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Electrical Resistivity Testing along Tunnel Alignment under Lonavla Lake, A Part of Mumbai Pune Expressway Missing Link Project – A Case Study

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Abstract. M/s Navayuga Engineering Company Ltd of Hyderabad is constructing a road tunnel below Lonavla Lake a part of Mumbai Pune expressway Missing Link Project under Maharashtra State Road Development Corporation. Apart from fifteen Bore Holes done for geotechnical investigation, ERT (Electrical Resistivity Test) was conducted for one km length below the lake, as per guidelines of IRC SP 91. The objective of the resistivity survey was to have a general idea about the nature of sub surface formations and to corroborate the data with the results of other direct and indirect exploration activities. For the one km stretch three geo-electric vertical sounding and three geo-electric profiling were done. Geo-electric sounding was conducted using Schlumberger electrode configuration and geo-electric profiling was done using Wenner electrode configuration. Geo-electric sounding indicates vertical extents of lithological layers while profiling indicates the horizontal extents. In Schlumberger configuration the electrical current is introduced into the ground through the outer pairs of the electrode and centrally located pairs of electrodes are used for potential measurements. In Wenner's configuration the electrical resistivity measurements are made using four electrodes arranged in a straight line. The field curves obtained were interpreted qualitatively and quantitatively. In qualitative interpretation type of sounding curve and its general nature was determined. Quantitative analysis was done both by direct and indirect methods.

Keywords: Resistivity, profiling, geo-electric.

1 Introduction

1.1 Purpose of Electrical Resistivity survey

The main purpose is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as mineral content, fluid content, porosity and degree of water saturation in rocks. Some other purposes include a) rapidly explore subsurface conditions in order to locate ground water, thickness of overburden, depth of different rock types and stratigraphic features, b) to delineate weak formations, faults and dykes, c) to delineate zones of seepage and identify the source, d) assessment of ground water potential, e) to correlate data obtained from bore logs with those obtained from resistivity surveys, f) earthing of electrical conductors.

Table 1. Resistivity of some common rocks

Material	Resistivity (Ohm – m)
Igneous and Metamorphic rocks	
Granite	5×10^3 to 10^6
Basalt	10^3 to 10^6
Slate	6×10^2 to 4×10^7
Marble	10^2 to 2.5×10^8
Quartzite	10^2 to 2×10^8
Sedimentary Rocks	
Sandstone	8 to 4×10^3
Shale	20 to 2×10^3
Limestone	50 to 4×10^2

1.2 Methodology

Electrical resistivity survey was conducted by geo-electric sounding and geo-electric profiling. The survey was conducted over a stretch of about 1000 meter. This 1000 meter stretch is again subdivided into three stretches. Altogether three geo-electric sounding (vertical electric sounding) was conducted and three geo-electric profiling was conducted. Geo-electric sounding was conducted using Schlumberger electrode configuration and geo-electric profiling was conducted using Wenner electrode configuration. Geo-electric sounding indicates vertical extents of geo-electric (lithological) layers while profiling indicates horizontal extents of geo-electric (lithological) layers. Resistivity survey was conducted adopting both Schlumberger electrode configuration and Wenner's electrode configuration. In Schlumberger configuration the electrical measurements are made using four electrodes arranged in a straight line. Electrical current is introduced into the ground through the outer pairs of the electrode and centrally located pairs of electrodes are used for potential measurement. The separation between the potential electrodes is kept very small compared to the current electrodes. The apparent resistivity ρ_a of the ground is calculated from the equation:

$$\rho_a = \pi\,[\{(L/2)^2 - (l/2)^2\}/l].R \qquad (1)$$

where, L = current electrode spacing
l = potential electrode spacing
R = Resistance

In Wenner's configuration the electrical resistivity measurements are made using four electrodes arranged in a straight line. These electrodes are uniformly spaced, i.e. the distance between any two adjacent electrodes is same. Current is introduced into the ground through the outer pair of electrodes known as current electrodes and centrally

located pair of electrodes used for potential measurement is called potential electrodes. Apparent Resistivity ρ_a of the ground can be obtained by using the expression:
$\rho_a = 2 \pi a R$
where, a = Electrode Spacing
R = Resistance

2 Field Work and Data Interpretation

Field work for all resistivity survey commenced with reconnaissance survey of site, preliminary assessment of site geophysical conditions was done. Field investigations were carried out as per theory discussed earlier using digital resistivity meter and its accessories like electrodes, cable, etc. Symmetrical Schlumberger Electrode and Wenner Electrode spread system was followed during the field investigation and each set of data was plotted on log-log graph for obtaining the field curves. Profiling survey was conducted by Wenner method using roll along technique.

