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Research paper

Geoelectrical and geotechnical investigation of foundation failure in and around Oroke high school, Akungba-Akoko, southwestern Nigeria

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Abstract

Engineering structures are designed and constructed with an air of lifelong expectancy. Moreover, building foundation may experience failure due to presence of concealed geologic features such as cavity and shear zones which can lead to subsurface subsidence. Hence, it is imperative, prior to building construction, to investigate the physical properties of foundation soils and determine its suitability for design and construction of building structures. In the light of this, a geoelectric survey, involving three (3) electrical dipole - dipole array and geotechnical analysis methods were carried out around a distressed building at Oroke High School, opposite Adekunle Ajasin University, Akungba Akoko to establish the cause of failure for the structures foundation via delineating the subsurface structural features. The field electrical data were plotted on log –log graph sheets and the resulting curves were interpreted qualitatively by visual inspection, and quantitatively via partial curve matching and computer iteration techniques. For the geotechnical analysis, a total of twelve (12) soil samples were taken from different locations of about 30 meters intervals, at the depth of 1.5 meters. The pseudo – section and electrical sections indicate that the subsurface is heterogeneous in geological composition. The 2D dipole- dipole resistivity and pseudo – section delineated zones having resistivity values ranging from 200 to 700ohm meter, and those approaching infinity all within a depth of 0-5 m, the resistivity values of 27 to 139ohm meter suggest the presence of clay. The geoelectric section identified three subsurface geologic layers comprising clay /sandy, clay top soil / sub grade soil, clay / sandy clay and sand weathered layer and the basement (fresh) beneath the failed segment. Additionally, prominent fractures were discovered within some areas on the pseudo-sections. The results of the laboratory tests also included those of natural moisture content, specific gravity, grain size distribution curves, Atterberg limit, compaction test and California Bearing Ratio (CBR). In conclusion, electrical resistivity method was found to be an effective measure or tool in the site characterization. The soil/rock in these zones may require reinforcement in order to enhance its bearing capacity and increase the life span of the engineering foundation.

Keywords: *Geoelectrical; Geotechnical; Dipole-Dipole and Foundation.*

1. Introduction

Building failure(s) could be defined as a discontinuity in structure, resulting in cracks, bulges and depressions (Aigbedion, 2007). However, waviness was adjudged the most common form of building failure (Gidigasu, 1972). Buildings of various categories in Nigeria have shown signs of failure in the form of cracking, rutting, deformation and peeling. In some cases, these signs of distress are visible within a short period of commissioning, yet the causes have not been fully established.

Engineering structures are designed and constructed with an air of lifelong expectancy. Moreover, building foundation may experience failure due to presence of concealed geologic features such as cavity and shear zones which can lead to subsurface subsidence (Fajana et al., 2016).Therefore, there is a need to investigate the geo-properties of foundation soils and determine how suitable they are for use as engineering materials. The geotechnical and geophysical methods are most suitable for this purpose of investigation as they provide information about the engineering properties of the foundation soils in relatively cost-effective and rapid manner (Oyedele and Bankole, 2009). Majority of building failures in the tropics can be attributed to geotechnical and geophysical factors as reported by workers such as Gidigasu (1972), Meshida (1985) and Adeyemi (1990) while other workers (Momoh et al., 2008) considered poor construction materials, bad design as some of the factors responsible for the failures. The aim of this research is to establish the cause of the failure for the structures foundation via delineating the subsurface structural features.

2. Description of the study area

The study area is located within Oroke High School, opposite Adekunle Ajasin University Campus, Akungba-Akoko, Ondo State, Nigeria. It falls within latitudes N 070°28'45.41" and N070°28'54.62" and Longitudes E005º44'8.617" and E005º44'18.064". The study area covers an estimated area of about 1.4 square kilometers. It has an approximated elevation of about 340 m and enclosed within the Nigeria topographic sheet 255 (Owo Sheet belt).

The topography of the area is characterized by highlands and low lands with the Northern part having topographically higher elevations than the Southern parts. The highlands are made up migmatite gneiss rocks which form inselbergs while the lowlands are valleys and plains covered by laterite (Ademeso and Adeyeye, 2011). The highest elevation in the region is slightly over 1820ft above the sea level (Figure 1).

