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Integrated Study of Geotechnical and Geophysical Methods to Assess the Soil Corrosion Potential for Construction Site

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Abstract: Corrosion of subsurface steel structures is very critical issue especially in moisture subsoil. The use of physiochemical properties such as pH, salts concentration, electrical resistivity is very common to quantify corrosive nature of subsoil. However, the laboratory measurements of these parameters are quite difficult due to time and budget constraints. In this work soil corrosion potential of a power plant site was evaluated using geophysical and geotechnical investigations. Soil samples were collected from 15 boreholes drilled up-to 50 m depth for laboratory testing whereas 3 probes of four electrodes vertical electrical sounding (VES) using Wenner configuration were also performed to measure the electrical resistivity of the subsurface soil up to 50 m depth. According to the USCS soil system silty clay (CL-ML) was interpreted as dominant material in all boreholes as shallow depth. Poorly graded sand (SP) including silt (SM) was found of variable depth in almost each borehole. The true resistivity values at the depth of 30 meters lies between the 19.9 ohm- meters to 59.8-ohm meters. All observation points of electrical resistivity survey VES-I, VES-II and VES-III near-surface material show moderate soil corrosion potential which is favorable for design of earthing. Up to depth of 4 m, the values of resistivity 52.6 to 59.8 ohm-meters shows adequate estimation of corrosion. According to the International standard these curves belong to bell type or K type curve of resistivity model. Their resistivity values with respect to depth show low to moderate corrosion potential which is satisfactory for construction at this depth after applying the nominal cathodic protections. Thus, electric pipe lines may be installed at this depth.

Keywords: Soil corrosion potential, electrical resistivity, vertical electrical sounding, cathodic protection.

Introduction

Soil corrosion in steel and cast-iron causes vast failure in buried pipe without insulation either due to wall pitting, voids or high soil corrosion potential. This problem is directly linked with building structure from shallow or deep foundation. The utilization of geophysical strategies can decide to determine the depth of bed rock, basic mapping and profiling of layers. The need for site exposure through these sub surface investigation techniques has turned out to be crucial to keep the loss of important lives (Olorunfemi and Meshida, 1987, Adepelumi et al., 2000). In this dynamic world exceptionally, cutting-edge innovation is being utilized in developments. Incorporated methodology through geotechnical and geophysical examination in structural building for development purpose has been promising mechanism to discover subsurface lithology and its qualities (Arshad and Ahmed,2007, Akintorinwa and Adeusi,2009). Geotechnical site examination is done to assess the physical and chemical properties of in-situ soil and rocks for design of foundation. The investigation is meant to assess the suitability of the surface lithology for the foundation material at site. Synchronization of such kind of problem is only possible when survey conducted before the construction and inquires the soil condition in upper and lower level of ground. This is possible using geophysical and geotechnical tools for investigation of subsurface material. So as to develop a high rise building or any other structure it is basic to investigate the surface and sub-surface material to select the suitable site for construction (BS 7361 1991, Schoor, 2002, Arshad and Ahmed, 2007, Jamiolkowski, 2012, Rahiman 2013).

Geological model and geotechnical tests proved the direct key to civil engineer for competency of material for any project. Geophysical methods are applyed all over the world to determine the characterization of subsurface condition and material identification. It is also useful for the construction of buildings and dams. In Saudi Arabia the subsurface exploration through geotechnical tools or geophysical methods have significance for preliminary feasibility reports of various projects (Frohlich and Urish 2002). Geotechnical and geophysical inspection are also help for the design foundations purpose so the electrical resistivity method is useful for solves the problems of groundwater (Matias, 2002). Therefore, study was directed to assess the aptness of the subsurface formation as foundation materials. Geotechnical application shows a connection that can be utilized to take care of many designing issues (Soupios, et al, 2005, Soupios, et al., 2007, Schoor 2002, Klimis et al., 1999).

In this study geotechnical and geophysical tools exploring the surface and subsurface material properties for the construction of Nishat Chunian coal-based power plant to generate the 45 MW electricity placed at Phool Nagar on Multan road near Jamber Kalan Tehsil

Pattoki district Kasur with coordinates 31^{0}07'20.19" N and 73^{0}54'19.36" E. The study site area is showing in (Fig.1) with boreholes and vertical electrical sounding (VES) points. The coordinates of the boreholes drilled at site are given in Table 1.

