COASTAL SOFT CLAY IMPROVEMENTS USING PRELOADING A CASE STUDY

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ABSTRACT: In most coastal area of Iran, there are very soft grounds. One of these regions is the southern part of Khouzestan Province, especially Emam-Khomeini Port and its suburbs, that the soil is soft silty clay. Foundation problems in this type of soils are high settlement and low bearing capacity. Due to large industrial development, a number of important structures should be constructed in the area and improvement of soil is therefore unavoidable unless deep foundations to be used.

This paper presents experiences of soil improvement using preloading and vertical drain in Emam-Khomeini Port. At first, it describes the fundamental theories used for the design of preloading with geosyntetic vertical drain. Then the method of construction, the important notes of operation and technical experiences are described. The instrumentation and obtained results will be also mentioned.

After preloading, a number of field tests were undertaken to control the effectiveness of preloading. The quality control tests, their selection and the comparison of results, will be also presented in the paper.

1. INTRODUCTION

Different methods are applicable encountering compressible and soft soils. The objective is soil improvement in some methods and making extra bearing elements in the others. Important methods of first group are grouting and preloading while in the latter group, the use of pile (deep foundation) and stone column methods could be mentioned.

The best option depends on the required improved area, effectiveness, costs, and time schedule. Soil improvement methods should be selected. According to sufficient recognition of sub-surface condition. In addition, the type of structure and allowable settlement, available equipments and material, access, accuracy of predictions, and costs should be considered as well.

"Preloading" is temporary loading to improve sub-surface soils and the most conventional method is embankment stockpiling.

Water level lowering is another common method for preloading. In this method, Water level reduction for one meter will impose a loading equivalent approximately to half a meter embankment loading. Embankment stockpiling and groundwater lowering method could be used at the same time.

The following points should be considered for a successful preloading:

-Execution of preloading should be considered in time schedule for entire project.

-Preloading should not cause any undesirable effects such as dust, noise, etc. to nearby area.

- Settlements after construction should be in a acceptable range.

-Actual cost should be according to estimation and should not exceed from costs of other methods.

Emam-Khomeini Port is located in Khouzestan Province in southern coast of Iran. This port has particular importance from petrochemical industries point of view. Construction of utility plant tanks is one of these projects located in area called Fajr Petrochemical Region.

Soil of the above mentioned area consists of soft-saturated clay to depth of 18 meter and is classified as CL type in Unified Soil Classification System. Mean values of SPT number, value of undrained cohesion (Cu), soil moisture (ω%), liquid limit (LL), plasticity index (PI), and void ratio (e_o) in different depths are presented in Table (1).

Table 1 – Soil specification in project site before preloading

Depth	Mean SPT	e_o	ω %	C_u (t/m^2)	LL	PI
0-1.5 (m)	5	-	-	3.8	35	23
1.5-5 (m)	2	0.957	31 %	1.3	-	-
5-10 (m)	1	0.929	33 %	0.6	36	13
10-18 (m)	3	0.889	32 %	1.9	30	6

Considering desirable condition of project site from compatibility point of view with items mentioned above, preloading method with geosyntetic drains, which is for facilitating clay layer consolidation, was used at three tanks positions with 70-meter diameter.

2. THEORETICAL AND CALCULATION IMPORTANT ASPECTS

The design of preloading with vertical drains should be performed according to imposed load in future and allowable settlement.

Calculation of height for embankment will be performed on two bases: soil shear strength and settlement value control. To determine the ultimate bearing capacity of existing soil, the Equation (1) are used at first stage.

$$q_u = ½\gamma B N_\gamma + C N_c + \gamma D N_q \qquad (1)$$

where N_γ, N_c ane N_q are bearing capacity factors. Width (B) and depth (D) of foundation and undrained shear strergth of clay (C) are other parameters.

Then it will be compared with required ultimate bearing capacity for soil (considering proper safety factor) and the difference between them are calculated.

$$\Delta q_u = q_{u,\,req.} - q_{u,\,exist} \qquad (2)$$

This additional bearing value should be provided by imposing pressure on soil that consequently soil undrained cohesion value will increase (ΔC_u).