The study area lies within the crystalline Basement Complex rocks of the Southwestern Nigeria. The main rocks recognised in the study area are Grey gneiss, Granite gneiss and Migmatite (Figure 3).

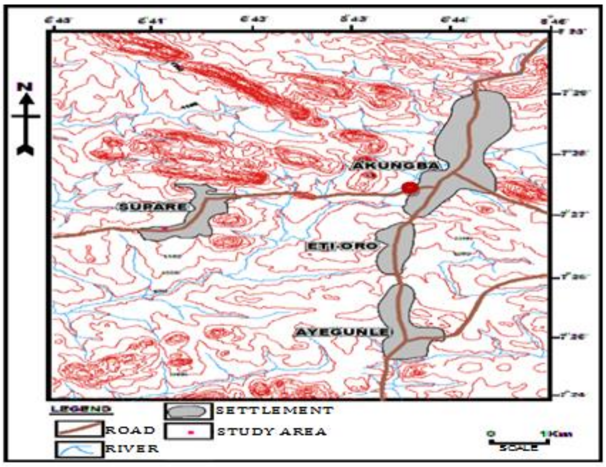

Fig. 1: Topographic Maps of Akungba and Its Environs (Source: Department of Geology, Aaua).

Fig. 2: Typical Cracks Along Building Walls in the Study Area.

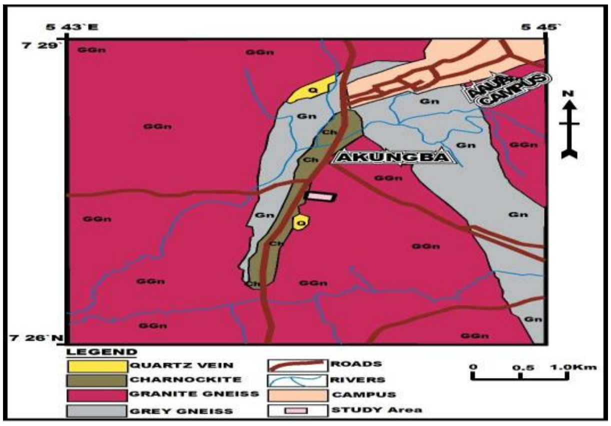

Fig. 3: Geological Map of the Study Area. Source: (After Geological Survey of Nigeria, 2015).

3. Methodology

Electrical and geoelectric survey, involving three dipole - dipole array and geotechnical analysis methods, were carried out around a distressed building at Oroke High School, opposite Adekunle Ajasin University, Akungba Akoko. The field electrical data were plotted on log –log graph sheets and the resulting curves were interpreted qualitatively by visual inspection, and quantitatively via partial curve matching and computer iteration techniques. For the geotechnical analysis, a total of twelve (12) soil samples were taken from different locations of about 30 meters intervals, at the depth of 1.5 meters. The collected soil samples from each horizon of the profiles were analyzed at the soil mechanical laboratory of Department of Earth Sciences, Adekunle Ajasin University, Akungba-Akoko. The soil samples were geotechnically tested according to the BS 1377 (1990) procedures.

The geophysical and geotechnical instruments used in this study include the following:

i) ABEM SAS 1000 Terrameter Equipment.

ii) Resistivity Meter.
iii) Electrodes (Metallic).
iv) Reels of Connecting Cables.
v) Tapes, thread, pegs, hammers, digger, chisel and cutlasses.
vi) Compass Clinometer and Global Positioning System (GPS)
vii) Sample bags

3.1. Dipole – dipole array

The dipole -dipole array has been, and is still, widely used in resistivity/I.P. surveys because of the low E.M. coupling between the current and potential circuits. The dipole-dipole electrode array consists of two sets of electrodes, the current (source) and potential (receiver) electrodes. The convention for a dipole-dipole electrode array is to maintain an equal distance for both the current and the potential electrodes (spacing = a), with the distance between the current and potential electrodes as an integer multiple of a. The electrodes do not need to be located along a common survey line (Aminu et al., 2014).
Additionally, the dipole - dipole data was interpreted via inverse modelling (automatic interpretation) using Dippro^{TM} SOFTWARE which is followed by qualitative interpretation of the generated pseudo-sections.

