GROUND IMPROVEMENT USING PRE-LOADING WITH PREFABRICATED VERTICAL DRAINS: A CASE STUDY

A. Gadihya Shadab, (Manager – Design, Techfab (India) Industries Ltd., shadabg@gmail.com)
D. Vyas Saurabh, (Head – Technical Services, Techfab (India) Industries Ltd., sdvyas18@gmail.com)

ABSTRACT: A Stock yard was constructed for handling Filter Cake, Coke Breeze, Limestone/Dolomite, Product Pellet, etc at 8MTPA Integrated Iron Ore Pellet Plant – Paradeep, Orissa. The Investigation revealed the presence of sub-soil that included a layer of soft silty clay at depths of 0 to 1.5 m below grade. Thicknesses of the soft stratum varied from 5 m to 7 m. Ground improvement using pre-loading with prefabricated vertical drains was undertaken to pre-consolidate the compressible sub-soils. A ground improvement work was designed and carried out to pre-consolidate the soft subsoil before construction of the Stockyard so that the settlements after stacking the material are minimized during the service life. Temporary surcharge fill height was designed to reduce long term creep settlement. Construction commenced in September 2011 and was successfully completed in April 2012. Though Instrumentation and Monitoring was not in scope, this paper presents the analytical aspects of the both stability and settlement performance with prefabricated vertical drains.

KEYWORDS: Ground improvement, consolidation, prefabricated vertical drain, settlement, slope stability, limit equilibrium method, numerical analysis.

INTRODUCTION
Essar Steel Orissa Ltd. has proposed to set up an 8MTPA Integrated Iron Ore Pellet/Steel Plant at Paradeep, which comprises of various facilities & stock pile areas where the movement of stacker cum reclaimer was planned. Heavy loading in terms of metric tons were expected and the subsoil beneath consist of soft soil in nature. At some places the area was already filled with dredged sand for 2-3 m. A ground improvement work was designed and carried out to pre-consolidate the soft subsoil before construction of the yard so that the settlements of the yard are minimized during the service life.

SUBSURFACE CONDITIONS
The project site lies in the coastal region of the Bay of Bengal, near Paradip port in Jagatsingpur district of Orissa state in Eastern India. The area under study is generally flat. The study area is primarily Deltaic Alluvial Sediments drained by Mahanadi River near its confluence with the Bay of Bengal. The topography of the area is such that it consists of low lying areas and creek nearby. A total of thirteen boreholes were drilled to gather subsoil information for the site, which were distributed over the area out of which ten boreholes were sink to 50 mt. depth and three boreholes were sink to 30 mt. depth. Seven Vane Shear Tests, four Static Cone Penetration Tests (SCPT) and three field CBR tests were also carried out at specified locations. The Samples were explored with the help of auger and shell operated by mechanized winch. An extensive laboratory investigation was then carried out for identification of soil and for determination of geotechnical design parameters. Laboratory test includes Triaxial test (UU, CU & CD), Direct shear test, Unconfined compression test, Hydrometer test, Consolidation test, Permeability test, Swelling...
pressure, Free swell index, etc. Based upon the soil stratification, the entire area was divided in few zones and an average profile was suggested by Investigation agency for further design of foundation system. Site condition during drilling of Bore Hole is shown in Fig. 2.

**Fig. 2 Bore Hole in Progress**

Observed and Corrected SPT values of bore holes which are falling in the stockyard area are shown in Fig. 3 & Fig. 4.

**Fig. 3 Observed SPT values with R.L.**

**Fig. 4 Corrected SPT values with R.L.**

**PROBLEM STATEMENT**

Looking to the soil stratification and properties, the top few mt. of soil was too weak to resist the load of stacking. And actual height of Stacking was undetermined at the time of proposal. So it was decided to stack 1.5 mt. ht. of preload with locally available soil. Considering 90% of degree of consolidation to be achieved, the design of Ground Improvement with PVD was done.

This paper reveals the futuristic analysis viz. Stability and Settlement of the embankment with 8 mt. of stacking over the ground where PVD was inserted and which was preloaded. The Stability and Settlement Analysis was carried out using Rocscience Slide v6.009 & Settle3D v2.015.

**GROUND IMPROVEMENT BY INSTALLATION OF PVD**

The time required for 90% consolidation was observed to be 3.87 years. This period is very much higher than practical considerations. Hence, the installation of PVDs was considered to be a viable option to accelerate the consolidation process. Calculation showed that the time for 90% could be reduced to 1.0 month by installing PVDs. Triangular Grid Spacing of 1.2 mt was suggested.
STABILITY ANALYSIS OF PRODUCT PELLET STACK

Product Pellet of 100 x 40 x 8 mt. is considered with 20 mt. space in between. Looking to the movement of Stacker and Reclaimer in the stockyard area, triangular stacking in 3 stages was assumed. The ht. of each stage of stack is 3 mt., 3 mt. & 2 mt. respectively. Table 1 shows the properties considered for design of embankment at different stages:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Unit Wt. (kN/m³)</th>
<th>C or Cu (kPa)</th>
<th>φ (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pret Pellet</td>
<td>Prod L</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Preloa d</td>
<td>18</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>I</td>
<td>22</td>
<td>.8</td>
<td>5</td>
</tr>
<tr>
<td>II</td>
<td>22</td>
<td>.8</td>
<td>5</td>
</tr>
<tr>
<td>III</td>
<td>22</td>
<td>.8</td>
<td>5</td>
</tr>
</tbody>
</table>

LC - Soft brownish grey to grey silty clay of 1.5 mt. thk.
DC - Loose to medium dense / dense grey silty clay of 6 mt. thk.

