GEOTECHNICAL CHARACTERIZATION OF DUNE SANDS OF THE THAR DESERT

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ABSTRACT: The aeolian sands of the Thar Desert are meta-stable in nature and experience volume change on contact with water even without application of load. The construction of a major power plant on such deposits requires a thorough appreciation of their engineering behavior. The paper documents the detailed geotechnical investigations conducted for the project. Highlights of the results include (i) SPT values are influenced by the overburden pressure, (ii) settlement increase of open foundations upon saturation is nearly 2.8 times, and (iii) poor dynamic response of the collapsible sands is observed at shallow depths with two peaks in the frequency versus amplitude curve.

1. INTRODUCTION

The Suratgarh Thermal Power Project is located in Western Rajasthan (India) in the Thar Desert. Dune sands cover the entire project area. The construction of a heavily loaded power plant with restrictive settlement criteria on the dune sand presents a veritable challenge to the geotechnical engineer.

2. THE POWER PLANT

The coal based power plant and associated facilities, spread over more than 5 km^2 area, has been constructed in four stages over the last 15 years. Stage I, started in 1992, has 2 × 250 MW units. Stage II has two additional 250 MW units and the recently commissioned Stage III has 1 × 250 MW unit. Stage IV currently under construction, shall have a 1 × 250 MW unit.

Various associated units include boilers, chimneys, coal and ash handling facilities, wagon tipplers, water treatment plants, switchyards etc. Intake water for the plant is being drawn from the Indira Gandhi Canal, which is about 8-10 km away from the plant.

3. REGIONAL GEOLOGY

A large tract of western and northwestern Rajasthan and Sindh, 640 km long and 160 km wide, constitutes the "Thar Desert" (Krishnan, 1986). The origin of the Thar Desert is attributed to a long, continued and extreme degree of aridity of the region, combined with the sand drifting action of the south-west monsoon winds which sweep through Rajasthan for several months of the year without precipitating any part of their contained moisture.

4. STABILITY OF DUNE SAND

Alam Singh et al. (1985) classify dune sand as a meta-stable or collapsible soil that goes through radical re-arrangement of particles and loss in volume upon wetting with or without load application. The SPT values and relative density of the soil are a function of the overburden. Thus, higher the overburden pressure, the lower is the relative density for the same SPT value. Table 1 presents SPT values for stable and unstable dunes.

Table 1. SPT N-Values for Stable and Unstable Dunes
(Source : Alam Singh et al, 1985)

Depth (m)	Condition	N – Value	
		Stable Dune	Unstable Dune
1.0	Dry	8 – 12	5 – 7
2.0	Dry	10 – 17	7 – 13
3.0	Dry	12 – 25	9 – 15
4.0	Dry	16 – 35	14 – 15
1.0	Submerged	-	1-2
2.0	Submerged	-	3-4

5. GENERALIZED SITE CONDITIONS

5.1 Site Stratigraphy

In general, the sands are poorly graded with an insignificant proportion of coarse and medium sized sand grains. The stratigraphy at the power plant site may be divided into two generalized strata as given below:

Stratum-I	:	Fine sand & silty fine sand
Stratum II	:	Cemented fine sand

Stratum-I sand occurs at the ground surface and extends to about 8 to 12 m depth.

