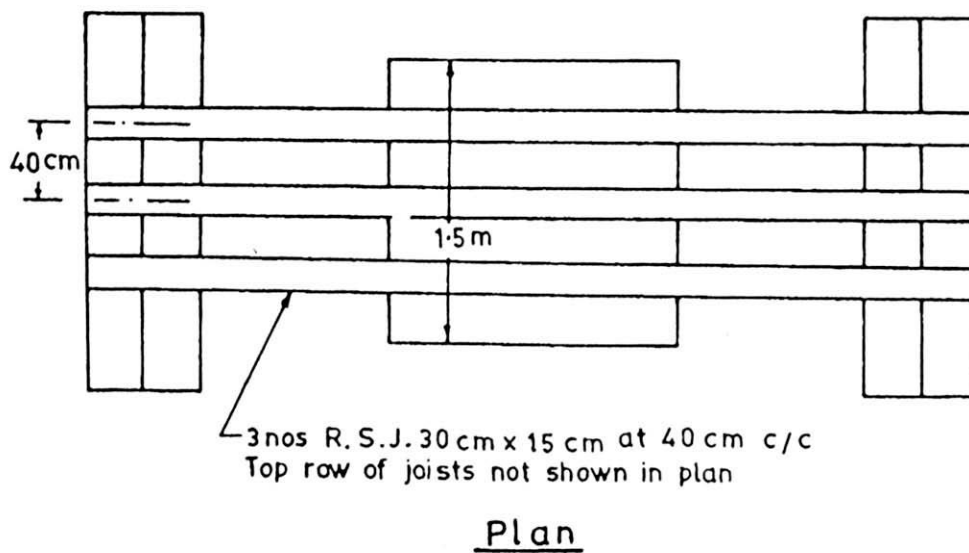
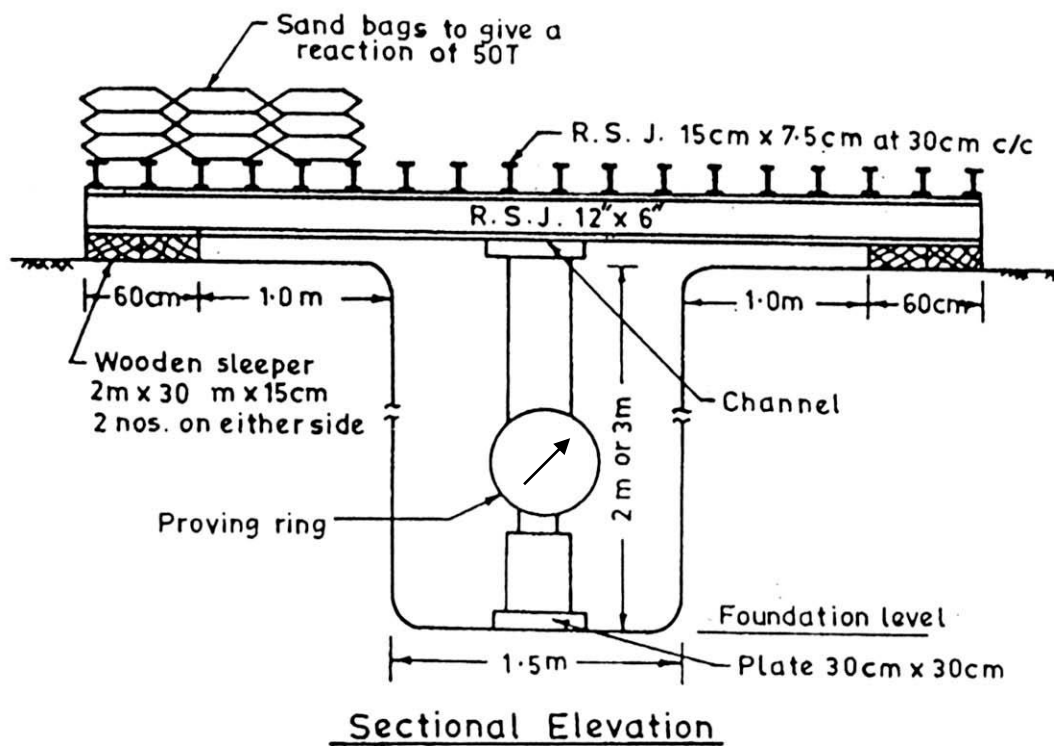


Fig. 2: Test Set Up for Vertical Plate Load Test

2. DYNAMIC CONE PENETRARTION TEST (IS 4968: 1992)

The dynamic cone penetration test (DCPT) is a test carried out to find the resistance value of the cone against the soil that helps us to determine bearing capacity of soil. It also gives an idea about the thickness of sub-layers of the soil, the condition of granular layers. DCPT consists of a standard-diameter steel rod, a hardened conical tip, and a hammer. The basic principle of this test is to measure the resistance offered by the soil layers to the cone used for conducting the test. It offers certain advantages over other methods. This test does not need a borehole. This test can be performed quickly so that it covers a large area making it economical.

Procedure: a 50-mm diameter 60° cone fitted to the driving rod (A rod) through an adopter is driven into the soil by blows of 65 kg hammer falling freely from a height of 750 mm (IS: 4968-1980, Part I). Assembly of test equipment for DCPT is shown in **Fig. 3**. The blow count for every 100 mm penetration of the cone is continuously recorded. The cone is driven to the required depth or refusal. The drill rods are withdrawn leaving the cone behind in the ground. The number of blows required for 300 mm penetration is termed as the dynamic cone resistance, N_{cd} . The test gives a continuous record of N_{cd} with depth. In this test no sample can be obtained.

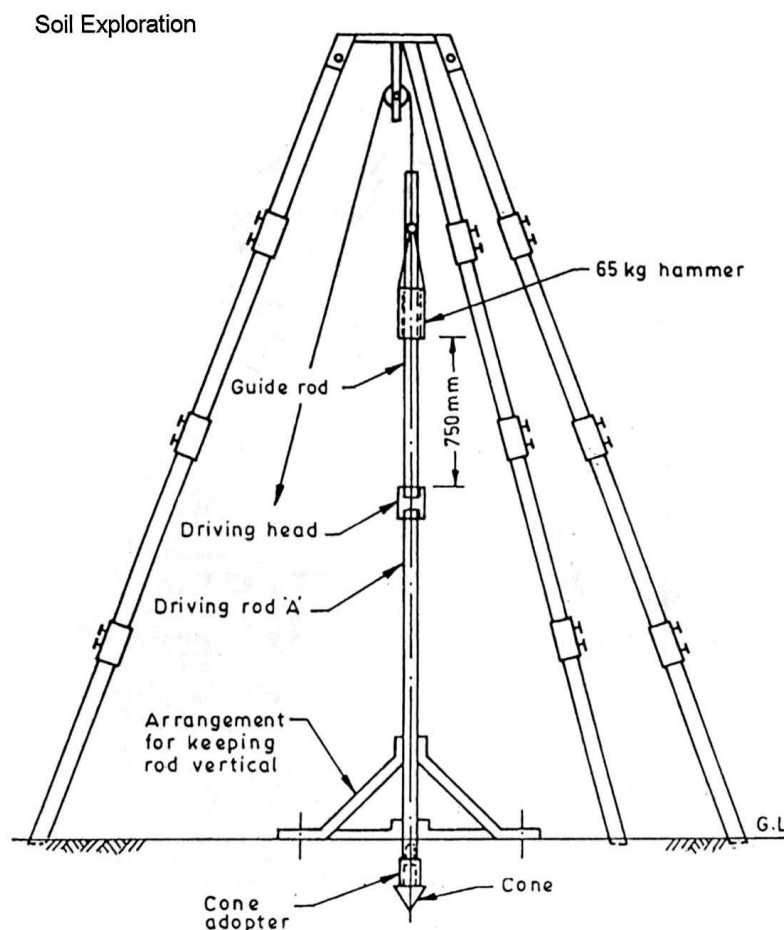


Fig. 3: Typical Assembly for Cone Penetration Test

3. FIELD DIRECT SHEAR TEST (IS 2720, Part 13, 1986 & IS 7746, 1991)

In many engineering problems, such as the design of foundations, retaining walls, slope stability assessment, the value of the angle of internal friction and cohesion of the soil involved are required for the design. In-situ direct shear testing is a method to evaluate the shear strength of soil in its natural state, without the need to remove and transport soil samples to a laboratory. This test is particularly useful for evaluating the shear strength of weak as well as cohesionless soils, where sample disturbance during sample collection can significantly alter the soil's strength parameters.

Testing Procedure: The in-situ direct shear test is a useful method for evaluating the shear strength of soils in their natural state. The tests were conducted as per IS 2720-13(1986). Test were conducted using Kentledge method. The test involves placing a shear box on a levelled surface, collecting a soil sample in the box, applying a normal stress weight, and shearing the soil sample while recording the shear force and displacement. The shear strength parameters of the soil are then calculated based on the recorded data. Details of the testing and test-set up (Fig. 4) are given below:

Kentledge: The kentledge for taking reaction was provided on a platform consisting of RSJs (steel girders) supported clear of pit to be tested, by placing about 300 bags full of sand, each weighing about 35kg, such that the centre of gravity was generally on the axis of the shear box and also coaxial of the load applied by the jack.

Load Applying Equipment: A hydraulic jack of 25 ton capacity, having least count of 100kg was used to load the pile. The jack was controlled by pump having 3.0m long flexible pipe, so that loading could be done from outside of the loading platform. To measure load, proving rings of 10 ton capacity were used, having a least count of 15kg to measure normal load as well as shearing load.

Measurement of Settlement of Plate: The settlement was measured by means of four dial gauges having a travel of 40mm and least count 0.01mm. The dial gauges were fixed to the steel plate kept on the soil top, by means of magnetic bases, the tips of the gauges were resting on datum bar, which was fixed to immovable supports clear of test plate.

Application of Normal Load on Box: The normal load on the box was applied on plate of size 300mm x 300mm in case of small shear box and 700 mm x 700mm in case of large shear box, kept in the box. The settlement of plate was measured by dial gauges provided. The load was maintained till the settlement of the plate became stationary.

Application of Shearing Force: The shearing force on the box was applied on the plate welded on channel of box of size 300mm x 300mm or 700mm x 700mm and the horizontal movement of the box of plate was measured by dial gauges provided. The load was maintained till the movement of the plate became stationary. The loading on box was continued till failure was observed.

A schematic diagram of field direct shear test is shown in **Fig. 4**.

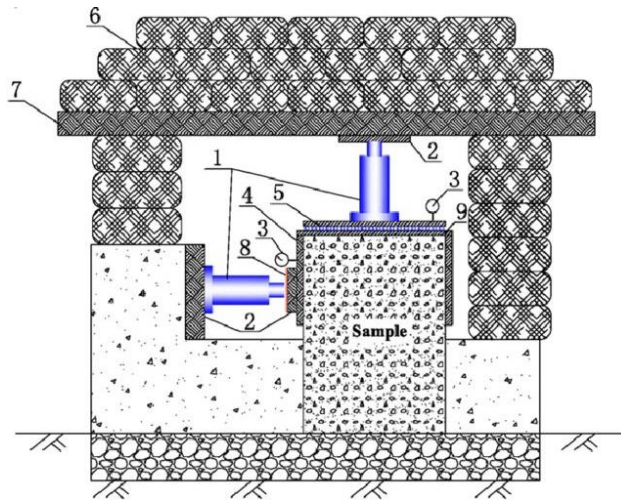


Fig. 4: Schematic diagram illustrating the test setup for large-scale direct shear test (Xu et al. 2011)

Note: 1-jacks; 2-crosstie; 3-dial indicator; 4-shear box; 5-sliding steel plate; 6-backpressure system; 7-beam; 8-slideway; 9-bearing plate

4. MASW & HVSr Studies

One of the objectives of the study is to investigate the stiffness variations of the shallow subsurface strata, which would be responsible for bearing capacity of the foundations of structures. In this study, the shallow subsurface stiffness of the layers is estimated using MASW and HVSr. The near surface S-wave velocity (V_s) was estimated using the joint inversion of MASW and HVSr. These methods are based on the measurement and analysis of the seismic waves (Kramer 1996).

The **MASW** method utilizes the dispersive nature of Rayleigh type surface waves to characterize materials in a very wide range of scales. Data were recorded using a multichannel seismic system with a linear array of 4.5 Hz vertical-component geophones. Theoretically minimum wavelength and depth resolution are governed by the spacing of geophones, whereas the maximum wavelength and depth of penetration are controlled by the geophone resonant frequency and spread length.

We used 9-channel system with 2m and 5m geophone spacing for a spread length of 16m and 40 m, respectively (**Fig. 5**). The first geophone from source is used as trigger. Soil Spy Rosina was used as a data acquisition system, which is a hardware and software platform of multichannel digital system for active and passive seismic surveys. It allows the user to set the acquisition parameters, view the recordings, and also pre-process the data. Data can be acquired in two different modes: (1) continuous mode and (2) trigger mode (fixed duration recording). For this study, we recorded continuous as well as fixed duration stacked data to achieve best possible dispersion curve. The record length was kept at 2s to 4s based on spread length and the sample interval was kept at 1 m (1000 Hz). In each record, twelve blows were stacked. Recording was started 0.128 s prior to trigger. Wooden hammer was used as a source. Source to first receiver spacing was kept between 4m to 5 m. Hammer strikes are not directly given on ground. Aluminium plate was used. The weight of the wooden mallet was 10 kg. Hammer blows were given vertically on the respective plates. Twelve blows were given at both the ends of the array and records were stacked separately. This helps in eliminating effect of heterogeneity conditions existing along the array/spread-length.

HVSr: MASW can provide data only up to shallow depths, though it is extremely popular. To estimate soil condition at deeper depths, horizontal-to-vertical spectral ratio (HVSr) method has been used jointly with MASW test results. In a single layer one-dimensional (1D) stratigraphy, the analysis of the H/V of the micro tremor allows us to measure the principal S-wave resonance frequency, f of the sedimentary cover overlying an infinite bedrock with reasonable accuracy. Without any constraint, an H/V curve can be fitted by an infinite number of synthetic models. By using joint inversion of HVSr and MASW, two objectives are achieved: (i) solutions get constrained and (ii) information of deeper layers is obtained. It is a single station method, which requires only one 3-component seismic recorder.

In the current study, microtremor data were collected using Micromed Tromino as shown in **Fig. 6**. Tromino has three channels connected to three orthogonal electrodynamic velocity meters with selectable gain for seismic tremor acquisition (Micromed, 2012). Microtremor vibrations were recorded for 30 minutes at each location at a sampling rate of 256 Hz for HVSr analysis.

Data Processing: Surface wave data processing was performed using software Grilla, which allows us to analyze the recordings from Soil Spy Rosina and Tromino. In that, we can

generate dispersion curves from the records of Soil Spy Rosina, and HVSR curves from the records obtained from Tromino. For MASW, data was processed for one record at a time. The experimental MASW data was given as input in Grilla and the dispersion curves of the sites were obtained after processing. In most of the active-source (MASW) surveys, dispersion curves can be picked from a minimum frequency of 5–10 Hz to a maximum frequency of 30–50 Hz.

In case of the Tromino data, HVSR was computed from the tri-axial record obtained. Each record was partitioned into 60s time windows hence providing 30 time windows for the generation of HVSR spectra. Mean HVSR of both the horizontal components is calculated from each window. Subsequently, all the 30 HVSRs are smoothened using Konno-Omachi window with a bandwidth of 20% and mean of all these 30 smoothened HVSRs is presented as final HVSR.

Finally, using the joint fit module of the software Grilla, the dispersion curve generated from dispersion curve module and H/V curve from H/V module were put together, the V_s model was obtained. HVSR curve obtained from microtremor recordings & dispersion curves extracted from MASW test are shown.

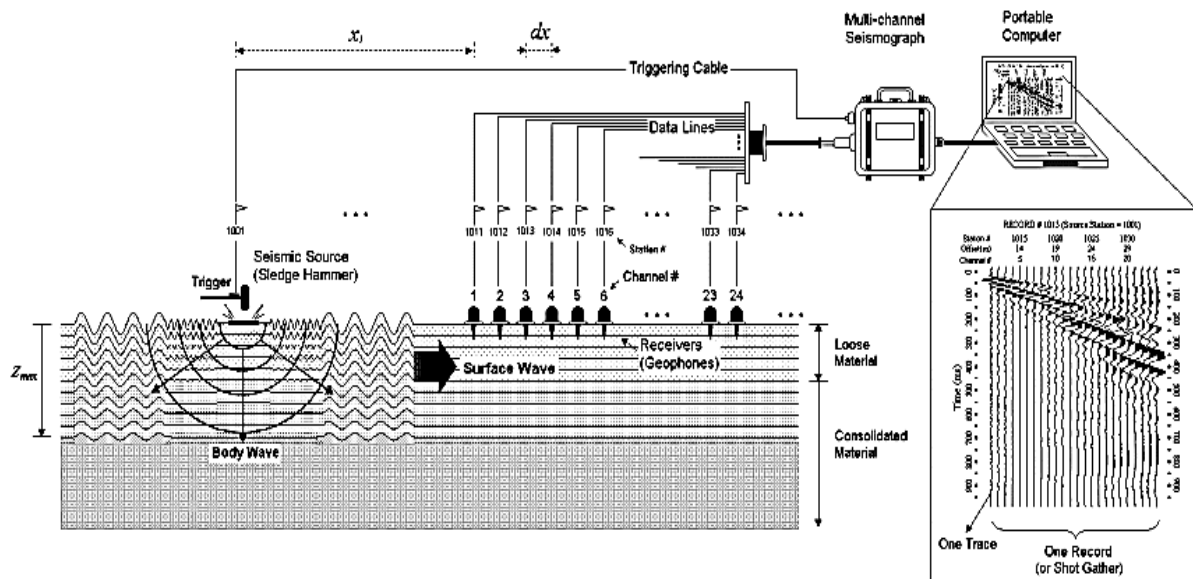


Fig. 5: Array setup for MASW testing (Park & Miller, 2004)



Fig. 6: Micromed Tromino for recording microtremors

5. Natural Moisture Content (NMC)

The natural moisture content also known as water content (w) is determined for all the samples collected from the field. Natural moisture content is the ratio of the weight of water to the weight of the solids in a given mass of soil. This ratio is usually expressed as percentage. "Oven Dry method" is followed to find the moisture content of soil samples as per the IS 2720 (Part-2)-1973. Samples collected in the field at different depths were properly sealed and transported to geotechnical laboratory, Soilex Consultants, Roorkee where the water content of the samples were determined.

6. Grain Size Analysis

Grain size analysis is a typical geotechnical laboratory test conducted to derive the particle size distribution of soils (IS 2720 – Part 4). Particle size distribution of samples helps in the classification of the soils. The data obtained from grain size distribution curves is used to determine the suitability of soil for construction of roads and foundations. The analysis is conducted via two techniques: Sieve analysis for soil fraction $+75$ micro-m, and Hydrometer analysis for soil fraction -75 micro-m. Sieve analysis is carried out with the utilization of a set of sieves with different mesh sizes. The test is conducted by placing a series of sieves with progressively smaller mesh sizes on top of each other and passing the soil sample through the stacked sieve "tower". A pan is also used to collect those particles that pass through the last sieve (75 micro-m).

Site 1: Gandhinagar, Near Govt. P.G. College

1.1: Plate Load Test (PLT) Results

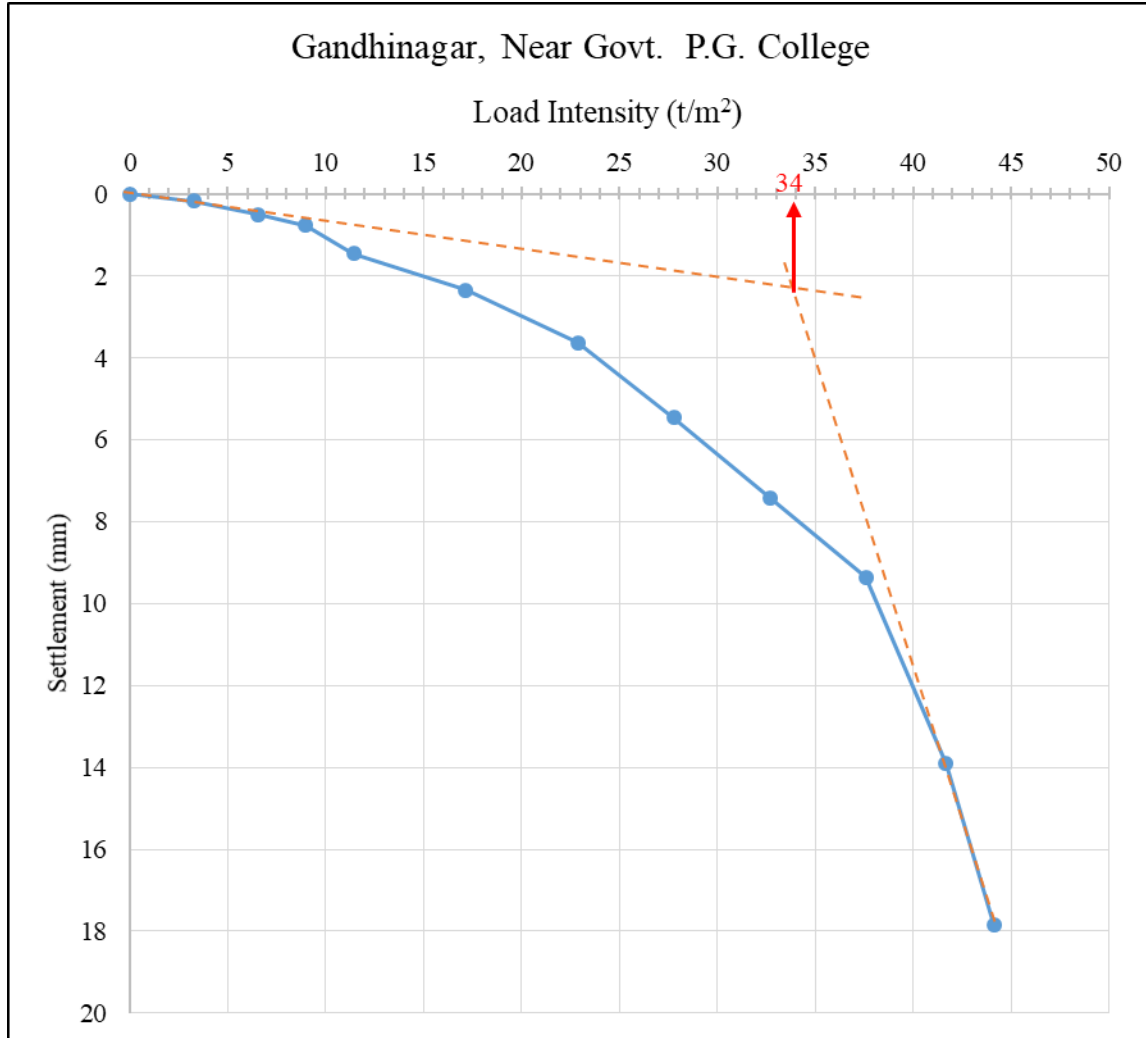


Fig. 1.1: PLT Result for Gandhinagar, near Govt. P.G. College

Analysis of **Fig. 1.1** using asymptotes yields a minimum failure load as 34 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 11.33 t/m^2 .

1.2: Dynamic Cone Penetration (DCPT) Results

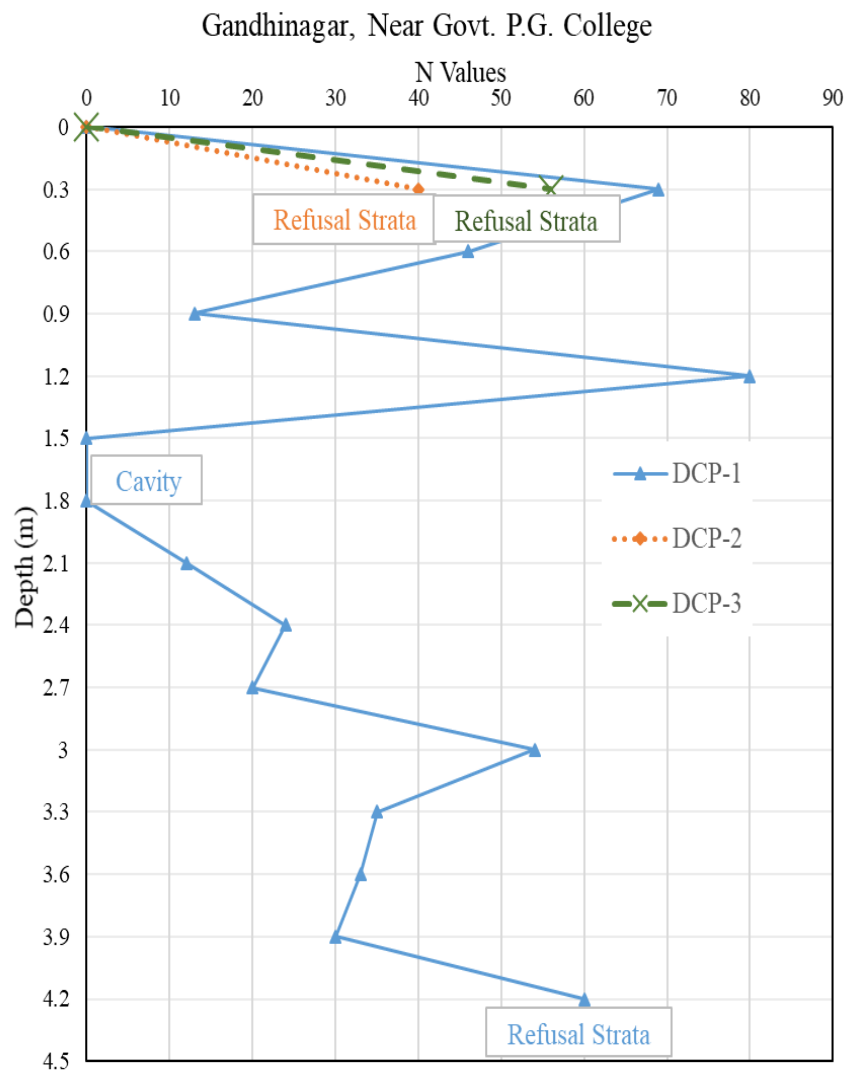


Fig. 1.2: DCPT Results for Gandhinagar, near Govt. P.G. College

In **Fig. 1.2**, Values of cone resistance is varying very much and indicating some cavities between depth 1.5 m to 2.1 m. At a depth of 1.2m, number of blows (N_{cd}) is 80. Due to refusal; cone could not be penetrated beyond 4.2 m as number of blows reaches 100.

1.3: Direct Shear Test (DST) Results

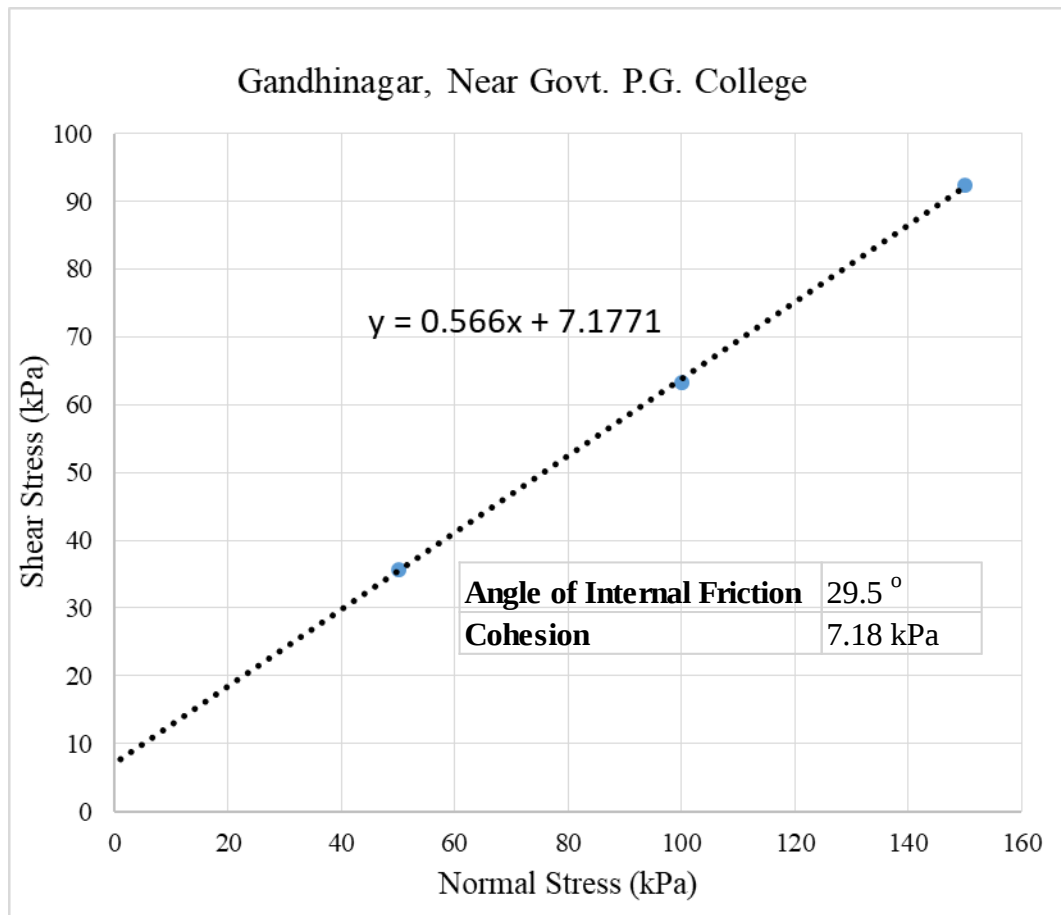


Fig. 1.3: DST Results for Gandhinagar, near Govt. P.G. College

From the result of direct shear test done at site having size 300 mm × 300 mm as shown in **Fig. 1.3**, the angle of internal friction of soil and cohesion are 29.5° and 7.18 kN/m², respectively.

1.4: MASW Test Results

Figs. 1.4 and 1.5 show the test results of Gandhinagar site. **Fig. 1.4(a)** shows dispersion curve extracted from the measurements of MASW, while **Fig. 1.4(b)** shows the HVSR curve obtained from the recordings of Micro-tremor.

Dispersion curves are found to be having high scatter in the image. In fact, scattering is observed even from very high frequencies, which is not common in regular soil strata. As noted later in the GSD analysis and field observations, the soil is a complex mixture of variable sizes of boulders, gravel and sands. The presence of boulder and large size gravel is responsible for such phenomenon. The wave velocity varies in different materials. Further, impedance contrast between boulders and soil is leading to multiple reflections and refractions, thus leading to very high scatter in the data.

HVSR curve is also found to be very peculiar as compared to regular soil site. No clear peak is observed even at low frequencies. This implies that no clear contrast strata is present even at greater depths. This further suggests that similar strata as seen at shallow depths may extending to greater depth.

Gandhinagar, near Govt. P.G. College

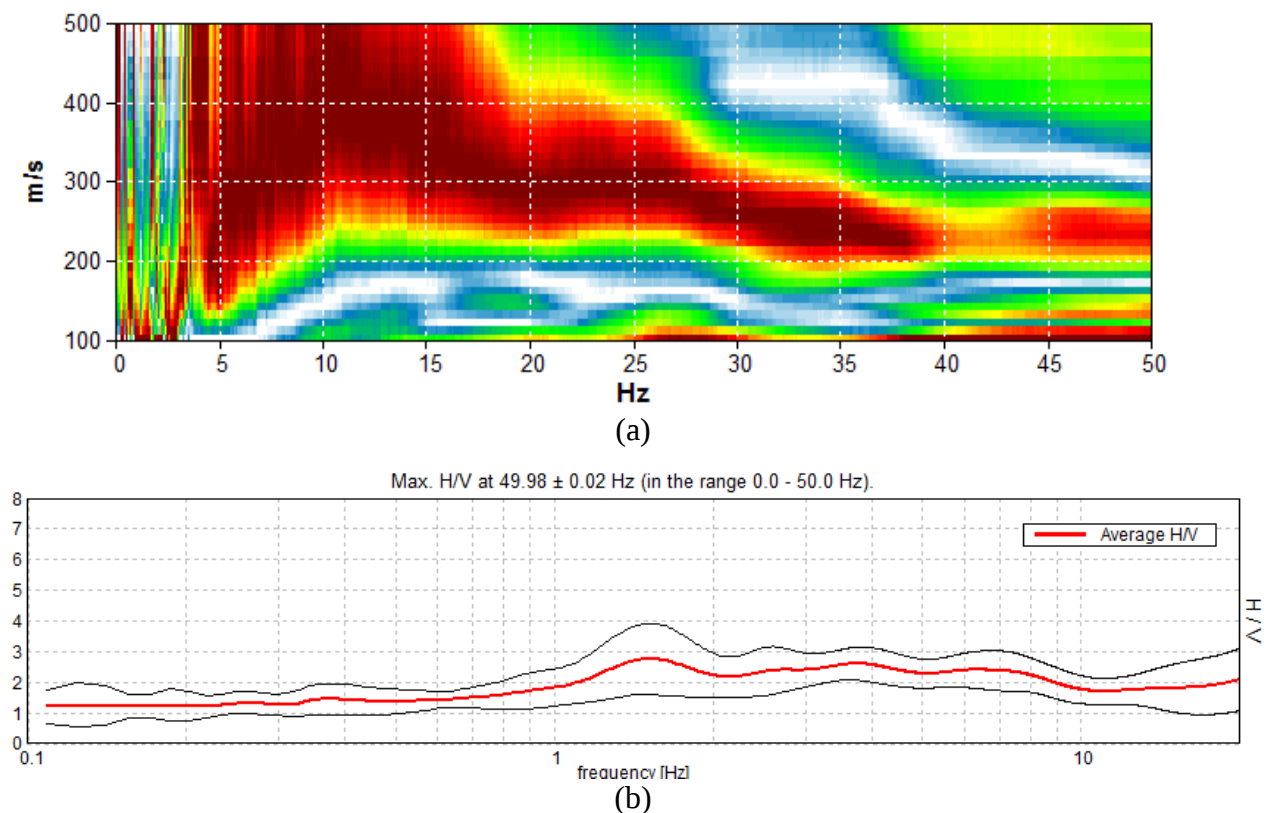


Fig. 1.4: (a) MASW & (b) HVSR Test Results for Gandhinagar, near Govt. P.G. College

Based on the extensive analysis, the best fitting soil profile has been obtained and presented in **Fig. 1.4**. It can be observed from **Fig. 1.5**, the Shear Wave Velocity (V_s) for Gandhinagar site lies in the range of 260 to 550 m/s up to a depth of 26m.

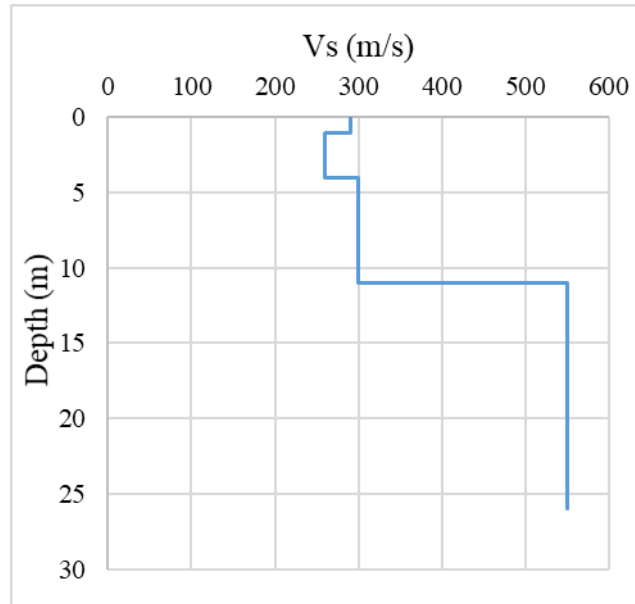


Fig. 1.5: Shear Wave Velocity Obtained at Gandhinagar, near Govt. P.G. College

1.5: NMC Results

Water content of the soil samples collected from PG College, Gandhinagar at depths of 0.5m, 1.5m, 3m and 4m are given in **Table 1.1**

Table 1.1: Natural moisture content of the soil for Gandhinagar, near Govt. P.G. College

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 28-01-2023		
Sampling location	Gandhinagar, Near Govt. P.G. College	
S.no	Depth (m)	Water content (%)
1	0.5	4.75
2	1.5	3.97
3	3	8.14
4	4	7.19

1.6: Grain Size Distribution Analysis

Results obtained from sieve analysis of samples collected from PG College, Gandhinagar is provided in **Table 1.2**. It is found from all the samples that the fraction below 75 micro-m is not significant. Therefore, no hydrometer analysis was carried out. Based on the grainsize analysis, the samples are predominantly found to be Gravelly Sands. Further, the soil samples are found to be non-plastic.

