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RECONSTRUCTION PRINCIPLES OF AIRPORTS COMPLEXES OBJECTS USING THE METHODOLOGY FOR BASES STABILITY MODELLING

The methodology for modelling and determining the strength of soil bases interacting with protective and buried structures in the over-limit state has been discussed. This methodology has been used in the reconstruction of airports complexes objects designed for operation in severe geotechnical conditions.

Definition of Problems

Reconstruction of airport complexes objects requires maximum use of space not only within towns and other settlements, but also within the boundaries of modern airport complexes, in the territories of which it is necessary to build modern terminals, undersoil structures and parkings, airsheds, new take-off runways, flying lines for heavy wide-body aircrafts, vehicles for servicing aircrafts, and other engineering structures.

In the process of reconstruction of airport complexes, there are certain problems associated with ensuring stability of the existing stressed-deformed state of supporting bases under the objects of airport complexes, specifically in areas with severe geotechnical conditions. The methodology for estimating the effect of severe geotechnical conditions on the stressed-deformed state of airport structures, with consideration for the limit state of the soil semispace balance, has been developed on the basis of the following criteria: the limit strength of airdrome pavement plates, maximum allowable elastic deflections of airdrome pavements, limit shearing strength of soil, and maximum allowable bending tension stress for monolithic layers of airdrome pavements. In this case, it is necessary to take into account combined multilayer natural pavements, artificial supporting bases, and soil bases when reducing the solution of the three-dimensional problem to the solution of the two-dimensional problem. In order to solve the assigned task, the simulation of effect of multiple-wheel undercarriages of modern heavy aircrafts was performed, by using numerical computation, with the reduction of actual load to the equivalent load on the take-off runaway, as is in the case of solution of the two-dimensional problem. In order to determine limit deformations of the whole design multilayer portion of the soil semispace, with consideration for the limit shearing strength of soil and allowable tension stresses in layers of the artificial base, the development of local plastic deformations was taken into account. On the basis of numerous experiments performed by using the method with fixed pattern of finite elements, recommendations with respect to correcting coefficients characterizing operating conditions were provided, which allowed the existing engineering analytical design methods to be used [1, 3].

The limit balance of soil within the elementary unit (finite element) being considered is equivalent to such a stressed state, at which even a minor additional effect can disturb the balance. This stressed state is characterized by that the shearing strength of soil within the elementary unit (finite element) should be equal to the limit shearing strength specified for the soil type. This state is defined as the limit soil state corresponding to the second phase of the limit soil states, which is possible at the intensive development of shearing deformations in the soil mass. In this case, the numerical solution of the problem of strength of soil masses is performed on the basis of the methods proposed in [4, 5, 6], with some corrections for the plastic yield criterion specified for the soil semispace.

Analysis of the Last Studies and Publications

The analysis of geotechnical conditions in Ukraine has been performed in order to determine their effect on the design decisions with respect to reconstruction of airport complexes, specifically the decisions for implementing some protection facilities, such as special complex structures of airdrome pavements, water disposal systems, drainage systems, and other protective systems.

At the present time, the analysis of the aforesaid systems is possible only by using methods of numerical simulation, for which a modern computer base and corresponding mathematical tools are required. The complexity of solution of the corresponding problems consists not only in developing or using the corresponding computer software facilities but, first of all, in the necessity to accept a reasonable physical model which most correctly describes nonlinear processes characterizing deformations of surrounding materials, including deformation of soil material, as well as in the necessity to select design diagrams and special calculation algorithms which ensure the reliability of computation data. The situation is complicated by that that there is, at the present rime, no uniform method or model which is suitable for any geomaterial or environment.

The analysis of normative documents and scientific works of national and foreign scientists, which were published in industries allied to the construction industry, has shown the availability of large number of methods and scientific works for determining data on deformation and stressed-deformed states of structures. But the use of any individual method or scientific work does not provide the possibility to take into account the complexity of the soil layer structure if there are weak intermediate layers in the soil or if subsurface erosion or boiling are developing in the soil, as well as take into account the effect of these conditions on the stressed-deformed states of airdrome pavements, protective structures for strengthened soil masses, and understructures and foundations of airport buildings and structures. There is no normative base required for performing corresponding design calculations, and methods for analyzing the stressed-deformed states of airdrome pavements, with discrete simulation of the soil bases, are virtually not available.

The use of existing standards and empirical relationships for estimating the effect of new construction on existing structures results in unreasonable margin of safety or destruction of the existing structures. Additionally, the provision of reliability of buildings and the reduction of financial and material losses are of great importance at the present time.

