

Settlement of Pile Foundations due to Secondary Compression

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In every moist or saturated soil, the soil particles are surrounded by a film of adsorbed water. In the immediate vicinity of the surface of the solid particles the adsorbed water is solid, as indicated in Fig. 1, and its density is far above normal. With increasing distance from the surface of this solid film both the density and the viscosity of the water decrease and beyond a certain distance d the properties of the water become normal. The distance d depends on both the chemical properties of the solid and on those of the substances other than water which are present within the zone of adsorption. Thus, for instance, if the water in the voids of a Bentonite contains Na salts in solution, the adsorbed layers are very much thicker than those in a Bentonite saturated with pure water. The views regarding the nature of the effect of the solid on the water are still in a controversial state. Yet the existence of the layers and the conspicuous deviation of their physical properties from those of normal water have been conclusively demonstrated by numerous and very different methods of investigation.

When two solid particles are pressed together with a force Q the outer zones of their adsorbed layers merge as shown in Fig. 1a. This event occurs instantaneously. However, in this state they are still separated from each other by a liquid though very viscous layer of adsorbed water. The further approach between the particles takes place with rapidly decreasing speed, until finally the solid portions of the adsorbed films come into actual contact. After the contact has been established the clay is in a solid state, because the clay particles are now connected with each other by solid links. Prior to this event there is no solid bond between the soil particles. Hence the gradual displacement of the viscous portion of the adsorbed films will be called the

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process of solidification. During this process the clay is in a lubricated state because each clay particle is separated from its neighbors by a film of liquid adsorbed water. At a given pressure p per unit of area of a section through the soil the pressure Q per point of contact decreases with the square of the grain size. Yet the thickness of the adsorbed layers and their physical properties seem to be fairly independent of the grain size. Therefore the time required for reaching a given degree of solidification increases with the reciprocal of the square of the grain size. After the solid portions of the adsorbed films have come into contact the clay is again in a solid state.

In nature every bed of sedimentary clay is in a solid state unless it has been disturbed by soil movements or by construction operations. However, when increasing the pressure on a bed of sedimentary clay by more than a certain amount, q_c , the rigid bond between the clay particles breaks whereupon the clay passes again temporarily into the lubricated state. The excess pressure q_c required for breaking the bond will be called the critical pressure. Construction experience seems to indicate that the critical pressure is of the same order of magnitude as the nonconfined compressive strength of the clay.

The pressure exerted by ^{only mentions} a pile foundation onto a bed of clay located below the points of the piles can either be smaller or greater than the critical pressure q_c . If it is smaller than q_c the presence of the clay has practically no influence on the settlement of the pile foundation. On the other hand, if it is greater than q_c the bond between the clay particles breaks as indicated in Fig. 1c. In this state it is highly compressible. As a consequence it undergoes the well-known process of consolidation. At the outset of this process practically the entire weight of the surcharge is carried by an excess hydrostatic pressure in the water contained in the voids of the clay. This has repeatedly been demonstrated by direct measurement in the field. As consolidation

(a minor example)

proceeds, the excess water gradually drains out of the clay and the settlement of the structure increases. However, as a result of the failure of the bond between the clay particles the clay has also passed into the lubricated state, involving the presence of liquid films between the individual clay particles and the clay does not return into the solid state until the contact between the solid portions of the adsorbed films has been reestablished. In this connection we must consider two possibilities. Either the solidification of the clay occurs simultaneously with the consolidation or else the solidification continues after the consolidation is complete. In the first case the time-settlement curve should be in agreement with the theory of consolidation while in the second case the settlement due to consolidation should be followed by a supplementary settlement which cannot be accounted for by a process of consolidation. Both field and laboratory experience demonstrates that we have to deal almost exclusively with the second case. Figs. 2a and b represent the results of a consolidation test on a typical clay, plotted on an arithmetic and on a semi-logarithmic scale respectively. In both diagrams the plain curve represents the test result and the shape of the corresponding theoretical time-consolidation curve. The difference between the ordinates of the dashed and the plain curve indicates the decrease of the void ratio associated with the process of solidification. As long as consolidation proceeds part of the load on the clay is carried by an excess hydrostatic pressure in the water and the balance by the liquid friction within the liquid adsorbed films which separate the clay particles from each other. After the consolidation is practically complete, the entire load is carried by liquid friction within the adsorbed layers until the contact between the solid films is established.

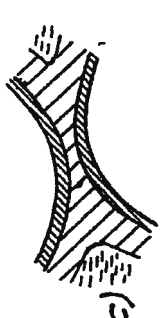
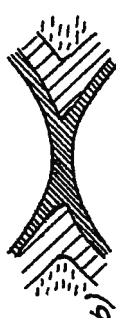
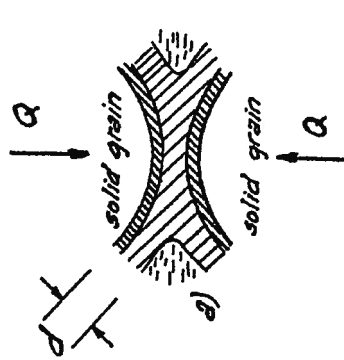
Since every particle of a moist or air-dried soil is surrounded by a film of adsorbed water the secondary time effect should not be limited to clays. This conclusion is corroborated by the results of confined compression tests on

sands. Fig.2c and d represents the relation between time and decrease of void ratio for a fine, moist quartz powder at constant load. In the left hand diagram the data have been plotted on an arithmetic and in the right hand diagram on a semi-logarithmic scale. Since the voids of the sand were partly filled with air the secondary time effect is not preceded by a process of consolidation. In perfect analogy to the secondary time effect in clays, represented by the slope of the straight line bc in the semi-logarithmic plot in Fig.2b. the slope of the line which represents the secondary time effect for sand in the semi-logarithmic plot Fig.2d is also a constant over the entire period of observation.

