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PERFORMANCE OF VERY SOFT MUDS UNDER VERY LIGHT LOADS AND CONSOLIDATION OF
A MUDY BOTTOM UNDER A WIDE SAND FILL

LA PERFORMANCE DES BOUES TRES MOLLES SOUS DE TRES FAIBLE CHARGES ET CONSOLIDA-
TION D'UN FOND SOUS UN REMBLAI SPACIEUX DE SABLE

ПОВЕДЕНИЕ СЛАБЫХ ГРУНТОВ ПРИ ОЧЕНЬ МАЛЫХ НАГРУЗКАХ И КОНСОЛИДАЦИИ ОСНОВАНИЯ,
СЛОЖЕННОГО СЛАБЫМ ГРУНТОМ ПОД ШИРОКОЙ ПЕСЧАНОЙ НАСЫПЬЮ

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SYNOPSIS. To prevent slides and plastic deformations of an underwater slope it has been found necessary to spread a wide sand fill on the bottom of the sea.

The aim of this measure was to establish a counterweight and to consolidate the muddy bottom. To investigate the performance of the muddy bottom laboratory consolidation tests with slurries have been carried out.

At the beginning the test pressures being very small, in the order of 0,06 - 32 gr/cm², a very simple test arrangement was used. The test results are presented as a $w - \log p$ curves. The test samples were slurries with an initial water content approximately equal to three times the liquid limit of the bottom material which is a silty clay with organic admixtures. To study the performance of this material under greater pressures tests in consolidometer were carried out. The observed results showed distinctly three phases of compressibility performances : For $w > 2.5 w_L$, $w = w_L - 2.5 w_L$ and $w < w_L$.

Between the settlement values calculated on the basis of these tests and the in situ measured values a practically tolerable agreement have been observed.

SAND FILL ON THE BOTTOM OF THE SEA

In connection with construction of the Champer of Commerce Building on the shore of the Golder Horn, Istanbul, an investigation of the soil conditions on and around the site have been carried out.

On the basis of measurements and the presence of excessively settled, tilted and moved buildings on this area it was found that a strip of ground along the shores was moved towards the sea and settled.(9).

The recommended and applied foundation system for the Champer of Commerce Building comprised among the other measures a sand fill of about 40 000 m³ spread on the bottom as shown in Fig. 1 to constitute a counterweight and a mean to consolidate the muddy bottom. A similar measure had been applied in 1895 in connection with construction of the quaywalls on the same shores some 1000 meters eastwards, Sirkeci Rihtımları. (7).

That was only to counterweight a very large underwater rockfill dam for the foundations, which, during its construction excessive settlements (6-10 m) observed and two failures occurred (8 m sinking, 4 m horizontal sliding, and finally a base failure).

In order to have an idea about the mode of the behaviour of the fill which was planned to be spread

according to a predetermined program tests on clayey slurries prepared with sieved bottom material have been carried out. The main aim of the spreading program was to obtain thin uniform sand layers and to prevent a bodily sinking of the fill into the mud, and to keep the volume of the fill as effective as possible to cause the consolidation of the mud and so to increase the factor of safety of the underwater slopes against sliding.

The fill consisted of two terraces. To spread the first terrace the area was divided into small areas of about 80 m² each and the sand was poured from barges fixed at the centers of these areas and with aid of grab buckets. The small amount of sand had travelled 20 to 40 meters in water before it reached the bottom in a dispersed state and constitute fairly uniform layers. Because of the slight bottom currents which depended on weather conditions some fines were drifted eastwards.

The first terrace of the fill is composed of seven layers with a total average thickness of 4.00 meters of fine to coarse sands, and the first layer has been kept to be not more than 25 - 30 cm of fine sands. The last layer was of coarse gravel and small stones.

The second terrace is composed of four layers of small stones and coarse gravels with a total average thickness of 2.00 meters.

Fig.1 Geological Section of the shore and the plan of the fill. M Direction of the observed movements

