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Foundations of Structures — (A) General Subjects of Theory and Practice of Foundations Engineering on Natural Soils (Other than Piled Foundations)

Fondations — (A) Questions générales de la théorie et de la pratique de la construction des fondations sur sols naturels

General Report

General Reporter : Prof. N. A. Tsytovich, D. Sc. (Eng.), Corresponding Member of the U.S.S.R. Academy of Sciences, Active Member of the U.S.S.R. Academy of Construction and Architecture

Introduction

Problems of theory and practice of Foundations Engineering on natural soil bases are of particular importance to a great number of engineers and scientists. This, among other things, is evidenced by the fact that 53 papers have been presented under this Division (3A) to the present Vth International Conference on Soil Mechanics and Foundations Engineering [Paris, 1961].

In order to emphasize the most important and valuable ideas contributed by each paper tō our knowledge in this field, to make the discussion more systematic and to isolate the most important problems which require detailed consideration at this High Assembly, the General Reporter has combined all the Division 3A papers into the following six groups :

1. Bearing capacity of soils : 13 papers;
2. Stress distribution in soils, including the contact problem : 6 papers;
3. Settlement of foundations : 13 papers;
4. Calculation and design of foundations : 7 papers;
5. Foundations in peculiar soil conditions : 8 papers;
6. Special problems (stability, dynamics, particular cases of foundations engineering : 6 papers.

Most of the papers describe the results of especially staged experiments and field observations which enable verification of particular theoretical statements and estimates, and provide the experimental base of the premises for the further development of the calculation theory; besides, 30 per cent of the papers are devoted to the elaboration of theoretical problems.

The main problem in the theory and practice of foundations engineering consists in the calculation and design of foundations.

In fact, all the other isolated groups of papers cover only particular aspects of this central problem. Thus, investigations into the bearing capacity of soils are necessary only for establishing the maximum permissible pressures in the bases. These pressures, however, will depend not only on the properties of the soils, but also on the dimensions of the foundations, their rigidity and the sensitivity of the structures to settlement. The service behaviour of the structures will be determined, not by the pressures in the structure base, if they do not exceed the limit values, but by the deformations (settlements) of the base soils, their magnitude and especially the non-uniformity and settlement rate.

1. Bearing Capacity of Soils

At present, investigations of the bearing capacity of soil foundations are based on ultimate equilibrium conditions, many of the suggested solutions being approximate, since the configuration of the slip surfaces developing in the soil under the action of an external load and the dead load of the soil are usually considered as given, and the solutions obtained satisfy the static conditions of the problem.

Thus, for instance, in papers on the bearing capacity of soils presented at the IVth Conference, the configurations of the slip surfaces were assumed to be known either in accordance with the solutions obtained previously (3A/26) or from the results of observations (3A/33) and (3A/41), or were selected taking into account the results of accurate solutions (3A/5), or, finally, had an arbitrary outline with subsequently gradual refinement (paper 5/4).

The following two general remarks should be made prior to proceeding with the general statement of the problem.

First—The ultimate equilibrium condition (the strength condition) is usually represented by the Coulomb equation which states that ultimate shear strength at a given point is a first power function of normal pressure, which corresponds to a linear Mohr envelope whereas for a number of soils the Mohr envelope is, as a rule, curvilinear.

Plastic soils are apparently more appropriately covered by the condition of R. Mises which states that the intensity of shear-stress is a direct function of the intensity of shear strain which is well approximated, for instance, by the power law.

Second—Many statically acceptable solutions may exist for one given problem of the ultimate stress theory. By a *statically acceptable* solution we mean any stress field satisfying equilibrium equations, the strength condition and the predetermined boundary conditions. As Prof. J. Brinch Hansen pointed out in his report at the IVth Conference on Soil

Mechanics and Foundations Engineering [London, 1957], the true solution will be one which is not only statically acceptable, but also *kinematically acceptable*. The latter is assumed to be any stress field concommittant with a field of displacement velocities in the initial stage of continuous plastic flow.

For practical applications one should pay attention to the kinematic theory of D. Drucker and W. Prager [2]* which assumes the following relationships between the components of mutually compatible stress and rate-of-strain tensors :

$$\left.\begin{aligned} \dot{\varepsilon}_x &= \lambda\left[\frac{\sigma_x - \sigma_y}{2} - \sigma \sin^2 \varphi\right] \\ \dot{\varepsilon}_y &= \lambda\left[\frac{\sigma_x + \sigma_y}{2} - \sigma \sin^2 \varphi\right] \\ 1/2\ \dot{\gamma}_{xy} &= \lambda\tau_{xy} \end{aligned}\right\} \quad \ldots \quad (1)$$

where $\dot{\varepsilon}_x$, $\dot{\varepsilon}_y$ and $\dot{\gamma}_{xy}$ are the respective rates of relative strains

$$\lambda = \frac{\sqrt{(\dot{\varepsilon}_x - \dot{\varepsilon}_y)^2 + \dot{\gamma}^2_{xy}}}{2\,\sigma \sin \varphi};\ \sigma = \frac{\sigma_x + \sigma_y}{2} + c.\text{ctg}\ \varphi.$$

Unfortunately, very few solutions satisfying both static and kinematic conditions of compatibility have been obtained so far owing to their exclusive complexity.

The papers on the bearing capacity of soils submitted to the Vth Conference cover : (a) theoretico-experimental investigations (6 papers) substantiating the principles of the suggested solutions; (b) the description of foundation tests in respect of the bearing capacity of soils (4 papers); and (c) particular problems of the bearing capacity of soils (3 papers).

(a) *Theoretico-experimental investigations:*

It should be noted that two types of solutions must be distinguished in analyzing the bearing capacity of soils, namely : (1) the type corresponding to the rigorous statement of the problem, where the shape of the slip surfaces developing in the soil in ultimate equilibrium conditions results from the solutions of F. Kötter's differential equations (1), and (2) the type where the shape of the slip surfaces is considered as given and substantiated essentially by the results of special experiments.

As is well known, the general method for the integration of F. Kötter's equations for the conditions of the two-dimensional problem was worked out in the U.S.S.R. by V. Sokolovsky [3] and later succesfully applied by V. Berezantsev [4] for the case of the axially symmetrical problem. At present, the Computing Centre of the U.S.S.R. Academy of Sciences has compiled tables to use this calculation method for the computation of the bearing capacity of soils and the stability of masses of soil; one of the tables is presented in the paper of M. Malyshev and I. Fjoedorov (3A/28) which we include in group a). This paper suggests an approximate method for the computation of the bearing capacity of soils, taking into account the finite width of the foundation and the effect or normal eccentric load, as well as moment. The proposed method is based on the rigorous solution of the theory of ultimate equilibrium of a loose medium (after V. Sokolovsky). The paper presents a grapho-analytical method for the determination of the ultimate value of reactive pressures for a strip of a definite width, accompanied by tabulated values of the bearing capacity factors.

The second part of the paper (I. Fjedorov) uses the solution of the *mixed problem* of the elastic-plastic equilibrium of a loose wedge under an inclined load to determine the dimensions of the plastic regions. It has turned out, for instance (at $\varphi = 30°$, $c = 0{\cdot}2$ kg/sq. cm and $p = 3{\cdot}1$ kg/sq. cm) that the magnitude of the plastic region is twice smaller that in the calculations for the Coulomb-Mohr plasticity condition with the aid of the stress components in the elastic solution (see Fig. 7, 3A/28).

This Section also includes Paper 3A/24 by A. Kézdi which considers the solution of the two-dimensional problem of the theory of ultimate equilibrium of an imponderable loose wedge with an inclined and uniformly load acting on its platform. The solution obtained is then extended to the case of the penetration of a settlement plate under the action of an inclined force, the suggested relationship approaching the formula of A. W. Skempton [1951] in a particular case (at $\varphi = 0$). It should be necessary to compare the numerical results obtained with the results of the rigorous solution of this problem after V. Sokolovsky [3] to whose work the author of the paper refers, or to verify them by appropriate experiments.