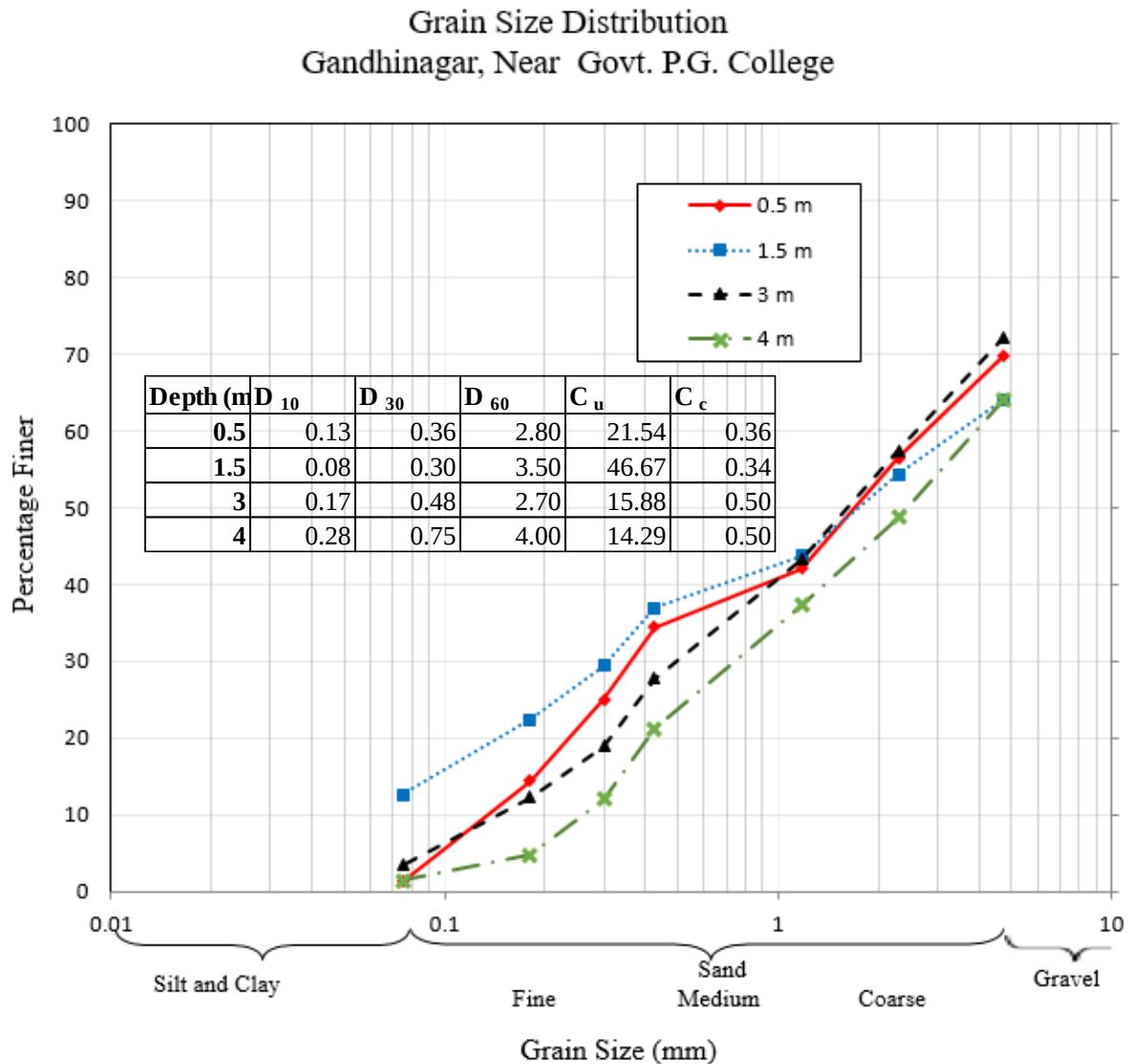


Fig. 1.6: Grain size distribution for Gandhinagar, near Govt. P.G. College

1.7: Summary of all the Results

Table 1.3: Summary of the soil properties for Gandhinagar Site, near Govt. P.G. College

LABORATORY TEST REPORT ON SOIL SAMPLES													
SAMPLING LOCATION:			Gandhinagar, Near Govt. P.G. College										
Depth (m)	IS Classification	N.M.C. %	Grain Size Analysis %			PL	Curv. Cu	Coeff. Cc	DD γ_d (kN/m ³)	Spec. Gravity	Void Ratio %	Shear Parameters	
			Gravel	Sand	Fines							c (kN/m ²)	ϕ (°)
G.L.													
0.5	SP	4.75	30.20	68.56	1.24	NP	21.54	0.36	14.99	2.68	78.81	-	-
1.5	SP	3.97	35.92	51.46	12.62	NP	46.67	0.34	15.10	2.68	77.47	7.18	29.5
3	SP	8.14	27.78	68.75	3.47	NP	15.88	0.50	14.52	2.68	84.59	-	-
4	SP	7.19	35.89	62.75	1.35	NP	14.29	0.50	14.65	2.68	82.98	-	-

1.8: Overview of the Site

Test site is located near the entrance gate of Govt. P.G College, Gandhinagar (Ward 1). All the proposed field tests, Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT), Direct Shear Test (DST) and Multi-channel Analysis of Surface Waves (MASW) along with HVSR were conducted at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) analysis were also conducted on the samples procured from the field. Standard Penetration Tests (SPT) couldn't be conducted due to the presence of gravel/boulders everywhere.

Plate load test was conducted at a depth of 1.5m using a plate size of 300mm x 300mm. Load-settlement curve obtained is appeared to be normal to typical soil mixtures. Ultimate and safe load carrying capacities of the soil are found to be 34 t/m² and 11.33 t/m² respectively from the plate load test results.

Interesting facts are noticed from DCPT tests. DCPT test is repeated three times due to the difficulties encountered during the testing. Initial two DCPT tests were conducted only up to 0.3m due to the refusal strata. However, third test conducted slightly 1m away from the initial two tests, went up to 4.5m. This is typical situation encountered in all most all test sites in Joshimath. It is primarily because of presence of boulders and gravel along with soil. From the field excavations and sampling, it is clearly noticed that subsurface strata consists of mixture boulders, gravels and soils. Further, it is observed that there are some cavities even at shallow depths within 2m. Third DCPT reported no soil resistance between 1.5m to 1.8m. overall soil resistance is found to be varying from 0 to 80 indicating high degree of heterogeneity at the testing site.

Field direct shear tests of size 300mm x 300mm were conducted at three normal stresses. The angle of shearing resistance and cohesion are found to be 29.5° and 7.2 kPa respectively from the direct shear tests.

MASW tests were conducted along with the HVSR. Dispersion image obtained from MASW testing is found to be having very high scatter. In fact, scattering is observed even at high frequencies, which is not common in regular soil strata. This scatter is ascribed to the complex mixture of variable soil particular sizes. The presence of boulder and large size gravel is responsible for such phenomenon. The wave velocity variations in different materials and the impedance contrast between boulders and soil is leading to multiple reflections and refractions, thus leading to very high scatter in the data. The Shear Wave Velocity (Vs) for Gandhinagar site lies in the range of 260 to 550 m/s up to a depth of 26m. HVSR curve is also found to be very peculiar as compared to regular soil sites. No prominent peak is observed even at low frequencies. This implies that no clear contrast strata is present even at greater depths. This further suggests that similar strata as seen at shallow depths may extending to greater depths. Natural Moisture Content of the field samples is found to be varying between 4 to 8.2%. GSD analysis conducted on samples collected from 0.5 to 4m depths revealed that the soils are predominantly Gravelly Sands. Further, soils are found to be non-plastic.

Concluding Remarks: Based on PLT, the site is having fare enough bearing capacity. The DCPT results indicates high degree of variability in soil resistance. Reduction in DCPT values are observed between 1.5m to 3m, particularly no resistance is observed between 1.5m to 1.8m due to the presence of cavity. Similarly, low soil stiffness is observed between 1.5m to 3.5m from MASW test results. Field tests results are in support of field damages observed. In the field, not much sever damage was observed, only minor cracks were visible in the ground.

Site 2: Marwadi: Near gate of Jaypee Colony

2.1: Plate Load Test (PLT) Results

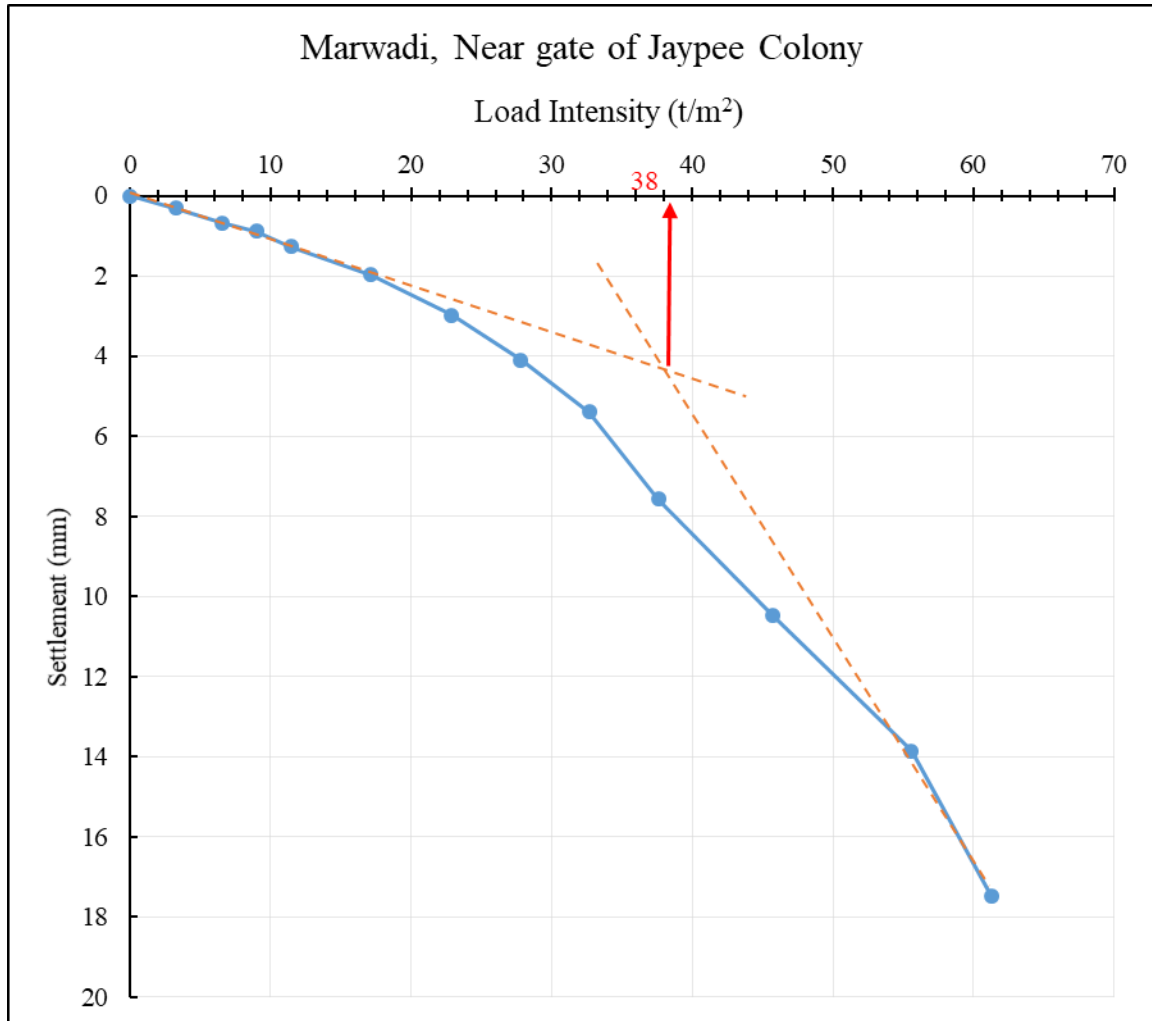


Fig. 2.1: PLT Result for Marwadi, Near gate of Jaypee Colony

Analysis of **Fig. 2.1** using asymptotes yields a minimum failure load as 38 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 12.67 t/m^2 .

2.2: MASW Test Results

Marwadi, Near gate of Jaypee Colony

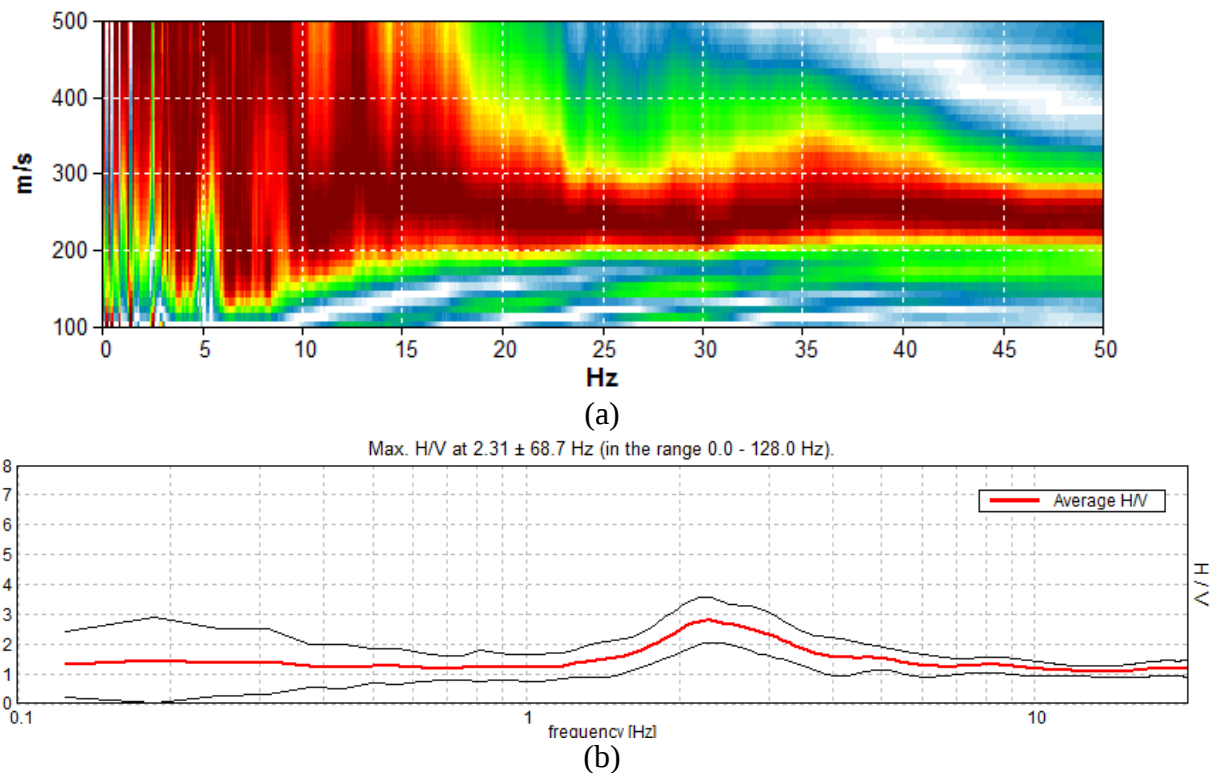


Fig. 2.2: (a) MASW & (b) HVSR Test Results for Marwadi, Near gate of Jaypee Colony

Based on the analysis, the best fitting soil profile has been obtained and presented in **Fig. 2.2**. It can be observed from **Fig. 2.3**, the Shear Wave Velocity (V_s) for Marwadi, Near gate of Jaypee Colony lies in the range of 250 to 490 m/s up to a depth of 35m.

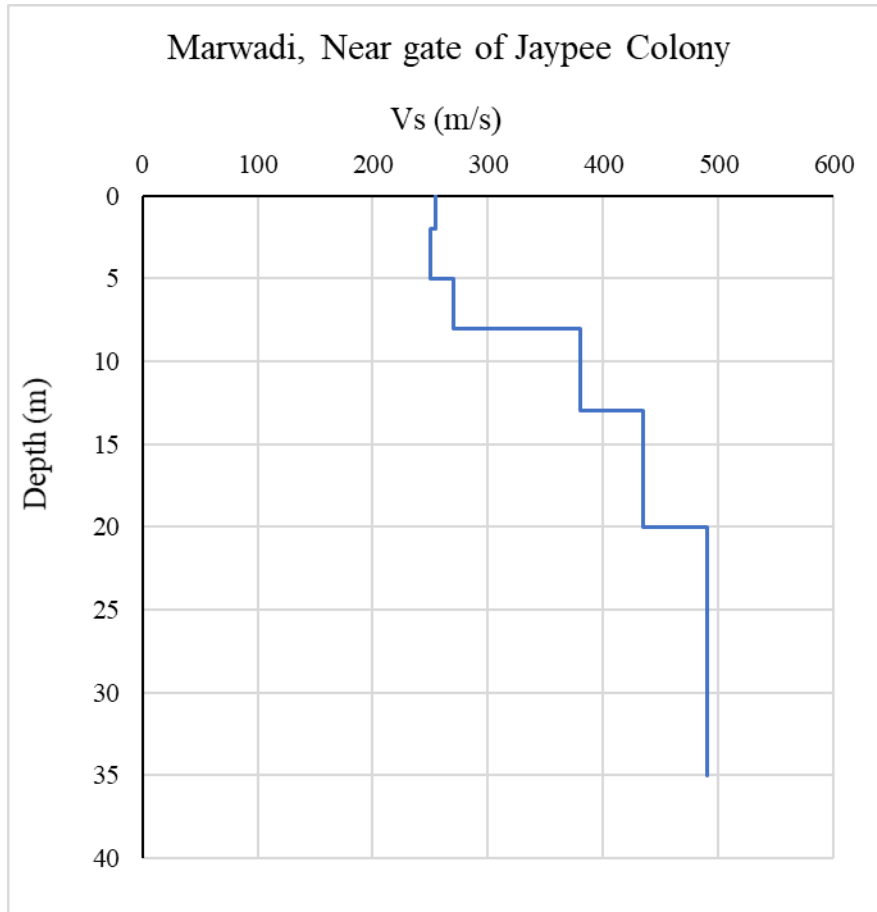


Fig. 2.3: Shear Wave Velocity Obtained at Marwadi, Near gate of Jaypee Colony

2.3: NMC Results

Water content of the soil samples collected from Marwadi, Near gate of Jaypee Colony at depths of 1m, 2m, 3m and 4.3m are given in Table 2.1.

Table 2.1 Natural moisture content of the soil for Marwadi, Near gate of Jaypee Colony

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 20-02-2023		
Sampling location	Marwadi, Near gate of Jaypee Colony	
S.no	Depth (m)	Water content (%)
1	1	11.49
2	2	7.09
3	3	9.28
4	4.3	7.03

2.4: Grain Size Distribution Analysis

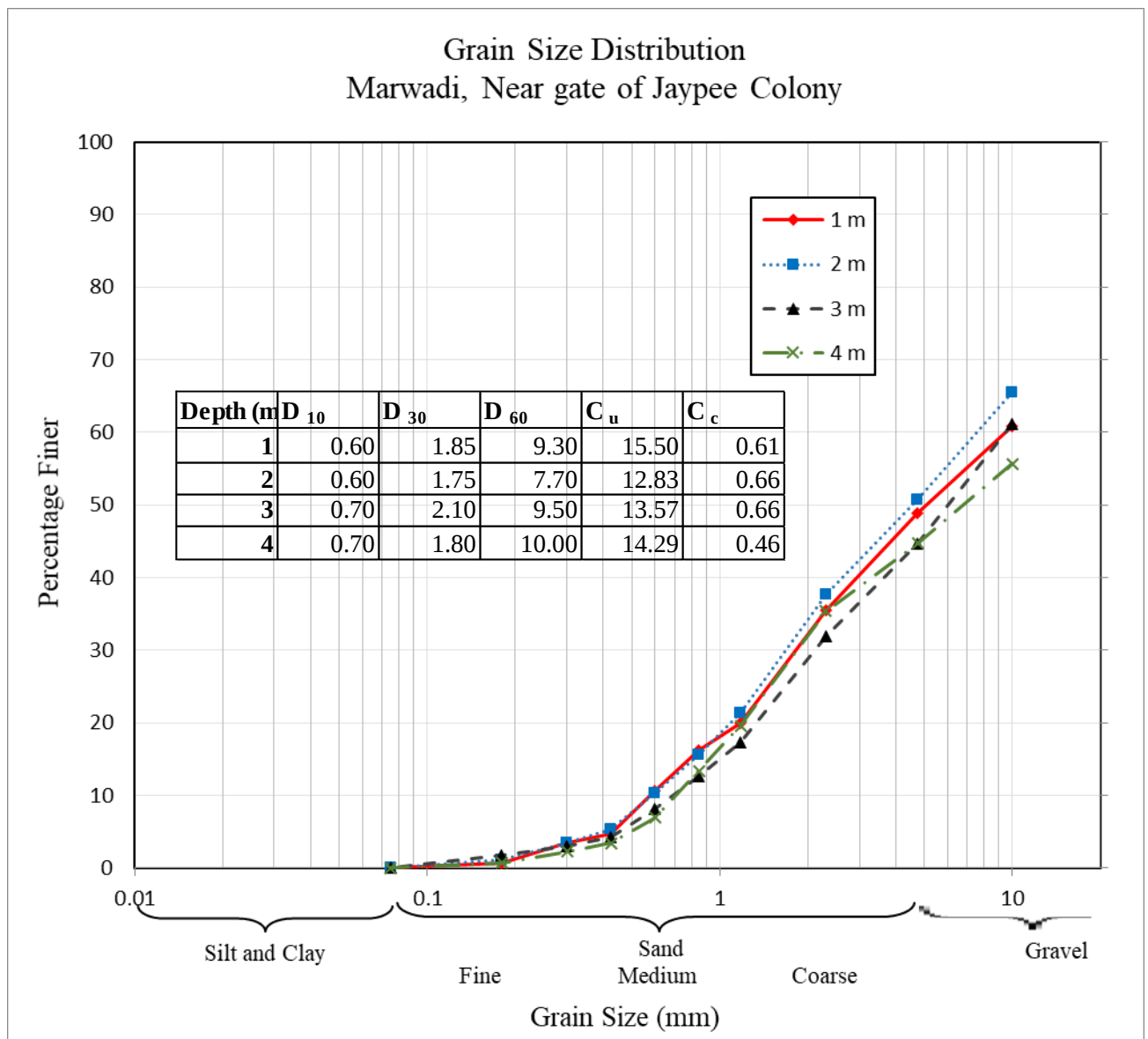


Fig. 2.4: Grain size distribution for Marwadi, Near gate of Jaypee Colony

2.5: Summary of all the Results

Table 2.2 Summary of the soil for Marwadi, Near gate of Jaypee Colony

LABORATORY TEST REPORT ON SOIL SAMPLES											
SAMPLING LOCATION:			Marwadi, Near gate of Jaypee Colony								
Depth (m)	IS Classification	N.M.C. %	Grain Size Analysis %			PL	Curv.	Coeff.	DD	Spec. Gravity	Void Ratio %
			Gravel	Sand	Fines		Cu	Cc	γ_d (kN/m ³)		
G.L.											
1	GP	11.49	51.15	48.85	0.00	NP	15.50	0.61	12.92	2.67	106.71
2	GP	7.09	49.34	50.66	0.00		12.83	0.66	13.45	2.67	98.56
3	GP	9.28	55.34	44.66	0.00	NP	13.57	0.66	13.18	2.67	102.62
4.3	GP	7.03	55.29	44.71	0.00	NP	14.29	0.46	13.45	2.67	98.46

2.6: Overview of the Site

Test site is located near main gate of Jaypee Colony in Marwadi (Ward 2). Initially, it was planned to conduct the tests within Jaypee Colony. Later, the site was selected a little far away below the gate of Jaypee Colony due to the accessibility issues of vehicle and space restriction. The Plate Load Test (PLT) and Multi-channel Analysis of Surface Waves (MASW) along with HVSR were conducted at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) analysis were also conducted on the disturbed samples collected from the field. DST and DCPT tests couldn't be conducted due to the presence of gravel/boulders in this site.

Plate load test was conducted at a depth of 1.5m using a plate size of 300mm x 300mm. The ultimate and safe bearing capacity of the soil are found to be 38 t/m² and 12.67 t/m² respectively from the plate load test results.

MASW tests were conducted along with the HVSR. Similar to the Gandhinagar site, the dispersion image obtained from MASW testing is observed to be having high scatter. Similarly, no prominent peak is observed even at low frequencies from HVSR. This implies that no clear contrast strata is present near the shallow depths. Shear Wave Velocity (V_s) lies in the range of 255 to 490 m/s up to a depth of 35m. Natural Moisture Content of the field samples is found to be varying between 7 to 11.5%. GSD analysis conducted on samples collected from 1 to 4.3m depths revealed that the soils are predominantly Gravelly Sands. Further, soils are found to be non-plastic.

Concluding Remarks: From the field test results, the soil is in medium dense condition having good bearing capacity. The damages to the structures would have not resulted from bearing failure of soils, rather due to subsidence of the ground. The subsidence observed here is primarily because of the internal erosion caused by the subsurface seepage as evident from the muddy waters emerging from the damaged retaining wall.

Site 3: Lower Bazar: Near Narsingh Mandir

3.1: Plate Load Test (PLT) Results

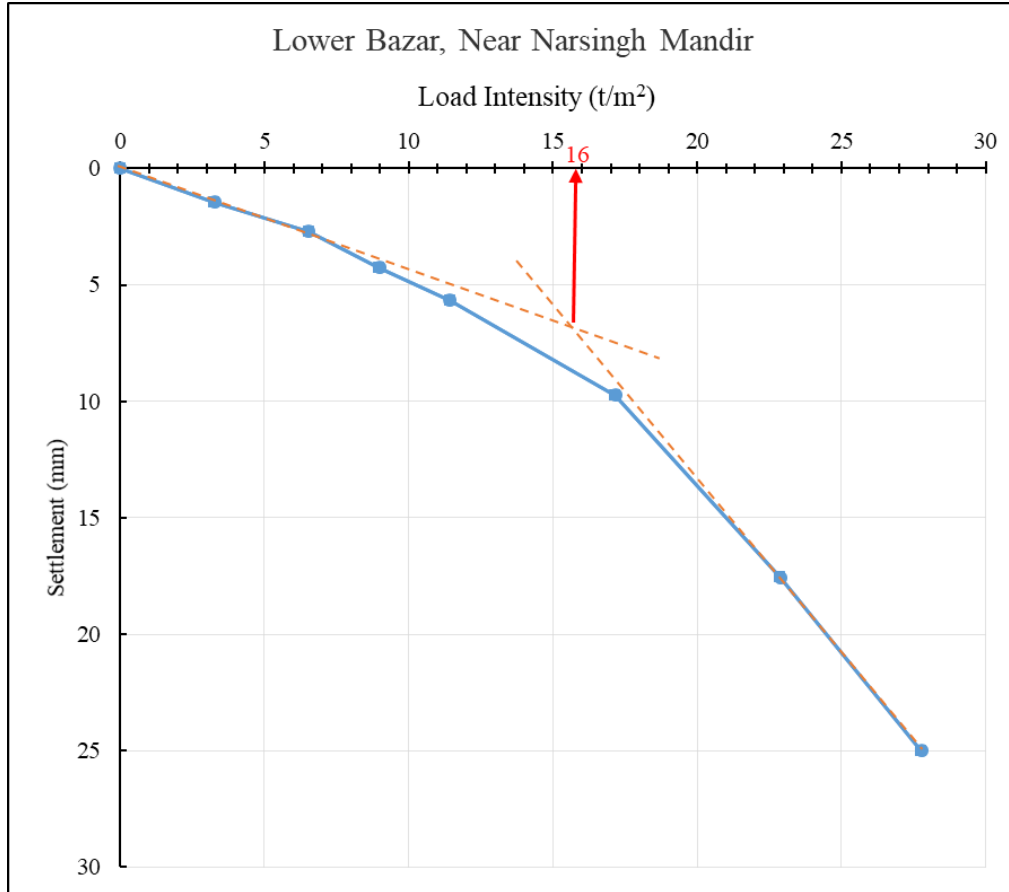


Fig. 3.1: PLT Result for Lower Bazar, Near Narsingh Mandir

Analysis of **Fig. 3.1** using asymptotes yields a minimum failure load as 16 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 5.33 t/m^2 .

3.2: Dynamic Cone Penetration (DCPT) Results

Lower Bazar, Near Narsingh Mandir

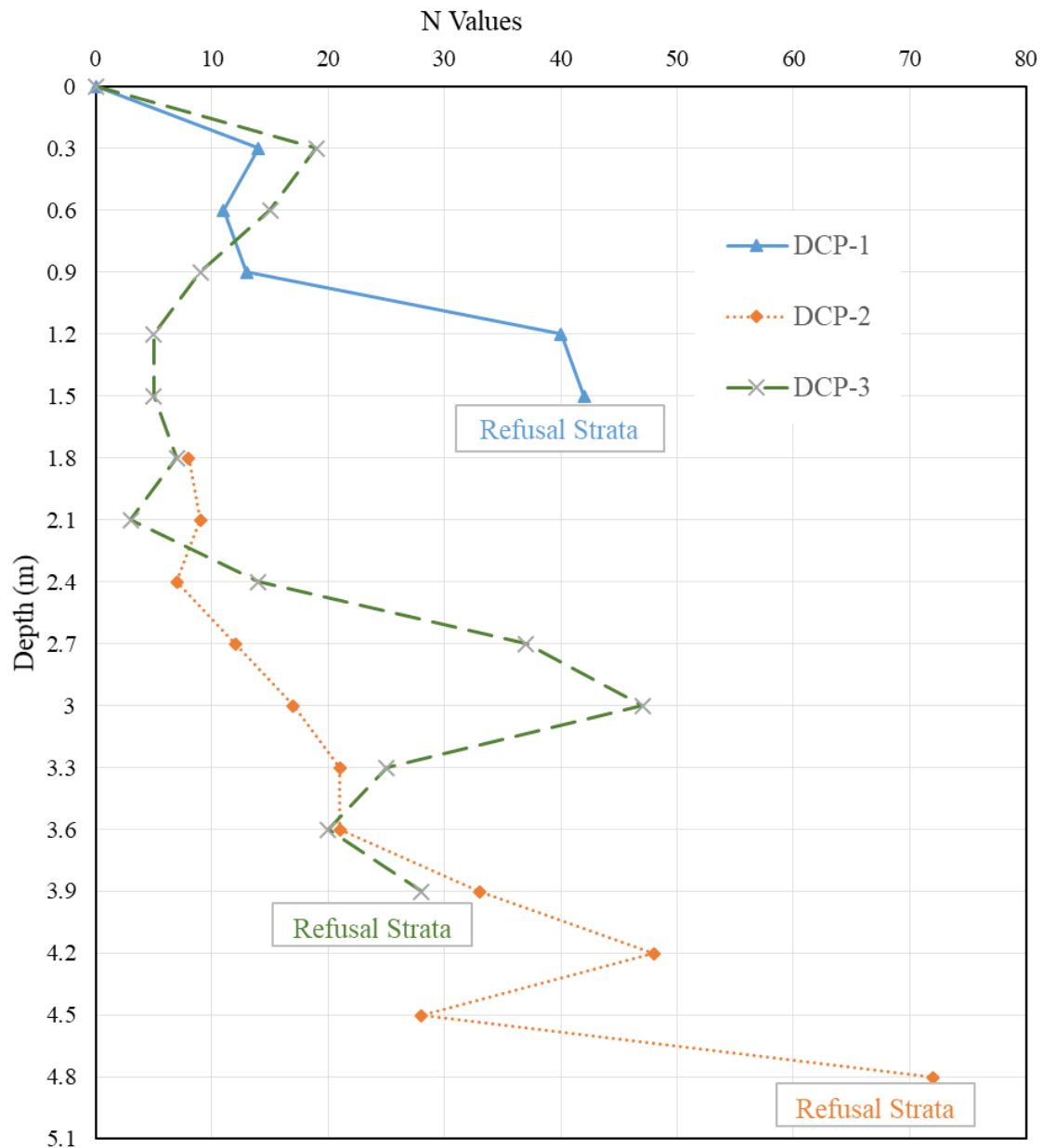


Fig. 3.2: DCPT Results for Lower Bazar, Near Narsingh Mandir

In **Fig. 3.2**, Values of cone resistance is varying very much. At a depth of 3m, number of blows (N_{cd}) in DCPT 2 is 18 and in DCPT 3 is 46 which is due to the presence of boulders. Due to refusal; cone could not be penetrated beyond 4.8 m as number of blows reaches 72.

3.3: MASW Test Results

Lower Bazar, Near Narsingh Mandir

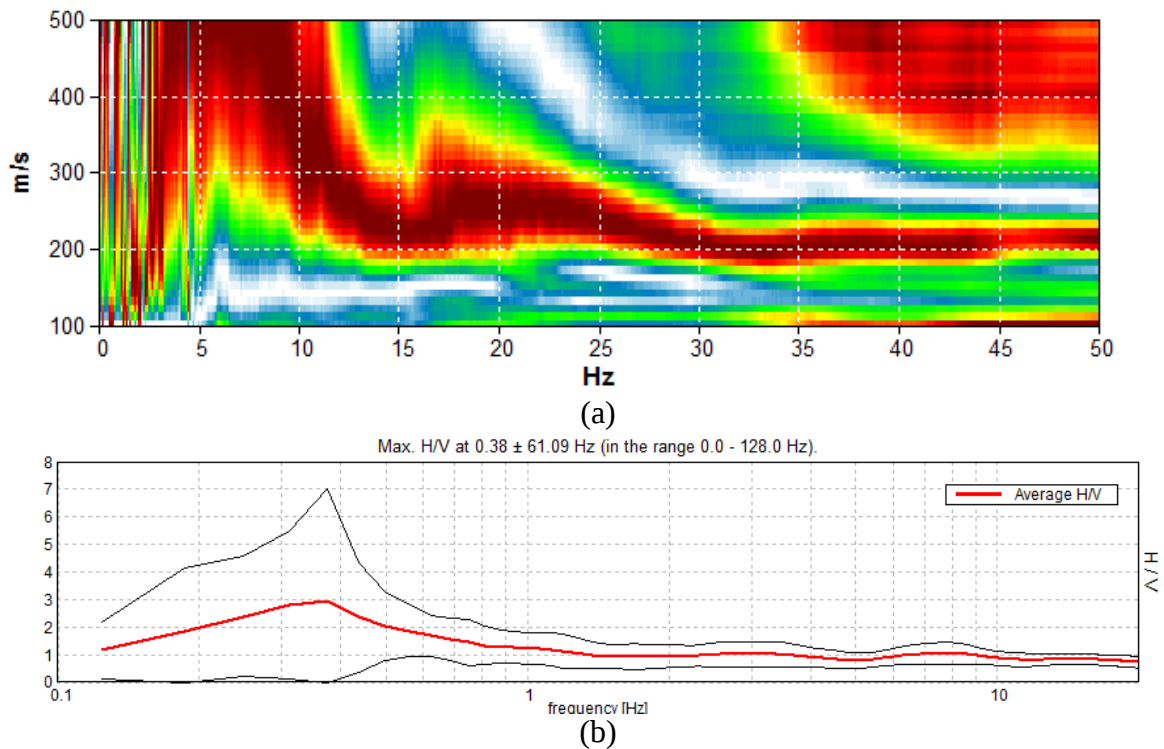


Fig. 3.3: (a) MASW & (b) HVSR Test Results for Lower Bazar, Near Narsingh Mandir

Based on the analysis, the best fitting soil profile has been obtained and presented in **Fig. 3.3**. It can be observed from **Fig. 3.4**, the Shear Wave Velocity (V_s) for Lower Bazar, Near Narsingh Mandir lies in the range of 215 to 480 m/s up to a depth of 40m.

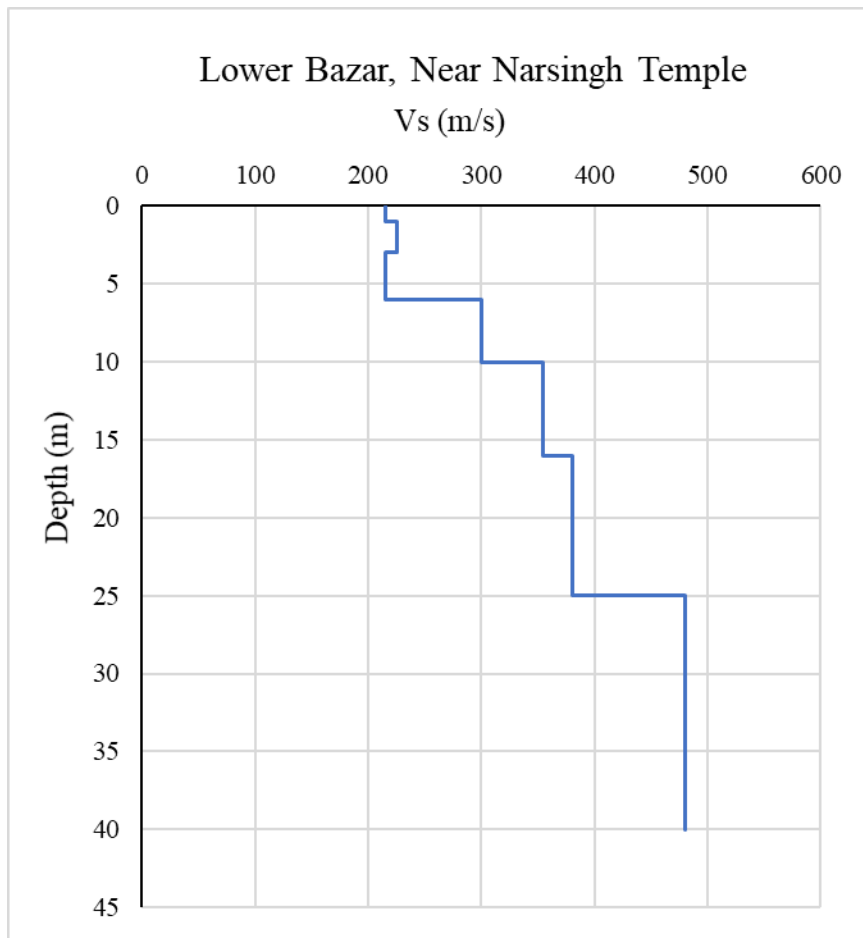


Fig. 3.4: Shear Wave Velocity Obtained at Lower Bazar, Near Narsingh Mandir

3.4: NMC Results

Water content of the soil samples collected from Lower Bazar, Near Narsingh Mandir at depths of 1m, 2m, 3m and 4.4m.

