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Geotechnical investigations in the southern part of Ahmedabad district, Gujarat, India

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ABSTRACT

Geotechnical investigations of soil consisting of surface and subsurface studies are performed in the southern part of Ahmedabad district in Gujarat state of western India. Surface investigations include detailed geological and geomorphological mapping, whereas subsurface investigations involved selected drilling, soil sampling and laboratory analysis of the samples. About 700 samples were collected at every 1.5m depth interval from 64 boreholes, each of about 50 m depth for soil classification. The study area is covered by alternate layers of fine and coarse grained sediments. We used Standard Penetration Test (SPT)-N values, Soil Bearing Capacity (SBC) and Soil Bearing Pressure (SBP) for soil classification. The SPT-N values are noted during drilling while the SBC and SBP are estimated from the soil properties. The measured soil properties both physical and mechanical include: density, specific gravity, permeability, stiffness, strength, grain size analysis, liquid limit, plasticity index and shear strength parameters (Cohesion co-efficient and Friction Angle). A relationship has been obtained between SBC and N-values derived from the above studies.

Key words: Geotechnical investigation, Engineering geology, Geotechnical properties, Surface exploration, subsurface exploration.

INTRODUCTION

The study area, about 50km in N-S direction and 20km in E-W direction, lies in the southern part of Ahmedabad district, bordering Bhavnagar district of Gujarat. It is situated on the western flank of the Gulf of Cambay while the northern end of the area is about 50 km south of Ahmedabad.

Geotechnical investigation involves analysis of the soil composition to determine its structure and strength index by surface as well as by subsurface exploration. Surface exploration includes geological mapping, remote sensing and geophysical surveys. We prepared geomorphological map and soil maps from the geological mapping and remote sensing studies. The geophysical surveys provided information on the faults and structure of deep layers of sediments and rocks. The subsurface exploration involves soil sampling by test pits and trenching, followed by laboratory testing of the samples to obtain the subsurface soil properties.

In geotechnical engineering, classification of soil is mainly done in accordance with their physical and mechanical properties such as density, specific gravity, permeability, stiffness, strength etc. The investigation involves soil classification according to IS code, estimation of safe bearing capacity (SBC) and safe bearing pressure (SBP) based on shear parameters of soils in selected boreholes. Seismic site classification based on blow count obtained from standard penetration test (SPT – N values) was carried out according to National Earthquake Hazard Reduction Program (NEHRP). This study provides preliminary guidelines for construction and for land use planning.

GEOLOGY OF THE STUDY AREA:

The study area is situated at the western side of South Cambay basin. The area is covered by about 100m thick Quaternary alluvium and 250 m of Tertiary sediments deposited on the subsiding side of the Cambay basin. The Quaternary formations exposed in the study area include the tidal deposits brought by marine agencies and flood plain deposits brought by fluvial agencies. The Cambay basin is formed at the end of the Cretaceous due to rifting of the western continental margin of India (Biswas, 1982). It is a 500 km long and 50-60 km wide basin trending NNW-SSE. The sediments are marine up to Miocene, while the lower Pleistocene deposits are fluvio-marine indicating shallow marine and continental condition. The topography of the Cambay basin varies between 80 to 100 m. The first major transgression during Quaternary took place only in middle Pleistocene. The evidences of tectonism, differential uplifts within the graben (Ghosh, 1982; Sareen, 1993), eustatic changes in the base level, uplifts of the Aravalli mountain ranges and faulting (Ahmed, 1986) during middle to late Quaternary, can be seen in the form of entrenched rivers and cliffy banks. The study area is almost flat, gently sloping towards east with elevations ranging between 2-12 m, and thus the major drainage in this region flows from west to east.

Three main creeks trending NW-SE are present in the study area; first creek is in the northern most part of the study area originating from Gorasu village, second is in the central part and third is along the southern most boundary of the study area. The tidal flats are 8-10 km wide and numerous creeks cut tidal flats. All the water bodies of this region are full during the monsoon/post monsoon season but dry for the rest of the year. Rivers are also ephemeral since the region falls under semi arid climatic zone.

Rivers drain the Saurashtra peninsula and erode the Deccan Trap and deposit the finer sediments along the present day mud flats. Mud flats are present all along the south-eastern part of the study area and gradually merge with the Gulf of Cambay. Mud flats are formed all along the coastline trending NE-SW. Towards west of the present day Mud Flats are the Old Mud Flat deposits, which cover almost the whole study area. Presence of the older mud flats also indicates that the region was submerged under the sea water in the past. These older mud flats are at present at higher elevation than the high tide level and do not get water logged by the sea water. Salt Flats are present all along the western margin of the present day mud flats fringing the water logged area as well as all along the tidal creeks. The saline sea water from the Gulf enters the mud flats and the creeks and gives rise to low lying salt encrusted flat valleys, which are almost flat to gently sloping towards the sea. In the study area, all the salt flats are present along the three major creeks.

ESTIMATION OF SOIL PROPERTIES:

Soil property details are given below. Detailed exposition of these properties could be obtained from standard published articles/ internet.

