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Studies on geotechnical properties of subsoil in south east coastal region of India

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Abstract. Soil testing and analysis has become essential before commencement of any activity or process on soil i.e. residential construction, road construction etc. It is the most important work particularly in coastal area as these areas are more vulnerable to the natural disastrous like tsunami and cyclone. In India, there is lack of facility to collect and analyse the soil from the field. Hence, to study the various characteristics of the coastal region sub soil, Old Mahabalipuram area, which is the South East region of India has been chosen in this study. The aim of this study is to collect and analyse the soil sample from various localities of the Old Mahabalipuram area. The analysed soil data will be helpful for the people who are working in the field of Geotechnical in coastal region of India to make decision. The soil sample collected from different boreholes have undergone various field and laboratory tests like Pressuremeter Test, Field Permeability Test, Electrical Resistivity Test, Standard Penetration Test, Shear Test, Atterberg Limits etc. are performed including rock tests to know the geotechnical properties of the soil samples for each and every stratum

1. Introduction

Natural disasters, such as flood, drought, cyclone or tsunami are unavoidable in the earth crust. Although science and technology is getting advance day by day, but, such types of natural disastrous can't be controlled fully. But, the damages caused due to such natural disasters can be minimized up to certain extent, if the subsoil analysis has been done properly before any design of work. It is quite common that the coastal region of India is getting affected very often by flood, cyclone or tsunami. These natural disasters are the opening windows of opportunities for the researchers to reduce the vulnerability due to disaster. The physical, social, economic and institutional are the main components which should be focused to reduce the loss due to disaster. The physical component deals with providing multi-hazards resilient houses with better infrastructure such as road and water supply [1]. To achieve this, proper investigation of the geotechnical properties of the coastal region soil should be performed before any construction work. Many investigations have proved that majority of the coastal regions soils consist of only sandy soil [2, 3, 4]. Further, in most of the studies the chemical compounds and toxic metal like phosphorus have reported [5, 6, 7]. But, there is lack of a thorough investigation of engineering properties such as composition, its gradation and other essential properties of soil. Hence, it is necessary to study the engineering properties of soils which are available in coastal regions before going for any construction work.

It has observed that during 2004 tsunami all the 13 coastal districts of Tamil Nadu have been affected severely [8]. Recently in 2015, Chennai, the capital of Tamil Nadu has seriously affected by

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flood. Hence, to know the engineering properties of this coastal region soil, Old Mahavalipuram Road or IT Corridor has been chosen which is situated 60 km from South of Chennai city and is a coastal region. So that, in future damage may be minimized. It is advised by the Govt. of Tamil Nadu to know the geotechnical properties of soil before designing the work to avoid loses due to natural hazards. But, to get sub soil data for the common people is not an easy task. There is no any detail study available for this region regarding soil data. Hence, in this present study an effort has been done to provide the geotechnical properties of subsoil data to the public domain so that the common people or those groups of people, they can’t afford for soil testing before their construction work can make use of these data. Further, it can help to the research workers who wants to pursue his/her research work in the area of geotechnical engineering in this coastal region as they can use these data directly without wasting time and money for soil testing. Hence, the geotechnical investigation has been done to ascertain the soil properties in this area. The second importance of this study is share information to the investigator about the tests which should be performed on this coastal region soil or other similar region before starting any construction work. Keeping all in mind the objectives of this study is fixed as: (i) to know the thickness of the various soil strata present below the foundation zone up to the influence zone; (ii) to study the various engineering properties (i.e. consistency limit, natural density, shear strength, natural water content) of the soil strata at various levels; (iii) to determine the physical characteristics of the soil strata and (iv) to analyze the variation of the strength of the strata with respect to depth.

2. Description of study area

The site which is selected for study is irregular in shape and enclosed by barricade. The topography of the ground surface was uneven. The average elevation difference found to be 4 m. There were water logged areas due to recent rain during field investigation. The site was covered with vegetation in the form of grass, bushes, tress like tamarind, coconut and other trees. A well of 20' diameter is situated in northern side of the site and the depth of water table from ground surface was found to be as 3.3 m during the field investigations. The color of the exposed soil surface was Brown/Grey.

