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Controlling the Stability of a Foundation Through Neutral Pressure Measurements

Contrôle de la stabilité d'une fondation par la mesure des sur-pressions hydrostatiques

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Summary

In the construction of large oil tanks at Santos, Brazil, several types of foundation have been used. In this article the foundation conditions of one of these tanks, recently constructed at the site, are examined and the process of controlling the stability during the loading through the measurements of neutral pressures in the soft foundation soils is described.

Sommaire

Au cours de la construction de grands réservoirs à huile lourde à Santos (Brésil), différents types de fondations ont été employés. L'auteur examine dans cet article les conditions de construction de l'un de ces réservoirs et décrit le procédé adopté pour contrôler la stabilité au cours de l'épreuve de charge par la mesure des pressions neutres dans les sols tendus des fondations.

Subsoil Conditions

The subsoil conditions at the site are given in Fig. 1. The fine sand, which is slightly clayey, is not compressible as compared to the clay immediately below. This clay has liquid limits that range from 42% to 110% with an average of 65%. Plastic limits range from 25% to 45% with an average of 30%.

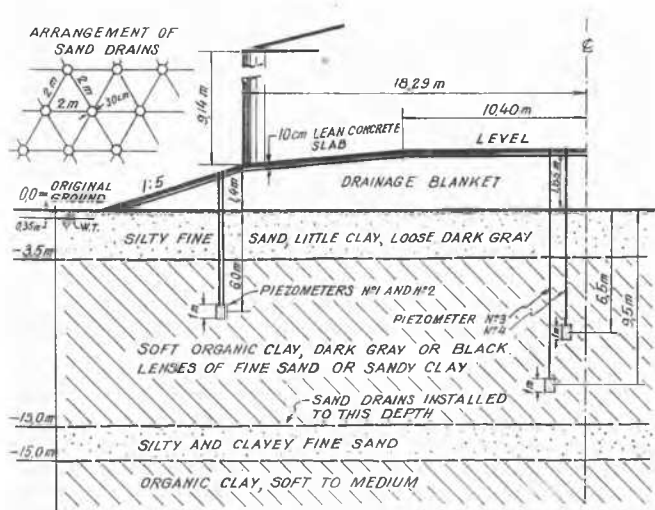


Fig. 1 Dimensions of tank and subsoil conditions
Dimensions du réservoir et conditions du sous-sol

(Results from boring in Fig. 2.) Its unconfined compressive strength determined by tests on 43 mm \varnothing Shelby tube samples has values that are plotted in Fig. 2 in which natural water contents are also seen. Consolidation tests made on this clay in 10 cm \varnothing specimens from the depth of 8 m showed compression indices of the order of 1.50 and preconsolidation pressures of 1.1 kg/cm² at a void ratio of 2.3.

Dimensions of Tank and Sand Drains

The tank is 36.58 m in diameter and 9.14 m high at the edge. Sand drains were installed to the depth of 13 meters from the original ground surface, reaching a sand layer that is seen in Fig. 1. The diameter of the drains was 30 cm. For their installation open-end steel pipes were driven into the soil to the proposed depth. After having their inside cleaned by water-jetting they were withdrawn at the same time as the hole was being filled with clean sand, by means of a bucket at the upper end. The spacing of the drains was 2 m centres, on a triangular net.

A drainage blanket connected the tops of the drains. The thickness of the blanket was 1.85 m at the center and 1.40 m at the edge. The tank rests on a 10 cm thick lean-concrete slab constructed on top of the drainage blanket. The bottom plate of the tank therefore slopes down from the center to the edges; this was done because of anticipated differential settlement.

