Vinnitsky National Technical University ________________________

(Full name of higher education institution)

Faculty of Construction, Civil and Environmental Engineering __________________

(full name of institute, name of department (department))

Department of Construction, Urban Management and Architecture ______

(Full name of department (Subjective, Cycle Committee))

Explanatory Note

To master's qualification

The master of the master is the master of the master.

(Education level)

On the topic _ _ "Engineering assessment of bearing capacity of piles by boundary element method"

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Performed by: Master of course, groups 2B-23MZ

Specialties 192 _ _ Construction and Civil Engineering

(Crypto and name of course, specialty)

Pan Ruijia ___ Pang Ruijia __ (last name and initials)

Head ____ Morgun A.S. (Surname and initials)

Reviewer (last name and initials)

Opponent ___ (last name and initials)

2024 ________________________

Technical Task

Ministry of Education and Science of Ukraine

Vinnitsky National Technical University

Confirmed

Head of the Department of the BMG,

K.T.N., Associate Professor ____

__ Sweetness Shvets Vitalii

Technical Task

FOR SCIENTIFIC RESEARCH WORK

"Engineering assessment of bearing capacity of piles by boundary element method"

Affiliated

County Chief,

DTN, Prof. ____ A.C.Morgun

Responsible performer,

Master ____ Pang Ruijia

Vynnitsa 2024

Vinnitsky National Technical University

College: Faculty of Construction, Civil and Environmental Engineering

Department of Construction, Urban Management and Architecture

Higher Education Level II (Master's)

Knowledge area : 19 Department of architecture

speciality: 192 Faculty of Civil and Environmental Engineering Education

major: Industrial and civil buildings

Confirming

Head of the Department of the BMG

K.T.N., Associate Professor Svetch V.V.

2024

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ ФАКУЛЬТЕТ ... ЦИВІЛЬНОЇ ТА ЕКОЛОГІЧНОЇ ... НАЦІОНАЛЬНИЙ ТЕХНІЧНИЙ ...

ZAVDANNYA

Master's qualification for Master's degree

Pang Ruijia's

(Surname, surname, father)

1. The topic of work. **"Engineering assessment of bearing capacity of piles by boundary element method"**

Director of work _ _ _ _ _ Morgun Alla Serafimivna, DTN, Prof.

Approved by Order of Higher Education of March 2024 No. 81 _

2. Student submission deadline 27.05.2024

3. Outputs: Architectural solutions of the technical design object, results of engineering geological exploration, results of literature review. Dimensions of the fuel foundation

4. Content of the text: Introduction (relevance and novelty of scientific research, object, subject, purpose and task, practical significance, research methods, testing)

1. Research section (literature review, analysis of the current state of the question of the applicability of MGE to the calculation of bearing capacity of fuel foundations.

2,3. Modeling of VAT fuel base and analysis of calculation results

4. Technical part (VAT analysis and adoption of the most cost-effective option).

5. Develop labour and civil protection measures.

6. Economic part (definition of the economic effect of introducing the results of scientific research into a technical object).

Conclusion

5. Illustrative material list (with precise designation of mandatory chairs)

1. Research section-6 Ark. (Banners illustrating the results of research

2. Architectural-building solutions3 Arc. (General plan, plans, facades, cuts).

3. Technological solutions-1 ARC. (Technology map for setting up monolithic overlay, calendar schedule, TEP, workplace organization).

6. Division of Work Consultants

Section	Name, initials and position of consultant	Signature, Date	
		Task Issued	Execution of Receipts
Economics	Ljujuk O.G., Assoc.	[signature]	[signature]
Safety of work	Kobilanska I.M., Associate.	[signature]	[signature]
Technical part	Morgun A.C.	[signature]	[signature]
Scientific part	Morgun A.C.	[signature]	[signature]

7. Task Issue 25.09 2023

Calendar

№ Z	Stage Name Master's Qualification	Time to run steps	Pre-tag
1	Task layout and entry to the ICR	02.09-06.09.23	
2	Research part	07.09-30.09.23	
3	Architectural solutions	01.10-09.10.23	
4	Fundamentals and foundations	10.10-06.11.23	
5	Labour and civil protection	07.11-15.11.23	
6	Economic Part	16.11-20.11.23	
7	Border Layout	21.05-26.05.24	
8	Submit the county to the department for verification	27.05-29.05.24	
9	Previous Protection	06.06-10.06.24	
10	Review	10.06-12.06.24	

Master Pan Ruijia [signature] (Signature)

Job Manager Morgun A.C. _____________ (Signature)

Annotation

UDK 624.15

Mr. Ruijia. Engineering assessment of bearing capacity of piles by boundary element method. Master's degree in Engineering and Civil 196-Engineering, Education Program Industrial and Civil Engineering. Vinnitza: VNTU, 2024. 57 c.

On the UCPR Speak. Librarian: 24 names; Figure: 19; Table: 2.