Table 3.1 Natural moisture content of the soil for Lower Bazar, Near Narsingh Mandir

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 16-02-2023		
Sampling location	Lower Bazar, Near Narsingh Mandir	
S.no	Depth (m)	Water content (%)
1	1	9.34
2	2	12.36
3	3	13.69
4	4.4	18.48

3.5: Grain Size Distribution Analysis

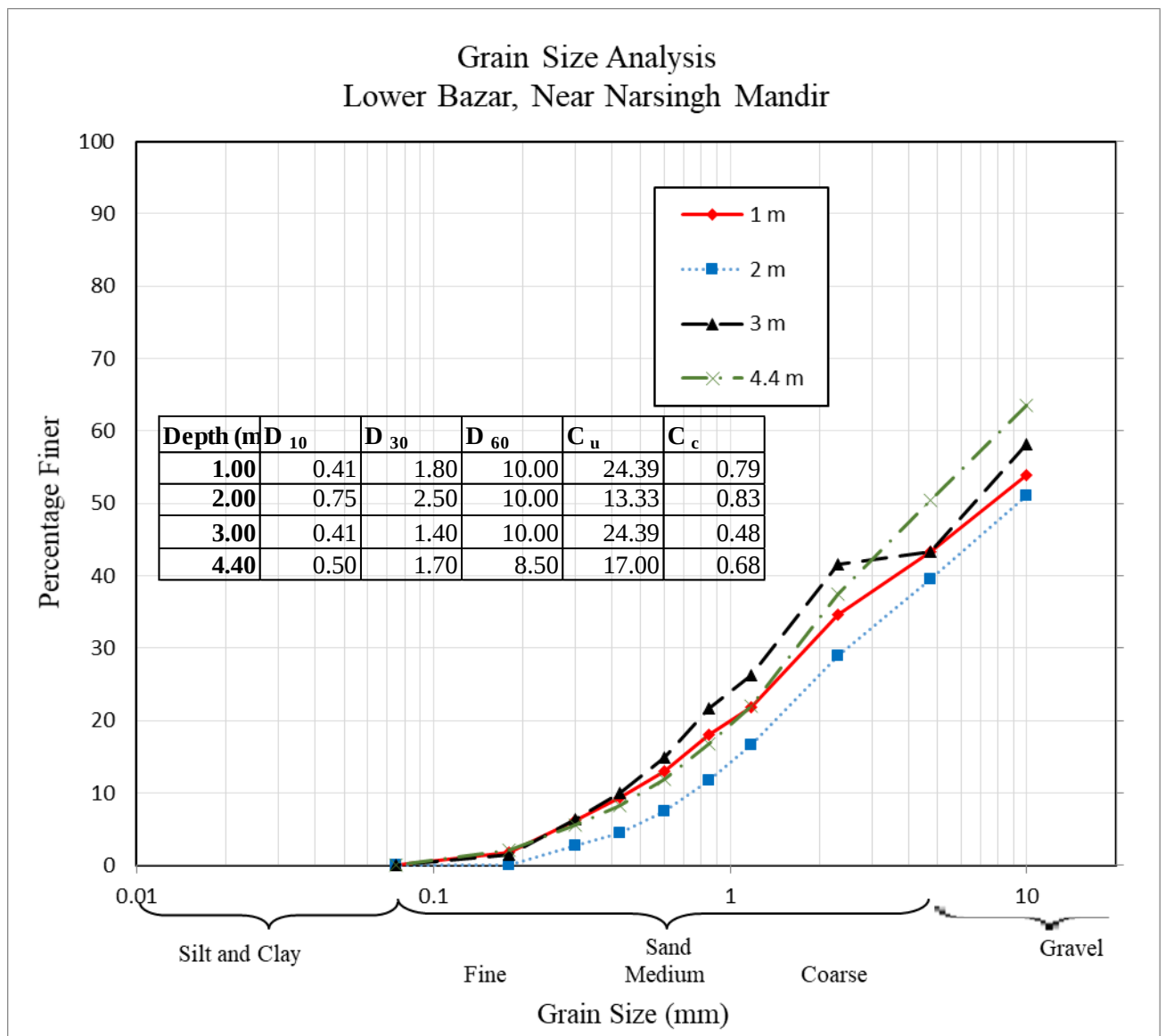


Fig. 3.5: Grain size distribution for Lower Bazar, Near Narsingh Mandir

3.6: Summary of all the Results

Table 3.2 Summary of the soil for Lower Bazar, Near Narsingh Mandir

LABORATORY TEST REPORT ON SOIL SAMPLES											
SAMPLING LOCATION:			Lower Bazar, Near Narsingh Mandir								
Depth (m)	IS Classification	N.M.C. %	Grain Size Analysis %			PL	Curv.	Coeff.	DD	Spec. Gravity	Void Ratio %
			Gravel	Sand	Fines		Cu	Cc	γ_d (kN/m ³)		
G.L.											
1	GP	9.34	56.76	43.24	0.00	NP	24.39	0.79	13.99	2.66	90.10
2	GP	12.36	60.53	39.47	0.00	NP	13.33	0.83	13.62	2.66	95.34
3	GP	13.69	56.65	43.35	0.00	NP	24.39	0.48	13.46	2.66	97.66
4.4	GP	18.48	49.55	50.45	0.00	NP	17.00	0.68	12.91	2.66	105.99

3.7: Overview of the Site

Test site is located near Narsingh Mandir in Lower Bazar (Ward 3). Except Direct Shear Test (DST), all the proposed field tests, Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT) and Multi-channel Analysis of Surface Waves along with HVSR were conducted at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) analysis were also conducted on the samples picked up from the field.

Plate load test was carried out at a depth of 1.5m using same plate size. As per IS:1888 (1982), load-settlement curve obtained is appeared to be loose to medium cohesionless soil. The ultimate and safe bearing capacity of the soil are found to be 16 t/m² and 5.33 t/m² respectively from the plate load test results, which is on the lower side.

Due to the presence of boulders and gravels present at the site, it became necessary to repeat the DCPT test thrice. First one DCPT test were conducted only up to 1.5m due to the refusal strata. In the second test conducted 2m away from the initial location, went up to 3.9m. The third test were performed at the pit of PLT and went up to 5.1m. It is evident from the field excavations and sampling that the subsurface layers are made up of a variety of boulders, gravels and soils. Further, it is observed from the DCPT-2 and DCPT-3 that the soil resistance is very different from these two DCPT data. The differences among three DCPT values indicates high degree of heterogeneity at this site.

MASW tests were conducted along with the HVSR. Similar to the Gandhinagar and Marwadi sites, the dispersion image obtained from MASW testing is observed to be having very high scatter. HVSR curve is also found to be similar to the other sites. The Shear Wave Velocity (Vs) lies in the range of 215 to 480 m/s up to a depth of 40m.

Natural Moisture Content of the field samples is found to be varying between 9.3 to 18.5%. GSD analysis conducted on samples collected from 1 to 4.4m depths revealed that the soils are predominantly Gravelly Sands. Further, soils are found to be non-plastic.

Concluding Remarks: The bearing capacity of site near Narsingh Mandir in Lower Bazar is found to be very poor, which is well correlated with low soil resistance observed in DCPT testing (DCP-1) at shallow depths. MASW test results indicates the moderate soil stiffness.

Site 4: Singhdhar: Near Panchvati Inn

4.1: Plate Load Test (PLT) Results

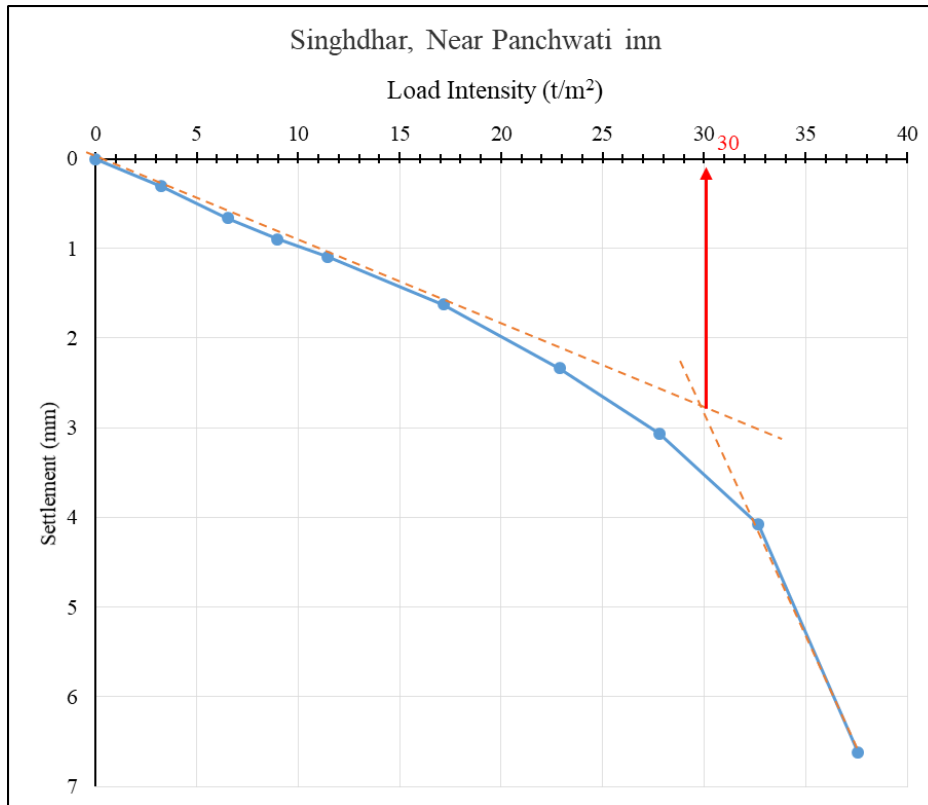


Fig. 4.1: PLT Result for Singhdhar, Near Panchvati Inn

Analysis of **Fig. 4.1** using asymptotes yields a minimum failure load as 30 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 10 t/m^2 .

4.2: Dynamic Cone Penetration (DCPT) Results

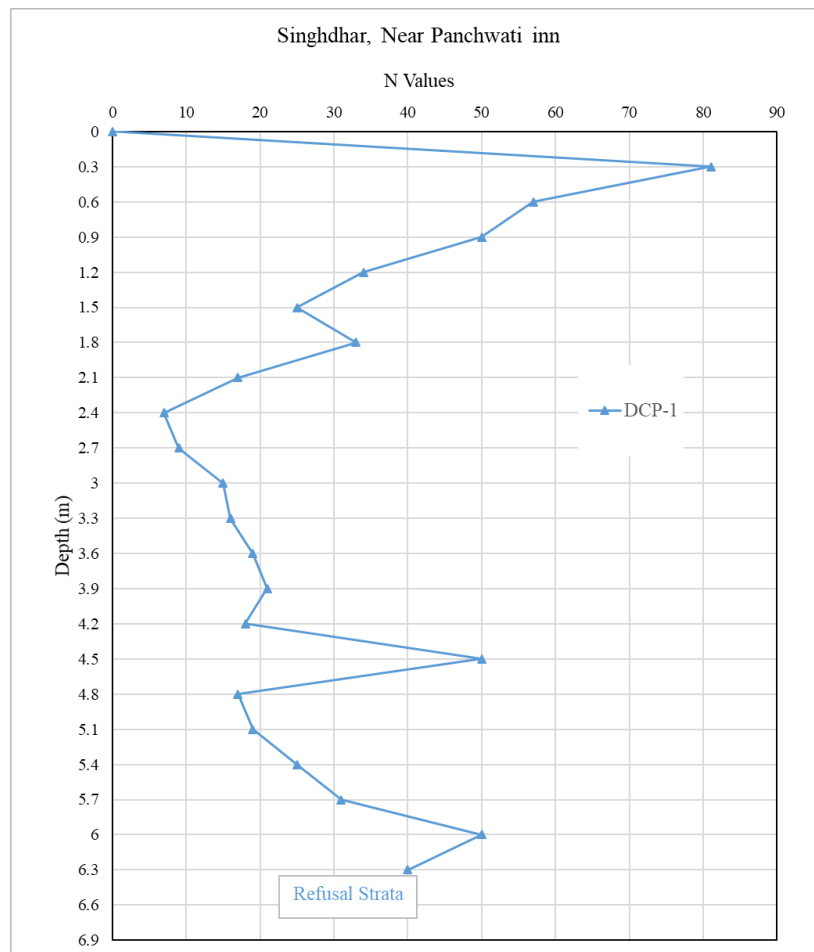


Fig. 4.2: DCPT Results for Singhdhar, Near Panchvati Inn

In **Fig. 4.2**, Values of cone resistance is varying very much, on surface it reflects hard strata. For ignition depth of 0.3m, number of blows (N_{cd}) is 81. Due to refusal; cone could not be penetrated beyond 6.3 m.

4.3: Direct Shear Test (DST) Results

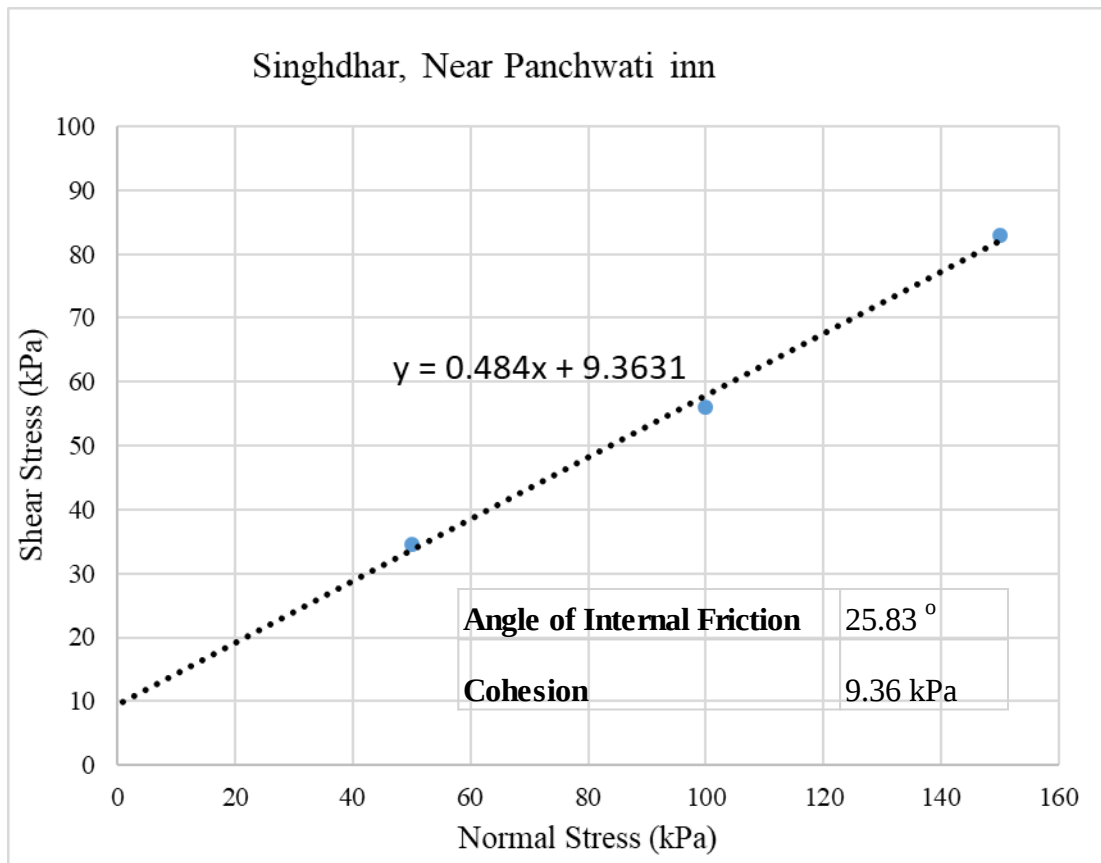


Fig. 4.3: DST Results for Singhdhar, Near Panchvati Inn

From the result of direct shear test done at site having size 300 mm × 300 mm as shown in **Fig. 4.3**, the angle of internal friction of soil and cohesion are 25.83° and 9.36kN/m² respectively.

4.4: MASW Test Results

Singhdhar, Near Panchvati Inn

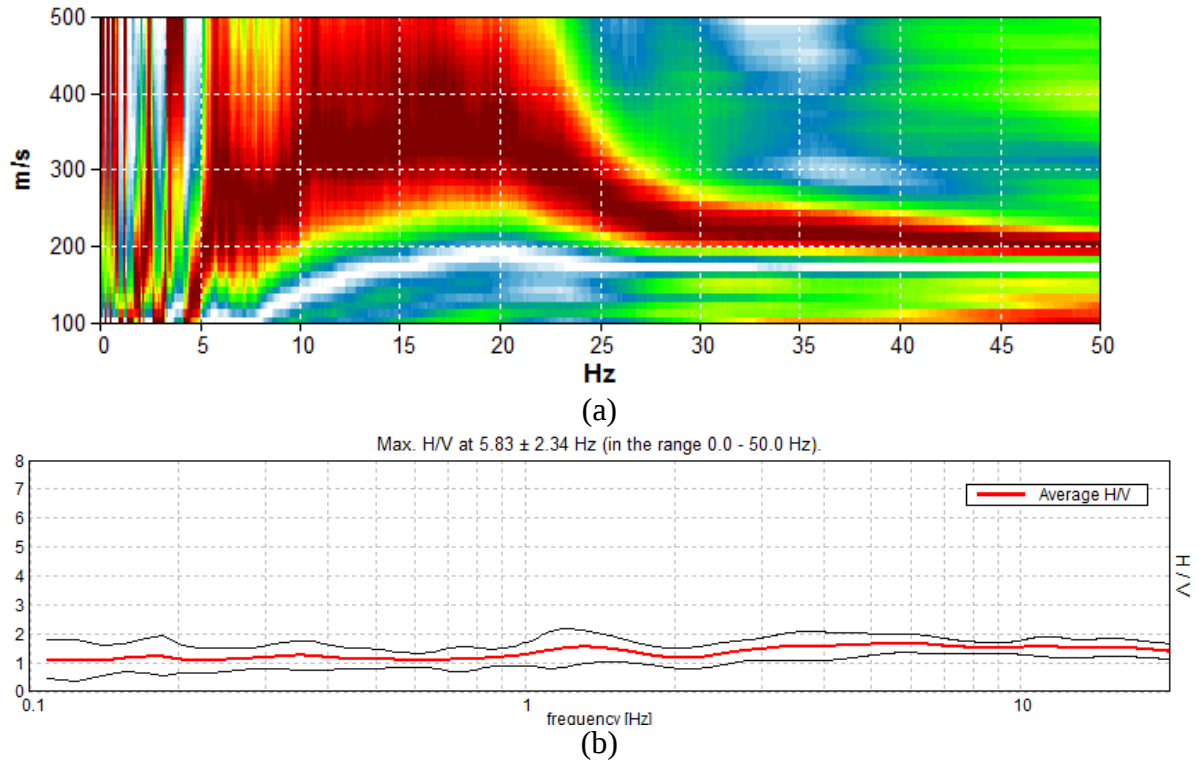


Fig. 4.4: (a) MASW & (b) HVSR Test Results for Singhdhar, Near Panchvati Inn

Based on the analysis, the best fitting soil profile has been obtained and presented in **Fig. 4.4**. It can be observed from **Fig. 4.5**, the Shear Wave Velocity (V_s) for Singhdhar, Near Panchvati Inn lies in the range of 210 to 570 m/s up to a depth of 30m.

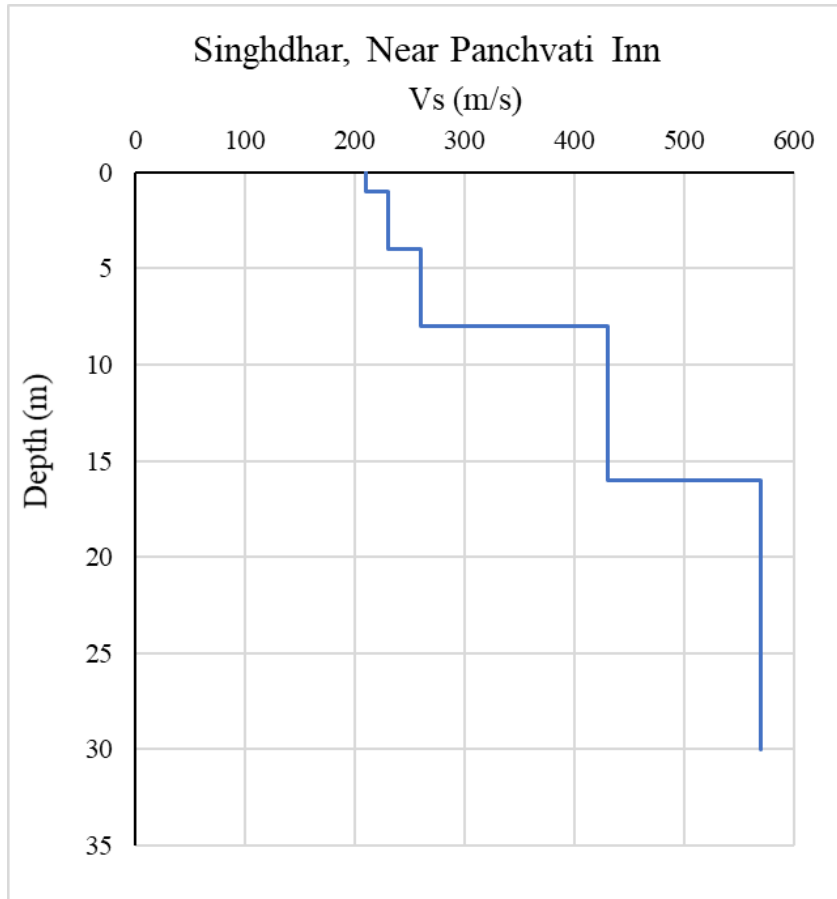


Fig. 4.5: Shear Wave Velocity Obtained at Singhdhar, Near Panchvati Inn

4.5: NMC Results

Water content of the soil samples collected from Singhdhar, Near Panchvati Inn at depths of 1m, 2m, 3m and 4m.

Table 4.1 Natural moisture content of the soil for Singhdhar, Near Panchvati Inn

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 18-02-2023		
Sampling location		Singhdhar, Near Panchwati inn
S.no	Depth (m)	Water content (%)
1	1	11.25
2	2	10.77
3	3	12.91
4	4	10.46

4.6: Grain Size Distribution Analysis

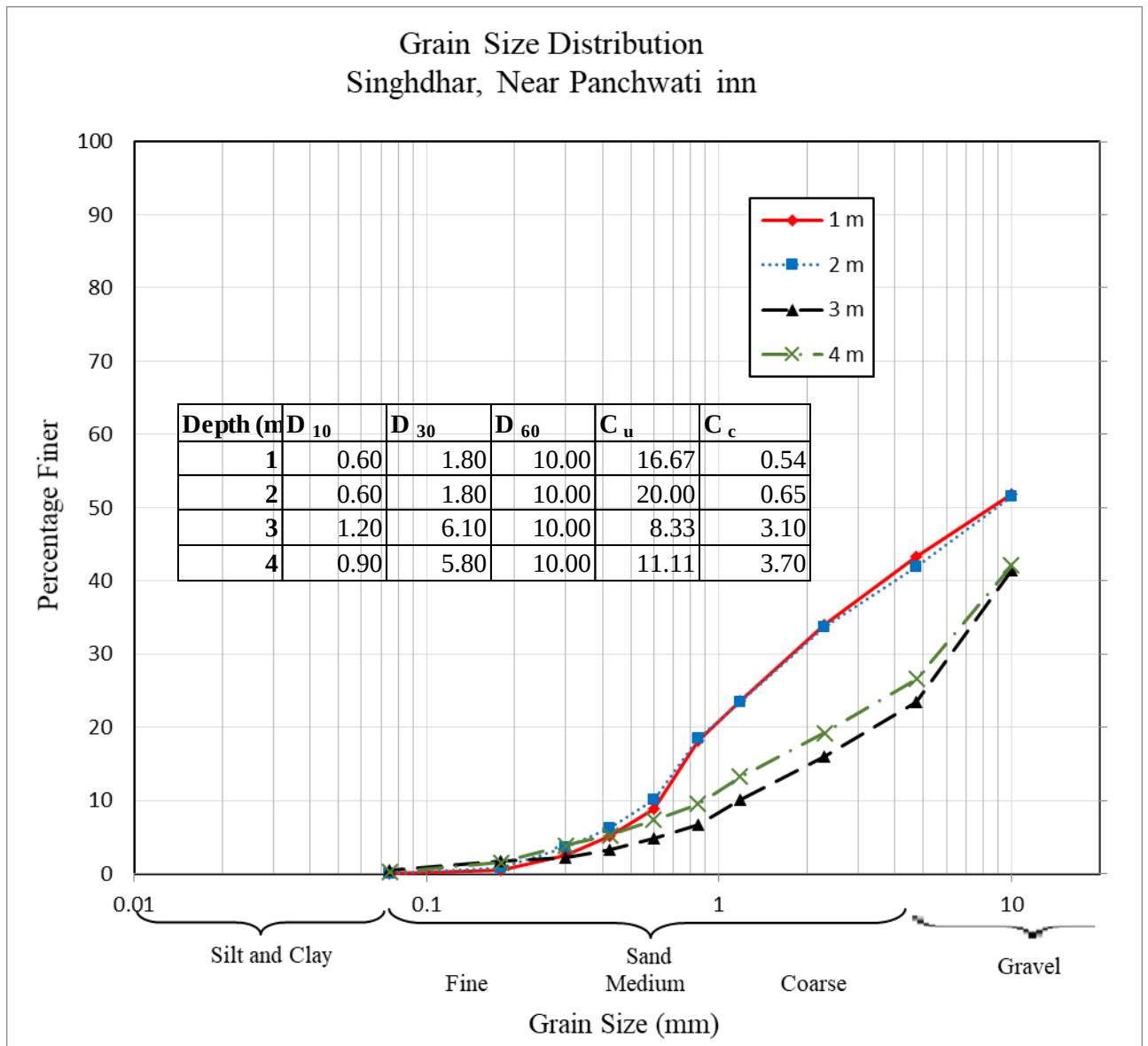


Fig. 4.6: Grain size distribution for Singhdhar, Near Panchvati Inn

4.7: Summary of all the Results

Table 4.2 Summary of the soil for Singhdhar, Near Panchvati Inn

LABORATORY TEST REPORT ON SOIL SAMPLES													
SAMPLING LOCATION:				Singhdhar, Near Panchvati inn									
Depth (m)	IS Classification	N.M.C. %	Grain Size Analysis %			PL	Curv.	Coeff.	BDD	Spec. Gravity	Void Ratio %	Shear Parameters	
			Gravel	Sand	Fines		Cu	Cc	γ_d (kN/m ³)			c (kN/m ²)	ϕ (°)
G.L.													
1	GP	11.25	56.71	43.29	0.00	NP	16.67	0.54	14.38	2.69	87.04	-	-
2	GP	10.77	58.13	41.87	0.00	NP	16.67	0.54	14.44	2.69	86.24	9.36	25.83
3	GP	12.91	76.48	23.04	0.48	NP	8.33	3.10	14.17	2.69	89.83	-	-
4	GP	10.46	73.40	26.41	0.19	NP	11.11	3.74	14.49	2.69	85.71	-	-

4.8: Overview of the Site

Test site is located near Panchvati Inn in Singhdhar (Ward 4). All the proposed field tests, Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT), Direct Shear Test (DST) and Multi-channel Analysis of Surface Waves along with HVSR were performed at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) analysis were also carried out on the samples collected from the field.

Plate load test was carried out at a depth of 1.5m using same plate size. The ultimate and safe bearing capacity of the soil are found to be 30 t/m^2 and 10 t/m^2 respectively from the plate load test results.

At this site one DCPT test is performed and went up to depth of 6.3m. At the surface 0.3m the DCPT values is higher. As stated earlier, it is primarily because of presence of boulders and gravel along with soil. It is evident from the field excavations and sampling that the subsurface layers are made up of a variety of boulders, gravels and soils. Further, it is observed from the DCPT that the soil resistance is maximum (81) at 0.3 m which decreases continuously between 0.3 to 2.4 m but still greater than 8. After this increases and varies. Finally, refusal is arrived at 6.3 m. The variation of the DCPT values indicates high degree of heterogeneity at this site also.

Field direct shear tests were conducted at three normal stresses. The angle of shearing resistance and cohesion are found to be 25.8° and 9.4 kPa respectively from the direct shear tests.

The shear wave velocity obtained from the MASW tests along with the HVSR are in the range of 210 to 570 m/s. The shear wave velocity increases with the depth. Further, Natural Moisture Content of the field samples is found to be varying between 10.5 to 13%. GSD analysis conducted on samples collected from 1 to 4m depths revealed that the soils are predominantly Gravelly Sands. Further, soils are found to be non-plastic.

Concluding Remarks: The bearing capacity at the Singhdhar near Panchvati Inn is found to be fair enough, which is well correlated with high soil resistance observed in DCPT testing. Though higher soil resistance is observed in DCPT at shallow depths, soil resistance decreased significantly after 2m depth. MASW test results are also indicates the moderate soil stiffness. It is also found that the structural damaged at this site is not significant.

Site 5: Singhdhar: Near Parking Plot

5.1: Plate Load Test (PLT) Results

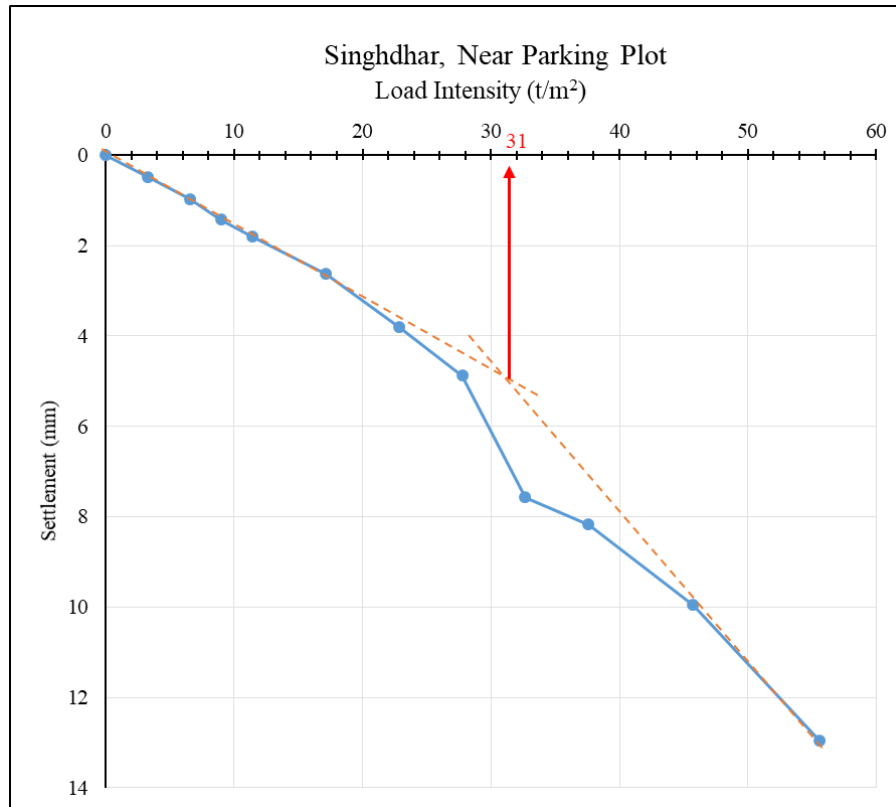


Fig. 5.1: PLT Result for Singhdhar, Near Parking Plot

Analysis of **Fig. 5.1** using asymptotes yields a minimum failure load as 31 t/m², where using a factor of safety equal to 3 it yields a safe bearing capacity as 10.33 t/m².

5.2: Dynamic Cone Penetration (DCPT) Results

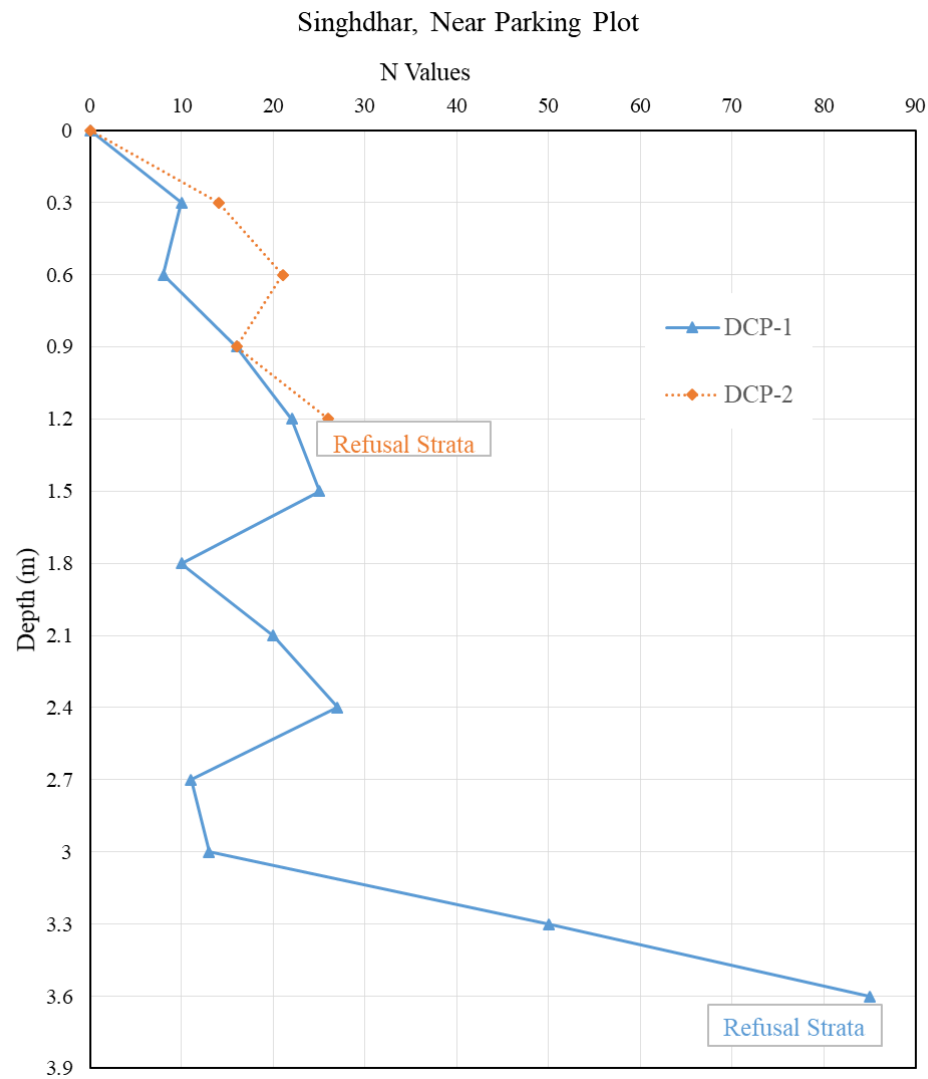


Fig. 5.2: DCPT Results for Singhdhar, Near Parking Plot

In **Fig. 5.2**, Values of cone resistance is not varying too much till 3m depth. Below 3m the soil observed harder than above. At a depth of 3.6m, number of blows (N_{cd}) is 85, beyond this the DCPT cone could not be penetrated and reflects the refusal strata.