3. Collection of Soil Sample and Sub-Soil information

The subsoil samples have been collected from the study area and tested in Porur based Soil Testing Laboratory in Chennai. During the field investigation, 15 (bore halls) BHs were dug in different locations and the sample of sub-soils have been collected from those BHs during excavation and shown in Figure 1. To differentiate BHs, number has been assigned as BH No. 1, 2, 3 up to 15. Out of these 15 BHs, 10 BHs (designated as BH No.1, 2, 5, 6, 8, 9,10,12,13 & 15 in this article) were progressed down to 20 m depth including rock strata (where N value is >100), 3 boreholes (designated as BH No.3, 4 & 11) were progressed down to 50 m and the remaining 2 boreholes (designated as BH No.7 & 14) progressed down to 25 m depth. The N value is known as standard penetration resistance and it is defined as the number of times the hammer strikes to penetrate into the soil up to the depth of 150 mm for 2nd and 3rd trial [9]. The mechanically operated rotary core drill calyx and mechanically operated rotary core drill were used to progress the BHs by using hydraulic feed as per IS 1892 – 1979. The relative density and shear strength parameters of the soil were determined by using the standard penetration test during the BHs progression at regular intervals [10]. The depths of groundwater table have been recorded when it comes across during the progression of BHs (Table 1).

The parameter like elastic modulus of soil can be obtained from stress-strain relationship. This helps to determine in-situ stress and strain (i.e. Menard modulus) of the soil/rock. Hence, the in-situ stress-strain relationship of the soil at different depth has been obtained by using Menard pressuremeter test apparatus of 80 bar capacity [11]. The Menard modulus is determined by:

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$$E_m = 2.66\left(V_c + V_b + \frac{V_1+V_2}{2}\right)\left(\frac{P_2-P_1}{V_2-V_1}\right) \quad (1)$$

where, V_c = initial volume of the measuring cell of the probe = 700 cm^3; V_b= volume expansion of the measuring cell of the probe required to make contact with walls of the borehole; V_1= volume at the start of the straight portion of the pressure test curve; V_2 = volume at the end of the straight portion of the pressure test curve; P_1 = Pressure at the start of the straight portion of the pressure test curve; P_2=

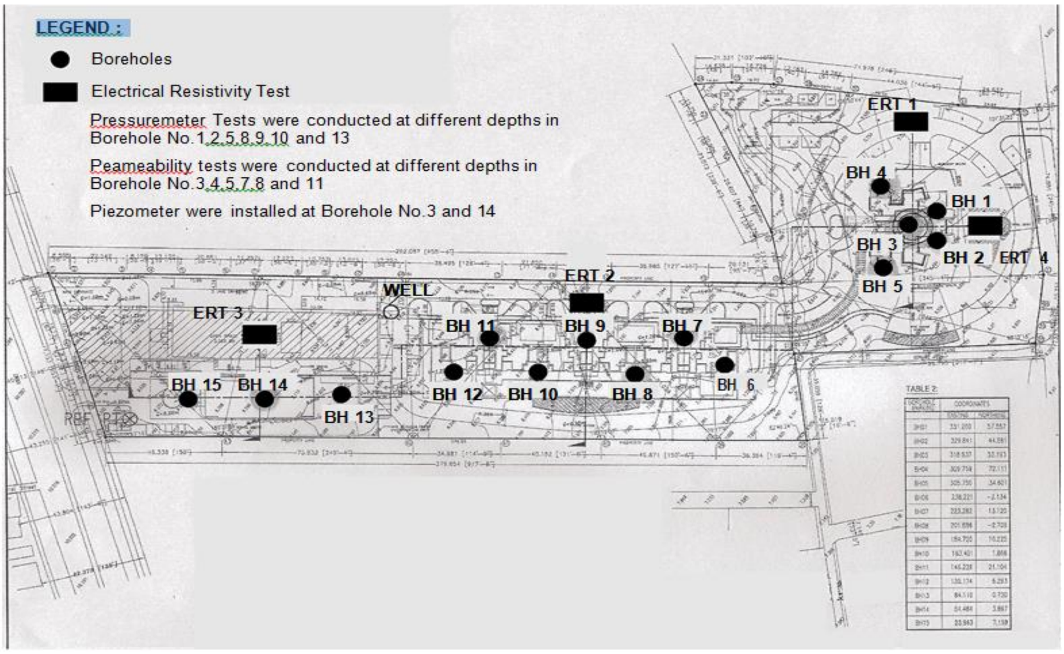

Figure 1. Location of Bore Hole (BH)

Table 1. Elevation, termination and water table depth of boreholes

BH No.	RL (m)	Termination Depth from Existing Ground Level (m)	Depth of Water Table from Existing Ground Level (m)
1	5.831	20	1.5
2	6.284	20	1.5
3	5.781	50	1.5
4	5.473	50	1.5
5	6.224	20	1.5
6	7.086	20	3.0
7	7.060	25	2.5
8	7.148	20	2.0
9	7.260	20	2.5
10	7.943	20	2.5
11	8.324	50	2.2
12	8.306	20	3.5
13	8.757	20	2.5
14	9.037	25	2.5

15	9.248	20	3.5

Pressure at the end of straight portion of the pressure test curve. The pressure test curve has shown in Figure 2.