Purpose of the Work and Definition of the Problem

In every case, the problem definition procedure should include the individual analysis of reliability of the data obtained in the process of the problem solution, as well as provide a special approach which requires from the designer not only to develop the design documentation properly but to have corresponding knowledge and skills in numerical simulation and soil engineering.

The development of a reliable design model of the soil base, which would ensure sufficient compliance of the design calculation results with the actual conditions, is one of the most important problems in construction. The existing methods of design calculations for soil bases, available according to the soil engineering, allow the problems only partially to be solved. The use of the limit value corresponding to the end point of the linear section of the characteristic of dependence of soil upsetting on loading, as a designed pressure value, results, as a rule, in the acceptance of not always economically effective solutions. A large part of studies of plastic deformations cannot be taken into account using the methods of the classical linear soil engineering. So, it is necessary to develop more advanced design calculation methods, which provide a possibility to take into account the actual pattern of loads acting on foundations, and the actual nonlinear properties of soil bases.

The current actual problem is to develop a mathematical model for calculating the strength of foundation piles for the purpose to increase the validity and reliability of design decisions by taking into account geometrical and physical nonlinearities of soil bases and dilatancy effects in soil bases, as well as to correct the criteria for estimating limit states of soils.

The process of construction of airdrome pavements also depends on the stability of the existing stressed-deformed state of the soil base under the pavement. In such conditions, protective engineering structures and technologies for constructing such structures, which would provide minimum changes in the stressed-deformed state of the soil base, are of great importance. The design analysis of protective structures, such as protective shields, diaphragms, retaining walls of different configurations, and walls in the soil made of built-in-place or drilled piles buried under 40 m or more of the soil, should be performed with consideration for the nonlinear properties of the soil, specifically when stripping soil for deep excavations.

The use of existing standards and empirical relationships for estimating the effect of new construction on existing structures results in unreasonable margin of safety or destruction of the existing structures. Additionally, some existing building technologies, for example the technology with pile driving without soil excavation, are novel and not presented in normative documents.

The reliable and economically effective solution of any problem is possible by performing the analysis of interaction between the elements of the following systems: the existing building - protective structures - the excavation for the new building; the soil bases and foundations of the existing buildings - protective structures - surface-based structures as a whole; various combinations of interaction between the soil semispace under the existing buildings and protective structures between the existing buildings and the designed new buildings.

At the present time, the analysis of the aforesaid systems can be performed only by aids of numerical simulation, for which a modern computer base and mathematical tools are required. The complexity of solution of the corresponding problems consists not only in developing and using the corresponding computer software facilities but, first of all, in the necessity to accept a reasonable physical model which most correctly describes nonlinear processes characterizing deformations of surrounding materials, including deformation of soil material, as well as in the necessity to select design diagrams and special calculation algorithms which ensure the reliability of computation data. The situation is complicated by that that there is, at the present rime, no uniform method or model which is suitable for any geomaterial or environment.

In every case, the problem definition procedure should include the individual analysis of reliability of the results obtained in the problem solution, as well as provide a special approach which requires from the designer not only to develop the design documentation properly but to have corresponding knowledge and skills in numerical simulation and soil engineering.

The design of protective structures for new construction objects in areas with existing structures should be performed with consideration for the effect of various stages of construction on existing structures and adjacent soil masses, such as the stages for 1) installing protective structures and 2) constructing excavations with consideration for the effect of unloading of the soil base and for the sequence of installation of engineering structures.

In most cases, the reliable results of system simulation are possible due to the use of elasticity models based on the plastic flow theory. In this connection, it is important to take into account the design characteristics and nonuniformity of the construction process with respect to the accepted system.

The requirements for assurance of reliability of buildings and structures, as well as the requirements for reduction of financial and material losses, are very important at the present time. These requirements apply to soil bases and foundations as the most critical elements of engineering structures.

According to cost accounts, the expenses for reconstructing or strengthening foundations or for correcting design errors exceed many times over the initial cost of the foundations and, in some cases, the cost of the whole structure. Therefore, corrected design calculations for foundations and soil bases are of great importance at the present time. One of the optimal foundations is a pile foundation. Piles have high load-carrying capacity and ensure minimum foundation settlement. The objective causes for introducing pile foundations in Ukraine are the following: the existence of collapsible soils and the vital necessity to build multilevel industrial and civil building and structures for the purpose to preserve agricultural land. Notwithstanding the longstanding and wide use of pile foundations in housing, industrial, and civil construction, the characteristic features of the interaction of pile foundations with soil bases have been studied insufficiently, and at the present time, there are problems which are not solved in full.