3.2. Laboratory ananlysis

Laboratory testing of the undisturbed soil samples collected at the established locations proceeded. The following analyses were conducted on the samples collected.
i) Natural moisture content (NMC)
ii) Atterberg or consistency limit test (Liquid Limit, Plastic Limit, Plasticity index, Linear Shrinkage)
iii) Specific gravity
iv) Grain size analysis
v) Compaction test
vi) California bearing ratio (CBR)

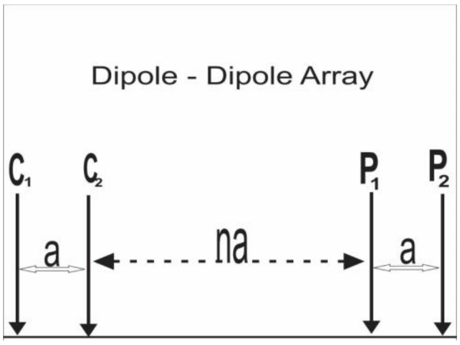

Fig. 4: Diagram Showing Dipole - Dipole Array Configuration.

Table 1: Longitude, Latitude and Elevation of the Sample Points

Samples	Latitude	Longitude	Elevation (m)
L1	7^{0}28'54.63"N	5^{0}44'18.06"E	361
L2	7^{0}28'53.30"N	5^{0}44'15.98"E	350
L3	7^{0}28'54.35"N	5^{0}44'15.00"E	360
L4	7^{0}28'53.50"N	5^{0}44'10.5"E	346
L5	7^{0}28'53.38"N	5^{0}44'13.33"E	346
L6	7^{0}28'48.82"N	5^{0}44'12.30"E	345
L7	7^{0}28'49.89"N	5^{0}44'19.95"E	340
L8	7^{0}28'48.09"N	5^{0}44'19.67"E	335
L9	7^{0}28'45.42"N	5^{0}44'13.10"E	320
L10	7^{0}28'46.17"N	5^{0}44'18.62"E	325
L11	7^{0}28'47.82"N	5^{0}44'12.08"E	335
L12	7^{0}28'50.99"N	5^{0}44'13.82"E	346

4. Results

4.1. Dipole – dipole pseudo-sections along traverse TR1

The calculated apparent resistivity values of the acquired field data were used to generate the pseudo-sections that is illustrated in Figure 5. The sections give the details of the lateral and vertical variations in ground apparent resistivity beneath each specific traverse line as opposed to the profile 1 that entailed 2–D vertical probing of the subsurface. The surface resistivity response beneath the T1 profile can be divided into three patterns.
The first pattern has a continuous low resistivity response with resistivity in the range of 27 – 139 ohms-m. Its distribution is not continuous but appear in localized regions as pockets of resistivity material between stations 0 and 20, 45 and 50 and 140 m to the end of the traverse. The second layer delineated is the partly weathered layer/ fractured layer (green pseudo - section) with resistivity value ranging between 200 and 700ohms-m. This pattern is extensive and occur as the first pattern in some places along the profile where the localized pockets of low resistivity materials are absent. The third pattern is the fresh Basement (Yellow / Red coloration) having very high resistivity that

approach infinity. On the pseudo section, there is an observable Basement depression between stations 45 and 50 m. There is also a prominent fracture between station 80 and 100 m. The Basement appears to be shallow in the region, occurring at the depth of approximately 3 m.