5.3: MASW Test Results

Singhdhar, Near Parking Plot

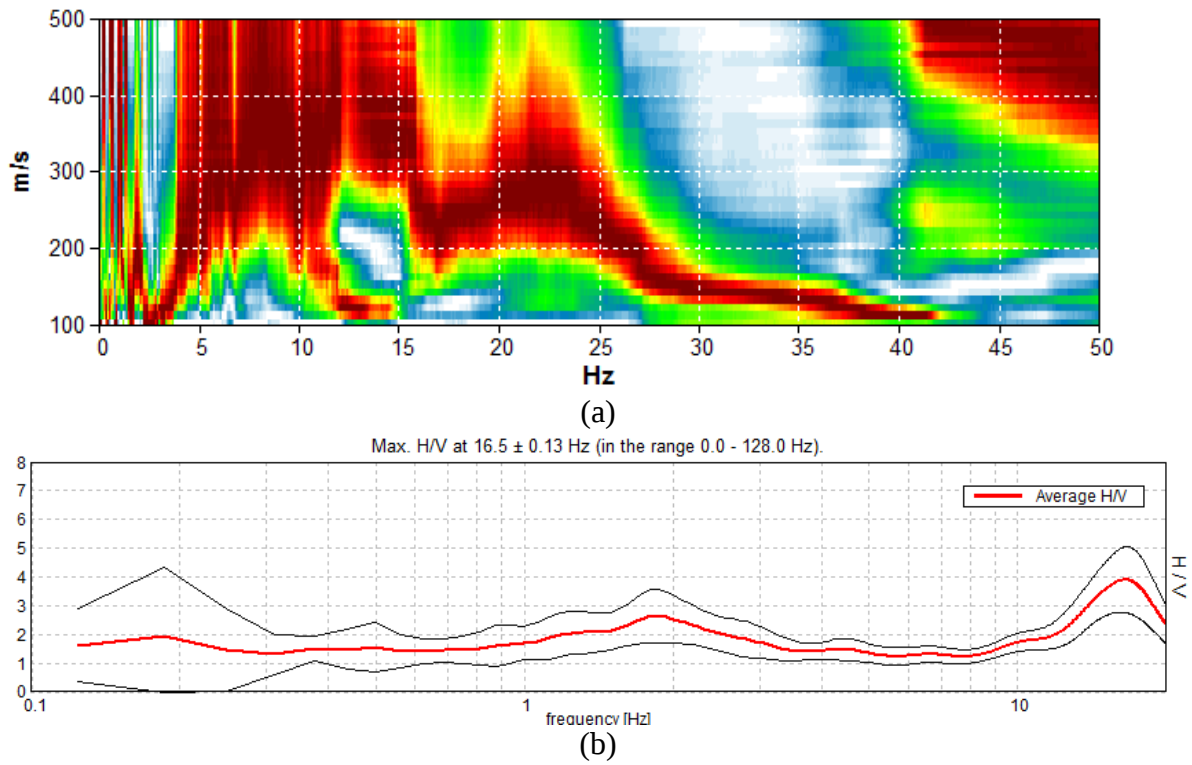


Fig. 5.3: (a) MASW & (b) HVSR Test Results for Singhdhar, Near Parking Plot

Based on the analysis, the best fitting soil profile has been obtained and presented in **Fig. 5.3**. It can be observed from **Fig. 5.4**, the Shear Wave Velocity (V_s) for Singhdhar, Near Parking Plot lies in the range of 110 to 490 m/s up to a depth of 23m.

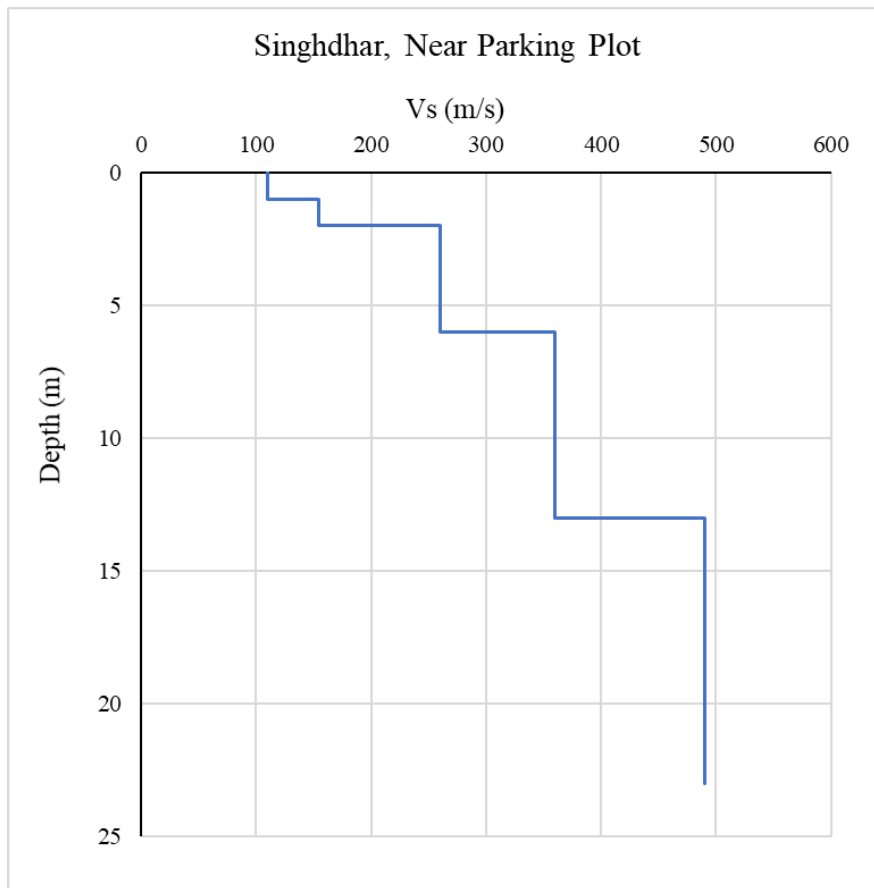


Fig. 5.4: Shear Wave Velocity Obtained at Singhdhar, Near Parking Plot

5.4: NMC Results

Water content of the soil samples collected from Singhdhar, Near Parking Plot at depths of 1m, 2m, 3m and 3.5m.

Table 5.1 Natural moisture content of the soil for Singhdhar, Near Parking Plot

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 16-02-2023		
Sampling location	Singhdhar, Near Parking Plot	
S.no	Depth (m)	Water content (%)
1	1	6.80
2	2	5.48
3	3	8.25
4	3.5	8.76

5.5: Grain Size Distribution Analysis

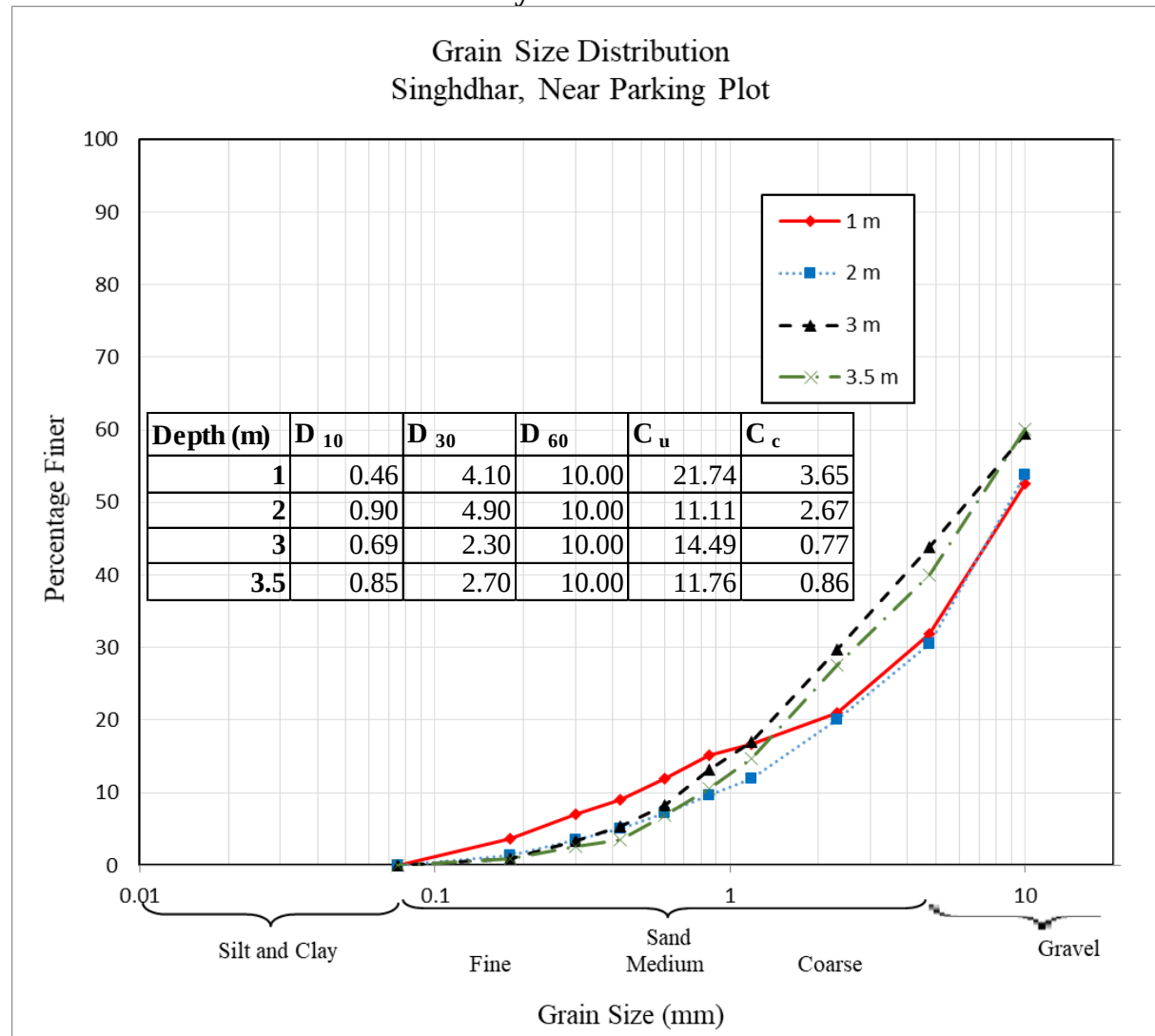


Fig. 5.5: Grain size distribution for Singhdhar, Near Parking Plot

5.6: Summary of all the Results

Table 5.2 Summary of the soil for Singhdhar, Near Parking Plot

LABORATORY TEST REPORT ON SOIL SAMPLES											
SAMPLING LOCATION:			Singhdhar, Near Parking Plot								
Depth (m)	IS Classification	N.M.C. (%)	Grain Size Analysis %			PL	Curv. Cu	Coeff. Cc	DD γ_d (kN/m ³)	Spec. Gravity	Void Ratio %
			Gravel	Sand	Fines						
G.L.											
1	GP	6.80	68.17	31.83	0.00	NP	21.74	3.65	13.48	2.67	98.03
2	GW	5.48	69.57	30.43	0.00	NP	11.11	2.67	13.65	2.67	95.58
3	GP	8.25	56.15	43.85	0.00	NP	14.49	0.77	13.30	2.67	100.71
3.5	GP	8.76	59.97	40.03	0.00	NP	11.76	0.86	13.24	2.67	101.65

5.7: Overview of the Site

Test site is located near Parking Plot in Singhdhar (Ward 4). All the proposed field tests, Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT) and Multi-channel Analysis of Surface Waves along with HVSR were performed at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) analysis were also carried out on the samples collected from the field. The Direct Shear Test (DST) is not performed at this site due to space restriction and limited scope of the testing.

Plate load test was carried out at a depth of 1.5m using same plate size as other sites. The ultimate and safe bearing capacity of the soil are found to be 31 t/m^2 and 10.33 t/m^2 respectively from the plate load test results.

At this site, two DCPT tests is performed and went up to maximum depth of 3.6m. It is observed from the DCPT that the soil resistance, in general, increases with the depth. However, in DCPT-1, the refusal is arrived at 3.6 m depth which may be due to the presence the gravel and boulder in the soil.

The dispersion image obtained from MASW testing for this site is very high scatter which is not common to regular soil strata. The values of the shear wave velocity vary from the 110-490 m/s. On the other hand, HVSR curve is also found flatten with lower amplitudes. Natural Moisture Content of the field samples is found to be varying between 5.5 to 8.8%. GSD analysis conducted on samples collected from 1 to 3.5m depths revealed that the soils are predominantly Gravelly Sands. Further, soils are found to be non-plastic.

Concluding Remarks: The results obtained from DCPT and MASW are clearly indicating that the soil resistance is low at this site. PLT though showing moderate bearing capacity, it could be due to presence of some boulders present underneath the plate. Several ground failures in terms of open cracks are visible at this site with major cracks in the buildings.

Site 6: Manoharbagh: Near Ropeway Tower No. 1

6.1: Plate Load Test (PLT) Results

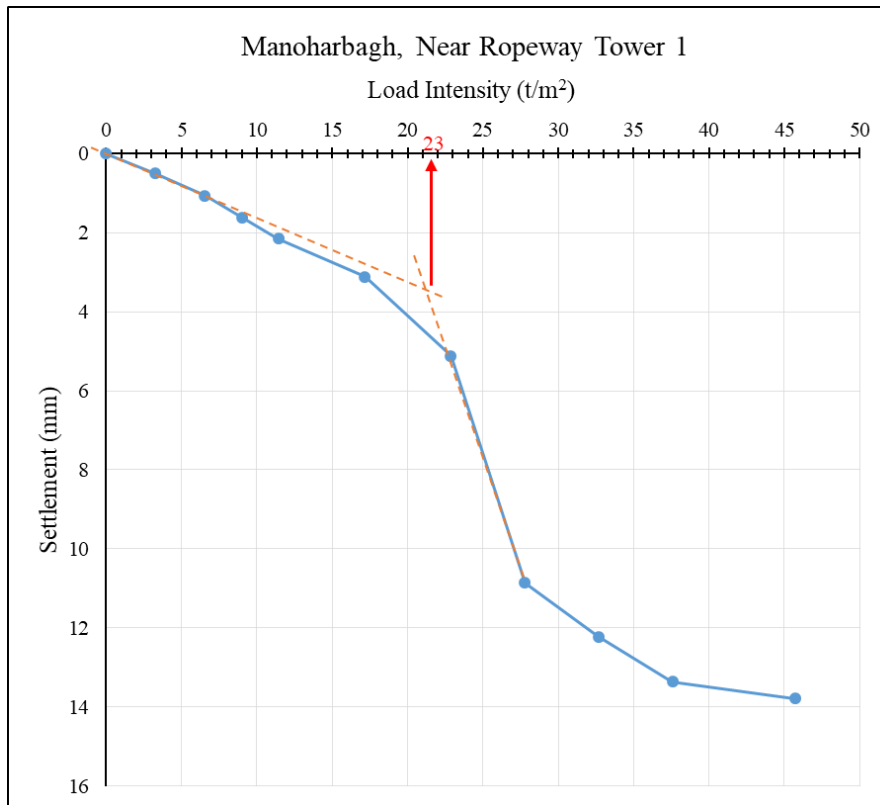


Fig. 6.1: PLT Result for Manoharbagh, Near Ropeway Tower No. 1

Analysis of **Fig. 6.1** using asymptotes yields a minimum failure load as 23 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 7.67 t/m^2 .

6.2: Dynamic Cone Penetration (DCPT) Results

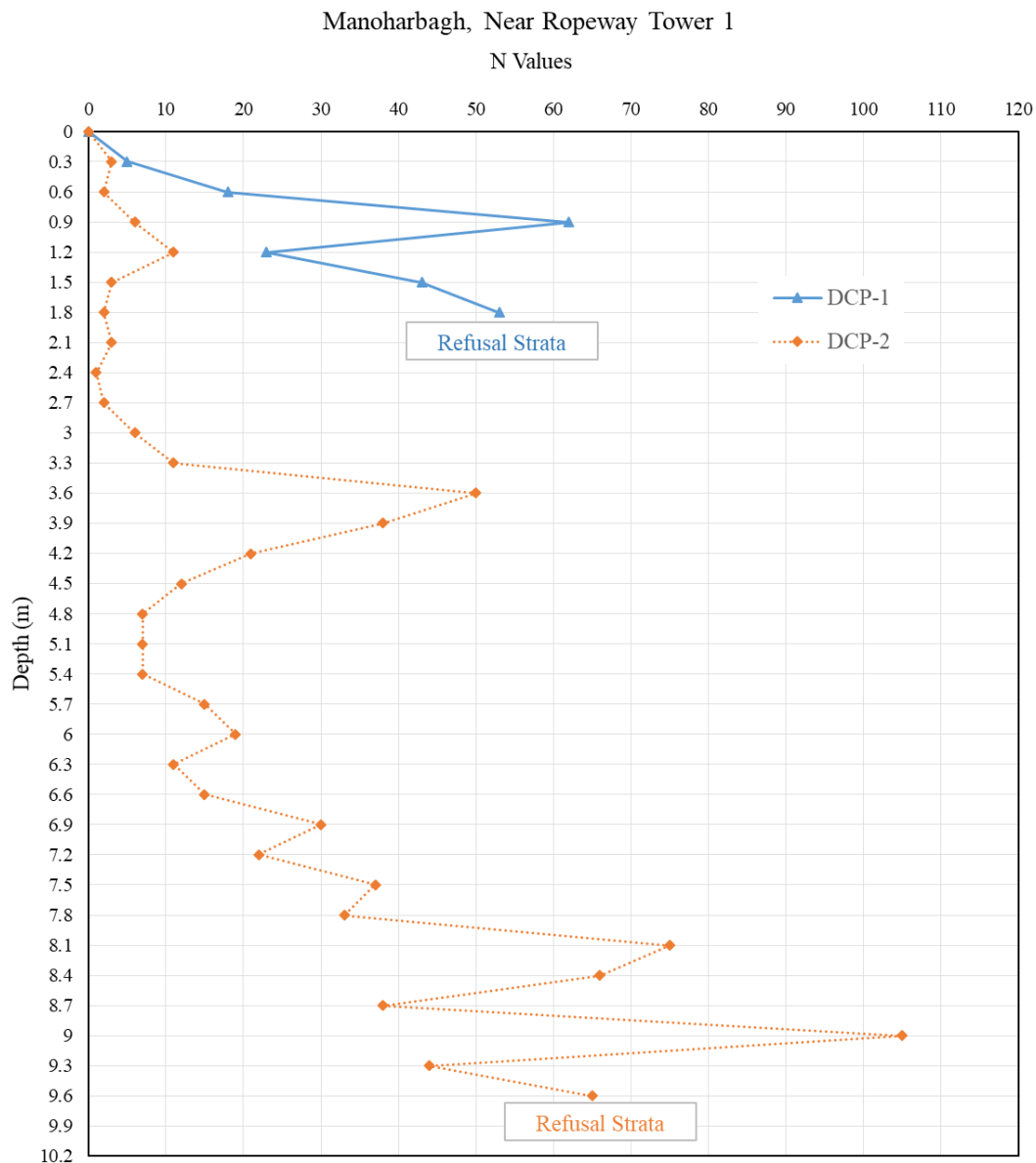


Fig. 6.2: DCPT Results for Manoharbagh, Near Ropeway Tower No. 1

In **Fig. 6.2**, Values of cone resistance initially is not varying too much but below 8.1 m depth variation in the values is very large. At a depth of 3.6m, the DCPT value jumps suddenly this may be due to presence of boulder because below this depth DCPT number again decreases. Due to refusal; cone could not be penetrated beyond 9.6 m. The DCPT values are varied from 1 to 105.

6.3: Direct Shear Test (DST) Results

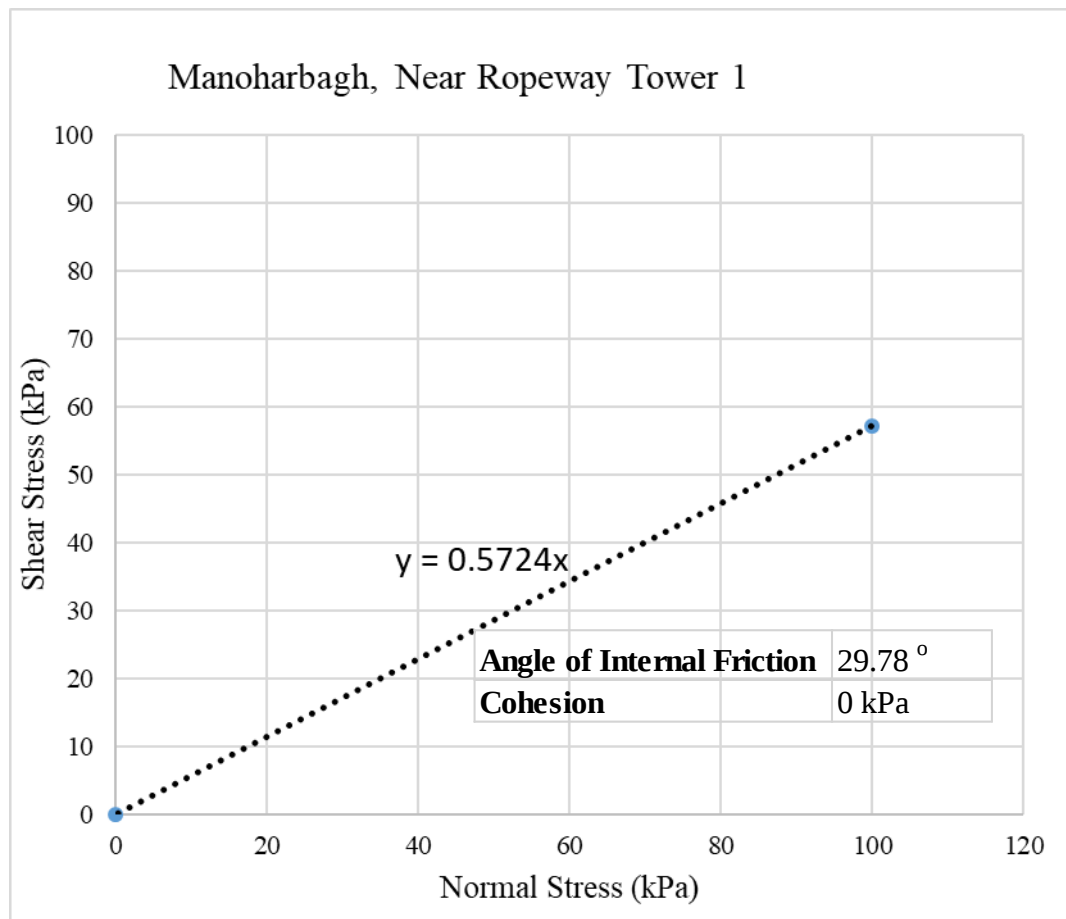


Fig. 6.3: DST Results for Manoharbagh, Near Ropeway Tower No. 1

Only one DST having size 300 mm × 300 mm was possible because of difficult site conditions. From the result assuming the cohesion to be 0, as shown in **Fig. 6.3**, the angle of internal friction of soil is 29.78°.

6.4: MASW Test Results

Manoharbagh, Near Ropeway Tower No. 1

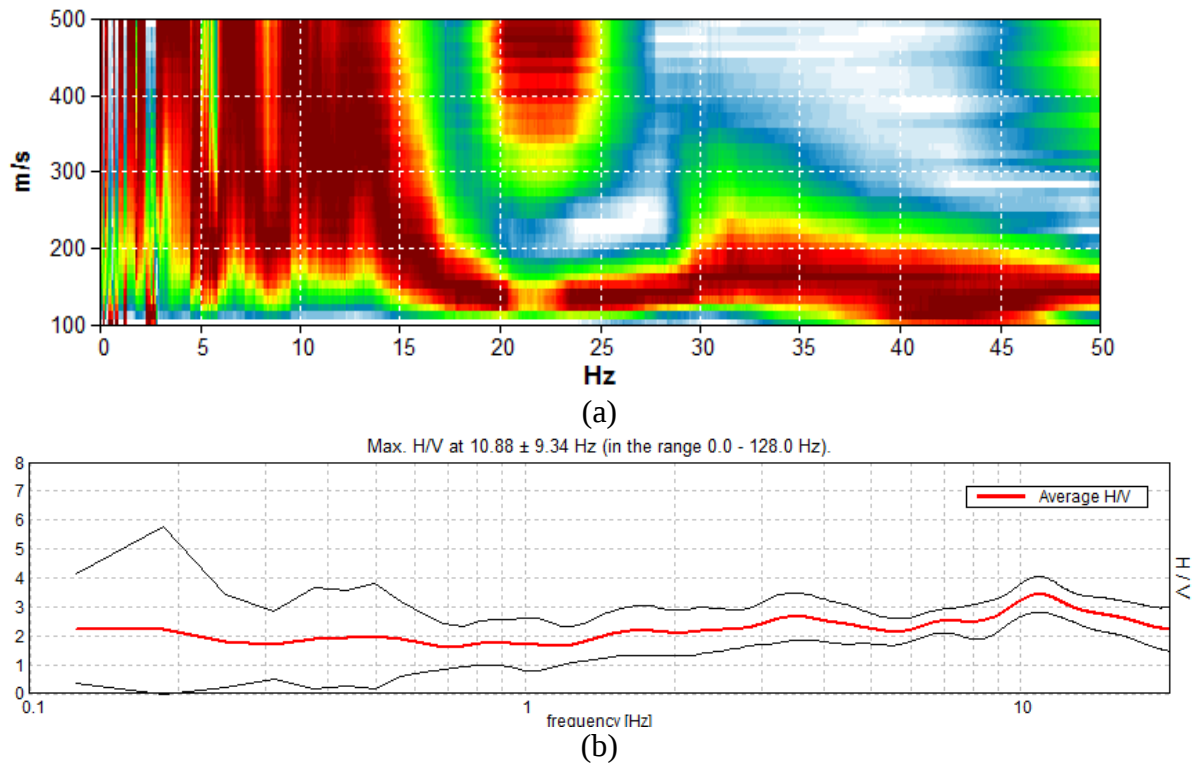


Fig. 6.4: (a) MASW & (b) HVSR Test Results for Manoharbagh, Near Ropeway Tower No. 1

Based on the analysis, the best fitting soil profile has been obtained and presented in **Fig. 6.4**. It can be observed from **Fig. 6.5**, the Shear Wave Velocity (V_s) for Manoharbagh, Near Ropeway Tower No. 1 lies in the range of 130 to 440 m/s up to a depth of 33m.

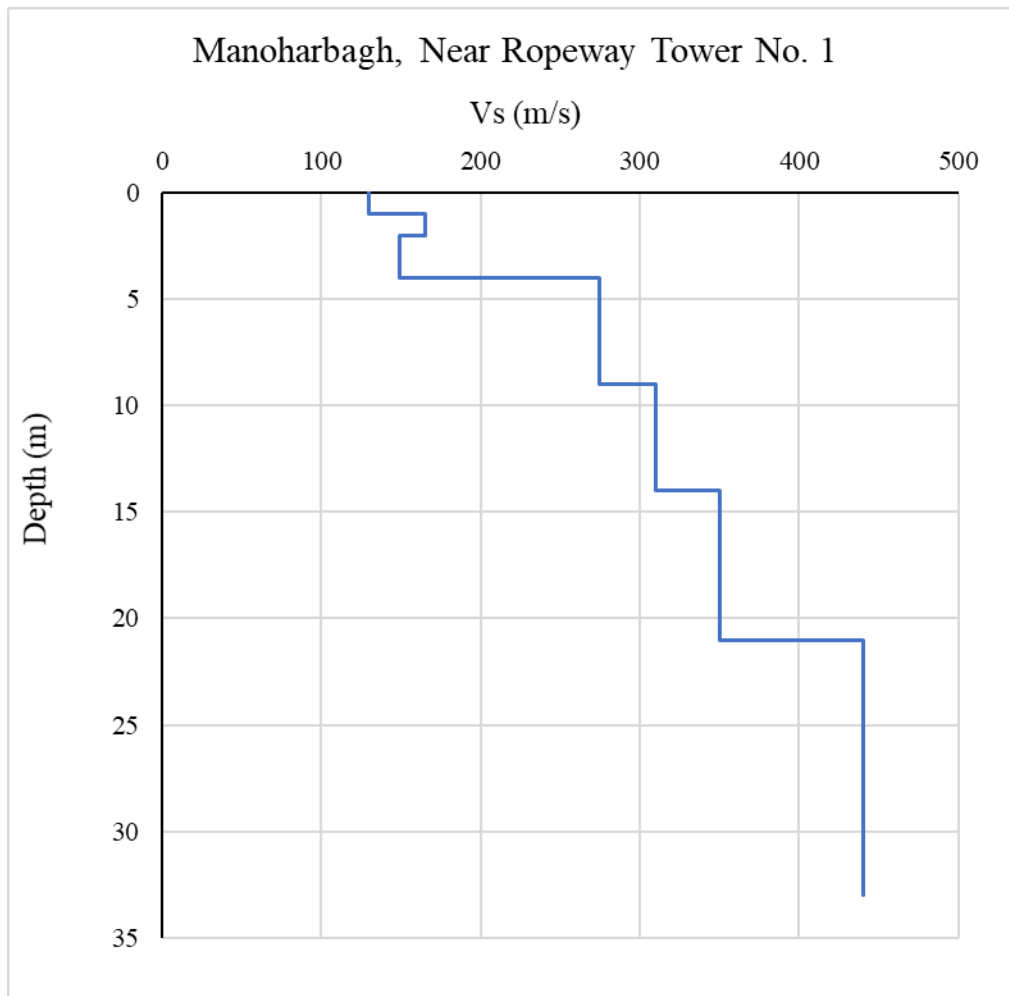


Fig. 6.5: Shear Wave Velocity Obtained at Manoharbagh, Near Ropeway Tower No. 1

6.5: NMC Results

Water content of the soil samples collected from Manoharbagh, Near Ropeway Tower No. 1 at depths of 1m and 1.5m.

Table 6.1 Natural moisture content of the soil for Manoharbagh, Near Ropeway Tower No. 1

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 15-02-2023		
Sampling location	Manoharbagh, Near Ropeway Tower No. 1	
S.no	Depth (m)	Water content (%)
1	1	11.21
2	1.5	9.60

6.6: Grain Size Distribution Analysis

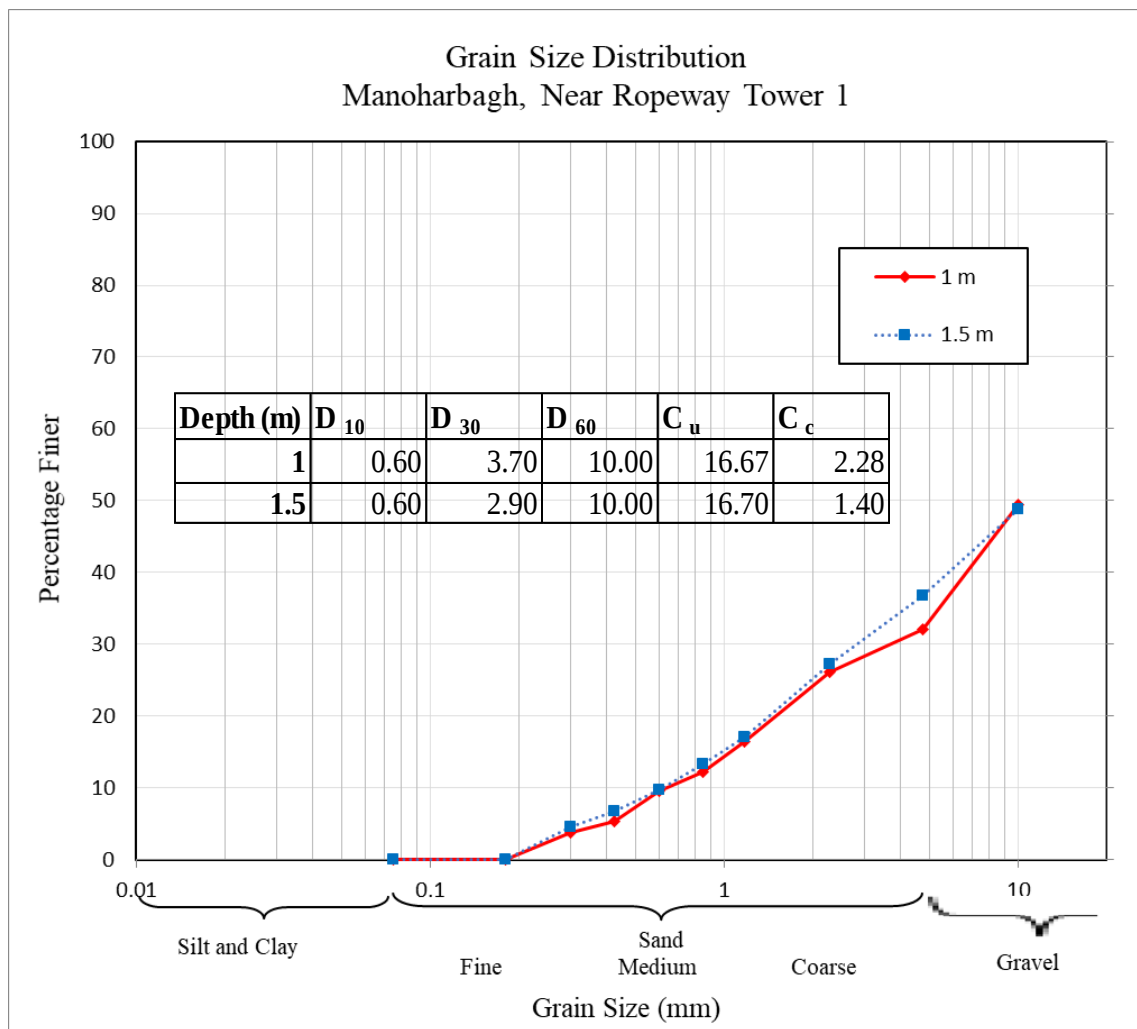


Fig. 6.6: Grain size distribution for Manoharbagh, Near Ropeway Tower No. 1

6.7: Summary of all the Results

Table 6.2 Summary of the soil for Manoharbagh, Near Ropeway Tower No. 1

LABORATORY TEST REPORT ON SOIL SAMPLES													
SAMPLING LOCATION:			Manoharbagh, Near Ropeway Tower 1										
Depth (m)	IS Classification	N.M.C. %	Grain Size Analysis %			PL	Curv. Cu	Coeff. Cc	DD γ_d (kN/m ³)	Spec. Gravity	Void Ratio %	Shear Parameters	
			Gravel	Sand	Fines							c (kN/m ²)	ϕ (°)
1	GW	11.21	67.85	32.15	0.00	NP	16.67	2.28	13.49	2.66	29.81	-	-
1.5	GW	9.60	63.31	36.69	0.00	NP	16.67	1.40	13.69	2.66	25.54	0.00	29.78

6.8: Overview of the Site

Test site is located near Ropeway Tower No. 1 in Manoharbagh (Ward 5). All the proposed field tests, Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT), Direct Shear Test (DST) and Multi-channel Analysis of Surface Waves along with HVSR were performed at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) analysis were also carried out on the samples collected from the field.

Plate load test was carried out at a depth of 1.5m using same plate size. The ultimate and safe bearing capacity of the soil are found to be 23 t/m² and 7.67 t/m² respectively from the plate load test results, which is on lower side.

At this site two DCPT tests is performed and went up to maximum depth of 9.6m. DCPT-1 is located just near the Ropeway tower and DCPT-2 is 2m away from the tower where surface cracks are observed. The refusal strata in the DCPT-1 at 1.8m depth may be due to the presence of the gravel and boulders in the soil. However, it is also observed from the DCPT-2 that the soil resistance is not high between 4.2 to 7.8 m.

Field direct shear tests were conducted at three normal stresses. The angle of shearing resistance and cohesion are found to be 29.8° and 0 kPa respectively from the direct shear tests. Which indicates that the soil at this site is loose and purely cohesionless.

Similar to the other sites, the dispersion image obtained from MASW testing is observed to be having very high scatter and drops at 20 to 30 Hz. The values of shear wave velocity at this site varies between 130 to 440 m/s which is in the low range compared to other sites. From the HVSR curve, no certain variation in the amplitude is observed. Natural Moisture Content of the field samples is found to be varying between 9.60 to 11.21%. GSD analysis conducted on samples collected from 1 to 1.5 m depths revealed that the soils are predominantly Gravelly Sands.

Concluding Remarks: This site consists of the loose soil having low shear strength parameters. The DCPT and MASW test results indicates that the site has low soil resistance even at a higher depth. Due to presence of boulder and random soil matrix, the bearing capacity may be higher. Several open cracks parallel to the slope with long span are visible. The low soil resistance, land subsidence and high-rise building/tower loads may aggravate the slope failures. Further detailed studies are required.

