A review of geotechnical investigation data for site characterization – a case study

Un rapport des données d'investigation géotechnique pour la reconnaissance du chantier – un étude de cas

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ABSTRACT: Geotechnical investigation was carried out at the proposed 650mW combined cycle power project site located in northern India. Investigation comprised of exploratory boreholes, subsoil soundings such as DCPT, SPT and SCPT, insitu tests such as plate load tests and pressuremeter tests. Geophysical investigation comprising of seismic refraction and electrical resistivity tests was also carried out. Undisturbed and disturbed soil samples were collected for determining physical, mechanical and chemical characteristics of subsoil. Review and analysis of various field and laboratory test results were carried out to characterize the ground for interpretation of soil parameters and hence estimation of bearing capacities and settlements of footings. Site specific correlations between SPT, cone resistance and pressuremeter test results were developed. Field and laboratory tests presented divergent strength and deformation characteristics of soil. At the present site greater degree of insitu tests coupled with laboratory investigation proved to be an excellent tool for site characterization.

1 INTRODUCTION

At the proposed 650mW expansion of combined cycle power project of NTPC located in U.P, India a detailed geotechnical investigation comprising of exploratory bore holes, subsoil soundings such as dynamic cone penetration tests, standard penetration tests and static cone penetration tests, insitu tests such as plate load tests and pressuremeter tests was conducted. Geophysical investigation comprising of seismic refraction and electrical resistivity tests was also conducted. This paper presents a review and analysis of various field and laboratory test results to characterize the ground for interpretation of soil parameters and hence estimation of bearing capacities and settlements of footings. The results of geophysical investigation are not in the scope of this paper.

2 FIELD TESTS

The spacing of the bore holes, SCPT and DCPT was selected based on the general layout of the various power plant structures. Boreholes were generally advanced upto about 25m. SPT was conducted at regular intervals within the boreholes. SCPT was conducted upto a depth of about 20.0m and continuos profiles of cone and friction resistance values were recorded. DCPT was done upto about 25.0m depth at 0.3m intervals. The results of SPT, DCPT and SCPT (cone resistance and friction ratios) obtained from the investigation are presented through Figures 1 to 4. Pressuremeter tests were conducted at regular intervals in preformed bores uniformly covering the entire plant area. Menard's pressuremeter of NX size was used. The limit pressure (p_l) and pressuremeter modulus (E_p) values obtained from the test are presented through Figure 5. Plate load tests were conducted on 600mmX600mm size plate at 9 locations covering the site uniformly and the test depths varied from 3.0m to 4.0m.

3 LABORATORY TEST RESULTS

Various laboratory tests were conducted on soil samples collected from the bore holes to determine physical, strength, deformation and chemical properties of soil layers encountered at site. The summary of laboratory test results are presented through Table 1a to 1c.

Table 1a. Summary of grain size and Atterberg test results

Layer	Particle size distribution G	S	M	C	LL	PL	PI
	%					%	
Medium to stiff clayey silt(ML-MI)	0-5	10-20	40-55	16-40	30-47	20-30	10-17
Silty sand (SM)	0-5	70-85	10-25	---	---	---	---
Hard clayey Silt(ML-MI)	0-5	15-20	40-50	16-35	30-39	20-29	10-15

Table 1b. Summary of test results from undisturbed soil samples

Layer	Bulk density kN/m³	Wn %	Shear parameters c kN/m²	ϕ	Consolidation e_0	C_c
Medium to stiff clayey silt(ML-MI)	17.9-19.2	15.4-22.2	60-90	2^0-6^0	0.68-0.75	0.05-0.14
Hard clayey Silt(ML-MI)	19.0-20.1	15.4-20.9	80-125	2^0-6^0	---	---

Table 1c. Summary of chemical analysis

	So_3	Chlorides	pH
Sub-soil	0.134%-0.165%	0.03%-0.04%	8.3-8.5
Ground water	370ppm-455ppm	150ppm-720ppm	7.6-7.8

4 INTERPRETATION AND SITE CHARACTERIZATION

The subsoil encountered at the present site, observed through borehole logs and soil samples collected from bore holes, may be described as clayey silt deposits varying from medium to hard consistency with increasing depth and extending upto the depth of investigation of about 25.0m. A layer of silty sand was observed sandwiched within the clayey silt layer. The thickness of silty sand layer varied from 2.5m to 5.0m. Ground water table was encountered at 1.5m below ground level. From Fig.1 through Fig.3 it can be seen that SPT, DCPT and SCPT profiles show similar variation of subsoil consistency. Further, all the three tests indicated occurrence of weak zone at a depth of about