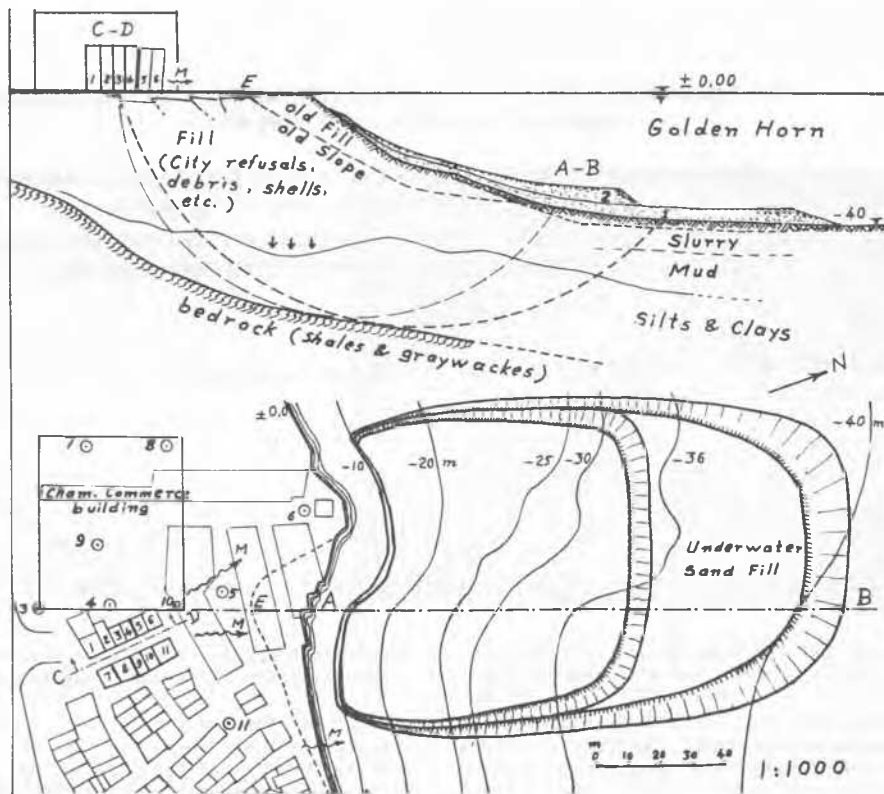
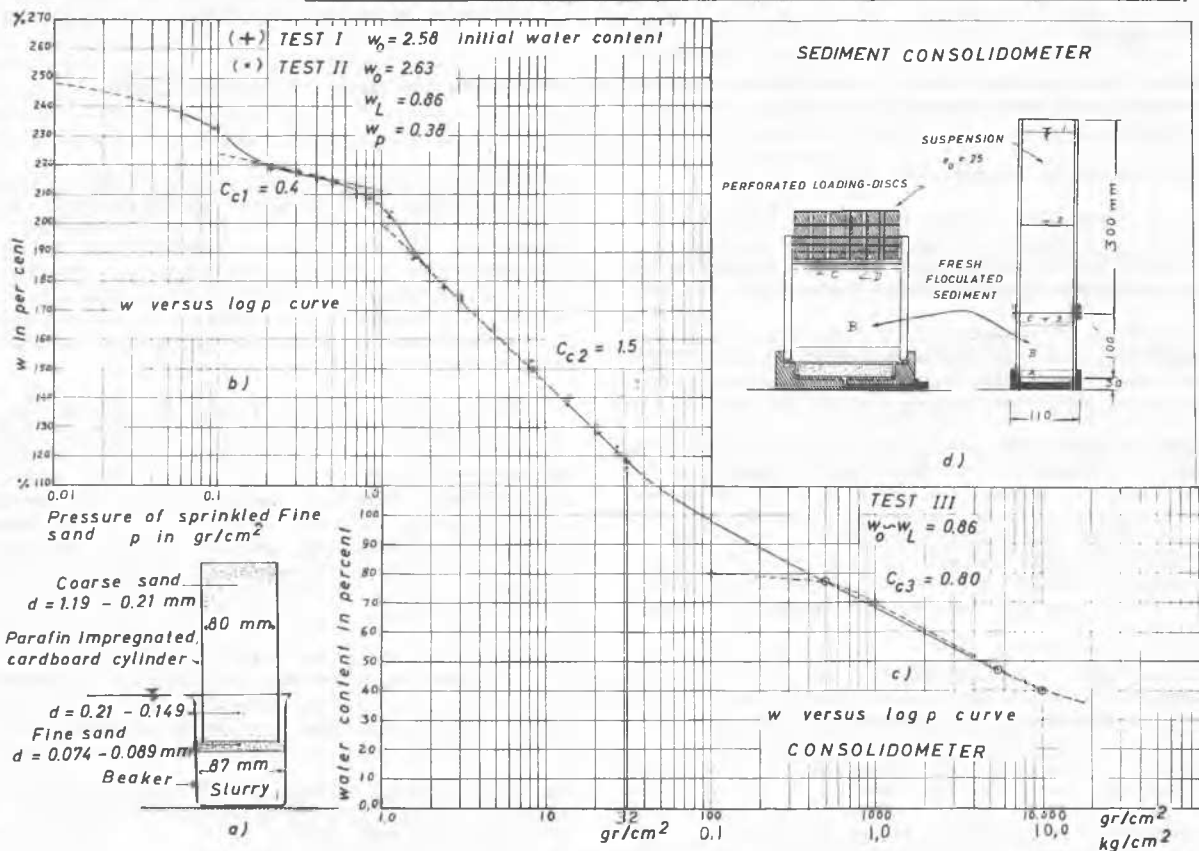