Of great interest are the experimental investigations of the configurations of failure surfaces in dry sand quoted by A. R. Jumikis (3A/23). As a result of a great number of carefully conducted experiments, A. Jumikis established that the failure surface developing in sand under the action of an inclined force is well described by a polar curve of a ogarithmic spiral whose parameters depend on the angle of internal friction of the sand, the width of the model, the point of application and the direction of the resultant force. The data obtained may be used in working out a semi-empirical method for the determination of the bearing capacity and for the computation of the stability of strip foundations under the action of inclined forces.

The bearing capacity of rigid foundations under the action of inclined forces is also considered by E. Zaharescu (3A/52) which presents interesting photos of a soil wedge below a foundation, originating under the action of inclined forces on the foundation. On the basis of his experiments, E. Zaharescu also assumes that the position of the edges of a compacted soil wedge has the shape of straight lines inclined at an angle $\alpha = \varphi + \delta$ and $\beta = \varphi - \delta$, where δ is the angle of inclination of the resultant force to the normal. The simple relationships obtained are very enducing, but they require verification, since the accurate solution gives a curvilinear shape of the compacted soil wedge. In addition to this, the adopted diagram of the rupture line envelope (Fig. 4) can hardly be regarded as probable. By comparing the relation introduced by E. Zaharescu for the bearing capacity of foundations with the experiments made on models, concording results have been obtained but only in the case of higher experimental angles of internal friction ; this must be explained by difference of values of external pressure in the case of model experiments and in the case of the laboratory measurement of the angle of internal friction. The results of the experimental investigation of ultimate loads may be used in improving the methods of computation.

The same purpose will be served by the results of the unique experiment on the determination of the bearing capacity of a bridge support (with an area of 56·5 sq. m) described by Z. Wilun (3A/50) which has demonstrated the significant importance of preloading.

The problem of the bearing capacity of foundations under the action of inclined forces is also treated in the highly interesting Paper by J. Biarez, M. Burel and B. Wack (3A/7) describing experiments with model material (thin aluminium rods) investigating flow lines in sands by the photographic method * which enables drawing important

* Figures in brackets relate to the references at the end of the report.

* The photographic method for the investigations of flow lines in soils was originally proposed by Prof. V. Kurdiumov, a Russian scientist (1891).

conclusions for the further development of the theory. The authors of the paper present a clear-cut configuration of the compacted soil wedge, and state that the bearing capacity factor increases with depth according to the linear law, that the total bearing capacity increases as the square of the footing width (under the conditions of the two-dimensional problem), and the lateral friction — as the square of the depth of the foundation. The quantitative results of the determination of the bearing capacity of foundations are very close to the results of computations using formulas of the ultimate equilibrium theory (see, e.g. [4]). At the same time, the direction of the trajectories of the movement of the particles of the model soil in zones located within the depth of the foundation requires refinement, because it disagrees with the results of other investigations, for instance those published in the Proceedings of the IVth International Conference.

A great number of papers, both those of basic significance and those refining the value of the computed bearing capacity factors of soils belong to the second type of solutions where the shape of the slip surfaces is preset.

Of this type of formulas, the bearing capacity formula derived by K. Terzaghi (1943) is most popular. The derivation of this formula [5] is based on the use of the configurations of the rupture lines obtained without considering the volumetric forces due to the dead weight of the soil, but considering the existence of a compacted soil wedge under the foundation and the effect of the foundation depth and the overburden consisting in the weight of the soil layer from the surface down to the level of the foundation footing.

As is well known, the Terzaghi formula is :

$$q_f = c \cdot N_c + \gamma \, D \cdot N_q + \gamma \frac{B}{2} \cdot N_y \qquad (2)$$

where N_c, N_q and N_y are bearing capacity factors;
c = soil cohesion;
γ = soil bulk density;
D and B = respectively depth and width of foundation.

The thesis of Shen Cgu-Tsien [7] prepared at the Moscow Civil Engineering Institute under the direction of the General Reporter demonstrates that the replacement of the foundation depth by a lateral overburden makes any solution kinematically impossible, and the true ultimate bearing capacity will always exceed the one determined by such formulas, which fact is confirmed by the results of numerous experiments.

(b) *The description of foundations tests:*

Papers (3A/26), (3A/4), (3A/17) and (3A/13) are included in the group devoted to the experimental investigation of the bearing capacity of soil foundations, mainly to the elucidation of the values of computed bearing capacity factors and the effect of the shape of the footing area of foundations on their bearing capacity.

R. L'Herminier, P. Habib, J. Tcheng and J. Bernede (3A/26) describe the results of the effect of the shape of shallow foundations on their bearing capacity (P. Habib, J. Bernède) and the investigation of the bearing capacity of round and square settlement plates under field conditions (R. L'Herminier, J. Tcheng).

As a result of a tremendous number of laboratory and field tests carried out by the authors, they state that :

1. In determining the bearing capacity of sands the role of cohesion in sands should be taken into account;

2. L. Prandtl's formula is well corroborated for ideally cohesive soils (at $\varphi = 0$).

3. Despite the considerable scatter of the experimental data it has been established that the experimental values of the bearing capacity exceed the theoretical data 1·5-2·5 times.

4. The bearing capacity of a square foundation is about 1·2-1·25 times as great as a strip foundation.

Bent Hansen (3A/17) describes the results of detailed laboratory tests of the bearing capacity of circular plates on sand. These tests were accompanied by thorough investigations of strength characteristics of sand (values φ and c) on triaxial apparatus, which is of scientific and practical interest in itself, and were aimed at determining the bearing capacity factors, N_γ and N_q, in the Terzaghi formula. Experiments have shown that the bearing capacity of circular plates on sand by far exceeds the formula values. It should be important to compare the very interesting experimental data obtained with the results of the rigorous ultimate equilibrium theory, for instance with the well known solution of the axially-symmetrical problem.

The same conclusion that the bearing capacity of sand soils considerably exceeds the value computed by the formulae of K. Terzaghi [5] as well as of A. Caquot and J. Kerisel [6] is arrived at by E. E. De Beer and B. Ladanyi whose Paper (3A/4) describes the results of their laboratory experiments on the determination of the bearing capacity of sand under shallow foundations. The authors of this paper also aimed at determining the factor allowing to pass from the capacity of a circular foundation to that of a rectangular foundation.

The Bent Hansen's paper also establishes a significant difference in the behaviour of dense and loose sand under load. The latter problem was thoroughly investigated by J. Feda (3A/13) who established two types of failure : local (in dense sands) and general (in loose sands) whose shape depends also on the dimensions of the footing area and the depth of the foundations. Furthermore, the paper establishes an empirical exponential relation between the bearing capacity factor, N_γ , and the magnitude of the angle of internal friction of the soil. The measured value of the bearing capacity is in good agreement with computations by the formula of V. Berezantsev.

(c) *Particular problems:*

Papers (3A/3), (3A/43), and (3A/31) are included in the Section of particular problems of the bearing capacity of soil foundations.

A. Balla (3A/3) describes the ultimate strength of mushroom foundations of transmission lines of power and uses the results of experimental investigations of rupture surfaces originating in the sand when pulling out the foundation, and their approximation with circular lines, to derive a formula for the ultimate load for pulling out foundations, formula which yields results that well agree with the experimental data. This work is undoubtedly of practical value.

Wishing to reconcile the contradictory results of the computed and experimental data on the bearing capacity for shallow foundations, and to avoid excessively underrated results, H. U. Smoltczyk (3A/43) suggests a somewhat new approach for the estimation of the bearing capacity of foundations, based on the hypothesis that the critical load corresponds to the upheaval of the boundary region of the topsoil near the foundations due to the deviator stress. The paper is based on the previous works of the same author and on a number of assumptions (which arguments are not given). Thus, many things remain unclear for the lack of a detailed presentation of the assumptions made.

