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Geoelectrical investigations for Flyover Bridge construction in marine environment of Visakhapatnam: A case study

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ABSTRACT
This present study impresses the advantage of inverse slope method of interpretation of Wenner geoelectrical data for shallow investigations. In addition to geological and geomorpological data collection, geoelectrical survey has been carried out to map the depth of hard rock for pile foundations for a flyover in the Port city, Visakhapatnam. The study includes 100 geoelectrical soundings and monitoring of 252 pile borings. An excellent correlation has been obtained between the geoelectrical results and borelog data. Inverse slope method of interpretation of resistivity data is compared with curve matching technique.

STUDY AREA

National Highway Authority of India (NHAI) has mandated to develop an adequate road connectivity to major Ports in India. The project aims at improvement of basic infrastructure facility by undertaking construction of a 12 km long link road with paved shoulders from NH5 to the Port gate in Visakhapatnam utilizing the existing road. A 2.5 km long flyover of Port Connectivity Bridge has been proposed at the end of the alignment. Three additional ramps of 1.3 km length have been suggested at intermittent places to connect the Port yard. The total length of the connectivity road, including flyover and bridges lies between 83.21^{o}to 83.29^{o} East longitude and 17.17^{o} to 17.72^{o} North latitude and falls in the tidal flat and mangrove wetland of the coast (Fig.1). Figure.1 shows the PAN image of IRS-1D of Visakhaptnam and the alignment under study. The study has been made to determine the soil profile and the depth of hard rock to decide the foundation of piles for the pier locations of the bridge. Geoelectrical sections are prepared and given to site engineers as guidance prior to drilling for foundation. The study also utilized the geological and geomorphological studies of the area by various authors and their data in the interpretation of geoelectrical results for the identification of type and nature of rock. The role of geoelectrical results in finalizing the founding depth for a part of Main Flyover (Pier 49 to Pier 75) and two ramps B and C of the alignment is discussed Huge quantity of data are collected for flyover and other minor bridges but only three parts are selected to demonstrate the utility of geoelectrical survey in the foundation studies. The study displays results at 28 piers from Main Flyover, 18 piers from B-Ramp and 15 piers from C-Ramp. Data collected from 80 soundings and the results are compared with 252 pile boring data in the form of subsurface sections to draw an analogy between the surface investigations and the drilling data. Each pier location has 4/6 piles that led to a single pier through a pier cap to support pier and the super structure. The average depth of pile borings is taken to correlate the sounding results.

GEOLOGY AND GEOMORPHOLOGY

Geologically the study area is a part of Eastern Ghat Super Group. The major rock types within the area are Charnokite, Leptynite and Khondalites. Geology of Visakhapatnam and its surroundings was mapped by King (1886) and Mahadevan & Sathapathi (1949). A Leptynite hill is located at a distance of 100 m north of the flyover bridge alignment. The abutment of the main fly over and the piers P1 to P8 are bypassing about 100 m away from the Leptynite hill. Outcrops are seen near open foundation area from piers P120 to P125. The alignment is mostly across the marine tidal flats and a part is crossing the fluvial plain of Megadrigedda. It was a marshy tidal basin of 5140 hectares in 1972, which after reclamation for various industries reduced to about 650 hectares in 2002.

