CASE STUDY FOR GROUND IMPROVEMENT USING PVD WITH PRELOADING FOR COAL & IRON ORE STACKYARD

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ABSTRACT: PVD with Preloading was used as the technique for the ground improvement below the Coal and Iron Ore Stackyards at port near Visakhapatnam, AP. The top layer of subsoil consisted very soft clay upto a depth of 12 m to 18 m. PVD was effectively used to accelerate the settlements. The settlements and pore pressure dissipation was monitored using instruments as Piezometers and Settlement Recorders. The paper describes the effectiveness of the technique and monitoring of the instrumentation. The settlements recorded were analysed by Asaoka Method and Hyperbolic Method. The analysis indicated close proximity between the percentage settlements observed and pore pressure dissipation.

1. INTRODUCTION
1.1 Project
The development of the new port at Gangavaram located at about 15 kms south of Visakhapatnam Port, Andhra Pradesh commenced in December 2005. The site for Gangavaram Port is the best location for development of a modern all weather, deepwater, multipurpose and truly next generation port (Fig. 1). The development of port facilities included development of back up facilities for coal and iron ore storage and stacking and handling facilities. The proposed height of coal stack was 12.00 m and that of iron ore was 10.00 m.

Fig 1: Plan of the Project Site

The preliminary soil investigation revealed the presence of soft clay upto a depth of 10.00 to 18.00 m with very low safe bearing capacity and high consolidation parameters. It was hence decided to enhance the soil properties using a ground treatment method of “Use of Band Drains/PVD with Preloading”. The turnkey contract was awarded to M/s Sohams Foundation Engg. Pvt. Ltd., Navi Mumbai.

1.2 Geotechnical Investigation
As a part of the project, 8 Nos boreholes were taken to ascertain the design parameters. In general the area was fairly levelled and a thin layer of dredged sand of thickness 0.20 to 0.30 m was present at most of the locations. Immediately below the dredged sand was the marine clay with shells with thickness varying from 1.00 to 3.00 m. A layer of soft marine clay of thickness varying from 7 m to 15 m was observed following this layer of marine clay with shells. The standard penetration test was conducted in this stratum at various depths, indicated the penetration of 45 to 60 cms in one blows thus N resistance as 0 to 1. At a depth of 12.00 to 18.00 m below the existing ground level the penetration resistance “N” was observed to be increasing with depth. The laboratory tests conducted on selected disturbed soil samples and undisturbed soil samples indicated the following range of values (Table 1).

The safe bearing capacity of the existing soil was worked out as 3 T/m² which was very low to take the loads. The consolidation settlements were worked out about 1000–1600 mm.
### Table 1: Typical Soil Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Moisture content</td>
<td>12–81 (%)</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2.52–2.65</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>1.24–1.52 (g/cc)</td>
</tr>
<tr>
<td>Gravel</td>
<td>00 (%)</td>
</tr>
<tr>
<td>Sand</td>
<td>2–31 (%)</td>
</tr>
<tr>
<td>Silt + Clay</td>
<td>7–63 (%)</td>
</tr>
<tr>
<td>Liquid Limit</td>
<td>21–102 (%)</td>
</tr>
<tr>
<td>Plastic Limit</td>
<td></td>
</tr>
<tr>
<td>Initial Void Ratio, $e_0$</td>
<td>0.627–2.249</td>
</tr>
<tr>
<td>Compression Index, $C_c$</td>
<td>0.38–0.92</td>
</tr>
<tr>
<td>Coefficient of Consolidation, $C_v$</td>
<td>0.72–1.95 (m²/yr)</td>
</tr>
<tr>
<td>Cohesion, $C_{cu}$</td>
<td>0.19–1.05 (kg/cm²)</td>
</tr>
<tr>
<td>Angle of Friction, $\Phi_{cu}$</td>
<td>18–29 (deg)</td>
</tr>
<tr>
<td>Shear Strength from VST</td>
<td>0.095–0.991 (kg/cm²)</td>
</tr>
</tbody>
</table>

### 2. GROUND IMPROVEMENT SCHEME

#### 2.1 Salient Features of Scheme

- **Machinery Used:** Hydraulic Stitchers
- **Depth of PVD:** 10.00 m to 18.00 m below OGL
- **Spacing of PVD:** 1.00 m c/c in Triangular Grid below the stacker reclaimers; 1.50 m c/c in Triangular Grid in other area
- **Consolidation Period:** For 1.00 m spacing: 65 days; For 1.50 m spacing: 174 days
- **Thickness of sand mat:** 300 mm

#### 2.2 Post Treatment Assessment

The instruments as Piezometers; Settlement Recorders; Inclinometers were installed to assess the post treatment performance of the adopted method of treatment. Table 2 shows the details of the instruments installed in project area (Fig. 2).