Field Data

Table 1. Vertical Electrical Sounding (VES 1)

Observation No	L/2	l/2	K	V	I	SF	R	Apparent Resistivity
1	3	0.5	27.5	907	41	0.1	2.21	60.8
2	6	0.5	112.35	117	18	0.1	0.65	73.0
3	10	0.5	313.5	29	10	0.1	0.29	90.9
4	10	2	75.42	132	12	0.1	1.10	83.0
5	15	2	173.64	--	--	--	--	--
6	20	2	311.14	100	37	0.1	0.27	84.1
7	25	2	487.49	42	24	0.1	0.18	85.3
8	30	2	703.36	13	12	0.1	0.11	76.2
9	40	2	1254	9	15	0.1	0.06	75.2
10	40	8	301.71	24	11	0.1	0.22	65.8
11	50	8	478.5	146	79	0.1	0.18	88.4
12	60	8	694.51	119	100	0.1	0.12	82.6
13	70	8	949.92	26	30	0.1	0.09	82.3
14	80	8	1244.57	13	21	0.1	0.06	77.0
15	100	8	1951.71	9	23	0.1	0.04	76.4

Table 2. VES 2

Observation No	L/2	l/2	K	V	I	SF	R	Apparent Resistivity
1	3	0.5	27.5	500	55	0.1	0.9	24.998
2	6	0.5	112.35	129	46	0.1	0.3	31.458
3	10	0.5	313.5	20	13	0.1	0.2	48.279
4	10	2	75.42	8	13	1	0.6	46.383
5	15	2	173.64	179	47	0.1	0.4	65.983
6	20	2	311.14	84	29	0.1	0.3	89.919
7	25	2	487.49	72	37	0.1	0.2	94.573
8	30	2	703.36	20	12	0.1	0.2	112.538
9	40	2	1254	24	29	0.1	0.1	100.320
10	40	8	301.71	27	66	0.1	0.2	72.410
11	50	8	478.5	200	99	0.1	0.2	95.700
12	60	8	694.51	117	76	0.1	0.2	104.177
13	70	8	949.92	36	30	0.1	0.1	113.990
14	80	8	1244.57	45	46	0.1	0.1	120.723
15	100	8	1951.71	7	11	0.1	0.1	117.103
16	100	20	754.28	23	11	0.1	0.2	158.399
17	120	20	1100	120	99	0.1	0.1	132.000
18	140	20	1508.57	56	63	0.1	0.1	135.771
19	160	20	1980	46	67	0.1	0.1	138.600
20	180	20	2514.28	58	99	0.1	0.1	150.857
21	200	20	3111.42	15	31	0.1	0.1	155.571

Table 3. VES 3

Observation No	L/2	l/2	K	V	I	SF	R	Apparent Resistivity
1	3	0.5	27.5	68	30	1	2.3	62.4
2	6	0.5	112.35	20	30	1	0.7	75.3
3	10	0.5	313.5	90	30	0.1	0.3	94.1
4	10	2	75.42	37	31	1	1.2	89.7
5	15	2	173.64	12	21	1	0.6	99.0
6	20	2	311.14	58	14	0.1	0.4	127.6
7	25	2	487.49	30	11	0.1	0.3	131.6
8	30	2	703.36	18	8	0.1	0.2	161.8
9	40	2	1254	4	3	0.1	0.1	163.0