This work is two folded in which first is relevant to the engineering properties of surface and subsurface material using geotechnical parameters second is using geophysical tools to explore how earth material is suitable for the earthing system. In geophysical investigation, electrical resistivity method is the most common technique used to explore the water resources and subsurface material quality on the basis of conductivity values (Edgell, 1990, Grant and West, 1965, Oyedele, et al., 2011, Orellana and Mooney, 1966, Azoor, et al., 2019). Electrical resistivity method is reliable, efficient and cost effective. Using exploration method oil profiles are also used to interpret soil layer in term of thickness of material in subsurface (Soupios, et al., 2005, Patrick, 1990). The role of electrical resistivity survey (ERS) facilitates subsurface analysis about the strata variation and their geophysical properties (Sebastiano, 2012).

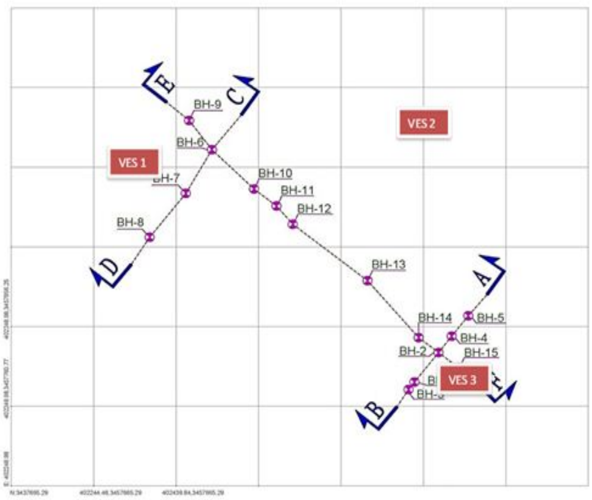

Fig. 1 Study site boreholes and VES points marked on base map.

Table 1 Geographical boreholes coordinates of the site.

Boreholes Points	Eastern coordinates	Northern Coordinates
1.	402691.778	3457783.643
2.	402729.678	3457818.987
3.	402430.925	3458097.321
4.	402457.214	3458062.112
5.	402427.123	3458009.782
6.	402385.178	3457957.423
7.	402515.927	3458014.243
8.	402525.047	3457994.618
9.	402550.932	3457972.665
10.	402634.533	3457900.719
11.	402696.649	3457836.898
12.	402754.123	3457863.051
13.	402734.887	3457836.567
14.	402684.897	3457774.569
15.	402723.276	3457781.396

Materials and Methods

A standard penetration test (SPT) was carried out in the field in accordance with ASTM (D1586 2011). Soil samples were collected from different boreholes depths. The main types of soil are sand, silt and clay. The schematic diagram shows the work and principal of standard penetration test (Fig.2). The maximum depth of BH1 was 50 meters. The subsurface material initially measured is alluvial deposits consisting mainly of fine to medium grained material deposited by Ravi river. The upper surface up to a depth of few meters' material is clayey silt. The site area was divided in three profiles according to the borehole's distribution. Soil profiles A to B, C to D and E to F were prepared during field testing. The water table was measured at approximately 13 feet depth which was varying with lithology thickness.

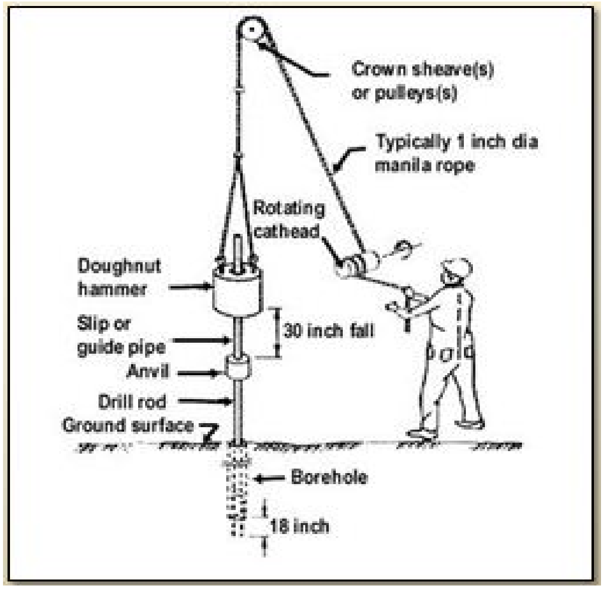

Fig. 2 Schematic diagram of standard penetration test in field (Krynine and Judd, 2001).

