RELATIONSHIP BETWEEN THE SETTLEMENT OF SOFT CLAYS AND EXCESS PORE PRESSURE DUE TO IMPOSED LOADS

RAPPORT ENTRE LE TASSEMENT DES ARGILES TENDRES ET LA SURPRESSION INTERSTITIELLE DUE AUX CHARGES IMPOSEES

ЗАВИСИМОСТЬ МЕЖДУ ОСАДКОЙ МЯГКОЙ ГЛИНЫ И ИЗБЫТОЧНЫМ ПОРОВЫМ ДАВЛЕНИЕМ ПРИ НАГРУЖЕНИИ

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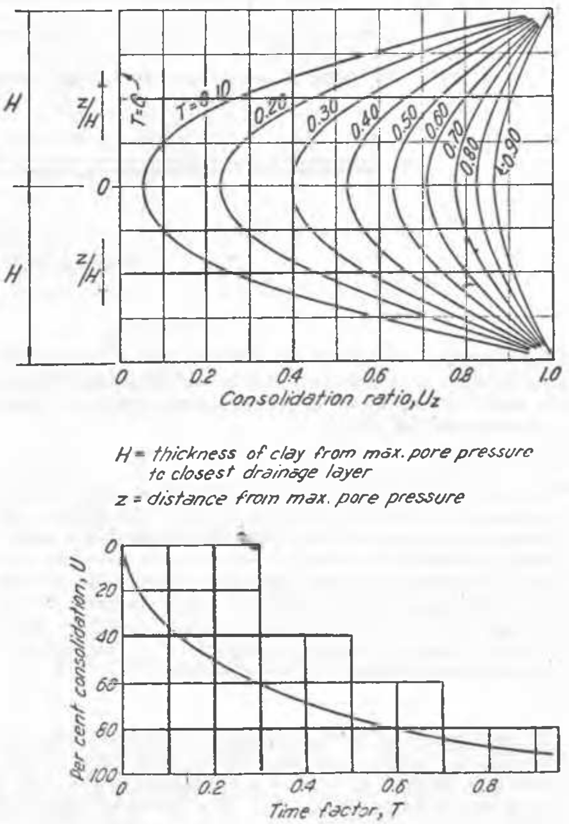
SYNOPSIS. Two 2.5 m thick gravel fills were constructed in 1945 and 1946 to study the secondary compression of a 13 m thick deposit of soft clay. The Kjellman cardboard drains were used below one of the fills. Drains were not used below the second fill. Settlements and pore pressure dissipation have been measured at various depths. The measured reductions in water content were found to correspond closely with the measured compression of the different soil strata. High excess pore pressures were measured below the two fills which correspond to a degree of consolidation of about 30 % and 25 %, respectively. The measured settlements of the two fills correspond to a degree of consolidation close to 100 % with respect to the calculated final settlements.

The computation of settlements of structures founded on clay or other soils with low permeability has become routine since Terzaghi proposed his consolidation theory in 1923. According to this theory the initial excess pore pressures are assumed to be equal to the total vertical stress increase from the superimposed load. The settlement is a result of pore-pressure dissipation as illustrated by the isochrones in Fig. 1 and by a corresponding increase of the effective vertical stress in the soil. The degree of consolidation corresponds to the ratio between the dissipated pore pressure and the initial excess pore pressure. Records from detailed field observations of the consolidation process are, however, rare. Decades are frequently required before meaningful data can be collected.

In 1946 Terzaghi proposed a long-term field load test by constructing a 2.5 m thick gravel fill at Väsby, Sweden, the site for a proposed international airport close to Stockholm, in order to investigate the secondary compression of soft organic clays which might cause extensive cracking of the runways. Moreover, another test fill, identical in size and shape, had already been constructed in 1945 at this site to investigate the effectiveness of the cardboard drains developed by Kjellman (1948). This test fill is known as the Drained Fill to denote the insertion of vertical drains; the fill proposed by Terzaghi, known as the Undrained Fill, was built in 1946. The settlements and the pore pressure dissipation beneath the two fills have been measured continuously since that time. The detailed results from these tests have been reported elsewhere (Chang, 1969). The observed excess pore pressures and settlements are summarized in this article.

The clay at the Väsby site was deposited during the Quaternary glacial and post-glacial periods in fresh or brackish water. It has a high sulfide content, probably from the organisms which were deposited with the clay particles.