10	40	8	301.71	15	3	0.1	0.5	150.9
11	50	8	478.5	204	46	0.1	0.4	210.5
12	60	8	694.51	8	3	0.1	0.3	180.6
13	70	8	949.92	13	7	0.1	0.2	180.5
14	80	8	1244.57	88	60	0.1	0.2	186.7
15	100	8	1951.71	13	99	1	0.1	253.7
16	100	20	754.28	21	99	1	0.2	158.4
17	120	20	1100	22	10	0.1	0.2	242.0
18	140	20	1508.57	24	13	0.1	0.2	271.5
19	160	20	1980	34	10	0.1	0.3	673.2
20	180	20	2514.28	5	2	0.1	0.3	628.6
21	200	20	3111.42	69	40	0	0.2	528.9

Sample Calculation: Refer VES 1 Observation 1
$L/2 = 3$ m, $(L/2)^2 = 9$
$l/2 = 0.5$ m, $(l/2)^2 = 0.25$
Therefore, $K = \pi \times (9-0.25)/1 = 27.5$
V = 907 (instrument reading), I = 41 (instrument reading),
SF = 0.1 (instrument adjustment factor / scale factor)
As per Ohm's law, V = IR, or R = V/I
Here, R = (V*SF)/I = (907*0.1)/41 = 2.21
Therefore, Apparent Resistivity ρ_a = KR = 27.5*2.21 = 60.8 (Ohm-m)

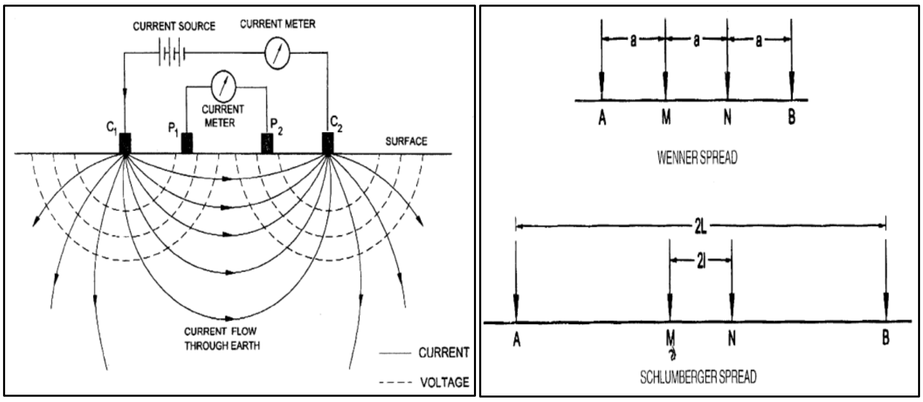

Fig.1. Schematic Layout

Fig.2. Testing Photos at site

3 Data Interpretation

Vertical Electrical Sounding data are recorded using Schlumberger method and interpreted in 'Inverse Slope' technique. The Inverse Slope method can be used with the following steps. While the inverse slope of the line segments directly gives the true resistivity of the layers, the intersections of the line segments have to be multiplied with (2/3) to get the depths to the interfaces.

1. Calculate the value ((AB/2)/ρa) for each observation.
2. Plot ((AB/2)/ρa) values on Y axis against 'AB/2' on X-axis on a linear graph.
3. Join the plotted points with best fitting straight lines such that a minimum of 3 points fall on each line.
4. Some points may not be covered by any line segment due to shift in potential electrodes. Each segment represents one subsurface geo-electric layer.
5. Take any point on a segment. Read its coordinates. X coordinate represents value of 'AB/2' and Y coordinate represents ((AB/2)/ρa).
6. Calculate the Inverse Slope of each line segment. Y-coordinate value divided by x-coordinate value. This value directly gives the true resistivity of the subsurface layer represented by the line segment.
7. Read the X-coordinate values of all the intersection points of the line segments (t1, t2, t3, etc.). Multiply each 't' value with (2/3). These multiplied values (t1 x 2/3, t2 x 2/3, t3 x 2/3, etc.) represents the depth to the interfaces 1,2,3, respectively.