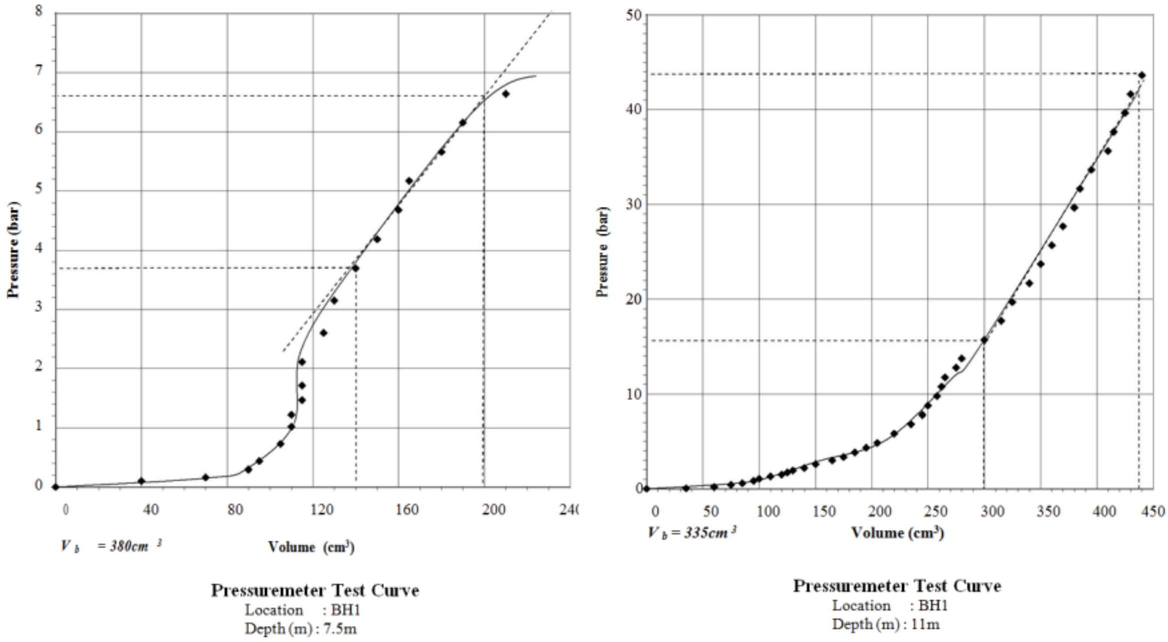

Figure 2. Pressuremeter test curves for BH1 at 7.5m & 11m depth

The field permeability of soil has been obtained by using open ended borehole method at various depth of sub-soil in the different BHs [12]. The falling head method is used to estimate the permeability as:

$$k = \frac{\pi r}{5.5(t_2 - t_1)} log_e \frac{H_1}{H_2} \tag{2}$$

where, k = coefficient of permeability (cm/s); H_1= Piezometric head at time t_1; H_2= Piezometric head at time t_2; r = Inside radius of casing (cm).

The Wenner four - electrode method has been used at different locations to know the electrical resistivity of sub-soils as per IS 3043 [13]. The following equation has used to calculate electrical resistivity of the soil:

$$D=2\pi sR \tag{3}$$

where, D is resistivity of soil in Ohm-m; s is spacing of electrodes in m; R is resistivity reading in the meter in ohms.

Standard Penetration Test (STP) was conducted at 1.5 m intervals during the progression. For further analysis of soil in the soil laboratory the disturbed and undisturbed soil sample were collected.

The disturbed soil samples were collected by split spoon and those are packed and labeled in polythene bag. The undisturbed soil samples were collected by thin walled tubes as per IS 2132. The diameter of soil samples were 50 mm and its length was 45 cm. The ends of the tubes containing soil sample were sealed by wax to prevent loss/ ingress of moisture.

The following properties of the undisturbed and disturbed soil samples have been determined in soil laboratory: (i) Soil type and its gradation (ii) Consistency limits (iii) Natural density (iv) Natural water content (v) Shear strength properties and (vi) Chemical properties of soil and water [6; 7; 8; 14; 15; 16]. In order to determine the above listed properties, the following tests were conducted such as (i) Sieve analysis on the coarse grained soil fraction (ii) Hydrometer analysis on the fine grained soil fraction (iii) Liquid and plastic limits (iv) Natural Density and Water Content (v) Triaxial Shear tests (vi) Specific Gravity (vii) Free Swell Index tests and (viii) Chemical analysis of soil and water samples.