Standard Penetration Test (SPT):

SPT is an in-situ dynamic penetration test designed to provide information on the geotechnical properties of soil. It is commonly used to check the consistency of stiff or stony cohesive soils and weak rocks, by driving a standard 50 mm outside diameter thick walled sampler into soil using repeated blows of a hammer falling through 76 cm. The measured SPT blow count (N_{SPT}) is normalized for the overburden stress at the depth of the test and corrected to a standardized value of $(N_1)_{60}$ using the recommended correction factors given by Robertson and Fear (1998):

$$(N_1)_{60} = N_c * (C_N * C_E * C_B * C_R * C_S)$$

Where, C_N = Overburden Pressure, C_E = Hammer Energy, C_D = Bore Hole Diameter, C_S =Presence or Absence of Liner, C_R = Rod Length.

Plastic limit (W_p):

It is defined as the minimum water content of the soil at which the soil will just begin to crumble into pieces (plastic behaviour). Clay has finer particles and has higher Plastic limit as compared to silt.

Liquid Limits (W_l):

Liquid Limit (LL) is the minimum water content at which soil changes from plastic to a liquid behavior. The Liquid limit is the measure of water content at which the soil paste groove gets vanished in 25 blows.

Plasticity Index (I_p):

It is the range of water content within which a soil behaves as plastic substance. When a sandy soil is used the plastic limit must be determined first. In case where, plastic limit is equal to liquid limit the plasticity index is treated as Zero. Plasticity Index (I_p) of a soil is estimated using the following equation

$$W_p = W_l - W_p$$

where, W_l = Liquid limit of the soil
W_p = Plastic limit of the soil

Grain Size Analysis:

The percentage of various sizes of particles in a given dry soil sample is determined by means of particle size analysis. Particle size analysis can be performed by the Sieve Analysis (for coarse soil fraction) and Sedimentation Analysis (for fine soil fraction < 75μ).

Sieve Analysis preferably is used if the soil size is 0.075 mm or more in diameter/size. When the size of the soil is less than 0.075 mm, usually sedimentation analysis is used. Sieving is carried out by arranging various sieves of different mesh sizes. Wt% of each mesh/sieve size is evaluated using the following equation:

$$\text{Wt \% of a size fraction} = (\omega/W) \times 100,$$

where, ω = weight retained in a sieve
W = total weight of the sample

Sedimentation Analysis is based on the principle of Stokes law and evaluated using hydrometer:

$$v = cr^2$$

where, v = settling velocity
r = radius of the particles
c = a constant

The hydrometer reading is taken at different intervals of time from which the size of the largest particles suspended at those times is determined.

Soil Classification:

The classification of soil is carried out according to Indian Standards (IS-1498-1970). According to this classification,

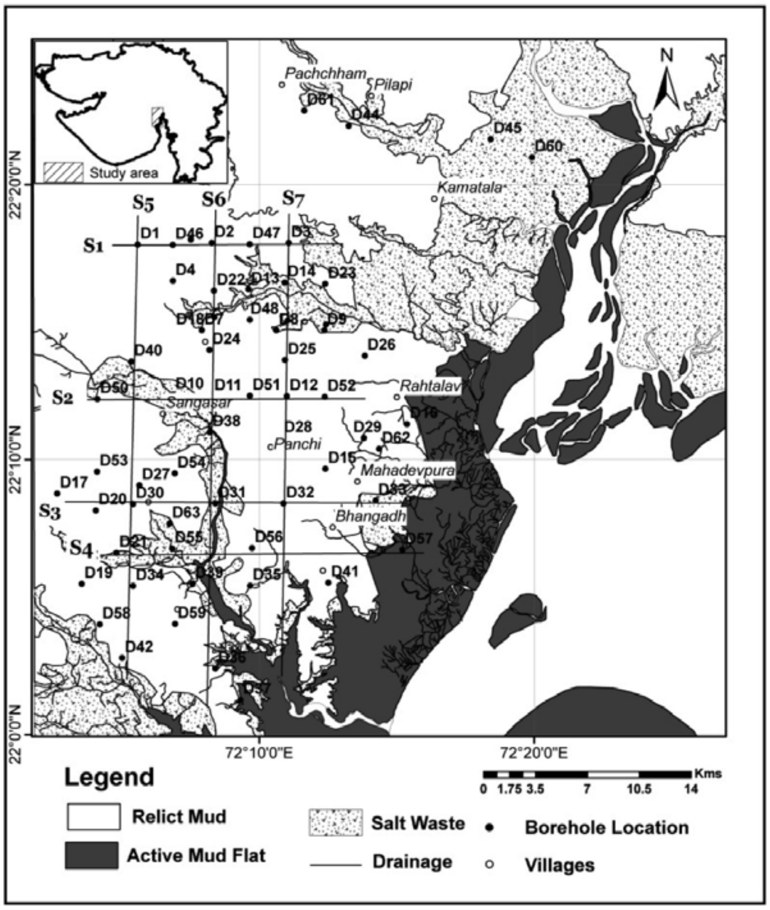

Figure 1. Geomorphology of the study area along with the borehole locations and selected cross sections.

soil is divided into coarse soil (gravel and sand) and fine soil (silt and clay). Classification of soil using plasticity chart provides comparison of soil at equal liquid limits. Toughness and dry strength increase with increasing plasticity index.

