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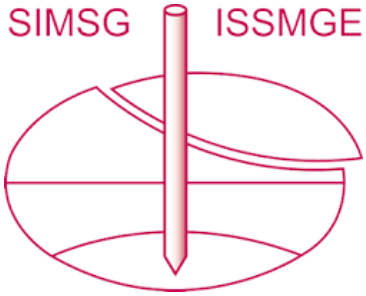

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Adjustable Box Foundation as a Measure against Excessive Settlement and Tilting

Fondation rigide réglable pour rectifier les tassements et les flexions excessifs

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SUMMARY

This paper discusses an economical solution for a foundation known to be liable to undergo excessive settlement and tilting. The foundation soil consists of a loose fill underlain by a soft and organic clay layer with a considerable but variable thickness, resting on inclined bedrock. Geotechnical soil properties have been determined in the laboratory and in the field by means of a large, flexible, long-term test loading. After estimating the amount of the probable settlements and tilt, the building was constructed with a reverse inclination. In addition, considering the uncertainties connected with settlement forecasts, niches for hydraulic jacks, tubes for mortar injection, and reaction mats have been placed under the rigid box. During construction and in the following months the reverse inclination has almost levelled off. It seems that recourse to jacking up will not be necessary. The cost of these precautionary arrangements is negligible, and the costs for a probable levelling operation are small.

SOMMAIRE

Ce communiqué expose une solution économique pour la fondation d'un ouvrage, dont on sait au préable, qu'elle sera soumise à des tassements et à des flexions excessifs. Le sol de la fondation est une argile organique, molle, située sous une couche meuble de remblai. La couche d'argile est d'une épaisseur grande et variable et repose sur une surface rocheuse inclinée. Les propriétés géotechniques du sol ont été determinées en laboratoire et aussi sur le terrain. A cet effet, un essai à grande échelle de chargement flexible et de grande durée a été exécuté sur place. Après le calcul des tassements probables, le bâtiment a été construit avec une inclinaison en sens inverse. En plus, tenant compte de l'approximation qui existe dans le calcul de ces tassements, des niches pour des vérins hydrauliques, des tuyaux d'injection de mortier et des plaques de réaction ont été disposées sous la fondation rigide. Pendant le période de construction et les mois qui suivirent l'inclinaison en sens inverse a été compensée. D'après les constatations effectués jusqu'à maintenant, il semble qu'on n'aura pas besoin d'avoir recours aux vérins hydrauliques pour corriger l'inclinaison du bâtiment. Les dépenses pour les mesures de précaution, comme les niches et les tuyaux d'injection sont négligeables par rapport au prix de la fondation rigide. En outre les dépenses pour une correction d'inclinaison éventuelle ne seront pas grandes.

DESCRIPTION OF THE SITE

A FIVE-STOREY MILL BUILDING, with two silos at the ends, was to be constructed at the site of an 80-year-old mill building which was destroyed by fire in July, 1960. The author was called to investigate the problem and to recommend an economic and safe foundation. The plan of the site is given in Fig. 1 which shows the existing buildings, store rooms, and areas, and the location of the four boreholes. The geological section of the subsoil and the dimensions of the two buildings subject to investigation are shown in Fig. 2.

During clearing operations at the site it was observed that the original ground floor lay about 55 cm under the lowest sea level, and that it had been raised by filling several times. The same conditions were observed in a neighbouring grain silo built in 1928. This silo was built on a reinforced mat resting on a sand and gravel cushion of about one hundred centimeters thickness. Dimensions and the amounts of total and differential settlements are given in Fig. 3. Excessive settlements and tilting are very common on the shores of Golden Horn. Fig. 4 gives an example of a building which has suffered excessive settlement and tilt. This building, 1,400 meters north of the present site, is also a mill with a flour silo on the sea side. The differential settlement of this building is about 56 cm.

FIG. 1. Plan of the site.

