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PRINCIPLES GOVERNING INTERPRETATION OF RESULTS OBTAINED
THROUGH THE EXPLORATION OF SOILS FOR FOUNDATION PURPOSES

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The present state of soil science and the growing ranks of engineers and practical builders familiar with this new branch of Structural Engineering, brings forward the necessity of working out--even in the first approximation--building rules for a foundation design based on the principles of soil mechanics. Such rules would contribute to a more conscious application of the modern principles of soil exploration and stimulate in the ranks of builders a greater interest in the observation of settlements of the structures which they had erected. This, in turn, would help to accelerate the accumulation of results of widely extended experience which is necessary for the correction of the accepted theoretical principles.

It is very important to unify the methods of soil exploration adopted in various countries, as it would provide the possibility of an extensive exchange of experience between the builders, in the same way as it is done in other branches of structural engineering.

Therefore, it would be useful to discuss the basic principles adopted by the All Union Foundation Research Institute of the USSR for the design of foundations on soft soils.

These are as follows:

1. The preliminary soil study, which supplements the general geological exploration, is carried out for the entire depth of the bearing strata. This depth is determined from the data concerning the relative increase of the normal vertical pressure in soil, as compared with the same pressure due to the soils own weight.

Curves of pressure distribution in soil from a uniform, as well as a triangular loading, have been plotted for this purpose according to the general equation of Prof. N. M. Gersevanov for spatial rigid foundations with ratios of sides 1:1, 1:2, 1:3, 1:5, 1:10 and 1:∞ (Fig. 1)

The boundaries of the bearing strata are graphically determined by means of these standard curves in the following way:

A curve showing the distribution of vertical pressure with the increase in the depth of the soil strata is drawn to the right side of the foundation axis, while a curve showing the increase of pressure γz_0 produced by the soils own weight is drawn to the left side of the same (y denoting the depth of the point under investigation, and γ_0 - the weight per unit of volume of the given soil. This weight is assumed to be diminished by hydrostatic uplift pressure if the degree of saturation is 0.75, i.e. if more than 75% of voids are filled with water. In this case $\gamma_0 = \frac{\gamma - \Delta}{1 + \epsilon_0}$, where γ is the specific weight of the soil, Δ - the specific weight of water = 1, and ϵ_0 the voids ratio of the undisturbed soil). The boundary of the bearing strata is assumed at the elevation below which the pressure, produced by the external loading, attains 0.3 of the pressure existing in the soil before the erection of the structure.

In the indicated way the sizes of the loaded area, the pressure transmitted to the soil and the relative increase of the pressure in the soil are considered; which points are of interest only to an engineer.

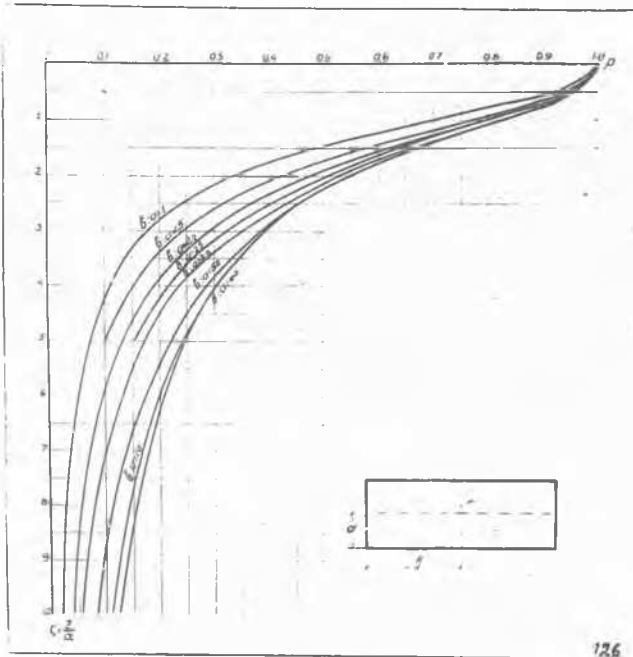


Fig. 1

2. In accordance with the rigidity or elasticity of the soil skeleton (sands or clays) the following physical properties are determined.

a. For sands. The weight γ_0 per unit of volume of the undisturbed soil (i.e. the natural structure and water content of the soil being preserved), the specific weight of the soil γ , the water content, W (From these data the porosity and the degree of saturation are determined; the porosity corresponding to the given water content being computed by the formula

$$N_w = \left(1 - \frac{\gamma_0}{(1+W)\gamma}\right) \times 100$$

W the granular constituency, the angle of natural slope, the consolidation curve and the coefficient of permeability.