In the plasticity chart A-line is drawn which separates clay from silt. The soils that lie above the A-line are clay while those below the A line are silt. A-line has a linear equation between the liquid limit (W_l) and the plasticity index (I_p):

$$I_p - 0.73(W_l - 20)$$

Plasticity index of 4 to 7 indicates transition zone of clay and silt.

Cohesion co-efficient (C: kg/cm^2) and Friction Angle (Ø: Degree):

Cohesion co-efficient (C: kg/cm^2) and Friction Angle (Ø: Degree) are shear strength parameters. The shear strength is important in determining the bearing capacity for foundations, stability of slopes or cuts and calculating the pressure exerted by a soil on a retaining wall. For the present study, direct Shear test is performed as per IS 2720(13)-1986 to determine the bearing capacity of foundation.

GEOTECHNICAL PROPERTIES OF THE STUDY AREA:

As stated above, the present study area is covered with thick fluvio-marine sediments. In order to know the geotechnical characteristics of the subsurface lithology, 64 boreholes varying in depth from 30 to 100 m (as shown in Figure1) were, for collecting both disturbed and undisturbed samples for laboratory analysis.

The Standard Penetration Tests (SPT) were conducted as per IS- code (IS 2131, 1981) at every 3m depth interval in all boreholes to determine the SPT-N values.The SPT-N values at depth of 3m and 6m were generally low, less than 10 and 20 respectively. With increase in depth the measured SPT-N values increase due to the densification of sediments and overburden stress. The SPT-N values above 50 blow counts were encountered at an average depth of 15m. In some boreholes, sudden increase in SPT-N values was observed which may be due to the presence of gravel layers at that particular depth.

Water table of the study area was obtained from borehole data collected during drilling. The water table is shallow and varies from 1m to 3.9m. Soil samples were collected as per IS: 2132 (1986) for determination of the physical properties of sediments. Determination of index properties of sediments was carried out according to IS: 2131 (1985). After laboratory analysis, the boreholes were classified into two categories i.e. domination of fine grained and coarse grained soils, based on presence of more than 60% clayey, silty and sandy soils in each borehole. Physical properties of the sediments and SPT-N values were plotted separately for the fine and coarse grained categories of boreholes against the depth (Figures 2 & 3). It is observed that in both categories, the fine content (%) is high, nearly 100% down to the depth of 8 km. Fine content decreases to less than 40% below 8 to 20m in coarse grained dominating boreholes (Figure 2a). Below 20m depth, approx. 50% of samples for both categories are sandy and 50% are silty and clayey soil. The liquid limit (LL) for the fine grained soil boreholes was generally higher, ranging from 35-60 (Figure 2b). The coarse grained soil boreholes, on the other hand, show LL values 20 to 30 (Figure 3b). Plasticity index of the fine grained soil is also higher than the coarse grained soil.

Soil classification is carried out as per IS-1498-1970. The fine-grained soil can be classified as silty soil with intermediate plasticity to clayey soil with high to low plasticity. Only a few of them are silty soil with high plasticity (Figure 4). The coarse grained soil, on the other hand, can be classified as poorly sorted sand (SP) to silty sand (SM).

VERTICAL CORRELATION OF GEOTECHNICAL PARAMETERS

The boreholes are vertically correlated using geotechnical parameters and SPT- N values along seven different cross sections (Figure 1), four along EW direction (S_1 to S_4) and three along N-S direction (S_5 to S_7). Locations of cross sections are shown in Figure 1 and soil profiles are shown in Figures 5 and 6. The vertical profiles show that the entire study area is covered by fine grained sediment with intermediate to low plasticity having an average depth of 15m which reaches to 30m at a few locations. The fine grained layer is followed by the coarse grained sediment with an average thickness of 20m. Low SPT-N value (N_{SPT}) less than 15 were encountered at depth 6m except in boreholes D51 and D16 in Section-S_2**,** and in borehole D17 in Section-S_4**.** N_{SPT} greater than 15 but less than 50 were found at the depth 6m to 30m. N_{SPT} greater than 50 were found at depths 30m and below.

ESTIMATION OF FOUNDATION PARAMETERS

Safe Bearing Capacity (SBC) and Safe Bearing Pressure (SBP) are the two main parameters for designing foundation structure. These parameters are estimated considering shear and consolidation characteristics of the sub surface sediments. SBC and SBP have been estimated for 20 borehole locations. Results are presented for six boreholes (Table 1). For SBC estimation, the soil parameters like cohesion, angle of friction, specific gravity and corrected N values are used for foundation depth of 3m with width and length of 3m. The ground water level factor is considered along with the permissible 25 mm settlement of the footing.

The results show that the SBC value varies between 8.56t/m^2 and 45.04t/m^2. The low SBC in borehole D22 is due to silty sand with low plasticity and low $(N1)_{60}$ at 3m depth. On the other hand, the high SBC in borehole D61 is due to clayey nature of the soil at this particular depth. The plot of SBP with corrected N value (Figure 7) shows that the SBP increases with increase of N values.