H = thickness of clay from max. pore pressure to closest drainage layer
z = distance from max. pore pressure

Fig. 1 Relationship between pore pressure and degree of consolidation

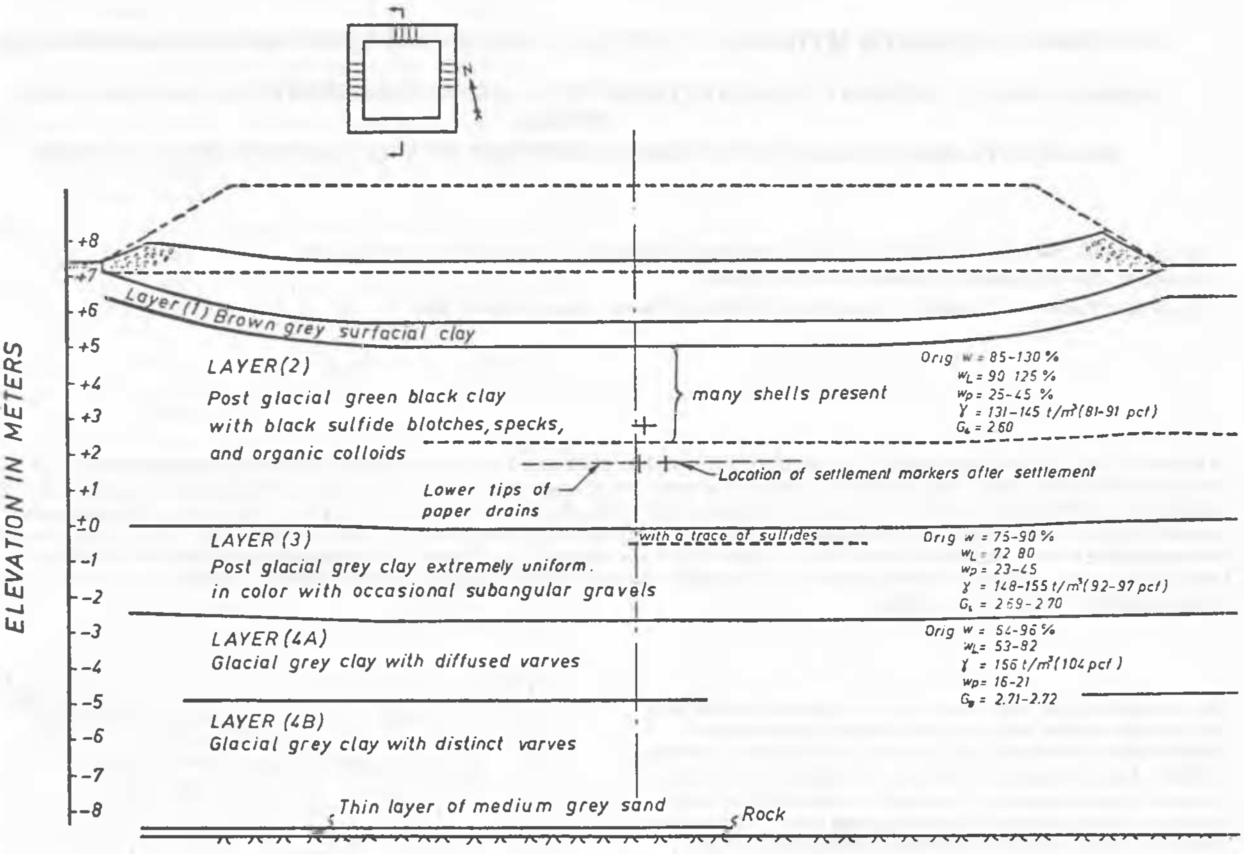


Fig. 2 Ground profile shown with one of the test fills

Consequently, the rate of secondary consolidation of the clay is high. A typical soil profile and an outline of one of the test fills are shown in Fig. 2 together with the index properties of the soil.