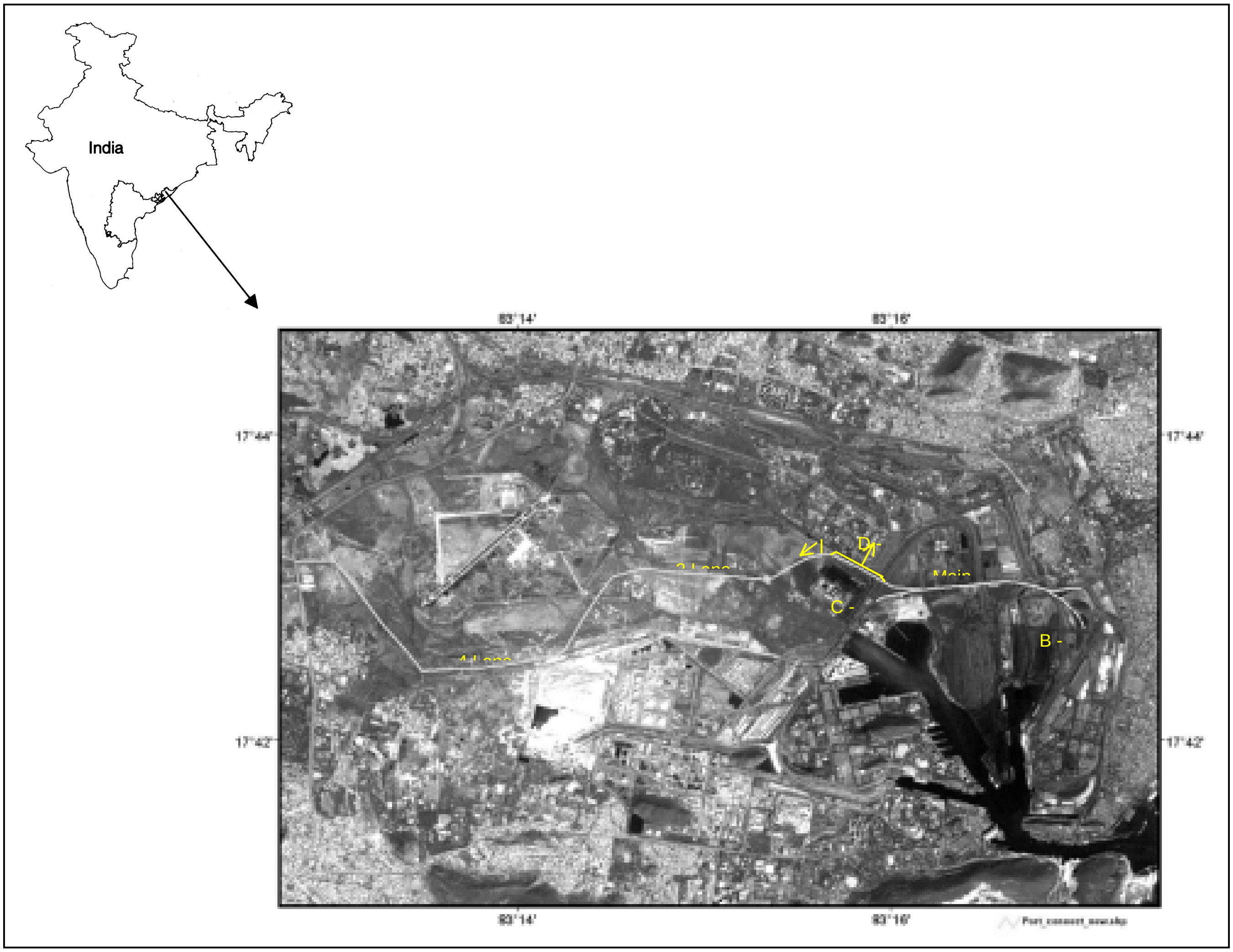

Figure 1. Port connectivity alignment on IRS-1D-Pan view of Visakhapatnam

Prudhvi Raju & Vaidyanadhan (1978) reported 18m thickness of marine clay followed by weathered rock towards the south of the study area. Natarajan, Nanda & Subrahmanyam (1979) reported 10 to 17 m red – loamy- sandy- clay or fine clay near Balacheruvu, and 40-80 m thickness of marine clay north of Tummedalametta. Jagannadha Rao et al. (2003) studied geomorphic features and landforms of Visakahapatnam. The marine clay has high moisture content, and organic content. The low shear strength (73.2 to 292.9 g/cm^2) and low bearing capacity result in considerable subsidence when it is placed under load (Nagarkar 1979). The water table is as high as 0.5 to 1m along C-Ramp and 2 – 3 m along the remaining alignment. As the study area is a part of marine tidal flat region, the groundwater is saline.

GEOELECTRICAL STUDIES

Geoelectrical studies have been carried out for flyover, minor bridges and culverts to suggest depth to pile foundation into the hard rock along the alignment. But only three parts; viz., profile B-Ramp, Pier 49 to Pier 75 of Main Flyover and C-Ramp are considered for discussion. There are 61 piers in total in the above three sections and soundings are carried out at all the pier locations. Collection of sounding data has been a difficult task because of the existing railway tracks, coal-dumping yards, drains and filled soils (building debris & dredged material) along the alignment. This nonhomogeneous nature of overburden leads to some discrepancies in the sounding data. More than 100 soundings have been carried out to cover 61 pier