So far the only attempt to establish a theory of the secondary time effect has been made by Taylor and Marchant (1940). The theory has been worked out for the purpose of predicting the secondary time effect in the field on the basis of data obtained from consolidation tests in the laboratory. The theory is based on assuming that the rate of secondary compression follows a simple law resembling that for viscous flow or for creep. In reality this law is likely to be very complicated, for two reasons. First of all the viscosity of the liquid part of the adsorbed layers decreases with increasing distance from the surface of the solid particles. Second, as the rate of slippage at the points of contacts decreases, the resistance due to the viscosity of the adsorbed films combines with a supplementary resistance due to thixotropic stiffening, that means due to the building up of stable groups of molecules within the adsorbed layers. Hence, before accepting the theory for practical usage, it would be advisable to investigate the importance of the error due to the assumptions by comparing the computed and the real secondary time effect in several typical cases. This could even be done for existing buildings with a known settlement record.

Bibliography.

Taylor, D. W. and Merchant, W., (1940). A theory of clay consolidation accounting for secondary compression, Journ. Math. and Physics. Vol. XIX, No.3.



- ▨ solid ads. water
- ▨▨ liquid ads. water
- ▨▨▨ normal water

Figure 1

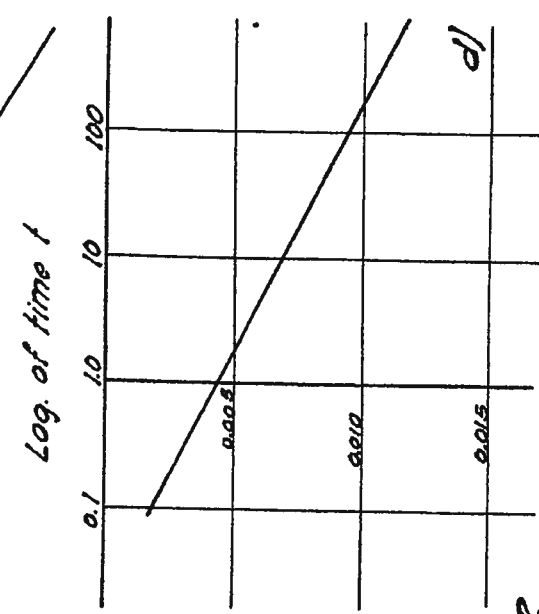
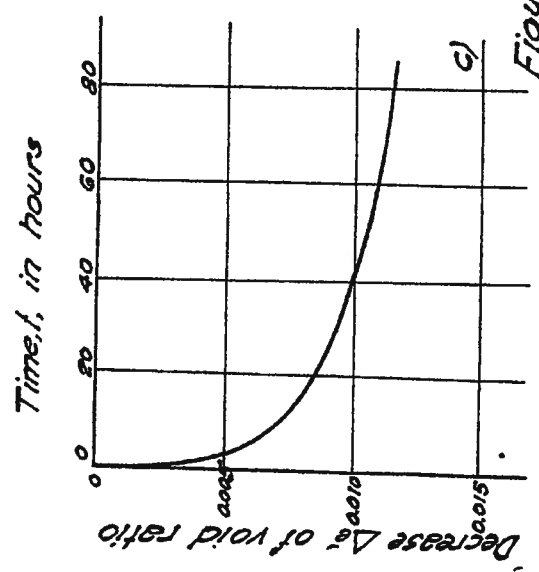
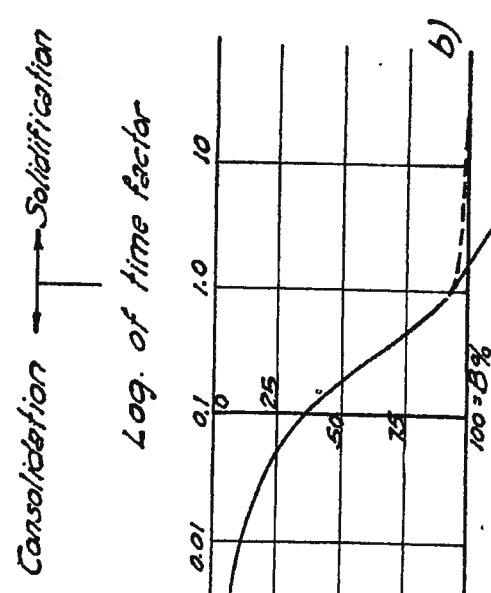
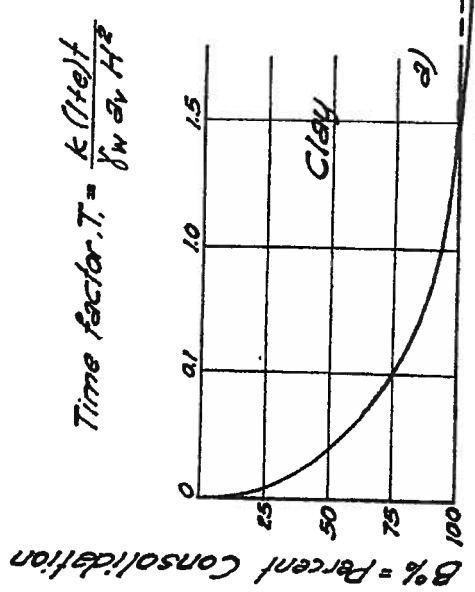


Figure 2