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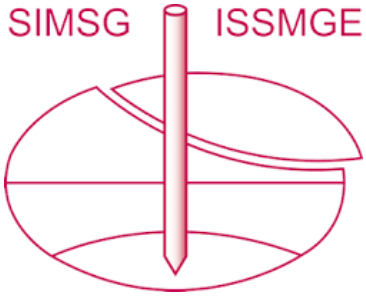

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On the Interaction between Structure and Loessial Soil

Sur l'Interaction entre la Structure et le Sol Loessique

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SYNOPSIS Full scale tests and also field measurements have revealed some peculiarities of the interaction between structures and foundation soil when the latter shows additional settlements due to wetting. Based on settlement observations, recorded over a period of more than ten years, on approximately 500 structures founded on loessial soils, correlations were established between their maximum and differential settlements. The paper describes some construction procedures and consolidation measures applied on sites where structures have been subjected to considerable tilting and settling due to accidental wetting of loessial soils.

1. GENERAL

Loess is a wide-spread foundation base over Romanian territory. If in-situ degree of saturation is less than 0.8 ... 0.9 and the soil is then submitted to additional wetting considerable settlements occur under the action of the own weight of the soil and/or under the loading transferred from the structure. These additional settlements may reach 3 ... 4% for each daN/sq.cm pressure increment. The original porosity of 45 ... 50% drops to 40 ... 42% after wetting. Besides their high values, settlements are usually very non-uniform, therefore inducing severe damages of structures and troubles in their normal use.

Extended studies and field works on this item have been carried out or supervised by the Civil Engineering Institute, the Hydraulic Research Institute, and the Building Research Institute in Bucharest.

2. LARGE SCALE EXPERIMENTS

2.1 Forecast of loessial soil behaviour over the area of some large cities in Romania

A thorough experimental programme was applied on the territory of some large cities in Romania. This programme involved in the main :

- surface flooding of square-shaped basins, whose sides were at least as long as the thickness of the underlying collapsible loess deposit;
- surface sand loading of 10 × 10 m size, up to 1 ... 2 daN/sq.cm pressures;
- special tests, varying from one site to the other, and involving : a central zone compacted by "earth piles" over the whole thickness of the collapsible loess deposit or only over a part of it; various founding systems (shallow foundations or piles).

Fig. 1 shows such an experimental plot, on a thick collapsible loess soil, liable to subside, when wetted, under its own weight. The main results obtained are as follows:

- deep compaction considerably reduces settlements by wetting under soil own weight.

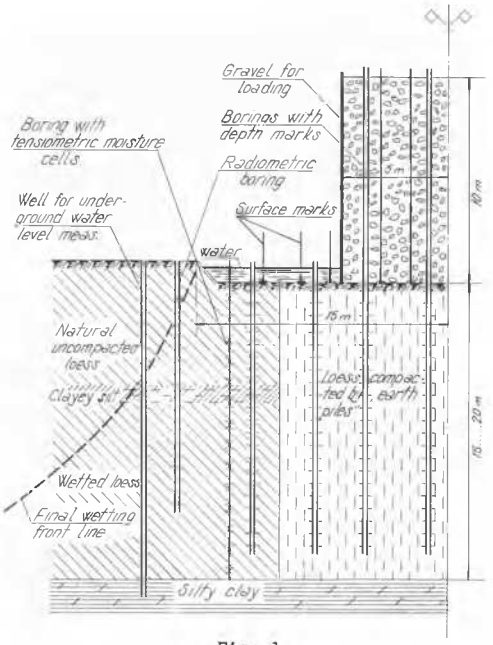

Fig. 1

- by deep compaction the loading of the soil up to 1.5 ... 2 daN/sq.cm becomes possible; settlements are in this case compatible with the normal operation of common buildings.
- the negative skin friction exerted by the surrounding, uncompacted, wetted soil on the compacted soil mass is acting over a distance approx. equal to one-third of the compacted thickness (Fig. 2) and induces a fundamental change in the vertical distribution of settlements under soil own weight (Fig. 3). For the uncompacted soil the settlements are larger on the deep zone, whereas in the compacted mass the contribution of the shallow zone is much increased.