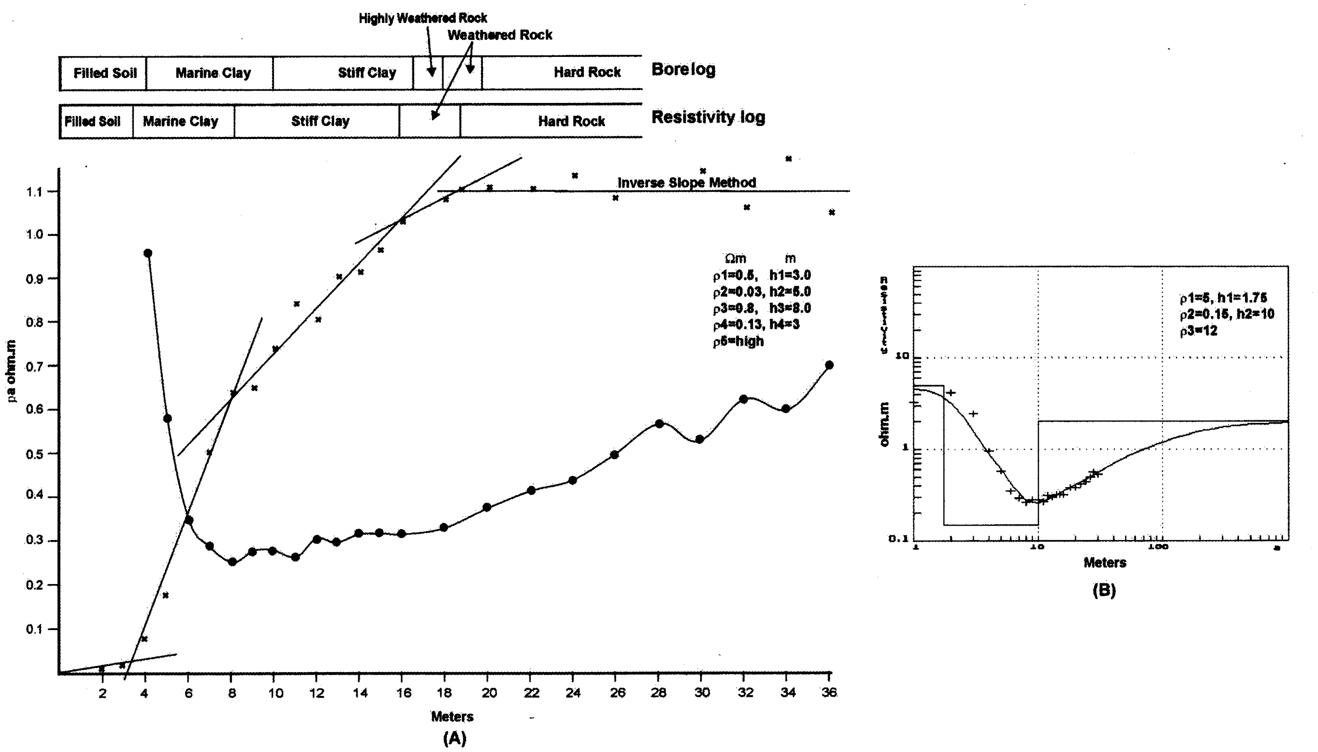

Figure 2. Resistivity curves at BP1 (B-ramp) on linear plot (A) and log-log plot (B)