To determine the engineering and physical properties of soil, a numbers of laboratory tests were conducted including Atterberg's limits (LL and PI) (ASTM D4318 2011), Direct shear test (ASTM D3080 2011) Unconfined compression test (ASTM D2166 2011), density and moisture content (ASTM D7263 2011) grain size, specific gravity and water absorption.

The second part of this study is geophysical survey which is used to evaluate soil corrosion potential of the soil up to the 20 meters' depth using electrical resistivity survey. The values obtained from resistivity survey had been utilized for design of electric installation at shallow depth at site specially for earthing system. In the vertical sounding technique, very low frequency (less than 1 Hz) current immunized inside the ground through two current electrodes (CE) and two potential electrodes (PE) injected in the ground surface in such a way that all the electrodes are aligned along a straight line (Fig 3) designed by Wightman et al., (2003). The current passing through two electrodes among the two electrodes CE and the associated potential difference (V) between the potential electrodes PE, the resistance (R) is calculated by the relation of Ohm's law in *equation* 1.

$$R = \frac{\boldsymbol{V}}{\boldsymbol{I}} * K \qquad 1$$

Where

K. = Geometric factor

V. = Potential difference in mill volts

I. = Current passing through ground in mill amperes

In uniform material in the earth, equation 1 gives the true resistivity values of the sub surface. On the other hand, anisotropic and inhomogeneous conditions, it shows the average values of resistivity with reference to the formations. Commonly the subsurface condition is mostly inhomogeneous and anisotropic. Therefore, resistivity values calculated by above equation is taken as apparent resistivity value on the ground level shown by "Ra" as in eq.2.

$$Ra = \frac{\boldsymbol{V}}{\boldsymbol{I}} * K \qquad 2$$

The estimation of the electrical resistivity of subsurface material was taken in the field by instrument called Terrameter SAS 1000 of ABEM (ABEM 2016), Sweden. Wenner config uration setup with vertical electrical sounding system is utilized. The Terrameter straight away records the estimation values in ohms.

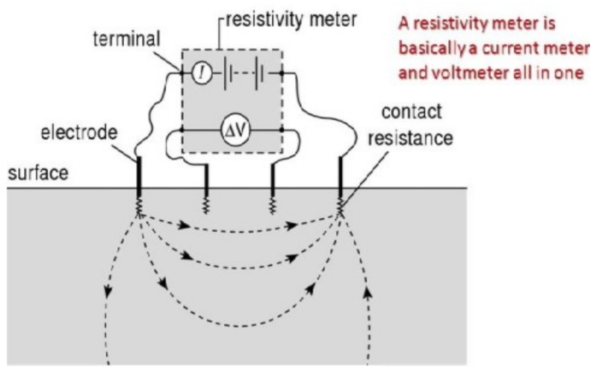

Fig. 3. Systematic view of ERS using VES technique (*Wightman et al.,* (2003)

Result and Discussion

To investigate subsurface material standard penetration test was conducted in accordance with the standard (ASTM D1586 2011). Undisturbed samples (UDS) or SPT soil samples were collected from each borehole at various depth for the laboratory testing. According to unified soil classification system (USCS 2011), all soil profiles were prepared and notified with their standard symbol accordingly. The soil profile A to B contained (BH1), (BH2), (BH3), (BH4) and (BH5). The depth of each bores hole differs from each other particularly depth fluctuates from 30 meters to 50 meters. Near the ground level the depth almost up to 2 m, the nature of soil was low in plasticity, soft to stiff, silty clay, whereas in lower part constitutes the dense, silty to poorly graded sand shown in soil profile A to B (Fig. 4). Each bore hole describes the level of water in each borehole profile. During grain size analysis gravel percentage varies from 0.0 % to 3.8 %, sand particles fall in 0.6 % to 89.4 % and fine particles of soil vary from 0.7 % to 99.1 %.