4.2. Dipole – dipole pseudo-sections along traverse TR2

The calculated apparent resistivity values of the acquired field data were also used to generate the pseudo-sections that are illustrated in Figure 6. The sections give the details of the lateral and vertical variations in ground apparent resistivity beneath each specific traverse line as opposed to the profile 2 that entailed 2–D vertical probing of the subsurface. The surface resistivity response beneath the T2 profile can be divided into three patterns. The first pattern is continuous low resistivity response with resistivity in the range of 24 – 64 ohms-m. Its distribution is not continuous but appear in localized regions as pockets of resistivity material between station 0 and 20, 40 and 50 and 70 m to the end of the transverse. The second layer delineated is the partly weathered layer/ fractured layer (green pseudo - section) with resistivity values ranging between 225 and 942 ohms-m. This pattern is extensive and occurs as the first pattern in some places along the profile were the localized pocket of low resistivity materials are absent. The third pattern is the fresh Basement (Yellow / Red colouration) having very high resistivity that approach infinity. On the pseudo section, there is an observable Basement depression between stations 55 and 60m. There is also a prominent fracture between stations 62 and 65 m. The Basement appears to be shallow in the region, occurring at the depth of approximately 2 m.
The sections in figure 7 give the details of the lateral and vertical variations in ground apparent resistivity beneath each specific traverse line as opposed to the profile 3 that entailed 2–D vertical probing of the subsurface. The first pattern has a continuous low resistivity response with resistivity in the range of 36 – 64 ohm-m. Its distribution is not continuous but appear in localized regions as pockets of resistivity material between station 0 and 36, 50 and 63 m respectively to the end of the transverse. The second layer delineated is the partly weathered layer/ fractured layer (green pseudo - section) with resistivity value ranging between 489 – 1219 ohm-m. This pattern is extensive and occurs as the first pattern in some places along the profile were the localized pocket of low resistivity materials are absent. The third pattern is the fresh Basement (Yellow / Red colouration) having very high resistivity that approach infinity. On the pseudo section, there is an observable Basement depression between station 60 and 70 m. There is also a prominent fracture between stations 27 and 35 m. The Basement appears to be shallow in the region, occurring at the depth of approximately 2.5 m.

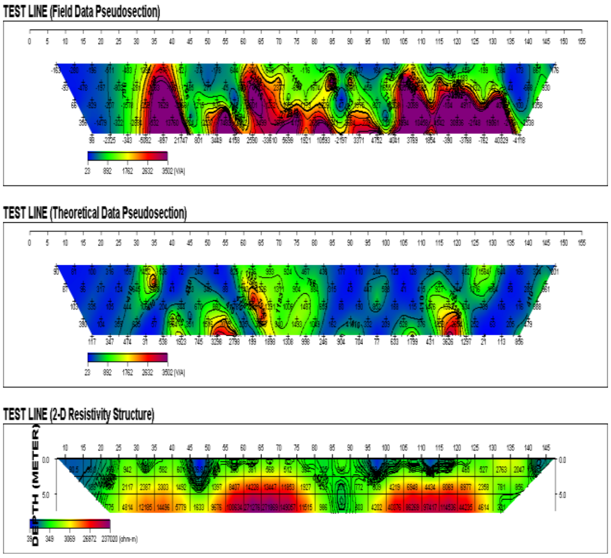

Fig. 5: Composite Plot of Pseudo- Section of Result of 2D Resistivity Inversion Beneath 1(A) Observed Resistivity Data, (B) Computed Resistivity Distribution and (C) Inverted Resistivity Structure.

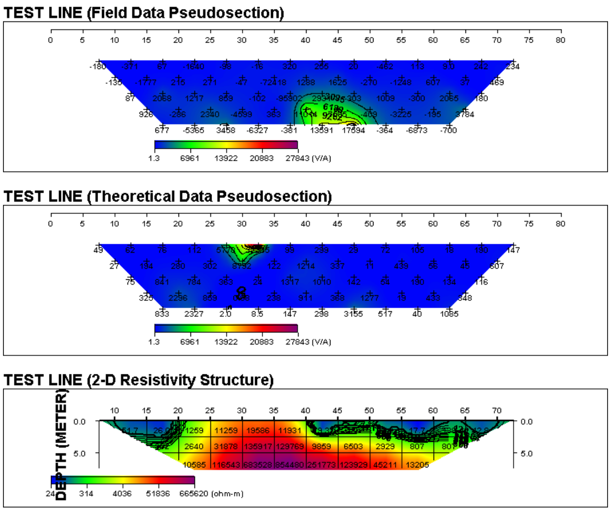

Fig. 6: Composite Plot of Pseudo- Section of Result of 2D Resistivity Inversion Beneath 2 (A) Observed Resistivity Data, (B) Computed Resistivity Distribution and (C) Inverted Resistivity Structure Dipole – Dipole Pseudo-Sections Along Traverse TR3.