Fig.2 (below) Consolidation test results and the test arrangements



The construction operations of the fill were controlled by skin divers and after the completion of layers several soundings have been made sufficient to draw 10 cross sections perpendicular to the shores. Because of the softness of the bottom of the sea the first soundings could not reflect the actual position accurately enough. But, as a whole, measurements and underwater inspections and the volume of the poured sand justifies that the measured average settlement of the order of 250 centimeters can be taken as the value for comparison with calculated settlement values.

In Fig.2d an apparatus for the study of settling rate of a flocculated suspension is presented. A suspension prepared with $e_0 = 25$ is poured into the cylinder and the lowering of its surface observed. After the equilibrium the surface of the suspension is loaded with perforated plastic and metallic discs. When the volume of the sediment into the part B, the upper part of the cylinder detached and the lower part loaded in an oedometer's loading frame.

LABORATORY TESTS

In order to have an idea about the order of the expected settlements and the degree of probabilities of a bodily sinking or penetration of the sand into the mud laboratory tests have been carried out.

1) A very thick suspension (slurry) with bottom material at a void ratio equal to 13,3 have been prepared (4000 gr sea water 8 gr dry clay which was passed through No.200 sieve initial water content of the slurry 500 %), and poured into a large cylindrical vessel ($d = 18$ cm) and left to settling. After 8 days the surface of the flocculated slurry became practically stationary and the thickness of the sediment reduced to about 10 cm.

By adding water the thickness of the water above the soft and fresh sediment increased to 20 cm, and a circular part of the surface loaded with fine sand sprinkled uniformly from the water surface. In this way a small sand fill of about 100 cm^2 came to existence. The surface of this fill was gradually loaded with metallic discs and the pressure on the slurry increased up to 100 gr/cm^2 . Forming the fill and loadings lasted 60 days.

There was no bodily sinking of the fill and no appreciable penetration of the sand grains into the sediment which was regarded of equal softness with bottom material.

During a previous boring operation the case pipe had sunk under its own weight about 8,5 meters into a similar bottom 27 meters deep in the vicinity of the actual fill. (8). In these tests volume decreases (settlements) could not have been measured accurately enough.

2) In order to have an idea about the compressibility of the bottom layers two consolidation tests in beakers have been carried out as shown in Fig.2a. In these tests slurries have been prepared with 500 gr water and 100 gr dried clay. The slurry left to settle, and after 8 days its water contents decreased to 258 % in the Test I and to 263 % in the

Test II and the consolidation under their own weights slowed down to such a rate that no further settlements were noticeable with these very simple test arrangements in 24 hours. After this stage loadings with sprinkled fine sand began. The results are given in Fig.2b. After 9 days under a pressure $p = 0.06 \text{ gr/cm}^2$ water contents decreased to 238 and 237 percents respectively which are approximately equal to three times the liquid limits. After $p = 1,55 \text{ gr/cm}^2$, to avoid the friction between the sand and the beaker walls, sand was poured into parafin impregnated cardboard cylinders.

The volume decrease could be read up to a precision of 15 cm^3 , which corresponds approx. to 0,25 mm. Considering the nature of the problem, this was regarded sufficient to give at least an idea useful in practice.

A third consolidation test in the consolidometer carried out with same material but prepared at a water content slightly above the liquid limit. Fig.2c.

The appearance of the $w - \log p$ curve drawn on the basis of the beaker and consolidometer tests suggests that the calculated compression indexes C_c reflects the compressibility of the slurries at different stages of their consolidations.

The first stage : $p < 1 \text{ gr/cm}^2$, $w > 2,5 w_L$

The array of particles is uncertain and there is no contact between them. Towards the end of this stage (or phase) an edge-to-face contact can be expected in flocculated type of structure. (1,2,3,4,5,6,10).

In order to have at least a very crude idea about the distances between the particles some very simplifying assumptions regarding shape and dimensions have been made.

Assumed types and arrangements and relative positions are given in Fig.3 and Table 1.

Silt and clay particles are accepted as square flakes and rounded particles as cubes. In the assumptions 1 and 2 particles are thought in parallel orientation.