SITE CLASSIFICATION

Site classification is an important part of the present study as the study area is expected to undergo extensive construction activities in near future. It is necessary to have subsurface litholog to estimate the effects of earthquake. Site classification can be carried out based on three different parameters i.e. undrained shear strength (S_u), SPT-N (N_{SPT}) and shear wave velocity (Vs) (NEHRP, 2000). The parameters used to define site classification are based on the upper 30m of the site profile (NEHRP, 2003). We used N_{SPT} for the site classification. The equivalent shear stiffness values of soil based N_{SPT} values over 30m depth can be estimated by using the following equation:

$$N_{30} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \left(\frac{di}{N_i}\right)}$$

where, N_{30} is the measured N_{SPT} value without correction and should not be taken greater than 100 blows/ft, of distinctly different soils and rocks are segregated by a number that ranges from 1 to n in the upper 30m. Average N_{30} values were calculated using equation1. The calculated N_{30} ranges from 8 to 57 and classification according to the US National Earthquake Hazard Reduction Program (NEHRP) is given in Table 2. It is observed that the entire study area comes under the site 'class D' which belongs to stiff soil except in four boreholes out of total 64 (three of which come under the site class-E (soft soil) and one in site class-C (much dense soil).

Detailed site classification at every 3m depth were carried out using average N_{SPT} values down to 3m ($\mathbf{N_3}$), 6m ($\mathbf{N_6}$), 9m ($\mathbf{N_9}$), 12m ($\mathbf{N_{12}}$), 15m ($\mathbf{N_{15}}$) and 18m ($\mathbf{N_{18}}$) depth and classified them as per NEHRP site classification.

Figure 8 shows site classification of the study area at different depths of 3m, 6m, 9m, 12m, 15m and 18m. At 3m depth soft soil is revealed over a major part of the