Site 7: Manoharbagh: Near PWD Guest House

7.1: Plate Load Test (PLT) Results

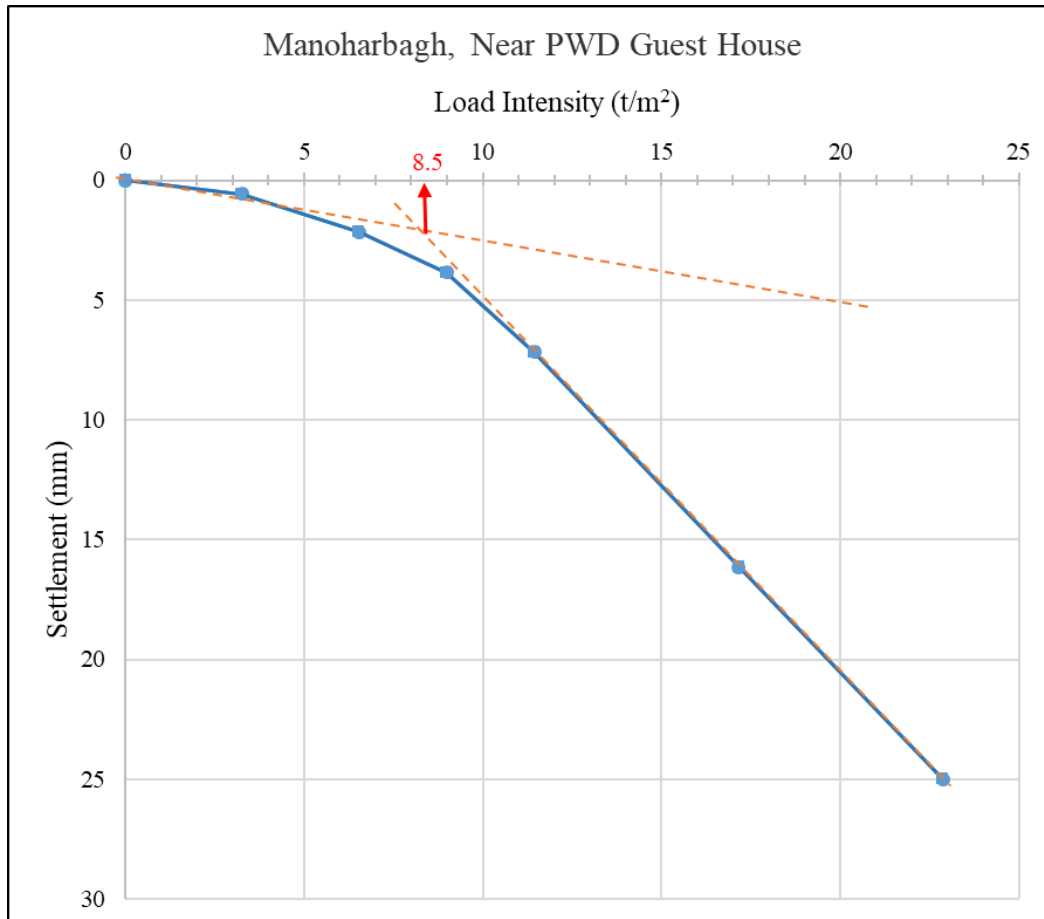


Fig. 7.1: PLT Result for Manoharbagh, Near PWD Guest House

Analysis of **Fig. 7.1** using asymptotes yields a minimum failure load as 8.5 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 2.83 t/m^2 .

7.2: Dynamic Cone Penetration (DCPT) Results

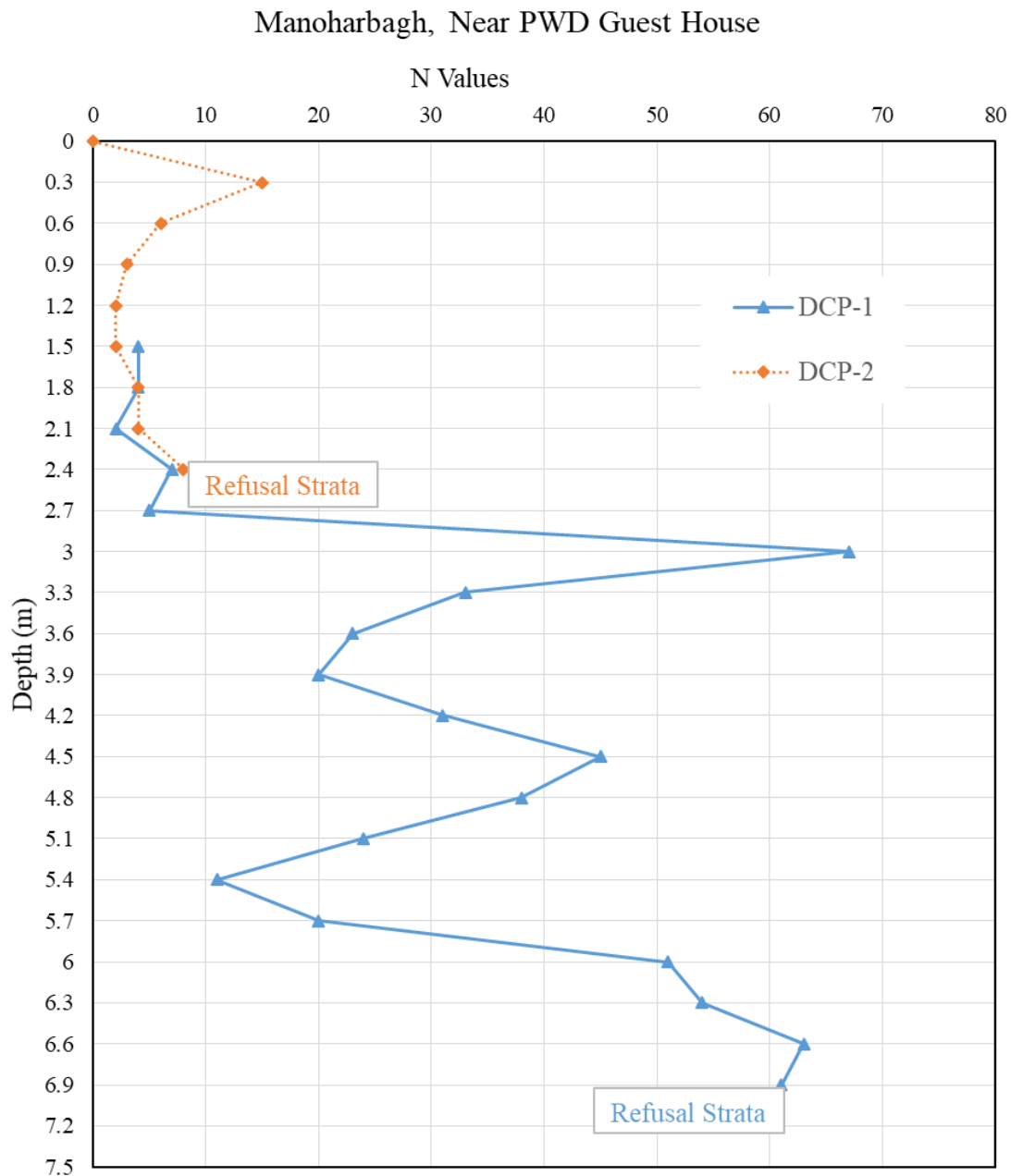


Fig. 7.2: DCPT Results for Manoharbagh, Near PWD Guest House

In **Fig. 7.2**, two DCPT curves are observed one start from ground surface other start at a depth of 1.5m. The second DCPT is conducted in the pit of PLT because of the difficulties arises due to boulders present on the surface. At a depth of 2.1m the value is minimum i.e. 2 and at 3m, number of blows (N_{cd}) is 67, due to the boulders. Due to refusal; cone could not be penetrated beyond 6.9m.

7.3: Direct Shear Test (DST) Results

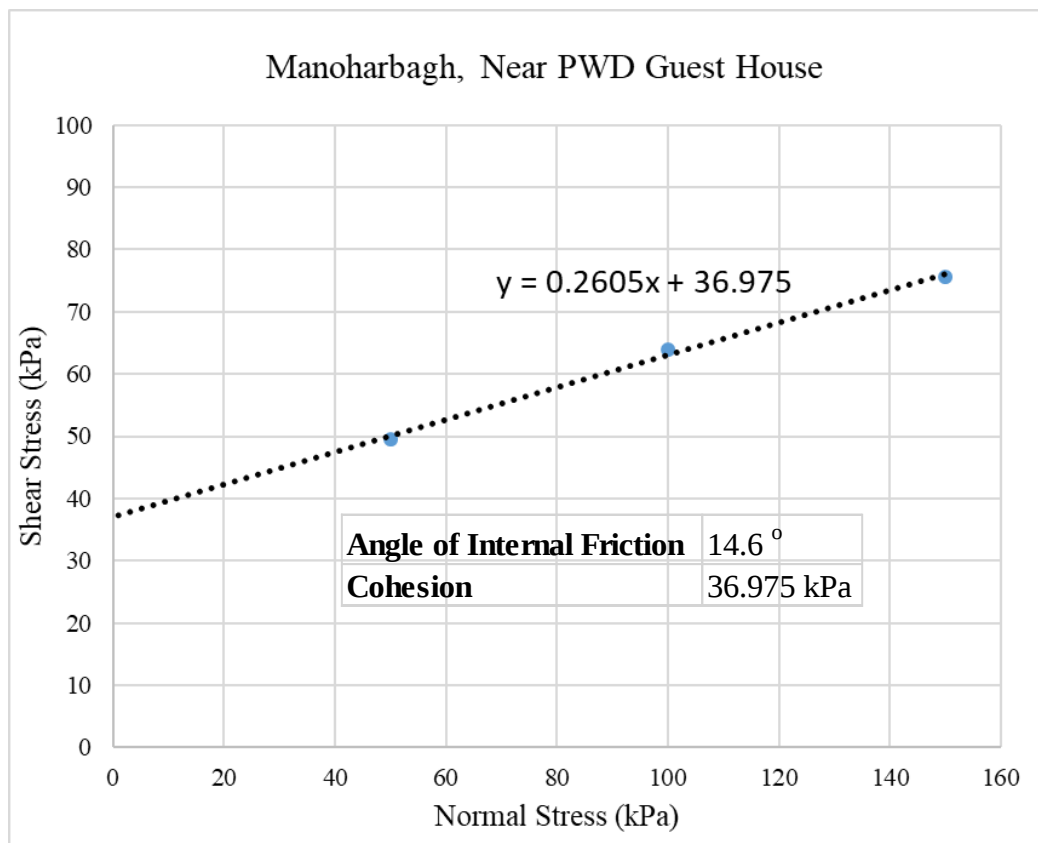


Fig. 7.3: DST Results for Manoharbagh, Near PWD Guest House

From the result of direct shear test done at site having size 300 mm × 300 mm as shown in **Fig. 7.3**, the angle of internal friction of soil and cohesion are 14.6° and 36.98kN/m² respectively.

7.4: NMC Results

Water content of the soil samples collected from Manoharbagh, Near PWD Guest House at depths of 1m, 2m, 3m, 4m and 5m.

Table 7.1 Natural moisture content of the soil for Manoharbagh, Near PWD Guest House

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 15-02-2023		
Sampling location		Manoharbagh, Near PWD Guest House
S.no	Depth (m)	Water content (%)
1	1	7.10
2	2	8.76
3	3	10.85
4	4	13.51
5	5	14.47

7.5: Grain Size Distribution Analysis

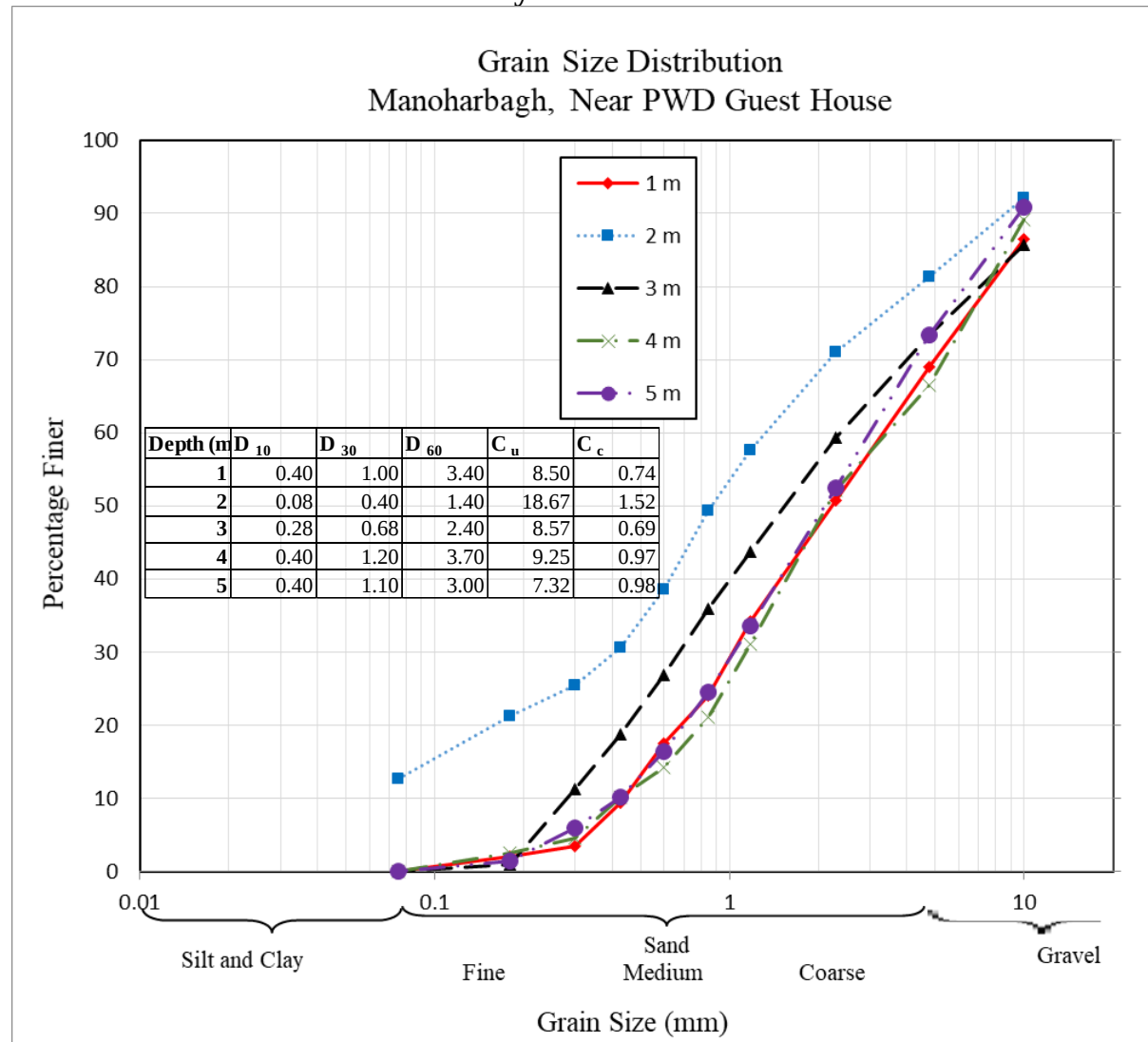


Fig. 7.4: Grain size distribution for Manoharbagh, Near PWD Guest House

7.6: Summary of all the Results

Table 7.2 Summary of the soil for Manoharbagh, Near PWD Guest House

LABORATORY TEST REPORT ON SOIL SAMPLES															
SAMPLING LOCATION:			Manoharbagh, Near PWD Guest House												
Depth (m)	IS Classification	N.M.C. %	Grain Size Analysis %			Atterberg's Limits			Curv.	Coeff.	DD	Spec. Gravity	Void Ratio %	Shear Parameters	
			Gravel	Sand	Fines	LL	PL	PI	Cu	Cc	γ_d (kN/m ³)			c (kN/m ²)	ϕ (°)
G.L.															
1	SP	7.10	30.98	69.02	0.00	-	NP	-	8.50	0.74	13.45	2.65	18.81	-	-
2	ML-CL	8.76	18.67	68.63	12.70	27.00	23.00	5.00	18.67	1.52	13.24	2.65	23.21	36.98	14.6
3	SP	10.85	26.69	73.31	0.00	-	NP	-	8.57	0.69	12.99	2.65	28.75	-	-
4	SP	13.51	33.57	66.43	0.00	-	NP	-	9.25	0.97	12.69	2.65	35.81	-	-
5	SP	14.47	26.57	73.43	0.00	-	NP	-	7.32	0.98	12.58	2.65	38.33	-	-

7.7: Overview of the Site

Test site is located near PWD Guest House in Manoharbagh (Ward 5). The Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT) and Direct Shear Test (DST) were performed at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) analysis were also carried out on the samples collected from the field. Multi-channel Analysis of Surface Waves along with HVSR is performed at this site due to space restriction as well as demolition of the PWD guest house.

Plate load test was carried out at a depth of 1.5m using same plate size. The ultimate and safe bearing capacity of the soil are found to be 8.5 t/m² and 2.83 t/m² respectively from the plate load test results, which is very low.

At this site, two DCPT tests were performed. DCPT-2 represents the shallow depths up to 2.4m. Whereas, DCPT-1 is conducted about 0.3m away went up to 6.9m. The refusal strata in the DCPT-2 may be due to the presence the gravel and boulder in the soil. However, it is also observed from the DCPT-1 that the soil resistance increases at a higher depth. It appears that the top soils is a filled up soil.

Field direct shear tests were conducted at three normal stresses. The angle of shearing resistance and cohesion are found to be 14.6° and 36.98 kPa respectively from the direct shear tests. Natural Moisture Content of the field samples is found to be varying between 7.1 to 14.5%. GSD analysis conducted on samples collected from 1 to 5m depths revealed that the soils are predominantly Gravelly Sands. However, 12% fine content observed from GSD at a depth of 2m.

Concluding Remarks: The bearing capacity of the site is very low (bearing capacity is 8.5 t/m²) compared to the other sites. This may be a reason for the observed damages to the PWD guest house. The DCPT values at shallow depth are very low (within 3m depth). However, these values increases as the depth increase. Many minor cracks are also visible on the road indicating the effect of subsidence at open surface.

Site 8: Manoharbagh: Near CPWD Office

8.1: Plate Load Test (PLT) Results

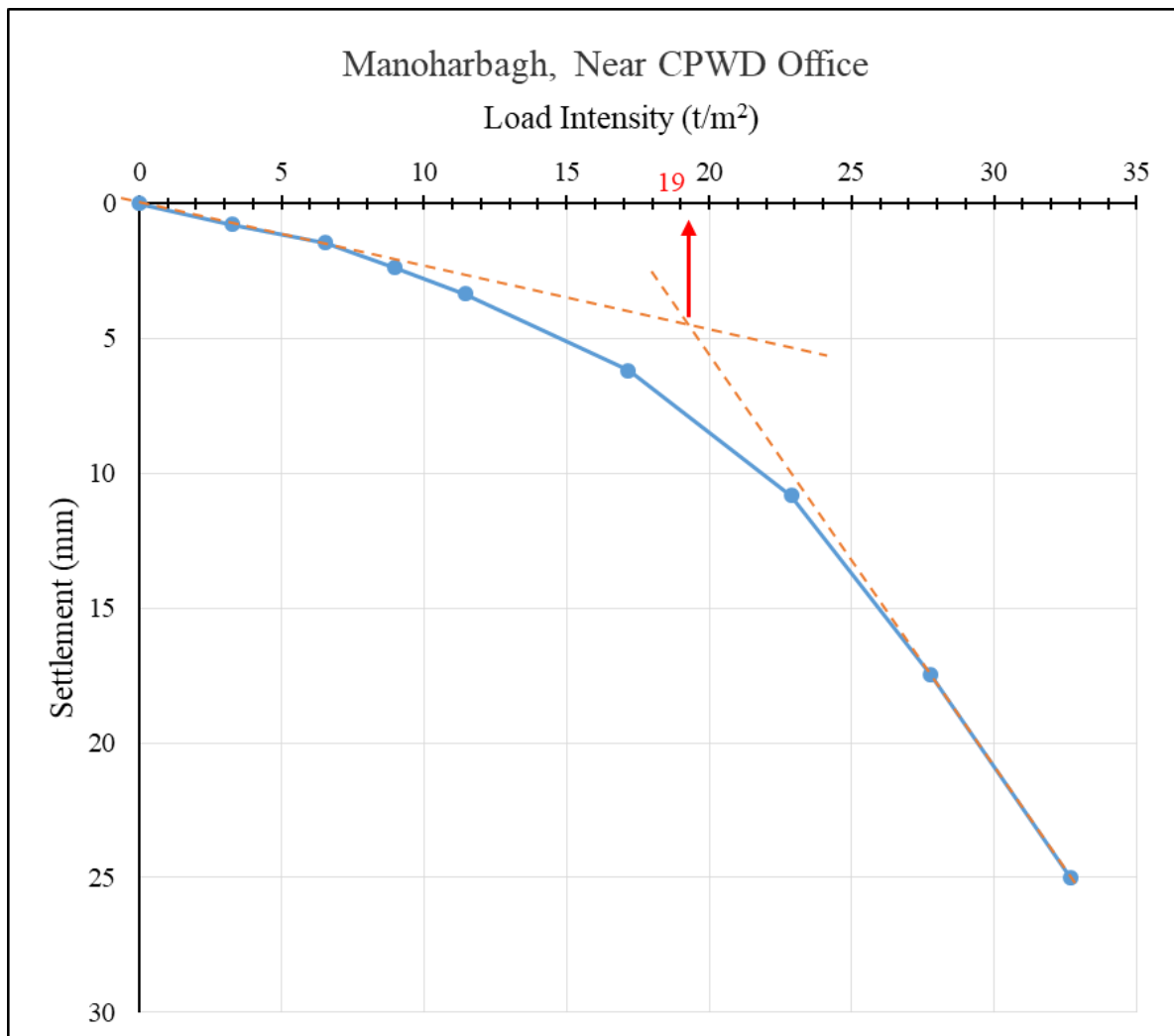


Fig. 8.1: PLT Result for Manoharbagh, Near CPWD Office

Analysis of **Fig. 8.1** using asymptotes yields a minimum failure load as 19 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 6.33 t/m^2 .

8.2: Dynamic Cone Penetration (DCPT) Results

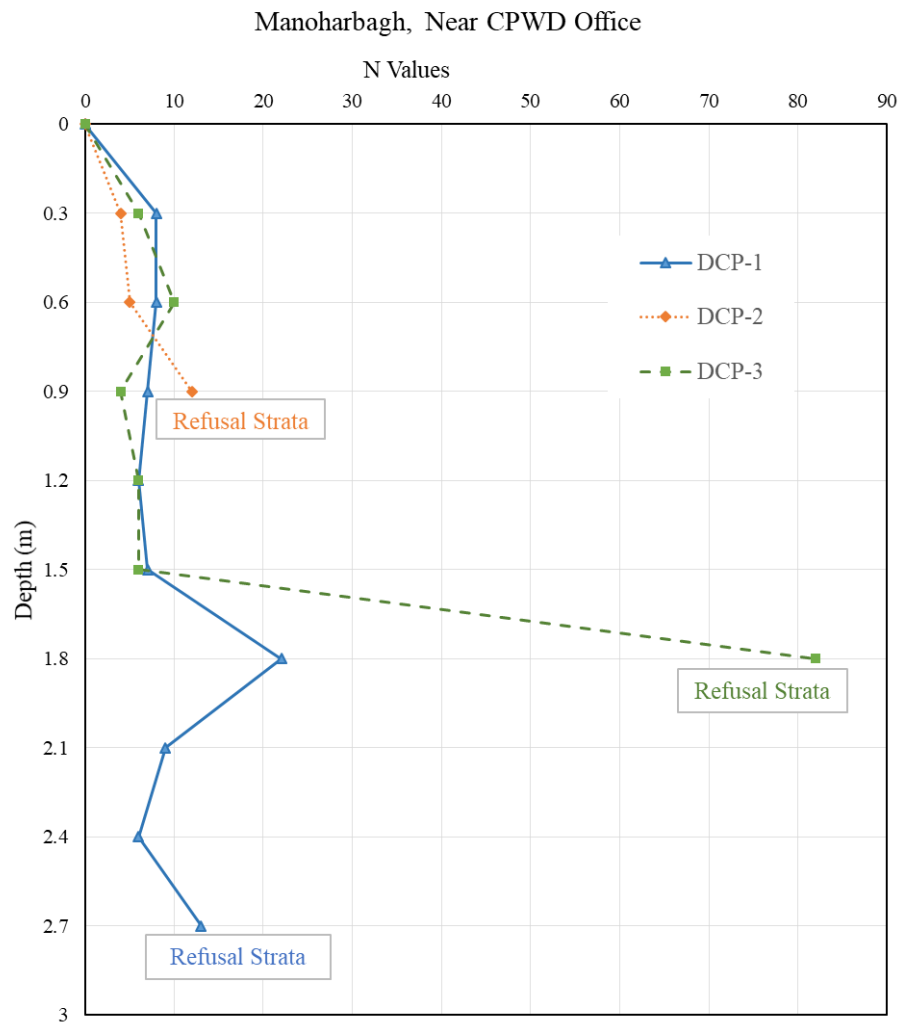


Fig. 8.2: DCPT Results for Manoharbagh, Near CPWD Office

In **Fig. 8.2**, Values of cone resistance is not varying very much but observed refusal for two DCPTs at depths 0.9m and 1.8m. The DCPT cone could not be penetrated beyond 2.7m. Based on the DCPT-1, the minimum and maximum values are 6 and 22 respectively.

8.3: MASW Test Results

Though MASW tests has been conducted on this site, however, when the data was processed, results obtained were very abnormal. This is because proper dispersion image couldn't be obtained from MASW testing, due to presence of nearby sub-structures/retaining walls. Hence, results for MASW are not presented here.

8.4: NMC Results

Water content of the soil samples collected from Manoharbagh, Near CPWD Office at depths of 0.5m, 1m, 1.5m, 3m and 4m.

Table 8.1 Natural moisture content of the soil for Manoharbagh, Near CPWD Office

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 27-01-2023		
Sampling location	Manoharbagh, Near CPWD Office	
S.no	Depth (m)	Water Content (%)
1	0.5	6.99
2	1	8.74
3	1.5	6.82
4	3	12.12
5	4	11.13

8.5: Grain Size Distribution Analysis

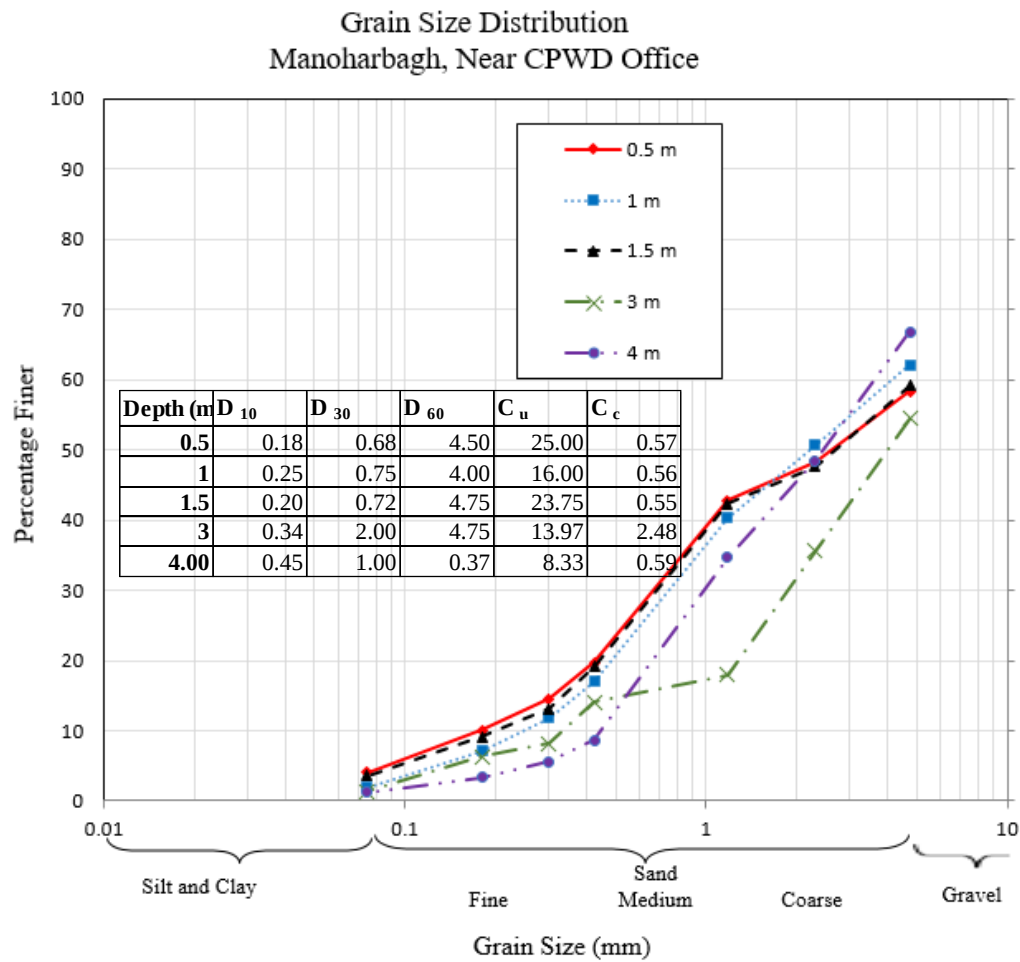


Fig. 8.4: Grain size distribution for Manoharbagh, Near CPWD Office

8.6: Summary of all the Results

Table 8.2 Summary of the soil for Manoharbagh, Near CPWD Office

LABORATORY TEST REPORT ON SOIL SAMPLES											
SAMPLING LOCATION:			Manoharbagh, Near CPWD Office								
Depth (m)	IS Classification	N.M.C. %	Grain Size Analysis %			PL	Curv.	Coeff.	DD	Spec. Gravity	Void Ratio %
			Gravel	Sand	Fines		Cu		γ_d (kN/m ³)		
G.L.											
0.5	SP	6.99	41.64	54.28	4.09	NP	25.00	0.57	13.83	2.66	92.29
1	SP	8.74	37.91	60.19	1.90	NP	16.00	0.56	13.61	2.66	95.44
1.5	SP	6.82	40.82	55.62	3.56	NP	23.75	0.55	13.86	2.66	91.98
3	SW	12.12	45.58	53.06	1.36	NP	13.97	2.48	13.20	2.66	101.52
4	SP	11.13	33.17	65.55	1.28	NP	8.33	0.59	13.32	2.66	99.74

8.7: Overview of the Site

Test site is located near Malalai Inn hotel in front of CPWD office, Manoharbagh (Ward 5). Initially, it was decided to conduct all the proposed tests in front of Malalai Inn. However, due to ongoing demolition work, it was decided to carry out the testing bit away from Malalai Inn and in front of the CPWD office. Though the available space was not so large but it was good location to mimic a typical damaged condition nearby Malalai Inn. The proposed field tests, Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT) and Multi-channel Analysis of Surface Waves along with HVSR were conducted at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) Analysis were also conducted on the samples procured from the field.

Plate load test was conducted at a depth of 1.5m. Load-settlement curve obtained is appeared to be normal to typical soil mixtures. Ultimate and safe load carrying capacities of the soil are found to be 19 t/m^2 and 6.33 t/m^2 respectively from the plate load test results, which is lower side.

DCPT test is repeated three times due to the difficulties encountered during the testing. Initial two DCPT tests were conducted only up to 0.9m and 1.8m due to the refusal strata. However, third test conducted slightly away from the initial two tests, went up to 2.7m. This is typical situation encountered in almost all test sites in Joshimath. It is primarily because of presence of boulders and gravel along with soil. From the field excavations and sampling, it is clearly noticed that subsurface strata consist of mixture boulders, gravels and soils. The values of all three DCPT other than refusal location are approximately 10, this indicates the soil as very loose.

As discussed, proper dispersion image couldn't be obtained from MASW testing, due to presence of nearby sub-structures/retaining walls. Natural Moisture Content of the field samples is found to be varying between 6.8 to 12.1%. GSD analysis conducted on samples collected from 0.5 to 4 m depths revealed that the soils are predominantly Sandy with some gravels. Further, soils are found to be non-plastic.

Concluding Remarks: Based on PLT, the site is having very low bearing capacity. The DCPT results indicates low soil resistance. Field tests results are in support of field damages observed. In the field, sever damage was observed in the nearby hotels as well as in other buildings.

Site 9: Upper Bazar: Near Nagarpalika

9.1: Plate Load Test (PLT) Results

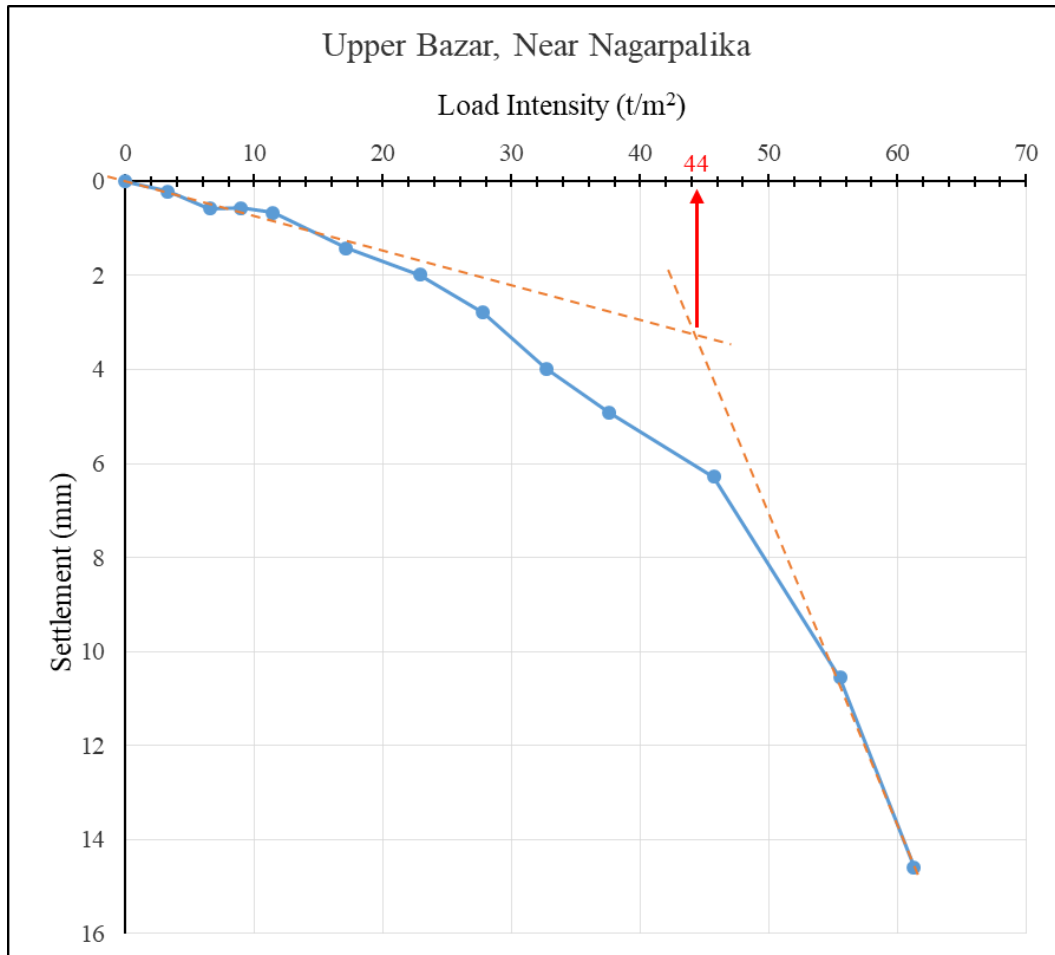


Fig. 9.1: PLT Result for Upper Bazar, Near Nagarpalika

Analysis of **Fig. 9.1** using asymptotes yields a minimum failure load as 44 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 14.67 t/m^2 .