### Table 2: Details of Instruments

<table>
<thead>
<tr>
<th>Section</th>
<th>Casagrande piezometer</th>
<th>Vibrating wire piezometer</th>
<th>Plate settlement markers</th>
<th>Magnetic settlement recorder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1</td>
<td>CP1, VP1, VP3</td>
<td>VP2, PS1, PS2</td>
<td>MS1, MS2</td>
<td></td>
</tr>
<tr>
<td>Section 2</td>
<td>CP4, VP9, VP10, VP11</td>
<td>PS8, PS9, PS10</td>
<td>MS6</td>
<td></td>
</tr>
<tr>
<td>Section 3</td>
<td>CP3, VP6, VP7, VP8</td>
<td>PS5, PS6, PS7</td>
<td>MS5</td>
<td></td>
</tr>
<tr>
<td>Section 4</td>
<td>CP2, VP4, VP5</td>
<td>PS3, PS4</td>
<td>MS3, MS4</td>
<td></td>
</tr>
<tr>
<td>Section 5</td>
<td>CP5, VP12, VP13, VP14</td>
<td>PS11, PS12, PS13</td>
<td>MS7</td>
<td></td>
</tr>
</tbody>
</table>

The readings were taken every 4 days when loading started, continued for a month after final preload height is achieved. The frequency was later extended to 7 days.

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**Area - B**

**Section 5**

**AREA - B**

**Fig. 2: Location Details for the Instruments**
2.3 Methods of Data Analysis

From the observed data of excess pore pressure variation and settlements the degree of consolidation can be assessed as,

2.3.1 Excess Pore Pressures

The piezometers indicate the increase in excess pore pressure on application of the load. As the load is transferred to the virgin soil i.e. with consolidation in progress, the increased excess pore pressure dissipates. The degree of consolidation is then determined as,

\[ \%U = \frac{U_{\text{max}} - U_t}{U_t - U_i} \times 100 \]

\( U_{\text{max}} \): Maximum Excess Pore Pressure after load application
\( U_t \): Excess Pore Pressure at time ‘t’
\( U_i \): Initial Excess Pore Pressure

2.3.2 Settlements

From settlements, the degree of consolidation can be assessed by Asaoka Method and Hyperbolic Method. By these methods the ultimate settlement \( S_{100} \) is evaluated based on the observed data. Then the degree of consolidation is determined as,

\[ \%U = \frac{S_t}{S_{100}} \times 100 \]

\( S_t \): Settlement at time ‘t’
\( S_{100} \): Ultimate Settlement

Asaoka Method: This method is based on the Barron’s solution for radial drainage. From the time—settlement curves the settlements at different time (with equal interval \( \Delta t \)) is determined. Then the points (\( S_i, S_{i-1} \)) are plotted. The interception of this line and the line drawn with slope = 1 gives the ultimate settlement \( S_{100} \).

Hyperbolic Method: This is based on the Terzaghi’s theory for pore water pressure distribution. The average degree of consolidation when plotted in the form of \( U \) Vs \( T/U \) is a hyperbola. Hence, the graph is plotted for time/settlement \( V_S \) settlement. The settlement is determined as the inverse of the slope of this hyperbola.

However, for the case of Terzaghi’s theory, the slope of the hyperbolic line is not constant. In fact, it is valid for \( U_{av} \) between 60% and 90%, and hence it must be evaluated between these two points. Theoretically, the average slope of the first straight line portion is equal to 0.824. The inverse of this slope gives a corresponding settlement of 1.21%, which overestimates the ultimate primary consolidation settlement by 21%. Consequently, Tan (1994) proposed that if the slope of the first linear portion, \( \theta \), of the hyperbolic plot is used, the predicted ultimate primary settlement, \( \delta p \), should be multiplied by the theoretical slope \( \alpha \) such that \( \delta p = \alpha/\theta \).

2.4 Analysis of Data

Piezometers were installed at two different depths 6 m and 9 m. Figures 3 & 4 indicate the excess pore pressure variations with time. For the piezometers installed below the stacker reclamation the degree of consolidation was observed as 55–65%. For the piezometers installed in other area (PVD spaced at 1.50 m c/c) the degree of consolidation was observed as 30–40%.

Figure 5 indicates the settlement data with time. The observed settlements were in the tune of 300–500 mm.
The degree of Consolidation by both the methods was observed as (Table 3).

**Table 3: Degree of Consolidation from Settlement Data**

<table>
<thead>
<tr>
<th>Spacing</th>
<th>Asaoka Method</th>
<th>Hyperbolic Method (Slope = 0.824)</th>
<th>Hyperbolic Method (Slope = 1.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>78–115</td>
<td>63–84</td>
<td>52–70</td>
</tr>
<tr>
<td>1.50</td>
<td>85–92</td>
<td>39–53</td>
<td>32–43</td>
</tr>
</tbody>
</table>

3. CONCLUSIONS

- Plate Settlement Recorders are more reliable than the Magnetic Settlement Recorders for marine clays.
- With the application of the load the pore pressure increased and dropped down slowly with time. The pore pressure variation indicated about 55–60% dissipation i.e. degree of consolidation.
- The Degree of consolidation based on Asaoka Method was evaluated as 78–115% whereas based on Hyperbolic method it was evaluated as 32–70%.
- Hyperbolic Method is more comparable with the Pore Pressure Dissipation Results. Further the results obtained with theoretical slope of hyperbola as 1.00 are more closer to the predicted by pore water pressure analysis.
- The consolidation settlements worked out theoretically from laboratory test results were much higher than that predicated by Asaoka and Hyperbolic Method.

REFERENCES

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