ABSTRACT

This article describes the subsoil improvement works realised in the Dinh Vu Industrial Zone, Haiphong, Vietnam. The Dinh Vu Industrial Zone is located along the Cam and Bach Dang Rivers adjacent to the sea. Before land reclamation, the area was below the water level of a pond. The land was reclaimed by using sand dredged from the sea and pumped into the area to be reclaimed (thickness of the sand 3 m). The subsoil in Dinh Vu consists of soft alluvial and marine clay deposits with a thickness of about 35 m. The soft subsoil has low bearing capacity and excessive settlement characteristics.

In order to accelerate the settlement process, subsoil consolidation has been performed in an area of 40 ha in the industrial zone, including installation of prefabricated vertical drains (PVDs) combined with a surcharge preloading. PVDs provide a shorter drainage path in a radial direction which decreases the excess pore pressure and increases the effective stress. In order to realise the design of PVDs (spacing and depth), a pre-soil investigation was performed and theoretical predictions of settlement were calculated.

During the project the consolidation process was recorded with settlement marker plates. Settlement recordings have been analysed using the Asaoka method. Theoretical consolidation behaviour predicted before subsoil improvement matched the recorded consolidation. A model was developed and in order to test its accuracy under different loads, a trial embankment was performed (thickness of sand 6 m). A post-soil investigation has also been realised and compared to the pre-soil investigation highlighting the subsoil improvement.

INTRODUCTION

Vietnam has been a predominantly agricultural civilisation based on wet rice cultivation. A few years ago, governing authorities introduced economic reforms to encourage the growth of industries and commerce which lead to an increase and diversity in economic activities. To serve that target, Vietnam has converted agricultural land into industrial land intensively since the economic reforms. However, the ratio of agricultural land must be secured while industrialisation is in progress. In fact, the conversion of agricultural land into industrial land has already exceeded the limit. Therefore land reclamation could be a good solution in order to create more economic activities without using land reserved for agricultural purposes.

LAND RECLAMATION PROJECT DESCRIPTION

In December 2011, Dinh Vu Industrial Zone (DVIZ) was chosen by Bridgestone to establish its new tire plant. The area to be reclaimed is 102 ha of which 40 ha was requested to be consolidated by DVIZ.
the settlement process. The consolidation process consisted of the installation of Prefabricated Vertical Drains (PVDs) up to a depth of 25 m combined with a surcharge preloading (area reclaimed up to +6.5 mCD) (Figure 5). The contractual specifications between the client and DVIZ required an achievement of a degree of consolidation of 90% (in the area to be handed over at a final level of +4.8 mCD) and 75% (in the area to be handed over at a final level of +5.8 mCD) of the primary consolidation. When consolidation criteria have been reached, the surcharge can be removed to the final level required for the hand-over (Figure 6).

Within the framework of the project, soil investigation has been performed before land reclamation in order to realise the design of PVDs (spacing and depth) and theoretical predictions of settlement have been calculated. During this project the consolidation process was recorded with settlement marker plates. Settlement recordings have been back analysed. Furthermore, a post-soil investigation has been performed after completion of the consolidation criteria to compare geotechnical parameters before and after subsoil consolidation.

**GEOLOGY AND SITE CONDITION**

The land to be reclaimed is located on the right bank of the Cam River adjacent to the sea. This area is directly affected by the tidal regime. Geological phenomena in the region are mainly storage accumulations of materials originating from rivers and seas; concretely there are silt aggregations brought about by the flow of the Cam River and the tide. The subsoil in Dinh Vu consists of soft alluvial and marine clay deposits with a thickness of about 35 m. The two first layers are softer and have an average thickness of 13 m, underlain by medium stiff to stiff clay layers (Figure 7).

**SOIL INVESTIGATION**

In order to determine soil parameters needed to calculate the settlement, a soil investigation was carried out. Six deep boreholes have been drilled with Standard Penetration Tests (SPT) and the lab tests included particle size analysis, unit weight, Atterberg limits, direct shear test and consolidation test. Soil parameters used for settlement calculation are given by the soil investigation.
An average profile has been used for the model coming from data of the 6 boreholes (see Table I). The secondary compression index was not tested in the laboratory; therefore values have been adapted from literature resources. The horizontal coefficient of consolidation has not been defined, but a ratio of 2 is assumed for the clayey materials as it is often the case in natural sediments that the horizontal permeability is larger than the vertical permeability (a ratio of 1 is assumed for the mud).