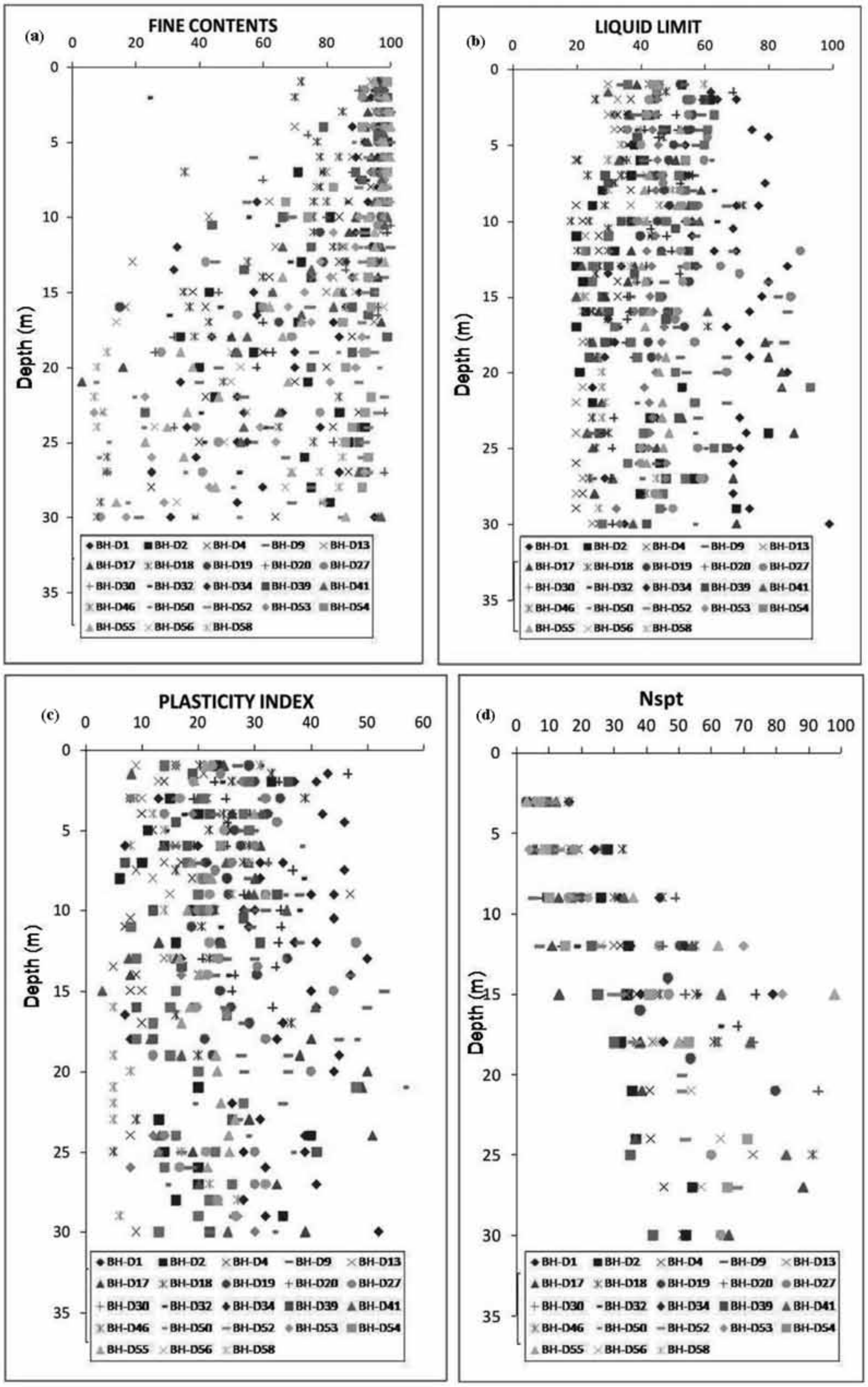

Figure 2. Plot of geotechnical properties (Fine content, Liquid Limit, Plasticity Index and SPT-N value) for fine grained dominated boreholes.

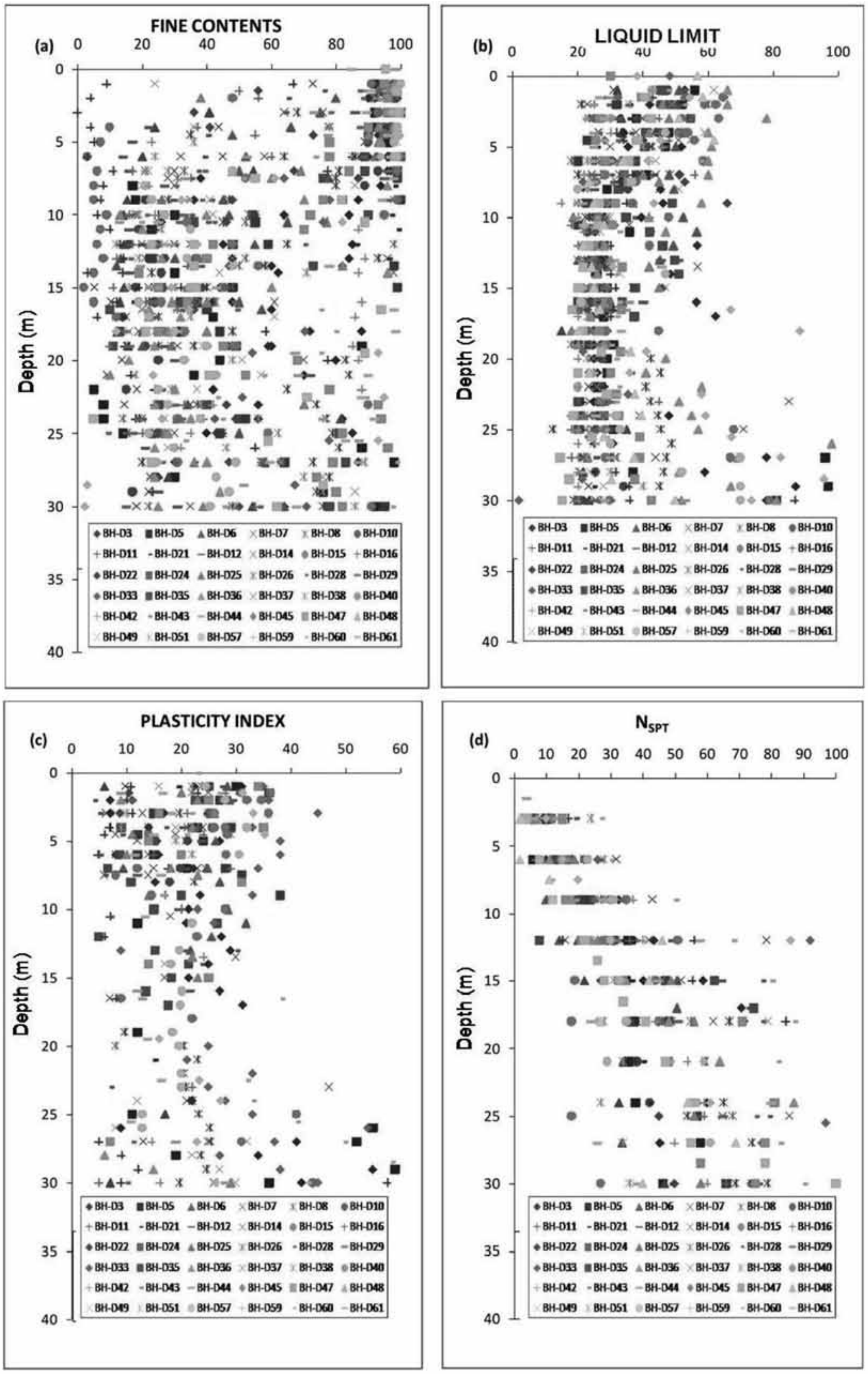

Figure 3. Plot of geotechnical properties (Fine content, Liquid Limit, Plasticity Index and SPT-N value) for coarse dominated boreholes.