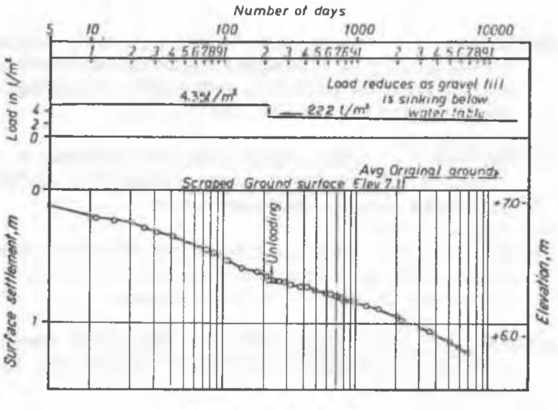
The original thickness of the two test fills, each of which covered an area of 30 x 30 meters, was 2.5 meters. To investigate the preloading effects the Drained Fill was partially unloaded in 1946 by removing 80 cm of the gravel fill. It continued to settle, however, despite the unloading. The thickness of the Undrained Fill has not been changed. By June 1971, the Drained and the Undrained Fills had settled 1.3 and 1.5 meters, respectively. The former had settled less on account of the unloading.

The settlements of the original ground surface below both test fills are plotted on a logarithmic time scale in Fig. 3. All except the initial 5 cm of the observed settlements are due to consolidation of the clay. The observed settlement of each layer corresponds closely to the measured reduction in water content since the beginning of the test. That is, the compression of each layer is equal to the decrease in voids computed from the water content reductions.

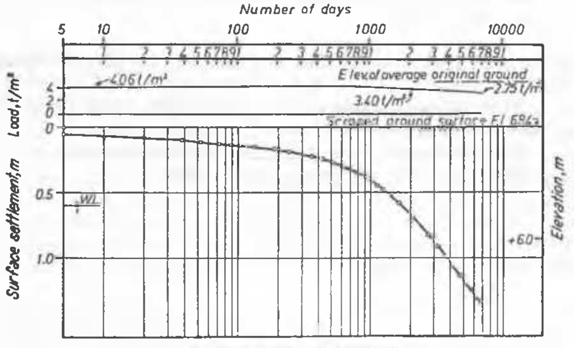
In Fig. 4 is shown the accumulative compression of the different clay layers of the Undrained Fill from the bedrock upwards. One of the curves represents the settlements determined from the settlement markers buried at various depths. The other curve has been computed from observed water content changes. The two curves almost coincide.

The ground water table has varied between 1.0 and 1.5 m below the natural ground surface during the last 26 years. Because of the high water table the net load from the fill has decreased slightly with time as part of the fill settled below the ground water table. The weight of the fill has been reduced by the buoyant force of the water. The net stress increase for the two test fills is shown in Fig. 3 for the same time scale as the settlement rate.

The shape of the settlement curves, Fig. 3, suggests that the settlements are still in their primary stage. The final settlements for the imposed test loading computed from the compression index C_c determined either by oedometer tests or by the procedure proposed by Bjerrum (1967) suggest, on the other hand, that the settlements have reached or have passed the primary stage.



Settlement of drained fill



Settlement of undrained fill

Fig. 3 Ground surface settlement

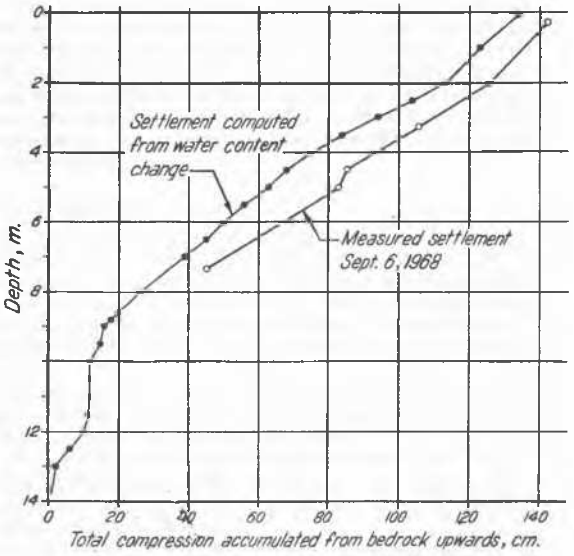


Fig. 4 **Undrained** fill. Comparison between measured **and computed** compression

The significance of this discrepancy cannot be appreciated until the excess pore pressures are taken into account.

Two hydraulic piezometers were inserted under each of the fills in 1947 to observe the pore pressure dissipation. Additional pore pressure gages were installed between 1966 and 1968. Three types of piezometers were used: Swedish, Norwegian vibrating-wire, and Norwegian open-pipe. The pore pressure distribution was determined at five different locations within, and at four different locations outside, each of the two test fills. The pore pressures at each location were determined for every meter of depth. The piezometers located outside the test fills were used to establish the pore pressure distribution in the natural ground, unaffected by the fills. Figs. 5 and 6 show the excess pore pressures below the centers of the Drained and Undrained Fills, respectively, in relation to the increase in vertical stress as computed by the Boussinesq equation.

