Case Study

# PERFORMANCE OF PVD & PRE-LOADING IN SOFT CLAY CONSOLIDATION USING TRIAL EMBANKMENTS

## INTRODUCTION

The subsoil conditions at a major project site consisted of more than 20m thick deposits of soft clay underlying medium dense silty sand stratum. To reduce cost of foundations for the project, the possibility of constructing shallow foundations for structures where foundation loading did not exceed 7T/sq.m was considered. Safe bearing capacity of the underlying soft clay stratum was low and excessive foundation settlement could be expected under the expected foundation loading. The feasibility for improving the bearing capacity as well as to reduce the post construction settlement in soft clay, several methods to improve the soft clay were considered. It was finally decided that the most cost-effective method for achieving this would be by accelerating the clay consolidation with prefabricated vertical drains (PVD) and pre-loading. In order to confirm this proposal, trial embankments were constructed at three locations adopting three different PVD spacing and pre-loading.

## SUBSOIL CONDITION

Soil investigation at the site confirmed the average subsoil profile as follows. Medium dense silty sand existed from ground level to a depth of 6-7 m which is underlain by soft compressible silty clay up to approx 20m below GL. Below the soft clay layer existed stiff clay to considerable depth. The soft silty clay was normally consolidated with low shear strength and was highly compressible, CH soil.

## TRIAL EMBANKMENTS

Three separate trial embankments were constructed for the trial- Area-1 size 50x50m, PVD spacing 1.5m c/c triangular, Area-2 size 50x50m, PVD spacing 2.5m c/c triangular and Area-3 size 50mx10m PVD spacing 1.25m c/c triangular. PVD penetration in all cases was 20m.

Geotechnical instruments installed included platform settlement gauges and Casagrande Piezometers at the centre of embankment as well as at different spacing from the center. Instrument observations were continued for a period of approx.10 months.

PVD was installed using a hydraulic drain stitcher using a steel mandrel and a disposable drain shoe. The maximum depth of band drain installation was 20m below GL. The upper silty sand layer overlying the soft clay stratum was medium dense and the drain stitcher had difficulty penetrating this hard layer. Pre-drilling was required through the hard upper layer prior to PVD installation by the drain stitcher.

All three test areas were pre-loaded with earth up to height 4m above GL with side slope 1V:2H. Area-02 & 03 were preloaded within a period of one month. However, Area-01 preloading took a much longer period of more than three months due to delay in procuring soil for construction.

## SETTLEMENT OBSERVATIONS

Even though settlement observations were made at several locations only that at the center of the pre-loaded areas after full preload placement have been included here. Observed settlement is included in Fig- 1.

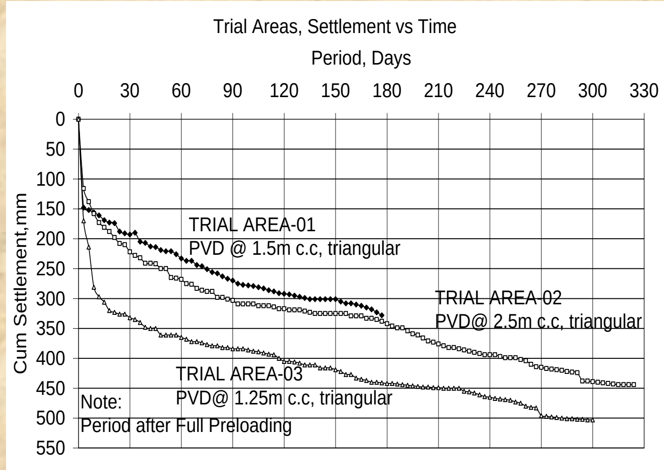


**Fig.1** Settlement Observations

Consolidation settlement was rapid initially but the rate of settlement reduced considerably afterwards for larger PVD spacing as expected. It is clear from the above, that much longer periods are required to achieve the required degree of consolidation as the PVD spacing increases.

Settlement at Area-01 was slower initially compared with that for Area-02 even though the preload area and height were similar. The reason for this could be much longer preloading period for Area-01.

**PIEZOMETER OBSERVATIONS**

Piezometers were installed at two different depths- mid depth and about 2m below clay surface for all three trial areas and they showed peak excess pore pressures soon after full preload was placed. Dissipation of pore pressure took place gradually during the period of observation. The observations are included in Fig- 2.

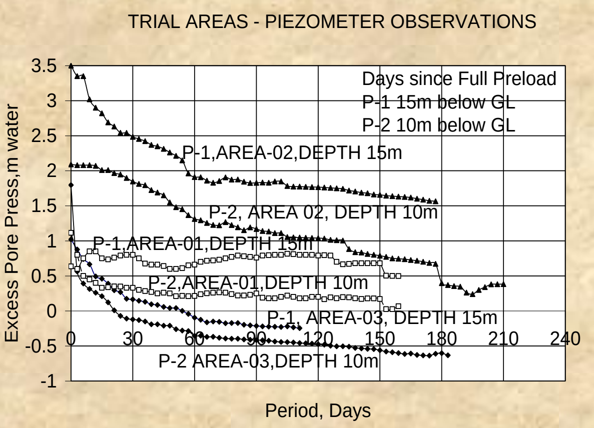


**Fig.2** Piezometer Observations

It may be noted that maximum excess pore pressure registered was only about 50% of applied pre-load at the centre of the clay layer. When large areas are pre-loaded, this could be higher. The stress distribution in clay may also have been influenced to some extent by the thick medium dense sand layer overlying the clay layer.