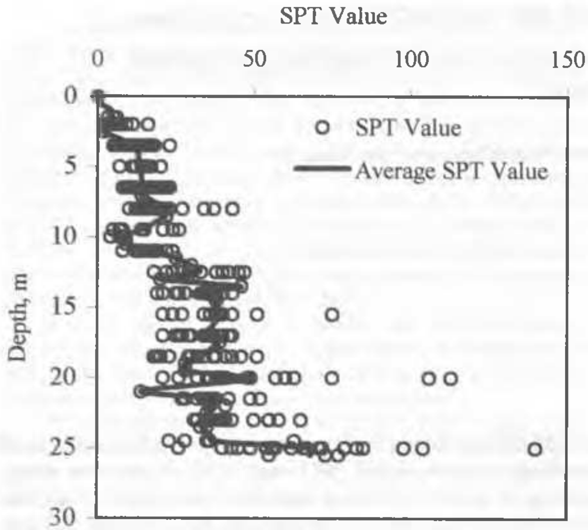

Figure 1 SPT values observed at site

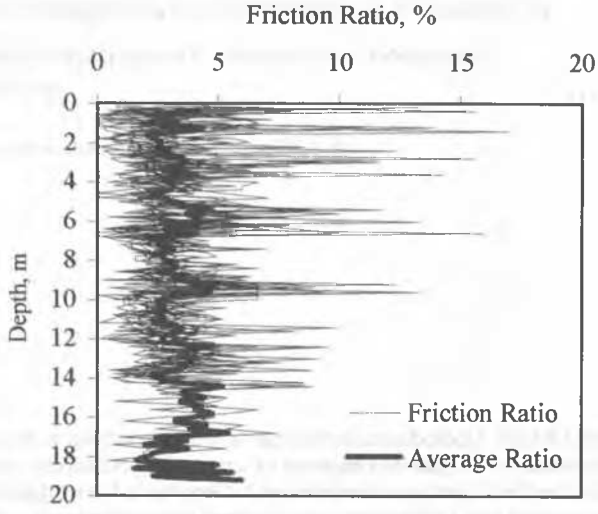

Figure 4 Friction ratios

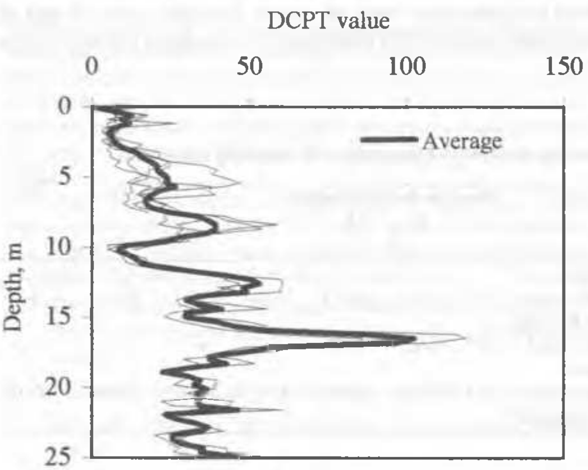

Figure 2 DCPT values observed at site

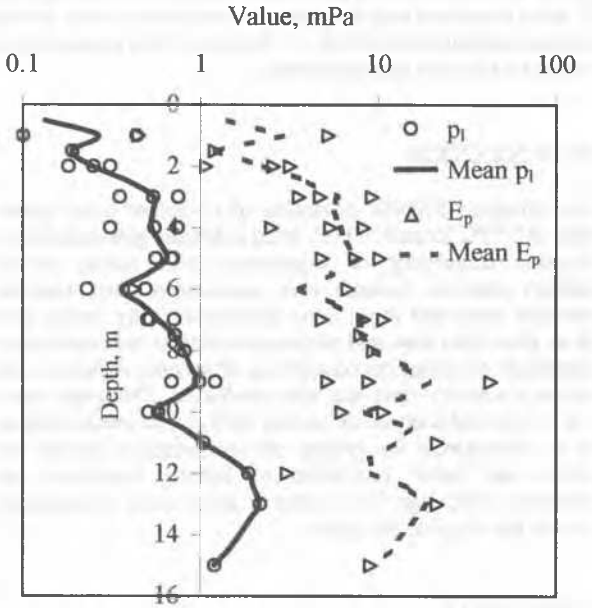

Figure 5 Pressuremeter values

10.0m. Based on field identification of SPT soil samples this weak zone was identified as a thin layer of soft to medium clay. The cone resistance, q_c values (Fig.3) and friction ratios (Fig.4) observed at the present site also indicated that the soil encountered at this site is predominantly silt. However, at about 10.0m depth the average friction ratio and cone resistance, q_c was observed to be 5% and 2mPa respectively, indicating existence of a