For all layers a preconsolidation pressure of about 60kPa has been found from the lab testing results. Such a preconsolidation stress, however, seems to be too high. Because of this uncertainty and the important effect of this, the preconsolidation stress will (conservatively) be neglected in the calculations.

SUBSOIL IMPROVEMENT WORKS

The low bearing capacity and high compressibility of soft subsoil affects the long-term stability of buildings. Therefore, the stabilisation of soft subsoil before commencing construction was recommended.

Surcharge (preloading) is one of the most successful techniques for improving the shear strength of soft subsoil because it loads the ground surface to introduce a greater part of the ultimate settlement that is expected to bear after hand-over. When PVDs combined with surcharge preloading are applied, vertical drains provide a much shorter drainage path in a radial direction which decreases the excess pore pressure and increases the effective stress; this reduces the required preload period significantly (see Figure 8).

In order to determine the PVD design – depth of the PVDs and spacing between PVDs – settlement calculations have been performed based on the formula of Terzaghi assuming one dimensional deformation. Installation of the PVDs disturbs the soil surrounding the PVD which has an impact on the rate of consolidation. For this reason the smear effect was taken into account in the model. The ratio \( d_1/d_w \) was chosen as 2 (size of PVD and mandrel) and the ratio \( k_h/k_s \) of 3 is assumed. The target was to reach 90% of consolidation under a load which is a final level +4.8 mCD or 75% of consolidation under a load which is a final level +5.8 mCD. Calculation coming from the model indicated that without any PVD installation the time required to reach 90% of consolidation is more than 10 years.

With PVDs, the time required to reach 90% of consolidation is reduced to 3 months. Thanks to settlement calculation, the design of PVD has been chosen as follows: Spacing between 2 PVDs is 1 m (square grid) and depth of the PVD is 25 m which means that PVD also penetrate layers 3 and 4.
**MONITORING AND ANALYSIS**

The consolidation process was recorded with settlement marker plates (Figure 9). Settlement and sand elevation data recorded on site are shown in Figure 10. As can be seen, the area has been filled up to +6.7 mCD. During the surcharge installation, the settlement velocity is significant; then the settlement velocity decreases, until the installation of PVDs. After PVD installation, the settlement velocity increases again.

Variations in the settlement velocity after PVD installation are mainly a result of the variations of the ground water level (hydraulic land filling in an area close to the settlement marker plate). Settlement develops mainly during the surcharge installation and during the two months after PVDs installation. Settlement recordings (from 39 rod settlement gauges) were analysed by the Asaoka method in order to obtain the final settlement. From these analyses final settlements vary between 0.7 m and 0.85 m.

The contractual specifications indicate that the land has to reach 90% or 75% of consolidation under a load which is a fill to a final level +4.8 mCD or +5.8 mCD. As the land was reclaimed to +6.5 mCD, the final settlement obtained by the Asaoka method corresponds to the final settlement under a load which is a fill (originally) to level +6.5 mCD. Therefore a correction – based on the effective stress increase – has been applied to the final settlement obtained by the Asaoka method to define the final settlement under a load which is a fill to final level +4.8 mCD or +5.8 mCD.

Results indicate that 2 months after the PVD installation, the consolidation reached the contractual specifications everywhere. The theoretical time-settlement behaviour calculated before soil consolidation has been compared to the evolution of the time-settlement behaviour recorded on site. Results show a theoretical settlement behaviour that
matched quite well with the recorded settlement; however the magnitude of calculated settlements was slightly higher than the recorded settlements. This is because the preconsolidation pressure was chosen to be neglected (0kPa). Therefore, the preconsolidation pressure was modified in the input of the model in order to obtain similar calculated and recorded settlements. The preconsolidation pressure was adjusted to 10kPa in all layers. With this small modification in the input values, both the settlement behaviour and the magnitude of the calculated settlements show a good fit with recordings (see Figure 10), and the final settlement obtained using the Asaoka method matches the final settlement calculated with the model.