VES-1 (AB/2 in m, and Rho_a (or ρ_a) in Ohm-m) AB = Current Electrode Spacing

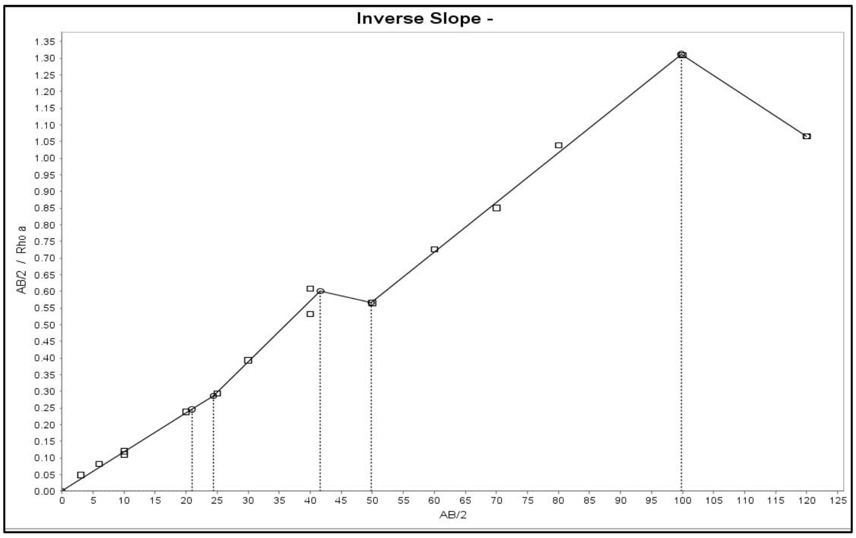

Fig.3. Sounding curve for VES 1

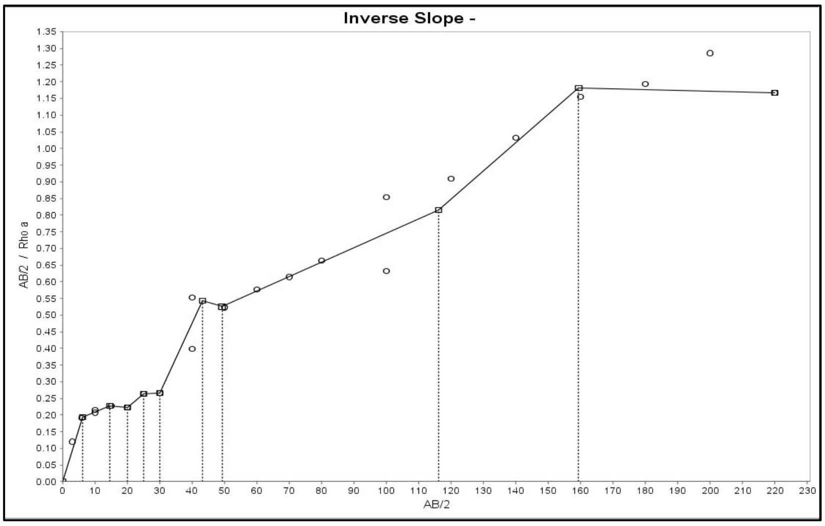

Fig.4. Sounding Curve for VES 2

VES-3

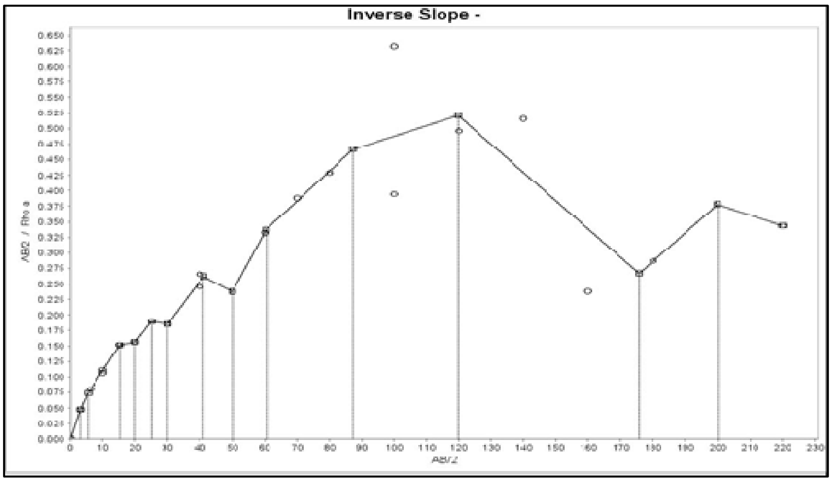

Fig.5. Sounding Curve for VES 3

3.1 Profiling survey

Profiling curve has been processed by using imaging software Resist 2D. Altogether three profiling has been done at the site. Profiling images have been presented in figures below. Maximum depth of profiling is 20 m.