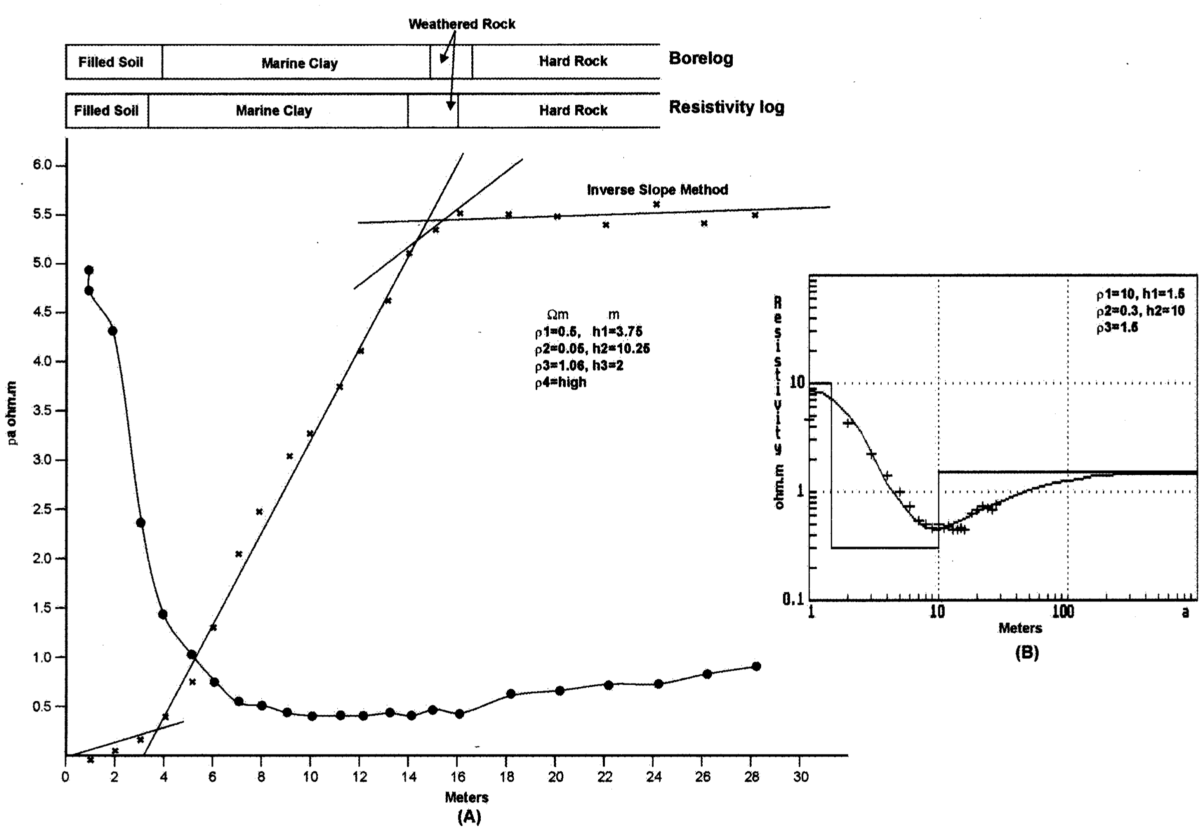

Figure 3. Resistivity curves at P73 (main flyover) on linear plot (A) and log-log plot (B)

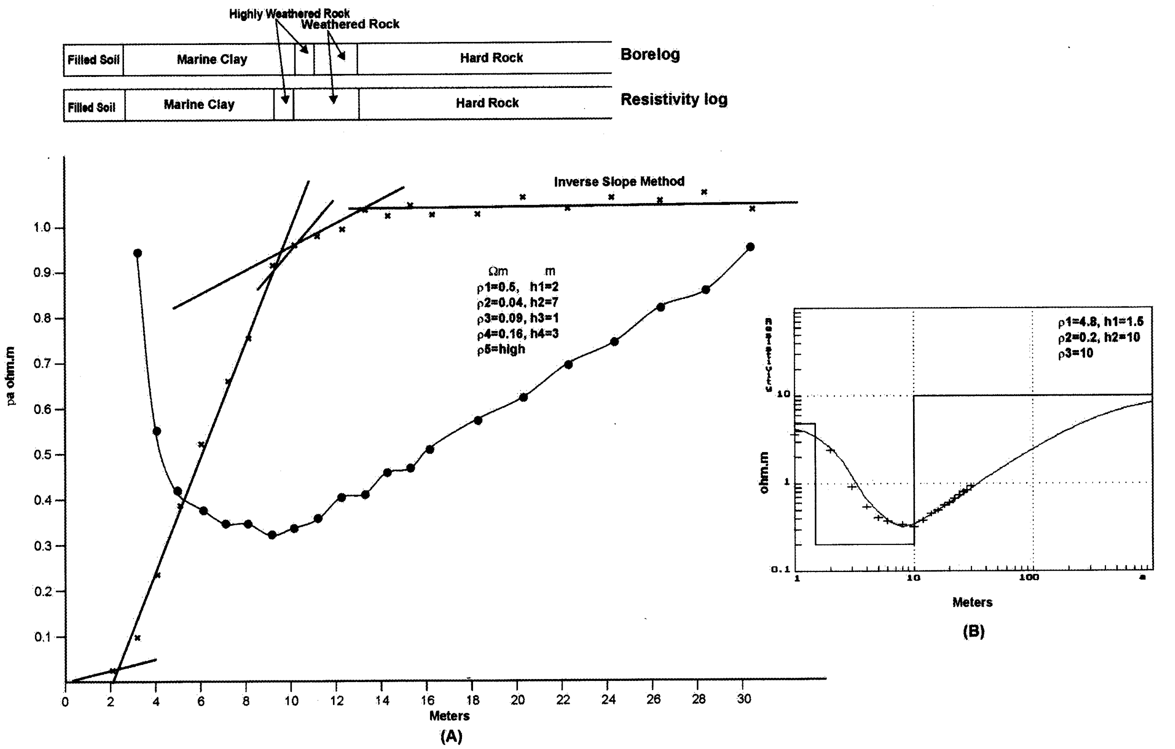

Figure 4. Resistivity curves at CP5 (C-ramp) on linear plot (A) and log-log plot (B)