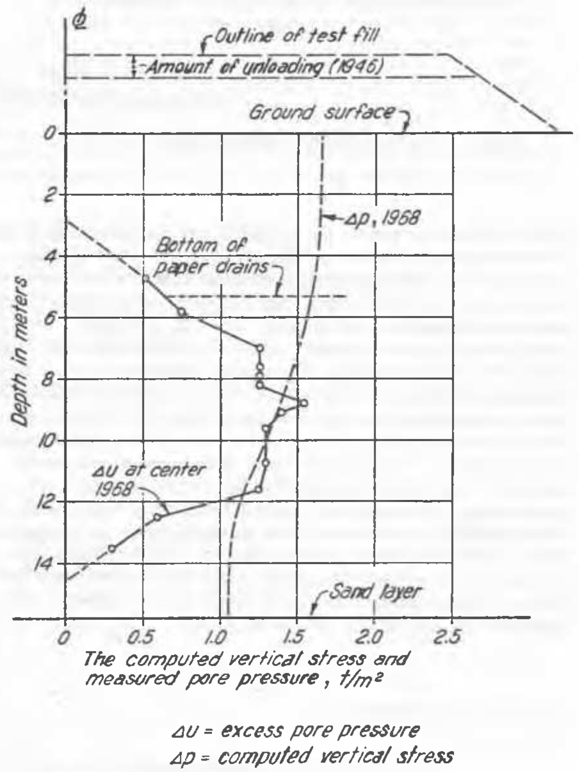


Fig. 5 Pore pressure beneath Drained Fill

The degree of consolidation from the measured excess pore pressures according to the method shown in Fig. 1 is about 30 % for the Drained Fill and 25 % for the Undrained Fill. The degree of consolidation with respect to the calculated final settlement of the two fills is, on the other hand, close to 100 %, although the computed final settlement varies somewhat with the method of computation. The range is between 1.5 and 1.8 meters.

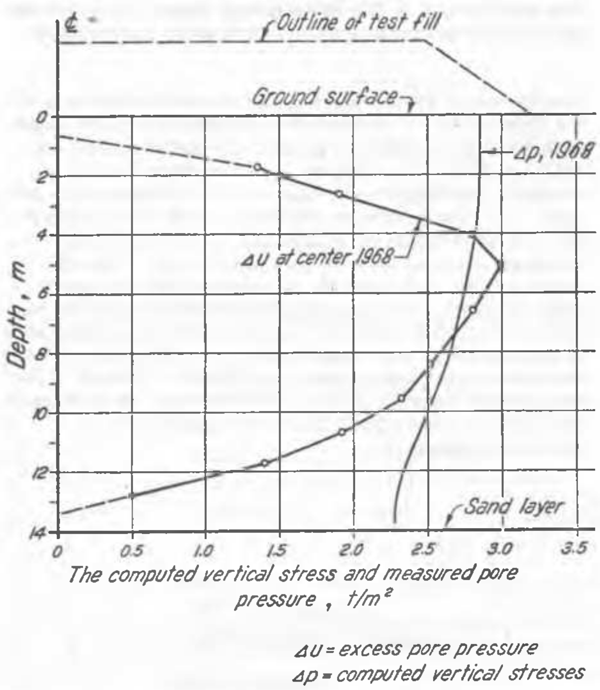


Fig. 6 Pore pressure beneath Undrained Fill

The test results point out a significant shortcoming of the Terzaghi consolidation model and theory. It is tacitly assumed that the superimposed load alone is the cause of excess pore pressure in a clay deposit. The Väsby tests indicate that other factors may have an influence. The dissipation of pore pressure due to consolidation at Väsby may have been partially off-set by a regeneration of pore pressure due to collapse of the clay structure during the initial loading and during the continuing distortions or creep of the subsiding deposit as consolidation proceeded. Consequently, the dissipation of pore pressures due to consolidation was compensated by a pore pressure regeneration. This portion, called secondary consolidation, has generally been considered to begin after the completion of the primary phase, and no or very low excess pore pressures have been thought to exist during the secondary phase. This concept may sometimes be erroneous, as indicated by the observations at Väsby.

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