For cohesive soils: The weight per unit of volume of the soil, the natural structure and water content of the same being preserved, the specific weight and the water content of the soil, Atterberg's plasticity limits, the granular constituency, the consolidation curve, the value of capillary pressure, the coefficient of permeability, the molecular moisture holding capacity and the shear resistance (if necessary).

Both types of soil are tested in the field in

order to determine the generalized modulus of elasticity E.

The loading test is carried out at the elevation of foundation base, with a standard plate having an area of 5000 sq cm and as well for each of the layers contained within the bearing strata. These are tested in bore hole by means of a plate, the area of which is less than 600 sq cm. This plate is lowered in the hole on a previously planed surface of the undisturbed layer. The load is applied gradually, being increased by 0.25 or 0.5 kg per sq cm, according to the compactness of the soil.

After each increment of the loading an interval is made during which the time-settlement relation is observed, until a conditional stabilization of the settlement is reached (i.e. if the settlement is not more than 1 mm per day). The time of this interval depends on the exactness of the settlement indicators.

The loading test is continued until the ultimate pressure is reached, which is determined by the following symptoms: by the bulging out of the soil, by a sharp increase of the settlement corresponding to the same increments of loading as before, and finally by a continuous and uniform velocity of the settlement during more than 24 hours.

3. The obtained data are worked up for each single physical characteristic according to the commonly used principles of statistical mechanics. If the ratio of probability that a given layer is confined within an interval differing less than by 2-3% from the next one is equal or exceeds 0.5 according to the formula of Gauss, then it is considered as uniform.

This adaptation permits the indication of the most characteristic (most frequently repeated) physical properties for each layer (the voids ratio and the granular constituency for sands, the coefficient of plasticity and the consistency for cohesive soils, the condition of moisture and the degree of saturation, the modulus of elasticity, the coefficient of consolidation, as well as the limit of proportionality, the ultimate pressure and the character of the time-settlement curves).

4. In order to arrive at a certain decision the results are interpreted, taking into consideration the character of the structure and the stiffness of the same being regarded as a spatial system, according to the indications of Prof. K. Terzaghi which he already pointed out during the first discussion organized by the American Society of Civil Engineers.

For this purpose the most commonly used types of structures are divided in the following groups:

- I Absolutely rigid structures, for which no relative shift of their parts is possible, but which settles as a single spatial integer, e.g.--chimneys, silos on continuous plates, etc.
- II Comparatively rigid structures consisting of elements rigidly connected in all directions, including the lines of footings, but in which a very small relative shift is possible e.g.--framed structures of reinforced concrete, structures supported by foundation walls having a complete perimeter, buildings with brick bearing walls, with reinforced concrete floors, with closely distributed cross walls, etc.
- III Partially rigid structures, in which the various elements are rigidly connected only in some directions, e.g. shored structures as frames supported by single foundations, or by foundation walls running only in one direction, etc.

IV Nonrigid structures which consist of single self-supporting columns supported by single foundations, and of freely supported roof-trusses, the relative shift of which does not produce additional stresses in the elements of the structure.

The group to which the given structure is to be referred is determined through the individual investigation of each single case.

5. The structure is placed directly on the ground if the soil is characterized by the following properties:

a. The settlement of structures in Groups I and II must be uniform and the value of this settlement must be admissible from the point of view of the conditions of their use.

b. The difference between the settlements of the individual foundations of structures belonging to Group III must not exceed the limit admissible for the given structure from the point of view of the possible deformations of the same.

c. The difference between the settlements of single columns of structures belonging to Group III must not disturb the general statical equilibrium and stability of the structure.

At the same time for all groups of structures the additional settlement caused by different factors, as the fluctuations of groundwater level or of temperature, must be uniform under the entire area of the structure.