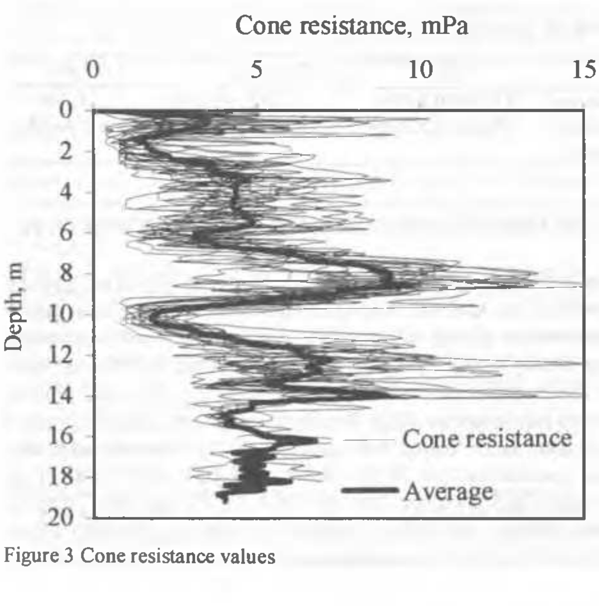

Figure 3 Cone resistance values

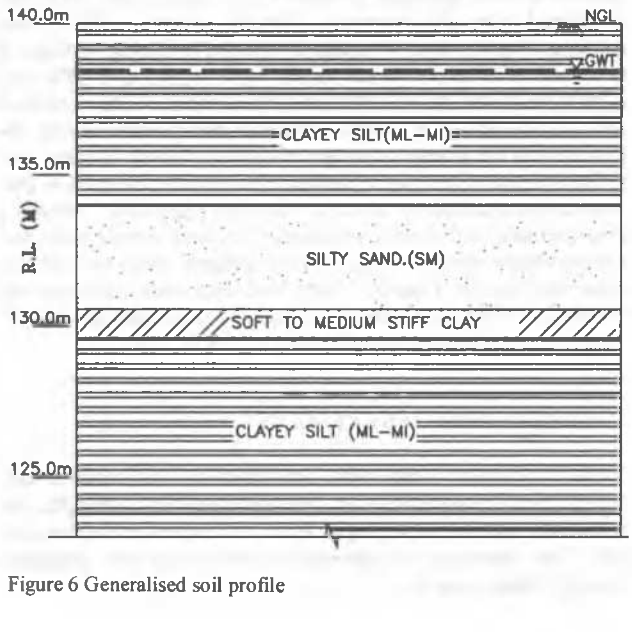

Figure 6 Generalised soil profile

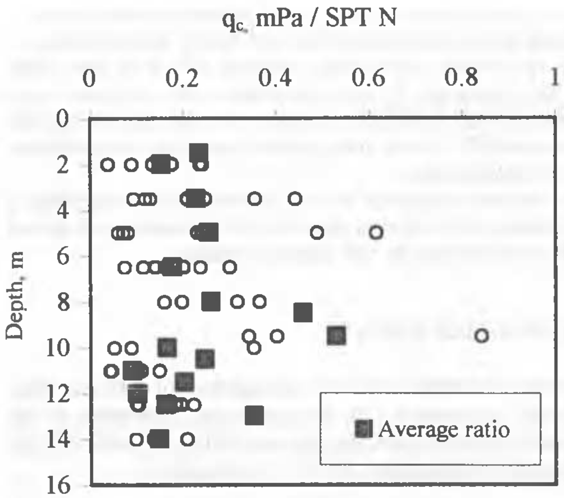

Figure 7a Correlations between SPT N & q_c

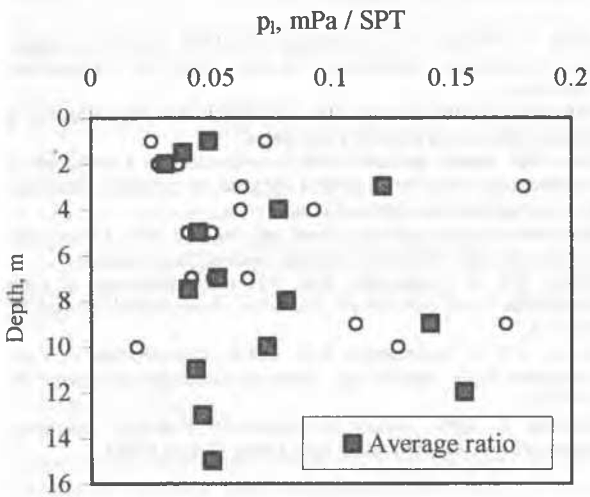

Figure 7b Correlations between SPT N and p_l

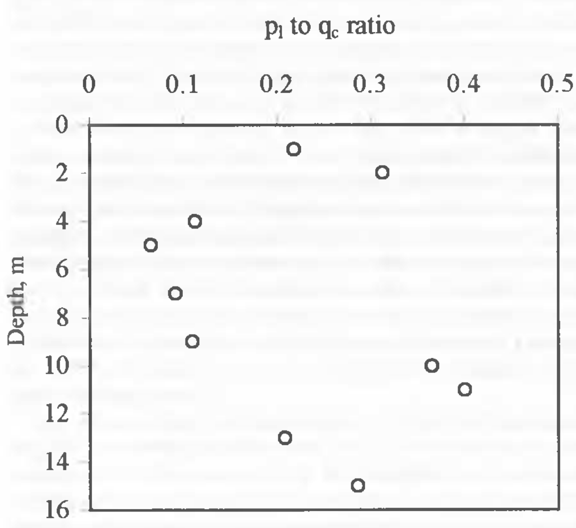

Figure 7c Correlations between p_l & q_c

thin clay layer. From Figure 5 it can be seen that the limit pressure, p_l increases consistently with depth. The limit pressure value at about 10.0m depth is of the order of 750kPa, which indicated medium stiff consistency (Venkatesan, 1992) for the clay layer. Based on the above review the generalized soil profile shown in Figure 6 was constructed for convenience of design.

Correlations between SPT N value & q_c, SPT N value & p_l and between p_l and q_c specific to the site are presented through Figures 7a, 7b & 7c. Correlation between deformation modulus obtained from plate load test (E_s) and that obtained from pressuremeter test (E_p) is shown through Table 2.

5 ANALYSIS OF RESULTS AND DESIGN OF FOUNDATION SYSTEM

It can be seen that q_c to SPT N ratio (Fig.7a) is generally about 0.2 for the clayey silt layers and it varies between 0.3 to 0.5 for the silty sand layer. The ratio is observed to be about 0.1 for the thin clay layer. These correlations are generally in agreement with the published literature (Robertson et al. 1983a).