In soft clay soils, the lower limit increment of soil shearing resistance caused by effective stress increment has been presented in the equation (3). (Jewell, R.A., 1996)

$$\Delta C_u = 0.22\ \Delta\sigma'_v \qquad (3)$$

Where $\Delta\sigma'_v$ = effective stress increment.

Therefore, if pressure equal to ΔP is imposed to soft clay soil, its undrained cohesion value will be increased equal to 0.22 ΔP after soil consolidation. As a result, if γ is specific weight of embankment, its required height will be obtained from the following equation:

$$h = \frac{\Delta P}{\gamma} \qquad (4)$$

Soil allowable settlement value, as mentioned above, should be controlled in determination of embankment height and this condition is usually controlling criteria.The value of soil consolidation settlement according to Terzaghi theory will be obtained from the equation (5):

$$S = \frac{C_c}{1+e_o} H \log\left(\frac{\sigma'_o + \Delta\sigma'}{\sigma'_o}\right) \qquad (5)$$

So the value of settlement will be obtained for pressure equal to Δσ’ after 100% consolidation. Now if the value of Δσ’ is greater than pressure imposed to soil in future, we can get the same settlement value in shorter period.

For this purpose consolidation degree (U) will be and the value of required surcharge will be calculated according to equation (6):

$$\log\left(\frac{\sigma'_o + \Delta\sigma'_s}{\sigma'_o}\right) = U \log\left(\frac{\sigma'_o + \Delta\sigma'_p}{\sigma'_o}\right) \qquad (6)$$

Where $\Delta\sigma_s'$ = The value of imposed sucharge to soil in future; U = Consolidation degree and $\Delta\sigma_p'$

= The value of imposed sucharge to soil during preloading operation.

The relation of waiting period and consolidation degree, considering the application of triangular pattern of wick drains, could be calculated by Kjellman formula (Kjellman, 1984):

$$t = \frac{D^2\alpha}{8C_h}.Ln\frac{1}{1-U} \quad (7)$$

$$\alpha = \frac{n}{n^2-1}\left[Ln(n) - \frac{3}{4} + \frac{1}{n^2}(1-\frac{1}{4n^2})\right] \quad (8)$$

$$n = \frac{D}{d} \quad (9)$$

$$D = S\sqrt{\frac{2\sqrt{3}}{\pi}} = 1.05S \quad (10)$$

$$d = \frac{b}{2} \quad (11)$$

Where t = consolidation period; S = spacing of the drains; b = width of wick drains; C_h = horizontal consolidation coefficient and d = equivalent diameter of sandy drain.

According to performed calculus in this project for a 5 month-waiting period, 9-meter required height for embankment and wick type drains in triangular grid with 10 cm width and 1.35 m spacing were designed and installed to 20 m depth.

It is to be mentioned that sucharge caused by embankment is approximately equal to pressure imposed on soil caused by a tank in future and calculated settlement value is equal to 115cm.

Obviously in addition to accurate design, proper execution of preloading method is highly essential to obtain acceptable result. In this regard, the following items are very important:

1. Before stockpilling of embankment material, the area should be deplanted from surface plants and covered with a layer of drain materials with proper grading.
2. Regarding the shear strength of lower soft layers, the speed of execution of embankment should be in such away that failures do not occur.
3. Specific weight of embankment layers should be determined during execution to check design value.
4. Outflow water from drains during consolidation and preloading operation should be transferred to far distance not to create any problems in consolidation operation.
5. To examine the sufficiency of overcharge volume and its waiting period, some geotechnical tests after and before removing embankment should be performed.

3. MONITORING AND INSTRUMENTATION

The monitoring of settlement, pore water pressure, and consolidation progress during preloading operation are highly important. If this task is done accurately and permanently, the accuracy of calculation and predictions could be examined in order to ensure that desired criteria would be obtained.