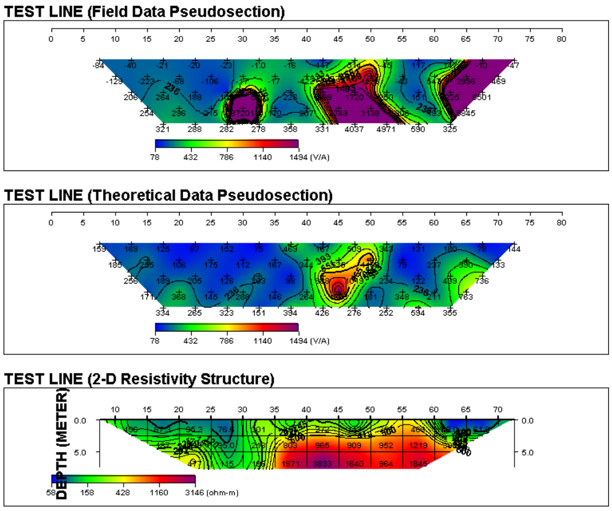

Fig. 7: Composite Plot of Pseudo- Section of Result of 2D Resistivity Inversion Beneath 3(A) Observed Resistivity Data, (B) Computed Resistivity Distribution and (C) Inverted Resistivity Structure.

4.3. Geotechnical studies

The natural moisture content of soil samples ranges from 27.4% to 37.8 %. The value of specific gravity of the unstable soil samples in the study area ranges between 2.59 and 2.75. According to Okogbue and Ene (2008), specific gravity is a reflection of the densities of constituent materials in each sample excluding the voids they contain

The soils were compacted at the standard proctor AASHTO level of compaction to determine the compaction level for sub-grade materials. The maximum density of failed building from the soil samples (MDD) ranges from 1290 kg/rn^3 to 1984 kg/rn^3 with optimum moisture content (OMC) ranging from 13.7 % to 33.7%, The MDD of all the soil samples have values less than the recommended va1ue of 1984 kg/rn^3 for Nigeria soils. So, regardless of failed building sections, the soils can be regarded as poor sub-grade materials. For the consistency limits, the liquid limits value of the soil samples ranges from 51.3 % to 64.6 %. While the plastic limits ranges from 18.0 % to 29.9 %. Plasticity index ranges from 30.39 % to 40.10 %.

The values of the unsoaked CBR for the soils ranges from 11% to 35 %. While the soaked CBR range from 5 % to 13 %. The Federal Ministry of Works and Housing (1974) specified a minimum value of 11% and 15% for soak and unsoaked CBR for a sub-grade soil compacted OMC and MDD using BS proctor compaction method. Soil samples from unstable and stable portions have values less than the Federal Ministry of Works and Housing (1974) specification for the soaked CBR, hence, this may be responsible for their instability. Soaked and unsoaked percentages higher than the specified values may also be attributed to poor drainage construction. Soil samples from failed section in and around the locations falls within the specification for the unsoaked CBR, thus, making the soil samples suitable for road construction.

The activity (A) of a soil is the plasticity index (PT) divided by the clay content in the soil. Different types of clays have different specific surface areas which controls how much wetting is required to move a soil from one phase to another such as across the liquid limit or the plastic limit. From the activity, one can predict the dominant clay type present in a soil sample. High activity signifies large volume change when wetted and large shrinkage when dried. Normally the activity of clay is between 0.75 and 1.25, and in this range clay is normal. It is assumed that the plasticity index is approximately equal to the clay fraction (A 1). When A is less than 0.75, itis considered to be inactive. When it is greater than 1 .25, it is considered active. The values of the soil samples ranges from 467.3 % to 485.0 %. The grain size of a soil is very important in making a number of important engineering property judgments. On the other hand, hydrolysis values range from 48.5 % to 60.3 %.

5. Conclusion and recommendations

In this study, 2D electrical resistivity imaging technique has been employed to study the stability of materials around the Basement Complex rocks within Oroke High School, opposite Adekunle Ajasin University Campus, Akungba-Akoko, southwestern Nigeria.