Piezometers Installed

Piezometers for the measurement of neutral pressures in the soft soil were installed in the following manner: a 15 cm Ø steel pipe was driven into the soil, open-end, at the same time as it was cleaned. When reaching a convenient depth a drain cylinder connected to a rubber hose was lowered into the hole. This drain consisted of a cylindrical bag of very porous fabric filled with clean coarse sand; the rubber hose was embedded

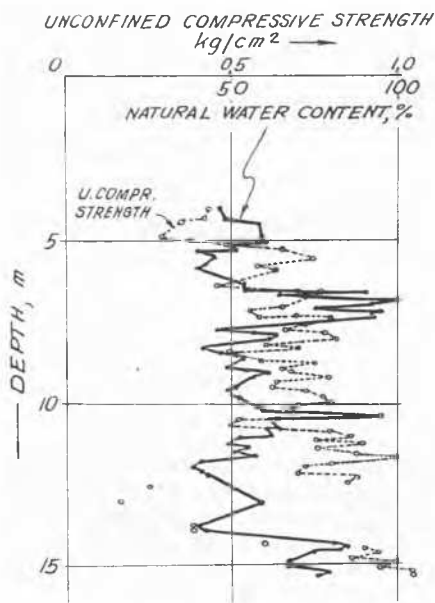


Fig. 2 Variation of unconfined compressive strength and water content with depth
Variation de la résistance à la compression non confinée et teneur d'eau selon la profondeur

in the sand, the embedded end having lateral holes for a length of 40 cm. The length of the bag was 1 m and its diameter was only about 1 cm smaller than the inside diameter of the pipes. This was to cause the least disturbance of the clay when closing in around the sand bag, after withdrawal of the lining. The spacing around the hose between the top of the drain and the ground surface was packed with clay. The inside diameter of the rubber hose was 12 mm. The comparative large water intake area of the cylinder and the small volume necessary to establish the piezometric equilibrium in the hose, due to its small diameter, makes this piezometer of very quick response to neutral pressures. Before the ground was loaded the zero piezometric level was determined by filling the hose with water to a certain level and observing the drop. A semi-log plot of this drop in function of time is of the shape of a consolidation time curve, showing an asymptotical level of equilibrium (practically obtained in about 24 hours) that is taken as the zero-piezometric level.

Criterion of Stability Taking into Account the Neutral Pressures

Consider a point in the interior of the soil in its natural state: all pressures are effective, that is the vertical stress σ_1 , and the horizontal one $\sigma_3 = K\sigma_1$ (Fig. 3a). A value of K of 0.7 was taken for this soil. When an increment $\Delta\sigma_1$ is applied the situation of total pressures is as in Fig. 3b. The neutral

pressure at the instant of the application is $\Delta\sigma_1$. So the situation of effective pressures, immediately after the application, is as in Fig. 3c.

Drawing a Mohr's diagram for effective stresses (Fig. 3d) we would have circle (I) as the initial state, circle (II) at the instant of the application of the increment and circle (III) final state after complete consolidation of soil under new conditions of stresses ($\sigma_1' = \sigma_1 + \Delta\sigma_1$ and $\sigma_3' = K\sigma_1'$) (K supposed constant).

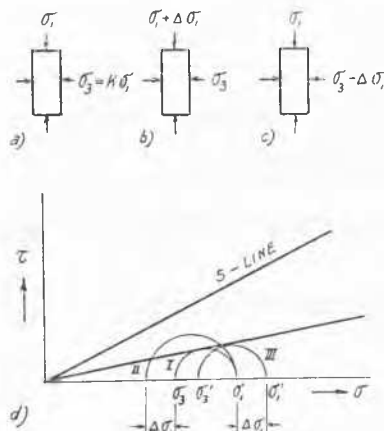


Fig. 3 Triaxial loading of a soil specimen
Chargement tri-axial d'un échantillon de sol

If the increment of pressure $\Delta\sigma_1$ is such that circle II becomes tangent to the line S (line S being Mohr's envelope of slow tests), we will have a condition of rupture at the instant of the application. That gives us a criterion for examining the conditions of stability of a soft foundation soil when neutral pressures are known.

Load Testing of the Tank

Using this criterion a plan for the load testing of the tank was prepared.

