Constructing Foundations on Red Mud

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ABSTRACT For the expansion of an Aluminium plant in eastern Uttar Pradesh (India), it was required to construct an industrial facility on a slurry pond formed by pumping Red Mud, the waste product of the processing of aluminium ore. Since the Red Mud deposition behaves as a soft clay, ground improvement was done by provision of granular piles / rammed stone columns. The granular piles were load tested to verify the efficacy of the improvement.

INTRODUCTION

For the expansion of an aluminium industry in eastern Uttar Pradesh (India), it was required to construct a Drum Filter Plant on a Red Mud Slurry Pond. Since the slurry pond was soft in consistency, ground improvement was done by provision of rammed stone columns. The site location is illustrated on Fig. 1.

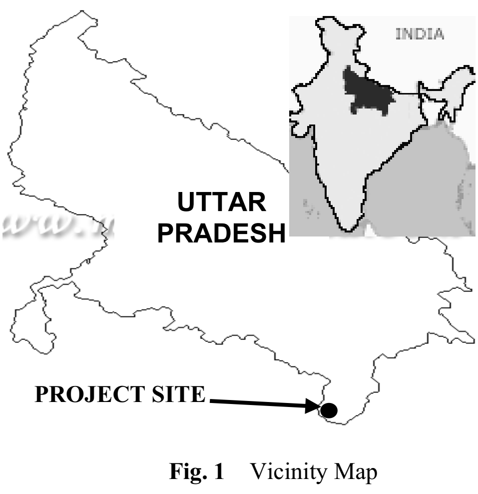

Fig. 1 Vicinity Map

RED MUD

Red Mud is a waste product of the aluminium industry formed by washing and purifying bauxite (aluminium ore). It is pumped in slurry form into a disposal pond. Over a period of time, as the water partly seeps into the ground and partly evaporates. The red mud slurry thickens to form a soft deposit with very low SPT values.

Since the red mud behaves like very soft clay with SPT values in the range of 1 to 5, ground improvement was done by provision of rammed stone columns. This resulted in substantial savings to the owner in comparison to the cost for installing concrete piles.

SITE CONDITIONS

Geological Setting

The Precambrian rocks exposed in the project area (Renukoot, Distt. Sonebhadra, Uttar Pradesh, India) are sedimentaries of the Vindhyan Group (Maithani, 1986). These rocks classify as grey and red phyllites, red shale with inter-bedded sandstone, purple phyllite with cherty bands, greywacke, ferruginous and manganiferrous shales.

Site Stratigraphy

The area for the project has been formed by filling a large area which is a valley between two hills. The filling is composed primarily of Red Mud with some intermediate layers of fly ash, bauxite fragments and rock fragments. The filling is non-uniform and varies in thickness and lateral extent.

The underlying rock is in the form of a synclinal valley. It classifies as phyllitic shale. It has undergone low-grade metamorphism.

The rock is thinly bedded, striking in the NW-SE direction with dip varying from 62° to 74° at places. It is highly fractured and closely laminated. Core recoveries in the rock range from less than 10 percent to about 40 percent and the RQD value is nil.

On the northern side of the plot, the rock is encountered at 15~18 m depth. The depth to rock increases southwards and ranges from 34 to 42 m. Typical borehole profiles are illustrated on Fig. 2.

Engineering Properties of Red Mud

As per the gradation, the Red Mud classifies as a clayey silt of medium plasticity. It as a high specific gravity, in the range of 2.85 to 2.95 due to the presence of silica and oxides and other compounds of metals such as titanium, iron, aluminium, etc. During the processing of the bauxite, it is treated with caustic soda. Therefore, it is highly alkaline.

Since it contains 30 to 40% clay sized particles, it has a high water retention and low permeability. As a consequence, pore water pressure dissipates at a very slow rate. Consolidation tests indicated that the Red Mud is slightly under-consolidated to normally-consolidated.

The properties of the Red Mud at the project site are summarized in Table 1. Results of one consolidation test performed on a sample at 5.25 m depth is presented on Fig. 3.

