CONSTRUCTING A POWER PLANT ON BENTONITE DEPOSITS: GEOTECHNICAL ASPECTS

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ABSTRACT: The paper presents details of a geotechnical investigation done for a lignite based thermal power plant in western Rajasthan. The study involved characterizing the highly expansive clay (bentonite) encountered at the project site. The investigation included advanced testing methods such as static cone penetration tests and pressuremeter tests in addition to the routine boreholes and plate load tests. The foundation system selected in view of the difficult soil conditions and the protection measures adopted are presented.

1. INTRODUCTION

A lignite based thermal power plant is planned to be constructed in western Rajasthan, about 45 km from Barmer town. The site location is presented on Figure 1.

The deposits at site consist of highly expansive clay (bentonite). Construction of a power plant in such strata poses a veritable challenge to the geotechnical engineer. The paper outlines the geotechnical investigations performed to characterize the soil conditions and the foundation system adopted.

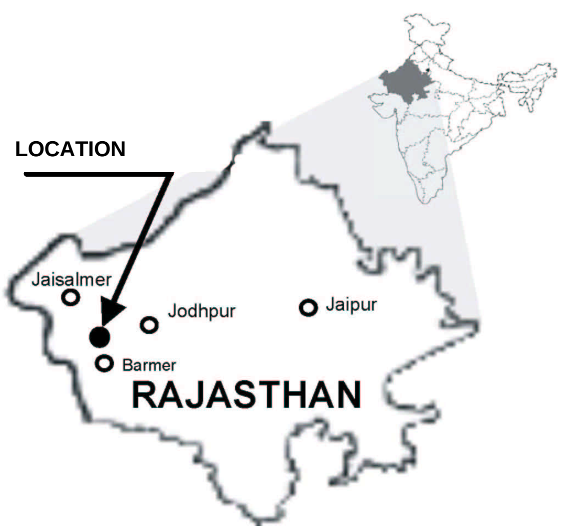

Fig. 1: Vicinity Map

2. THE POWER PLANT

The lignite-based power plant and associated facilities cover a large area of over 2 sq. km. The Power Block of the Stage 1 Plant (1 × 125 MW) covers an area of about 200 m × 700 m.

Various facilities investigated for this study include the TG, Boiler, Bunker, Chimney ID Fans, Electrostatic Precipitator (ESP), etc.

3. GENERAL SITE CONDITIONS

3.1 Geology

Bikaner, Jaisalmer and its surrounding areas were under the sea in Eocene Times (Krishnan 1986). The strata exposed belong to Laki Series. These areas are oil and gas-bearing rocks of North Western Rajasthan. It also contains lignite.

The Middle Division of the Lakis comprise of considerable thickness of white or pale buff limestones. The Lakis are succeeded by the Ranikot beds and are sometimes found overlying the Cretaceous. The Eocene beds contain lignite and are overlain by Fuller's earth (bentonite). Both lignite and bentonite are mined in this area.

3.2 Site Location

The project site is in Western Rajasthan at the edge of the Thar Desert. It is located at a distance of about 1.5 km from a bentonite mine and about 1 km from a lignite mine.

3.3 Geotechnical Investigations

For important facilities of the power plant such as TG Building, boiler, chimney and other heavily loaded facilities on the highly expansive clay, the settlement criterion is restrictive.

To characterize the soils effectively and select appropriate parameters for geotechnical design, the geotechnical investigation program included in-situ tests in addition to the routine boreholes.

Advanced testing methods such as pressuremeter tests and static cone penetration tests provided reliable data for foundation analysis. Plate load test using a 1 m × 1 m size test plate helped validate the settlement estimates.

Backed up by detailed laboratory testing to confirm the swell, shrinkage and strength behavior, the in-situ testing assisted in generating reliable geotechnical parameters that were used to select the foundation depth and safe bearing pressures for design.

3.4 Site Stratigraphy

The stratigraphy at the site consists of highly expansive silty clay (bentonite) underlain by lignite.

A thin surficial layer of dune sand is met all over the site. In general, the thickness of the sand layer is about 0.6 to 1.5 m. Below this, a 1.5–2.5 m thick discontinuous layer of weak to moderately cemented calcareous gravel is encountered. The underlying formation is a bentonite deposit. It classifies as a stiff to hard clay of high plasticity. It is highly expansive in nature with differential free swell index exceeding 100%. The boreholes were terminated at 16–18 m depth in a lignite deposit.