V. Mencl and L. Pruška (3A/31) consider two problems associated with the stability of soils : first, the necessity of a differentiated approach to the selection of the safety factor and its division into a number of factors (V. Mencl), which is already known in the technical literature to some extent (see, Ctenerol Report of Division 3A, Fourth International Conference and the U.S.S.R. Construction Standards); second (L. Pruška), the value of pore pressures and effective stresses in a three-phase system of the soil at the initial moment of its consolidation; this problem has never been studied in such detail.

It is interesting to see that the value of the pore pressure falls off considerably for unsaturated soils, even at the initial moment (Fig. 3, etc.). The results of the computed pore pressures are compared with the measurements made in the soils of the footing of an oil tank (Cooling, L. F., 1955) and the authors' opinion is that a satisfactory agreement has been reached. The paper does not indicate, however, how the results obtained should be used in calculating the strength and stability of soils.

To conclude this part of the report, we shall note that the more up-to-date problems in the considerated field should apparently be the following: the development of works on the application of the kinematic method of analysis of the ultimate bearing capacity of soils, the further elaboration of rigorous methods of the ultimate equilibrium theory, the solutions of the mixed problem of the theory of elasticity and plasticity accompanied by simultaneous field observations and the comparison of the theoretical data with the experimental ones with the aim of establishing the degree of confidence in the theoretical methods of computation.

2. Stress Distribution in Soils Including the Contact Problem

Six papers on stress distribution in soils have been presented to this Vth International Conference on Soil Mechanics and Foundations Engineering. Four of them cover theoretical problems: (3A/39), (3A/42), (3A/44), (3A/41).

There are also two papers on the experimental determination of pressures over foundation bases, namely: (3A/21) and (3A/45).

R. L. Schiffman and B. D. Aggarwala (3A/39) emphasizes that in determining stresses and displacements under a rigid rectangular settlement plate, an approximation could be made by using the formulae obtained for an elliptical settlement plate.

The paper presents the Boussinesq's formula for contact stresses under an elliptical settlement plate and general formulae for stresses and displacements in a halfspace. Graphs are given for the determination of stresses along the vertical symmetry axis. The report points out that stresses can be determined experimentally on the basis of electric analogy.

J. Škopek (3A/42) gives formulae for vertical normal stresses under a uniform load distributed within an elastic halfspace at a certain depth from its surface under a horizontal infinite strip and a rectangle. The solution has been obtained by integrating the well-known formulae of Melan and Mindlin. It is of great importance for the calculation of structures layed in the soil, for instance, anchor plates. The author himself indicates, however, that this scheme is suitable only for soils capable of withstanding tensile stresses.

Data are also presented on stress distribution in the case where the load is transferred by a settlement plate filling a rectangular cut near the surface of a halfplane; these data have been obtained by the photoelasticity method. They point to the softening of the stress concentration at the edges as compared with the results of M. Sadovsky for a shallow settlement plate.

I. Sovinc (3A/44) gives a formula for the determination of stresses in a thick rectangular plate loaded at the centre of the upper surface over a rectangular surface. The place rests on an incompressible base. From a sufficiently great plate surface area, compared with the loaded surface, the author derives the solution for the case of an infinite elastic layer on an incompressible base. A graph is given for the determination of vertical stresses inside the layer, and of the settlements at different levels for the Poisson ratio value $T = 0{\cdot}5$.

It is well known that the problem considered in the paper has attracted the attention of a great number of scientists and, as we have noted before, is most comprehensively covered in the works of D. M. Burmister (1956) [8], M. I. Gorbunov-Posadov [9] and others. The author's contribution consists in the fact that he has given an analytical solution which is rather approximate, but has a relatively simple analytical form.

E. Schultze (3A/41) sets forth a method of approximation of M. Sadovsky's solution for contact pressures under a rigid strip, to diagrams of pressures under foundations established by field measurements. To this end, a method is suggested taking into account the effect on the pressure diagram of the zones of plastic strain originating in the soil under the foundation edges. The author uses M. Sadovsky's formula for the middle part of the diagram; he suggests that the determination of the pressure diagram at the foundation edges should be carried out according to the limit pressure equation after Prandtl-Buisman, provided that the diagram has no failure at the separation of elastic and plastic sections. The results obtained are compared with all the field-measured pressure diagrams known to the author, and a qualitative agreement of the results is observed.

It should be mentioned that similar methods for evaluating the effect of plastic strains were suggested in the U.S.S.R. by V. A. Florin (1937, 1959) [12], M. I. Gorbunov-Posadov (1949, 1953) [9] and others. However, the solutions of these authors, as well as that of Schultze, are of conventional nature since they neglect problems associated with the extention of plastic zones down to a certain depth and the origination of an elastic soil wedge under the foundation base.

The summary of field measurements is of great scientific interest, though it cannot be regarded as complete.

The introduction of the safety factor into the calculations of edge pressures (as is done in the paper) seems to be unjustified. On the one hand, this factor increases the divergence between the experimental and theoretical data, and on the other hand, it is not generally included in the safety margin when calculating foundation strength.

J. H. Hubbard and E. A. Lotz (3A/21) deal with the determination of the optimum (in respect of stability) underground part of an anti-flood wall by using photoelasticity methods. The underground part has the shape of the shelf of letter *T* with a spur. Gelatine was used for modelling the soil. The paper includes isochromes photos and isostat graphs, as well as the corresponding calculated curves of normal and tangent stresses along the edge verticals and the most probable rupture plane. The paper does not contain any radically new information, but it provides a practical solution to a particular problem.

H. B. Sutherland and J. A. Lindsay (3A/45) quote data on the results of measurements of stresses under the foundations of two adjacent pillars transferring loads of 230 and 30 tons. In order to measure the stress, the foundations were supported on 16 and 9 separate blocks respectively, with string dynamometres placed between the foundations and the blocks. The results obtained correspond to the theoretical data on the distribution of stresses under a rigid foundation on cohesive soils; the bending moments calculated according to the experimental stress diagram proved to be 10 per cent higher than in the case of usually assumed uniform distribution of reactive pressures.

3. Settlement of Structures

In the final analysis, civil engineers are interested, not in the stresses originating in the soil, particularly if they are below the limit values, but in the displacement of foundations dut to external loads. When investigating foundation displacements we distinguish their settlement (vertical displacement), slide (horizontal displacement) and subsidence (sudden irreversible local soil strains due to an abrupt change in the structure, for instance during the wetting of loess soils or the thawing of frozen soils which are often accompanied by the squeezing of the soil from under the foundation).

This Section will cover only the settlement and, in part, the horizontal displacement of foundations on compressible soils. Subsidence will be discussed in Section 5.

The basic components of the settlement of soil foundations are : (1) elastic deformations of soils and their consolidation under load; (2) plastic-viscous flows of the soil skeleton (so-called secondary consolidation) and (3) deformation originating under the effect of technological processes of construction. The latter type of settlement components may be quite considerable, but should be avoided by all means. It does not lend itself to analytical forecast with the exception of soil swelling during trench digging, and is not considered in the General Report.

Section (3) includes 13 papers and one additional paper (3A/44) previously mentioned in Section (2). For convenience, all these papers have been combined under the following heads :

(a) The determination of complete stabilized settlement of foundations : 4 papers (3A/44, 3A/51, 3A/11, 3A/18);

(b) Problems of the consolidation theory : 3 papers (3A/29, 3A/9, 3A/1) and problems of consolidation acceleration : 2 papers (3A/16 and 3A/30);

(c) The results of observation of structure settlement : 5 papers (3A/27, 3A/48, 3A/34, 3A/35 and 3A/12).