locations to map hard rock and other overburden layers along the three parts of the alignment. The survey has been repeated at many times, to get proper sounding data. Wherever the sounding data is irregular, the sounding is repeated by changing the direction of the electrode alignment as well as by making proper contact of the potential electrodes with the ground. This problem is encountered in the filled in soils that consist of shells, gravel and pebbles. These materials are removed and replaced with water at electrodes for good contact between the ground and the potential electrodes. Non-polarisable electrodes are used to pick up equipotential lines and to suppress the natural ground potentials. Subsurface lithological sections are prepared from geoelectrical results.

Wenner sounding method is employed in conducting the survey with a uniform increment (one meter) in electrode spacing. The apparent resistivity values are in the range of 0.1 to 2.5 ohm.m even up to 40 m separation. The higher value of apparent resistivity (1-3 ohm.m) is only due to filled in soils in the surface through out. Beyond 2-4 m separation, the apparent rsistivity value drops to a range of 0.1 to 0.9 ohm.m, because of marine clay underlaying the thin layer of overburden and shallow saline water table. Sankar Narayan & Ramanujachary (1967) developed an Inverse Slope technique to interpret the Wenner sounding data, which is followed in the present study for the interpretation of the sounding data. This method is based on the assumption that the depth of penetration of current is equal to the electrode separation adopted. The maximum electrode separation varies from 30- 40 m in the survey. Earlier, these types of studies were conducted by Prakasa Rao et al. (1999) using geoelectrical surveys for bridge foundations.

Soundings curves:

H-type sounding curves are obtained in the study area. Three sounding curves, obtained at pier locations BP1, P73 and, CP5, one from each profile, are selected to show the comparative study of the results obtained from inverse slope and curve matching method with borelog at those locations. Fig.2 shows sounding curves and results obtained at the pier location BP1 from the B-ramp profile. Five layers are indicated in inverse slope method and are comparable with the drilling log except 1m layer of murum that is shown in borelog. The subsurface model derived from conventional curve matching is not comparable with drilling data. Inverse slope method has enabled in distinguishing the soft and hard marine clay layers, which correlate well with the drilling log. The change