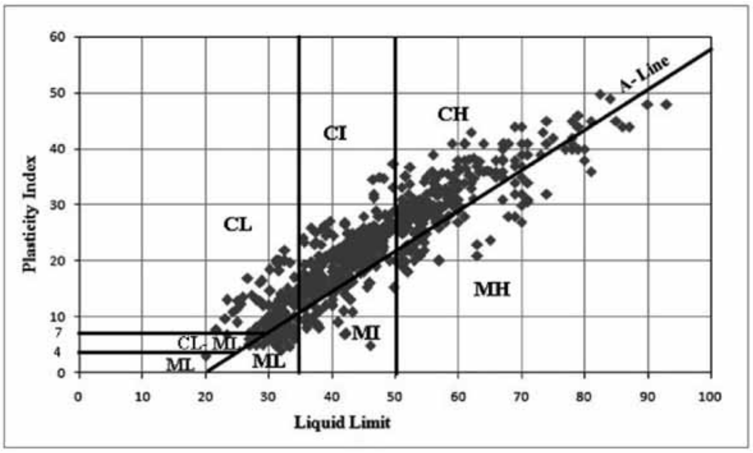

Figure 4. Classification of Fine Grained Soil for the study area based on plasticity chart as per IS**: 1498 – 1870**. Plasticity Index and Liquid Limit for each of 645 samples are shown by diamonds. The letter C indicates clay and M indicates silt. Subsequent letters L, I and H indicate low, intermediate and high plasticity, respectively.

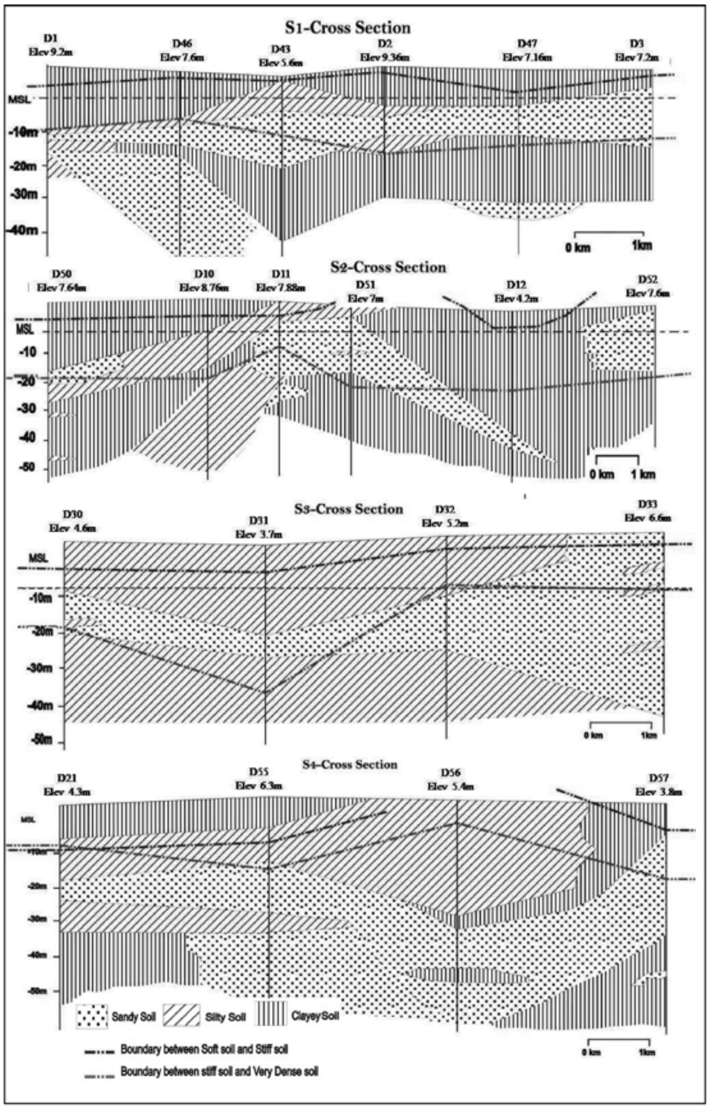

Figure 5. Soil profiles along west to east (see Figure 1).