The master's thesis is devoted to the topical question of modern foundation construction and soil mechanics-improving the soil foundation model for nonlinear practical calculations. The paper provides the theoretical basis for the study of the work of suspended flame foundations of deep foundation by modern numerical boundary element method (MGE). The work of the foundation in both linear and nonlinear stages has been studied using the dilatancy model and the plastic flow theory. The general mechanical properties of the soil that makes up our planet Earth, for their practical use, are formulated in the form of deterministic laws (in the form of state equations). In his master's thesis from the point of view of the mechanics of a dispersed elastic-plastic environment, the idea of the characteristics of the behavior of the fuel-based foundation under load is introduced. Theoretical questions are asked in such a way that it is possible to evaluate the work of the foundation and the ability to design it outside of the elastic foundation. The steps of calculating PAL using this method based on MGE are given. The application of numerical MGE is supported by theoretical studies, supported and illustrated by numerical calculation. The master's work introduces the technical and economic solutions for the building, the technical and economic justification for the effectiveness of the decisions taken, the technical issues of safety and the safety of life.

Key words: pile foundation, stress-deformation state, boundary element method.

UDC 624.15 ABSTRACT Engineering assessment of bearing capacity of piles by boundary element method.

Pan Ruijia. Engineering assessment of bearing capacity of piles by boundary element method. Master's thesis on Specialty 192-Construction and Civil Engineering, Educational Program-Industrial and Civil Construction. Vinnytsia: VNTU, 2024. 57 p.

In Ukrainian speech Bibliography: 24 titles; Figure: 19; table 2.

This master's thesis is devoted to the topical issue of modern foundation construction and soil mechanics-improvement of soil foundation model for nonlinear practical calculation. This paper presents the theoretical basis of the study of the operation of suspended pile foundation of deep laying by using the modern numerical method of boundary element (BEM). The study of soil foundation operation in both linear and non-linear stages is carried out with the involvement of dilatancy model and plastic flow theory. The general mechanical properties of the soils that make up our planet Earth are formulated in the form of deterministic laws (in the form of equations of state) for the purpose of their practical use. In the master's thesis, from the point of view of mechanics of a dispersed elastic-plastic medium, the idea of the characteristics of the behavior of pile foundation under load is put forward. Theoretical questions are presented in a volume that allows a thoughtful approach to the evaluation of the work of soils in the foundations of foundations and the possibility of their design beyond the limits of elasticity. The stages of calculation of piles according to this method based on MGE are given. The application of numerical MHE is justified by theoretical statements, supported and illustrated by numerical calculation data. In the master's thesis, the technical and economic solutions of the construction, the technical and economic reasons of the effectiveness of the adopted decision, the problems of safety technology and life safety are given.

Key words: pile foundation, stress-strain state, boundary element method.

List of conditional signs and abbreviations

B - Boundary of the research foundation structure

Dbnp - Government building standards and rules

FEM - Finite element method

MGE -Boundary element method

SDS -Stress-deformation state

σ^*_{ij}, u^*_{ij} -Tension and displacement in fundamental

Solutions of R. Mindlin

FE -Finite element

BE -Boundary element

ξ -Application point p = 1

X -Monitoring point

CAD -Automated Design Systems

MQW -Master's Qualification Work

Contents

Introduction

For foundation laying and foundation construction, the optimal solution is selected, determined by alternative design using modern calculation methods.

At present, the most acceptable solution is chosen by comparing the different options for laying foundations and foundations.

The options are analysed by the following indicators:

-economic efficiency by determining the costs involved;

-Materiality;

-the need to carry out the work within a tight time frame;

-the amounts of permissible precipitation and their possible imbalances;

-the ability to perform work in winter;

-the workload of the construction of the wells (water reduction, reinforcement of the walls of the wells).

The task of design is to make the most effective decision that can be obtained from a reliable assessment of the engineering geological conditions of the construction site, the interaction of foundation soil with foundation and superstructure, methods of optimal design and methods of foundation construction that ensure the preservation of the natural soil structure.

The most efficient solution is related to the large number of calculations that require widespread use of the EOM. The correct use of electronic computing means requires the development of new design methods for both foundation and ground building.

It is also important to improve the methods of calculating the foundations and foundations.

In this connection, it becomes essential to consider the nonlinear and rheological properties of the foundation.

Nonlinearity and deformation rheology, which predict the dependence of the stress state on the mode and the load level, with the use of optimization design methods, allow substantial savings in material costs for laying foundations.

The use of optimization design methods related to minimizing the objective cost function in the context of nonlinear deformation greatly complicates the calculation, and the use of numerical methods (finite element method) and modern EMS allows the desired results.

The master's thesis considers the incorporation of modern boundary element method (MGE) into the calculation of foundation structures (PAL).

Topics relevance

The trend of increasing construction of high-rise buildings has increased significantly in recent years. The design of high-rise structures requires the use of modern methods of calculation, taking into account the nonlinearity of the foundation work, in order to obtain an economical design solution and solve the problems of the foundation's behavior under load. The need for these kind of computational models is already felt.

In this context, the Master's Qualified Work (MCR) "Engineering Evaluation of PAL Boundary Element Method", which corresponds to the current level of knowledge in the field of nonlinear VAT prediction of fuel foundation structures and uses the modern MGE and the dilatancy model of the dispersed soil environment, is relevant.