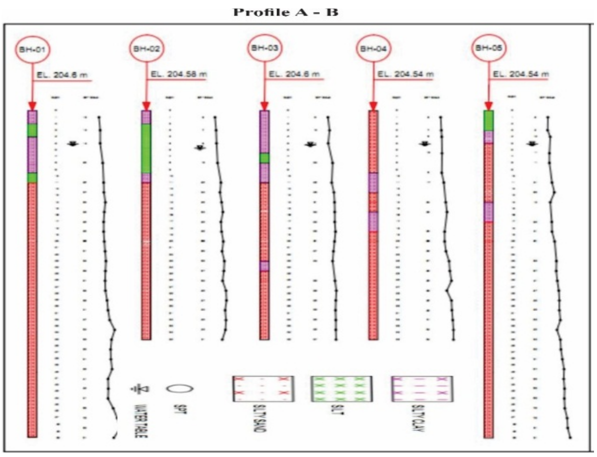

Fig. 4 Borehole soil profile A to B.

Three boreholes (BH6), (BH7) and (BH8) lie in the soil profile C to D (Fig 5). The depth varies from 29m to 40m. Initially 11m was silt and sandy silt, below this poorly graded sand exists, after 14m silty sand (SM) material was encountered. Particles size analysis of the in-situ soil samples show percentage of gravel, sand and fine particles suitable for shallow depth foundation. The percentage varies from 0.0% to 12.3 % for gravel, the sand percentage from 0.7% to 92.3% and the fine particles range from 4.5 % to 99.7 %.

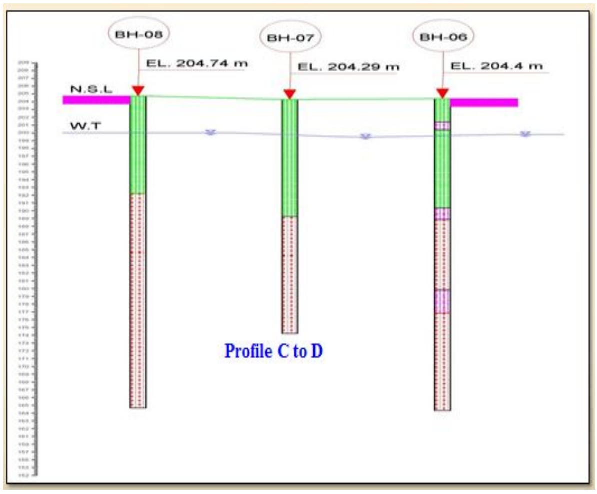

Fig. 5 Borehole soil profile C to D.

This soil profile E to F contained 9 boreholes (BH9), (BH10), (BH11), (BH12), (BH13), (BH14) and (BH 15) including BH2 and BH6 (Fig 6). The soil strata are fine to medium grained particle of gravels, sand and fine. The percentage of gravels varies from 0 % to 9.6 %, sand grain varies from 0.60 % to 93.7 % and fine particles of soil range from 6.8 % to 99.7 %. The lithology varied from silty clay (CL-ML) to brown silt (ML), medium dense to very dense silty sand (Fig 7).

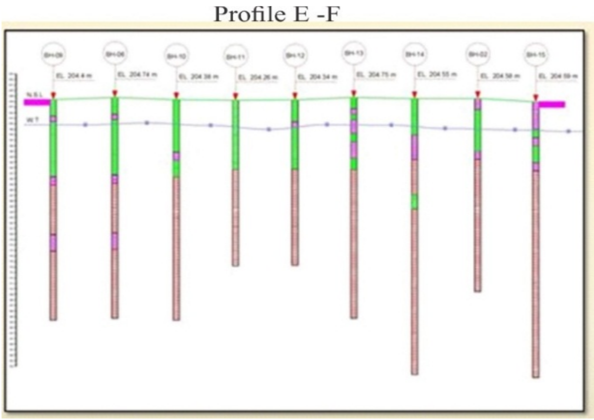

Fig. 6 Borehole soil profile E to F.

Generally, the subsurface material was sandy silt (ML) to silty sand (SM) minor with silty clay then again sandy silt. The behavior of this soil is due its composition whereas some bore holes also show the narrow layer of lean clay (CL).