The core and disturbed rock samples were brought to the laboratory for different test and the following properties have been determined: (i) Uniaxial Compressive strength (ii) Water Absorption (iii) Unit Weight. In order to determine the above listed properties, the following tests were conducted such as (i) Compressive strength of rock (ii) Point load index (iii) Porosity (iv) Water absorption and (v) Unit weight.

4. Results & Discussions

4.1 Sub-Soil Characteristic of Different Bore Holes

The observations, analysis and result of the soil samples collected from Old Mahavalipuram, South Eastern coast of India have been presented here. During field investigation the depth of groundwater table was found to be at 3.3 m below the ground surface. It has seen in Table 1 that, the variation in the depth of groundwater table encountered during boring in all the location is from 1.5 m to 3.5 m. The position of the groundwater table below the foundation level has a significant effect on the bearing capacity of soil. The bearing capacity of the soil will not decrease, if the depths of water table will more than the width of the foundation. Hence, to keep the bearing capacity of the soil in safe side, the width of the foundation should be provided more than 3.5 m.

The sub-soils stratum and their thickness are presented in Table 2. The soil is consisted of seven sub-soil profiles in this region, which are (a) Stratum I: Filled up soil (soil with brickbats) (b) Stratum II: Brown/Grey/Reddish brown clayey silty sand (c) Stratum III: Brown silty sand (d) Stratum IV: Severely weathered rock (e) Stratum V: Highly weathered rock (f) Stratum VI: Moderately weathered rock and (g) Stratum VII: Slightly weathered rock.

The stratum-I is missing all the locations except at the location of BH No.15, whereas the stratum-VI is present in all the location with thickness of 3 to 4 m at a depth of 15 m from ground surface. The top surface soil up to the depth of 8 m from ground surface is clayey, silt and sand type of soil. To ascertain the type of soil in more accurately further soil properties have been studied.

The specific gravity of the soil particles are determined by using density bottle method as per IS: 2720 (Part III/Sec 1). It has found that specific gravity of the soil sample varies from 2.60 to 2.65 (Table 3). Similarly free swell index has been determined to know the expansive characteristic of the soil sample as per IS: 2720 (Part XL) – 1977. The free swell index of the soil samples are varied from 6.3 % to 21.6 % as shown in Table 3. These results indicate that the soil has low to medium swelling in nature. The higher free swell index means more expansive soil, because water holding capacity of soil will increase through its large volume of diffused double layer [17]. Soils having free swell index value as high as 100 % can show considerable expansion in field [18].

In many studies it is reported that the soil having free swell index less than 50 % don’t exhibit much volume changes in the field. But, [19] reported that several Texas clay within the range of 50 % of free swelling index caused lots of damage due to soil expansion. It may be due to the combination of extreme climatic condition and expansive nature of soil. Hence, the current site is safe from damage cause by expansion as it is coming under low expansion potential range [20].

The distributions of N values with respect to depth of soil at the different locations of BHs are estimated. The curve shows that as depth is increasing the N value is also increasing. It reflects that, there is directly relationship between N values and the depth of soil. The resulted N values indicate the soil to be in a medium dense to dense state [21]. Soil is getting denser with depth

Table 2. The typical sub-soil profile of the study area

BH No.	Stratum-I (m)	Stratum -II (m)	Stratum-III(m)	Stratum -IV (m)	Stratum –V (m)	Stratum - VI(m)	Stratum -VII(m)
1	-	0.0-8.7	-	8.7-10.5	10.5-15.0	15.00-20.00	-
2	-	0.0-8.8	-	8.8-10.5	10.5-15.0	15.00-20.00	-
3	-	2.6-8.8	0.0-2.6	8.8-14.2	-	14.20-17.20	17.20-50.00
4						25.85-28.85	14.2-25.85
	-	2.4-8.3	0.0-2.4	8.3-11.0	11.0-14.2	33.55-37.05	28.85-33.55
							37.05-50.0
5	-	0.0-8.1	-	8.1-10.5	10.5-15.0	15.0-20.0	-
6	-	0.0-8.2	-	8.2-10.5	10.5-15.0	15.0-20.0	-
7	-	0.0-8.4	-	8.4-12.0	12.0-13.5	13.5-15.0	15.0-25.0
8	-	0.0-8.8	-	8.8-10.5	10.5-15.0	15.0-20.0	-
9	-	0.0-8.5	-	8.5-10.5	10.5-15.0	15.0-20.0	-
10	-	0.0-9.0	-	9.0-10.5	10.5-15.0	15.0-20.0	-
11					10.0-15.5	15.5-17.2	
	-	0.0-10.0	-			22.15-26.0	26.0-50.0
				17.2-18.4	18.4-22.15		
12	-	0.0-8.2	-	8.2-11.5	11.5-16.0	16.0-20.0	-
13	-	0.0-8.8	-	8.8-10.5	12.0-16.5	16.5 -20	-
14	-	0.0-8.2	-	8.2-10.5	10.5-12.0	12.0-15.0	15.0-25.0
15	0.0-1.0	1.0-10.3	-	10.3-12.0	12.0-18.0	18.0-20.0	-