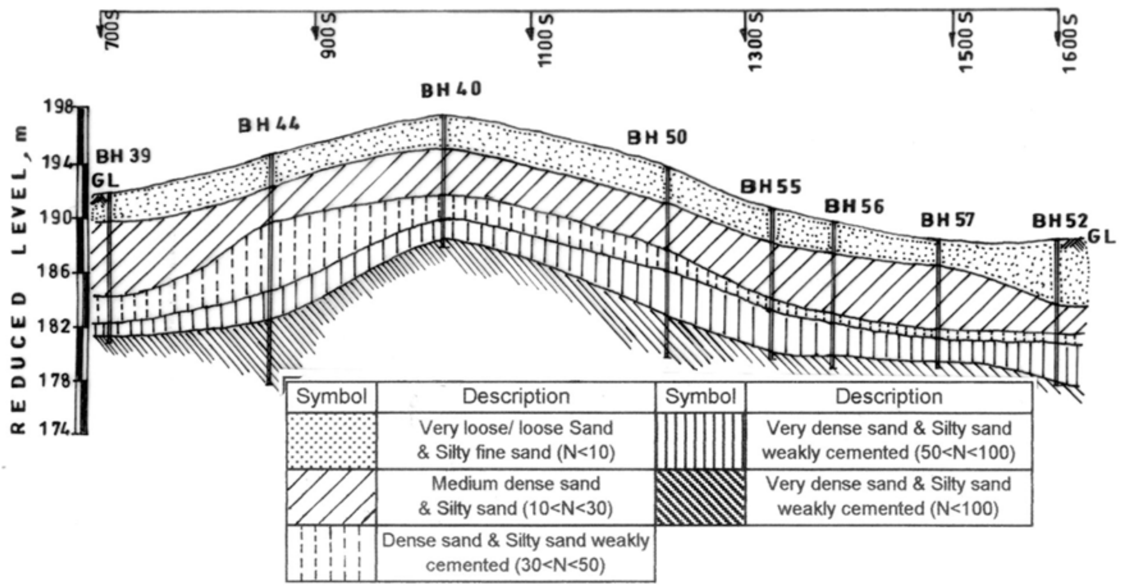

Fig. 1. Generalized Cross-Sectional Profile

The underlying sand of Stratum II is weakly cemented. SPT values exceed 100. The cementation tends to break up on addition of water.

Groundwater was not encountered to 50 m depth. The moisture content of the sands is as low as 4 to 8 percent, even at deeper depths, suggesting that the area is dry.

SPT Values

The trend of SPT values is the most important feature of this aeolian deposition. In general, SPT values increase with depth. There is no correlation between SPT value and reduced level. The SPT value at a particular level is a function of its depth below the ground surface. The depth-wise trend is given on Table 2.

Table 2. Trend of Field N-Values

Depth, m		Range of N -Values	Remarks
From	To		
0	3~4	< 10	Loose, unstable dune
3~4	6~8	15-30	Stable dune
6~8	9~11	40-100	Weak carbonate cementation
9~11	50 +	> 100	Weak to medium carbonate cementation

A typical cross-sectional profile across the site is illustrated on Fig. 1. It illustrates the following features:

1. The profile of the ground surface is roughly parallel to the profile of the refusal stratum (N > 100).
2. Treating the refusal profile as a part of the stable, older deposition, the aeolian deposition appears to roughly follow the trend of the underlying cemented sand deposit.
3. The soils with N-values less than about 10 to 12 may be treated as unstable portion of the dune (Ref. Alam Singh).

6. BEARING CAPACITY AND SETTLEMENT

Dune sands have low bearing capacities. The traditional and standard methods of computation of soil bearing capacity and settlement tend to over-predict the soil bearing capacity. This is because dune sands have a collapsible soil structure and are highly compressible.

Settlement of these soils is higher than that for other soils with similar engineering characteristics. The behavior of dune sands is not governed by the normal laws of soil-water relationship. SPT values decrease on addition of water. Settlement also occurs on contact with water even without application of load.

It has been observed that in loose desert sands of Rajasthan, the total settlement due to rise in water table is much larger than twice the initial settlement.

7. PLATE LOAD TESTS

To assess the behavior of the dune sand on saturation, two plate load tests were conducted at about 6.9 m depth at the TG location. These tests were conducted on a 600 mm × 600 mm size test plate. The purpose was to assess the additional settlement that would occur on saturation. The additional settlement is a pre-cursor to identifying instability.