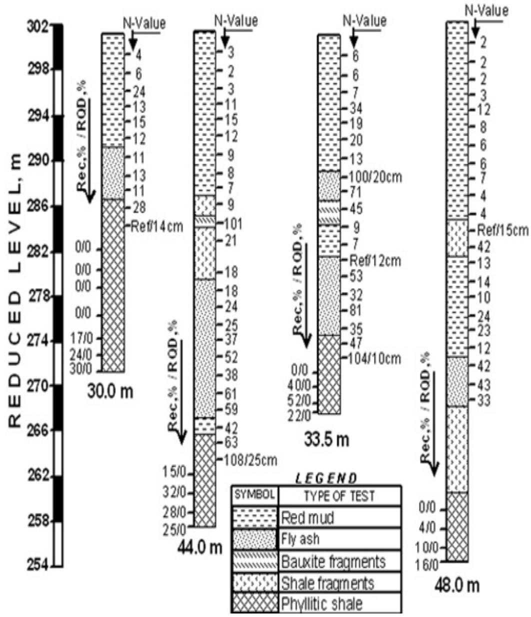

Fig. 2. Typical Borehole Data

Table 1. Red Mud at Renukoot: Engineering Properties

Parameter	Typical Range of Values
Moisture Content	32 – 38 %
Liquid Limit	39 – 45 %
Plastic Limit	27 – 29 %
Shrinkage Limit	19 – 22 %
Specific Gravity	2.85 - 2.97
Gradation: Sand Size	10 – 14 %
Silt Size	43 – 57 %
Clay Size	32 – 39 %
Undrained Shear Strength	0.4 – 1.4 kg/cm^2
Effective Stress ($\overline{CU}$) parameters	c = 0.1 - 0.2 kg/ cm^2 ϕ = 26 - 28°
Apparent Electrical Resistivity	1.5-2.0 ohm-m to 5 m depth 4-8 ohm-m to 10 m depth
Total Soluble Solids	0.44 – 0.56 %
pH value	9.3 – 10.2

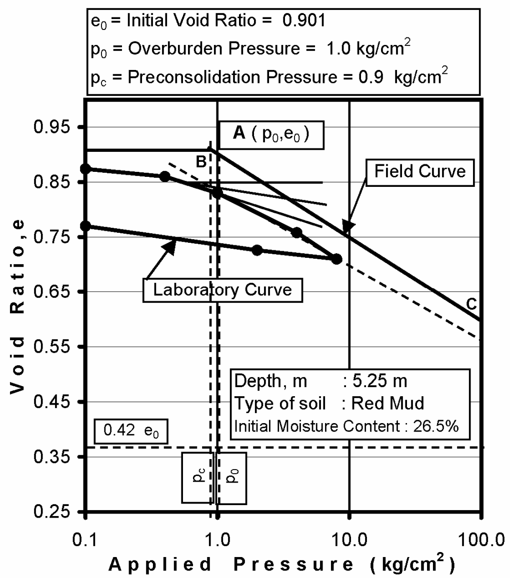

Fig. 3: Consolidation Test Results

ALTERNATIVE FOUNDATION SYSTEMS

Since the Red Mud is soft in consistency at shallow depths and under-consolidated to about 5-8 m depth, it was not feasible to construct open foundations / raft foundations at shallow depths.

The following options were evaluated in order to assess the feasibility of supporting the Drum Filter Plant on the Red Mud Slurry Pond:

- Pile Foundations: Negative skin friction is likely in the top 5-8 m due to the under-consolidated nature of the Red Mud. To develop adequate end bearing, pile length was substantial, in the range of 20 to 28 m.
- Ground Improvement: Granular piles may be used to improve the ground. This shall increase the shear strength and create a drainage path for faster consolidation (Gopal Ranjan et al 2009) of the Red Mud.

After detailed engineering analysis and cost evaluation, it was decided to strengthen the ground by provision of granular piles. Since the Red Mud is under-consolidated to about 5-8 m depth, it was decided to improve the ground to about 12 - 14 m depth.

GRANULAR PILES

In soft / weak deposits, granular piles or rammed stone columns can successfully improve the soil bearing capacity and reduce foundation settlements (Gupta & Sundaram, 1996). It also accelerates the rate of settlement with the result that a major part of the total settlement may occur during the construction period. Thus, the long-term settlement of the foundation reduces significantly.