**DEGREE OF CONSOLIDATION**

In order to determine the degree of consolidation achieved within each trial area, it is necessary to determine the total expected primary consolidation settlement under the applied pre-load (U= 100%). The graphical procedure proposed by Asaoka (1978) was adopted for determining the total primary consolidation settlement from observed settlement. This procedure had been adopted successfully for several ground improvement projects earlier. Based on this, the degree of consolidation achieved at the centre of the pre-load area for the three trial locations were computed and results are shown in Fig-3. Please note that the period to achieve the degree of consolidation shown is the period after the full pre-load placement.

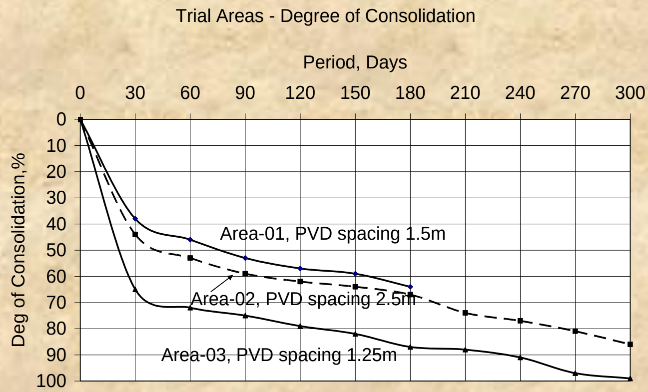


**Fig.3** Degree of Consolidation

For Area-01 with PVD spacing 1.5m, the period of observation was not sufficient to achieve U=90%. However from the trend of observed settlement, this could take longer than 12 months after preloading. For Area -02 with PVD spacing 2.5m also U=90% was not achieved within the observation period. By extrapolation it may also be expected to take much more than 12 months after preloading. For Area-03 with PVD spacing 1.25m, U=90% had taken place 240 days or about 8 months after pre-loading. It was therefore clear that given the low clay permeability at the site, if the consolidation period is to be shortened, it is necessary to reduce the PVD spacing or increase the pre-load or both

**SOIL INVESTIGATION & TESTS**

Confirmatory soil investigation included boreholes, soil sampling and in-situ tests at the centre of the three trial areas up to a depth of 20m below GL after the clay consolidation. Laboratory tests for shear strength and consolidation parameters were determined on undisturbed clay samples collected from the boreholes

In-situ vane shear tests were conducted after ground improvement to determine un-drained shear strength of the soft clay. Laboratory unconfined compression tests on undisturbed samples of clay were also carried out to confirm the results. The results have been presented in Fig. 4. For comparison, initial average profile of un-drained cohesion with depth has been included.

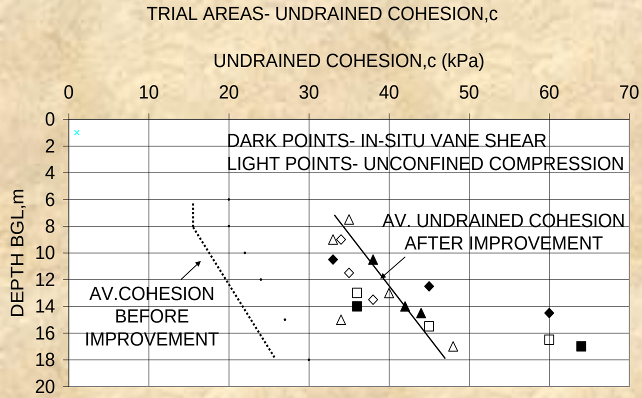


**Fig.4** Un-drained Cohesion

Un-drained clay cohesion after consolidation varies from 35 to 60 kPa for the soft clay layer up to depth 18m as may be seen from Fig. 4. The average cohesion may be considered as about 40kPa. The average soft clay cohesion before ground improvement had been established as not more than c= 20 kPa. Considering this initial cohesion, it may be concluded that the increase in un-drained cohesion after ground improvement expressed as a percentage of the applied preload, $\Delta c/\Delta p$ varied from 25%-30%.

## BEARING CAPACITY

The safe bearing capacity for shallow foundation may be considered based on the following.

- The shear strength of the soft clay layer should be adequate to support the imposed foundation load without failure.
- The long term and uneven settlement should not exceed recommended values for the proposed structures.

Considering the minimum post consolidation un-drained cohesion c=35kPa, the allowable safe bearing capacity for shallow foundations on clay may be considered as 8T/sq.m. However maximum foundation load intensity may be limited to 7T/sq.m to reduce post construction settlement.

If requirement of degree of consolidation U=90% is achieved under the imposed foundation load, expected future settlement should not exceed 10% of the total primary consolidation settlement expected. In this case, the post consolidation settlement may not exceed 50-60mm under the foundation load considering a total expected settlement of 510mm under the applied pre-load.

## CONCLUSIONS

Trial ground improvement reported using PVD and preloading has achieved the requirements set out for the project in terms of post construction settlement and safe bearing capacity. The trial ground improvement established the basis for selecting optimum PVD spacing and preloading to be adopted to achieve the required degree of consolidation as well as the period required to achieve it.

The increase in un-drained cohesion of soft clay after ground improvement expressed as percentage of pre-load intensity ($\Delta c/ \Delta p$) was found to vary from 25% - 30% for this site.
(Work was carried out under Bharat Geosystems Pvt Ltd)

*Reference: Radhakrishnan R (2011), 'Performance of Pre-fabricated V. Drains & Pre-loading for a Major construction Project', Proc. IGC, Kochi, Dec 2011.*

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