9.2: Dynamic Cone Penetration (DCPT) Results

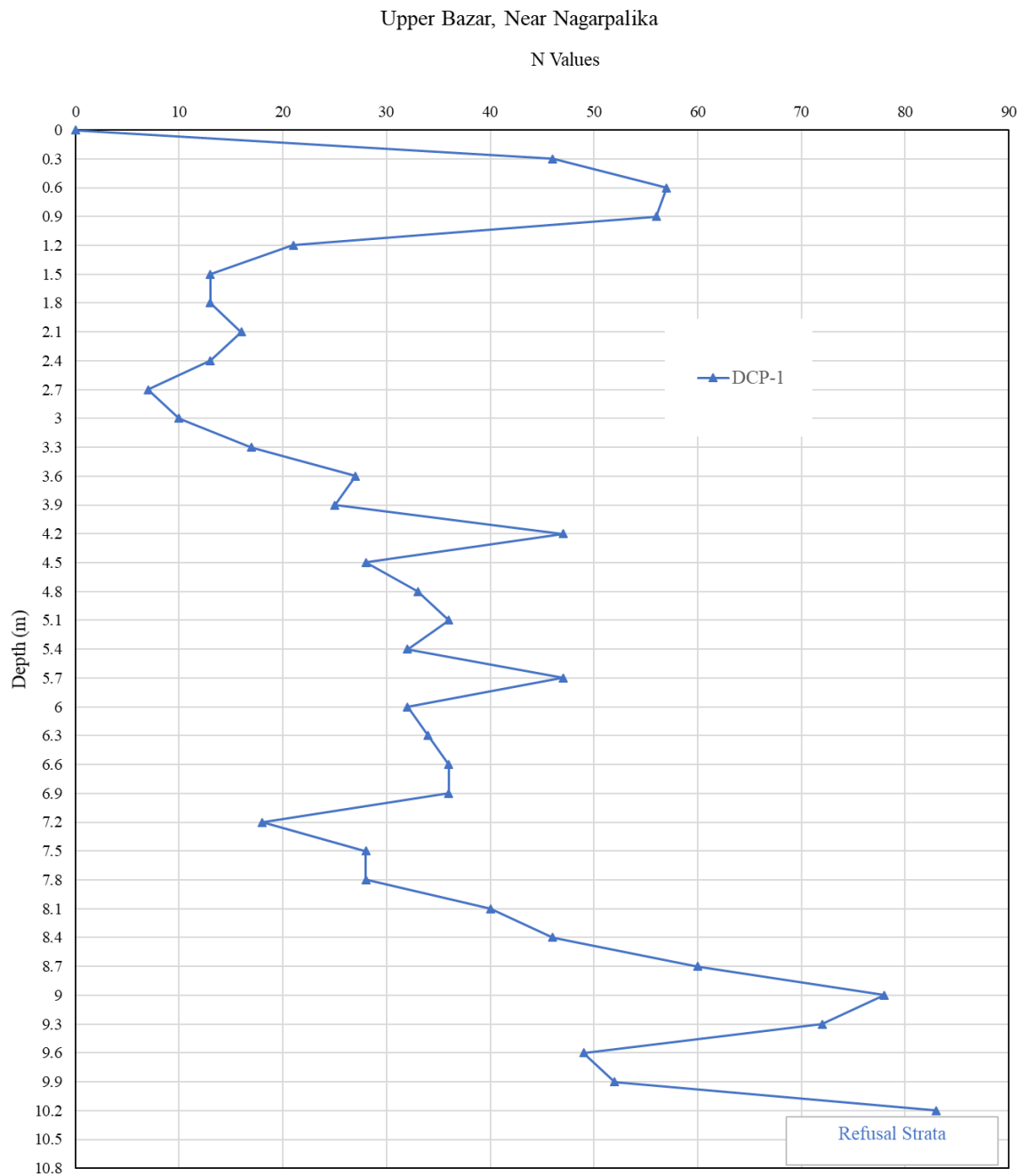


Fig. 9.2: DCPT Results for Upper Bazar, Near Nagarpalika

In **Fig. 9.2**, Values of cone resistance is varying very much. The cone at this site reached more than 10m depth before refusal. The minimum and maximum value of DCPT anticipated are 7 and 83 respectively.

9.3: Direct Shear Test (DST) Results

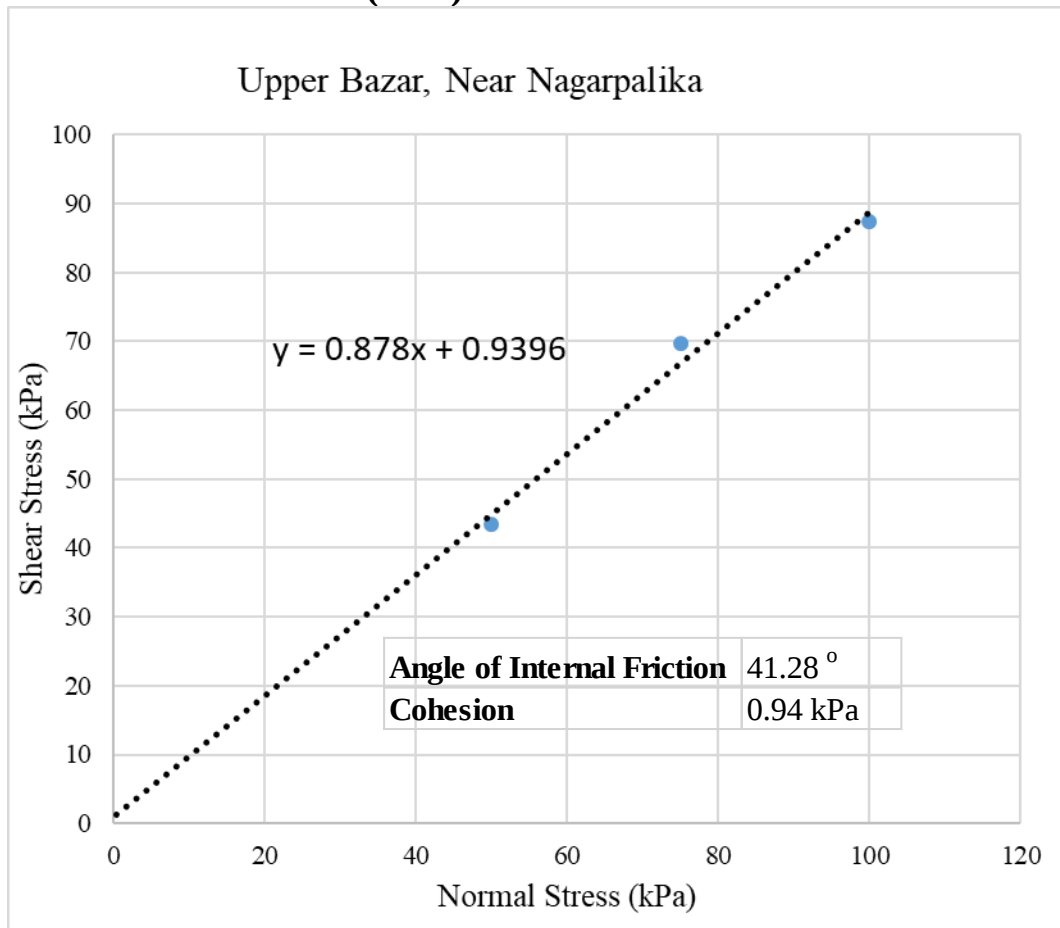


Fig. 9.3: DST Results for Upper Bazar, Near Nagarpalika

From the result of direct shear test done at site having size 700 mm × 700 mm as shown in **Fig. 9.3**, the angle of internal friction of soil and cohesion are 41.28° and 0.94kN/m² respectively.

9.4: MASW Test Results

Upper Bazar, Near Nagarpalika

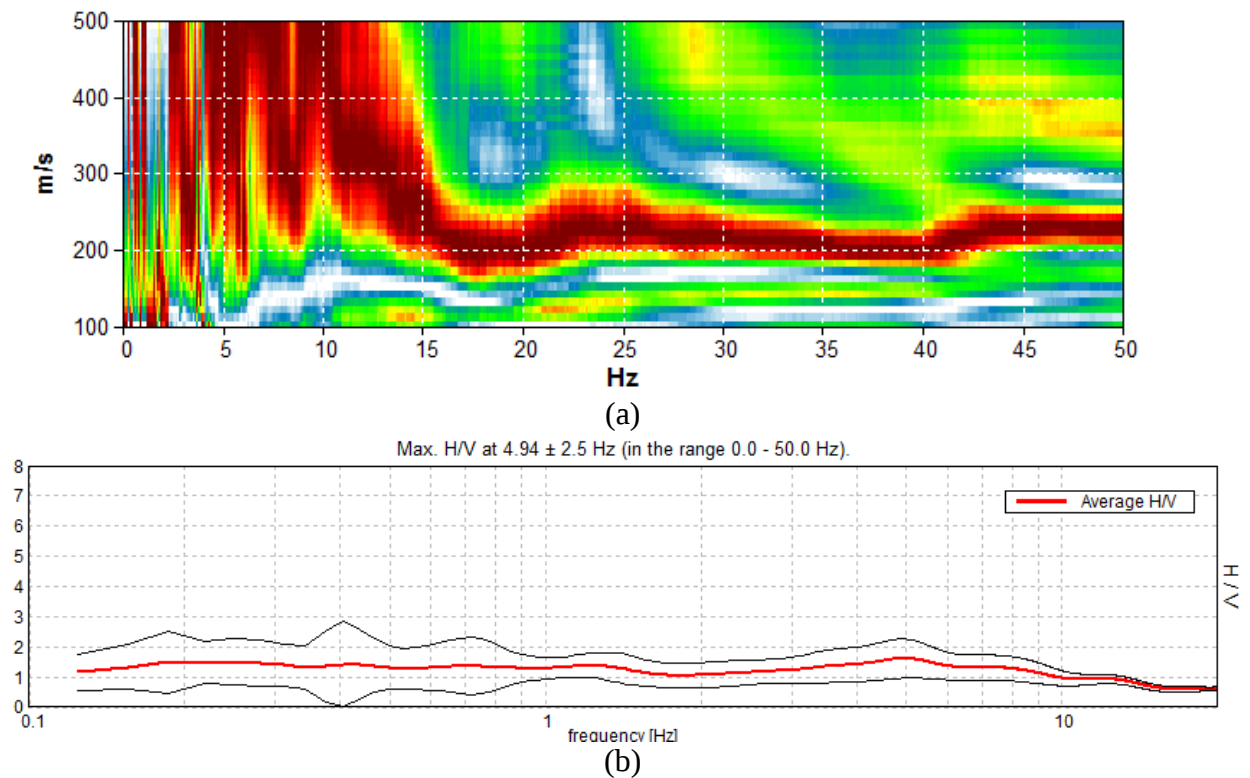


Fig. 9.4: (a) MASW & (b) HVSR Test Results for Upper Bazar, Near Nagarpalika

Based on the analysis, the best fitting soil profile has been obtained and presented in **Fig. 9.4**. It can be observed from **Fig. 9.5**, the Shear Wave Velocity (V_s) for Upper Bazar, Near Nagarpalika lies in the range of 220 to 480 m/s up to a depth of 30m.

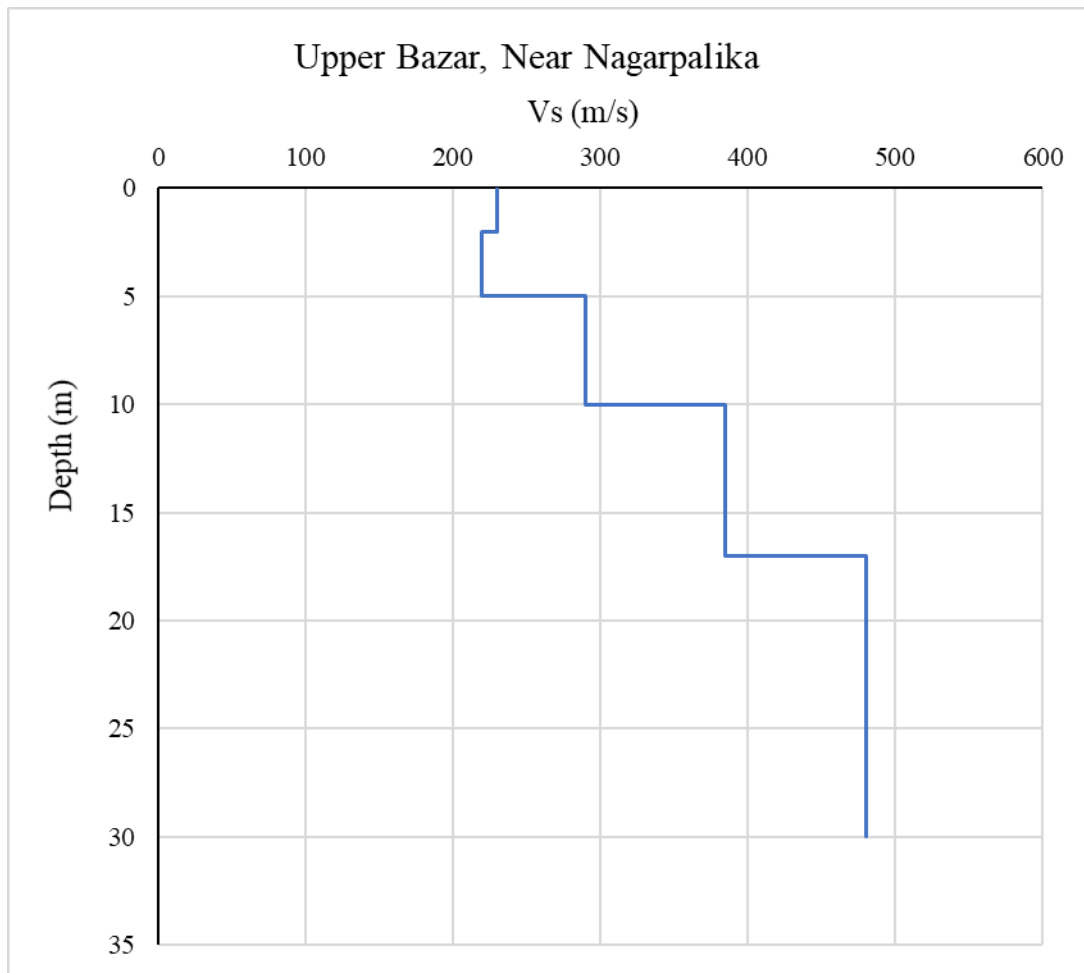


Fig. 9.5: Shear Wave Velocity Obtained at Upper Bazar, Near Nagarpalika

9.5: NMC Results

Water content of the soil samples collected from Upper Bazar, Near Nagarpalika at depths of 1m, 2m, 3m, 4m and 4.5m.

Table 9.1 Natural moisture content of the soil for Upper Bazar, Near Nagarpalika

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 20-02-2023		
Sampling location	Upper Bazar, Near Nagarpalika	
S.no	Depth (m)	Water content (%)
1	1	8.07
2	2	12.31
3	3	10.78
4	4	10.80
5	4.5	12.56

9.6: Grain Size Distribution Analysis

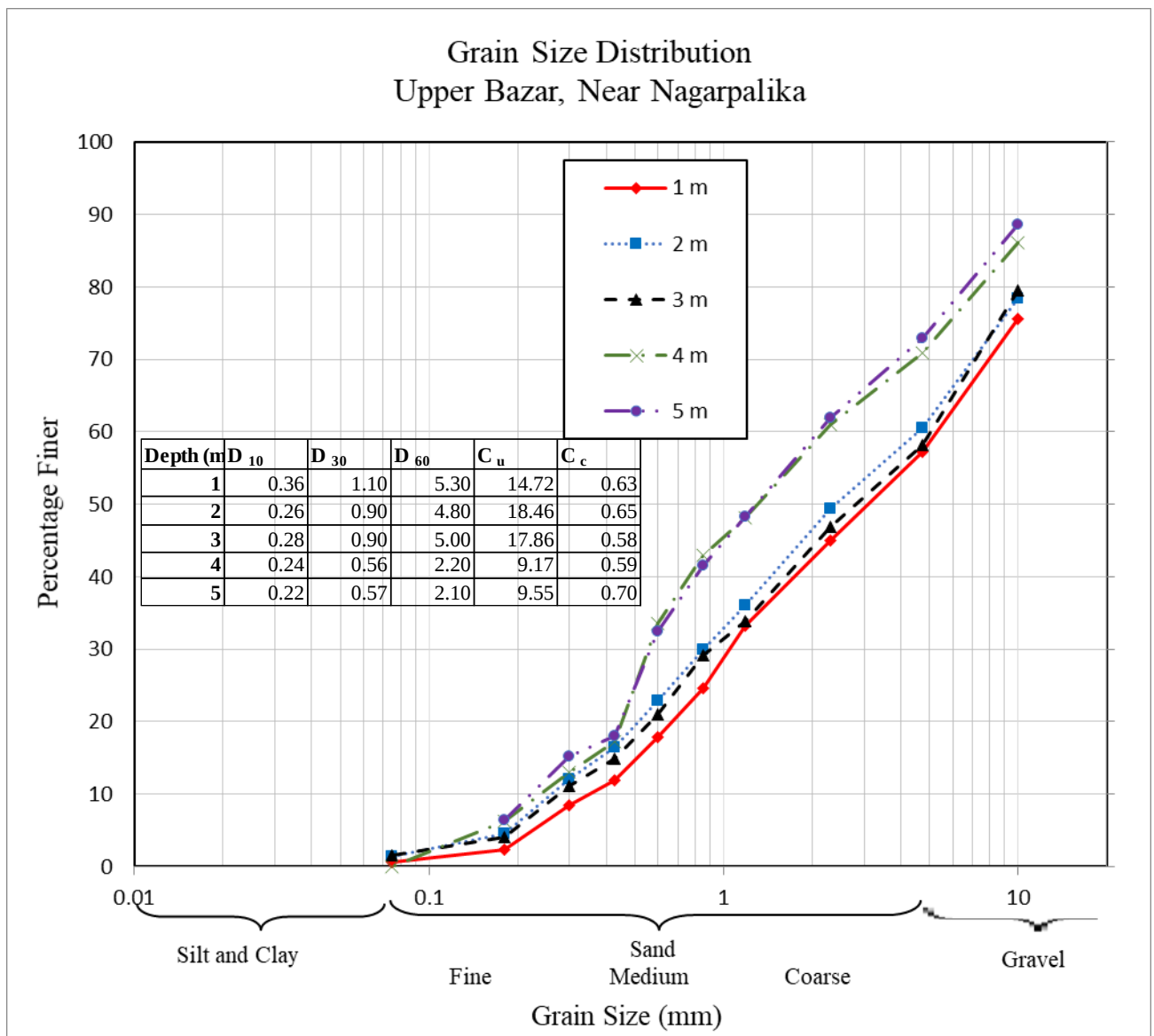


Fig. 9.6: Grain size distribution for Upper Bazar, Near Nagarpalika

9.7: Summary of all the Results

Table 9.2 Summary of the soil for Upper Bazar, Near Nagarpalika

LABORATORY TEST REPORT ON SOIL SAMPLES													
SAMPLING LOCATION:			Upper Bazar, Near Nagarpalika										
Depth (m)	IS Classification	N.M.C. %	Grain Size Analysis %			PL	Curv.	Coeff.	DD	Spec. Gravity	Void Ratio %	Shear Parameters	
			Gravel	Sand	Fines		Cu	Cc	γ_d (kN/m ³)			c (kN/m ²)	ϕ (°)
G.L.													
1	SP	8.07	42.70	56.69	0.61	NP	14.72	0.63	13.32	2.66	99.63	-	-
2	SP	12.31	39.54	59.12	1.34	NP	18.46	0.65	12.82	2.66	107.46	0.94	41.28
3	SP	10.78	41.84	56.58	1.58	NP	17.86	0.58	13.00	2.66	104.64	-	-
4	SP	10.80	29.17	70.83	0.00	NP	9.17	0.59	13.00	2.66	104.67	-	-
4.5	SP	12.56	27.15	72.85	0.00	NP	9.55	0.70	12.79	2.66	107.92	-	-

9.8: Overview of the Site

Test site is located at Gandhi field near the Nagarpalika in Upper Bazar (Ward 6). All the proposed field tests, Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT), Direct Shear Test (DST) and Multi-channel Analysis of Surface Waves along with HVSR were conducted at this site due to the available space and accessibility. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) Analysis were also conducted on the samples procured from the field.

Plate load test was conducted at a depth of 1.5m. Load-settlement curve obtained is appeared to be normal to typical soil mixtures. Ultimate and safe load carrying capacities of the soil are found to be 44 t/m² and 14.67 t/m² respectively from the plate load test results.

Interesting facts are noticed from DCPT test that due to the movement of vehicles and parking on this field harden the top soil surface. DCPT values for top 1m layer crosses 50 and then start decreasing. For the depths between 1.2m to 3.3m, the values are less than 20 reflecting that this layer is loose. Below 3.9m the soil is medium dense up to 8m. Depth more than 8m encounter stiff soil having DCPT value above 40. The overall soil resistance is good compared to DCPT values at other site.

Field direct shear tests were conducted at three normal stresses with large shear box having dimensions 750mm x 750mm. the large size shear box has been chosen because of the more accuracy and availability of space. The angle of shearing resistance and cohesion are found to be 41.28° and 0.94 kPa respectively from the direct shear tests.

MASW tests were conducted along with the HVSR. Dispersion image obtained from MASW testing is found to be good up to 10Hz frequency with some kinks in it. These kinks are due to soft soil layer encountered between stiff soils. The scattering of dispersion curve is not visible confirms that the large boulders are not present in this soil. HVSR curve is also found to be very peculiar as compared to regular soil sites. In this site also no prominent peak is observed even at low frequencies. This implies that no clear contrast strata is present even at greater depths. This further suggests that similar strata as seen at shallow depths may extending to greater depths. Natural Moisture Content of the field samples is found to be varying between 8 to 12.56% denotes that the moisture is almost constant throughout the depth of 5 m. GSD analysis conducted on samples collected from 1 to 4.5m depths revealed that the soils are predominantly Sands with some gravels. Further, soils are found to be non-plastic.

Concluding Remarks: Based on PLT, the site is having fare enough bearing capacity. The DCPT results indicates soil is not much variable but consist of soft soil layer of thickness 2m below the 1.2m top surface. Similarly, low soil stiffness is observed between 2.5m to 5m from MASW test results. Field tests results are in support of field damages observed. In the field not much sever damage was observed.

Site 10: Sunil: Near Shivalik Cottage

10.1: Plate Load Test (PLT) Results

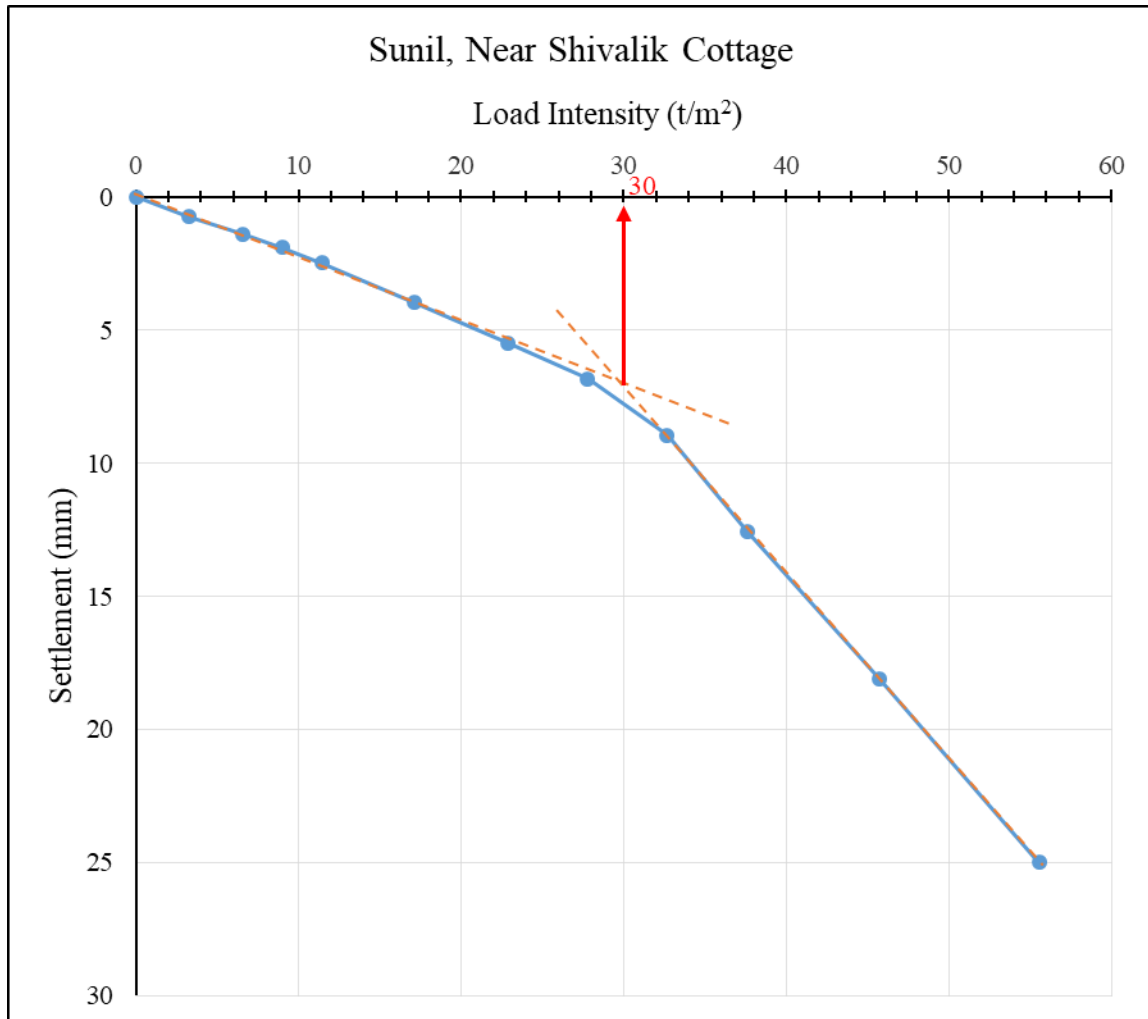


Fig. 10.1: PLT Result for Sunil, Near Shivalik Cottage

Analysis of **Fig. 10.1** using asymptotes yields a minimum failure load as 30 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 10 t/m^2 .

10.2: Dynamic Cone Penetration (DCPT) Results

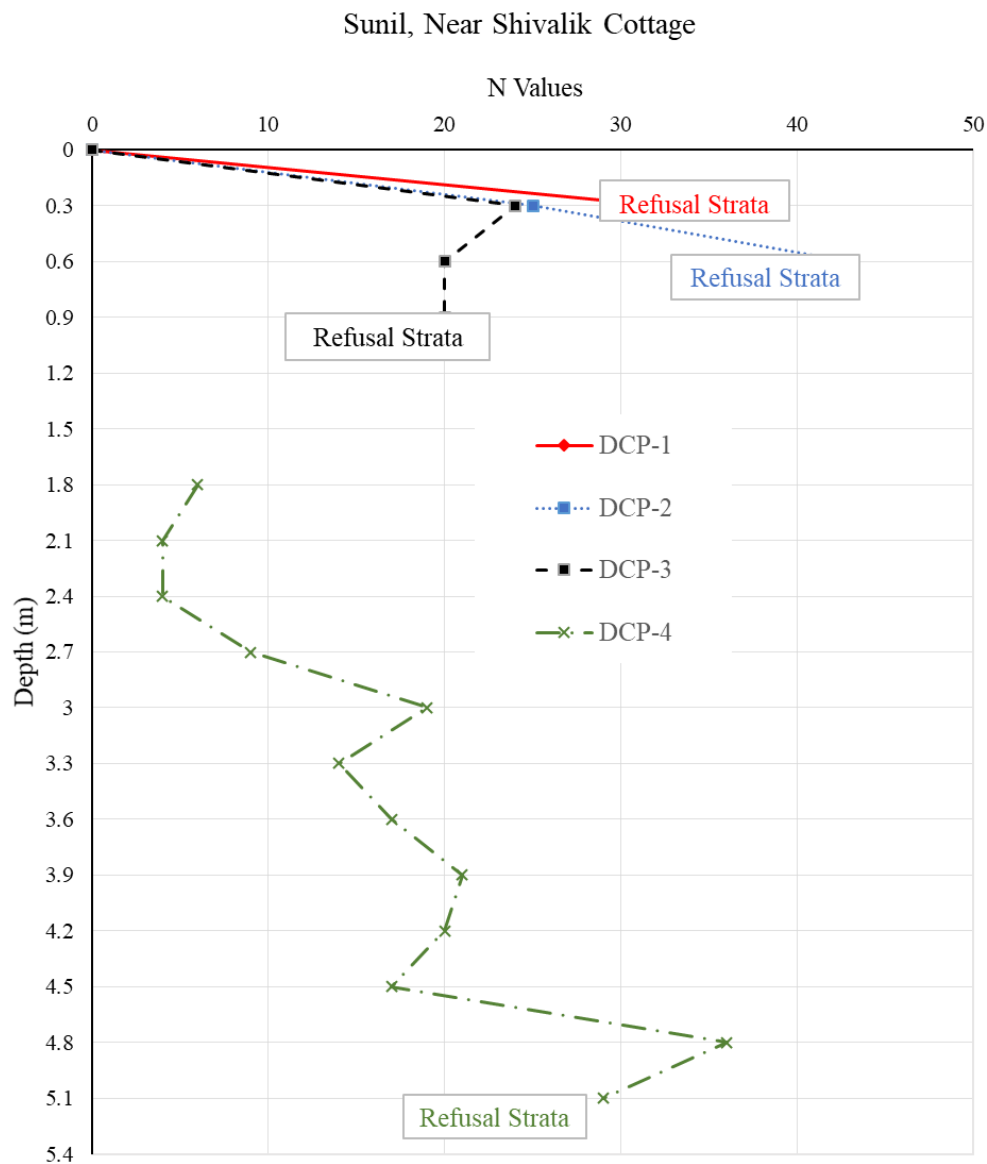


Fig. 10.2: DCPT Results for Sunil, Near Shivalik Cottage

At this site in the Sunil as shown in **Fig. 10.2**, the three refusal are obtained due to anticipation of boulders. The forth DCPT is conducted in PLT pit which starts from depth of 1.8m. The maximum and minimum values of cone resistance is varied from 4 to 36. Due to refusal; cone could not be penetrated beyond 5.1m.

10.3: Direct Shear Test (DST) Results

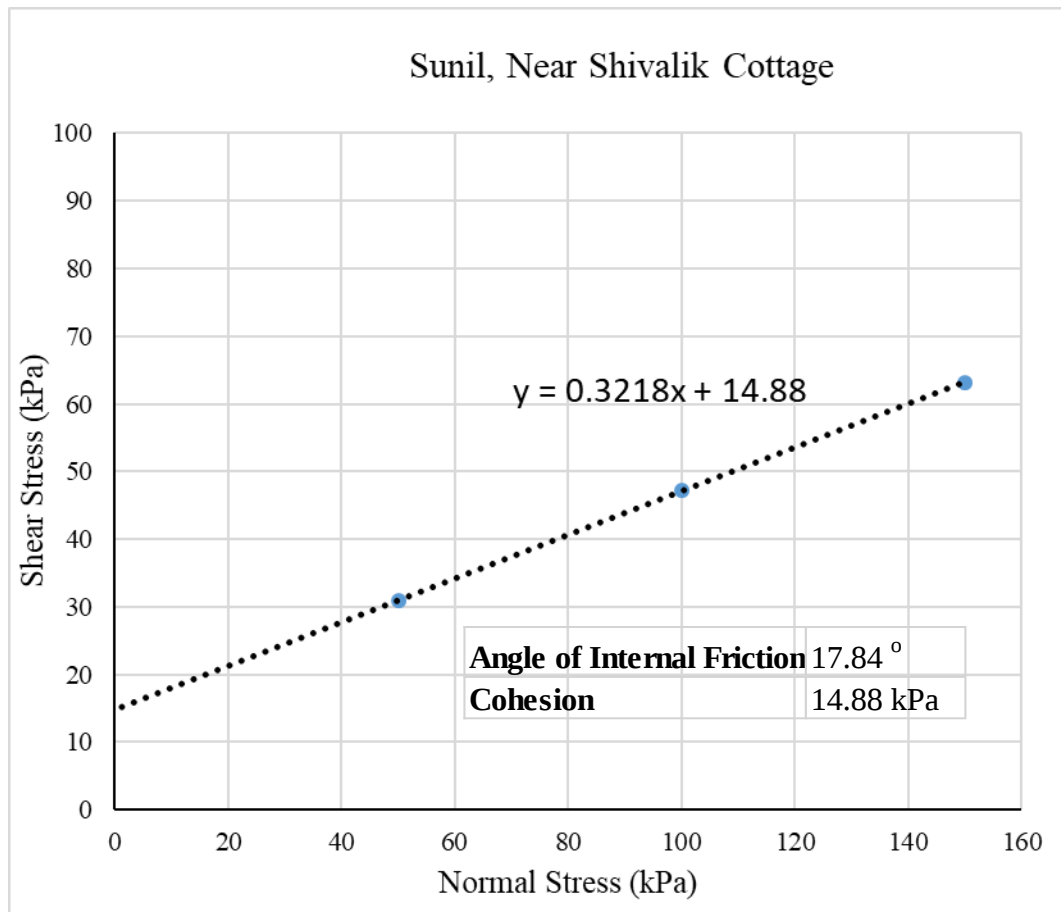


Fig. 10.3: DST Results for Sunil, Near Shivalik Cottage

From the result of direct shear test done at site having size 300 mm × 300 mm as shown in **Fig. 10.3**, the angle of internal friction of soil and cohesion are 17.84° and 14.88kN/m² respectively.

10.4: MASW Test Results

Sunil, Near Shivalik Cottage

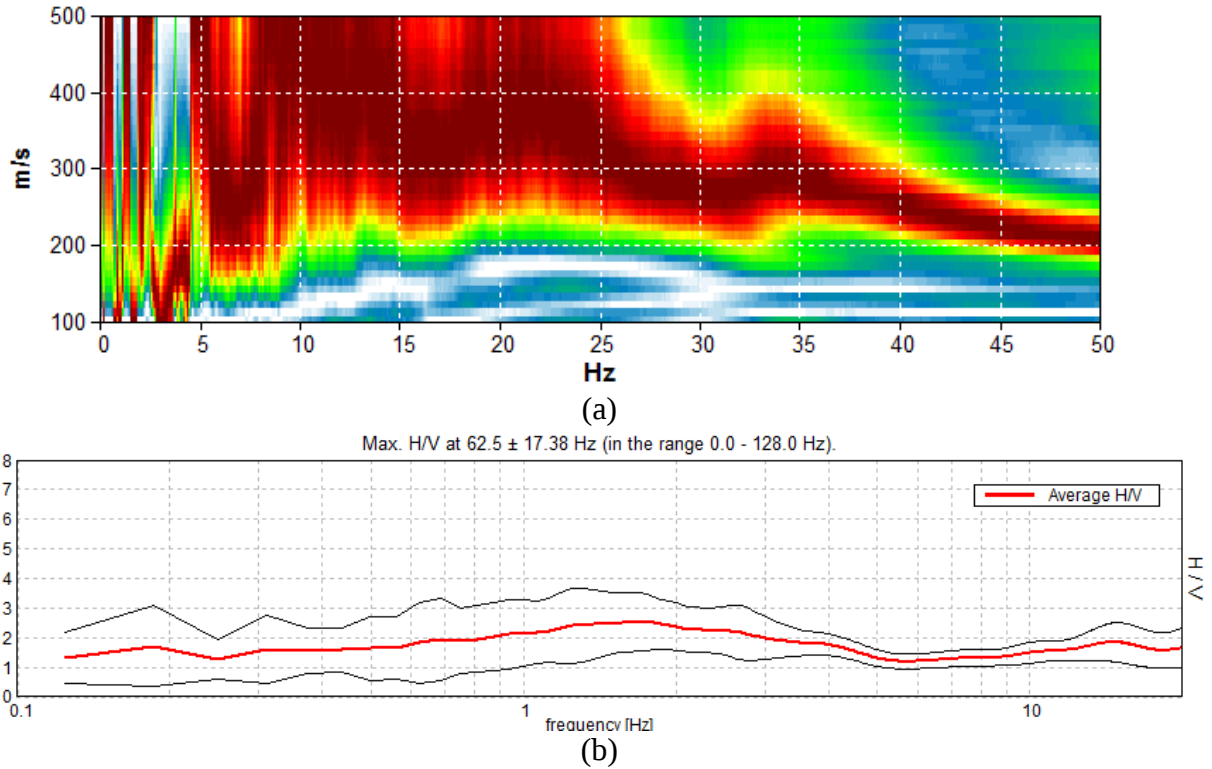


Fig. 10.4: (a) MASW & (b) HVSR Test Results for Sunil, Near Shivalik Cottage

Based on the analysis, the best fitting soil profile has been obtained and presented in **Fig. 10.4**. It can be observed from **Fig. 10.5**, the Shear Wave Velocity (V_s) for Sunil, Near Shivalik Cottage lies in the range of 222 to 530 m/s up to a depth of 33m.

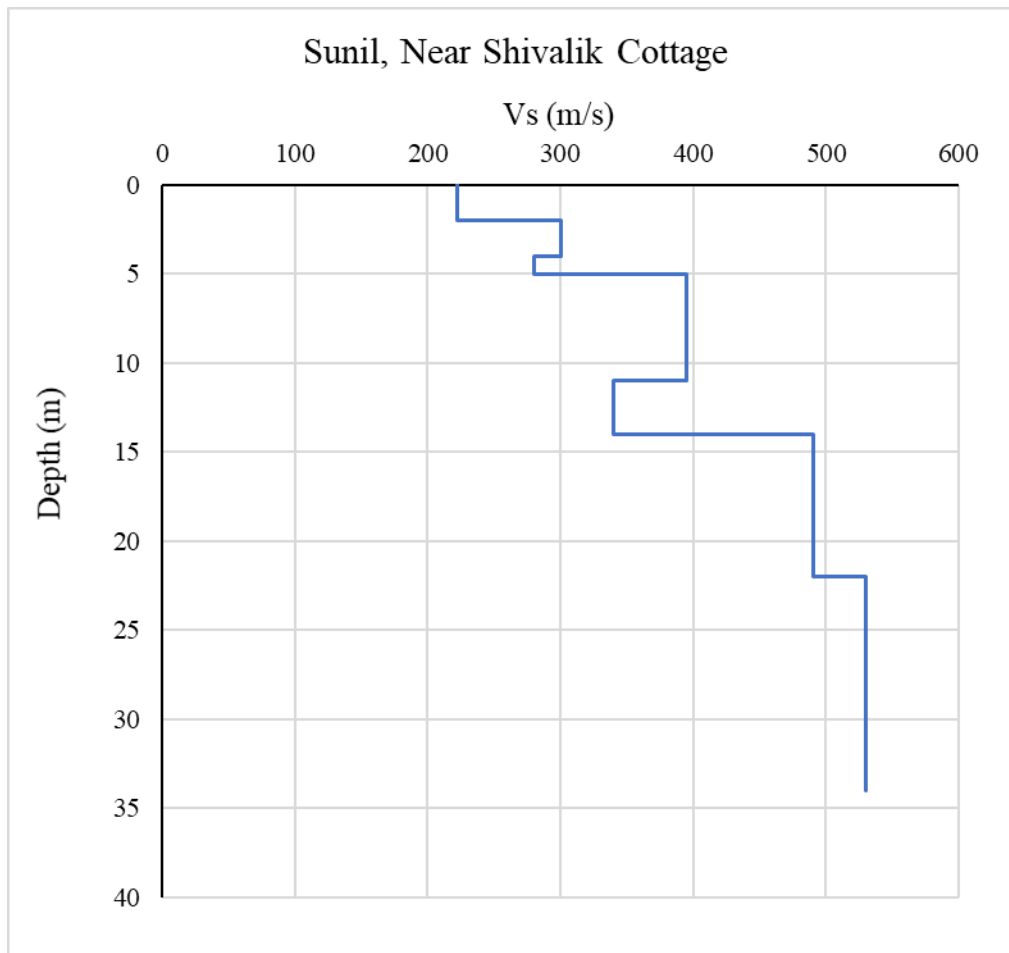


Fig. 10.5: Shear Wave Velocity Obtained at Sunil, Near Shivalik Cottage

10.5: NMC Results

Water content of the soil samples collected from Sunil, Near Shivalik Cottage at depths of 1m, 2m, 3m and 3.5m.