The m factors reflect the horizontal distances between the edges of the particles in parallel orientations. If $m = 10$ there is no contact between the edges. For $m = 10$ particles constitute continuous sheets. In the assumptions 3 and 4 vertical and inclined particles are thought to exist between the horizontal particle sheets. Vertical distances d between the faces depends to void ratio, to the ratio of thickness to length and to m factors and are given in Table. 1 as the multiples of their thicknesses, a and for rounded particles of their sides, b .

This is being not a discussion of the physico-Chemical factors governing the bearing capacity of the thick suspensions (slurries) it will only be referred to the deduced results that even at the liqued limit the assumed double layer water boundaries of caolinite flakes have no contact in parallel orientation whereas in the assumptions 3 and 4 a direct edge to-face contact may be expected. In montmorillonite flakes the thickness of the double layer water being of the order of $21a$ such a contact is even by very thin

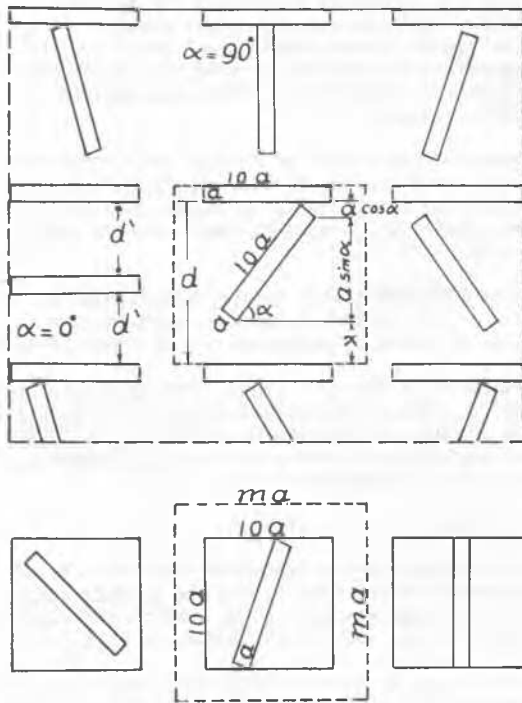


Fig. 3 : Assumed shape, relative dimension and array of clay particles.

TABLE 1. Distances between particle faces as a function of e and m

State of the slurry	e	ASSUMPTIONS				
		1 m=10 d' = e.a	2 m=15 d' = a(4e-5)/9	3 m=15 d' = a(8e-1)/9	4 m=10 d' = a(2e+1)	5 Cubic d' = (T+e-1)b
Slurry 500 gr water 100 gr clay	13.5	13.5a	5.5a	12a	28a	1.44 b
After 8 days p=0	7.0	7a	2.56a	6.1a	15a	b
After 62 days p=1.00 gr/cm	5.5	5.5a	1.9a	4.75a	12a	0.87b
After 173 days p=32gr/cm	3.2	3.2a	0.87a	2.74a	7.4a	0.61b
All the w _L	2.32	2.32a	1.03a	1.95a	5.64a	0.5 b
Consolidated p=10kg/cm ²	1.08	1.08a	0.5a	0.85a	3.16a	0.28 b

The lengths of the squares are assumed ten times their thickness.

slurries present.

The second Stage : $w_L < w < 2,5 w_L$

Towards the end of the first stage the compressibility begins to decrease at water content of about $2,5 w_L$. This may be attributed to a change in the array of particles. Vertical and inclined particles gradually assumes horizontal orientations. The external loads increase the attractive forces between the particles. So the average value of the compressibility index increased from 0,4 to 1,5 . (1, 2, 3).

The Third Stage : $w < w_L$.

In this stage the average value of the compressibility index decreased to a value of about 0,8. This may be due to the fact that the rigidity of the double layer water begins to increase because of the decreasing distances.

FORECAST OF THE SETTLEMENTS

To calculate the settlements on the basis of the w-log p curves, among the others, assumptions have been made to simplify the geological configurations of the soft layers.

On the basis of the observations made during the boring operations and the laboratory tests and the local experiences the average thickness of the very soft slurry like bottom layer has been assumed as 400 cm. The pressure exerted by the sand fill increased from 1 gr/cm² to 500 gr/cm². And, assuming the initial water content as 200 % the calculated settlement have been found to be 211 cm. Settlements due to deeper clayey layers estimated to be of the order of 40 centimeters.

Between these figures and the in situ measured settlements there are practically tolerable agreements This gives a useful clue for the interpretation of the nature of settlements and so the effectiveness of the measures taken and applied.

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