

# **Investigating Performance of Soil Improvement Project using Preloading Method by Back-Analysis Results Based on Numerical Simulation and Instrumentation Data-A Case Study**

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## **Extended Abstract**

(Paper pages 247-276)

### **Introduction**

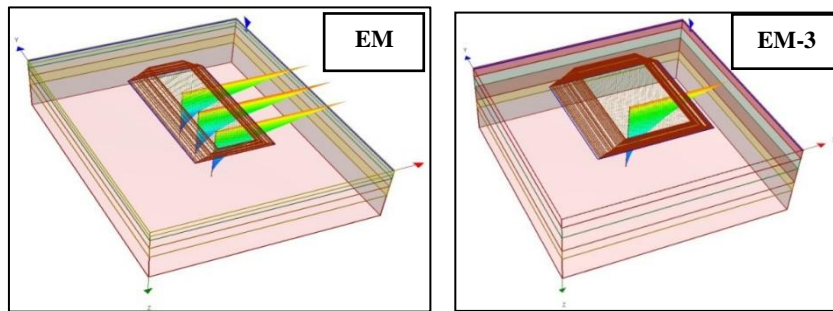
Construction of highways and high weight structures on compressible soft soils requires planning and sufficient knowledge of geotechnical conditions of the site. Before construction of the desired structure on this type of soils, it is unavoidable to improve and modify these soils to prevent large unpredictable settlements resulting in damages to the structure. "Preloading" is a method widely used in soil improvement that dates back to 1930s and earlier. It is a simple and economic method of increasing the strength parameters of saturated fine-grained soft soils. Easy implementation, monitoring and measuring the settlement of ground using instrumentation and checking the behavior of this method during the procedure are among the advantages of this method. Preloading approach can be applied using radial drainage to enhance consolidation settlement rate, and without radial drainage by either embankment or vacuum. In general, soft clayey soils require a long time for settlement consolidation due to their low permeability. To increase the consolidation rate in these soils, radial drains are installed beneath the soil. These drains cause artificial drainage paths under clay soils that increase the rate of consolidation process by curtailing the drainage path, which in turn will rapidly increase the strength of soil, increasing the capacity of bearing new load on soil.

In this regard, in order to improve subsurface soft saturated clayey layers under the oil storage tanks in Mahshahr project, the preloading method by embankment along with prefabricated vertical drains (PVDs) with a triangular pattern has been used, which has been assessed in this paper as a case study. Considering the different layers of soil and subsurface conditions in project site of Mahshahr oil depot and compressible layers located in relatively large depths, the improvement extent has been high to modify soil characteristics in order to avoid soil settlement and failure due to application of high loads from tanks. Inaccuracy of embankment settlement estimates and the prolonged preloading operations are among the challenges of soil improvement using preloading. Therefore, the proper selection of soil parameters including effective parameters in consolidation settlement values ( $C_s$ ,  $C_c$  and  $P_c$ ) and soil consolidation time ( $K_h$  and  $K_v$ ) can address preloading as a viable and practical option for soil improvement.

In this paper, back-analysis results of instrumentation data have been compared using Settle 3D software, and the initial effective geotechnical parameters obtained from laboratory and field experiments have been modified using this method. Using the modified results of this study can lead us to successfully evaluate and control the design of the mentioned project.

### **Material and Methods**

In order to perform numerical modeling, the Settle 3D software based on Finite Difference Method has been used. This software was used to examine consolidation settlement according to consolidation theory formulations. For three-dimensional modeling of embankments, dimensions of both sides of the embankment must be set so that the actual ground conditions are considered with the least impact on general behavior of the model. The embankment heights of EM-2B and EM-3 are 14.6m and 13.9m, respectively. In order to determine the boundary conditions, three times the base of embankment is considered from both sides of the model, and for the height of geotechnical region influenced by creation of embankment, which has been modeled in the program, a height equivalent to 5 times the height of embankment has been considered based on boreholes data. The Figure 1 shows numerical modeling of EM-2B and EM-3 embankments in the Settle 3D.