The 2D dipole- dipole resistivity and pseudo – section delineated zones having resistivity values ranging from 200 to 700 ohm-m to infinity within a depth of 0-5 m. The electrical resistivity values of 27 to 139 ohm meter within this zone, suggest the presence of clay. From the sections, there are indications of clay layers that form around the major basement depressions within the area; the depression is possibly a result of weathering of feldspar and amphibolites rich sections within the fresh basement as a result of preferential channeling and storage of groundwater.

From the probing of the subsurface sections, it could be observed that the resistivity of the top soil varies between 331 and 445ohms with average thickness ranging from 2 to 3 m. From the study area as well, it was observed that the magnetic susceptibility is high which may likely be due to the presence of iron ore mineralization in the study area. The number and varying trend of faults is an evidence that the region has undergone more than one tectonic event. It was observed that there could be presence of fault within the basement of the subsurface on which the building is sited. Therefore, the study area is underlain by incompetent materials which cannot support building construction; however, the geologic structures beneath the subsurface create fractures.

Finally, electrical resistivity method is an effective measure or tool in site characterization. Therefore, it can be employed prior to any building construction proposal and engineering works and also it is useful in mapping of the sub-surface sequences.

Acknowledgement

We acknowledge the technical members of staff of the Department of Earth Sciences, Adekunle Ajasin University, Akungba-Akoko for providing us with the necessary information, equipment and support.

Appendix

DIPOLE- DIPOLE METHOD
Traverse one
a =5, n=1,5, Total length = 80 m

NUMBER	1	2	3	4	5	6	7	8	9
1	-163 Ω	-280 Ω	-196 Ω	-511 Ω	-483 Ω	1399 Ω	-376 Ω	-52 Ω	-3 Ω
2	-93 Ω	-478 Ω	-197 Ω	-803 Ω	-281 Ω	3283 Ω	-136 Ω	485 Ω	277 Ω
3	66 Ω	-927 Ω	-207 Ω	-1578 Ω	-259 Ω	7629 Ω	-3368 Ω	1215 Ω	920 Ω
4	356 Ω	-1479 Ω	-322 Ω	-2884 Ω	-532 Ω	13760mΩ	324 Ω	2337 Ω	7483 Ω
5	98 Ω	-2325 Ω	-343 Ω	-5082 Ω	-897 Ω	21747m Ω	801 Ω	3449 Ω	4158 Ω

NUMBER	10	11	12	13	14	15	16
1	-178 Ω	644 Ω	-300 Ω	678 Ω	1045 Ω	-116 Ω	433 Ω
2	-45 Ω	3091 Ω	731 Ω	2337 Ω	-694 Ω	-1674 Ω	5504 Ω
3	142 Ω	6801 Ω	-1262 Ω	1055 Ω	1173 Ω	-2929 Ω	47 Ω
4	942 Ω	3499 Ω	-2688 Ω	4117 Ω	2680 Ω	-5341 Ω	2684 Ω
5	2590 Ω	-33610 Ω	56994 m Ω	1921 Ω	10593m Ω	-2197 Ω	3371 Ω

NUMBER	17	18	19	20	21	22	23
1	133 Ω	137 Ω	164 Ω	137 Ω	-15 Ω	160 Ω	120 Ω
2	3080 Ω	459 Ω	1655 Ω	8357 Ω	1809 Ω	2812 Ω	1562 Ω
3	1375 Ω	627 Ω	2300 Ω	-2089 Ω	1360 Ω	-104 Ω	4917 Ω
4	2281 Ω	215 Ω	3994 Ω	10458 Ω	4542 Ω	30936 Ω	-2148 Ω
5	4752 Ω	4041 Ω	3769 Ω	1854 Ω	-390 Ω	-3768 Ω	-762 Ω

NUMBER	24	25	26	27	28	29
1	458 Ω	-199 Ω	584 Ω	173 Ω	867 Ω	176 Ω
2	1132 Ω	-42 Ω	44 Ω	-668 Ω	930 Ω	
3	1036 Ω	4070 Ω	100 Ω	1358 Ω		
4	19061mΩ	-2113 Ω	-2538 Ω			
5	40329m Ω	-4118 Ω				

