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Determination of the mechanical characteristics of soils by results of plate load tests

Définition des caractéristiques mécaniques des sols d'après les resultats des tests estampés

A.Zh.Zhusupbekov & A.S. Zhakulin
Geotechnical Institute, L.N. Gumilyev Eurasian National University, Astana, Kazakhstan
H.Z. Bakenov
Interparliamentary Assambley of CIS, St. Petersburg, Russia

ABSTRACT
The complex of field researches by plate load tests on loamy and loam sandy soils of water-saturated bases on the construction site of New Airport Astana have been carried out by the authors. The means for reconstruction of the airport in capital of Kazakhstan are allocated as the grant by Japanese Bank for Development and Reconstruction, and also the Japan company "Marubeni" taking active part in the construction. And also the spatial task by a method of final elements for estimation of stressed – deformed condition of water-saturated bases is solved. The elastic and plastic model of soil, supposing elastic work within the limits of surface, described by criterion Mor-Kulon and coextensive current on this surface is considered. As a result of the numerical analysis the model of soil environment for the forecast of the stressed-deformed condition of water-saturated base is chosen.

RÉSUMÉ
Les auteurs ont fait le complexe de recherches des champs à l'aide des ètampes de la terre argileuse et aréno- argileuse saturée et non-satureé d'eau sur la base du chantier du nouvel aéroport d'Astana. Les ressorces de la reconstruction de l'aéroport d'Astana ont été assignéss sous la forme du grant par la Banque japonaise du dévellopement et de la 'reconstruction. La firme "Maroubény" du Japon prend une part active à la contruction. On a résolu le problème de l'espace par des méthodes des éléments ultimes pour apprécier l'état intensivement déformé de la base saturée d'eau. On a examiné le modèle du sol élastique plastique présumantle travail élastique dans les linutes de la superficie décrite d'aprés le critère de More-Koulone et le courant e'gal en volume sur cette surface. On a trouvé le modéle du milieu du sol pour le pronostic de l'état de la base saturée d'eau à l'aise de l'analyse numérique.

1 INTRODUCTION

The researches were carried out on the Reconstruction of the International Airport in Astana construction site.
Reconstruction of the international airport provides for construction of new buildings and structures, including: air traffic control center with a tower; freight terminal; central distribution station; boiler installation; on-site fuel storage; 3,000 m3 aviation kerosene reservoir and water reservoir; rescue and fire services buildings; administrative building with a laboratory; pump station; repair shops, etc. Foundations under the buildings are designed mainly as shallow foundations of monolithic reinforced concrete. Engineering-geological section of the construction site is represented by soils of Middle Quaternary aged alluvial deposit, represented by loamy sand, loamy soil and sand (Zhusupbekov & Zhakulin, 2003). Analyses of soils physicomechanical characteristics results (data by the Kazaeroproject Institute, Almata city) shows, that the bearing layers under the shallow foundations are water-saturated ($S_r > 0.81 \div 0.88$) loamy sands and loamy soils of plastic and highly plastic ($J_L = 0.76 \div 0.87$) consistence, with low deformation (E = 4.5 – 5.0 MPa) and strength (c = 4.8 – 8.7 kPa and $\varphi = 12 \div 14$ degrees) characteristics. At this the level of ground waters is at a depth of -2.4 ÷ -2.7 m.

2 ANALYSIS OF SOIL TESTS RESULTS

2.1 *Equipment used for researching*

In order to research the stressed-deformed condition of base soils and to choose optimal size of shallow foundations footing the plate load tests were carried out.