At the site of the present investigation the fill is composed of silty and clayey mud, sand and gravel, bricks, and all sorts of city refuse. The dark blue-green organic soft clay seems still to be under the process of decelerated consolidation, or plastic flow, or both. The soil layers contain the gaseous products of decayed substances. The surface of the soil specimens oxidized and became olive green in about 24 hours and appeared as if covered with a crust about 2 mm thick.

SOIL PROPERTIES

The geotechnical properties of the organic clay were determined in the laboratory and the results are given in Figs. 5 and 6. In order to assess the influence of disturbance occurring during sampling and specimen preparation, long-

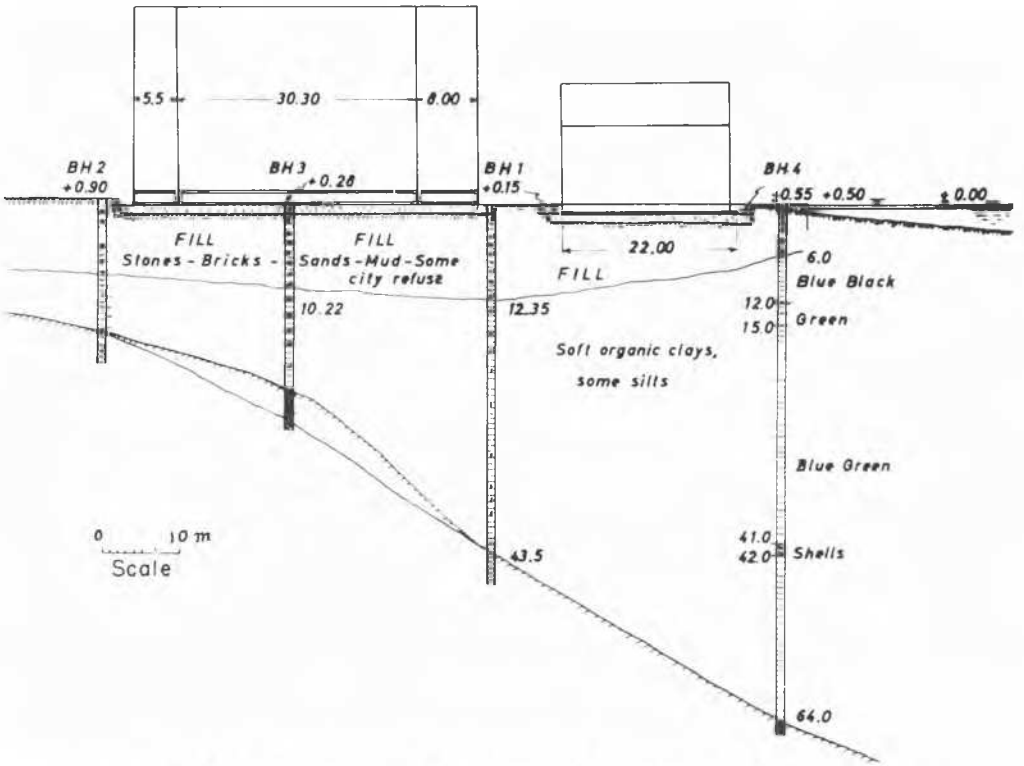

FIG. 2. Geological section of the subsoil and dimensions of the buildings.

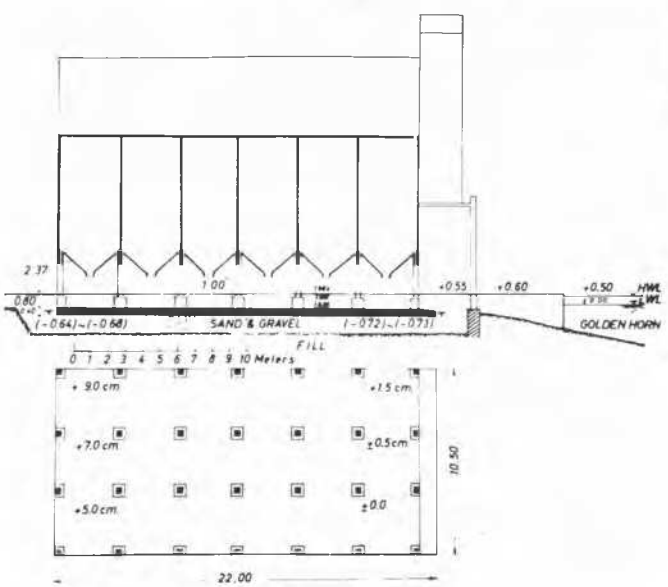

FIG. 3. Total and differential settlements of the grain silo.