Relationship with scientific programs, plans, topics

The MRC is produced as part of the research work of the Department of Construction, Urban Management and Architecture of the FBECA of the WTO on the theme of the Department of Science-Research Work No. 60K1/14 "Research of

VAT system of buildings-foundation-foundation in whole and individual elements of it and innovative technologies for automated design, documentation and management of engineering projects in buildings".

Research objectives and tasks

The purpose of the MRC is to apply the theoretical calculation apparatus for the design of fuel efficient foundations for MGE, taking into account the development of new methods and methods for their calculation and modeling in the foundation-foundation system. The following main research tasks have been developed and resolved to achieve the goal:

-Analysis of the normative documents and scientific work of the studied geotechnical field and identification of a complex design problem

Fuel foundations;

-Calculation of the dilatancy of the foundation deformation in numerical studies of the work of the foundation;

-Deformability studies of high-rise buildings that are bonded to fire foundations;

-the theoretical basis of design for MGE fuel foundations and the development of calculation and modeling methods in the foundation-foundation system, as well as evaluation of the effectiveness of the design scheme;

-Comprehensive numerical and theoretical research on the VAT of the soil foundation and comparison with the experimental results.

Research Object

Interaction with the ground floor of the building's fuel foundations.

Subject matter of the study

VAT on the fuel foundations and the ground foundations of a high-rise building.

Research Methods

The research methods of the task include: analysis of normative and literary sources, scientific and technological achievements, analytical studies using the methods of elasticity and plasticity theory. Methods of solving the problems of soil mechanics and foundation construction using the boundary equilibrium theory, the numerical method of MGE for the VAT system "foundation-foundation", comparative analysis of the results of mathematical modeling with similar data of known solutions and experiments.

Scientific innovation of results

- The mechanical essence of the problem of bearing capacity prediction of a fuel foundation is revealed and its characteristics are shown in a numerical example. A method is used that combines the ability to calculate foundations under two groups of boundary conditions: deformation and bearing capacity.
- She's been further developed in the process of determining the compressible thickness of the ground.
- A new method for evaluating the effectiveness of design solutions of thermal foundations with optimal ranges is used, which takes into account the degree of use of the deformation and strength properties of the foundation and the foundation.
- The numerical results of both the whole system and individual parts of the system are obtained and compared with the experiment.

Practical value of the results obtained

It consists of:-use to determine the bearing capacity of fuel foundations and to quantify the effectiveness of design solutions of fuel foundations in design and research organisations;

-the use of effective methods of building fire foundations in scientific research and scientific research in the design and construction of facilities in research organisations; Uses in the teaching process of the Bachelor's degree in Bachelor's degree, Master's degree in Construction and Civil Engineering.

Master's personal contribution

Assembling research tasks, preparing input data for calculation, processing and analysis of results.Collection of input data (engineering geological parameters of the foundation); The "foundation-fuel foundation" system sampling; Analysis of numerical results; The existing regulatory sources are analysed.

Testing the results of the Master's work

The testing of the main positions and results of the ICRC was conducted at the 2024 Conference "Youth in Learning", at the 55th Conference of the ICRC of the World Trade Organization on 15.05. 2023.

Publications

The main findings, results and conclusions of the Master's Qualification thesis are presented in the papers at the 55th WTO Conference "Youth in Learning"-2024, WTO.

Section 1. The current state of the issue of calculating the stress-strain state of pile foundations

1.1. Literature review

Currently, the design of the supporting structures of a building or other building is based on the assumption that the building is based on an uncompressed foundation.

In fact, the weight of each building compresses and deforms the subsoil, and as a result, the assumption of the output is never strictly satisfied.

If the floor of a building remains flat, the settlement of all the points of the building is almost the same. And when the surface of the foundation is bent under the weight of the building, the bottom of the foundation structure of the building also becomes bent, causing the whole system to deform. The additional stresses caused by this deformation were not taken into account in the design of the ground structures, according to previous standards.

But in many cases they're so significant that they can make the building look worse or cause damage to it. Due to the complexity of the mechanical properties of the soil and the influence of the characteristics of the foundation, settlement can only be predicted in a few cases, and theoretical analysis of the settlement phenomenon is necessary. Experience has shown that the vertical pressure can be calculated with sufficient accuracy, assuming that the foundation of the building is elastic and uniform.

Once the designer has determined the dimensions of the foundations so that the inhomogeneity of the settlement is not too large and threatening to the building, he has to calculate them by strength. For this, the critical moments and the transverse forces in those elements of the foundation that transmit loads from the building to the ground are defined. The pressure that acts on the bottom of a foundation or a foundation plate on the ground is called contact pressure.

The plate-hard stamping scheme-the surface deformed under the load of the base must coincide with the bottom of the stamping, i.e. the plane. Although this scheme for calculating structural stiffness of a building is in a sense "simplest", it basically reflects the reality of the foundation load of high-rise buildings, for which tiles greater than 1 to 1.5 m provide considerable structural stiffness, including first floors. Further increases in the surface area of the building (usually monolithic frame type) make the interaction scheme a "stamp" model. Contact pressure editions at the bottom of a hard foundation for different foundations at initial loading stage (P_1) and when the load on the foundation reaches the limit (p_G) have different descriptions (Figure 1.1 a, b).