During the tests the equipment and devices of Model 35TO121-V of Controls, Italy, were used. The equipment consists of the following: standard plate 30 cm in diameter, 706 cm^2 in area and 3 cm in depth; hydraulic jack up to 20 tons; hand-operated pump with pressure gage with a scale interval of 0.025 MPa, connected to the hydraulic jack with an extension hose; extension metal rods of different lengths of 125; 225 and 425 mm, used at transmission of load to the plate; indicating gages with accuracy within 0.01 mm, with a movable rod stroke up to 10 cm; control system consisting of metal extenders in the form of triangle, fast on the surface of the ground be means of three pins. Feet of the indicator rod, fixing the plate settlement in three reciprocally diametrical directions; load platform, which consists of a metal No.45 H-beam and is used as the plate rod brace, and extended ferroconcrete blocks used as weight of up to 10 ÷ 15 tons, are installed on the control system.

2.2 *Tests procedure*

Plate load tests of water-saturated and water-unsaturated base soils were carried out according to two procedures pursuant to the purpose of the research.

1. According to Kazakhstan GOST 30672-99 – until conditional plate settlement stabilization within a regulated period of time under fixed loads. Speed of the plate settlement not acceding 0.1 mm an hour was taken for criteria of the conditional stabilization of deformation (Abelev, 1983).
2. According to British standard BST-1372 – until complete loss of bearing resistance of soil base.

Load on the plate was increased by pressure stages of 0.025 MPa, for soils with a porosity factor of 0.638 ÷ 0.65 and water-saturation degree of 0.81 ÷ 0.88, and for water-unsaturated base soils ($S_r < 0.8$) pressure stages corresponded to 0.5 MPa.

To research the qualitative picture of compaction process, plate load tests were carried out on water-unsaturated and water-saturated bases, formed by loam sandy and loamy soils.

The tests were carried out in foundation pits of 1.0m to 2.8m depth and in order to achieve tight contact of the plate foot the area of installation was thoroughly planned and a bed of low-moisture fine sand 0.1 to 0.3 cm thick was arranged.

At that several schemes of testing were chosen:

- load on the plate under conditional stabilization of soil deformation at every pressure stage and full unloading;
- load on the plate under conditional stabilization of soil deformation at every pressure stage until complete loss of bearing resistance of the base;
- load on the plate under conditional stabilization of soil deformation at certain pressure stages and unloading with subsequent loading and unloading.

The choice of schemes was determined by the purpose of the research for evaluation of bearing resistance and determination of portions of elastic and plastic deformations of water-unsaturated and water-saturated base soils, as well as detection of settlements duration in time.

2.3 *Processing of the plate load tests of soils results*

Application of plates of 30 cm in diameter and 706 cm^2 in area allowed necessary number of experiments to be carried out and sufficient scope of information to be obtained. Processing of the experimental data is done according to the methods, developed in the theory of probability and mathematic statistics under GOST 20522-96. After processing of the experimental data the plate settlement from load $S = f(p)$ diagrams were plotted.

To determine the soil deformation module an averaging strait line by least squares or graphical method was drawn on the load diagram.

Pressure equal to tension $\sigma_{zg,0} = \gamma h$ (where γ - specific gravity of soil) and relevant settlement were taken for initial values p_0 and S_0 (first point included into averaging); p_i and S_i corresponding to the forth point in the diagram on straight-line zone were taken for finite values.

In case increment of settlement when pressure is p_i is twice as large than that one at the previous stage of pressure p_{i-1}, and at the next stage of pressure p_{i+1} increment of settlement is equal to or greater than increment of settlement under p_i then p_{i-1} and S_{i-1} ought to be taken for p_n and S_n finite values. At that the number of points included into averaging has to be no less than three. If not, lesser stages of pressure should be used when testing soil.

Soil deformation module E, MPa by the results of plate load experiments for linear range is determined by the following formula:

$$E = (1 - \nu^2) \cdot K_p \cdot K_1 \cdot D \frac{\Delta p}{\Delta S} \qquad (1)$$

where ν = Pousson's coefficient, taken equal to 0.35 for loamy soil; 0.30 – for sand and loamy sand;

K_p = coefficient, taken depending on deepening of the plate $\frac{h}{D}$ (h = depth of the plate positioning with respect to soil surface, cm; D = plate's diameter, cm);

K_1 = a coefficient, taken equal to 0.79 for rigid round-shaped plate;

Δp = increment of pressure to the plate (see diagram of plate settlement under pressure), equal to p_n-p_0;

Δs = increment of the plate settlement, in cm, corresponding to Δp, determined by averaging straight line.

