Deformation phenomena in collapsible soils

Le phénomène de déformation dans les sols collapsibles

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SYNOPSIS: It has been found that in the soil subjected to long-term moistening there occurs a deformation phenomenon due to soil compression both in the lower collapsible and in the underlying non-collapsible layers. Some regularities of development of this phenomenon are given. The important role of low permeability layers is indicated on which the domes of water filtrated from above are formed. Settlements are usually the greatest under the tops of the domes.

Experimental studies of 1970-80-s carried out on developed industrial sites with 2-nd soil condition type on collapsibility, established deformation phenomena as a result of long-term soil moistening (Grigoryan 1983, 1986). The 2nd type includes soil layers that compress if moistened under the weight of overlaying soils. The distinctive difference of these deformations from those of ordinary collapsible consists in the fact that if soils are moistened in downward direction soil compression takes place both in lower collapsible and underlying layers.

Earlier, it was a common belief that by moistening compression occurs in collapsible soil layers alone. Compression of the soil layers is testified by displacements of deep benchmarks installed from the earth surface at different depths with respect to a fixed (secular) benchmark. Below, data on settlements of a group of deep benchmarks set at 6-11 m from a building within the area of an energetic machine-building plant in Rostov region are given in Figure 1. The benchmarks are set at the depth of 6,12, 22, 26, 31, 37, 60 m from the earth surface. Collapsible layers occur up to 18 m depth marked at the figure by the dotted line. The greatest relative collapsibility ε_{sl} = 0.057 was found at the depth of 10-12 m from the earth surface. Porosity of the soil at this depth is 49.6-52.8 %. Moisture content of the collapsible layers lays within S_r = 0.45-0.57. Below the soil is water-saturated. The ground-water table (GWT) before the construction started was at 28.5 depth. At the time of benchmarks installation (August, 1983) the ground water table was registered at 20.6m depth, i.e. it has raised by 8 m. Monitoring of deep benchmarks settlements was held since August, 1983 to August, 1987 (18 levelling campaigns have been carried out). During this time the ground water table raised by 2 m and additional settlement achieved 12 cm; 8 cm of which being due to compression of non-collapsible almost fully saturated soils. Before the deep benchmarks were installed 15 cm settlement had occured on the site in accordance with surface benchmarks data. Therefore, the total settlement was 27 cm. Soil moistening was mainly provoked by technogeneous waters leakage from water supply lines as well as from atmospheric water precipitation on i.e. downward. Saucer-shaped depressions appeared on the earth surface.

The deformation saucers monitoring data in some regions of the Ukraine show that the greatest settlements at the centre of the saucers reach 1- 1.5 m and the greatest dimensions of the saucers is 250 m. Layers deeper than 12 - 15 m depth are the most intensively compressed; at such a depth soils normally feature low or practically negligible collapsibility.

These deformations are due to own soil weight and water pressure while loads from structures of ordinary types do practically not influence on their development. Consequently, the structures undergo absolute and relative settlements equal to the earth surface settlements at their location as regards to the developing deformation saucer . In this case the collapse due to external load (the weight of a building or a structure) is impossible since the collapsibility of the soils in the active zone under footings i either liquidated or this zone is cut through by deep footings.

Development in time of a deformation saucer when it is subjected to long-term steady moistening is characterized by the following stages:

(1) beginning of settlements development;
(2) active period of settlements development;
(3) deceleration and stabilization of settlements.

These stages can be discriminated on the settlements curve of the corner columh A-14 of the same plant building in Figure 2. The beginning of settlements 1979-1981, active period 1981-1985, beginning of deceleration 1985. The settlements are not still stabilized within this area.