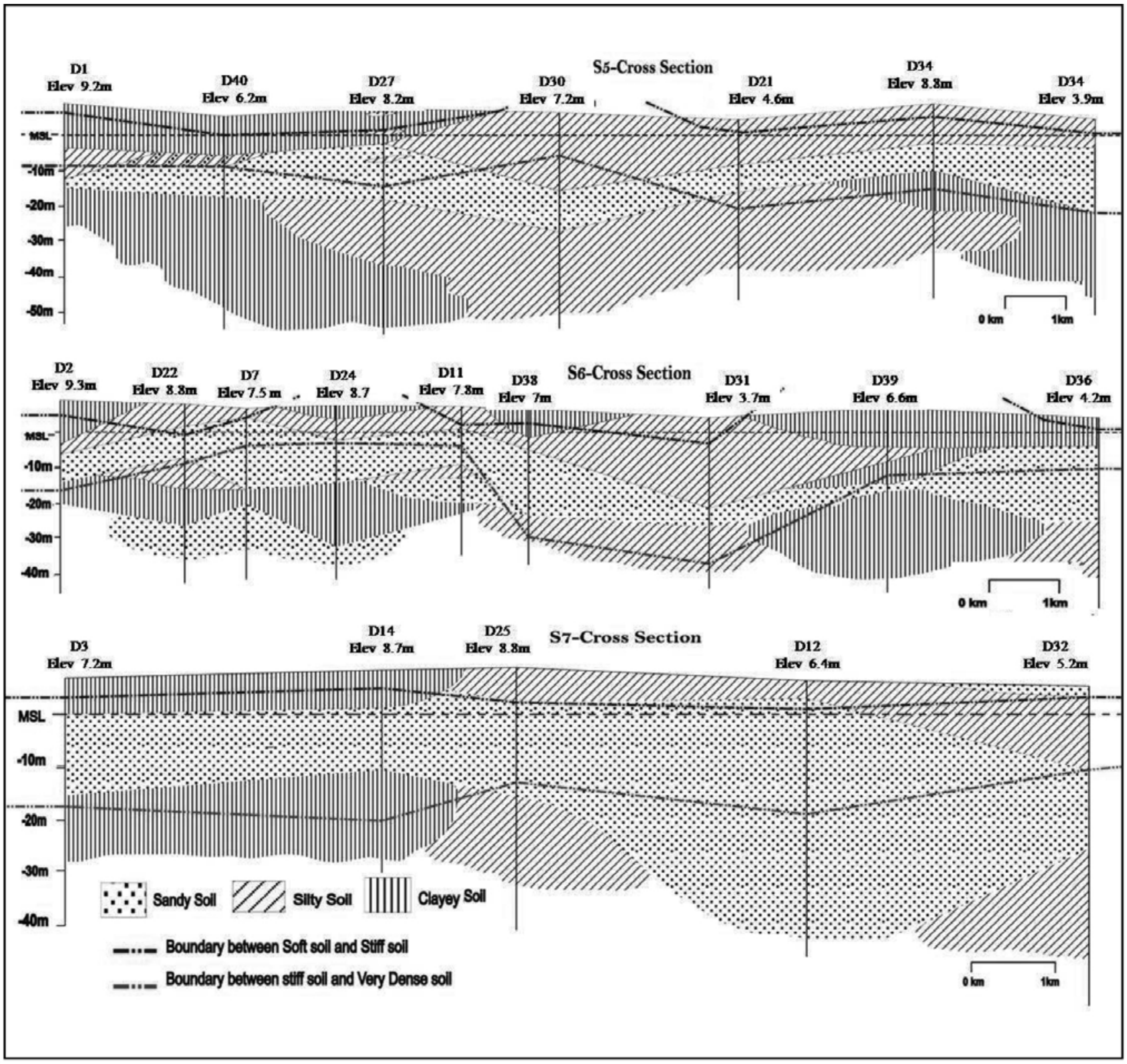

Figure 6. Soil profiles along north to south (see Figure 1).

Table1. Estimated SBP and SBC at 3m footing depth for selected boreholes in the study area.

Bore Hole No.	Water Table (in m)	Depth of Footing, D (in m)	Width of Footing, B (in m)	Water Table Factor	Corrected "N" value	Settlement / Unit Pressure (in mm)	Safe Bearing Pressure (in t/m^2)	Safe Bearing Capacity (in t/m^2)
D9	2.4	3	3	0.5	4	190	2.63	16.95
D22	2	3	3	0.5	6	160	3.12	8.56
D25	1.5	3	3	0.5	14	22	22.71	14.96
D26	2.1	3	3	0.5	15	20.5	24.38	29.63
D32	2.5	3	3	0.5	10	36	13.88	30.9
D61	2.44	3	3	0.5	8	58	8.62	45.04

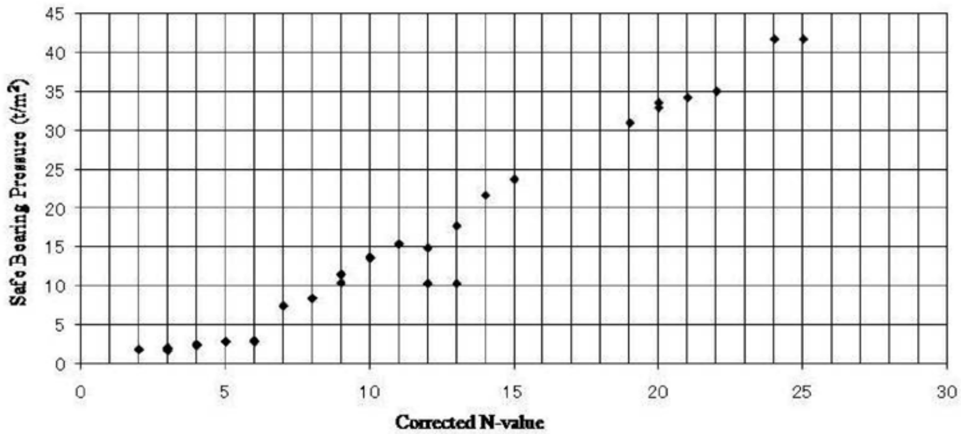

Figure 7. Graph showing a linear relationship between SBP and corrected N- values.