(a) *The Determination of Complete Settlement:*

All the above-enumerated papers of this group discuss the problem of determining the complete stabilized settlement of a soil layer of finite thickness; the first two papers (3A/44 and 3A/51) imply the action of a vertical, uniformly distributed load and the other two (3A/11 and 3A/18) the action of both a vertical and a horizontal load. The solutions given represent the further development of the theory of settlement calculation, which enables a closer approach to reality to be made, because natural soils always consist of one or several layers.

I. Sovinc (3A/44) develops the problem of D. Burmister [8] for a soil layer under the action of a load uniformly distributed over a rectangular platform and thus presents the solution to the problem of determining the settlement of different points inside a soil layer and on the surface; Figs. 3, 4, 5 and 6 show curves for the computation of the settlement. Note that the obtained values of surface settlement are very close to those obtained earlier by another method [9] and that, in addition, the use of the method of corner points eliminates the need for graphs 5 and 6; besides, if there is no friction on the contact plane, the dimensionless settlement factor can be computed independently of the value of ν.

K. E. Yegorov (3A/51) gives the general solution of the problem on the settlement and reactive pressures of a circular settlement plate on an elastic layer of finite thickness with an eccentric load. Observations of the settlement of a 23 m diameter smoke stack have shown a better agreement between the observed settlement and those computed by the suggested method as compared with the computed values ignoring the finite nature of the soil layer; it was established that shallow soil layers played the predominant role. The second part of the paper (A. A. Nichiporovich) contains the results of field measurements of the settlement of a number of hydro-engineering structures; of greatest interest are the data on the swelling of dense clayey soils of a trench bottom and also the approach to the evaluation of this swelling in the forecast of the settlement.

A very interesting paper, by E. H. Davis and H. Taylor (3A/11), uses the works of N. Steinbrenner [1934], D. M. Burmister [1956] and J. Mandel [1957] to consider the problem of displacements in different directions, of a corner of a rectangular platform on the surface of an elastic layer resting on a rigid base, under the action of a permanent vertical and horizontal load.

The solution is reduced to the computation of four weighing functions whose values, obtained with the aid of the " Silliac ", — the Sydney University Computer,—are quoted in the report in tabulated and, chiefly, graphical form.

The accuracy of the proposed solution is evaluated by comparing it with a particular case of the rigorous solution, and by confronting it with the results of specially staged experiments using the photoelasticity method. It has turned out that at $\frac{L}{D} = 4$ the error of the approximate solution will not exceed 17 per cent, and for horizontal displacements the proposed theory yields more accurate results.

R. M. Hardy, C. F. Ripley and K. L. Lee (3A/18) use field observations of one of the buildings of a metallurgical factory to establish a very simple geometrical relationship between horizontal displacements and the gradient of vertical settlements. The paper is interesting in that it draws one's attention to a phenomenon which is not receiving sufficient consideration in the theory of structure foundations.

(b) *Problems of the Consolidation Theory:*

Problems of consolidation held much attention at the previous, IVth Conference. Very interesting papers were presented, notably those on the problems of three-dimensional consolidation (authors : G. de Josselin de Jong; R. B. Gibson and J. McNamee; J. Mandel).

Submitted to this Conference are works dealing with the further elaboration of the problem of three-dimensional consolidation. Among the papers presented under this head, of greatest interest and importance is paper 3A/29 by J. Mandel quoting the results of the further development of his work published in the Proceedings of the IVth Conference (Paper 3A/21) and exhibiting additional graphs for the determination of complete settlement and degree of consolidation under the action of a loaded foundation on a thick layer of clay covered by a filter layer differing from the clay in compressibility.

S. J. Button (3A/9) presents auxiliary graphs for the determination of the integral of the vertical stresses from the surface down to some depth, and curves for the direct determination of settlement within a given time for strip and square foundations, taking into consideration only vertical drainage, and for a circular foundation under conditions of three-dimensional drainage. Judging from the references cited, in computing the graphs the authors assumed the soil to be uniform, and in a number of cases considered only one-dimensional drainage; therefore, in order to estimate the degree of accuracy of the results obtained, it would be very important to compare them with the results of a more rigorous solution, for instance according to J. Mandel's theory.

H. Aboshi and H. Monden (3A/1) point to the extreme mathematical complexity of computations according to the rigorous three-dimensional consolidation theory (M. A. Biot et al.) and suggest an approximate experimental method for the determination of cumulative settlement and the timing of settlement in the case of the three-dimensional problem of the consolidation theory by testing clay samples for triaxial compression at the corresponding value of the " equivalent stress ratio " and of the new notion of " equivalent drainage diameter " introduced by the authors. This suggestion is of great interest for computation practice, but it necessitates the comparison of the results obtained with the results of rigorous theoretical solutions or field observations.

The group of papers concerned with the problem of consolidation of saturated soils also includes papers (3A/16) and (3A/30) which consider the acceleration of consolidation processes by applying vertical drainage.

P. Habib (3A/16) describes a case of successful application of vertical drainage to a mound having a width of 30 m and a height of 8 m, on a layer of saturated, highly compressible, micaceous, sandy silts, embedded between two-metre layers of highly permeable sands. The boundary conditions corresponded to the classical problem of one-dimensional consolidation, which made possible their fairly accurate prediction and pointed to the necessity of accelerating the consolidation process, since the calculations showed that 80 per cent settlement would occur in 4 years, which could not be tolerated. The use of 30 cm dia. sand weep drains with a 3 m triangular grid enabled attaining 80 per cent settlement within less than one month. Burmister calculations were successfully used to compute the upheaval and settlement of a roadside chapel.

The example described has convincingly proved the high accuracy of the prediction of settlements, provided it is based on appropriate investigations of soils and a correct application of theory.

S. R. Mehra and T. K. Natarajan (3A/30) demonstrate a successful application of vertical drainage for the acceleration of the consolidation of a mound having an average height of 2·5 m (in places up to 4·6 m) on a 6·2 m layer of boggy deposits. The computations forecast up to 75 cm settlement at 50 per cent settlement in 7 years, which necessitated the application of vertical drainage, and this enabled attaining 68 per cent settlement during the first 10 months. To avoid rheological flows and to provide a gradual increment of the soil strength, the authors had to build up a mound in layers not exceeding 2 m each.

Although the method described is not new, it doubtlessly presents some interest, and its realisation is very valuable as an example of staging serious soil experimentation and a skilful utilization of soil mechanics methods for the successful solution of an actual problem posed by life.

(c) *The Results of Observations of Structure Settlements:*

Field observations were continued in order to establish the degree of accuracy of the theoretical methods for the forecasting of structure settlements.

Five papers have been submitted to the present Conference on this problem, namely : (3A/26), (3A/48), (3A/34), (3A/35) and (3A/11).

It is the General Reporter's belief that among these, J. Machado's one (3A/27) deserves special mention for the remarkable thoroughness of measurements and the comprehensive documentation both with regard to settlement itself and the properties of soils underlying the foundations. For a further detailed analysis it would be advisable to add structural cross sections of the buildings studied, which the reporter undoubtedly has in his possession, so as to enable the rigidity of these structures to be evaluated. On the whole, J. Machado's paper may be regarded as an exemplary work showing how to conduct observations of structure settlements.

In his paper, J. Machado draws comparison between the calculated and observed settlements of 4 high, 12-15-story buildings erected under very similar geological conditions on a layer of pure dense sand resting on soft organic clays. The measurements continued for 7 years since the foundations were set up; in two cases the pore pressure of the underlying clay layers was measured. The settlement forecast was carried out by using formulas of the one-dimensional theory of consolidation on the basis of careful œdometric testing of undisturbed specimens of the soil sampled by a 6 in. drilling unit. The author has arrived at the conclusion that the theoretical calculations are in full agreement with the observations.