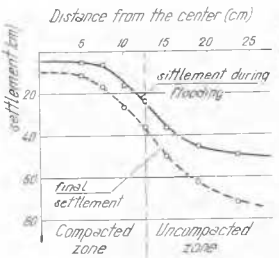

Fig. 2

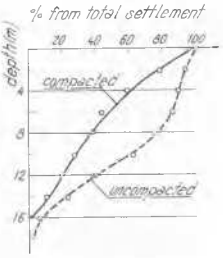

Fig. 3

- by deep compaction the advancing rate of the wetting water front towards deep zones is reduced by 3 ... 4 times.

An attempt to simulate the behaviour of the wetted loess deposit under a sand flexible load showed that a non-linear model where the Young modulus E and Poisson's ratio υ are modified, within a finite element programme, at each load increment, according to the shear stress stage attained by the soil, is able to describe the main features of the load/settlement relation pointed out by in-situ measurements (Fig. 4). The model ensures also a better approach to observed values than elastic calculations, as regarding stress distribution on the depth (Fig. 5).

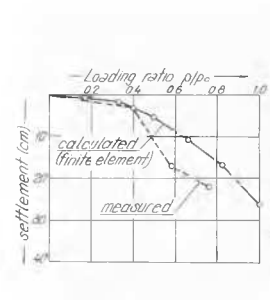

Fig. 4

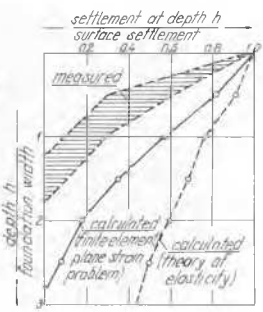

Fig. 5

2.2 Controlled wetting of foundation soil under an apartment building

Ten to fifteen years ago a group of five-storey apartment buildings was founded on a collapsible loessial deposit of 12 ... 15 m thickness; only a layer of 6 m had been compacted just under the foundations. Later on, casual wetting of soil and the heave of the underground water level caused the settlement of the underlying loess mass - remained uncompacted - and nuisant deformations of some structures occurred.

For estimating the settlement potential and searching the proper means to control the additional settlements it was proceeded to soil wetting by injecting water into the ground under the base of an apartment building of 240 sq.m area. On the average, 60 ... 70 litres per sq.m and day were introduced; the wetted zone attained 400 sq.m, i.e. it extended by 2 ... 3 m outside the limits of the building.

It was found that pore water gradually moved downwards and induced the wetting and settlement of the lower part of the loessial deposit, after the end of injections. Although settlements by controlled wetting reached 18 cm (with a maximum rate of 1.2 cm/day) no structural damage was observed during this operation : on the contrary, previous deformations have been partially restored.

Controlled wetting under existing structures with the aim to exhaust the settlement potential has been already suggested and applied /Chernyi, 1968; Dikovski, 1975/ without getting, however, into current use. The above-mentioned experimental results prove the possibility to extend this procedure even in very difficult situations, when settlements under the own weight of the soil are preponderant and attain large values.

2.3 In-situ observations on the effect of foundation soil collapse by wetting on soil/structure interaction

In order to study the behaviour of structures founded on compacted loess over the entire thickness of collapsible layer and subjected to differential settlements due to wetting of the foundation loessial soil, in-situ observations were initiated on a five-storey apartment building 12 m wide and 20 m long, whose structure consists on longitudinal and transversal reinforced concrete diaphragm walls, with continuous foundation beams resting on a compacted loess deposit of 20 m thickness. The experiment was meant to reveal the soil/structure interaction (a) when relatively small non-uniform settlements occur by local accidental wetting of the foundation soil, and (b) when large differential settlements are to be expected due to the collapse of loessial deposit caused by the rise of groundwater table.