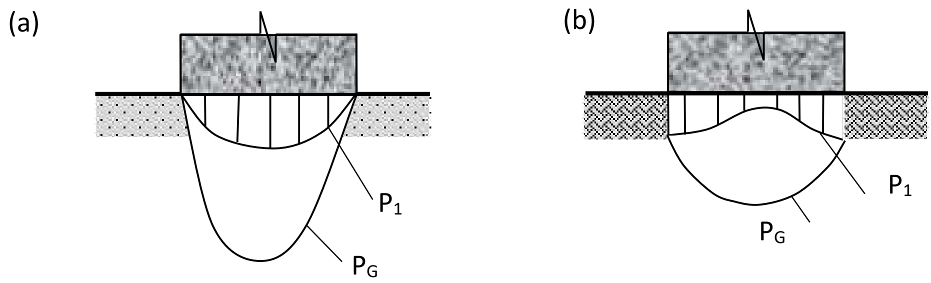


Figure 1.1- distribution of contact pressure on the bottom of a smooth hard foundation based on: unbonded sand (A); The soil between pure soils (clay) and pure soils (sand) (b).

The main difference in stress levels is seen at the places where the structural inhomogeneity is broken. If the foundation or plate is not absolutely rigid, the distribution of the ground reaction depends on the stiffness of the foundation to the bending (Figure 1.2). As can be seen from Figure 1.1, the relationship between the deformation of the foundation and the contact pressure at the bottom of the hard foundation is far from simple. But when the foundation is flexible, this ratio becomes even more complex, and even the rough definition of the actual contact pressure is too cumbersome.

But without knowing at least the near contact pressure, it's impossible to design the foundation structures. It is therefore generally accepted to define contact pressure based on simplified assumptions and correct the error caused by these assumptions by entering a reserve ratio.

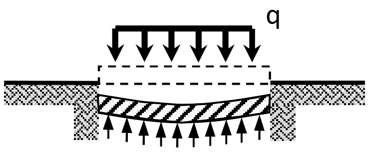


Figure 1. 2 - Elastic plate on elastic foundation under distributed load

Simplified assumptions in the previous norms and classical calculation methods [6, 7, 8, 9] are based on the assumption that the S settlement of any element of the loaded area is completely independent of the load on the attachments. It is assumed that, unlike the fact that the ratio (1.1) between the intensity of the pressure p

$$K = \frac{P}{S} \tag{1.1}$$

For the element and the corresponding precipitation s is going to be constant and equal to K (kN/m) ^{3}). Unlike the actual contact pressure acting on the foundation floor, the fictitious pressure p that satisfies (1.1) is called the elastic bed reaction. The coefficient K is called the coefficient of bed.

Simplified foundation work models do not take into account the nonlinearity of the soil beyond its computational resistance using traditional characteristics defined in engineering geological surveys.

1.2. Scheme of foundation in foundation soil

The total cost of laying foundations can be as high as 40% of the total cost of the building, and reducing this amount can provide significant savings, but it is important that the reduction of these costs does not reduce the reliability of the building, as poor foundations can lead to partial or complete destruction of the building.

Achieving a high quality level of capital construction involves improving planning, using new technologies, advanced scientific and technological and computational achievements, and improving the reliability of buildings and structures.

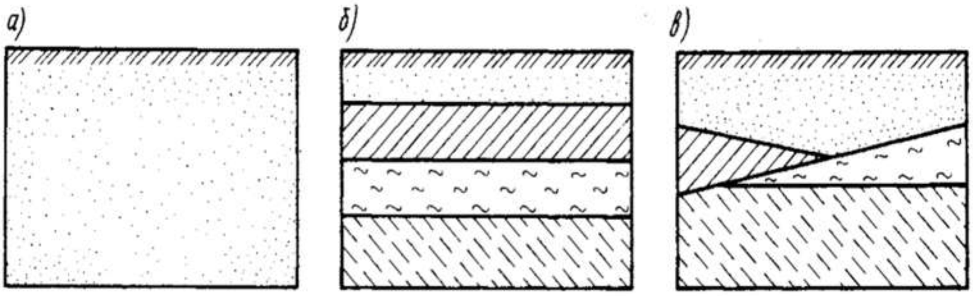
The laying of foundations and foundations requires consideration of the fact that the strength of the soil is hundreds of times less and the deformation is thousands of times greater than the strength and deformation of the ground. To prevent uneven settlement of foundations, it is necessary to evaluate their physical and mechanical properties reliably, as uneven settlement of foundations causes additional stress in the ground structures of structures and can lead to their operational performance or complete destruction.

More sophisticated design and calculation methods are being developed that take into account the reliability, nonlinearity of deformation and the geological properties of the foundation soil.

Numerical simulation and optimal design methods of foundations and foundations using EOM are now widely used, allowing foundations to be built with minimal material costs and costs.

Soil is a mountain rock that forms the upper spheres of the earth's surface, which are formed by the weathering.

The foundation is the thickness of the soil, with all the characteristics of its layering (fig. 1.3), which accepts the load of the building and the structure. It's a difference between rock and non-rock foundations.