Figure 2 presents one typical substrata profile together with various soil properties.

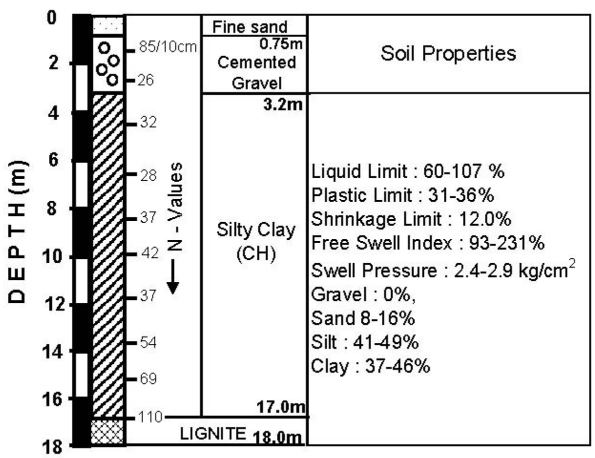

Fig. 2: Typical Borehole Data & Soil Properties

3.5 Groundwater

The area is a dry belt with hardly any rainfall. Groundwater was not met to the depths investigated. As per local information, groundwater is likely to be met at about 70–75 m depth.

3.6 Static Cone Penetration Tests

Static cone penetration tests were performed in accordance with IS 4968 Part 3—1976 using a 20-Tonne capacity cone penetrometer. Where refusal was met on the shallow cemented gravel layer, pre-drilling was done and the test was conducted from the predrilled hole. Typical results are presented in Figure 3.

3.7 Plate Load Tests

For an assessment of the load-settlement behaviour of the natural soils, plate load tests were conducted as per IS 1888–1982 at the TG and Chimney locations. The test was performed using a 1 m × 1 m size test plate. Results are summarized in Table 1. Typical load-settlement curve for the test performed at the Chimney location is presented in Figure 4.

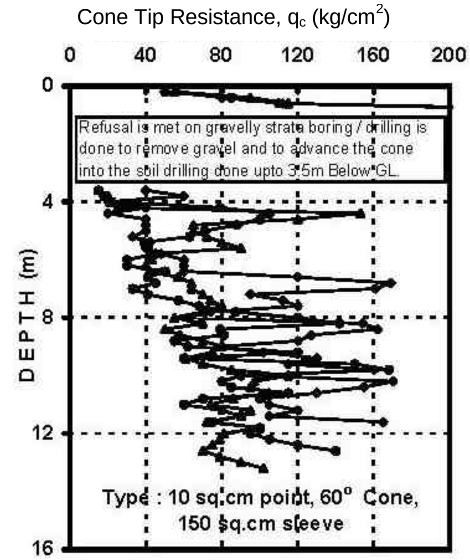

Fig. 3: Static Cone Penetration Test Results

Table 1: Plate Load Test-Load Settlement Data

Structure	*Test No.*	*Depth m*	*Measured settlement (mm) under applied bearing pressure of*				
			15 T/m^2	*20 T/m^2*	*25 T/m^2*	*30 T/m^2*	*35 T/m^2*
Chimney	1	5.5	2.0	2.4	3.4	4.0	5.0
TG	2	3.4	5.0	6.7	8.3	10.0	11.9

Test results were extrapolated using a linear correlation between foundation size and settlement for cohesive soils (Terzhaghi 1955).