M. Vargas (3A/47) presents the results of measurements of the settlements of 7 high buildings in Sao Paulo erected on dense sand overlying clayey deposits. The forecast of the settlement has been made on the basis of triaxial tests taking into consideration, not only vertical, but also horizontal normal stresses. The admissible pressure was determined by an empirical rule based on soil testing with a test load.

Two papers, by H. Peynircioglu (3A/33), (3A/34) render the results of observation of several buildings erected under different geological conditions on foundations of different systems, and compare the observed with the calculated settlements. The author finds it necessary to introduce corrections into the calculations, based on the results of soil testing with test loads, which may be disputed. Of great interest and value are the author's data on the magnitude of settlement of ancient buildings on the shores of the Golden Horn Bay reaching 180 cm, which is a vivid demonstration of flagrant errors made in the design stage when the entire attention was centred on the admissible pressures, rather than on the possible value of settlements and their non-uniformity.

D. U. Deere and M. T. Davisson (3A/12) describe vertical displacements (settlement and upheaval) of two reinforced concrete grain elevators on solid foundation slabs under a cyclic load varying in magnitude 3-5 times in the course of the year. The foundation slabs are embedded on alluvial deposits, they exhibited a non uniformed of settlement of up to 6·25 in. (15,9 cm) during 5 years, which was accompanied by serious disturbances in the slabs. In spite of the fact that the admissible pressures had been well substantiated by using test loads, inadmissible strains in the slabs arose, which shows clearly that when designing such foundations it is advisable to proceed from the magnitude and non-uniformity of settlement, rather than from the admissible pressures on the soil.

In winding up this Section, we shall note that, in the General Reporter's opinion, the expenses on the observations of settlement and other displacements of structure foundations can be justified only if they are accompanied by detailed testing of the soils (particularly by determining the characteristics of consolidation and shear strength) of the whole compressed zone under the foundation and are conducted from the initial moment of foundation loading, taking into account the rates of loading and the rigidity of the superfoundation structures. It is advisable to choose objects having the simplest possible system and shape of the foundations and a clear-cut distribution of external loads.

4. Foundation Calculation and Design

The analysis of the papers of the previous Section, as well as the references [10] show clearly that foundation calculation and design in respect of admissible pressures on the soil, neglecting the dimensions and the shape of their bases and the rigidity of the foundations does not always guarantee the steadiness (strength and stability) of the foundations and the structures themselves, so that often it is necessary to take into account the deformations (settlement) of compressible soils and their non-uniformity.

On computing flexible foundations it is necessary to consider simultaneously the behaviour of the foundation and of the deformating bases; on computing rigid (massive) foundations it is essential to keep in mind the base settlements, their non-uniformity and deformability of the superfoundation structures.

The papers to be considered in this Section are combined into the following groups :

(a) Flexible foundations;

(b) Rigid (massive) foundations;

(c) The peculiarities of designing foundations for certain types of structures.

(a) *Flexible Foundations:*

Three papers have been submitted under this head: (3A/14) by M. J. Gorbunov-Possadov and R. V. Serebrjanyi (3A/25) by D. Krsmanovic and (3A/48) by A. B. Vesic.

Paper (3A/14) describes the results of using the author's solutions to the problem of the interaction between bending foundations and deformed soil, which is assumed to be a uniform elastic (or linearly deformed) halfspace. These solutions have been developed in detail for the first time.

In the first part of the paper, M. I. Gorbunov-Possadov describes his methods for calculating foundation beams and slabs of any rigidity and dimensions in the plan, the base being rectangular. The author has made use of a formula for the linear relationship between the coefficients of a double power series expressing the distribution of normal pressures over a rectangular platform, and the coefficients of a similar series expressing the vertical displacements of the platform points.

The solutions have been shaped into tables and graphs of dimensionless computed curves of reactive pressures, bending moments and soil deformations corresponding to the overwhelming majority of types of loads and structures which are encountered in design practice. The radical simplification of computations permits a wide use of the elastic halfspace model in computing practice, which is successfully done in the U.S.S.R.

In the second part, R. V. Serebrjanyi describes a method for calculating hinged plates resting on an elastic layer o finite thickness, based on an accurate solution of the corresponding mathematical problem giving numerical values of computed magnitudes.

Paper (3A/25) by Krsmanović suggests a method for calculating discontinuous, free-lying foundations under the action of two symmetrical forces, taking into account the interaction between them and the elastic soil characterized by the deformation modulus E_s of soil. A comparison of the bending moments for discontinuous and continuous foundations has shown that the bending moments in a discontinuous foundation are much lower. However, the non-uniformity of settlement in a discontinuous foundation considerably exceeds that in a continuous one. Therefore, the author arrives at the conclusion that discontinuous foundations could be rationally used whenever the superfoundation structure has very low rigidity, i.e. when the non-uniformity of the settlement does not present any hazard, for instance in calculating individual sections of spillway dams.

The suggested calculation method has been reduced to graphs of calculated values which are very convenient for practical use, however, the presentation of the method itself and the premises for its substantiation are lacking in the paper (only a reference is given to the author's book, published in Sarayevo, apparently in Serbian), though a mention is made that the calculations require solving equation systems with many unknowns.

The value of the paper is enhanced by the thorough elaboration of the contribution due to the overburden from adjacent foundations.

Paper (3A/48) by A. Vesic is concerned with calculating foundation beams on an elastic Winklerian soil and setting the conditions under which calculations according to the hypothesis of a local elastic Winklerian soil do not differ essentially from calculations according to the hypothesis of uniform elastic halfspace. The author has demonstrated that Winkler's hypothesis can be applied in calculating long beams, which ensures insignificant disagreement with Biot's solution for an infinite beam on an elastic halfspace, provided the selection of the ratio of the bedding value and the deformation modulus of the soil is correct.

Some of the author's assumptions whose accuracy has not been evaluated by him (such as the approximation of $J_2(x)$, the conversion of the deformation modulus to the bedding value and the constancy of the linear bedding value for a settlement plate and a beam) had no appreciable effect on the calculation results, since the special, carefully conducted experiments of the author's resulted in a fair agreement between the calculated and experimental graphs of pressures and deflections, and small (up to about 12 per cent) divergences between bending moments.

As to when flexible foundations should be calculated according to Winkler's hypothesis and when, according to the hypothesis of an elastic halfspace, the following conclusion may be drawn on the basis of a special discussion of this problem [11]: in the case of weak bases with an insignificant layer of compressible soil resting on rock, more acceptable results are yielded by calculations according to Winkler's hypothesis, particularly for long beams; in all other cases and especially for dense uniform soils, calculations according to the hypothesis of an elastic halfspace would be closer to the reality.

(b) *Rigid (Massive) Foundations:*

As was reported at the IVth International Conference on Soil Mechanics (Paper 3A/31 by D. E. Polshin and R. A. Tokar), in calculating rigid, massive foundations the decisive data are the deformations of the superfoundation structures as a whole, rather than the deformations of the foundations themselves. This problem has been studied for many years at the Soil Base Research Institute of the U.S.S.R. Academy of Construction and Architecture, with the resulting conclusion that it is necessary to calculate massive foundations by settlement and differences in settlements, keeping in mind their rate limiting value which is determined from the deformation of the superfoundation structures.

This suggestion is substantiated in Paper (3A/32) by V. V. Mikhejev, D. E. Polshin, R. A. Tokar and V. P. Ushkalov submitted to the Vth Conference on Soil Mechanics. The most essential point in this paper consists in the suggestion that all structures should be designed by the magnitude of limit settlements, their difference and their rate. The paper demonstrates the practical feasibility of applying this principle not only to usual unfrozen soils, but also to permanently frozen soils and subsidable loesses. The condition for the applicability of settlement forecast in calculating bases by deformations consists in the prevention of large (exceeding 1/4 width of the foundation in depth) plastic regions (limit equilibrium zones) under foundations, which will take place wherever the pressure is below the so-called rated pressure determined from N. P. Puzyrevsky's formula (6) which is recommended by the authors.