The p_l to SPT N ratio (Fig. 7b) is observed to be some what scattered. In the upper clayey silt layer the ratio varies from 0.02 to 0.12 and in the lower clayey silt layer it varied from 0.04 to 0.16. In the silty sand layer the ratio is observed to be about 0.06 and it varies from 0.04 to 0.14 in the thin clay layer. No definite correlation for each type of soil layer could be established with the available data. However, the observed correlation of 0.06 for silty sand layer is in agreement with the published literature (Baguelin et al. 1978).

It can be observed that p_l to q_c ratio (Fig.7c) varies generally from 0.1 to 0.3 in the clayey silt layers. The ratio is about 0.1 for the silty sand layer and it is about 0.4 for the thin clay layer encountered at site. The p_l to q_c ratios observed for the site are generally comparable to the correlations provided in the published literature (Venkatesan,1992).

The modulus of elasticity, E_s of clayey silt layer at 3.5 m to 4.0 m depth was interpreted from plate load test results assuming μ (Poisson's ratio) varying from 0.3 to 0.35. The average value of E_s was compared with the average soil deformation modulus obtained from pressuremeter test results, E_p. The results are shown in Table 2. It can be observed from table 3 that the E_s/E_p ratio varies from 6 to 9 for the clayey silt layer.

The load intensities likely to be induced by the proposed structures are generally of the order of 100 to 250kPa. Permissible