Note: Strength Model as Mohr – Coulomb envelope is considered for embankment stacking and Undrained type is considered for sub soil being clay.

Increase in strength parameter is accounted after preloading and for every next stage stacking.

The factor of safety was obtained by three different methods namely Bishops’s method, Spencer’s method and Morgenstern-price’s method (see Ranjan and Rao, 2000). The analysis is done considering Circular slip surface with overall slope method. More rational approach to probabilistic slope stability analysis i.e. Critical Probabilistic Slip Surface is looked at. Figure 5 shows the factor of safety (FOS) obtained by all three methods. Factor of safety by all three methods during various stages of constructions are summarized in Table 2. It was observed from the stability analysis that constructing the Product Pellet in three stages, as 3.0m, 3.0m and 2.0m is stable. Hence, the same construction sequence was proposed.

(a) Calculation of FOS by Bishop’s Method

(b) Calculation of FOS by Spencer’s Method

(c) Calculation of FOS by Morgenstern-Price’s Method

Fig. 5 Factor of Safety obtained by different methods for Product Pellet stacks for stage III
Table 2. Comparison of factor of safety values obtained by various methods for different stages of Product Pellet

<table>
<thead>
<tr>
<th>Stage</th>
<th>Height (mt)</th>
<th>Bishop’s Method</th>
<th>Spencer’s Method</th>
<th>*M-P’s Method</th>
<th>IS 1528 P’s Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preload</td>
<td>1.5</td>
<td>3.612</td>
<td>3.549</td>
<td>3.569</td>
<td>4</td>
</tr>
<tr>
<td>I</td>
<td>3</td>
<td>3.895</td>
<td>3.888</td>
<td>3.894 &gt; 1.25</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>2</td>
<td>2.664</td>
<td>2.643</td>
<td>2.657</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>2</td>
<td>2.420</td>
<td>2.392</td>
<td>2.408</td>
<td></td>
</tr>
</tbody>
</table>

* Morgenstern-Price

From the analysis, it can be seen that Spencer method gives the most critical factor of safety. Since during all the stages of loading, the factor of safety was found within the allowable limit of ≥1.25 as specified in IS 15284 – Part II (2004), the suggested stages of construction are safe.

SETTLEMENT ANALYSIS OF PRODUCT PELLET STACK

The embankment was modelled in SETTLE 3D software for settlement computation. Complete cycle of preloading, removing and actual stages of loading was modeled assuming the pressure distribution as 2:1 as explained by Ranjan and Rao (2000). Fig. 7a and 7b shows the plot of time versus loading stress and effective stress. The estimated settlement was 1.02 mt as can be seen from Fig. 6.

Table 3. Time - Stage scenario considered for Pellet stack

<table>
<thead>
<tr>
<th>Time in days</th>
<th>Stage Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Preload Start</td>
</tr>
<tr>
<td>30</td>
<td>Preloaded to full height (1.5 mt.)</td>
</tr>
<tr>
<td>40</td>
<td>Preload Removed</td>
</tr>
<tr>
<td>85</td>
<td>Stage I Product Pellet stacking (3 mt.)</td>
</tr>
<tr>
<td>130</td>
<td>Stage II Product Pellet stacking (3 mt.)</td>
</tr>
<tr>
<td>160</td>
<td>Stage III Product Pellet stacking (2 mt.)</td>
</tr>
</tbody>
</table>

Fig. 7a Distance v/s Loading Stress

Fig. 7b Distance v/s Effective Stresss

CONCLUSIONS

Based upon the field data, it was revealed that the existing ground had inadequate bearing capacity and will undergo large settlements on application of surcharge load. A large settlement of such magnitude may damage the structures constructed on such soils. So to improve the Load carrying capacity of soil, Ground Improvement in terms of Prefabricated Vertical Drain (PVD) was proposed with a preload of 1.5 mt. Installation of the vertical drains reduced pre-consolidation time significantly.
(from about 3 to 5 years without vertical drain to about 31 days with PVDs).
For product pellet stacking, stability and settlement analysis was carried out. Man made slope stability analysis was done with Limit equilibrium approach using software “Slide”. Anticipating the construction sequence and slope stability, stacking in three stages viz. 3mt., 3mt., and 2mt., was found safe. The factor of safety for all the stages was ensured more than intended in codal provision. Rigorous settlement analysis was computed using software Settle3D.

REFERENCES

4. IS 15284– Part II (2004), Indian Design Code, Bureau of Indian Standard, New Delhi, India.
5. SETTLE 3D, Settlement and Consolidation Analysis, Rocscience Inc., Toronto, Ontario.