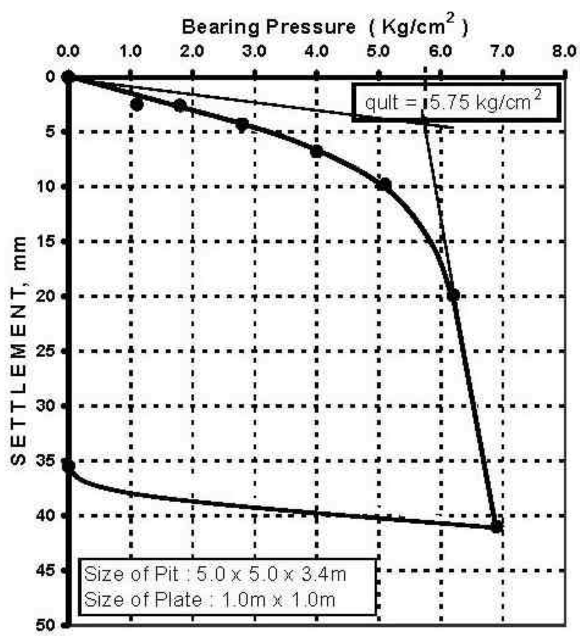

Fig. 4: Plate Load Test Results—Chimney

3.8 Pressuremeter Tests

Menard's Pressuremeter tests were performed at different depths in NX size boreholes. The limit pressure and deformation modulus were determined from the test. Figure 5 presents typical pressuremeter test results.

The profile of pressuremeter parameters *versus* depth is presented on Figure 6. Table 2 presents the limit pressure and deformation modulus at different depths for the Chimney and TG Building.

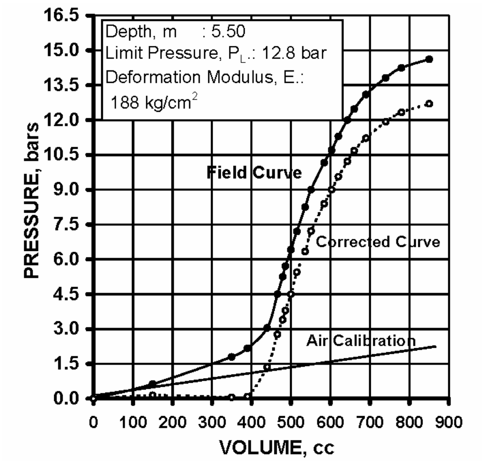

Fig. 5: Typical Pressuremeter Test Results

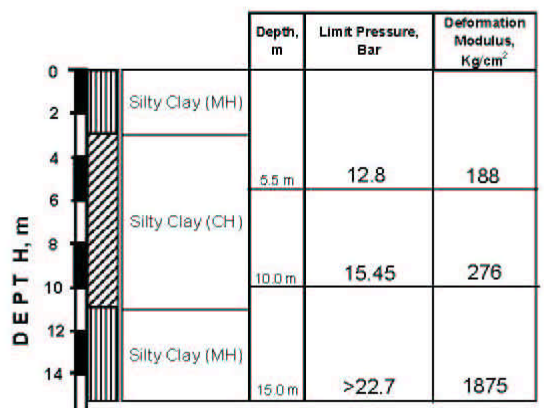

Fig. 6: Profile of Pressuremeter Parameters: Chimney

Table 2: Soil Parameters Interpreted from Pressuremeter Tests

Structure	*Test depth, m*	*Soil classification*	*Limit pressure, kg/cm^2*	*Deformation modulus, kg/cm^2*
Chimney	5.5	Silty Clay	12.80	188
	10.0		15.45	276
	15.0		>22.7	1875
TG Building	7.5	Silty Clay	>22.5	2565
	12.5		>22.7	1240
	17.6	Lignite	>28.2	2425

3.9 Laboratory Testing

Detailed laboratory testing was performed to characterize the soils. Tests performed included the following:

- classification tests such as grain size distribution, liquid, plastic and shrinkage limits,
- undrained shear strength by unconfined compression and UU Triaxial tests,
- free swell index and swell pressure to assess the swelling characteristics, and
- consolidation tests

4. ENGINEERING EVALUATION

4.1 Active Zone

The active zone in a deposit of expansive soil (Chen 1975) is the zone which is subject to swelling and shrinkage on account of variations in moisture content.

Based on the data collected by various researchers in different parts of the country (Ramaswamy 1986) the active zone in most areas of India is usually on the order of 2.5 to 3.5 m below the ground surface. Due to the extremely low permeability of the soils, the hydraulic gradient caused by the groundwater level fluctuations is insufficient to reduce or increase the moisture content of such clays. The change in moisture content is mainly due to the suction forces created by thermal gradients.

At the project site, a thin surficial layer of dune sand is underlain by highly expansive clay with a discontinuous cemented sand/gravel zone.