The settlement curve is approximated by the following function

$$y = a + \frac{b}{x} + \frac{c}{x^2} + \frac{d}{x^3} ;$$

with y - settlements /s/, x - time /t/, a, b, c, d - coefficients. For the case in question a = 310.7/s/, b = - 801 /st /,

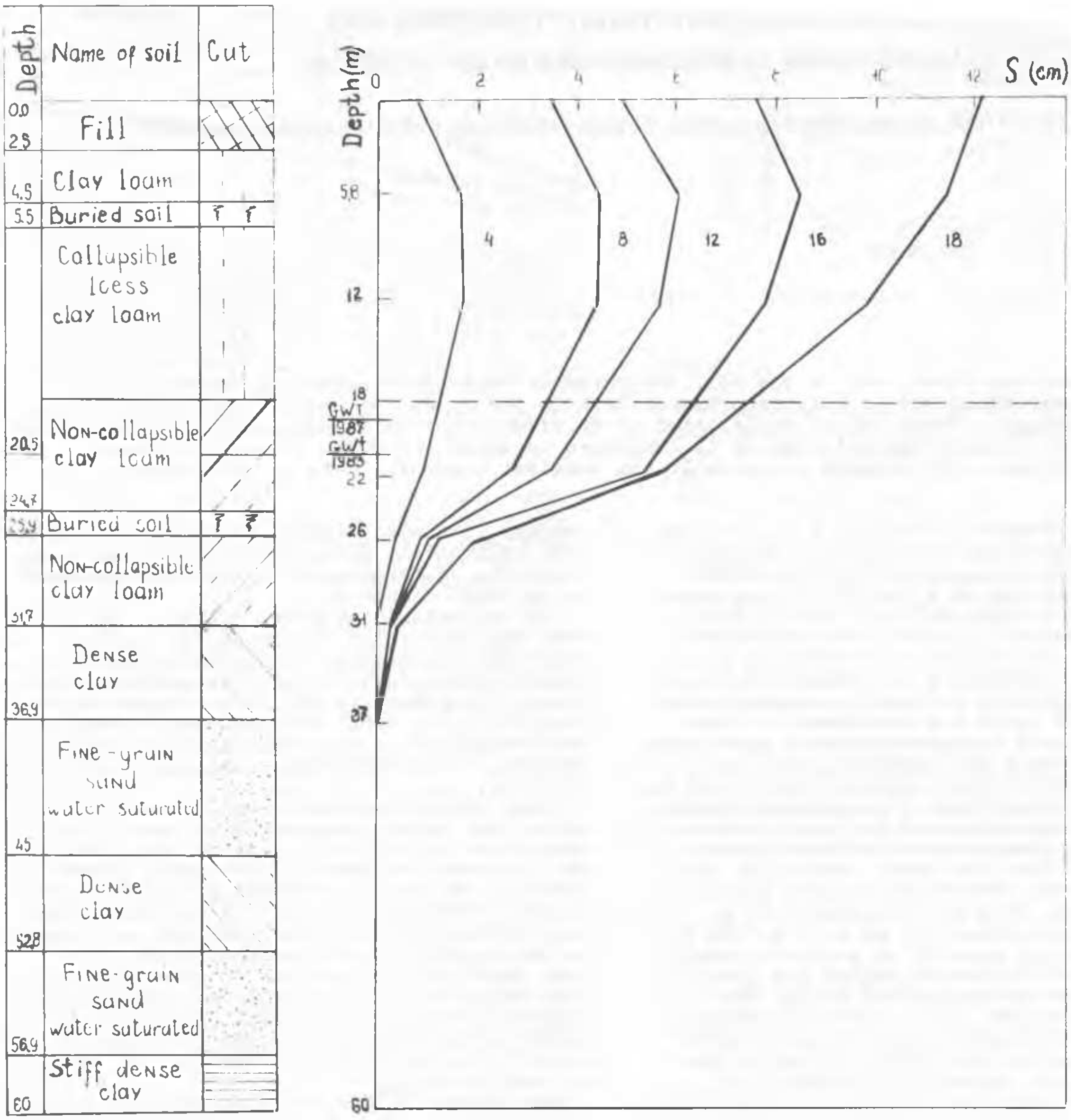

Figure 1. Geological section of the site and deep benchmarks curves for different levelling compaigns.

c = 492.2 /st^2/, d = 4.6 /st^3/. The free term "a" is the maximum possible settlement of the footing equal to 31 cm. Correlation index is equal to 0.977. The curve has a S-shape and represents the total process of settlements development for $x \geq 1$.

The mentioned building was erected on cast-in-situ piles 22 m long that cut through the collapsible soil layer. The earth surface settlements as registered by surface benchmarks installed near the column and of the column are practically equal.