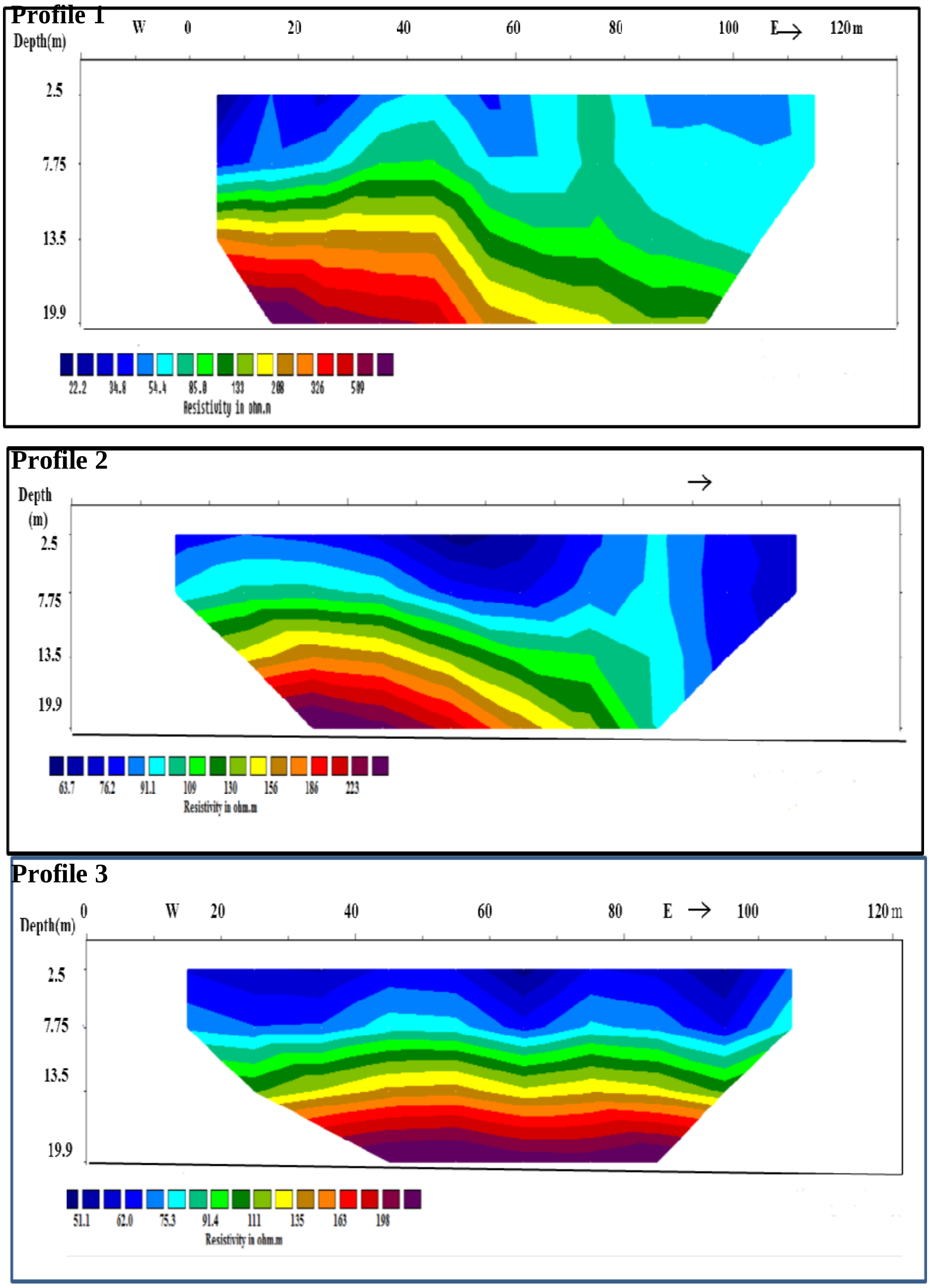

Fig .6. Profiling Curves

4 Results

4.1 Results of sounding survey

Table 4. Results of VES 1

Layer	Resistivity (Ohm-m)	Thickness (m)	Cumulative Depth (m)	Lithology
1	79	16.3	16.3	Compacted Basalt with top weathering
2	90	2.3	18.5	Compacted Basalt
3	55	11.5	30	Highly Fractured Basalt
4	210	5.4	35.4	Highly Compacted Basalt
5	67	33.3	68.7	Fractured Basalt
6	213	----	-----	Highly Compacted Basalt

Table 5. Results of VES 2

Layer	Resistivity (Ohm-m)	Thickness (m)	Cumulative Depth (m)	Lithology
1	32	4.1	4.1	Top weathered soil
2	249	5.7	9.8	Highly Compacted Basalt
3	614	3.6	13.4	Very Highly Compacted Basalt
4	120	3.3	16.7	Semi Compacted Basalt
5	639	3.3	20	Very Highly Compacted Basalt
6	48	8.8	28.8	Highly Fractured Basalt
7	657	4	32.8	Very Highly Compacted Basalt
8	231	44.6	77.4	Highly Compacted Basalt
9	118	28.8	106.2	Compacted Basalt
10	680	----	----	Very Highly Compacted Basalt

Table 6. Results of VES 3

Layer	Resistivity (Ohm-m)	Thickness (m)	Cumulative Depth (m)	Lithology
1	62	2	2	Top soil
2	95	1.6	3.6	Highly weathered clayey Basalt
3	125	6.5	10.1	Semi Compacted Basalt
4	962	3.2	13.3	Highly Compacted Basalt
5	``152	3.3	16.6	Semi Compacted Basalt

6	1274	3.3	19.9	Very Highly Compacted Basalt
7	143	7.3	27.2	Fractured Basalt
8	1196	6	33.2	Very Highly Compacted Basalt
9	105	7	40.2	Highly Fractured Basalt
10	208	17.8	58	Compacted Basalt
11	593	21.7	79.7	Highly Compacted Basalt
12	7943	37.3	117	Very Highly Compacted Basalt
13	218	16.1	133.1	Highly Compacted Basalt
14	9999	----	----	Very Highly Compacted Basalt

4.2 Results of Profiling Survey