Table 3. Variation of specific gravity and free swell index with respect to depth

BH	Specific Gravity				Free Swelling Index (%)			
No.	1.0 m	1.5 m	2.5 m	3.0 m	1.0 m	1.5 m	2.5 m	3.0 m
1	-	2.62	-	2.65	-	20.4	-	14.5
2	-	2.60	-	2.64	-	18.3	-	14.1
3	-	2.61	-	2.62	-	6.3	-	19.2
4	2.63	-	2.65	-	7.6	-	17.6	-
5	-	2.64	-	2.65	-	21.6	-	16.5
6	-	2.62	-	2.64	-	19.4	-	15.2
7	-	2.65	-	2.62	-	20.3	-	17.4
8	-	2.64	-	2.63	-	18.1	-	15.5
9	-	2.63	-	2.61	-	20.2	-	19.3

10	-	2.62	-	2.63	-	21.0	-	17.6
11	2.61	-	2.65	-	19.7	-	17.2	-
12	2.60	-	2.61	-	18.3	-	15.7	-
13	-	2.62	-	2.65	-	20.6	-	19.4
14	-	2.61	-	2.64	-	21.2	-	18.7
15	-	2.64	-	2.63	-	20.1	-	18.8

The consolidated drained shear test was performed to know the cohesiveness of the soil. The value of cohesive stress was found between negligible to 0.16 kg/cm² and the range of the angle of shearing resistance Φ of the soil was varied from 20^0 to 28^0. In case of the weathered rock sample the angle of shearing resistance Φ was varied from 38^0 to 44^0. The young's modulus was determined by triaxial test under consolidated drained and constant stress condition.

The pressuremeter test had been conducted in different depth and at different location of BHs. The results have been obtained in the form of pressure vs volume for all the locations. The results for pressure vs volume are presented for location BH1 at 7.5 m and 11 m depth for V_b 380 cm^3 and 335 cm^3 respectively in Fig. 2. The straight lines shown in figures by dashed line. To estimate Menard modulus by using Eq.1 the values for V_1, V_2, P_1 and P_2 had been taken from the straight line portion of the graph. The continuous increase of volume was not noticed in any of the tests in this study. Hence, the limiting pressure condition was not been reached in this case.

The plots for remaining locations have not shown here. But, Menard Modulus is determined for different locations by using the Eq.1 and the values have been presented in Table 4. It is observed from Table 4 that in all the cases the Menard Modulus is increasing when, depth is increasing. This is due to rate of increase of pressure is more than the rate of change of volume with respect to depth. It indicates that, soil can withstand more strain and it is hard in nature.

Table 4. Menard's Modulus at different depths

Test	Depth (m)	Menard's Modulus	Test	Depth (m)	Menard's Modulus
1	7.5	191	9	7.5	145
	11	759		11	891
2	8	114	10	8	65
	11	858		11	926
5	7.5	30	13	7.5	61
	10.5	417		10.5	245
8	8.0	141			
	11	671			

4.2 *Field Permeability Tests*

The coefficients of permeability k, at the different locations and in the different depth of the BHs had estimated by falling head method. The coefficients of permeability k at different depth for BH3, BH4, BH5, BH7, BH8 and BH11 have been presented in Table 5. It has seen that, the value of k has been increasing with respect to depth from ground surface. It means, as one goes below the ground in this region, the sub soil has more open structure like rammed sand.

The rate of water transfer will increase from top to bottom. Though, it is intuitive to believe that, with increase in depth, permeability will decrease due to increase in over burden stress and it causes flow inducing fracture to close. In this study, it is just reverse; it means this region is more geological active. The test has been done up to 6 m depth only and the range of permeability is 10^{-6} cm/s.