Throughout both construction stage and experimental stage, settlements, contact pressures, quantities of water injected into the

ground, and changes in moisture content of the soil under foundations were observed. Measurements were also taken to record the structure response to differential settlements. The main features of the soil/structure interaction recorded so far are summarized in Fig. 6. Local wetting of the com-

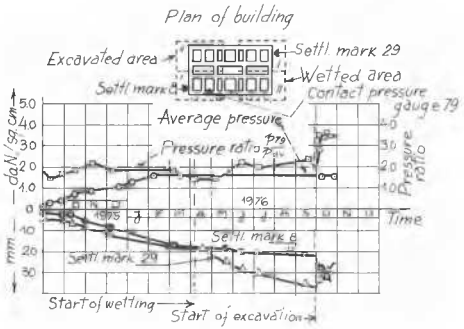

Fig. 6

pacted soil (a) can cause a redistribution of contact pressures up to 30% of initial values which is thrown onto the adjoining non-wetted parts of the contact. In turn, this redistribution has induced a general "torsional settlement" of the building of 0.12‰/10 m and a differential settlement due to bending effect of 13.6/20 m. The corresponding values recorded during excavation under the foundations, which simulates large settlements (b), are: redistribution of contact pressure up to 48% from initial values, "torsional settlement" 0.06‰/10 m differential settlement 17.7/12 m.

It is estimated that during experiments the structure of building was subjected to a maximum additional bending moment of 28000 kN.m and shear force of 2000 kN, without causing serious damages.

The experiment is being in progress to record soil/structure interaction over a longer period of time.

2.4 Loess compaction by prewetting and deep explosions

Experimental study was based on a method developed and applied in the USSR /Litvinov, 1973/. The procedure intended to hasten and intensify the compaction of collapsible loess deposits by an abundant prewetting associated with deep explosions. Experiments were performed in 1974 and 1975 on a test plot of 62 × 31 m, the loess deposit being approx. 20 m thick. Prewetting was ensured by 100 mm dia. borings 14 m deep, located at 3.5 ... 4 m distances; the same boring served also for bursting.

Explosions provoked a sudden subsidence of about 80 cm of ground surface, accompanied by an intense water expulsion from the borings; this expulsion went on more slowly during the subsequent 24 hours. The settlement process was prologed: 20 days after bursting an additional settlement of about 50% as against the first day value was recorded. Three months later, average final settlements reached 150 ... 170 cm over the central area and about 120 cm near the sides of the plot. The average settlement obtained exclusively by surface flooding during 100 days on a neighbouring plot was only 50 cm.

By laboratory tests and subsequent plate loading tests it was stated that prewetting and deep explosions allow the complete removal of loess collapsivity.

3. STATISTICAL ANALYSIS AND PREDICTION OF SETTLEMENTS DUE TO WETTING OF THE LOESSIAL FOUNDATION SOIL

The additional settlement due to wetting of the loessial soils may mainly occur either (1) under pressures transmitted by the structures (sometimes these settlements are reactivated at each new local wetting of the soil) or (2) due to the heave of groundwater table which may, in turn, be local or over a large area.

To separate the effects of these two factors out of the total surface settlement is a difficult task; a method to analyse the available measurements and observations carried out over a period of ten years, on approximately 500 structures, mainly five-storey apartment buildings, 16 ... 44 m long and 11 ... 16 m wide, has tentatively been proposed. The settlement observations were taken at each corner of the buildings, and the tiltings θ, torsion effects δ, and ratio between minimum and maximum settlements α were computed from corner settlements (Fig.7). The following conclusions may be drawn from the available measurements:

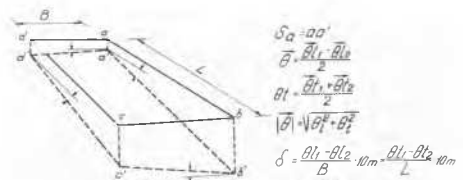

Fig. 7

- the tilting of structure does not necessarily increase when settlements are increased; sometimes a decrease of tilting or even a coming back to vertical of the building is recorded. A considerable variation of tilting direction is also revealed by the observations (Fig. 8).
- tall buildings with high structural rigidity have undergone tiltings as high as 8 ‰ without any damage for the structure or its normal operation; diaphragm wall structures have shown also torsion or bending effects which increase with the increasing maximum tilting, but this situation occurred only for maximum tilting less than 8 ‰. In addition, the probability that this type of structure should not

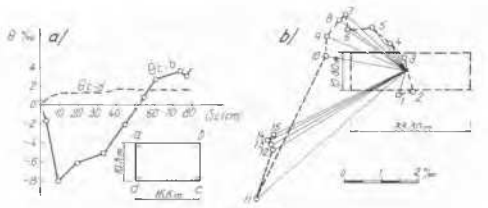

Fig. 8

suffer damages is about 90% if tilting is less than 6 °/oo and torsion does not exceed 0.8 °/oo in 10 metres.