FIG. 4. Excessively settled and tilted building 1,400 m north of the site.

term consolidation tests were carried out on samples of remoulded clay. Two clay specimens were prepared at about the liquid limit and were left to consolidate under approximately equal loads for periods of 396 and 428 days, and then unloaded. In Test 1 the sample was reloaded. In Test 2 the sample was taken out and transferred into a narrower ring and then reloaded in a similar fashion to Test 1. The results of these tests are given in Fig. 7. These curves show that sample disturbance during manipulation has no effect on C_c values beyond a certain load in excess of p_c, the maximum preconsolidation pressure, in this case beyond about (p_c + 1.5) kg/sq.cm. These curves suggest further that the sample disturbance causes a decrease in the structural resistance of the clay up to a load somewhat greater than p_c.

In the present paper C_c values for the line AD in Fig. 6 are considered in the settlement analysis. In nature there is no sample disturbance and the loads are increased much more slowly. Thus it is reasonable to assume that the C_c values in nature are smaller than the values for field curves. This investigation is still continuing.

FLEXIBLE TEST LOADING

In order to estimate the compressibility of the fill a large, flexible test loading was carried out. In this test an area 7.00 by 8.55 m was loaded with hand-packed stones and the settlements were measured. The arrangement and the results of this test loading are given in Fig. 8. Fig. 9 is a photograph of the test arrangement. Whenever sufficient time and loading material are available large test loadings of this kind seem to have many advantages over the routine types. Assuming that 90 mm of the total settlement was due to the compression of the fill the modulus of compressibility was calculated, to be of the order of M_c = 84 kg/sq.cm.

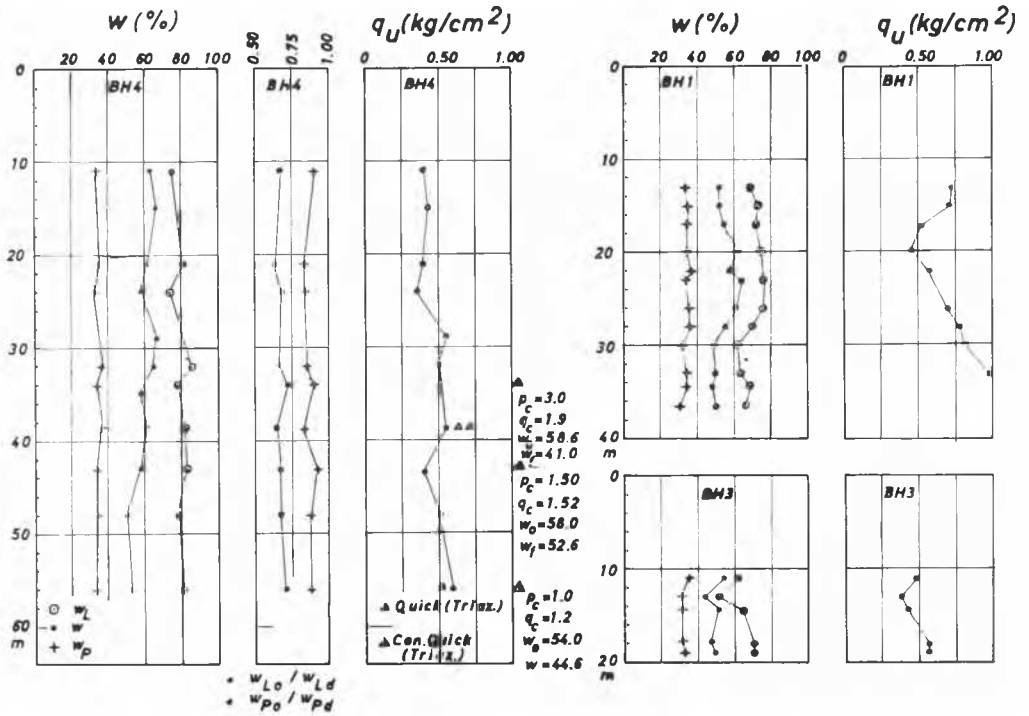

FIG. 5. Atterberg limits and q_u values of the soft organic clay.