Table 10.1 Natural moisture content of the soil for Sunil, Near Shivalik Cottage

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 16-02-2023		
Sampling location		Sunil, Near Shivalik Cottage
S.no	Depth (m)	Water content (%)
1	1	10.72
2	2	24.61
3	3	12.81
4	3.5	15.61

10.6: Grain Size Distribution Analysis

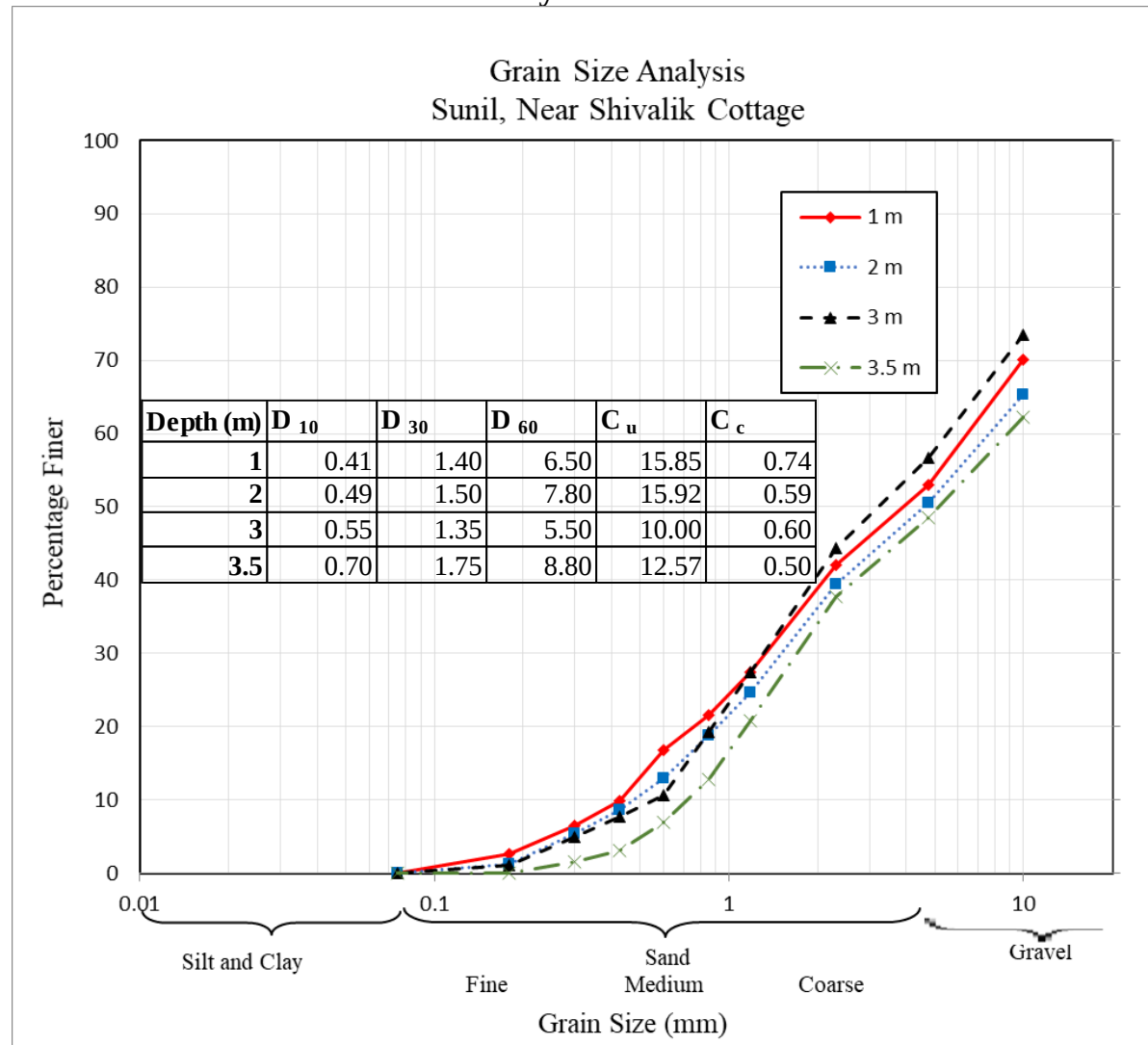


Fig. 10.6: Grain size distribution for Sunil, Near Shivalik Cottage

10.7: Summary of all the Results

Table 10.2 Summary of the soil for Sunil, Near Shivalik Cottage

LABORATORY TEST REPORT ON SOIL SAMPLES													
SAMPLING LOCATION:			Sunil, Near Shivalik Cottage										
Depth (m)	IS Classification	N.M.C. (%)	Grain Size Analysis %				Curv.	Coeff.	DD	Spec. Gravity	Void Ratio %	Shear Parameters	
			Gravel	Sand	Fines	PL	Cu	Cc	γ_d (kN/m ³)			c (kN/m ²)	ϕ (°)
G.L.													
1	SP	10.72	47.06	52.94	0.00	NP	15.85	0.74	13.01	2.66	104.52	-	-
2	SP	24.61	49.53	50.47	0.00	NP	15.92	0.59	11.56	2.66	130.18	14.88	17.84
3	SP	12.81	43.36	56.64	0.00	NP	10.00	0.60	12.76	2.66	108.38	-	-
3.5	GP	15.61	51.54	48.46	0.00	NP	2.57	0.50	12.46	2.66	113.56	-	-

10.8: Overview of the Site

Test site is located near the Shivalik cottage, Sunil (Ward 7). Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT), Direct Shear Test (DST) and Multi-channel Analysis of Surface Waves along with HVSR were conducted at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) Analysis were also conducted on the samples procured from the field.

From PLT, load-settlement curve obtained is appeared to be normal to typical soil mixtures. Ultimate and safe load carrying capacities of the soil are found to be 30 t/m^2 and 10 t/m^2 respectively from the plate load test results.

The presence of the boulders causes the DCPT to fail three times for the depths less than 1m. DCPT test is repeated fourth time in this pit excavated for PLT so that the top surface boulders could be eliminated. This method allows to reach 5.1m. The value of DCPT at 0.3 m depth is relatively good (may be due to compaction of top layer). However, it suddenly drops. At the depth of 4.8 m, the DCPT value reached is about 35 but again drops below 30 at 5.1m. This type of variable behavior is because of presence of weak boulders which sometimes get breaks by DCPT.

Field direct shear tests were conducted at three normal stresses. The angle of shearing resistance and cohesion are found to be 17.84° and 14.88 kPa respectively from the direct shear tests. These values are also low indicating the soft soil.

The share wave velocity obtained from MASW tests are ranges between 222 to 530 m/s. However, tendency of shear wave velocity drop was observed at frequency 17 and 32.5 Hz. HVSR indicates that similar strata as seen at shallow depths may extend to greater depths as there is no chance of contrast. Natural Moisture Content of the field samples is found to be varying between 10.72 to 24.61% this large amount of moisture is due to the site location as it is very close to the auli and there are frequent snowfalls in winter. GSD analysis conducted on samples collected from 1 to 3.5m depths revealed that the soils are predominantly sandy up to 3m and at 3.5m it is gravelly. Further, soils are found to be non-plastic.

Concluding Remarks: Based on PLT, the site is having fare enough bearing capacity. The DCPT results indicates high degree of variability in soil resistance. Low DCPT values are observed in the top layers. Low soil stiffness is observed up to 5m depth from MASW test results. Field tests results are in support of field damages observed. In the field, sever damage was observed in one house which may be combined effect of loose soil below top surface and ground subsidence.

Site 11: Parsari: Near AT Nala

11.1: Plate Load Test (PLT) Results

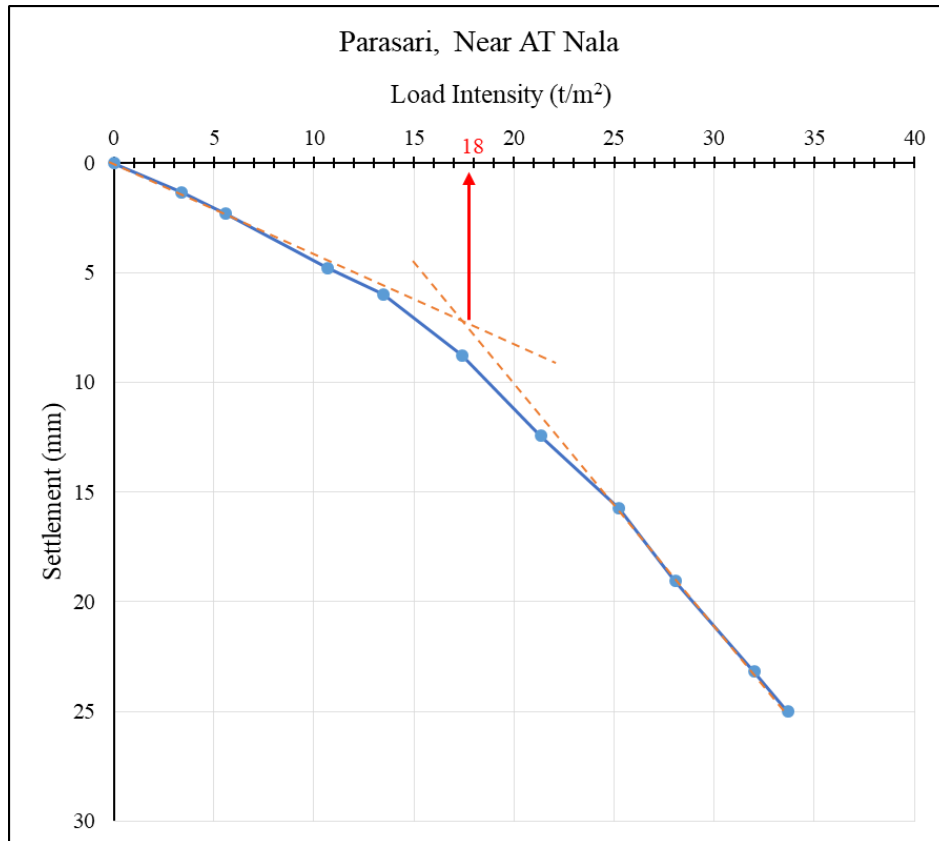


Fig. 11.1: PLT Result for Parsari, Near AT Nala

Analysis of **Fig. 11.1** using asymptotes yields a minimum failure load as 18 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 6 t/m^2 .

11.2: Dynamic Cone Penetration (DCPT) Results

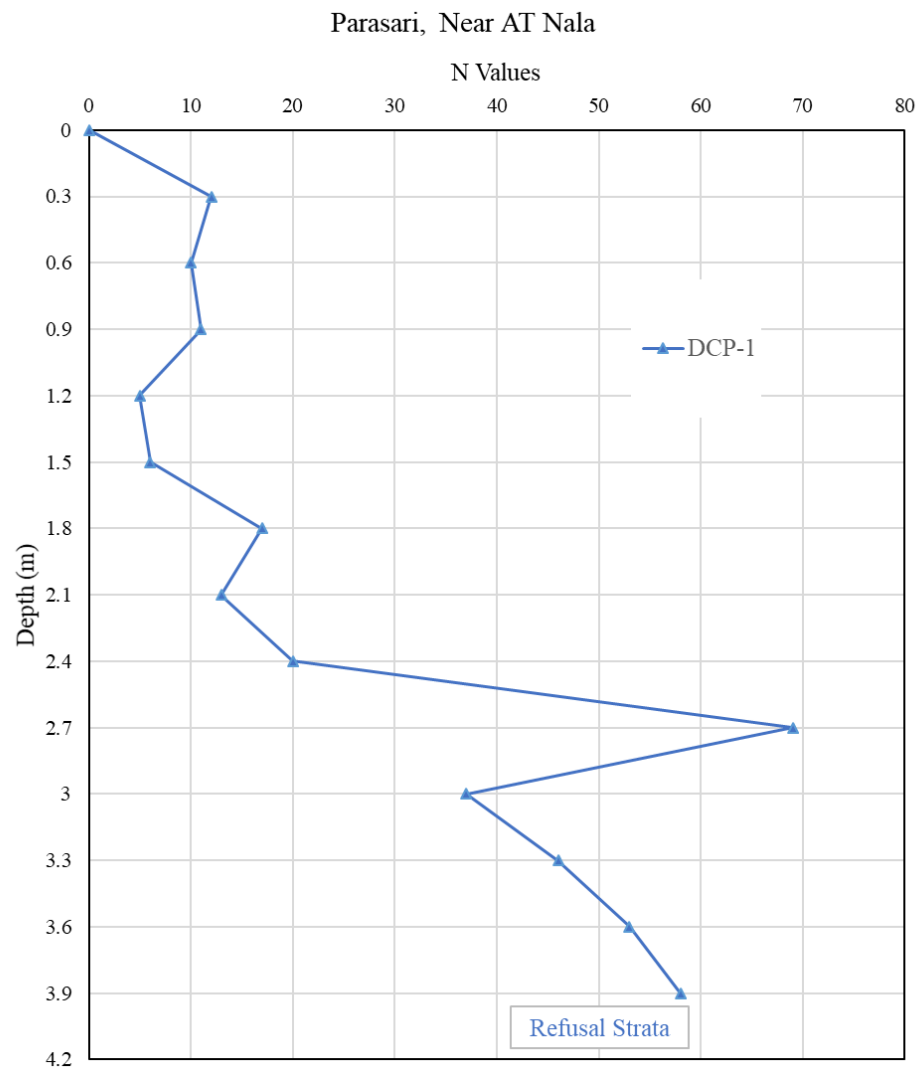


Fig. 11.2: DCPT Results for Parsari, Near AT Nala

In **Fig. 11.2**, Values of cone resistance is varying very much and indicating boulders at depth 2.7m. Due to refusal; cone could not be penetrated beyond 3.9 m. The minimum and maximum number of blows in this DCPT are 5 and 69 respectively.

11.3: MASW Test Results

Parsari, Near AT Nala

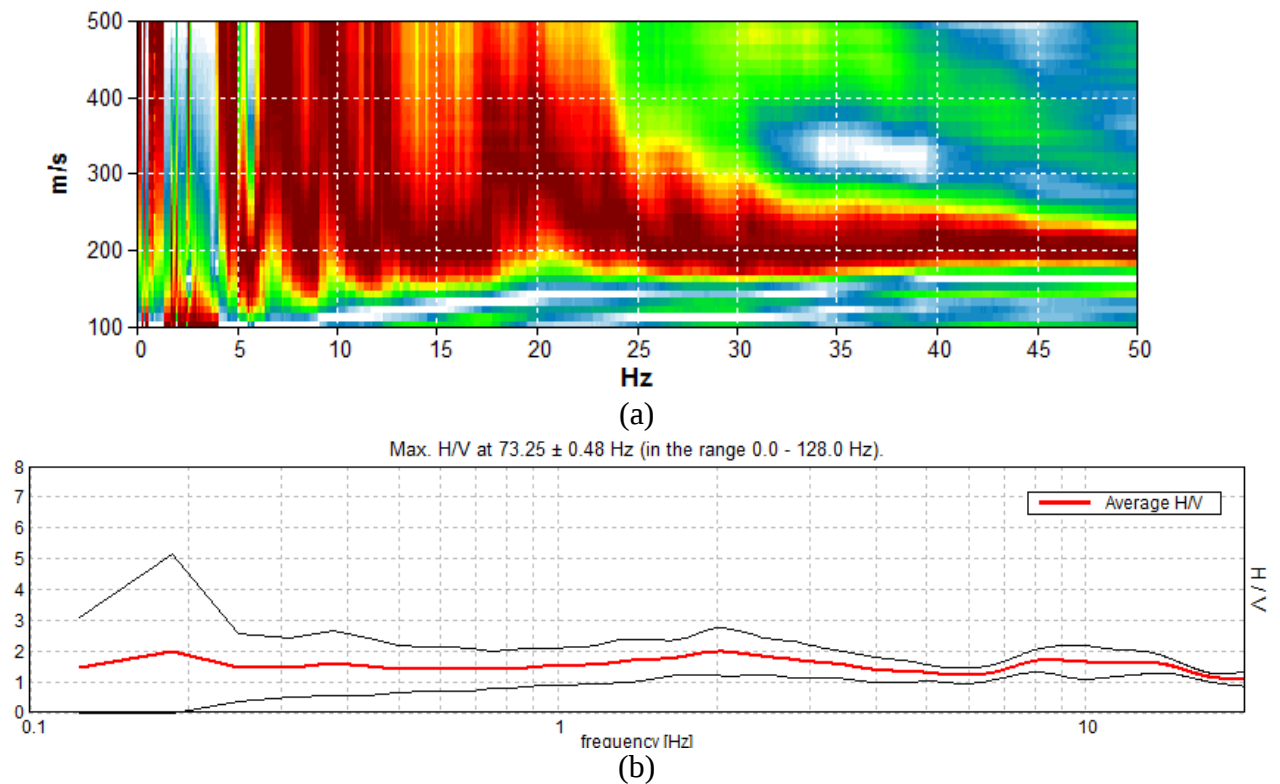


Fig. 11.3: (a) MASW & (b) HVSR Test Results for Parsari, Near AT Nala

Based on the analysis, the best fitting soil profile has been obtained and presented in **Fig. 11.3**. It can be observed from **Fig. 11.4**, the Shear Wave Velocity (V_s) for Parsari, Near AT Nala lies in the range of 210 to 420 m/s up to a depth of 33m.

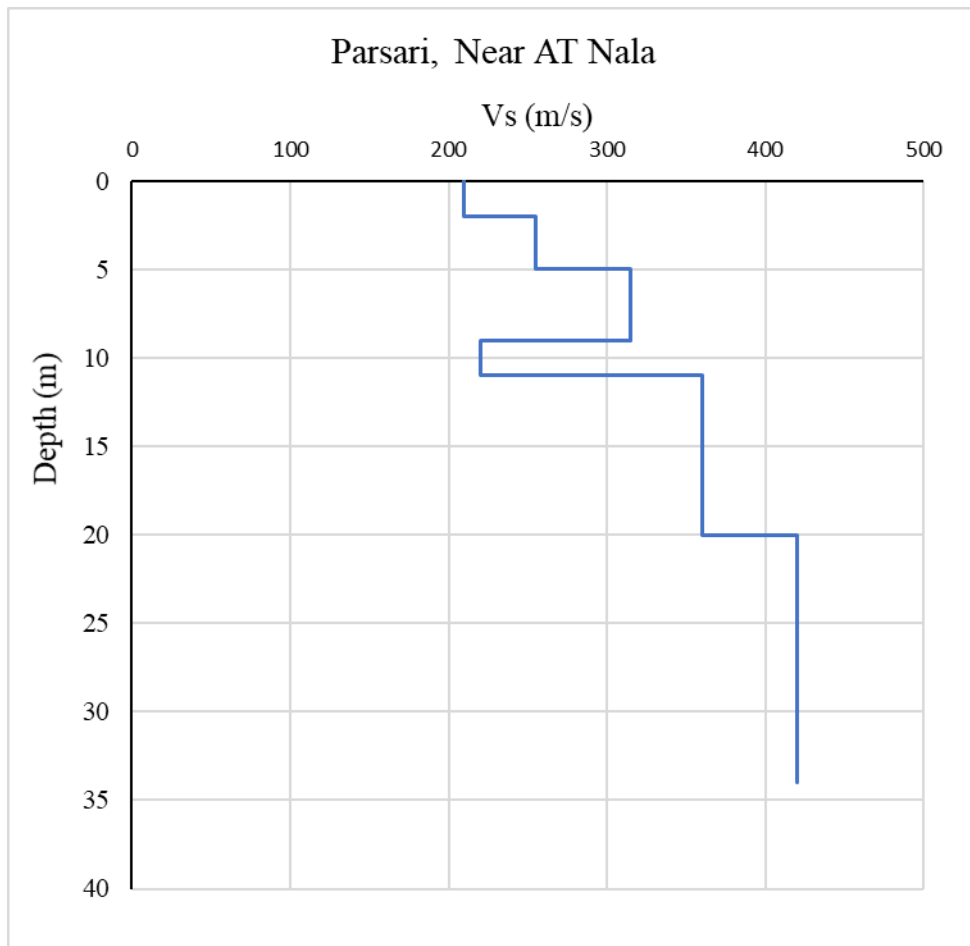


Fig. 11.4: Parsari, Near AT Nala

11.4: NMC Results

Water content of the soil samples collected from Parsari, Near AT Nala at depths of 1m and 1.5m.

Table 11.1 Natural moisture content of the soil for Parsari, Near AT Nala

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 15-02-2023		
Sampling location	Parasari, Near AT Nala	
S.no	Depth (m)	Water content (%)
1	1	11.22
2	1.5	9.10

11.5: Grain Size Distribution Analysis

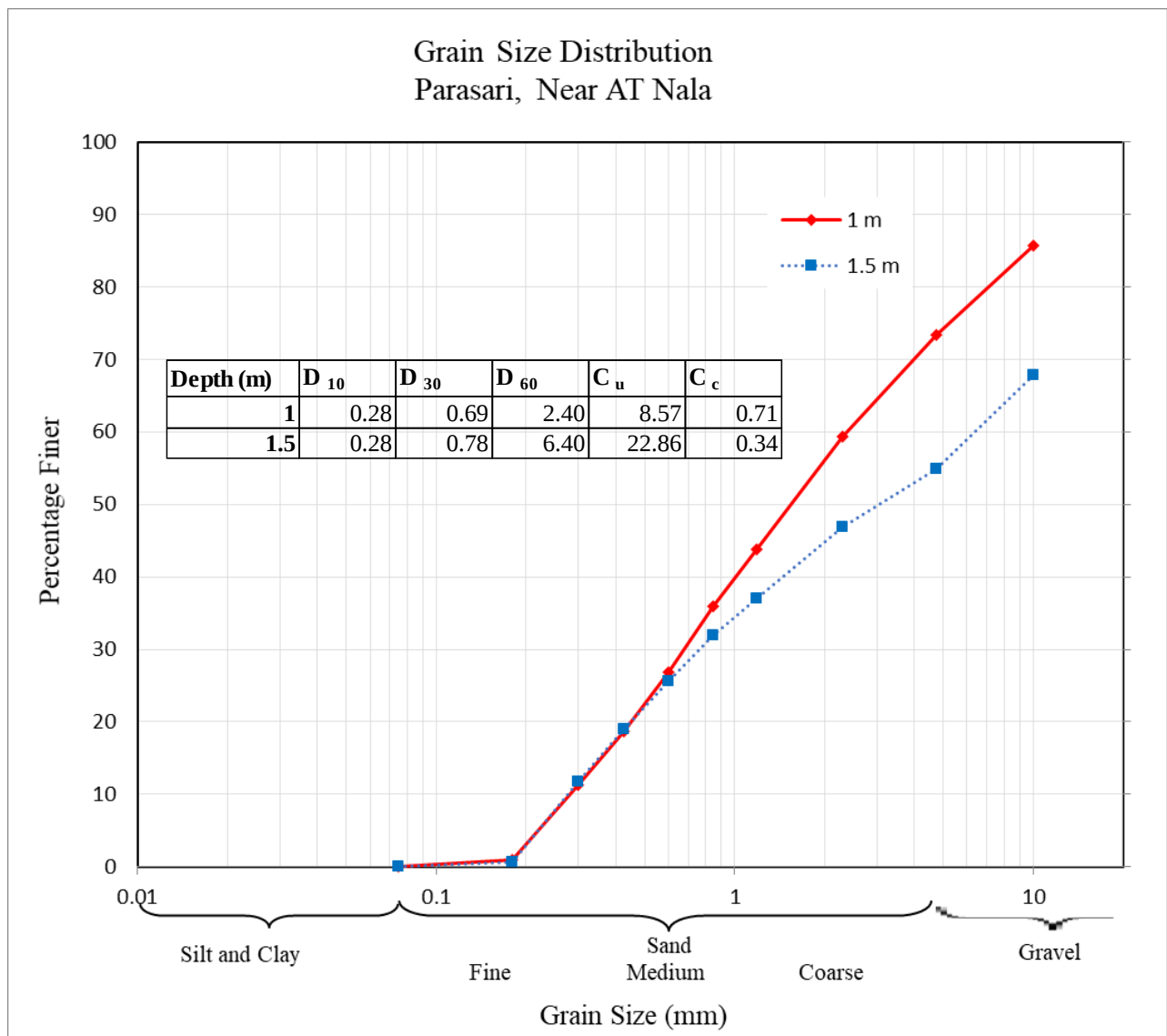


Fig. 11.5: Grain size distribution for Parasari, Near AT Nala

11.6: Summary of all the Results

Table 11.2 Summary of the soil for Parsari, Near AT Nala

LABORATORY TEST REPORT ON SOIL SAMPLES											
SAMPLING LOCATION:			Parsari, Near AT Nala								
Depth (m)	IS Classification	N.M.C. %	Grain Size Analysis %				Curv.	Coeff.	DD	Spec. Gravity	Void Ratio %
			Gravel	Sand	Fines	PL	Cu	Cc	γ_d (kN/m ³)		
G.L.											
1	SP	11.22	26.69	73.31	0.00	NP	8.57	0.71	13.13	2.66	102.63
1.5	SP	9.10	45.05	54.95	0.00	NP	22.86	0.34	13.38	2.66	98.76

11.7: Overview of the Site

Test site is located near AT Nala, in Parsari (Ward 8). The testing site is so selected such that there is sufficient space available for carrying out various tests, while it also represents typical conditions existing in the ward considered and situated near to the subsidence on the road. The all field tests, Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT), and Multi-channel Analysis of Surface Waves along with HVSR were conducted at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) Analysis were also conducted on the samples procured from the field up to the depth 1.5m.

From the PLT, ultimate and safe load carrying capacities of the soil are found to be 18 t/m^2 and 6 t/m^2 respectively from the plate load test results. This is quite low value reflects the soil condition as loose.

Important facts are noticed from DCPT test that in single test depth is reached to 3.9 m which indicates that the top surface does not contains boulders. The value of DCPT is less than 20 up to the depth of 2.4 m. Below this depth, the DCPT value increases which reflects that the soil below this depth becomes stiffer compared to top layer.

MASW tests were conducted along with the HVSR. Dispersion image obtained from MASW testing confirms that the top surface is loose having shear wave velocity near to 200 m/s. the stiffness increases till 9m then soft soil layer of thickness 2 to 3 m is encountered. After this soft layer the stiffness again increases with depth. The shear wave velocity varies from 210 to 420 m/s at this site. Natural Moisture Content of the field samples is found to be approximately 10%. GSD analysis conducted on samples collected from 1m and 1.5m depths revealed that the soils **are predominantly sand** which can be perfectly corelated with the DCPT results. Further, soils are found to be non-plastic.

Concluding Remarks: Based on PLT, the site is having low bearing capacity. The DCPT results indicates the same soil resistance. The DCPT values are observed less than 20 at shallow depth indicates this loose soil. These results are also correlated with the MASW results having low shear wave velocity. Field tests results are in support of field damages observed. In the field subsidence problems are observed on the road surface that have visible cracks.

Site 12: Ravigram: Near Helipad in front of NTPC Gate

12.1: Plate Load Test (PLT) Results

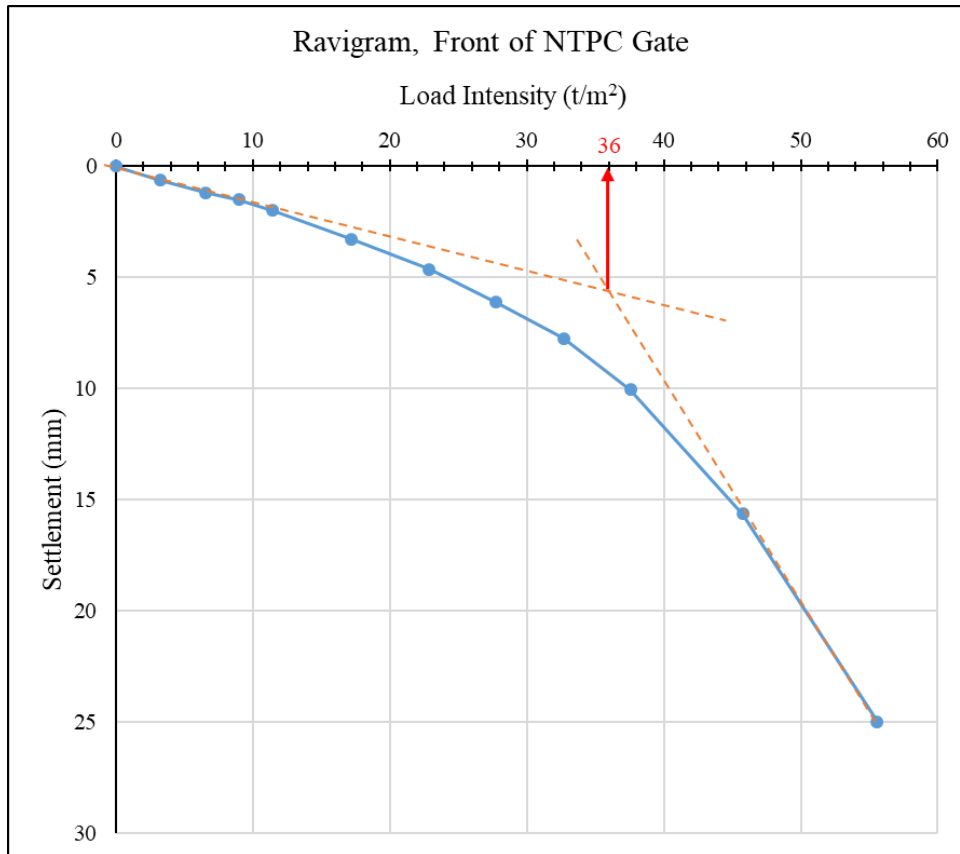


Fig. 12.1: PLT Result for Ravigram, Near Helipad in front of NTPC Gate

Analysis of **Fig. 12.1** using asymptotes yields a minimum failure load as 36 t/m^2 , where using a factor of safety equal to 3 it yields a safe bearing capacity as 12 t/m^2 .

12.2: Dynamic Cone Penetration (DCPT) Results

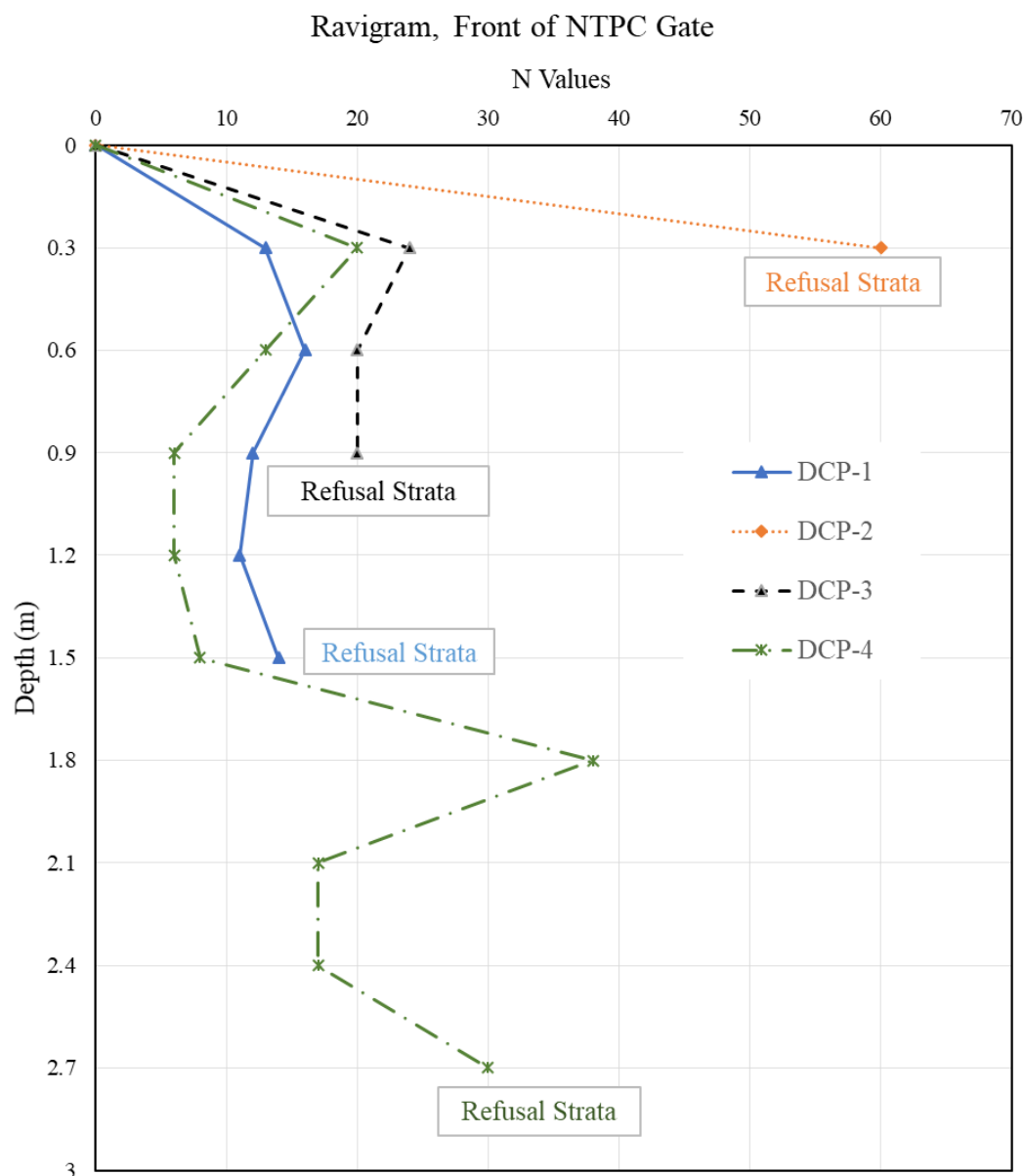


Fig. 12.2: DCPT Results for Ravigram, Near Helipad in front of NTPC Gate

In **Fig. 12.2**, Values of cone resistance is not varying very much but initial three DCPTs got refusal only up to the depth 1.5m. Forth DCPT reached up to 2.7m depth and its values are varied from 6 to 38.

Direct Shear Test (DST) Results

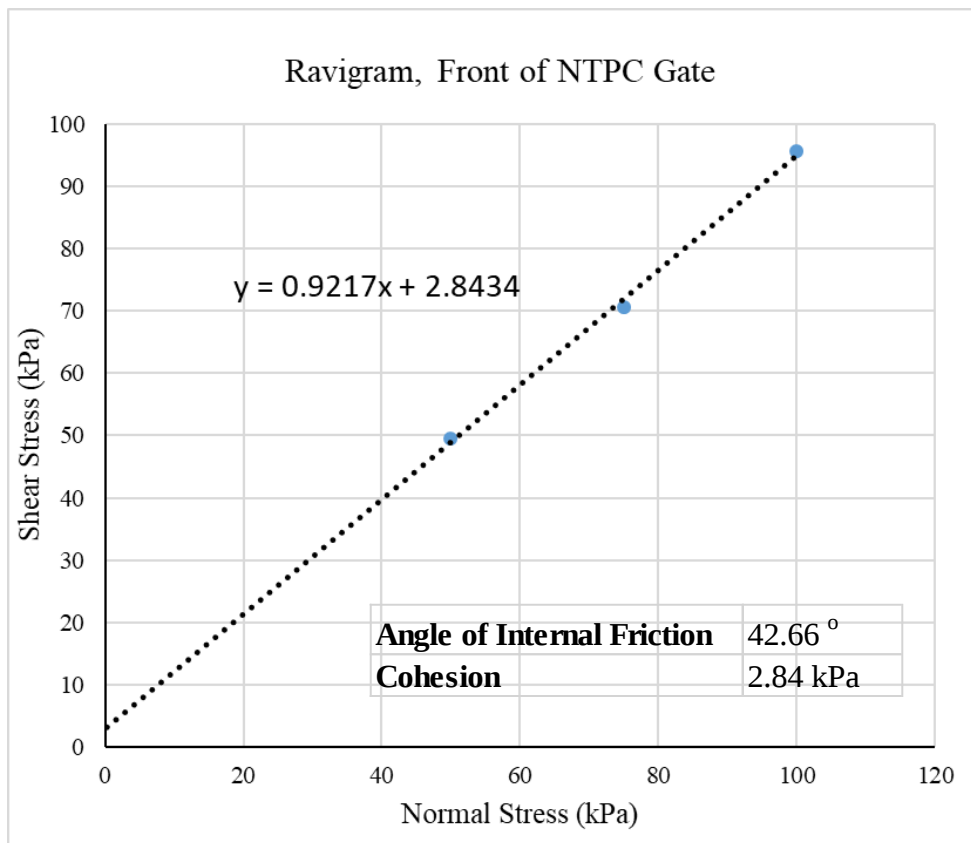


Fig. 12.3: DST Results for Ravigram, Near Helipad in front of NTPC Gate

From the result of direct shear test done at site having size 700 mm × 700 mm as shown in **Fig. 12.3**, the angle of internal friction of soil and cohesion are 42.66° and 2.84kN/m² respectively.