A neutral pressure equal to 0.6 the maximum was admitted to be quite safe.¹⁾ Complete consolidation of the soil under

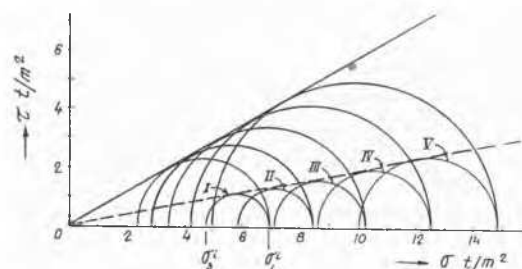


Fig. 4 Mohr's diagrams for the various stages of loading of the tank
Diagrammes de Mohr pour les différentes étapes de chargement du réservoir

¹⁾ In fact, perhaps higher neutral pressures could be admitted because piezometers were all located at the most unfavourable points from the standpoint of drainage, that is at the center of equilateral triangles formed by three sand drains. The average neutral pressures are therefore much smaller than shown by piezometers. Another reason is that local zones of failure may exist without general failure of the soil mass under the structure.

the weight of the drainage blanket had taken place, and neutral pressures were practically zero at the start of the filling. Conditions of equilibrium for a point at the vertical of the centre of the tank and at the depth of 8 m below original ground surface are presented here and shown in Fig. 4. In this figure circle (I) represents the state of this point just before filling of tank (σ_1^i = pressure due to buoyant weight of overlying soil plus 0.88 of pressure at the base of drainage blanket; $\sigma_3^i = 0.7 \sigma_1^i$). Circles II to V represent the several final stages of consolidation corresponding to the several stages of filling. An angle of internal friction (the influence of pre-consolidation was disregarded) of 30° was assumed and the following table was prepared.

Table 1 Basis for the Loading Programme

Effective vertical stresses t/m^2	Neutral pressures m of water		Increment of height of water in tank corresp. to allowable neutr. pressure ¹ -m-	Total height of water in tank -m-
	Rupture	Allowable		
6,89	8,39	2,50	1,50	1,77
8,39	10,22	3,05	1,83	3,92
10,22	12,47	3,75	2,25	6,57
12,47	14,82	5,05	3,03	9,14

¹) Due to pressure spreading numbers in 4th column = numbers in 5th column $\times 0,85$ (except in last line in which the total height of tank is reached).

For the purpose of this reasoning it was assumed that complete dissipation of neutral pressures would take place before the application of a new increment. This is not the

practical case, and one does not have to wait for complete dissipation of neutral pressures. Since at any height of water in the tank the corresponding allowable neutral pressure is not exceeded stability is satisfied. Loading could also be continuous, taking care that these allowable values are not exceeded.

Observed Settlements and Neutral Pressures

The tank at the time of the writing of this article is being filled in accordance with the programme of loading in the table of the preceding paragraph.

Fig. 5 shows time-load-settlement-neutral pressure curves. It can be seen in the drawing that the sand drains are working properly since neutral pressures dissipate quickly when the load remains constant. One sees also that observed neutral pressures in the initial phase of the loading are much smaller than anticipated. Piezometers also show quick response to neutral pressures.

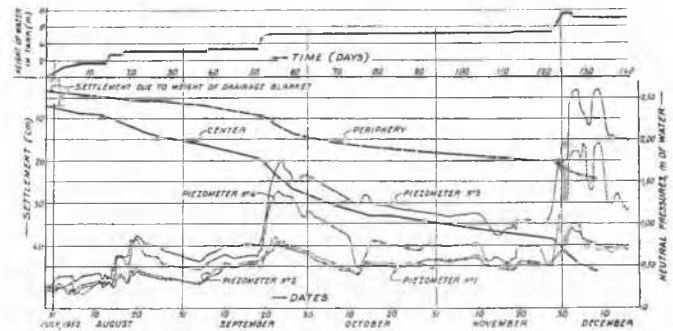


Fig. 5 Neutral pressures and settlement observations
Observations des tassements et des surpressions hydrostatiques