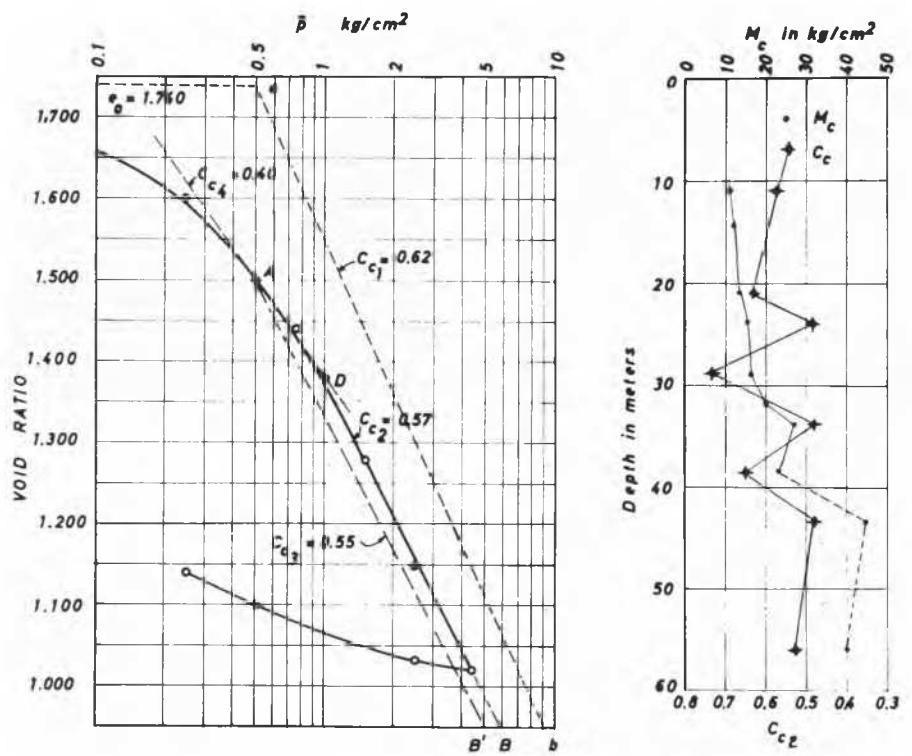

FIG. 6. A typical e log p curve and the variation of the compressibility of the clay with depth.

SETTLEMENTS OF THE 1928 GRAIN SILO

On the basis of the soil properties the settlement of the 1928 grain silo was calculated and compared with the observed value. The total weight of the silo is 1,400 tons and the weight of the grain is 1,000 tons. The results of this routine calculation are summarized in Table I. The great difference between calculated and observed values of the settlements can be attributed to the shear stresses.

Because of the distributed loads (0 to 0.3 kg/sq.cm. on the store area) differential settlements did not exceed 9 cm, and the tilt towards the sea remained comparatively small. Values of the calculated settlements given in Table I include compression due to primary, and to some extent, secondary consolidation, and the immediate settlement. Settlements due to the low shear strength (to plastic flow) are greater than one-half of the total settlement.