In accordance with this scientific work, the methodology is developed which is designed for studying the interaction of enclosing and protective structures with the soil semispace in the over-limit state, with consideration for geometrical and physical nonlinearities at the stage of problem definition, in the conditions of complex loading of the soil base with consideration for active and passive loading and the effect of unloading of the soil semispace. The methodology has been developed on the basis of the nonlinear soil mechanics theory, nonlinear elasticity and plasticity theory, nonlinear programming methods, and finite element method. New modified models have been proposed, which provide the possibility to account for nonuniformities and effect of anisotropic properties of the multilayer semispace in conditions without friction between the individual layers.

This scientific work is based on the use of the generalized functions of the soil mechanics, which provide the possibility to more correctly determine the values of the stressed-deformed state of airport structures that are in interaction with complex soil bases.

The basic tasks of the work are the following:

1. Developing a mathematical model for studying nonuniform soil semispaces;
2. Improving the mechanical model for analyzing the strength of soil semispaces;
3. Developing basic equations for determining the state and balance of complex systems with consideration for geometrical and physical nonlinearities at the stage of problem definition;
4. Developing a special algorithm for solving nonlinear equation systems;
5. Performing the numerical analysis for the purpose to confirm the validity of the results obtained;
6. Detecting conformity in the development of deformations in the structures of airdrome pavements and foundations of building and structures of airports with consideration for the nonuniformity of soil bases.

The study of interaction of soil bases with structures of airport objects is connected with the determination of the stressed-deformed state and strength of the soil mass, as well as with the determination of deformability and strength of the structures.

The methodology for design calculations of elastic soil semispaces, using one of the effective net methods, that is, the finite element method presented in the form of relationships which are characteristic for the fixed pattern of finite elements, at the stage of definition of the plane problem with respect to a nonlinearly deformed solid body, is analyzed with consideration for geometrical and physical nonlinearities. At the stage of problem definition, when simulating the soil semispace, the significant nonuniformity of intermediate soil layers is assumed. To estimate the stressed state of the soil semispace, it is necessary to compare the design calculation results with the maximum allowed deformations and displacements, because local areas with loss of strength and development of plastic deformations are possible.

The methodology for studying soil semispaces with the use of nonlinear elasticity theory provides the possibility to obtain reliable results in the solution of the plane problem of the soil mechanics with consideration for the nonuniformity of the soil semispace, availability of layers with different physical and mechanical characteristics, different boundary conditions, and random external effects. The use of this methodology ensures the sufficiently reliable description of stressed-deformed states of soil semispaces in interaction with the structures of airport objects, and provides the possibility to perform studies of stressed-deformed states of soil semispaces when solving actual problems with respect to design of airport objects in complex geotechnical conditions in Ukraine.

The characteristics of the dependence of the effect of nonuniform soil bases on stressed-deformed states of the aforesaid structures of airport objects have practical importance, and the estimation of the effect of nonuniform inclusions of rocks with different physical and mechanical properties in soil bases, as well as the determination of relationships required for estimating deformations of airdrome pavements and other objects of airport complexes located on soil bases, are considered as actual and important problems in the construction industry.

Conclusions

The developed methodology for simulating the strength of soil bases and estimating the effect of complex conditions on stressed-deformed states of structures when reconstructing airport complexes provides the possibility to perform the corrected design calculations of elements of structures of airdrome pavements in conditions characterized by implementing the advanced technologies for exercising external influence on the soil semispace, as well as to perform the corrected design calculations of filling dams and transport road beds with consideration for multilayer reinforcing of these objects and in conditions with the development of limit plastic deformations. The methods for the numerical analysis of strength of airport objects, with consideration for the limit balance state of the soil semispace and the effect of the field of the airport ramp anisotropy of the multilayer space, were corrected by improving the mathematical model of strength of airdrome pavements, with consideration for the limit balance state of the soil semispace, and by developing algorithms for solving nonlinear equation systems using the combination of methods for extension of the numerical analysis methods depending on perturbation parameters and development of plastic deformations.

The numerical analysis results in the solutions of the problem of optimal design of reconstruction of airport complexes in compliance with the generalized design parameters. The results of the analysis of the stressed state of airdrome pavements with consideration for complex geotechnical, physical-and-mechanical, and hydrological features characterizing the structure of the soil column, obtained in performing, as an example, the procedure for strength analysis of the real structures of a rigid airdrome pavement using different discrete models and different types of soil bases, confirm the versatility of the proposed methodology for studying stressed-deformed states, and the possibility to define, on the basis of the methodology, the reconstruction principles of airports complex objects.

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