**TRIAL EMBANKMENT**
In order to test the accuracy of the model under different loads, a trial embankment was built. On the top of the reclaimed area to average +6.5 mCD, 2 m of dry sand was added. The trial embankment is 2 m in height, 20 m wide and 20 m long. The settlement beacon was located in the middle of the embankment. This trial embankment has been built after installation of the PVDs as seen in Figure 11a.

During all this time, settlements were recorded. In Figure 11b, the recorded settlements are compared to the calculated settlements (1: calculated settlement under a fill to +7 mCD but without PVD; 2: calculated settlement under a fill to +7mCD with PVD; 3: calculated settlement when 2 m of dry sand are added with PVD). The geotechnical parameters used in the model for the calculations of the settlement are the same as presented in Table I, except for the preconsolidation pressure which is 10kPa, coming from the back-analysis results explained above. As can be seen in Figure 11b, the settlements recorded on site and settlements calculated with this model are

<table>
<thead>
<tr>
<th>Soil type</th>
<th>$\gamma_{sat}$ [kN/m$^3$]</th>
<th>$\sigma'_p$ [kPa]</th>
<th>$C_v$ [-]</th>
<th>$C_s$ [-]</th>
<th>$C_w$ [m$^2$/y]</th>
<th>$C_h$ [m$^2$/y]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1 very soft</td>
<td>17.5</td>
<td>0</td>
<td>0.25</td>
<td>0.05</td>
<td>0.004</td>
<td>6.1</td>
</tr>
<tr>
<td>Layer 2 very soft to soft</td>
<td>16.0</td>
<td>0</td>
<td>0.44</td>
<td>0.09</td>
<td>0.018</td>
<td>1.2</td>
</tr>
<tr>
<td>Layer 3 stiff to very stiff</td>
<td>18.6</td>
<td>0</td>
<td>0.10</td>
<td>0.02</td>
<td>0.003</td>
<td>2</td>
</tr>
<tr>
<td>Layer 4 medium stiff</td>
<td>17.4</td>
<td>0</td>
<td>0.18</td>
<td>0.04</td>
<td>0.007</td>
<td>3.3</td>
</tr>
<tr>
<td>Layer 5 dense to very dense</td>
<td>20.0</td>
<td>0</td>
<td>0.04</td>
<td>0.01</td>
<td>0.00</td>
<td>&gt;&gt;</td>
</tr>
</tbody>
</table>
close. For example, 2 months after the installation of the embankment, the settlement recorded was 0.935 m and the settlement calculated was 0.926 m. The settlements recorded on site under a constant load (after installation of the embankment) were also analysed by the Asaoka method to define the final settlement. The result is a final settlement of 1.16 m. The final settlement coming from the model is 1.20 m. This trial embankment can prove that this model is quite accurate under different loads.

POST SOIL INVESTIGATION

Once the consolidation criteria have been reached, a post-soil investigation was realised in order to compare the evolution of geotechnical parameters before and after the consolidation process (Figure 12). Two deep boreholes were drilled close to the location of pre-soil investigation boreholes. Similar laboratory tests were performed. The results show a decrease in the moisture content and a significant increase in the shear strength especially in the 2 first layers which are softer. SPT values also slightly increase in the soft layers. It seems that most of the consolidation takes place in the two first layers (0-14m). At higher depths the difference of moisture content and shear strength values tends to diminish.

CONCLUSIONS

At Dinh Vu an area of 40 ha has been consolidated using PVDs (Prefabricated Vertical Drains) and surcharge preloading. Before land reclamation, a model was realised using data coming from the geotechnical survey in order to determine the design of the PVDs (spacing and depth). Settlements recorded on site have been analysed using the Asaoka method and compared to the settlement model. Settlement behaviour and magnitude of settlement calculated matched the recorded settlement rather well and the trial embankment proves that the model is accurate. The post soil investigation realised after consolidation highlights the improvement of geotechnical parameters and that it especially takes place in the two first layers. The subsoil consolidation performed at Dinh Vu Industrial Zone has reached the contractual specifications and the project was successfully completed on schedule.
### REFERENCES


---

**Figure 12.** Soil parameters before and after subsoil consolidation.