At plate load tests of soil in foundation pits K_p coefficient is taken equal to one. Also the modules of deformation were determined by the unloading diagrams, which are the modules of soils elasticity. According to "settlement-loading-unloading" diagram values of elastic and plastic deformations of water-unsaturated and water-saturated bases soils are determined.

2.4 *Evaluation and analysis of deformability of water-saturated soils*

According to the plate load tests of water-saturated and water-unsaturated soils bases results and processing of the experimental data the following dependencies are found:

- diagrams of the plate settlement under loading on water-unsaturated and water-saturated bases;
- comparative diagrams of the plate settlement under loading until the loss of bearing resistance on loam sandy and loamy soils of water-saturated and water-unsaturated bases;
- diagrams of dependence of settlement under loading and unloading of the plate on bases of loamy soils at different degrees of moisture;
- diagrams of the plate settlement in time on loamy and loam sandy water-saturated bases.

To evaluate the deformation module the diagrams of the plate settlement dependence on load at different depths: 2.0m; 2.5m; 3.0m and 3.5m under the ground surface for loam soils at different degrees of moisture S_r = 0.70; 0.80; 0.85 and 0.90 were worked out. The dependence diagrams results analysis shows, that as moisture degree increases (from 0.7 to 0.90) the deformation modules values decrease from 9.6 MPa down to 5.9 MPa. And herewith the deformation module value of 9.6 MPa was received for water-unsaturated loamy bases.

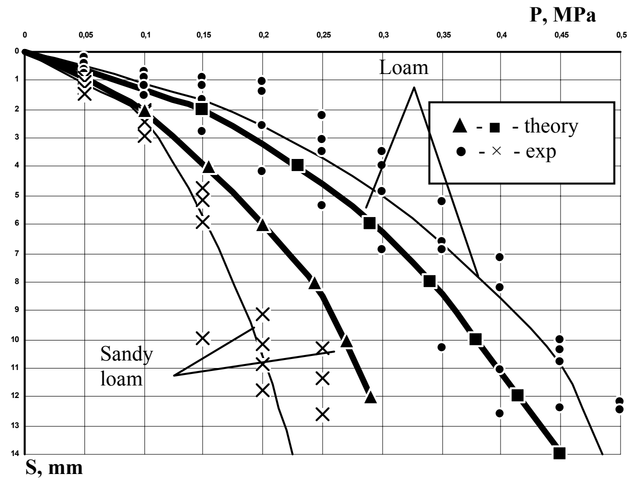

Figure 1. Diagrams of the plate settlement from load.

Development of settlements for water-unsaturated base within the pressure limits from 0 up to 0.25 MPa is done according to linear law. The diagrams of settlements on water-saturated bases within the pressure limits from 0 up to 3.0 MPa are of nonlinear nature. The value of the plate settlements on water-saturated bases irrespective of the depth of the plate installation under the maximum pressure of 0.3 MPa fluctuates within the limits from 10 mm up to 12 mm (Fig. 1), and under the same pressures for water-unsaturated bases amounts to 7.3 mm.

It should be noted, that an averaging module of deformation of water-saturated loamy bases made up E = 7.2 MPa, and for water-unsaturated bases the deformation module was equal E = 9.6 MPa, which is 25% greater.

Thus, deformability of water-saturated bases has nonlinear character, whereas in calculation of water-unsaturated bases the model of linear-deformation environment should be used, taken in calculation in accordance with the normative documents of the Republic of Kazakhstan.

The analysis of the results shows, that the loss of bearing resistance for water-unsaturated loamy soils bases occurs after loading of 1.0 MPa, while in loam sandy bases it occurs under the pressure of 0.25 MPa.