In this project, 3 to 5 settlement plates were used in each tank to register settlement variations. Settlement plate consists of steel base plate and a vertical bar on it that base plate will be located on the surface of ground horizontally after removing surface soil. Removed soil will be replaced with fine sand that is compacted suitably. Therefore, the rate of soil settlement will be simply measurable.

Some piezometers were used in each tank to measure pore water pressure variation and consequently determining progress of consolidation percentage rate.

Moreover, outflow water from tanks has been measured periodically. Results of these measurements are shown in Figs. 1 to 3.

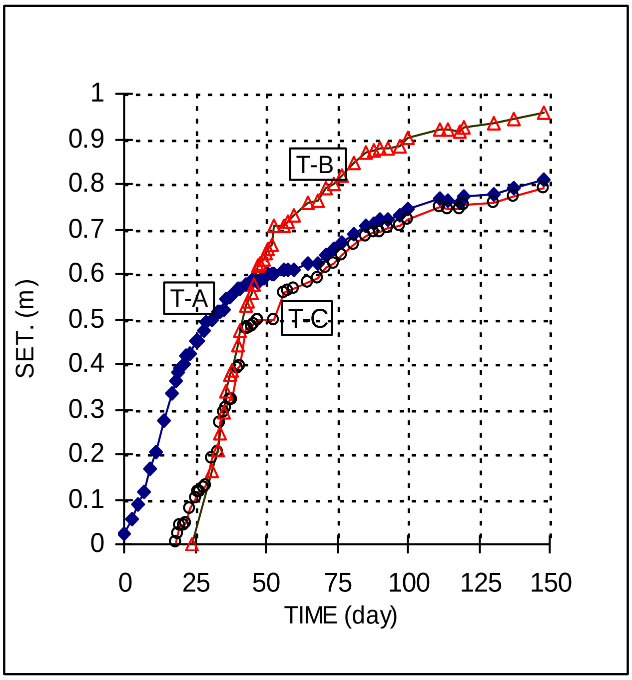

Figure 1. Variation curve of maximum settlement for tanks per time

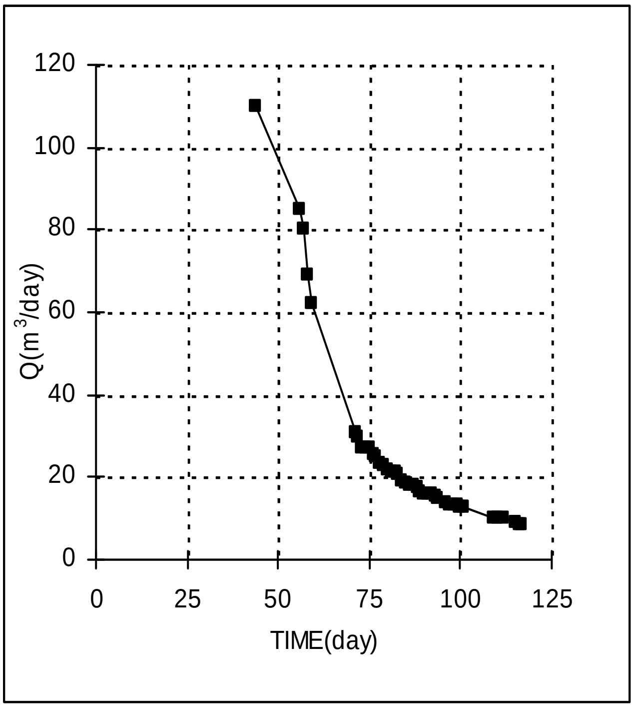

Figure 2. Variation curve of outflow water from tanks per time

Regarding monitoring results, it is specified that the percentage of consolidation progress in soil is nearly 100% after 5 months. Since sucharge from embankment was equivalent to imposed pressure to soil in future due to tanks, permission for removing embankment was issued.

It is to be mentioned when deciding for number of required tools for monitoring, some additional instrumentation should be regarded in the case of damage during operation. (20% is recommended)

4. GEOTECHNICAL EXAMINATION AFTER PRELOADING TERMINATION

The best suitable method for determination of preloading effectiveness on soil parameters is geotechnical investigations after preloding.