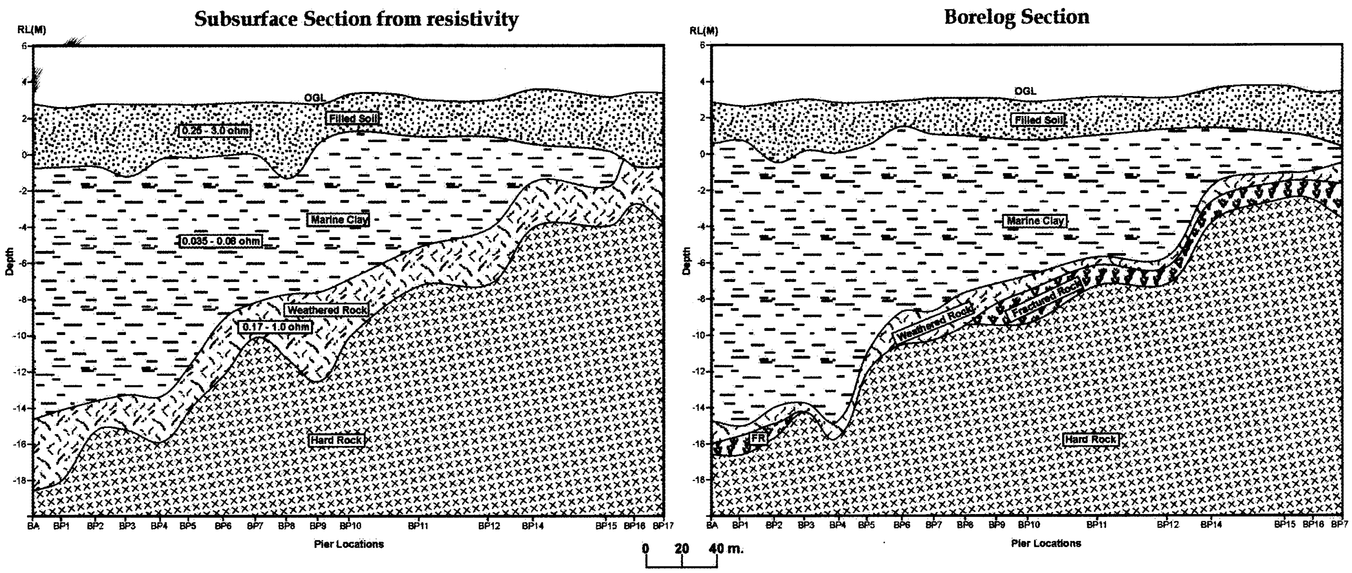

Figure 5. Resistivity and borelog sections along B-ramp

of slope within marine clay layer is due to stiff marine clay with seashells noticed in the soil samples. Fig.3 shows the sounding curves obtained in linear and double log plots along with interpreted results at P73 pier location. Four layers, topsoil, marine clay, weathered rock and hard rock are inferred from the inverse slope method and are comparable with the borelog. Whereas sounding interpretation with curve matching technique has indicated only three layers and are not comparable with the drilling data obtained at this site. Fig.4 shows a good correlation between the inverse slope results (4 layers) and the drilling log at location CP5.The top surface of the hard rock, derived from Inverse Slope method has exactly matched with bore data.

Geoelecrical Sections:

Three geoelectrical sub-surface sections are prepared with reduced levels based on results obtained form Inverse Slope method. Fig.5 showing the subsurface section, drawn for the B-Ramp consists of data of 17 soundings covering a distance of 322 m. The distance between the consecutive sounding locations is 18.9 meters, but the distance between contiguous piers BP9 and BP10 and between BP14 and BP15 is 40 meters. The section shows four layer sequence of topsoil, marine clay, weathered rock and hard rock. The resistivity of the surface soil varies from 0.25 to 3.0 ohm.m. Topsoil is underlain by marine clay having very low rsistivity (0.03 to 0.08 ohm.m). Weathered rock layer has a resistivity of 0.2 to 1.0 ohm.m. The geoelectric section prepared from P49 pier to P75 pier of the main fly over is shown in Figure. 6. The profile consists of 24 soundings and the separation between soundings in general is 18 meters, except the pier P49 to P50 and P50 to P51 where the separation is 42 m. The total length of this profile is 510 m. This section has recognized one more layer (fractured rock) than the previous profile between P61 to P71 piers with a true resistivity of 0.3 ohm.m. Figure.7 shows the geoelectric section along C-Ramp, consisting of 15 soundings conducted at the locations of 15 piers in the ramp. All the soundings are separated by the same distance (18.7 m) and the total length of the profile is 262 m. This section has also shown four layers similar to B-Ramp with similar resistivity values.

BORELOG STUDIES

Tripods and mechanized bore hole machines are engaged for drilling the piles with a diameter range from 0.75 to 1.2 m. Drilling has been made to penetrate 1.5 m into the hard rock. Drilling operations are supervised by engineers from LEA Associates South Asia Pvt. Ltd, based on the geoelectrical results supplied from the above studies. Each of the boreholes is logged visually and the rock type is determined to recommend the founding level for each pile. At each pier location, 4 pile bores are drilled and average depth of rock is considered in the preparation of the borelog. The borelog sections at B-Ramp, P49 pier to P75 and C-Ramp sites are presented along with geoelectrical sections. Founding level of each pile is determined based on the type of rock and crushing strength.