- the predominant component of the settlement could be identified from phenomenon history. An example of such identification is rendered in Fig. 9 where the effects of groundwater table heave (1), local infiltration (2) as well as settlement reactivation due to wetting of the active zone (3) are revealed.

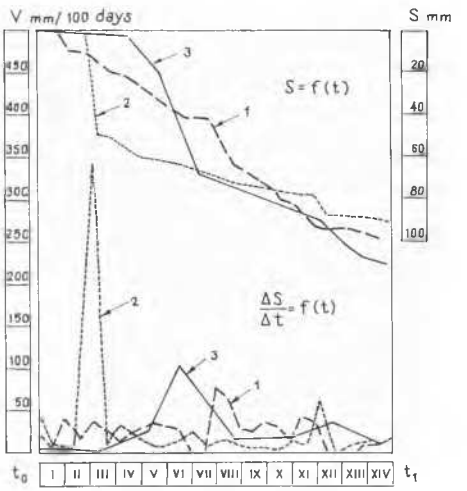

Fig. 9

4. PREVENTING AND REMEDIAL MEASURES

a. The method of "earth piles" has been frequently used in Romania as a means of compaction down to 10 ... 12 m of the loess deposit. Adequate technology and equipment for "earth piles" down to 20 ... 22 m have recently been developed.

The experience gained so far in Romania may be summarized as follows:

- "earth piles" of 40 ... 50 cm dia. and up to 20 ... 22 m long may be formed by using a special drop hammer having a weight of 15 kN and falling from 1 ... 1.5 m, at a rate of 40 ... 45 drops per minute. With this procedure the average time to form one meter of "earth pile" is approx. 5 min. The porosity of loess drops down to 38 ... 40%.
- static penetration is used to check the compaction of the soil. The device is mounted on a 8-ton truck; radiometric measurements are also used to determine soil unit weight (gamma-ray absorption) and moisture content (neutron scattering) in borings of 60 mm dia., without tubing.
- negative friction occurs on a zone around and inside the compacted area, and does not exceed one third of the collapsible depth.

b. Technical measures to remediate excessive tilting of structures due to soil wetting have been proposed and applied in some cases. They consist of controlled wetting of the soil together with soil grouting and also of controlled excavations under the foundations in the unsettled zone.

c. Electro-silicification has been largely applied in Romania to consolidate loessial soils having high moisture content. Recently, this method has been used to consolidate the foundation soil under the National Theatre Building in Iassy. The building had been erected by the end of the 19th century and has undergone damages due both to local wetting of soil and the heave of groundwater table.

The grouting was meant to reduce loess collapsivity over a zone down under the present groundwater table, to increase the contact area between the foundation and the loessial soil, and also to decrease the non-uniformity of contact pressures so that the maximum effective pressure should drop from 2.9 ... 4.3 daN/sq.cm to 1.6 ... 1.8 daN per sq.cm.

In a period of three months a volume of 6,600 cu.m of soil has been consolidated by grouting through 2,000 injectors down to 3 ... 4 m in 2 ... 3 grouting stages of 1 ... 1.5 m each. A natrium silicate solution of 1.15 density was used in an amount of 300 liters per each cu.m of grouted soil. The action radius of injectors varied between 0.4 and 0.55 m. The grouted soil has shown a compressive strength of 1.5 ... 2.4 daN/sq.cm. The treated zone became completely insensitive to water action.

REFERENCES

CHERNYI, B.I. (1968). O stroitelstve grazhdanskhih zdanii na lëssovyh osnovaniyah. "Mekhanicheskie svoistva gruntov i voprosy stroitelstva zdanii na uvlazhnyaemyh lëssovyh osnovaniyah", p.109-125.

DIKOVSKI, A. (1975). Opyt uplotneniya prosadochnyh gruntov v osnovanii sooruzheniya organizovannyh uvlazhneniyam. "Osnovaniya, fundamenty i mekhanika gruntov", No. 4, p.6 - 8.

LITVINOV, I.M. (1973). Contribution to the Specialty Session "Methods of soil stabilization", Proc. 8th Int. Conf. Soil Mech. Found. Eng., Vol.4.3, p.365-367.