Table 7. Profile 1 & 2

Layer	Resistivity (Ohm-m)	Thickness (m)	Cumulative Depth (m)	Lithology
1	51 – 62	4.5	4.5	Top weathered soil
2	75 – 110	9.5	14	Semi Compacted Basalt
3	160 – 205	6	20	Compacted Basalt

Table 8. Profile 3

Layer	Resistivity (Ohm-m)	Thickness (m)	Cumulative Depth (m)	Lithology
1	70 – 90	7.5	7.5	Top soil and highly weathered clayey Basalt
2	130 – 156	6	13.5	Semi Compacted Basalt
3	186 – 240	6.5	20	Compacted Basalt

Combining both sounding and profiling survey, a generalized lithological profile is presented below:

Layer	Thickness (m)	Cumulative Depth (m)	Lithology
1	4	4	Top soil and weathered Basalt
2	16	20	Semi Compacted Basalt with fractures
3	>20	>40	Compacted Basalt with fractures

5 Conclusion

Based on electrical resistivity test it may be concluded that Sub-soil profile is basically consists of basalt, upto about 100 meters below ground level. There are multiple layers of Basalt – Semi weathered, semi-compact, compact and fractured, which are repeating and overlapping. A conspicuous fractured Basalt horizon has been encountered from

20 to 40 meters below ground level. There may be seepage from the fractured basalt horizon which should be taken care of.

Advantages and Disadvantages or ERT Method

Advantages: a) Extremely economical and speedy, b) Delivers accurate results upto 30 to 40m depth, c) Simple test set up, d) Non-destructive testing method.
Dis-advantages: a) Cannot give independent idea of rock types, needs confirmatory bore hole and test reports, b) Results may get affected by underlying powerlines.

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