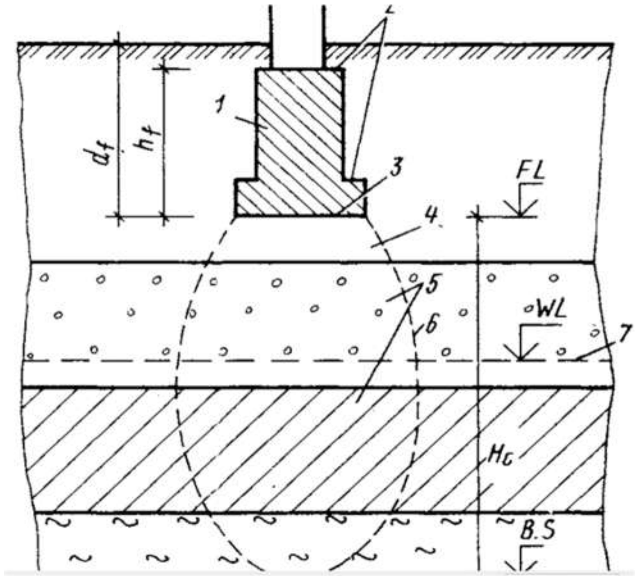


Rice. 1.3 - Natural-foundation schemes

In most cases, it is not enough to place a building on the surface of the earth, because the upper spheres of the earth usually have low bearing capacity and are unable to bear the gravity of the building's weight.

They can get significant deformations from climate factors from the effects of precipitation, drying, swelling or agitation.

All of this makes it necessary to use special structures called foundations, Figure 1.4.



Rice. 1.4 - Scheme of foundation in foundation soil

Foundation 1 is an underground part of a building that is intended to transfer loads from the building to the foundation at some depth. The plane of the foundation that stands on base 3 is called the floor. The surface of foundation 2, on which the ground structure is based, is called a cut. The ground ball 4 on which the sole is located is called the bearing ball. The other five balls are subtractive.

The distance from the surface of the earth to the bottom is the depth of the foundation D_f. Height of the foundation H_f Usually less depth of the laying, because the cut is located below the surface of the earth. As a result of the load from the weight of the building at the foundation, a deformed foundation 6 is formed, which is called the compression thickness or the working area of the foundation. The distance from the base floor marker FL to the bottom edge marker

BS is called the depth of the compressed thickness H_c. Groundwater level 7 at the base is marked WL.

1.3. Engineering geological exploration

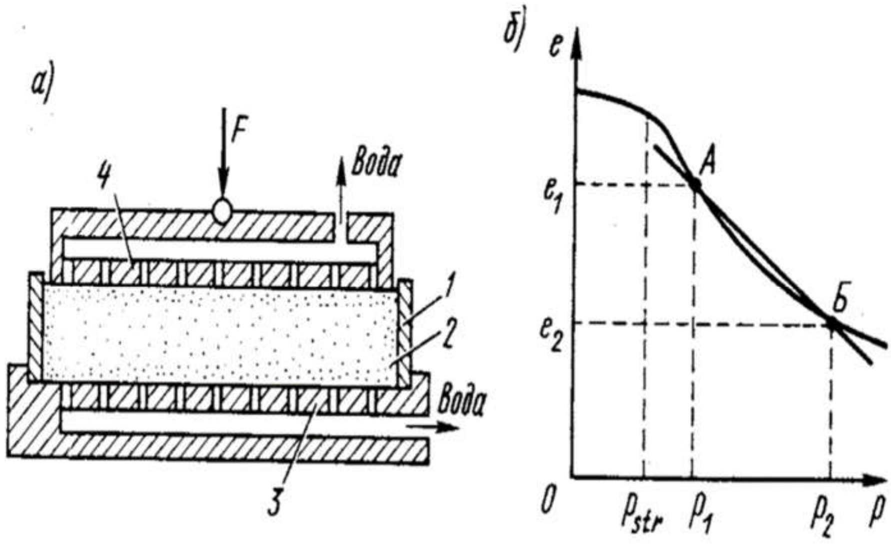
Before you start designing a building and building, you need to have information about the geological and hydrogeological conditions of the building site and the properties of the soil. For this purpose, engineering geological surveys are carried out on the construction site, which are combined with the following sequence of work: drilling wells and developing shears, sampling for geological structure and layering characteristics, laboratory tests for physical and mechanical properties of soils.

The soils are made up of solid mineral particles, liquids and gases, and they are a three-phase system. Soil differs in many ways, the most important of which are physical and mechanical properties.