Based on the "settlement-loading" diagrams analysis results the values of deformation module were determined. For loam sandy water-unsaturated bases the value of the deformation module under the pressure within 0 to 0.2 MPa was E = 26.5 MPa, while for loamy bases under the pressure within the limits of 0 to 0.3 MPa – E = 38.5 MPa. Deformation module in loam sandy soils of water-saturated bases (within the pressure limits of 0 ÷ 0.2 MPa) E = 8.6 MPa.

Hence, pressure value under which the loss of bearing resistance of water-unsaturated bases occurs is 1.6 ÷ 1.8 times greater than the value of pressure of water-saturated bases, while the deformation module values under $S_r < 0.8$ within different limits of pressure are 2.4 times greater for loam sandy soils and 4.4 times greater for loamy soils than those under the degree of humidity $S_r > 0.8$. The given spread in results of the deformation module value of loam sandy and loamy soils depends on the type and characteristics of the base deformability.

The analysis of the results shows that the portion of elastic settlements for water-unsaturated bases comes up to 45% of the total number of settlements, and for water-saturated soils the part of elastic settlements is 15% of the total value of settlements.

It should be noted, that deformability of water-saturated loamy soils has elasto-plastic character, and the models, describing nonlinear dependency between deformations and pressures, shall be taken for calculations.

Full discussion of the results demanded application of the method of dividing of the diagram by tangent line into three specific zones, (to precisely define and generalize the process of deformability) consisting of: phase of compaction, displacements and loss of bearing resistance. Points of intersection of tangents are indicated as $P_{кр}$ и P_n. Zone $0 - P_{кр}$ on the diagram of settlements corresponds to the phase of compaction and beginning of cutting of soil surface by the plate. Settlements increase in accordance with established straight-line dependence. This condition is related to the process of lower layers of the base starting to behave. Zone $P_{кр}$ - P_n clearly shows phase of displacements and the value of the plate settlements 6-7 times exceeds the initial one. During the phase of displacements, compaction or re-orientation of soil skeleton and extraction of interstitial water are obvious to occur. After P_n point in the direction of increase of the pressure to the plate the loss of base bearing resistance and following sinking occurs.

The analysis of the design and experimental curves of settlements of the plate due to load demonstrate good convergence within the limits of 15–20%, that proves the adequacy of the chosen soil model (in elasto-plastic definition) at solution of a spatial problem (Fig. 1).

Thus, in the process of deformation of water-saturated loam bases the relation between pressures and deformation is nonlinear and the operation of the given bases is of elasto-plastic character.

For calculations of water-saturated loamy clayey soil bases it is not recommended to use the model of elasto-linear deformable environment, that might lead to inevitable errors while designing shallow foundations.

3 MODELING OF THE PLATE OPERATION AND NUMERICAL ANALYSIS OF RESULTS

The purpose of the numerical modeling of the plate pressing into soil is a comparative evaluation of the effects, occurring in water-saturated when solving a spatial physically nonlinear problem of geomechanics in order to choose the model of soil environment and determine the deformation mechanism, as well as determine zone of limit condition of soil under deformation of loam sandy and loamy soils.

Solution of many problems in geomechanics is connected to evaluation of stressed-deformed bases condition, formed under the influence of the building, structure under construction. Calculation of the bases is done under two groups of limit conditions: according to bearing resistance and deformations, and is fulfilled by means of soil deformation law. In this direction, application of the elasto-plastic flowage theory is the most optimal, because its mathematical apparatus allows specific to soil nonlinear connection between stresses and deformations in both prelimit and limit condition of soil to be demonstrated in calculations. The latter allows evaluating of water-saturated base bearing resistance concurrently with the calculations, without applying any special proposals and approximate methods (Fadeev, 1989).

The task of a round centrally-loaded plate lying on the surface of water-saturated loam sandy and loamy base soil was considered. For comparison with the experimental data, the evaluation by numerical method of stressed-deformed conditions of water-saturated base soils loaded with a plate of $D = 30$ *cm* in diameter was carried out.