Construction Methodology

In this scheme, a bore is made to the required depth and a charge of gravel, 75 mm down, graded, is placed in the bore in layers and rammed with a heavy hammer of adequate weight. The granular piles are constructed in a triangular grid pattern below the foundations, with about two rows of stone columns extending beyond the edge of the foundations for peripheral restrainment.

Granular Pile Design

Considering the range of N-values and the loads on the drum filter structure, it was decided to strengthen the strata to about 12 m depth below the cut-off level of 2 m. Stone columns / granular piles of 600 mm diameter were installed on a triangular grid pattern at a spacing of 2 m. Each charge was placed in layers of about 1 m height. Ramming was done using a 1 ton weight down-the-hole rammer till a set was obtained.

Over the stone columns, a 200 mm thick compacted gravel blanket was placed so as to distribute the load uniformly over the granular piles. Raft foundation was constructed over the gravel pad. The raft foundation was designed for a net bearing pressure of 12 T/m^2.

Due to the high alkali content, the aggregate used was tested for alkali-aggregate reactivity to ensure good quality aggregate. Further, the primary function of the aggregate is to provide a drainage path for consolidation which is likely to be over 90% complete within a few months of construction.

Load Testing of Granular Piles

To verify the performance of the granular piles, load test was performed on a single granular pile.

A schematic of the test arrangement is illustrated Fig. 4. To ensure adequate peripheral restrainment, six granular piles were installed surrounding the test pile as shown on Fig. 5.

From the results of the load test (Fig. 5), it may be seen that the capacity of the single granular pile is about 42 Tons.

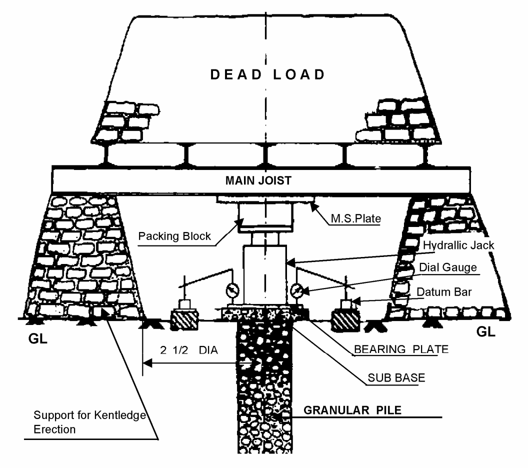

Fig. 4: Schematic of Granular Pile Load Test

Settlement analysis was done to estimate the contribution of the improved soils to 12 m depth and the underlying soils below the bottom of the granular pile. The total settlement of the raft foundation under the design bearing pressure of 12 T/m^2 works out as about 50 mm.

Based on the load test results, it was concluded that the ground improvement is a feasible option to support the foundation. Compared to the other option of using pile foundations, the cost savings was more than 50 percent.

CONCLUDING REMARKS

With rapid industrialization and expansion of existing facilities, there is a great demand on developing land that had previously been allocated for waste disposal / slurry ponds. The paper demonstrates effective utilization of space occupied by the closed Red Mud pond.

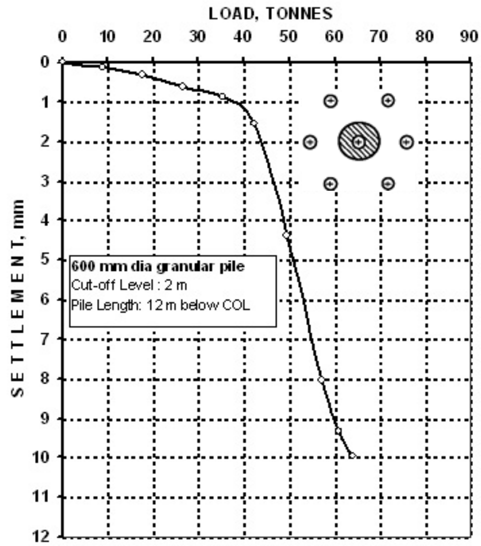

Fig. 5. Load Settlement Curve – Load Test on Single Stone Column

Ground improvement by provision of granular piles is an economical option to strengthen the soft Red Mud deposition. Foundations constructed on the improved ground can sustain the structural loads. Proper geotechnical investigation and load testing are the key to successful performance of the foundations on improved ground.

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