The problem of the regional characteristics of soils similar to those mentioned in the paper, which the authors recommend only for preliminary calculations, requires discussion; this discussion must turn on the possibility to restrict the calculations of soil deformations to tabular compressibility values, because this would essentially simplify the application of the principle of calculating bases by deformations in design practice.

This Subsection also includes Paper 3A/46 by E. Tochkov on the determination of the height of sand cushions for massive foundations on highly compressible soils. The author's photoelastic investigations have led him to the conclusion that the application of a sand cushion whose thickness exceeds 0·2 of the foundation width eliminates the plastic regions at the foundation edges and shifts them towards the middle; then, assuming that the stresses at the edges of the sand cushion are equal to zero, and neglecting the difference in the compressibility of the cushion and the base, the author derives approximate formulas for determining the thickness of sand cushions for circular, square and long rectangular foundations, the thickness of the cushion being about 0·6 B, where B is the foundation half-width.

The results presented in the paper are of practical interest.

(c) *Peculiarities of Designing Foundations for Certain Types of Structures:*

This problem is treated in two papers : Paper (3A/37) by Don V. ROBERTS which reviews the types of foundations used under different soil conditions for cylindrical reservoirs in connection with the specific requirements, and Paper (3A/40) by W. R. SCHRIEVER, C. B. CRAWFORD and R. F. LEGGET discussing the erection of light structures on flexible concrete slabs layed on the surface of a clayey soil on gravel fillings. The paper presents the results of field observations of the behaviour of such slabs (20 sq. ft. by 6 in. thick on an 18 in. gravel filling). These observations have shown that the maximum change in the slab level due to the shrinkage and swelling of the clays does not exceed 3/8 in. and the frost heaving (when the building is not heated) — 1/2 in., and they lead the authors to the conclusion that the above-mentioned type of construction is quite reliable under the given climatic and soil conditions.

5. Foundations in Peculiar Soil Conditions

The General Reporter has combined separately some papers dealing with foundations on soils of regional significance and those possessing special properties : subsidence on wetting under load, considerable swelling on wetting, shrinkage on drying, etc. These reports include : Paper (3A/5) by A. BELES and I. STANCULESCO, (3A/8) by A. B. A. BRINK and B. A. KANTEY, (3A/19) by L. V. HATHERLY, (3A/20) by W. G. HOLTZ and J. W. HILF, (3A/22) by J. E. JENNINGS, (3A/36) by L. RÉTHÁTI, (3A/49) by B. P. WARKENTIN and M. BOZOZUK, and (3A/53) by J. G. ZEITLIN and A. KOMORNIK.

In Paper (3A/5), A. BELES and I. STANCULESCO describe methods which were used successfully for the elimination of considerable tilts in two structures on highly porous soils (Loesses) and supply of the construction work.

As a method for preventing uneven settlement of structures on such soils, the authors recommend a preliminary wetting of the loess soil with a subsequent deep compaction.

It should be noted that experience in preliminary wetting of loess soil to eliminate its subsidability has shown that the efficiency of this method increases if the upper layer remains unwetted and serves as an overburden for the lower wetted layers.

A very interesting and poorly covered problem of observed subsidence of eluvial soils (formed as a result of soil weathering in South Africa) on saturation under load is discussed in Paper 3A/8 by A. B. A. BRINK and B. A. KANTEY.

The unstable structure of the skeleton is formed as a result of the mechanical piping of the colloidal substance from well drained eluvial soils under the conditions of yearly torrential rains. Interesting data are quoted on the properties of weathered granite soils, their compressibility, etc.

The authors arrive at a correct conclusion that when building foundations on such soils one should proceed from the principle of admissible settlement rather than permissible soil pressure.

Paper (3A/19) by L. W. HATHERLY familiarizes us with the experience in designing shallow foundations for the light structure of the Court Building in Basra (Iraq) on non-water-saturated brown clays. These clays possess the property of swelling and shrinking on wetting in a disturbed state. The same soils having undisturbed structure proved to be insensitive to seasonal wetting.

If the structure of these soils is not disturbed, it is possible to decrease the depth of the foundations for the Court Building to 30 cm (instead of the usually adopted depth of 60-90 cm).

The large and well illustrated Paper (3A/20) by W. G. HOLTZ and J. W. HILF considers the problem of base settlement in dry soils having high porosity on water saturation. When building on such soils, a great number of dam and canal accidents occur, which can be illustrated with a number of examples.

The authors discuss the physical causes of settlement, using the concept of negative pore pressure. Examples are quoted relating to the design of canals and slopes on such soils accompanied by measures eliminating their subsidability by clay grouting, etc.

Paper (3A/22) by J. E. JENNINGS generalizes the observation data concerning deformations caused by the heaving of building foundations in South Africa on dried soils which swell on wetting. The swelling is forecast on the basis of a duplicate test in a compression apparatus (with loading and unloading).

A good agreement has been reached in the case of dried and cracked clayey soils ; sandy, silty soils or uncracking clays require correction factors.

Paper (3A/36) by L. RÉTHÁTI quotes the results of the inspection of 60 deformed buildings erected on made grounds, which have shown that in most cases deformation is caused by the infiltration of water into the soil. The deformation hazard is greater in the case of low buildings of relatively small rigidity and on drier made grounds.

The author points out that in constructing buildings on such soils it is necessary to determine the expected settlement due to their wetting.

Paper (3A/49) by B. P. WARKENTIN and M. BOZOZUK elucidates the results of the investigation of the shrinkage and swelling of two Canadian clays as a function of changes in the moisture content in the course of drying and wetting; the soils discussed are a low swelling marine clay (illite) and a high swelling lake clay (montmorillonite).

Great attention should be given to the authors' attempt to explain the laws of the shrinkage and swelling of clays under the conditions of external effects, by the influence of the different genesis and mineralogical compositions of the clays.

Paper (3A/53) by J. G. ZEITLIN and A. KOMORNIK treats on deformations of light buildings based on swelling clays, as a result of seasonal variations in their moisture content leading to changes in the volume.

The authors recommend to lay foundations at a depth of 2 m, providing sand moundings, and to increase the load acting on the foundations in other words they recommend measures similar to those applied in counteracting the frost-heaving of foundations.

6. Special Problems

This group includes papers covering the following problems : (a) stability; (b) dynamics of soil bases and foundations and (c) special cases in foundations engineering.

(a) *Stability of Foundations:*

The problem of foundation stability is treated in one report, Paper (3A/15) by M. M. GRISHIN and P. D. EVDOKIMOV who consider the slip stability of structures built on rock bases.

In determining the safety factor or stability under the conditions of plane slip (K_s) the authors proceed from the well-known expression :

$$K_s = \frac{f \cdot \sigma_m + c}{\tau_m}$$

where $\sigma_m = \dfrac{P - U}{BL}$ is average effective normal stress

$\tau_m = \dfrac{Q}{BL}$ is average slip stress,

P = being the normal force, Q = the slip force, U = the pressure of the filtered water, B = the width, L = the length of the building base, c and f = parameters of the slip strength. Thus in the case under study the problem of slip stability reduces to a substantiated determination of the slip resistance of the base. The paper generalizes the results of broad large-scale laboratory and field investigations of resistance to displacement and shear of contacts between concrete and rocks. It has turned out that this resistance is actually higher than the value usually adopted; besides, a great influence on slip strength is exerted by the complex stressed state as well as by the non-uniformity of the deformation properties of cracked rock bases.