At the point of contact between the plate and the base, the angle of reactive pressure deviation from vertical line as not exceeding the angle of soils friction was preset, otherwise cohesion is disturbed and slipping occurs. The friction coefficient is taken equal 0.5 for loamy sand and 0.4 for loam, which complies with the conditions of contact between the base and the reinforced foundation. To evaluate the influence of nonlinear deformations, first the calculation in linear definition with physical-mechanical characteristics of soil as E = 4.5-5.0 MPa; ν = 0.3-0.35; φ = 12-14 degres; c = 8.7-15.8 кPa has to be done.

Design diagram presents a forth of the scheme, since the scheme is symmetric about two axes.

The geometric parameters of the design diagram to ensure complete decaying of local agitation by the plate within the limits of the area considered are chosen by depth $9D = 9 \times 30$ cm = 270 cm (where D = 30 cm is a diameter of the plate), while width to length relation is $6D$ = 180 cm.

Boundary conditions are as follows: horizontal interties in corners at vertical boundary and vertical interties at a lower boundary. Upper part is free.

Net area of a spatial problem in horizontal x- and y-directions is divided into 43 levels. Levels from 1 to 30 are 3 cm each, and levels 31 up to 47 are 7 cm each. In vertical z-direction it is divided into 30levels, levels 1 to 18 are 5 cm each, levels 18 up to 23 are 10 cm each, levels 24 to 27 are 15 cm each, and levels 28 to 29 are 20 cm each, level 30 is 30 cm.

Elasto-plastic model, proposing elastic behavior of soil within the limits of surface, described by Mor-Kulon criteria, and coextensive flowage on that surface, was considered at solution of the spatial problem of the plate's work (Segerlind, 1979). The problem was solved by applying shifts within the limits of the plate's diameter with 2mm steps, and the calculation was done by numeric analysis presenting the method of finite elements.

Analysis of the plate settlement under pressure results shows, that dependence is nonlinear, and allows to single out three phases of deformation: compaction (zone 1), displacements (zone 2), and loss of bearing resistance (zone 3).

Analysis of the results of the numerical analysis and "settlement to load" dependences show, that (elastis definition of the problem) for loam sandy soils under pressure of 0.22 MPa with the settlements values of 4.6mm ends under 0.43 MPa pressure to the plate with 15.0mm settlement. Correspondingly, (elasto-plastic definition) under minor values of pressure of 0.18 MPa and 0.33 MPa, with the same values of settlements (5.1 mm and 16.0 mm), the phases of compaction and displacement end.

There are significant differences for loamy soils under elastic and elasto-plastic definitions, correspondingly phase of displacements compaction ends under the value of 0.3 MPa, and 0.53 MPa with settlements of 2.2 mm and 8.0 mm (elastic), and 0.23 MPa, and 0.50 MPa with settlements of 3.1 mm and 15.0 mm.

Probably, this phenomenon is accounted for slower deformation in time of water-saturated soils, that is related to extraction of interstitial water.

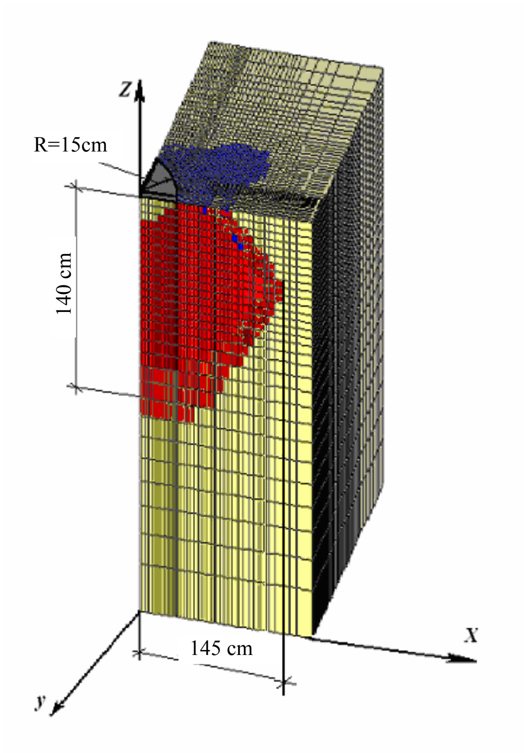

Figure 2. Zones of limit condition of the soil ground (loam).