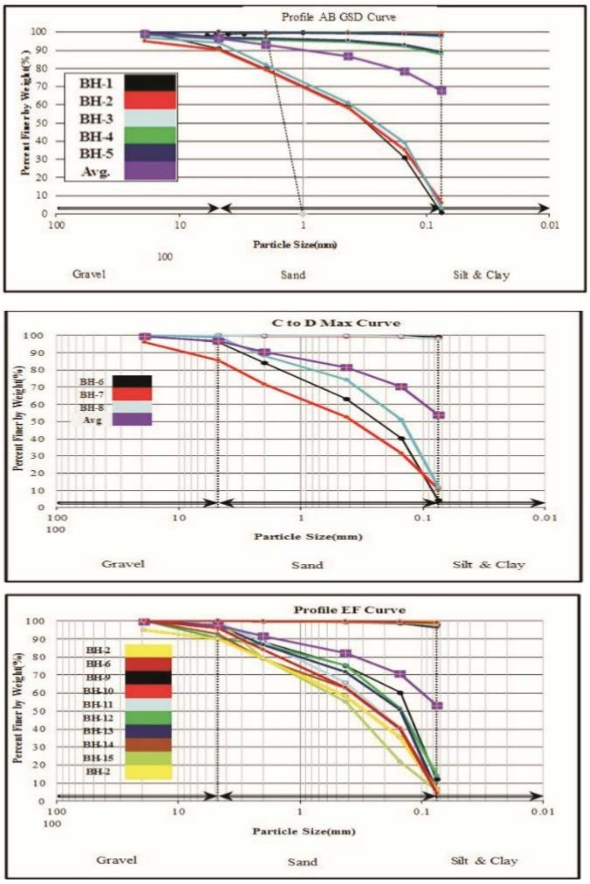

Fig. 7 Grain size distribution curves for all three soil profiles.

Electrical resistivity survey was carried out at three observation points marked on the base map (Fig 1) designated as VES-I, VES-II and VES-III. The international standard (ASTM D6431-99 2011, Baker and Schmeisneer 1999) was implemented for electrical resistivity survey. Apparent resistivity values were taken at electrode positioning of 1, 2, 3, 5, 7, 10, 15 and 20 meters.

The true resistivity layering model drawn by the software IXD Prex at three points namely VES-I, VES-II and VES-III (Fig. 8). The resistivity models show that subsurface material up to 20 meters' depth was ranges from 19.9 Ωm to 57.4 Ωm. In all these curves the initial trend increases and then decreases. The curve shows that resistivity values in sub surface layers have lower to higher (Tables 2). In VES-I top 1.2-meter depth resistivity value is 32.2 Ωm, below this at 4.0-meter depth resistivity is 57.4 Ωm which is higher value in this layer. Below the 4-meter depth resistivity value decreases up to 19.92 Ωm. In VES-II resistivity layer model 1.2-meter depth at first layer resistivity is 33.33 Ωm and below this at 3.6-meter resistivity value up to 52.6 Ωm. At third layer below 3.6-meter depth resistivity value is 23.3 Ωm. In VES-III top layer at 0.8-meter depth resistivity is 33.3 Ωm and below this higher resistivity value (59.8 Ωm) is encountered. The resistivity values of third layer at depth 23.1 meter are 23.1 Ωm.