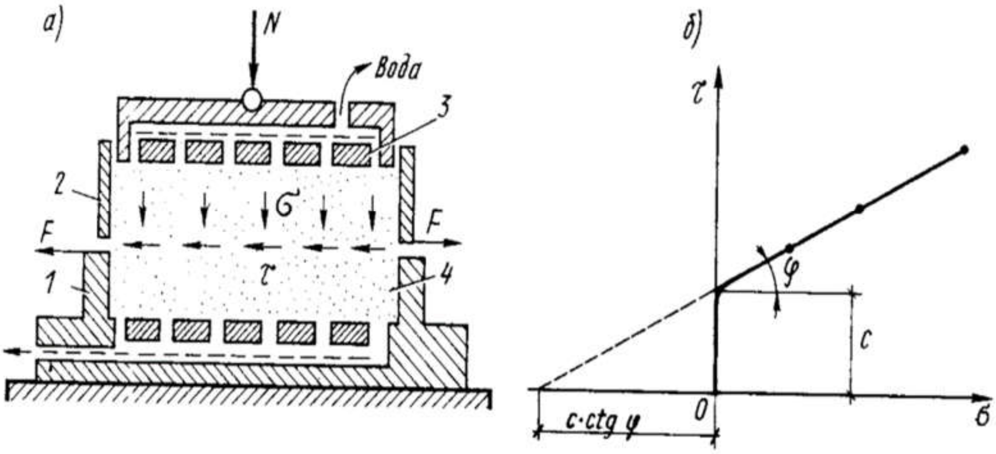
Laboratory studies are conducted to evaluate and classify the foundation soil with samples from engineering geological surveys. Soil samples must have an intact structure, so they are selected from relatively large volume soil samples (monoliths) obtained from shrubs and wells.

The physical characteristics obtained from laboratory studies are consistent with the classification for qualitative evaluation of soil properties and their applicability to building foundations.

Figures 1.5 and 1.6 show the test schemes for soil samples for compression and displacement.



Rice. 1.5 - Study on soil compression model



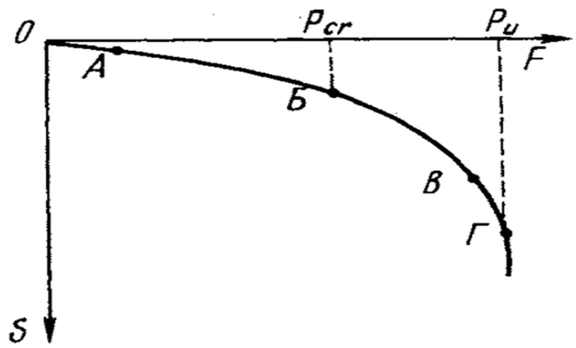
Rice. 1.6 - Soil survey on displacement

The work of the soil in the foundations of buildings and structures has some degree of randomness compared to the work of the materials that ground constructions, including the foundations.

As we've seen, the foundation soils have low strength and high deformation. The strength of the soil is hundreds and thousands of times less than the strength of stone, concrete, concrete, and metal, and the deformation of the soil is tens of thousands of times more than the deformation of the same material.

1.4. Phases of foundation works in the ground

The foundation soils can only accept compressive and displacement forces and hardly work for stretching.

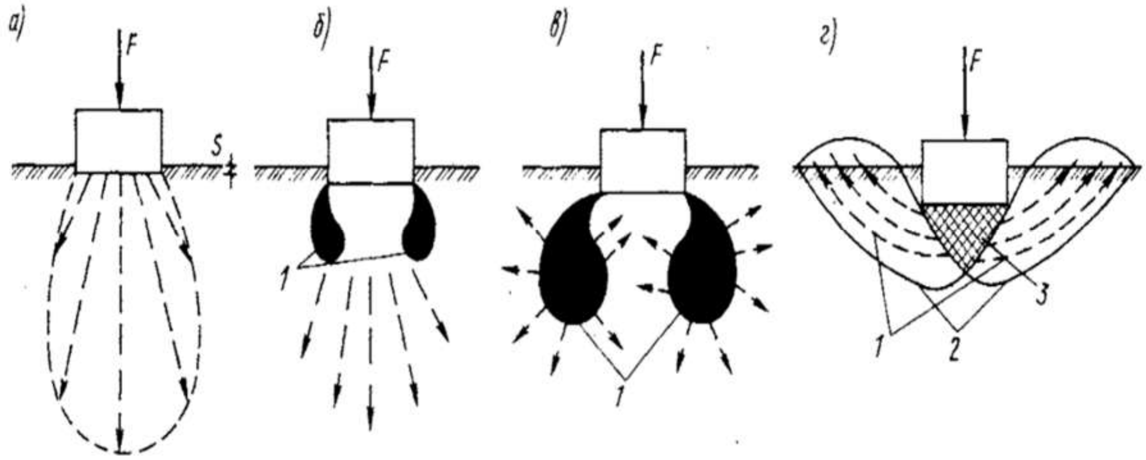


Rice. 1.7 - Graph of the dependence of the settlement of the foundation structure s on the load p

Rice. 1.7 Dependence of the hard-stamping settlement on the soil with structural strength on the action of a constant velocity of external load, Figure 1.7. On the graph, you can draw four characteristic areas: OA, AB, BW, BG.

In the first part of OA, the stress does not exceed the structural strength due to the presence of crystallization bonds. Under the edge of the stamp, the stress concentration can exceed the structural strength of the soil. The external load applied to the stamping causes the ground particles to move mainly downward, and the deformation zone at depth exceeds the width of the stamping floor (Figure 1.8. a). The precipitation at this stage of the load is basically elastic, so this area of the graph is called the elastic deformation phase. So the precipitation over these areas is proportional to the applied load, so this is linear.