Table 2. Comparison between E_s and E_p

Depth m	E_s mPa	E_p mPa	E_s/E_p
3.5	360	56	6.4
4.0	530	61	8.7

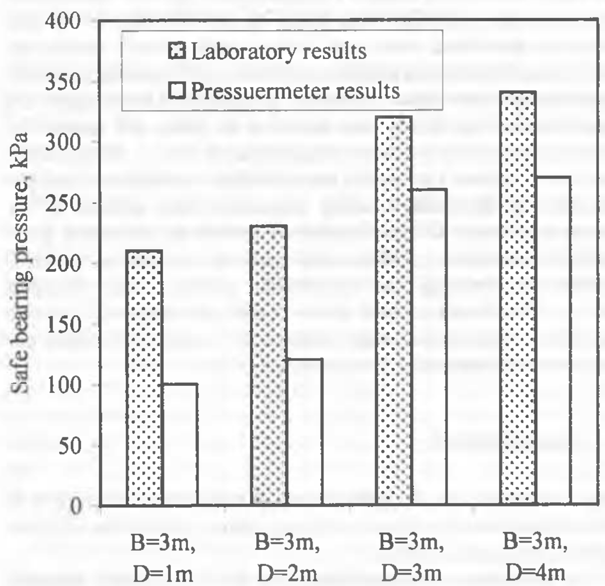

Figure 8 Comparison of estimated safe bearing pressures

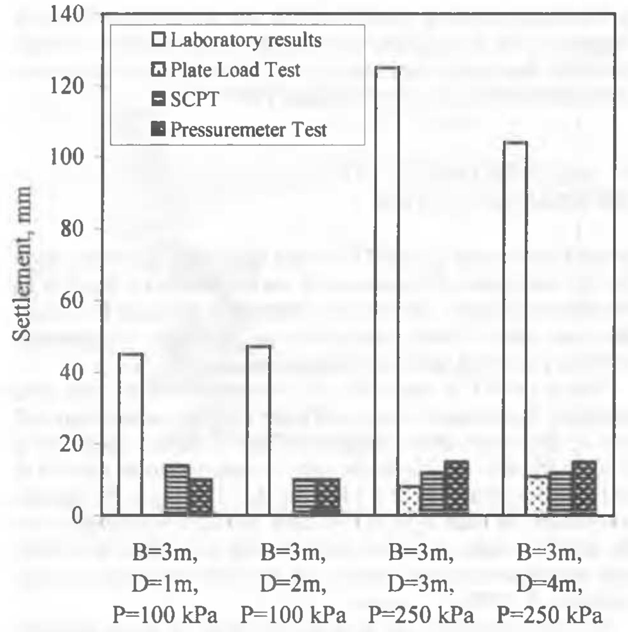

Figure 9 Comparison of estimated settlements

settlement of foundations were to be restricted as per IS: 1904, with total settlement not exceeding 25mm.

The safe bearing capacity of shallow foundations based on shear failure considerations has been evaluated from laboratory test results and limit pressure values. A comparison of safe bearing capacities for footing width, B=3.0m & depth, D varying from 1.0m to 4.0m is presented through Figure 8. The settlement of foundations were estimated using laboratory consolidation test results (IS: 8009, Part-I), plate load test results (IS: 8009, Part-I), deformation characteristics interpreted from cone resistance values (Robertson et al. 1983a,b), pressuremeter modulus (Baguelin et al. 1978). A comparison of estimated settlements is presented through Figure 9 for a typical foundation width of 3.0m.

It can be observed that the estimated safe bearing pressures (Fig.8) from laboratory and pressuremeter test results are generally comparable, whereas, the estimated settlements vary widely under identical loading intensities (Fig.9). The settlements estimated based on laboratory test results and that estimated based on insitu test results (Fig.9) were found to be at the extremes. Interestingly, the settlements estimated based on various insitu tests showed convergence (Fig.9). Such difference in settlements estimated from deformation characteristics of soil determined from laboratory and field tests could be probably due to the disturbances associated with soil boring, soil sample collection, handling and extraction techniques. In view of prevailing subsoil conditions and first hand experience of quality of investigation, a higher level of reliability was attached to insitu test results including pressuremeter. Accordingly, based on a comparative analysis of various test results and judicious selection of soil parameters the allowable bearing pressures were arrived at for various structures. Greater degree of field tests including good quality pressuremeter testing made shallow foundations feasible, thereby economizing the foundation system. The chemical analysis of soil and ground water (Table 1c) does not indicate aggressive environment and accordingly ordinary Portland cement was recommended for foundations.

6 CONCLUSIONS

Based on the results of geotechnical investigation conducted at this site and the discussions presented above, the following conclusions have been drawn.

The settlements estimated based on soil parameters obtained from laboratory test results and field test results showed wide variation under identical loads. Such variation could be attributed to the disturbances associated with boring and sampling.

The site specific correlations between SPT N & cone resistance, limit pressure & cone resistance were observed to be comparable with published literature, whereas definite correlation between SPT N and limit pressure could not be established with the available data.

An integrated approach to soil investigation comprising of greater degree of insitu tests coupled with laboratory tests proved to be an excellent tool for site characterization.

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