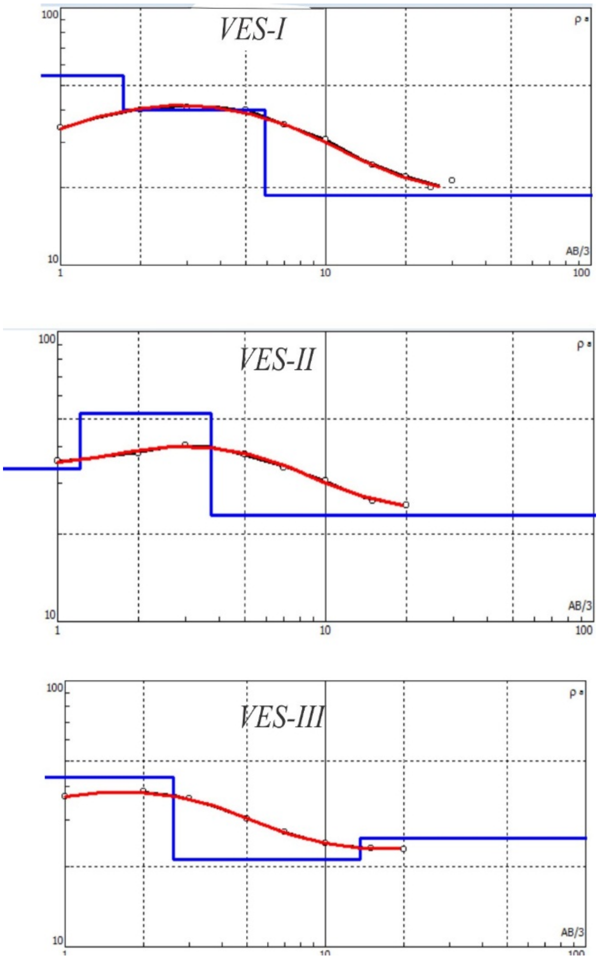

Fig. 8 True resistivity layers' model

Soil Corrosion Potential and Correlation with Electrical Resistivity Survey

Soil corrosion is most complex phenomena. This can vary according to the soil type with different amount of salts dissolved in it. Fine grained soil or soil having small particle size like silt, silt clay and clay are known to have a greater corrosion potential due to very lower hydraulic conductivity. On the other hand, coarse grained material like gravel and sand are considered to have a reduced corrosion potential due to high hydraulic conductivity in such a way that all salts in soil are seeped out after accumulation. Variables that can be boosted the soil corrosion in covered metals and other earthing electrical items are hydrogen particle, dampness content, molecule estimate, oxygen content, seepage and bacterial process action in the case of corrosion in pipelines and sewerage pipes.

Soil classification is commonly based on corrosiveness as per the standard BS 7361 (Bachrah and Nur, 1998, Kim, 2005, Choudhury et al., 2001) for cathodic protection and assessing the severity of corrosion. Electrical resistivity of this type of soil at normal water content is over 100 Ωm. If the soil is moderate permeable with low corrosivity for steel having coarser to medium texture, so this type of soil has 50-100 Ωm value. The soil having resistivity 20 to 50 Ωm is moderate by corrosive and this criterion mostly falls in well drained medium to fine texture. Very high values of resistivity in steel mostly at this stage material comprises poorly drained fine texture soils.

Soil resistivity has greater influence on soil corrosion. The true resistivity of the subsurface material in the site area varies from 20.0 to 59.0 Ωm, therefore material in subsurface indicates moderate to low soil corrosion potential (Table 2). In the study area soil having small resistivity a value from 19.9 Ωm to 23.4 Ωm was noticed below the depth of 1.8 m to 4.0 m. This material is favorable for the design electrical installation.

Table 2. True resistivity layer model with estimated corrosion potential.

Observation point No.	Depth (meters)	Thickness (meters)	True Resistivity (Ohm-meters)	Corrosivity
VES-I	1 - 1.2	1.2	32.6	Corrosive
	1.2 - 4.0	2.8	57.4	Moderately corrosive
	4.0 - 30.0	26.0	19.9	Corrosive
VES-II	0.0 – 1.2	1.2	33.3	Corrosive
	1.2 – 3.6	2.4	52.6	Moderately corrosive
	3.6 - 20.0	16.4	23.4	Corrosive
VES-III	0.0 – 0.8	0.8	33.3	Corrosive
	0.8– 1.8	1.0	59.8	Moderately corrosive
	1.8 – 20.0	18.2	23.1	Corrosive

At all three resistivity observation locations near-surface materials have the moderate soil corrosion potential, hence using nominal corrosion protection metal pipe and electric installation can be embedded at this depth. Cathodic protection measures galvanization is used for higher capacity coating wire with 100% guarantee for insulation with allowable metal loss rate. Bituminous and many other admixtures of coating may be used for earthing design.

Keeping in view of results obtained by geotechnical and geophysical techniques the strata in subsurface at site is capable to survive and bear the above structure load. The subsurface analysis at site facilitates the accuracy about material engineering properties for safe static and dynamic earthing design of electric cables and metal pipes.

Conclusion

In view of the consequences of geotechnical and geophysical investigation the accompanying ends are drawn for site characterization of subsurface material explored up to depth of 50 meters. At depth 3 to 6 meters' material was silty clay or clayey silt and less cohesive. As better soil is present at below 4-meter depth, shallow foundation is proposed from existing ground level, which will be finalized by the geotechnical engineer keeping in view the load of the structure. At the depth of 30 m true resistivity value varies from 19.9 to 59.4 ohm-meters. This three-layer model shows the maximum curve and according to the international standard curve of resistivity models is bell type or K type curve of resistivity and density of 2nd layer is higher than the other two layers. The true resistivity of the subsurface material in the site area varies from 20.0 to 59.0 Ωm, therefore material in subsurface indicates moderate to low soil corrosion potential. The depth at 4.0 m material is sufficient for design of earthing system with moderately low corrosive soil. So, metal pipes embedded at this depth would require only nominal corrosion protection measures.

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