6. The settlements of foundations in soils with a degree of saturation > 0.75 is computed by the formula

$$S = \sum a_n \frac{\sigma_n - \sigma_g}{1 + \epsilon_0} \times dh$$

where S is the final value of settlement, a_n - the coefficient of consolidation determined through the laboratory consolidation test or field loading test, dh - the height of the elementary layer within the depth of which the pressure is assumed to be constant, ϵ_0 - the voids ratio of the soil in natural state.

For relatively dry soils the settlement is computed by the formula

$$S = \sum \frac{\sigma_n - \sigma_s}{E_n} \times dh$$

where σ_n is the average stress produced within the layer under consideration by the external loading.

σ_s - the stress in the elementary layer produced by the own weight of the soil;

E_n - modulus of elasticity as determined through the tests.

7. The admissible pressure on a uniform soil is determined for structures in Groups I and II in connection with the full settlement of the entire structure.

For structures in Group III the admissible pressure is determined individually considering the general design of the structure and its use, but this pressure must not exceed the limit of proportionality determined through the tests.

For structures in Group IV the admissible pressure is determined from the ultimate pressure (see 2) taking a factor of safety 1.25 for relatively dry soils, and 1.50 for saturated soils.

If the ground is represented by plastic clay or by saturated silt with a small coefficient of permeability, then a bed of coarse gravel is made which serves as a drainage.

8. If a yielding (weak) layer is contained within the bearing strata, then the values of admissible pressure for structures in Groups III and IV are corrected according to the bearing value of this weak layer. It is to strive that the pressure transmitted to the soil would be of one and the same sign.

For cohesive soils in the plastic state the minimum edge stress at the base of the foundation must not be less than 0.25 of the maximum edge pressure.

9. If the ground is represented by a non-uniform soil but of one and the same lithological type and if the time settlement relation for the given soil has a uniform character, then the admissible pressure is determined, according to the aforementioned principle, from the mean values of E and " a ", from the limit of proportionality and from the ultimate pressure.

In designing structures in Group III the possibility of a difference in settlements exceeding the admissible one is considered.

The admissible difference between settlements of individual foundations included in one and the same design-scheme is determined as the double value of the deflection of the minimum span of the given structure.

10. For a continuous construction with single foundations and with ratio of its sides exceeding 1:2 for cohesive soils and 1:5 for non-cohesive soils, the value of admissible pressure is corrected so as to obtain an admissible difference between the settlements of the given structure.

11. If the soil strata within the area occupied by the structure area are non-uniform and if they are represented by different lithological types, having a different character of time-settlement relation, then the problem of the appropriate foundation system may be solved in following different variants.

For structures in Groups I and II, if they can not be divided into parts which would settle independently the depth of the foundation is determined so as to provide a minimum settlement, or to attain a uniform layer of soil (at least from the lithological point of view).

For structures in Groups III and IV the allowable pressure is designated independently for each type of soil, the structure being divided into parts by settlement joints.

12. If the value of the allowable pressure, as determined according to the aforesaid principles, can not be accepted from the economical point of view, and if at the same time the voids ratio of the undisturbed soil sharply reduces, with an increase of pressure; as it can be seen from a considerable curvature of the consolidation curve, then measures for an artificial consolidation of the soil are adopted or a deep foundation reaching a reliable layer is designed.

An artificial consolidation of the soil is adopted for relatively dry soils. It is attained by means of sand piles (or gravel, etc.) The same method can be adopted for watersoaked soils if the water can be easily forced out. In other cases pile foundations consisting of wood or reinforced concrete piles are designed according to the required depth; also the method of foundation construction under previous lowering of the groundwater by well points is adopted. For considerable depths different other known methods are applied which would suit the given conditions.

13. If the soil is uniform but has a "large voided" structure, and therefore deformations of the soil even after the final stabilization of the settlement can be produced through the accidental moistening of the soil (e.g. from a water supply, etc), then an entire offset of any accidental water from the bearing strata is required, or the soil is improved by means of sand piles.

14. The attention of the builder is drawn by the design to the necessity of preserving the natural soil conditions in order to avoid the loosening of sand or the bulging out of clay. The location of observation points is also indicated in the design. These points must be distributed over the entire area occupied by the structure and their settlements must be carefully and systematically observed beginning from the moment of laying of the foundation.