If the pressure under the stamping increases further, the structural strength will be increased, and plastic deformation zones or displacement deformation will be formed under the stamping edges (Figure 1.7). This deformation phase is accompanied by the compaction of the soil under the stamp and is called the compaction and local displacement phase. Although the relationship between sediment and load is nonlinear in this area (area AB in Figure 1.7), this nonlinearity is negligible and is not in practical terms replaced by the area AB in a straight line.



Rice. 1.8 - Soil deformation development scheme: a-at compaction; B-when developing local displacement areas; B-development of significant areas of displacement; D-when losing stability

As the load in the BV area increases, the plastic deformation zone develops both sideways and deep, involving more and more plastic deformation of the soil (Figure 1.8. c). The curve of the line BV is going to increase even more. This is called the phase of the development of significant displacement and compaction of the soil on the sides of the plastic deformation zone.

1.5. Methods for detecting the strain-deformed state (SDS) of the foundation

In the design of the foundation of the array, the ground is considered as a spatial system in a complex stress-deformation state. The stress and deformation at different points of the foundation depends on the size of the foundation, the properties of the soil and the load intensity.

The work of the foundation is considered from the point of view of the theory of elasticity and plasticity relative to a plane or space problem depending on the calculation scheme adopted.

Experimental studies on the work of foundation soil under external loads have shown that in most cases they are not ideal elastic bodies because the residual deformation is much greater than the elastic ones. These same observations showed that the soil properties are nonlinear between stresses and strain.

The analysis of the internal structure of the soils showed that they are not solid bodies, but have a granular structure and are made up of fine particles, pores filled with gas and water. Soil inhomogeneity in a number of cases results in anisotropy-different properties in different directions.

Elasticity theory only considers solid bodies that have a strict linear relationship between stress and deformation. And so the question arises, the eternal solution of elasticity theory can be applied to the calculation of foundations and foundations.

As noted above, the foundation soil has a nonlinear relationship between the working pressure and settlement, but under relatively small loads between the two deformation phases-elastic deformation, compaction and local displacement-this nonlinearity is considered to be a linearly deformed body.

Since the foundation settlement is nonlinear and consists of elastic and residual soil, the assumption of elasticity theory is an unacceptable assumption of the independence of forces, which states that when a group of forces is applied to a body, the result of their influence can be found by simply adding the results of each force obtained separately.

The design standards require that the stress at the bottom of the foundation be limited by the calculation of the foundation soil slope, as this is a condition for applying the linearly deformed environment model to the soil that allows for reliable settlement.

1.6. Rheological processes in the soil foundation

As we've already seen, the soil is essentially a rheological process, which is manifested by the skeleton's collapse and consolidation. The skeleton of the soil is explained by the regrouping of structural aggregates and soil particles, which is manifested in the gradual destruction of less strong and then stronger structural bonds, and the emergence of new colloidal and molecular contact bonds, which are manifested as the convergence of soil particles during deformation in areas with significant stress. Consolidation helps to squeeze water and air from the ground into less tense areas or the surface of the ground.

1.7 Methods for solving nonlinear problems, the method of sequential approximation

The work is on the current topic of the numerical simulation of the nonlinear behavior of the foundation by the potential method. The MGE allows you to break down the computational system of equations by considering each individual boundary element, which is very convenient to implement and is a feature of the method. In order to test the stability of the numerical simulation process and its errors in operation, calculations were carried out with different sampling grid densities and different loading steps. So this gives you an idea of the accuracy of the numerical calculation.The calculations with a 2-fold increase in the mesh density confirm the viability of the model. We've studied the presence of predominant diagonal coefficients of the impact matrices. Saving the dominant values of diagonal elements ensures that the only solution of the computational SLAR is obtained, and this requirement is done in the obtained influence matrices. The proposed model considers the deformation that allows the use of geometric equations of the basket. Because the design requirements limit the settlement of the foundation to ensure the normal operation of the structure, the quasi-linear element is used in the model and the elastic solution method is naturally incorporated. The acceptance of small lengths and infinitely small deformation leads to the possibility of using linear theory and, as a result, the superposition principle. One of the characteristics of the soil is that when the individual elements of the soil reach the boundary state, there is no spontaneous increase in plastic deformation. Adjacent elastic elements act as a limiting force by redistributing the force and determining the ultimate value of plastic deformation. As far as the limit of application is concerned, the model is limited to permissible soil deformation.

The integration methods used in classical elasticity theory are not acceptable when solving nonlinear problems. This calls for a method of sequential approaches, which replaces integration with sequential linear elasticity problems, and is called the method of elastic solutions.

The elastic-plastic approach is based on a separate description of elastic and plastic deformation by different physical dependencies. According to this application, the use of differential equations that associate the strain with the plastic and full deformation together with the step (sequential) loading procedure in accordance with the order of change and the application of external loads allows the calculation of the load trajectory (mode) as well as the expression of the inconsistency of the strain and strain tensor and other specific soil working conditions that cannot be obtained under the nonlinear elasticity theory.

Pile foundations often use a weak foundation in the upper soil area when there is a need to transfer load from the building to more dense soil, which is at some, sometimes steep depths.