Table 5. Coefficient of permeability at different locations with respect to different depths

Location	Depth Below Existing Ground Level (m)	Coefficient of Permeability 'k' (cm/s)
BH 3	4	5.38×10^{-6}
	6	7.69×10^{-6}
BH 4	1.5	1.20×10^{-6}
	4	7.40×10^{-6}
BH 5	2	6.42×10^{-6}
	4.5	9.05×10^{-6}
BH 7	1.5	7.46×10^{-6}
	5	7.49×10^{-6}
BH 8	2	5.52×10^{-6}
	4	6.10×10^{-6}
BH 11	3	5.84×10^{-6}
	5.5	$5.90\ 10^{-6}$

4.3 Electrical Resistivity Test

The Electrical Resistivity tests were conducted by Wenner four electrode methods at different locations and results are presented in Table 6. Test 1, 2, 3 and 4 are the location of four electrodes spaced in equal distance. Resistivity at different electrodes location at different soil depth are estimated and presented in Table 6. The resistivity results indicate the existence of soil up to a depth of 10 m below the ground surface and beyond which rock strata are available i.e. down to 50 m depth. This inference can be drawn from Standard Penetration and Pressure meter test. The test for SPT was difficult after a depth of 10 m as settlement did not occur even after 100 blows. The pressure meter test also failed after 10 m of depth. These two reasons clearly indicate that the hard rock strata occur after 10 m of depth below ground surface.

Table 6. Electrical Resistivity Test Results

Spacing of Electrodes (m)	Test Results (ohm-m)			
	Test 1	Test 2	Test 3	Test 4
1.5	67.16	39.97	7.44	61.19
5	43.53	49.56	6.06	43.52
10	32.83	21.96	7.69	26.72

15	35.4	28.6	12.09	24.73
20	43.16	34.06	16.04	27.04
25	45.38	39.12	20.55	30.31
30	35.95	43.12	25.81	34.32
40	35.14	48.95	33.21	40.54
50	37.61	58.8	49.88	47.99

4.4 In-situ Bulk Density, Water Content and Dry density

The in situ water content and bulk density have been estimated for all the BHs location. The dry density of the sub soil stratum have been estimated by using in situ moisture content and bulk density and presented in the graphical form in Figure 3.