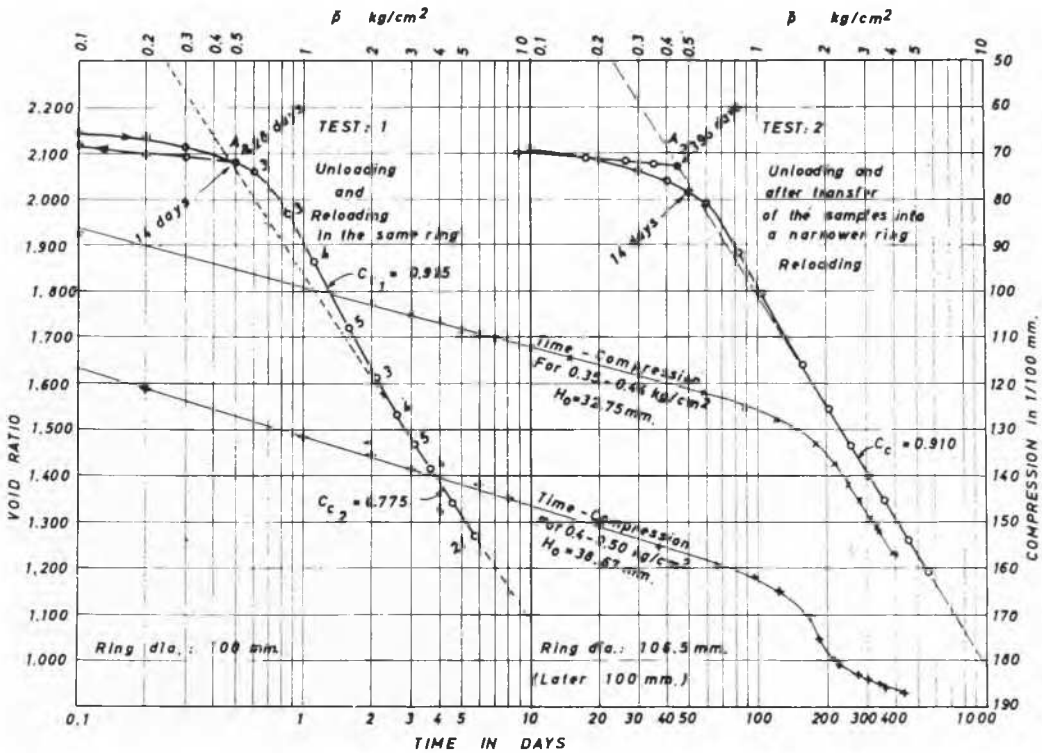

FIG. 7. Tests to study the influence of disturbance on the sample.

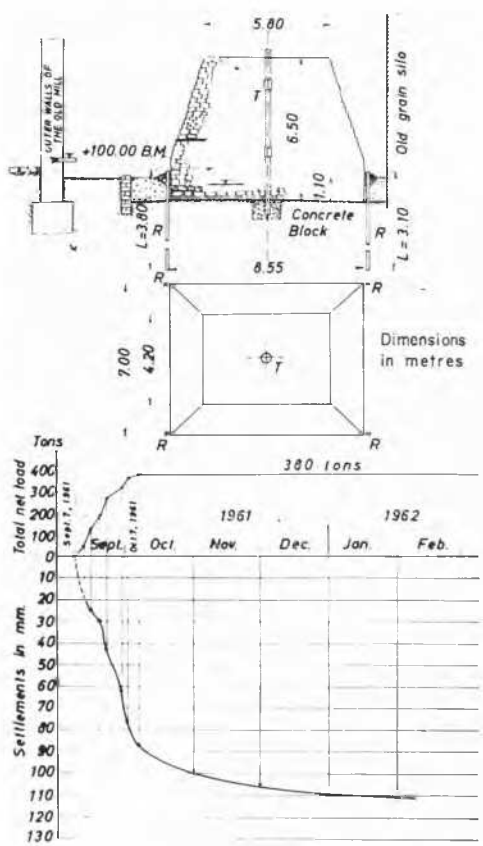

FIG. 8. Large flexible test loading.

FIG. 9. View of the test loading arrangement.

SETTLEMENT FORECAST FOR THE MILL BUILDING

The total weight of the mill is 2,600 tons, and the weights of the grain and flour silos are 1,840 and 920 tons respectively. The total weight of the burned mill building was estimated to be about half that of the new building. After the fire all silos and store areas remained empty for a period of about 14 months. In interpreting the results of the calculations all these facts have been taken into account. The amounts and distribution of the calculated settlements are corrected and balanced freely according to the rigidity and constructional arrangement of the buildings. Estimated values of the settlements are given in Table II.