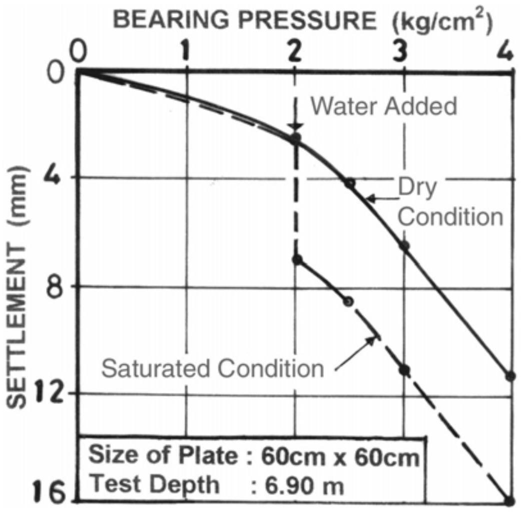

Fig.2. Plate Load Tests under Dry & Saturated condition

The first test was conducted by the standard procedure (maintained load method) on the natural soils in the in-situ condition, applying each load increment till the settlement stabilizes.

A second test was conducted about 2 m away under saturated condition. The test was initially started in the natural (dry) state and a bearing pressure of 2 kg/cm^2 was applied on the plate. The load was then held constant and the sands were saturated by flooding. After the settlement at 2-kg/cm^2 pressure stabilized under saturated condition, the test was carried out further. Results are plotted on Fig. 2.

The test results indicate an increase in settlement of about 2.8 times upon saturation in comparison to that under dry condition. The saturation/water table reduction factor, R_w, thus works out as 0.36. R_w factors of as low as 0.3 has been reported in literature from dune sands of Rajasthan.

8. BLOCK VIBRATION TESTS

8.1 Test Procedure

A mechanical oscillator with a DC motor was fixed on the top of the concrete block. A speed control unit and a display device were connected to the oscillator through a 220 volt calibrated prior to start of the test.

Forced vibration tests were conducted in both the vertical and horizontal modes. For conducting the vertical vibration test, the oscillator was mounted so as to generate vertical sinusoidal vibrations with the line of action of the vibration coinciding with the center of gravity of the block. For conducting the horizontal vibration test, the horizontal sinusoidal vibrations were generated in the direction of the longitudinal axis of the concrete block.

The dynamic force generated was varied by changing the angle of eccentricity of the rotating masses. The test procedure was in general accordance with Indian Standard Code of Practice IS 5249 - 1977. The tests were conducted on plain concrete blocks of size 1.5 x 0.75 x 0.7 m at 3.0 & 8.0 m depths.

8.2 Dynamic Behavior at 3.0 m Depth

The test location is near the dune crest. Therefore, the sands at this location are loose and unstable. The field SPT values are in the range of 7-12 and indicate that the top 3-4 m are loose and in the unstable part of the dune.

In the vertical mode of vibration, the test results show two peaks in the amplitude versus frequency curve (See Fig. 3). This suggests that the soil structure was probably collapsing and the sand was re-arranging into a more compact state. Initially, the resonant frequency was very low but as the sand compacted, the resonant frequency increased somewhat. This resulted in two peaks being observed in the amplitude versus frequency curve. Visual observation also confirmed that the block had settled by more than 50 to 60 mm during the test.

In the vertical mode of vibration, the first peak was observed at 30-35 cps. The second peak is obtained at a frequency of 39-40 cps. Using either of the two peaks for the analysis is fraught with uncertainty since the soil structure is probably collapsing. The resonant frequency in the horizontal mode of vibration is also fairly low (Gupta and Sundaram, 2001).

Due to the low resonant frequencies and the collapsible soil structure, there is a risk of the foundation system undergoing excessive settlement due to the vibratory loads. Therefore, the soils at 3 m depth are considered unsuitable for supporting dynamically loaded foundations.