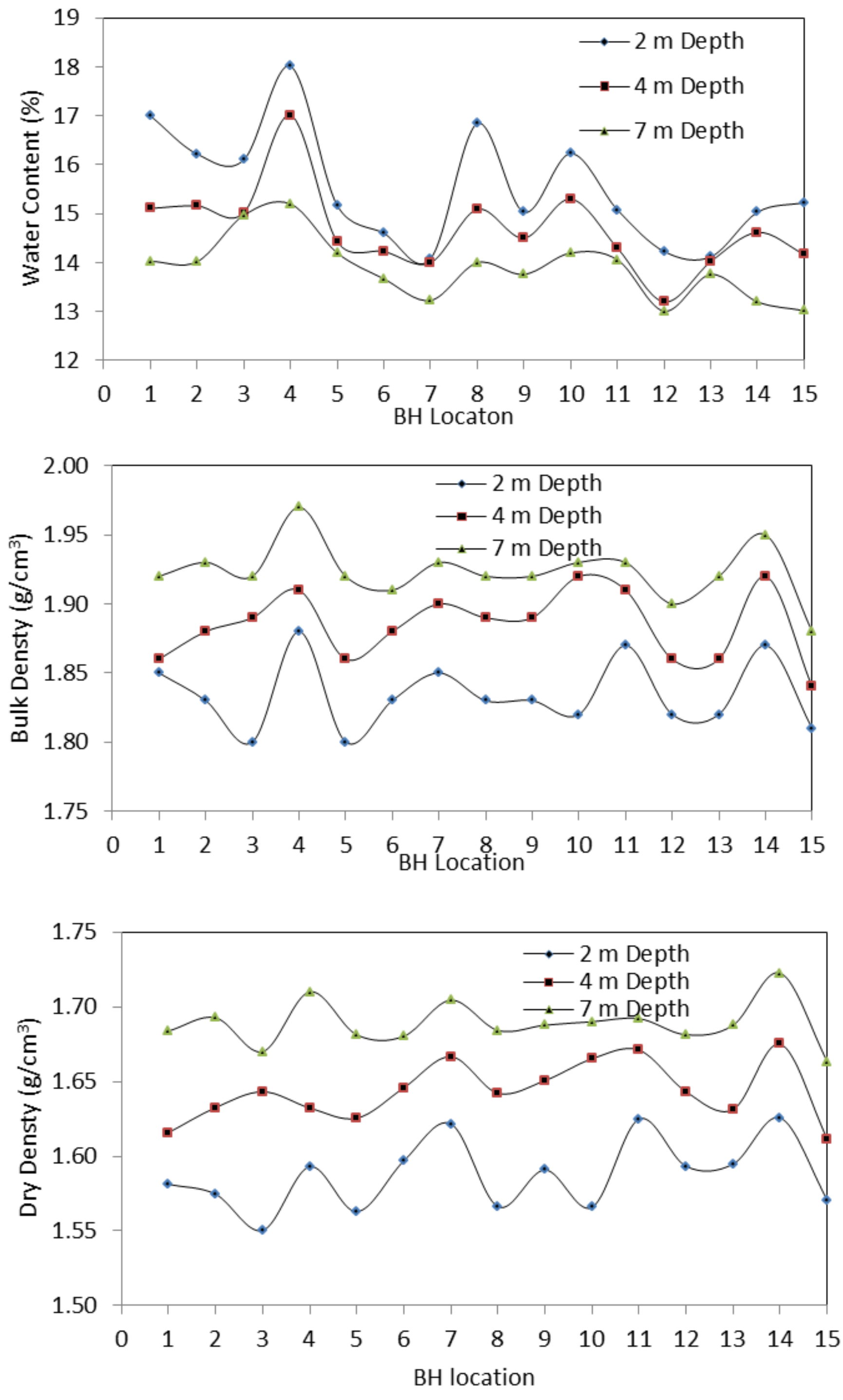

Figure 3. Variation of water content, in-situ bulk density and dry density with respect to depth of soil in different location of bore well (BH).

The value of water content varied between 11.71 to 17.01 % and whereas, bulk density varied between 1.80 and 1.97g/cm^3. The value of dry density of the sub soil stratum varies between 1.57 and 1.72g/cm^3. Fig. 3 shows that, with increasing soil depth from ground surface, water content is decreasing and in-situ bulk density is increasing and hence, dry density is increasing accordingly. That indicates hardness of soil increasing as depth of soil below ground surface is increasing.

Similarly, all the above parameters have been studied by Standard Penetration Test for the sample collected from weathered rock stratum.

The value of water content varies between 3.76 and 4.30% and in-situ bulk density varies in between 2.21 and 2.30 g/cm^3 respectively. The dry density of weathered rock in the sub soil stratum found to be in between 2.12 and 2.22 g/cm^3. Quantitatively, the sample collected from weathered rock has more bulk density and dry density, but, water content is reducing. It is obviously as soil having rock has less moisture and high dry density and bulk density

4.5 Soil Composition and Atterberg Limits

The grain size distribution for the collected soil samples from the various depths have been determined in the laboratory and presented in the form of grain size analysis curves in Figure 4 [22]. The % of sand, silt and clay present in different location of study area have estimated

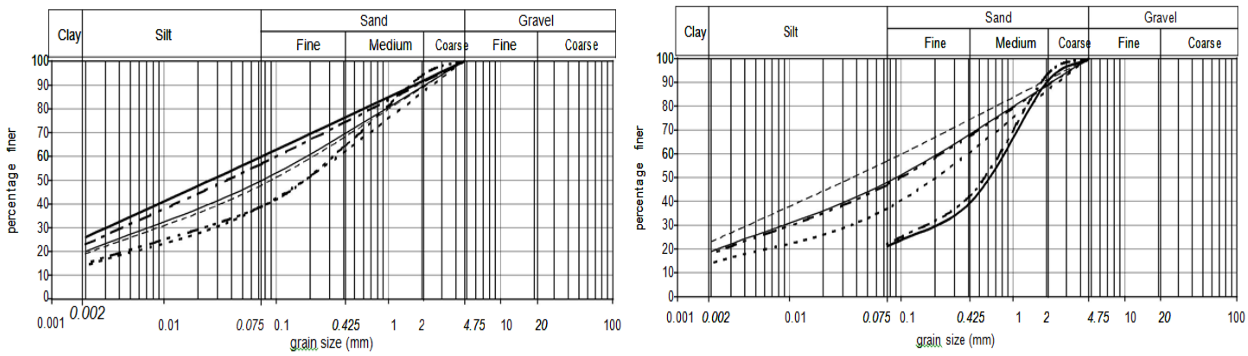

Figure 4. Grain size distribution curves for soil sample

from grain size analysis and presented in Figure 5. The % of clay is less and % of sand is more. It means, soil has sand-silt textured.