Deformation phenomena due to long-term moistening start spontaneously and their development is long. Structures that happen to be located on the slopes of the deformation saucers turn to their centers and get inclined. It is important that compression of the layers during that active period of the settlements takes place at considerable depths from the earth surface, 12-35 m as a rule, with considerable horizontal expansion of the deformation phenomenon that leads to rather low relative settlements of buildings and structures that normally do not exceed 0.006.

The cause of the deformation phenomenon has its theoretical and practical significance. Besides known factors inevitable for ordinary collapse such as low moisture content and high porosity, formation of water domes over dense

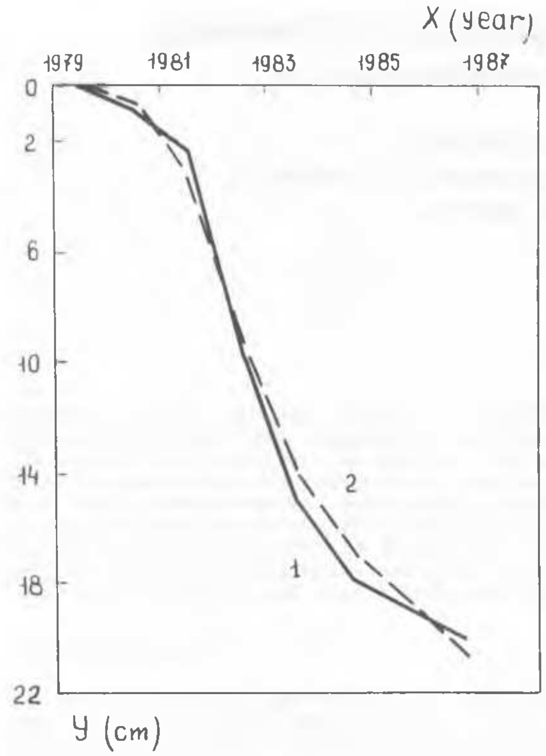

Figure 2. Pile footing settlements curve of column A-14 located within the zone of deformation phenomenon
(1) from field measurements
(2) from analytical data.

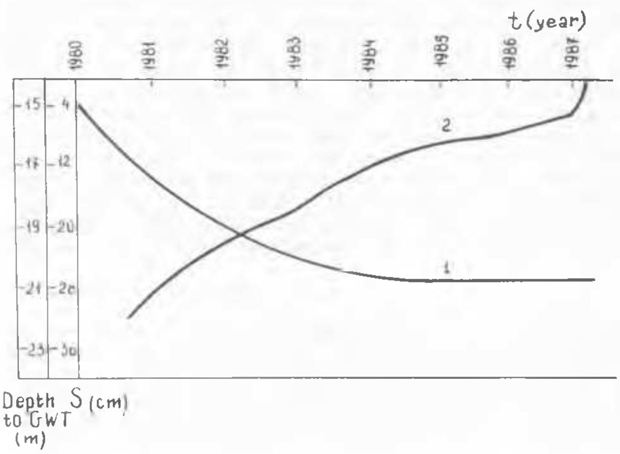

Figure 3. Curves 1-H-1 column settlements (s) versus time (t) curve and 2 - underground water table (GWT) rise.

soil layers that hamper filtration is essential. Such layers are frequently buried soils that are temporarily aquifluge.

Monitoring of real objects has shown that maximum settlements develop right at the places of water domes location. While water filtrates down and temporary water domes grow the settlements are develop. When water has passed through the layer completely the water dome merges with the ground water table rising from below. This merging results in weighing soils above the temporary aquitluge, the stresses in the soil structure decrease and the settlement stabilizes. Further watering of the soil layers from above and the resulting rise of the ground water table do not lead to considerable settlement growth.

Figure 3 shows a typical case of the settlements development of column H-1 of the Central laboratory of the same plant versus time. Ground water table rise is shown simultaneously on Figure 3. After 4-year long intensive settlements of this column since 1984 until now the settlements have not changed while ground water table continues to rise during the whole monitoring period. Numerical analysis shows satisfactory coincidence of total compression deformations of the layers with those measured on site before the beginning of settlements deceleration stage.

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