Figures 2, 3 demonstrate zones of limit condition of the base consisting of loam sandy and loamy soils at 1 cm shift of the plate, corresponding to the phase of displacements, and at 2 cm shift, corresponding to the phase of bearing resistance loss. Zone of loam sandy soils deformation is smaller compared to the loamy soils zone deformations. Therefore, volume, covered under the phase of loss of bearing resistance, rises under increase in load.

The resulting picture of deformation modules isolines allows singling out of heightened deformability zones, so called plastic areas, and heightened rigidness zone – compacted core, in the base.

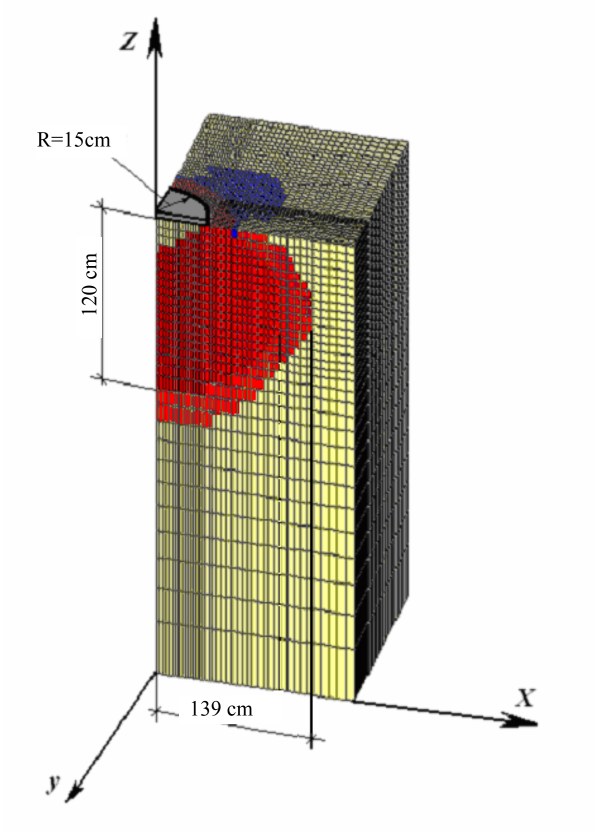

Figure 3. Zones of limit condition of the soil ground (loam sandy).

4 SUMMARY AND CONCLUSIONS

Pressure value under which the loss of bearing resistance of water-unsaturated bases occurs is 1.6 ÷ 1.8 times greater than the value of pressure of water-saturated bases, while the deformation module values under $S_r < 0.8$ within different limits of pressure are 2.4 times greater for loam sandy soils and 4.4 times greater for loamy soils than those under the degree of humidity $S_r > 0.8$. The given spread in results of the deformation module value of loam sandy and loamy soils depends on the type and characteristics of the base deformability.

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REFERENCES

Zhusupbekov, A.Zh. & Zhakulin, A.S. 2003. Investigation of soils of water-saturated bases by plate load tests. *Proceedings of International Geotechnical Symposium,* Saint Petersburg, 116-119.

Abelev, M.U. 1983. Construction of industrial and civil structures on weak water-saturated soils. Moscow: Stroiisdat. 248p.

Fadeev, A.B. 1989. Method of finite elements in the geomechanics. Moscow: Stroiisdat. 221p.

Segerlind, L. 1979. Application of method elements. Moscow: Publishing house "World". 301p.