**Figure 1. Three-dimensional modeling using Settle 3D Software**

In this software, degree of consolidation can be changed by placing drains in soil. In EM-2B and EM-3 embankments, in accordance with preloading operations of Mahshahr oil depot project, the length of drain was set at 25 and 22m, respectively, and drain spacing in each embankment was 1.5m with triangular configuration.

Hence, after numerical studies and back-analysis, the value of  $C_f$  (permeability ratio of site to laboratory) reaches 9 in Settle 3D software. In addition, ( $C_c$ ) and ( $P_c$ ) are modified with 0.14 and 190 kPa values in the software, respectively. Finally, the modified soil parameters are presented in Tables 1 and 2 for EM-3 and EM-2B, respectively.

**Table 1. Back-analysis results of consolidation parameters of EM-3**

|   | $K_h$<br>(ML)<br>(m/day) | $K_v$<br>(ML)<br>(m/day) | $K_h$<br>(CL-2)<br>(m/day) | $K_v$<br>(CL-2)<br>(m/day) | $C_f$<br>(ML) | $C_f$<br>(CL-2) | $C_c$<br>(ML) | $C_c$<br>(CL-1) |
|---|--------------------------|--------------------------|----------------------------|----------------------------|---------------|-----------------|---------------|-----------------|
| Settle 3D (After Preloading)                  | 0.146                    | 0.073                    | 0.036                      | 0.018                      | 17            | 21              | 0.16          | 0.08            |
| Initial Design Parameters (Before Preloading) | 0.00864                  | 0.00432                  | 0.00172                    | 0.00086                    | .....         | .....           | 0.17          | 0.17            |

**Table 2. Back-analysis results of consolidation parameters of EM-2B**

|   | $K_h$ (CL-2)<br>(m/day) | $K_v$ (CL-2)<br>(m/day) | $C_f$ (CL-2) | $C_c$ (CL-1) | $P_c$ (CL-1)<br>(kPa) |
|---|-------------------------|-------------------------|--------------|--------------|-----------------------|
| Settle 3D (After Preloading)                  | 0.0234                  | 0.0117                  | 9            | 0.14         | 190                   |
| Initial Design Parameters (Before Preloading) | 0.0026                  | 0.0013                  | .....        | 0.17         | 180                   |

According to the initial designs, for example, recorded value of settlement in the center of EM-2B settlement is approximately 122.2cm, while the settlement calculated in the center of EM-2B embankment has been 132cm. Therefore, initial values of calculated settlement based on assumed parameters was higher than the measured values of settlement. Lower values of measured settlements relative to calculated settlements can be attributed to conservative determination of geotechnical parameters and settlement equations based on one-dimensional theory of Terzaghi. Besides, parametric studies have been performed on the spacing and depth of vertical drains. Lastly, soil settlement induced by oil tanks has been compared before and after preloading based on modified soil parameters.

### **Conclusion**

In this paper, the numerical modeling of soil consolidation has been discussed using pre-loading method with radial drainages in Mahshahr oil depot as a case study. In this regard, back-analysis using instrumentation results was conducted by Settle 3D software based on finite difference method, and the results were compared with each other. The basic geotechnical parameters obtained by laboratory and field experiments have been modified using mention method. The results obtained from the analysis indicate that settlement values from the instruments data were less than those back-analysis results. Indeed, the effective laboratory parameters intended for primary calculations of consolidation settlement values of the soil ( $C_c$  and  $P_c$ ) were more and less than the actual measured values, respectively, and the effective laboratory parameters intended for time of soil consolidation calculations ( $K_h$  and  $K_v$ ) were lower than the actual measured values. Also, parametric studies have been conducted on the spacing and depth of vertical drains. Finally, soil settlement induced by oil tanks was compared before and after preloading, and it was found that using this method for soil improvement can be very efficient in large-scale projects.

**Keywords:** Preloading Method, Prefabricated Vertical Drain, Consolidation Settlement, Numerical Modeling

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