FOUNDATION SYSTEM

A foundation on long piles was found to be too expensive and the idea of constructing the mill building on a box adjustable in elevation and with an initial reverse tilt was accepted.

The general arrangement of the buildings is shown in Fig. 10. The rigid box rests on a concrete mat which is underlain by a compacted sand and gravel cushion. The concrete mat is 15 cm thick and the sand and gravel cushion 110 cm thick. At the base of each column niches for hydraulic jacks were constructed as shown in Figs. 10 and 11. The dimensions of the box were so designed that it can

TABLE I. CALCULATED AND OBSERVED SETTLEMENTS OF THE SILO

Method of calculation of σ_z	Average calculated settlement (cm)	Average observed settlement (cm)	Maximum shear stresses (kg/sq. cm.)	Determined shear strengths (kg/sq. cm.)
Based on Boussinesq	27	83	0.22 (in the fill) 0.18 (in the clay)	0.20 to 0.30 (in the clay)
Linear pressure distrubution (Koegler and Scheidig)	38			

TABLE II. PREDICTED AVERAGE AND DIFFERENTIAL SETTLEMENTS

Building	Predicted average settlement (cm)	Predicted differential settlement (cm)
Grain silo	24	5
Mill building	25	16
Flour silo	32	3

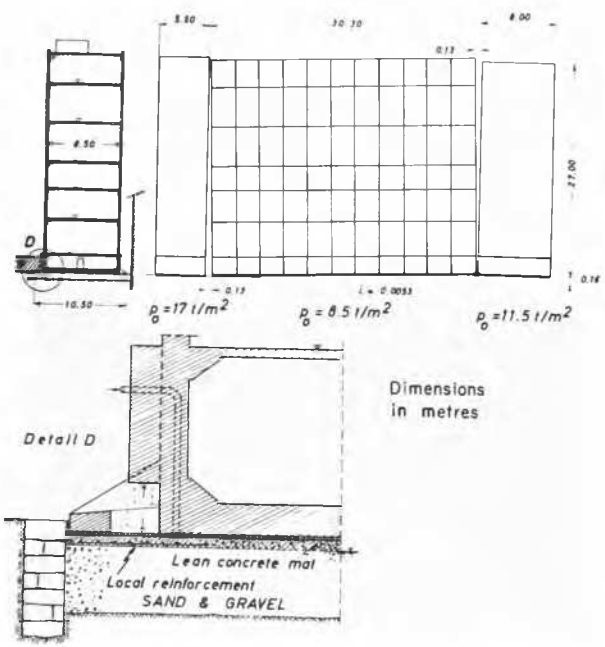

FIG. 10. General arrangement of new mill foundations.

FIG. 11. View of jack niches.

FIG. 12. Reinforcement of the box and injection tubes.

carry the building when it rests on 12 hydraulic jacks. Fig. 12 shows the reinforcement of the box and the tubes for mortar injection. It was planned that, if necessary, mortar will be injected between the raised sole of the box and the surface of the concrete mat. To resist the reactions the mat was reinforced under the jack niches. The surface of the concrete mat was covered with a waterproofing material followed by a 4-cm thick mortar layer to protect the membrane. The mat was given a reverse inclination as shown in Fig. 10.

Construction was completed in May, 1962, and early in 1963 the mill was put into operation. In the course of construction and the following months the initially reversed inclination has almost levelled off. During the operation period a tilt of about 1 cm was reported. It seems that recourse to future jacking-up will not be necessary. The cost of the precautionary arrangements was negligible compared with that of the box. Also the costs of future jacking-up are small. In a previous application of this technique a tilted building of a more delicate nature was levelled successfully, and without interruption of the work (Loos and Bernatzik, 1940; Bernatzik, 1950). In this case the cost of the rigid box was much lower, and the time for construction was much shorter than that of a foundation on long piles.

ACKNOWLEDGMENTS

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