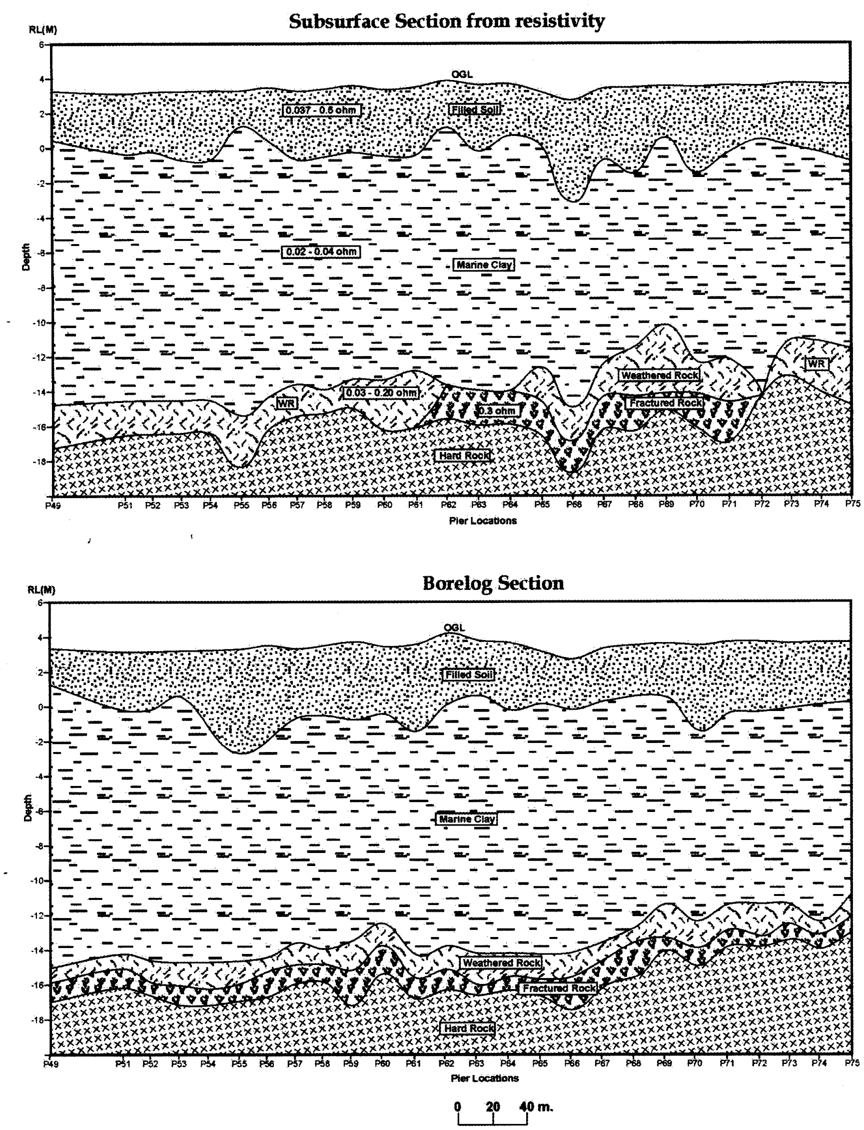

Figure 6. Resistivity and borelog sections along a part f main flyover from P49 to P75

RESULTS AND DISCUSSION

Figs 5, 6 and 7 show the subsurface sections prepared from geoelectric and borelog data that are drawn from the existing ground level to the hard rock along the B-ramp, C-Ramp and a part of main flyover. The thickness of marine clay with 15 m at pier location BA in B-Ramp decreases towards the pier BP17. Resistivity section shows continuous weathered rock layer through out the profile over the hard basement where as the borelog section indicates the presence of fractured rock between BA and BP3 and BP8 to BP17. The resistivity interpretation could not identified the thin fractured zone resting over the hard rock stratum as an independent unit as its resistivity overlapping with withered stratum. The resistivity section and borelog section show comparable depth level to the hard rock.

Fig. 6 shows the geoelectric section and the corresponding borelog section from P49 to P75 of the main fly over. The thickness of the first layer coincides in both the sections except at P55 and P66, with the former showing less thickness and latter more thickness in borelog section. The thickness of marine clay layer is comparable in both the sections. The litholog section has shown one-meter thickness of fractured rock layer all along the section where as the resistivity section has shown the fractured rock layer only from P62 to P71.

Subsurface geoelectric and borelog sections for C-Ramp extending from pier CA to CP14 show identical thickness of first layer (Fig.7). The thickness