It is to be mentioned that probing can be use to reduce borehole operation costs.

After embankment removal and surface grading, five boreholes to 20-m depth were drilled at site of each tank that laboratory and field tests results are shown in Tables 2 to 4 (Field tests consisted of SPT and Vane Shear test and laboratory tests consisted of Identification, Consolidation, and UU Triaxial tests).

Table 2 – Soil specification in tank A after preloading

Depth	Mean SPT	e_o	ω %	C_u (t/m^2)	LL	PI
0-1.5 (m)	13	0.57	23	8	36	17
1.5-5 (m)	5	-	-	3.5	42	16
5-10 (m)	4	-	-	2.5	30	11
10-18 (m)	6	-	-	3.8	30	12

Table 3 – Soil specification in tank B after preloading

Depth	Mean SPT	e_o	ω%	C_u (t/m^2)
0-1.5 (m)	15	-	-	9.5
1.5-5 (m)	5	0.765	30	3.4
5-10 (m)	4	0.903	33	2.7
10-18 (m)	7	0.758	27	4.0

Table 4 – Soil specification in tank C after preloading

Depth	Mean SPT	e_o	ω %	C_u (t/m^2)	LL	PI
0-1.5 (m)	17	-	-	10.8	21	17
1.5-5 (m)	4	0.650	26	4.4	42	16
5-10 (m)	3	0.70	25	2.8	34	16
10-18 (m)	4	0.715	27	3.4	29	11

As it is observed, the strength of the first layer has increased to 3 times and it has changed into a hard layer, but preloading has had less effect on the next layers and its effect has reduced with increment of depth. The most important reason for it is the effect of improved surface layer in

stress distribution in such a way that, load distribution angle has reduced greatly.
Being smaller the value of measured maximum settlement during monitoring in comparison with calculated settlement on the other hand confirms this point.

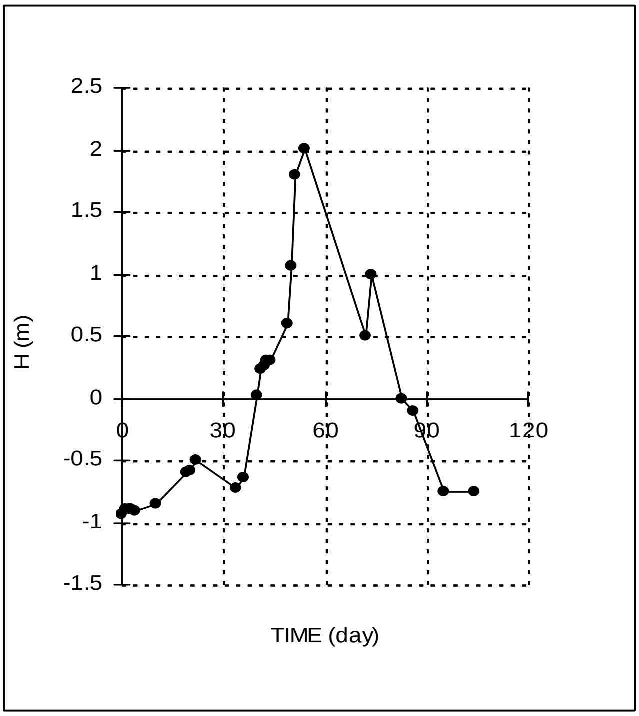

Figure 3. Variation curve of water level lowering in one piezometer per time

5. CONCLUSIONS

Preloading method is suitable method for soil improvement in projects that their object is not deep layers improvement. In other words, as the creation of an upper hard layer is the result of this method, it will cause that the form of stress distribution changes in such a way that stress increment due to embankment, is reduced in lower layers and consequently the characteristics of lower layers will not be improved noticeably. Therefore, other methods such as chemical grouting should be applied in projects where the object is soft soil improvement in depth. Moreover, in order to calculate and design preloading method, the effect of upper hard 1 to 2 m thick layer in the form of stress distribution during soil consolidation/waiting period should be regarded and settlement estimation as well.

6. AKNOWLEDGEMENT

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