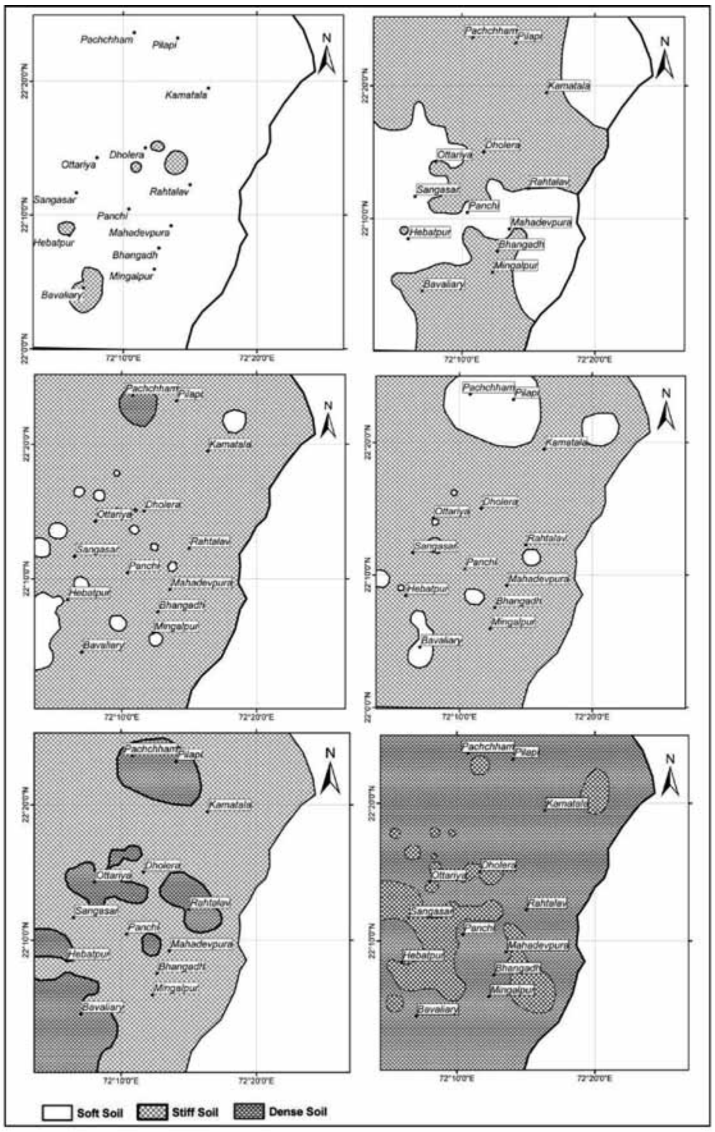

Figure 8. Distribution of different soil types based on SPT-N value according to NEHRP.

Table 2. Seismic site classification as per NEHRP.

Site Class	N_{SPT} value (N_{30})	Shear wave velocity (V_s)	Undrained shear strength (S_u)
Site-E (Soft soil)	<15	(< 180 m/s)	(< 50 kPa)
Site-D (Stiff soil)	15-50	(180 to 360 m/s)	(50 to 100 kPa)
Site-C (Very dense soil/ soft rock)	>50	(360 to 760 m/s)	(> 100 kPa)

area with small patches of stiff soil in the southern part at borehole D39 and D59 and at the central part at boreholes D2, D9 & D26. At the depth of 6m, the area shows soft soil and stiff soil in almost equal proportions. Northern and southern parts are characterized by stiff soil while the middle and north eastern portions are characterized by soft soil. At the depth of 9m, the entire area is covered by stiff soil with small patches of soft soil in southern part. Dense soil is found in the northern part in and around borehole D61. At the depth of 12m, the entire area is covered by the stiff soil with two patches of soft soil in northern part and a few small patches in the southern part. At the depth of 15m, there is no soft soil. Relatively denser soil occupies the northern part, central part and south western part while the stiff soil occupies the remaining portion. At the depth of 18m, the entire area is covered by the dense soil with small patches of stiff soil in the southern part.

DISCUSSION AND CONCLUSIONS

Geotechnical investigations, carried out using samples from 64 boreholes down to the depth of around 50m indicate that the study area is covered by fine grained sediments down to depth of 8m. The sediments are classified as silt with intermediate to low plasticity and clay with high to low plasticity. Site classification based on the measured SPT-N value and the US National Earthquake Hazard Reduction Program (NEHRP) indicates that the study area in general comes under class -D i.e. the soil in the area is stiff in nature for depth exceeding 3m. Such a type of soil possesses sufficient strength suitable for infrastructure development. For high rise buildings, detailed investigation should be carried out before construction to estimate low frequency amplification due to the possibility of large Kutch earthquakes. Safe Bearing Capacity of soils having N>15 (stiff soil) is acceptable but not for 3m top soft soil having N<15.

The present study provides preliminary guidelines to geotechnical engineers and researchers for land use planning and other constructional activities.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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