An apparatus has been devised in Leningrad in order to study the strength properties of rocks and their contacts with concrete. This apparatus allows tests on specimens submitted to proportional, increasing stresses in all directions; it also allows complex stress states, with a tensile stress in one direction and a compressive stress in another. Investigations carried out with this apparatus have shown that the strength of rocks in the compression region can be satisfactorily described by the Mohr theory, in the tensile-compression stress-region by the second strength theory and in the region where tensile stresses exceed compression stresses in absolute value — by the hypothesis of octahedral stresses. Models made of brittle materials were used to investigate the behaviour of rock bases; the investigation showed different shapes of failure surfaces depending on the direction of the layers, and the necessity of different approaches to the calculation of bases.

(b) *Dynamics of Soil Bases and Foundations:*

Three papers deal with this subject : (3A/2), (3A/6) and (3A/38).

The first paper (3A/2), by H. A. Balakrishna Rao presents the results of detailed laboratory investigations into the conditions of a dynamic regime occurring in the soil bases of machine foundations; these are used by the author to suggest a method which permits evaluating the soil volume participating in the dynamic regime of the system. The author concludes that the classical formula for natural oscillations of massive foundations on the elastic base needs a correction for the weight of a certain volume of soil which acquires oscillation movement together with the foundation; it is recommended to assume this volume according to the shape of the Boussinesq's pressure bulb.

The method proposed by the author and the experimental data obtained on foundation oscillation, together with the elucidation of the role played by the duration of excitation in the dynamic regime of the bulk of the base soil, present definite interest and will be of great benefit for the further investigation into the conditions of work of foundations with dynamic loads.

Paper (3A/6) by L. Bendel and D. Bovet describes instrumentation for dynamic investigations of soil bases and quotes a few cases of its successful application for practical purposes. Of indisputable interest are a number of recently designed instruments, for instance the triaxial dynamic apparatus, as well as certain observations of the regime of oscillation propagation in the soil mass, in particular, the observed better penetration of waves having a higher oscillation frequency.

Paper (3A/38) by O. A. Savinov reports on the experience in searching for new ways of development of vibration methods for carrying out different operations accompanying the construction of bases and foundations. These searches have resulted in many new suggestions concerning the application of vibration machines for sinking thin-wall plunging wells, ground excavation, trenchless laying of pipes, water lifting from narrow drill holes, etc.

The main achievement in the development of the vibration method in construction work consists in the considerable success in the theoretical and experimental investigation of the process of vibration sinking which has shown that the successful application of vibration machines is possible not only for sinking a steel sheet pile and drill pipes, but also for piles having a sizeable cross section area.

(c) *Special Cases of Foundations Engineering:*

Two papers are included in this group : Paper (3A/35) by R. Pietkowski describing a case of long-term action of a temperature of 900° C on the surface of the soil and its penetration into the soil during a period of over 10 years, and Paper (3A/10) by R. Czarnota-Boiarski reporting a case of an ingenious reinforcement of the foundations of an old building erected on a 25 m mass of loess after big caverns were washed out in the loess; the caverns were filled with concrete of yielding consistency.

In his report, R. Pietkowski uses the results of investigation into the problem of temperature penetration into the soil to derive a computation formula based on the Fourier thermal conductivity equation, which permits determining the soil temperature as a function of time under the conditions of a one-dimensional problem neglecting the latent heat of evaporation. The suggested solution reduced to numerical results will correspond to the conditions of sufficiently dry soils and may be used in solving problems of temperature penetration from stoves, furnaces and other heating units, which overheat the soil, thus causing considerable cracking and shrinkage in it, as was observed by the author in the building of a coke plant.

Summary and proposals for discussion

The study of the papers submitted to the Vth Conference and the publications issued in the period between the two Conferences clearly shows that no design of bases and foundations, particularly those for high class structures, is possible at present without a full utilization of the solutions of soil mechanics problems.

The correct evaluation of the limits of use of individual solutions of soil mechanics problems and the improved methods for determining the calculated characteristics of soils, enable us to apply the solutions of the theory of soil mechanics in practice with great confidence. Thus, papers (3A/16), (3A/27) and (3A/30) submitted to the Vth Conference, which deal with investigations into the settlement of soil bases, emphasize the good agreement between the calculated and observed values.

The reports to Division 3/A of the Vth Conference, although they do not contain great discoveries, still advance a number of useful suggestions that can be used in engineering practice. It is the development of engineering methods of calculation that is typical of the level of the scientific reports to this 3/A Division.

It should be noted that the contiguous branches of science such as physico-chemistry, the plasticity theory, rheology, etc., as well as fast computing techniques are still insufficiently utilized.

Important solutions have been obtained on the main problem discussed in Division 3/A, i.e. the design of foundations on natural soils, in particular with respect to the evaluation of the bearing capacity and deformability of bases, and especially new suggestions have been advanced concerning the calculation of bases and foundations.

1. *The Bearing Capacity:*

Detailed investigations were continued into rupture lines using the photographic method suggest:d by V. I. Kurdyumov in 1891. This problem was given much effort and attention, but little work was done in the field of improving theoretically rigorous methods of calculation and the investigation of physical processes under conditions of disturbed soil strength. For no reason whatever, no coverage was given to such an important problem as the limits of applicability of Mohr's strength theory, the octahedral theory, etc. The kinematic analysis of problems on the bearing capacity and stability of soils has not been developed to a sufficient degree.

It has been established that, as a rule, the magnitude of the bearing capacity of bases, as determined experimentaly, by far exceeds the calculated one, which points to the imperfection of a number of calculation methods, the insufficiently accurate evaluation of the boundary conditions (the depth of the foundation, the shapes of the elastic soil wedges under the foundation, the kinematic feasibility of the solution, etc.) and to the necessity of improving theory. The problems of the bearing capacity of loose deposits, the shape of rupture lines in the soil mass, above the foundation footing, and some others have not been cleared up either.

Proposals for Discussion—(a) Theories of soil foundation strength, their substantiation and limits of applicability.

(b) The bearing capacity under conditions of incomplete consolidation of clayey soils.

(c) The application of the kinematic method to the analysis of the bearing capacity.

(d) The elaboration of modelling methods for the conditions of a complex stressed state.

2. *Stress Distribution:*

The elaboration of solutions to the problem of stresses and deformations of a finite soil layer resting on a rigid base is a substantial contribution to the theory of stress distribution.

Proposals for Discussion—(a) The effect of the rigidity of individual soil layers on stress distribution in multilayer bases.

(b) The effect of the shape and rigidity of foundations on stress distribution in a soil base.

3. *Foundation Settlements:*

An important achievement in this field consists in the further elaboration of the problem on the deformation of a two-layer base (Mandel, Davis and Taylor) and the successful application of vertical drainage for the acceleration of the consolidation of clayey soils (Habib, Mehra and others).

However, the problems of secondary soil consolidation, the calculation of bases for creep and the limits of applicability of the filtration theory of consolidation have been largely neglected, although some interesting observations of structure settlements have been conducted (Machado and others).

Proposals for Discussion—(a) Forecast of deformation on unloading of bases under conditions of soil wetting and drying.

(b) Calculations of soil bases for creep and the role of secondary consolidation.

4. *Calculation and Design of Foundations:*

The problem of calculation and design of foundations has been greatly clarified. It may be considered as an established fact that in designing flexible foundations account should be taken of the interaction between the structure and the compressible base (Papers 3A/14, 3A/25 and 3A/47) while rigid (massive) foundations should be designed proceeding from the settlement of soil bases determined by the limit deformations of superfoundation structures (Paper 3A/32).

Proposals for Discussion—(a) The limits of applicability of the theory of a linearly-deformed (elastic) halfspace and a Winklerian base.

(b) The methods for establishing limit settlements of bases, their differences and timing.

(c) Regional generalizations of characteristics of soil compressibility and the limits of their applicability.

5. *Foundations in Peculiar Soil Conditions:*

Although a number of papers submitted to the Vth Conference are concerned with this problem, they consider only particular aspects; the problems of general theory of the mechanics of swelling soils, the mechanics of subsidable soils and the mechanics of organic masses have not been elaborated to any satisfactory degree.