12.3: MASW Test Results

Ravigram, Near Helipad in front of NTPC Gate

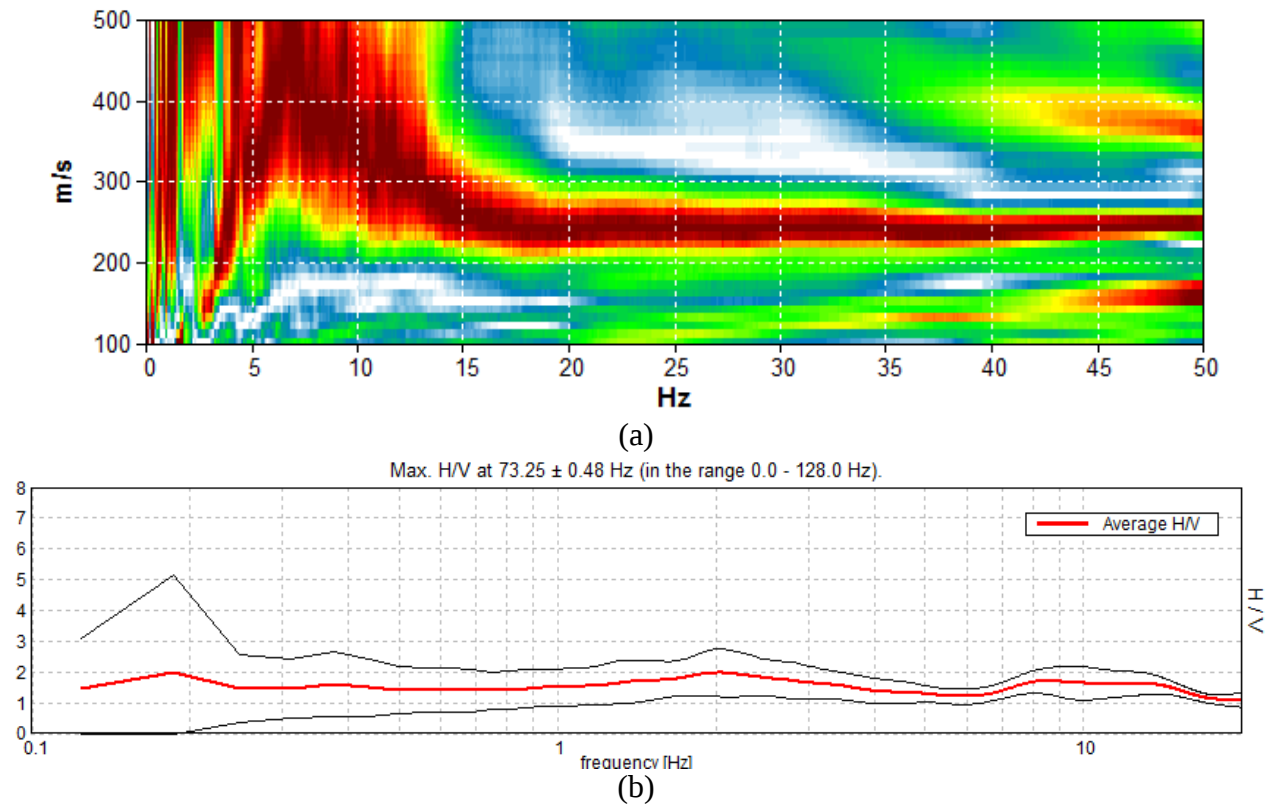


Fig. 12.4: (a) MASW & (b) HVSR Test Results for Ravigram, Near Helipad in front of NTPC Gate

Based on the analysis, the best fitting soil profile has been obtained and presented in **Fig. 12.4**. It can be observed from **Fig. 12.5**, the Shear Wave Velocity (V_s) for Ravigram, Near Helipad in front of NTPC Gate lies in the range of 245 to 500 m/s up to a depth of 27m.

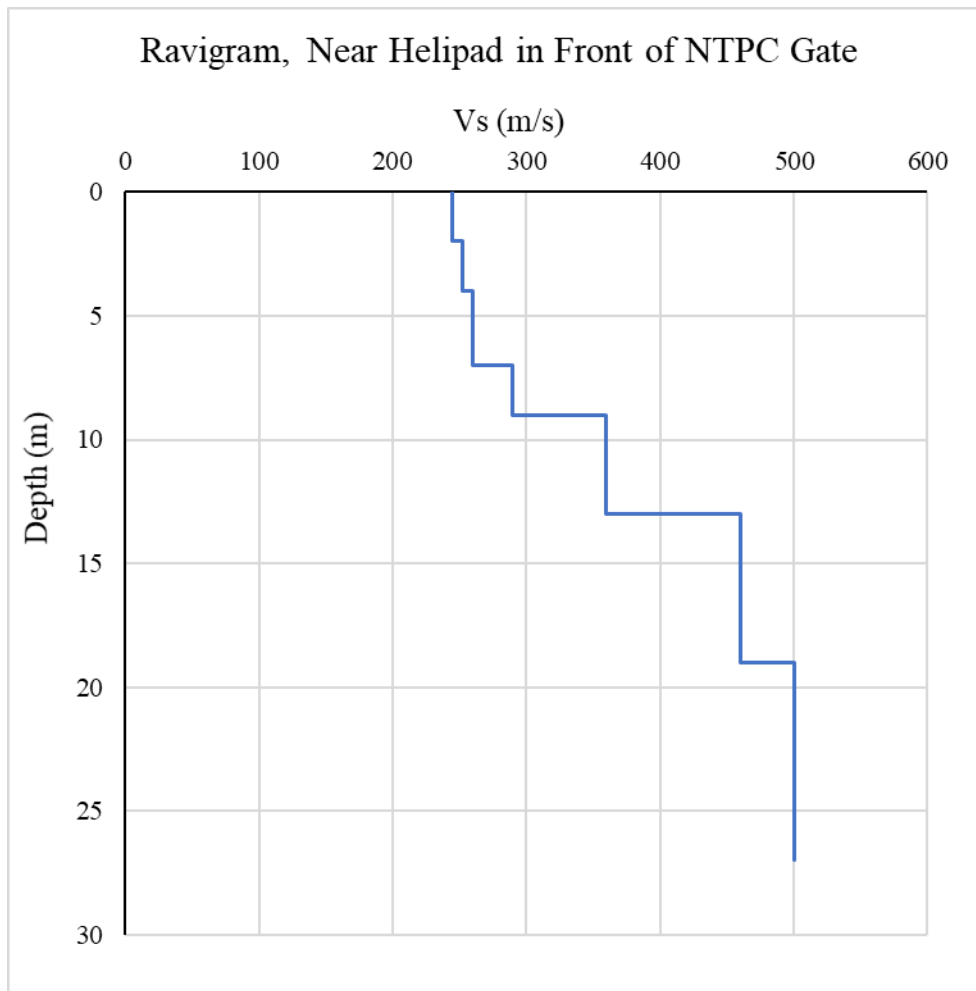


Fig. 12.5: Shear Wave Velocity Obtained at Ravigram, Near Helipad in front of NTPC Gate

12.4: NMC Results

Water content of the soil samples collected from Ravigram, Near Helipad in front of NTPC Gate at depths of 1m, 2m, 3m and 4m.

Table 12.1 Natural moisture content of the soil for Ravigram, Near Helipad in front of NTPC Gate

Determination of water content		
IS: 2720 (PART II)-1973		
Testing date: 28-01-2023		
Sampling location	Ravigram, Near Helipad Front of NTPC Gate	
S.no	Depth (m)	Water content (%)
1	1	11.40
2	2	2.68
3	3	8.38
4	4	9.29

12.5: Grain Size Distribution Analysis

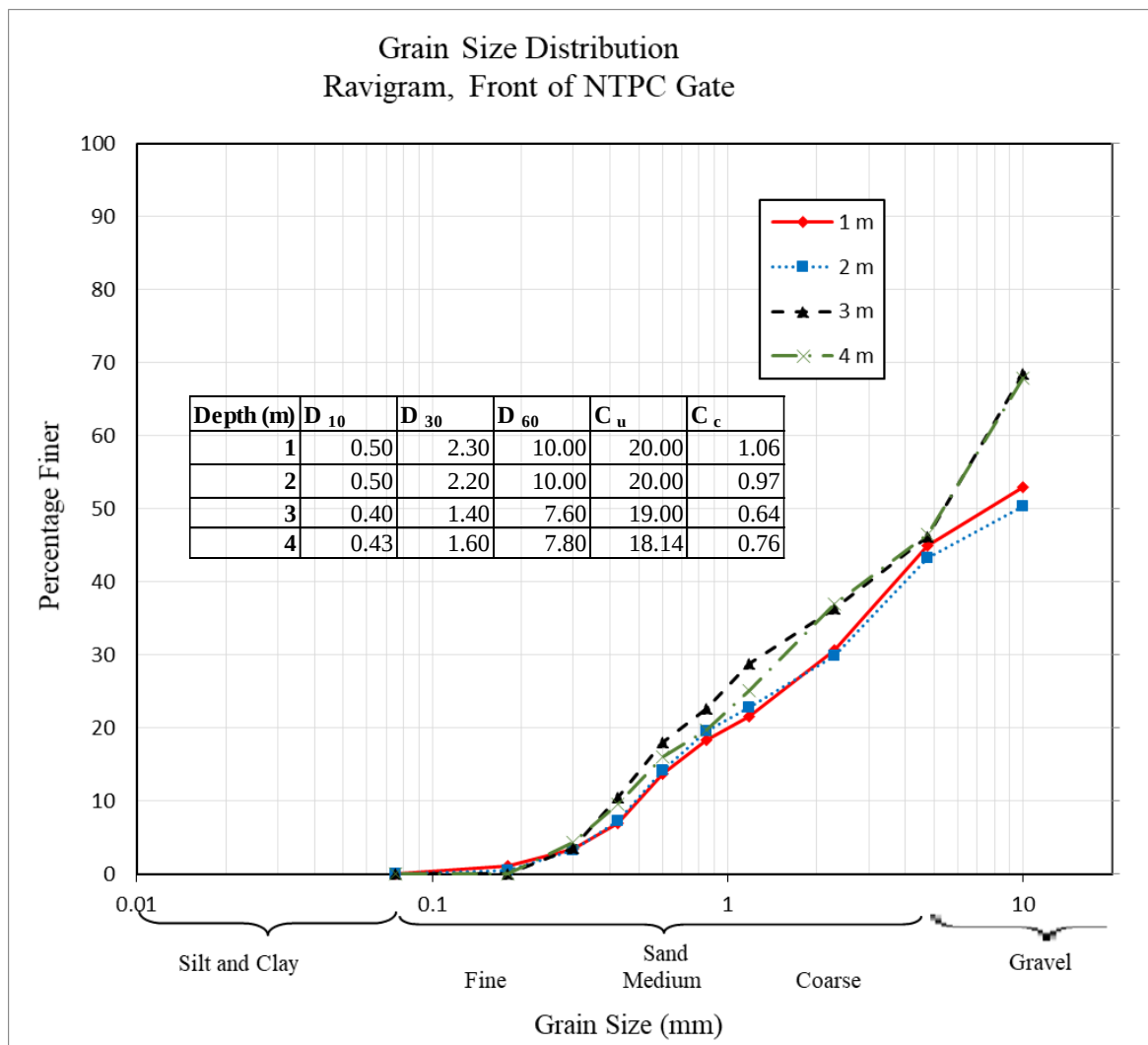


Fig. 12.6: Grain size distribution for Ravigram, Near Helipad in front of NTPC Gate

12.6: Summary of all the Results

Table 12.2 Summary of the soil for Ravigram, Near Helipad in front of NTPC Gate

LABORATORY TEST REPORT ON SOIL SAMPLES													
SAMPLING LOCATION:			Ravigram, Front of NTPC Gate										
Depth (m)	IS Classification	N.M.C. %	Grain Size Analysis %			PL	Curv. Cu	Coeff. Cc	DD γ_d (kN/m ³)	Spec. Gravity	Void Ratio %	Shear Parameters	
			Gravel	Sand	Fines							c (kN/m ²)	ϕ (°)
G.L.													
1	GW	11.40	54.97	45.03	0.00	NP	20.00	1.06	12.93	2.68	107.32	-	-
2	GP	2.68	56.66	43.34	0.00	NP	20.00	0.97	14.02	2.68	91.10	2.84	42.66
3	GP	8.38	53.85	46.15	0.00	NP	19.00	0.64	13.29	2.68	101.71	-	-
4	GP	9.29	53.48	46.52	0.00	NP	18.14	0.76	13.18	2.68	103.41	-	-

12.7: Overview of the Site

Test site is in front of NTPC gate located near helipad in Ravigram (Ward 9). The testing site is so selected such that it contains natural soil free of manmade infilling, while it also represents typical conditions existing in the ward considered and situated near to the damaged structures. All the proposed field tests, Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT), Direct Shear Test (DST) and Multi-Channel Analysis of Surface Waves along with HVSR were conducted at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) Analysis were also conducted on the samples procured from the field. SPT tests couldn't be conducted due to the presence of gravel/boulders everywhere.

The ultimate and safe load carrying capacities of the soil are found to be 36 t/m^2 and 12 t/m^2 respectively from the plate load test results.

In this site also, DCPT test is repeated four times due to the difficulties encountered during the testing. Initial three DCPT tests were conducted only up to 1.5m due to the refusal strata. Out of these three tests one was conducted inside the gate of NTPC but faced same difficulty. However, forth test conducted slightly 2 to 3m away from the initial two tests, went up to 2.7m. From the field excavations and sampling, it is clearly noticed that subsurface strata consist of mixture boulders, gravels and soils. From these DCPT results it is clear that the surface becomes hard due to surface activities up to 0.3m below which the cone resistance decreases up to 1.5m and again stiffness increases and decreases till 2.7m. Overall, soil resistance is found to be varying from 0 to 40 indicating soil is medium dense with boulders.

Field direct shear tests of size 750mm x 750mm were conducted at three normal stresses. The angle of shearing resistance and cohesion are found to be 42.66° and 2.84 kPa, respectively.

Dispersion image obtained from MASW testing is found to be very clear and can be traced up to less than 10Hz frequency. This is because of availability of free space without obstructions. For this site, the shear wave velocity ranges from 245 to 500m/s. Similar observation made from the HVSR curve. No prominent peak is observed even at low frequencies. Natural Moisture Content of the field samples is found to be varying between 2.7 to 11.4 %. GSD analysis conducted on samples collected from 1 to 4m depths revealed that the soils are predominantly Gravelly Sands. Further, soils are found to be non-plastic.

Concluding Remarks: Based on PLT, the site is having fare enough bearing capacity. The DCPT results indicates medium type of soil resistance with hard surface strata compared to lower layers. Small reduction in DCPT values are observed between 0.3m to 1.5 m. The DCPT results reveals that the stiffness of the soil goes on increasing with depth as a normal soil condition. Field tests results are in support of field damages observed. In the field, some serious damages were observed in the nearby area. That may be due to the subsidence of the ground not by the bearing capacity.

SUMMARY OF RESULTS FOR ALL THE SITES

In this section, the results of all the 12 sites are presented together which helps in its comparison and thus in preparing a risk map of the Joshimath.

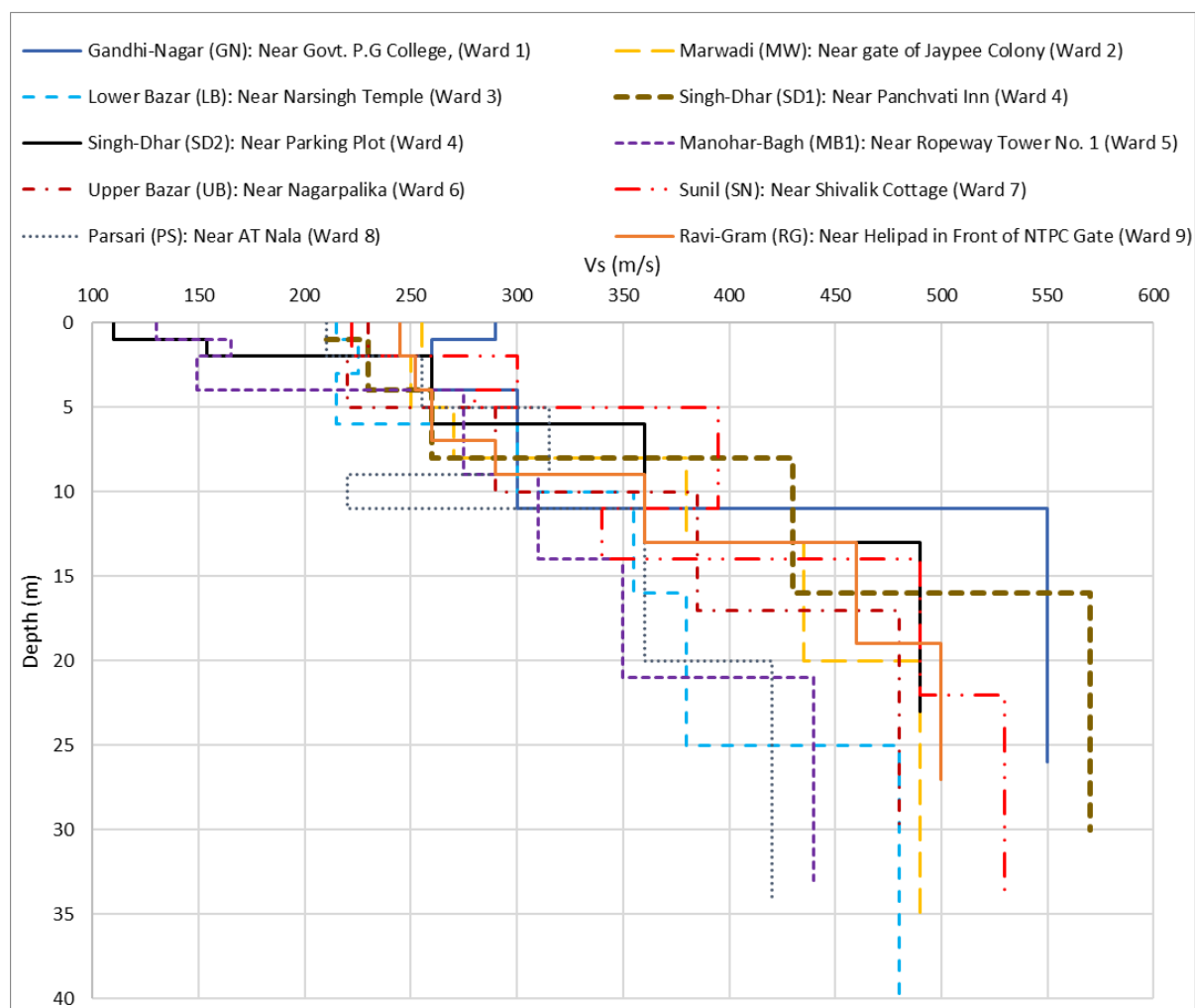


Fig. A1: Shear wave velocity profiles of 10 sites where MASW tests conducted.

Table A1. Summary of MASW test

S. No.	Site Name	Depth (m)	V_s (m/s)		V_{s30} (m/s)
			Min	Max	
1	Gandhinagar, Near Govt. P.G. College	26	260	550	411
2	Marwadi, Near gate of Jaypee Colony	35	250	490	372
3	Lower Bazar, Near Narsingh Mandir	40	215	480	326
4	Singhdhar, Near Panchvati Inn	30	210	570	392
5	Singhdhar, Near Parking Plot	23	110	490	352
6	Manoharbagh, Near Ropeway Tower No. 1	33	130	440	294
7	Upper Bazar, Near Nagarpalika	30	220	480	353
8	Sunil, Near Shivalik Cottage	33	222	530	401
9	Parsari, Near AT Nala	33	210	420	326
10	Ravigram, Near Helipad in front of NTPC Gate	27	245	500	371

Table A2. Summary of ultimate and safe bearing capacity

S. No.	Site Name	q_{ult} (t/m ²)	q_s (t/m ²)
1	Gandhinagar, Near Govt. P.G. College	34	11.33
2	Marwadi, Near gate of Jaypee Colony	38	12.67
3	Lower Bazar, Near Narsingh Mandir	16	5.33
4	Singhdhar, Near Panchvati Inn	30	10
5	Singhdhar, Near Parking Plot	31	10.33
6	Manoharbagh, Near Ropeway Tower No. 1	23	7.66
7	Manoharbagh, Near PWD Guest House	8.5	2.83
8	Manoharbagh, Near CPWD Office	19	6.33
9	Upper Bazar, Near Nagarpalika	44	14.66
10	Sunil, Near Shivalik Cottage	30	10
11	Parsari, Near AT Nala	18	6
12	Ravigram, Near Helipad in front of NTPC Gate	36	12

Table A3. Summary of DCPT

S. No.	Site Name	Min.	Max.	DCPT _{avg}
1	Gandhinagar, Near Govt. P.G. College	0	80	34.0
2	Marwadi, Near gate of Jaypee Colony	-	-	-
3	Lower Bazar, Near Narsingh Mandir	3	72	25.1
4	Singhdhar, Near Panchvati Inn	7	81	30.2
5	Singhdhar, Near Parking Plot	8	85	24.8
6	Manoharbagh, Near Ropeway Tower No. 1	1	105	24
7	Manoharbagh, Near PWD Guest House	2	67	29.7
8	Manoharbagh, Near CPWD Office	6	22	9.6
9	Upper Bazar, Near Nagarpalika	7	83	36.4
10	Sunil, Near Shivalik Cottage	4	36	16.3
11	Parsari, Near AT Nala	5	69	25.5
12	Ravigram, Near Helipad in front of NTPC Gate	6	38	17.2

Table A4. Summary of cohesion, friction angle and dry unit weight of the soil

S. No.	Site Name	c (kN/m ²)	ϕ (°)	γ_d (kN/m ³)
1	Gandhinagar, Near Govt. P.G. College	7.18	29.5	15.10
2	Marwadi, Near gate of Jaypee Colony	-	-	13.45
3	Lower Bazar, Near Narsingh Mandir	-	-	13.62
4	Singhdhar, Near Panchvati Inn	9.36	25.83	14.44
5	Singhdhar, Near Parking Plot	-	-	13.65
6	Manoharbagh, Near Ropeway Tower No. 1	0	29.78	13.69
7	Manoharbagh, Near PWD Guest House	36.97	14.6	13.24
8	Manoharbagh, Near CPWD Office	-	-	13.86
9	Upper Bazar, Near Nagarpalika	0.94	41.28	12.82
10	Sunil, Near Shivalik Cottage	14.88	17.84	11.56
11	Parsari, Near AT Nala	-	-	13.38
12	Ravigram, Near Helipad in front of NTPC Gate	2.84	42.66	13.18

Table A5. Summary of minimum and maximum Natural Moisture Content

S. No.	Site Name	Min (%)	Max (%)
1	Gandhinagar, Near Govt. P.G. College	4	8
2	Marwadi, Near gate of Jaypee Colony	7	11.5
3	Lower Bazar, Near Narsingh Mandir	9	18.5
4	Singhdhar, Near Panchvati Inn	10.5	13
5	Singhdhar, Near Parking Plot	5.5	9
6	Manoharbagh, Near Ropeway Tower No. 1	9.6	11.21
7	Manoharbagh, Near PWD Guest House	7	14.5
8	Manoharbagh, Near CPWD Office	7	12
9	Upper Bazar, Near Nagarpalika	8	12.5
10	Sunil, Near Shivalik Cottage	11	25
11	Parsari, Near AT Nala	9	11
12	Ravigram, Near Helipad in front of NTPC Gate	3	11.5

Table A6. Summary of Grain Size Distribution analysis

S. No.	Site Name	Gravels (%)	Sand (%)	Fines (%)
1	Gandhinagar, Near Govt. P.G. College	27-36	51-69	1-13
2	Marwadi, Near gate of Jaypee Colony	49-55	45-51	0
3	Lower Bazar, Near Narsingh Mandir	49.5-60.5	39.5-50.5	0
4	Singhdhar, Near Panchvati Inn	56.5-76.5	23-43	0-0.5
5	Singhdhar, Near Parking Plot	56-69.5	30.5-44	0
6	Manoharbagh, Near Ropeway Tower No. 1	63-68	32-37	0
7	Manoharbagh, Near PWD Guest House	18.5-33.5	66.5-73.5	0-13
8	Manoharbagh, Near CPWD Office	33-45.5	53-65.5	1-4
9	Upper Bazar, Near Nagarpalika	27-43	56.5-73	0-1.5
10	Sunil, Near Shivalik Cottage	43-51.5	48.5-57	0
11	Parsari, Near AT Nala	26.5-45	73.5-55	0
12	Ravigram, Near Helipad in front of NTPC Gate	53.5-56.5	43.5-46.5	0

RISK MAP OF JOSHIMATH

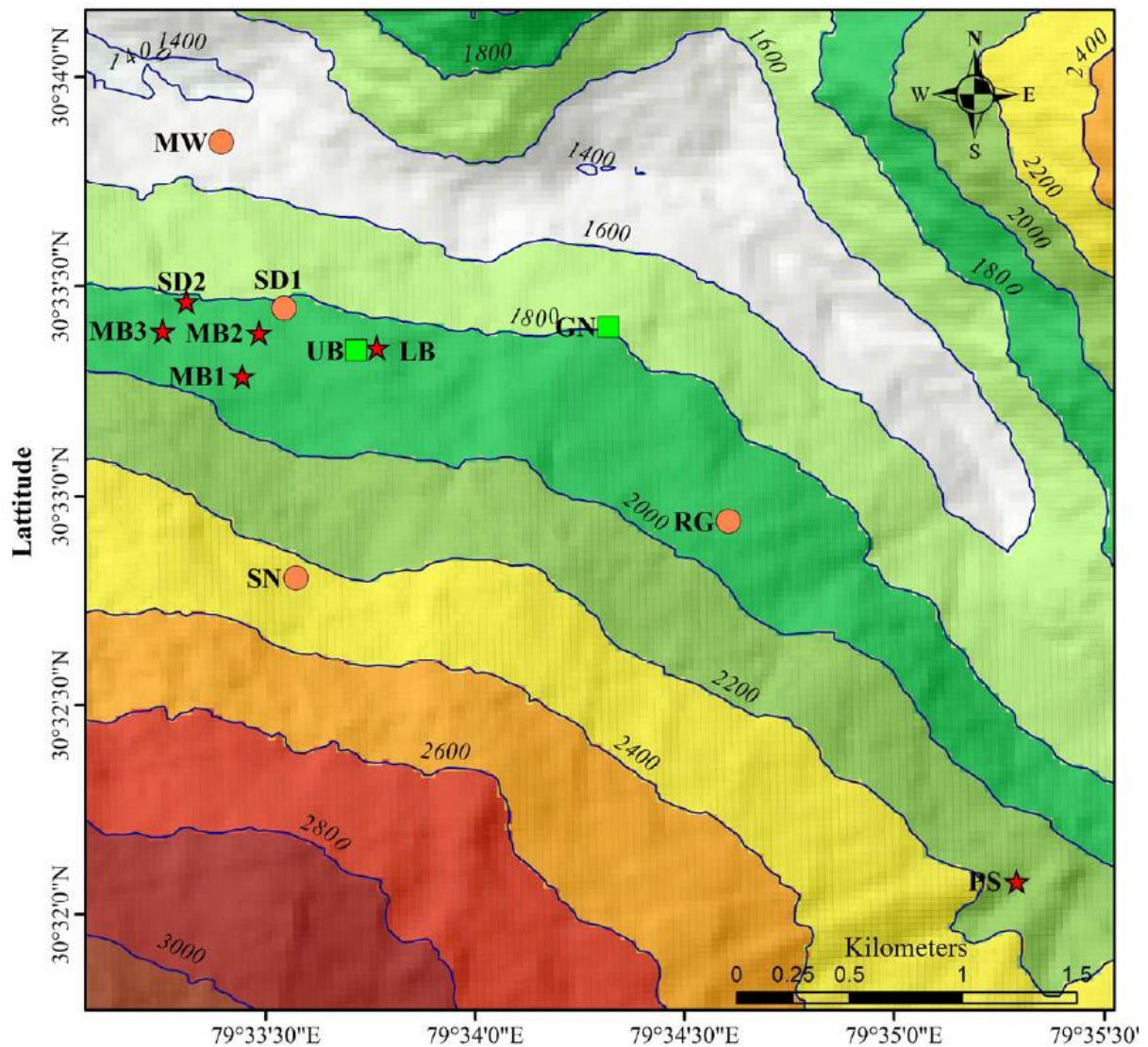
Based on the data presented in Fig. A1 and Tables A1 to A6, all the 12 sites are classified into 3 categories:

1. High Risk (HR) Zone
2. Moderate Risk (MR) Zone
3. Low Risk (LR) Zone

This categorization has been primarily based on the following approximate criteria:

1. Safe Bearing Capacity (q_s in t/m^2): HR < 8 and LR > 12
2. Average Shear Wave Velocity (V_{s30} in m/s): HR < 350 and LR > 400
3. Angle of Internal Friction of Soil (ϕ): HR < 30 and LR > 40
4. Average DCPT Cone Resistance (DCPT_{av}): HR < 25 and LR > 32

The classification of the sites was determined based on the combination of the above four criteria. If more than two criteria were met, they determined the category. In cases where the classification was on the borderline, a conservative approach was taken, leaning towards the high-risk side. Accordingly, a risk map is prepared, as shown in the figure on the next page.



Legend

- Low Risk
- Moderate Risk
- ★ High Risk

These 12 sites are classified into three categories:

1. High Risk (HR) Zone: LB, SD2, MB1, MB2, MB3 and PS
2. Moderate (MR) Zone: MW, SD1, SN and RG
3. Low Risk (LR) Zone: GN and UB

Thus out of the 12 sites, 6 sites falls in the high risk (HR) zone. However, it is emphasized that this categorization is simply based on the geotechnical data collected for that specific site and shall not be extrapolated. Thus the outcome of risk-map is for the location where the tests has been conducted and not represent the whole area.

Major Conclusions

Following can be considered as a final outcome based on overall observations on test results and damages of buildings.

1. Geotechnical investigations are carried out at 12 sites from different wards of Joshimath. The testing site/location is so selected such there is sufficient space available for carrying out various tests, while it also represents typical conditions existing in the ward considered and situated near to the damaged structures.
2. Plate Load Test (PLT), Dynamic Cone Penetration Test (DCPT), Direct Shear Test (DST) and Multi-channel Analysis of Surface Waves along with HVSR were conducted at this site. Natural Moisture Content (NMC) Tests and Grain Size Distribution (GSD) Analysis were also conducted on the samples procured from the field.
3. Twelve Plate load tests were conducted at a depth of 1.5m using a plate size of 300mm x 300mm. Ultimate and safe load carrying capacities of the soil are found in the range of 8.5 to 44 t/m² and 2.8 to 14.67 t/m², respectively from the plate load test results.
4. DCPT tests were repeated 3 to 4 times at every site due to the difficulties encountered in pushing the cone due to presence of boulders and gravels. DCPT tests showed high degree of variability indicating the heterogeneity in the sub-surface strata. Very high values are observed when boulders are encountered by the cone. In fact, refusals observed are primarily because of the presence of boulders rather than bedrock. DCPT value is found to be suddenly dropping, indicating presence of loose soil deposits underneath the gravels and boulders.
5. A total 7 field direct shear tests were conducted: 5 using 300×300 mm size of plate while 2 using 700×700 mm size of plate. Each test is conducted at three normal stresses. The angle of shearing resistance and cohesion are found to be varying in the range of 14° to 43° and 0 to 37 kPa, respectively.
6. MASW tests were conducted along with the HVSR at every test location. Dispersion image obtained from MASW testing is found to be having very high scatter. In fact, scattering is observed even at high frequencies, which is not common in regular soil strata. This scatter is ascribed to the complex mixture of variable soil particular sizes. The presence of boulder and large size gravel is responsible for such phenomenon. The wave velocity variations in different materials and the impedance contrast between boulders and soil is leading to multiple reflections and refractions, thus leading to very high scatter in the data.
7. HVSR curve is also found to be very peculiar as compared to regular soil sites. No prominent peak is observed even at low frequencies. This implies that no clear contrast strata is present even at greater depths. This further suggests that similar strata as seen at shallow depths may be extending to greater depths.
8. Natural Moisture Content of the field samples is found to be varying between 3 to 25 %.
9. GSD analysis conducted on samples collected from different depths revealed that the soils are predominantly Gravelly Sands with boulders. Further, soils are found to be non-plastic.

Final Concluding Remarks

1. Overall, the soil fabric of Joshimath is found to be a complex mixture of boulders, gravels and soil. Matrix of boulder is supported by gravels and soils. Internal erosion in such soils causes the instability of the whole fabric and results in the readjustment of the boulders resulting in subsidence.
2. Main reason for the subsidence appears to be internal erosion caused by the subsurface drainage, which may be due to infiltration of rain water/melting of ice/waste water discharge from house hold and hotels. Though subsidence is continuous phenomenon, it can be minimized by controlling infiltration of water, which helps in minimizing the internal erosion.
3. Based on the results of the various field and laboratory tests conducted, the sites are classified as High Risk, Moderate Risk and Low Risk region. A risk map for Joshimath is presented which is location specific and may not represent whole region.

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Some Photographs collected from the Field



Fig. P1: Field Direct Shear Test at Gandhinagar (GN), Govt. P.G. College (Ward 1)

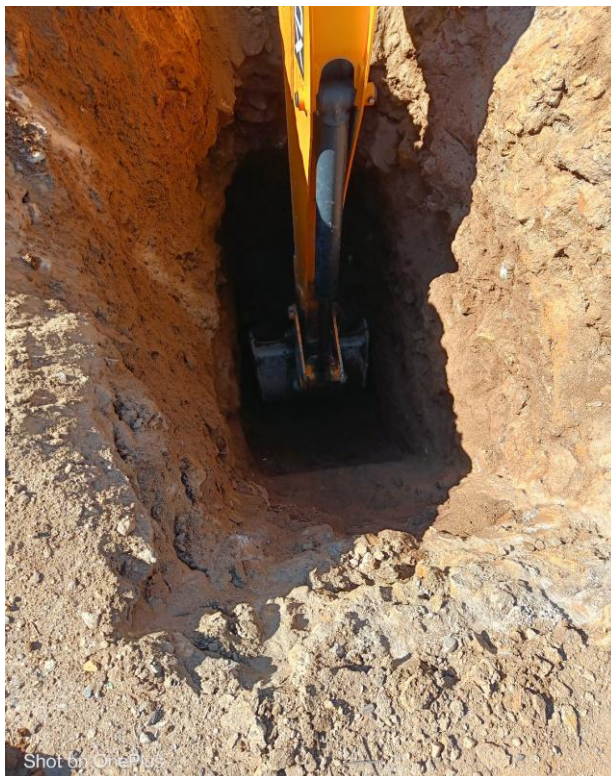


Fig. P2: Sampling at Gandhinagar (GN), Govt. P.G. College (Ward 1)



Fig. P3: Plate Load Test at Marwadi (MW) near Jaypee Colony (Ward 2)



Fig. P4: MASW Test at Marwadi (MW) near Jaypee Colony (Ward 2)



Fig. P5: Plate Load Test, Near Narsingh Mandir (Ward 3)



Fig. P6: Plate Load Test, Near Narsingh Mandir (Ward 3)



Fig. P7: Dynamic Cone Penetration Test, Near Ropeway Tower No. 1, Manoharbagh (MB1)



Fig. P8: MASW Test, Near Ropeway Tower No. 1, Manoharbagh (MB1)



Fig. P9: Field Direct Shear Test, Near PWD Guest House, Manoharbagh (MB2)



Fig. P10: Damage to retaining wall and play-ground at Marwadi (MW) near Jaypee Colony