TRAVERSE TWO
a = 5, n = 1,5, Total length = 80 m

NUMBER	1	2	3	4	5	6	7
1	-180 Ω	-371 Ω	67 Ω	-1640 Ω	-98 Ω	-16 Ω	320 Ω
2	-135 Ω	-1777 Ω	215 Ω	271 Ω	-47 Ω	-72418mΩ	1288 Ω
3	87 Ω	2068 Ω	1217 Ω	859 Ω	-102 Ω	-95902m Ω	2931 Ω
4	926 Ω	-286 Ω	2340 Ω	-4599 Ω	363 Ω	11014 Ω	7595 Ω
5	677 Ω	-5365 Ω	3458 Ω	-6327 Ω	-381 Ω	13591 Ω	17594mΩ

NUMBER	8	9	10	11	12	13	14
1	255 Ω	20 Ω	-462 Ω	113 Ω	9 Ω	242 Ω	234 Ω
2	1625 Ω	-270 Ω	-1248 Ω	607 Ω	37 Ω	469 Ω	
3	-303 Ω	1009 Ω	-300 Ω	2065 Ω	180 Ω		
4	-409 Ω	-3225 Ω	-195 Ω	378 Ω			
5	-364 Ω	-6873 Ω	-700 Ω				

Resistivity sounding field record

AB/2	Ves1	Ves2	Ves3	Ves4	Ves5	Ves6
1	590	376	909	664	516	632
2	469	291	531	431	327	455
3	416	308	506	380	562	399
4	418	379	322	333	230	358
6	411	386	326	228	185	363
6	430	374	278	384	162	356
8	475	343	259	357	165	403
12	616	380	311	385	182	496
15	735	461	307	458	229	558
15	797	496	408	456	276	557
25	1380	754	603	685	295	804
32	1737	818	723	876	446	857
40	1976	1109	799	1182	636	963
40	1667	1031	872	727	610	951
65		376	909	812	761	-

100	664	-

AB/2	Ves7	Ves8	Ves9	Ves10
1	250	896	1902	452
2	203	640	1632	345
3	171	506	1598	455
4	148	1697	2269	697
6	184	701	2689	391
6	192	757	2621	415
8	183	727	2600	308
12	251	347	2313	759
15	201	727	2723	760
15	208	558	2332	277
25	209	771	2006	255
32	202	436	1043	926
40	210	420	953	242
40	212	1156	871	716
65			800	950
100				120

Table: Summary of the geological results of the Subgrade soil under investigation

Depth/ Location (1.5m)	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Linear shrinkage (%)	Plastic-ity In-dex (%)	Parti-cle Size (%)	MDD (Kg/m^3)	OMC (%)	Unsoaked (%) CBR	Soaked (%) CBR	Specific Gravity	Hydrol-ysis (%)
L1	28.1	55.1	18.0	5.8	37.12	471.3	1290	33.7	11	6	2.59	48.5
L2	31.6	51.3	24.7	6.8	34.30	473.0	1953	14.6	34	11	2.67	48.8
L3	37.8	54.5	28.7	6.8	34.15	472.1	1564	25.8	19	6	2.75	55.1
L4	27.4	57.0	24.7	7.7	33.99	478.0	1869	17.0	30	13	2.71	52.2
L5	29.3	55.5	24.9	6.3	30.39	483.6	1865	17.1	27	11	2.63	60.3
L6	28.2	59.1	24.2	8.2	31.49	485.0	1854	17.4	29	10	2.64	52.1
L7	34.1	63.1	29.2	7.2	38.20	482.6	1599	24.8	15	5	2.72	55.6
L8	37.8	62.4	24.7	6.8	36.36	484.0	1984	13.7	35	12	2.64	52.1
L9	37.8	62.4	24.7	5.8	37.70	479.8	1539	26.5	19	7	2.75	48.5
L10	33.4	64.6	29.9	6.3	40.10	478.5	1546	26.3	17	9	2.71	48.8
L11	37.4	62.6	24.1	6.8	38.10	467.3	1315	33.0	13	7	2.66	55.1
L12	33.0	62.9	24.0	7.7	38.88	469.5	1879	16.7	32	9	2.71	55.2

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