It is interesting to note that the measures to counteract deformation of foundations on swelling soils which are introduced, are similar to those used for counteracting the frost-heaving of soils (increasing the load on the foundations up to the swelling pressures, use of pebble fillings, etc.).

It is also worth mentioning that the disturbance of the structure of soils having a low moisture content considerably increases their deformability due to humidification and other seasonal effects.

Proposals for Discussion—(a) Measures to counteract deformation of foundations built on swelling clayey soils.

(b) Assumptions for calculating the magnitude and rate of soil settlements due to the disturbance of their structure.

6. *Special Problems:*

Great achievements have taken place in the field of elaboration and application of instruments and machines both for investigating vibrations of soil bases and for utilizing the vibration method in foundations engineering.

A trend is observed towards trenchless construction of structures: the erection of buildings on sand and gravel fillings, on thin reinforced concrete slabs placed on a layer of gravel, etc.

Proposals for Discussion—Methods of trenchless construction and the conditions for their applicability.

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Résumé et sujets proposés pour la discussion

De l'étude des communications présentées au V^e Congrès et des publications parues dans l'intervalle des deux Congrès il découle indubitablement qu'actuellement tout projet de fondations, particulièrement pour les constructions de première classe, est impossible sans un emploi complet des solutions de la mécanique des sols.

Le calcul exact des limites de l'applicabilité de certaines solutions de la mécanique des sols et les méthodes plus parfaites de détermination théorique des caractéristiques des sols permettent avec grande certitude d'appliquer en pratique les solutions de la théorie de la mécanique des sols. Par exemple, dans les communications présentées au Ve Congrès : 3A/16, 3A/27, 3A/30 sur l'étude des affaissements des sols, il est indiqué que les valeurs obtenues par le calcul et celles observées coincident d'une façon satisfaisante.

Les communications dans la section 3/A du Ve Congrès traitent principalement de la mise au point ultérieure des questions se rapportant à la théorie et à la pratique de la construction des fondations. Ces communications, sans comporter de grandes découvertes nouvelles apportent cependant de nombreuses propositions utiles pour leur emploi dans la pratique du génie civil.

C'est le développement des méthodes de calcul qui caractérise le niveau scientifique des Communications de cette section.

Notons que le recours à des domaines connexes de la science comme la physico-chimie, la théorie de la plasticité, la rhéologie, etc., ainsi que la technique du calcul rapide, n'est pas encore suffisant.

En ce qui concerne le problème principal de la Section 3/A, celui du projet de fondations sur des bases naturelles, des solutions intéressantes ont été obtenues, tant pour l'évaluation de la capacité portante et de la déformation des bases que, en particulier, pour le calcul des sols de fondation et des fondations.

1. *Force portante :*

Les recherches expérimentales détaillées des lignes de glissement par la méthode photographique (proposée en 1891 par V. I. Kourdumov) ont été continuées.

Cette question a suscité beaucoup d'efforts mais il a été porté peu d'attention au perfectionnement des méthodes de calcul exact et d'analyse des processus physiques lors de perturbations de la solidité du sol. Il est regrettable que n'aie pas été élucidée une question comme les limites de l'application de la théorie de la résistance de Mohr, de la théorie octaédrique et autres. L'analyse cinématique des problèmes de la force portante et de la stabilité des sols n'a pas eu un développement suffisant.

Il a été établi qu'en règle générale la grandeur de la force portante des sols de fondations déterminée par voie expérimentale est beaucoup plus grande que celle calculée, ce qui montre l'imperfection de certaines méthodes de calcul, une évaluation insuffisamment précise des conditions limites (profondeur d'établissement, forme du massif élastique sous les fondations, admissibilité cinématique de la solution, etc.) et sur la nécessité de perfectionner la théorie. Peu claire est aussi la question de la force portante des terrains meubles, de la forme des lignes de glissement dans le sol au-dessus de la semelle et autres.

Propositions pour la discussion—(a) Les théories de la stabilité des sols de fondations, leurs bases et les limites de leur application.

(b) Force portante lors de consolidation incomplète des sols argileux.

(c) Application de la méthode cinématique pour l'analyse de la force portante.

(d) Elaboration de méthodes d'études sur modèles pour des conditions de contraintes complexes.

2. *Distribution des contraintes :*

Un apport important dans la théorie de la distribution des contraintes a été la mise au point de la solution du problème des déformations de la dernière couche du sol s'appuyant sur la roche.

Propositions pour la discussion. — (a) Influence de la rigidité de certaines couches du terrain sur la distribution des contraintes dans les sols de fondations multicouches.

(b) Influence de la forme et de la rigidité de la fondation sur la distribution des contraintes dans le terrain.

3. *Tassements des fondations :*

Les importants résultats obtenus dans cette section résultent de la solution du problème des déformations d'une double couche d'un sol de fondations (Mandel, Davis et Taylor) et l'utilisation avec de bons résultats du drainage vertical pour accélérer les processus de consolidation des sols argileux (Habib, Mehra et autres).

Cependant la question de la consolidation secondaire des sols, du calcul des sols de fondations pour le glissement et des limites de l'applicabilité de la théorie de la filtration de consolidation a été peu abordée (Machado et autres).

Propositions pour la discussion. — (a) Prévisions des déformations lors du déchargement des sols de fondations lors d'humidification ou de séchage des sols.

(b) Calcul des sols de fondations; le fluage et rôle de la compression secondaire.

4. *Calcul et projet des fondations :*

De grandes précisions ont été obtenues sur la question du calcul et du projet des fondations. On peut estimer établi que les fondations flexibles doivent être calculées en tenant compte de l'interaction entre l'ouvrage et la base compressible, et les fondations rigides (massives) suivant les tassements des sols de fondations, déterminés par les déformations limites des constructions portées par les fondations.

Propositions pour la discussion. — (a) Limites d'application de la théorie de l'espace semi-infini, à déformation linéaire (élastique) et du sol de fondations de Winkler.

(b) Les méthodes d'établissement des tassements limites des fondations, de leur différences et des vitesses de tassement.

(c) Les généralisations régionales des caractéristiques de compressibilité des sols et les limites d'application.

5. *Fondations dans le cas de types particuliers de sols :*

Bien que de nombreuses communications soient consacrées à cette section du Ve Congrès, elles n'analysent toutes que des questions particulières ; l'étude des questions de la théorie générale se rapportant à la mécanique des sols gonflants, à la mécanique des sols peu portants ou s'affaissant et à la mécanique des masses organiques est parfaitement insuffisante.

Il est intéressant de noter que l'on commence à employer les mêmes moyens de lutte contre les déformations des fondations sur sols gonflants que ceux utilisés dans la lutte contre le soulèvement des sols par suite du gel (augmentation de la charge sur les fondations jusqu'à la grandeur de la pression de gonflement, répandage de graviers, etc.).

Il est de même intéressant de noter que le remaniement de la structure de sols peu humides augmente considérablement leur déformabilité sous l'influence d'un accroissement de la teneur en eau ou d'autres facteurs saisonniers.

Propositions pour la discussion. — (a) Moyens de lutte contre les déformations de fondations sur sols argileux gonflants.

(b) Conditions premières pour le calcul de la grandeur et de la vitesse d'affaissements de sols dues à un remaniement important de leur structure.

6. *Questions spéciales :*

Il faut constater les résultats notables atteints dans la mise au point et l'emploi d'appareils et de machines tant pour l'étude des vibrations de sols de fondations que pour l'emploi de la méthode des vibrations dans la construction des fondations.

Lors de l'exécution des travaux de fondation on observe une tendance à passer à une méthode de construction d'ouvrages sans fouilles : construction de bâtiments sur des dalles minces en béton reposant sur des couches de sable et de gravier, etc.

Propositions pour la discussion. — Méthodes de construction sans fouilles et conditions d'application.

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