In the authors' opinion, the active zone at this project site may extend to about 3 to 3.5 m depth. For engineering design purpose, it was decided to place foundations in the stable zone below about 4.0 m depth in which moisture variations are unlikely to occur. Since the cemented gravel layer is discontinuous and of varying thickness, it cannot be considered as a reliable foundation bearing material.

4.2 Evaluation of Soils Data

Since expansive soil is encountered at site to about 3.0 to 16 m depth, careful planning is required to ensure long-term performance of the foundation system. In general, the soils to about 2.5~4.0 m depth are weak in condition with q_c values ranging from 18 to 20 kg/cm^2. Below 4 m depth, the soil conditions improve with depth. Further, in most areas of India, the active zone extends to 3~3.5 m depth.

In view of the above, the authors proposed that open foundations as well as raft foundations are a feasible foundation scheme that may bear at or below 4 m depth.

The option of providing pile foundations was also evaluated. However, after estimation of the costs involved, it was decided to go for open foundations.

4.3 Selection of Design Net Bearing Pressures

Bearing capacity analysis for open foundations and raft foundations was performed in accordance with IS 6403:1981. A factor of safety of 2.5 was applied to work out the safe net bearing capacity from shear criterion.

Settlement analysis has been done by the following methods:

- *Elastic Settlement:* E values of soil were interpreted based on N-values, q_c values, deformation modulus from pressuremeter tests, plate load tests and undrained shear strength. The analysis uses the Steinbrenner's influence factors as given in IS 8009 Part 1: 1976.
- q_c *profile:* As per de Beer & Martin profile as given in IS 8009 Part 1: 1976.
- *Pressuremeter Profile:* As per the pressuremeter design rules given by Clarke (1995).

The clay layer below 4 m depth is hard in consistency with groundwater fairly deep in the area, as such the strata is unlikely to experience any consolidation settlement and so considered to be negligible.

Based on the detailed analysis, the foundation depths and net bearing pressure for a permissible total settlement of 25 mm for some selected structures as recommended are given in Table 3.

Table 3: Net Bearing Pressures for Design

Structure	*Foundation depth, m*	*Width of foundation, m*	*Length of foundation, m*	*Design Net allowable bearing pressure, T/m²*
Chimney	7.0	32.0 (Raft)		28.0
TG Bldg	4.0	≥ 6	≥ 6	24.0
Boiler	4.0	≥ 6	≥ 6	24.0
Bunker	4.0	≥ 6	≥ 6	24.0

These bearing pressures include a bearing capacity safety factor of 2.5 and are applicable for a permissible total settlement of 25 mm.

4.4 Plinth Protection/Grade Slab

The successful performance of the foundations requires that there should be no moisture variation in the effective soil mass beneath the foundations. Since groundwater is very deep, it is not likely to influence the foundations. However, seepage from surface sources needs to be controlled. To this end, effective plinth protection is essential.

For this purpose, a specific backfilling scheme was proposed for the site (Fig. 7), which consisted of compacted local sand mixed with 3 percent cement, overlain by 150 mm thick sand cushion separated by a 250 micron thick LDPE film. Plinth protection consisting of a 100 mm thick lean concrete layer (M-15 grade) was then placed on the sand cushion. These layers are extended by 2.5 m beyond the outer edge of the foundations so as to cut off any water seepage from external sources in the immediate vicinity of the foundations.

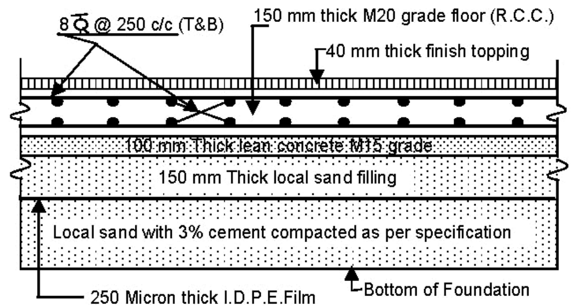

Fig. 7: Typical Details of Backfilling—Plinth Protection/Grade Slab

5. CLOSURE

Construction of heavily loaded foundations on highly expansive soils (bentonite) requires careful planning and ingenuity on part of the geotechnical engineer. The paper highlights the successful execution of the project under such difficult soil conditions.

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