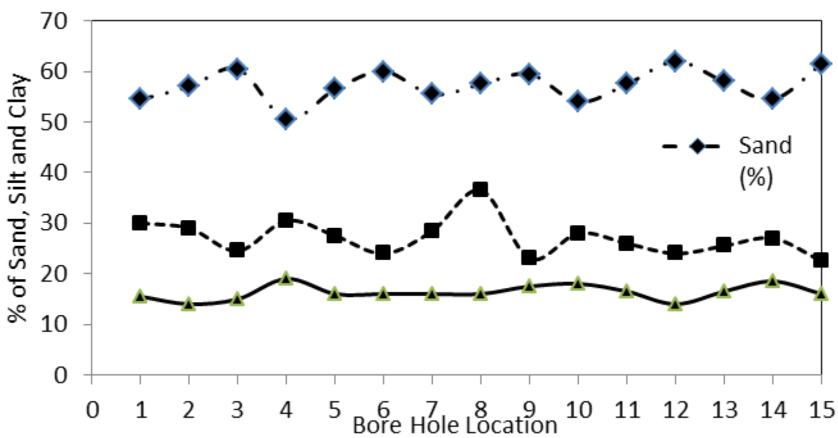

Figure 5. Sand, Silt and Clay % in different location of BH

The Atterberg limits are a basic measure of the critical water contents of a fine-grained soil, such as its shrinkage limit, plastic limit, and liquid limit. The liquid limit and plastic limit tests are conducted on soil samples and the Plasticity Index (PI) has been estimated. Based on these results plasticity chart has been prepared and presented in Figure 6. The PI obtained from the test is in between A and U line in the plasticity chart and liquid limit is less than 35 %. It indicated that soil is having moderate plasticity nature.

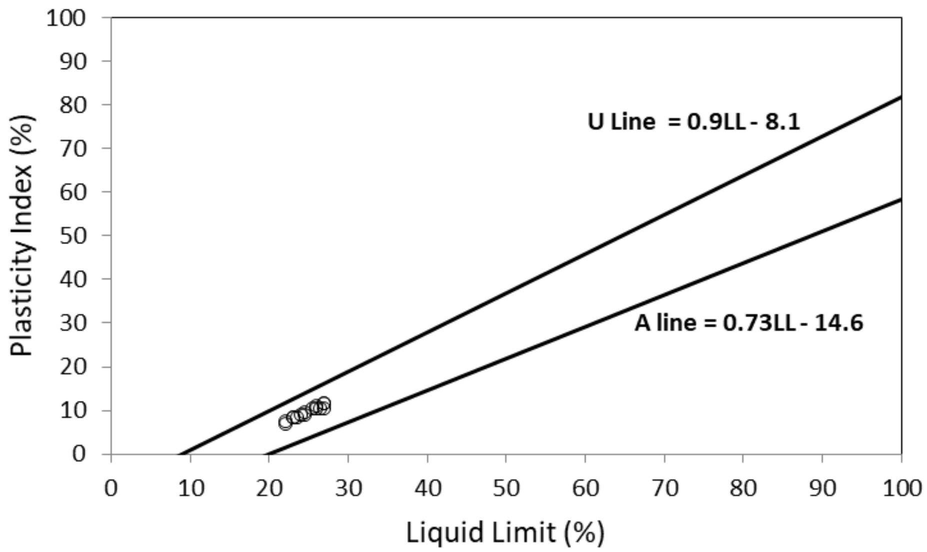

Figure 6. Plasticity chart for soil samples

5. Conclusions

This soil investigation study examined the soil properties and characteristics of the soil samples which were collected from Old Mahabalipuram area and that area belongs to the South Eastern coast of India. During test procedure, the methods which are defined by equipment agencies were adopted properly and the values obtained are used to determine the soil profile. The tests are done repeatedly and the accurate result obtained by performing iteration method. The water absorption of soil samples are varied from 0.05% to 1.21%. The plasticity index of the soil sample has been found and it is less than 28 %. According to China Ministry of Construction [23], this soil sample is coming under non expansive soil category (Water absorption (%), < 2.5, Plasticity Index (%), < 28, Free Swell Index, (%) < 40%). From this test analysis, it may be suggest for raft foundation or pile foundation for construction work in this study area.

Hence, these results can be used in future by any organization for design, construction or other purposes which will take place in this particular region. These data can be used for load calculation for column in software STAAD or may be any other design software.

Acknowledgements

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