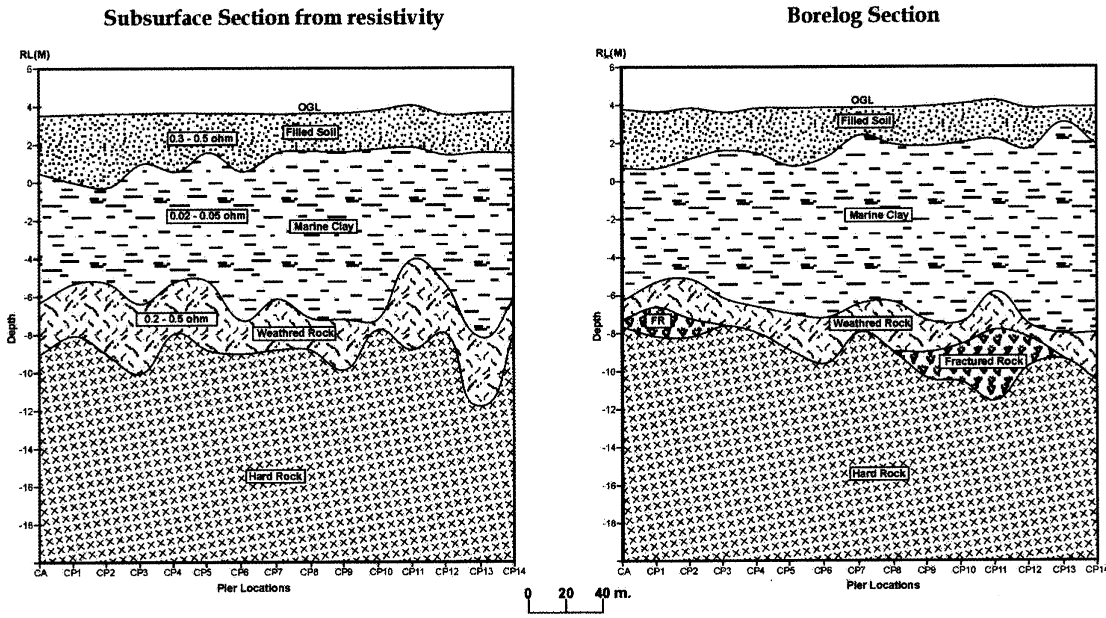

Figure 7. Resistivity and borelog sections along C-ramp

of marine clay layer is also same in both the sections except at CP11 and CP14 where the borelog section indicates a thickness of 2 meters more than geoelectric section. The geoelectric section does not show any fractured layer but it is presented as a layer (1or 2 m thickness) in the borelog from CA to CP3 and from CP9 to CP12. The demarcation of hard rock level from the geoelectric section matches with the borelog except at CP13 where it is 2 m lower in geolelectric section than in the borelog section.

CONCLUSIONS

A comparison between resistivity sections and borelog sections indicates that the geoelectrical results derived from Inverse solpe method have good correlation with the lithological results. The thickness of first layer top soil and the underlain marine clay layers from resistivity sections are well matched with the borelog data. The top of the weathered zone can be inferred from resistivity interpretation but the thin layer (1 or 1.5m) of fractured rock cannot be deciphered well. The demarcation of the hard rock (basement) is very well matches with the borelog data except at a couple of locations where resistivity interpretation has shown 1 or 2 m more than the borelog data mostly. The resistivity survey with close electrode separation and uniform increment in Wenner method, followed by inverse slope method of interpretation, yield reasonably accurate results for shallow investigations in marshy tidal zones. This method and interpretation are suitable for shallow investigations for demarcation of thin intermittent layers and hard rock level with reasonable accuracy. Geological and geomorphologic knowledge is prerequisite in understanding the area and for appropriate interpretation of sounding data.

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REFERENCES:

King, W., 1886. The geological sketch of Visakhapatnam District, Rec. Geol. Surv, India, 19, 43-156.

Jagannatha Rao, M., Syam Kumar, J., Surya Prakasa Rao, B. & Srinivasa Rao, P., 2003. Geomorphology and land use pattern of Visakhapatnam Urban- Industrial area, J. Ind. Soc. of Remote Sensing, 31(2), 119-128.

Mahadevan, C. & Sathapathi, N., 1949. The origin of Waltair Highlands. Ind. Geogr. J. 24, 1-26.

Nagarkar, P.K., 1979. Marine clays in India, Technical report No. 27, Central Board of Irrigation & power, New Delhi, 1-73

Natarajan, V., Nanda. K. & Subrahmanyam, M.R., 1979. Geology and its influence on physical environment of Visakahapatnam City and its neighborhood. Paper presented in workshop on integrated resource evaluation for Visahhapatnam urban growth center, vol. 2, 1-10.

Prudhvi Raju, K.N. & Vaidyanathan .R., 1978. Geomorphology of Visakhapatnam, Andhra Pradesh, J. Geol. Soci. Ind., 19 (1), 26 – 34.

Ragahav Swamy. V. & Vaidyanadhan, R., 1980. Morphology and land systems of a part of Visakhapatnam District, Andhra Pradesh form air photo studies, J. Ind. Soc. Photo-int & Remote Sensing, 8, No.1.1 – 15.

Sankar Narayan, P.V. & Ramanujachary, K.R., 1967. An inverse slope method of determining absolute resistivity, J. Geophysics, 1036 – 1040.

Prakasa Rao B.S., Vasu Babu, G., Gopalasastry, S. & Ramesh , V.B., 1999.The role of Geo-engineering studies in site investigations of a Bridge site – A case study. Jour. of Bridge Engineering Vol. 25.

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