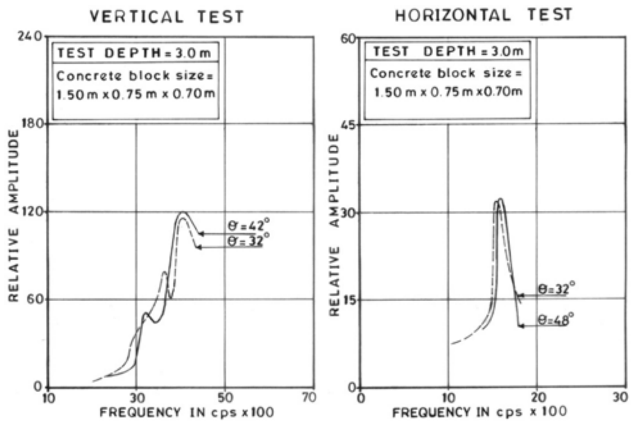

Fig. 3. Results of Forced Vibration Tests at 3 m Depth

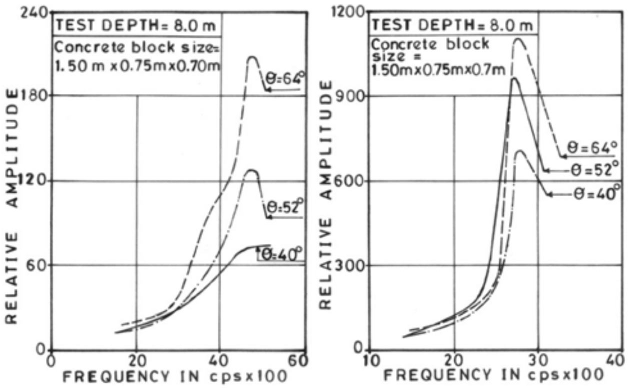

Fig. 4. Results of Forced Vibration Tests at 8 m Depth

8.3 Dynamic Behavior at 8.0 m Depth

The results of the block vibration tests at 8 m depth (See Fig. 4) indicate a substantial improvement in soil properties. The resonant frequencies also increase substantially. The test confirmed that the sand at this level is dense and compact, and therefore suitable to support the dynamic loads of the TG foundations.

9.0 NET BEARING PRESSURES FOR DESIGN

Selection of net bearing pressures for design of various settlement-sensitive structures of the power plant needs more than just performing bearing capacity and settlement analysis by normally used procedures / codes of practice. These methods may over-predict the bearing capacity due to the collapsible structure of the dune sands. .

Power plant facilities are settlement-sensitive. The project specifications allow a permissible total settlement of 25 mm. The consequence of failure in a power plant could be disastrous. Hence, suitable reduction factors should be applied to account for the collapsible nature of the soils and additional settlement that could occur if the soils experience partial saturation due to leakage of water from various sources, rains, etc.

The original ground level varied by over 7-15 m. The final finished level was fixed by the project authorities for the whole area. As a result, some areas required substantial cutting/filling operations.

Where cutting was done, the unstable part of the dune was removed and high safe bearing capacity could be achieved at 2-4 m below the final finished level (FFL). Where the natural ground surface was below the FFL, foundations had to be taken at least 3-4 below the original ground level to achieve the required safe bearing capacity.

Table 3 presents founding levels and net bearing pressures for some of the facilities.

Table 3. Foundation Design Details for Selected Facilities

Stage	Structure	OGL relative to FGL	Foundation Depth below FFL, m	Design Net Allowable Bearing Pressure, kPa
I	TG Foundations	±1.5 m	7.0	230
I	Chimney	±1.5 m	12.0	550
I	Coal Handling Plant	±1 m	5.0	175
I	Switchyard	+5 m	3.0	200
II	Crusher House	-6 m	9.0	500
II	Water Treatment Plant	+8 m	1.0	175
III	Boiler	-5 m	7.0	250
III	Ash Silos	-4 m	7.5	200

OGL: Original Ground Level FFL: Final Finished Level
\+ indicates OGL was above FFL, hence cutting was done.
\- indicates OGL was below FFL, hence filling was done.

10. CONCLUDING REMARKS

Dune sands of the Thar Desert are vulnerable to disturbance. These aeolian sands, particularly at shallow depths, are susceptible to excessive settlement due to collapse of the soil structure. The reason for this meta-stable nature lies in the mode of deposition.

Careful planning and thorough testing is required to ensure stability of foundations on aeolian sands of the Thar Desert. Foundation embedment depths should be decided based on the nature of the dune and its stability.

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