In modern construction, fiberboard foundations are widely used. Most residential buildings with a floor of 7 to 9 are built on fire foundations. This is due to their increased bearing capacity compared to the foundations that are built in open-pit mines, and also to their relatively less labor-intensive ground work.

1.8. Section conclusions

For foundation and foundation construction, the most important factor is the choice of the optimal solution, which is determined by alternative design and optimization calculation methods. At present, the most optimal solution is selected by comparing the different laying and laying options according to the following indicators:

- Economic efficiency in determining the costs incurred;
- Material capacity;

- The need to carry out work in a tight time frame;
- Allowable precipitation;
- The ability to perform work in winter;
- Labor costs in the development of boreholes (water reduction, reinforcement of boreholes, etc.).

The task of design is to make the most effective decision that can be obtained from a fair assessment of the engineering geological conditions of the construction site, the co-operation of the foundation with the foundation and the superstructure of the building, the construction methods of the foundation that guarantee the preservation of the natural structure of the soil.

Section 2.Numerical boundary element method (MGE) in applied geomechanics and foundation construction problems

2.1. Justification of the need to develop numerical methods

The most efficient solution is related to the large number of calculations that require wide involvement of the EMS. Software allows you to calculate and design foundations. In object design, automated design systems (CAD) are used, which allow computer-based large amounts of calculations related to the optional and optimal design of complex foundation systems, taking into account their compatibility with building designs and foundation soil on first and second boundary states. It is also important to improve the calculation and design methods of foundations and foundations. In this connection, it becomes essential to consider the nonlinear and rheological properties of the foundations, which allow for substantial savings in material costs in laying the foundations. But this is a very complicated calculation, but the use of numerical methods (both finite element and boundary element methods) and modern EOMs allow us to get the expected results. Today, mathematical modeling methods at the EMS have become one of the main and most economical aspects of theoretical and applied research into current problems of science and the national economy. The mathematical model is the most compact way to convey scientific information about the subject and is the idealization of the behavior of the material. Prediction of foundation deformation is a priority of soil mechanics.

2.2. Basic calculation ratio of numerical mge

Geotechnical calculations are based on physical or deterministic equations (also called "equations of state") when there is a mechanical action. They express the laws of soil deformation and destruction in analytical form and establish the relationship between the S-E (static and kinematic parameters).

Historically, MGE has been leading the corresponding MSE, which is based on the variational number, MGE is based on the weighted nonrelation method and Betty's theorem about the reciprocity of the work of two states of a system that are in equilibrium. An important precursor to MGE is the theory of integral equations--Mr. Green's theory of potential. Modern digital means have expanded and improved the definition of VAT in flexible environments.

The solution to the problem of the action of external forces on some body is to satisfy an equation of equilibrium, a geometric equation, a physical equation. These 15 equations include 15 unknown: six components of the tension tensor (the principal diagonal components are symmetric), six components of the strain tensor t T_{σ} E, 3 components of displacement. The exact solution of this system of differential equations in partial derivatives is so cumbersome that only a few exact solutions have been obtained so far. K. Brebbiya, J. Telles, L. Wroubel [1] transformed this system into an integral equation by using the weighted nonlinearity method:

$$\left.\begin{aligned} \sigma_{ij,j} + b_j &= 0 \\ \varepsilon_{ij} &= \frac{1}{2}(u_{i,j} + u_{j,i}) \\ \sigma_{ij} &= C_{ijkl}\varepsilon_{kl} \end{aligned}\right\} \Rightarrow C_{ij}(\xi)u_j(\xi) + \int_{\Gamma} p_{ij}^{*}(\xi,x)u_j(x)d\Gamma(x) = \int_{\Gamma} u_{ij}^{*}(\xi,x)p_j(x)d\Gamma(x), \tag{2.1}$$

$\sigma_{ij,j} + b_j = 0$ Where-static equilibrium equations;

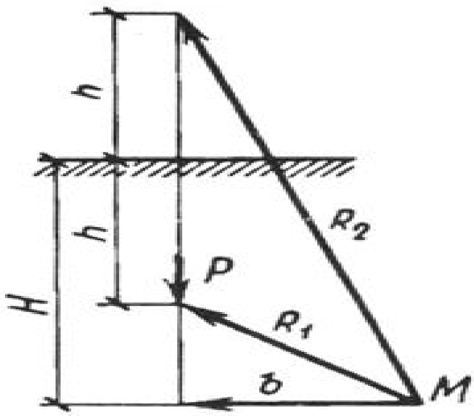
$\varepsilon_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i})$ -Geometric equations;

$\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$ -Physical equations of the environment.

The basic properties of the Einstein indices and the agreement on the sum of the Einstein rules (Einstein's rule of adding the recurring indices) are used to shorten the term equilibrium, geometric, and physical equations. So the entry is in Einstein's notation (derivative of variables is marked by a comma).

Singular solutions (marked *) are important for solving boundary problems for MGE, which are analytical solutions for the displacement of U, and the stress p, which correspond to point-shot in infinite semigroups. These functions perform well in the study area except for the point of explosion, where there is a mathematical anomaly-singularity. In the work, solutions of p are singular solutions.Alligator for the semiplane. In problems where boundary conditions are set on the ground, it's convenient to consider fundamental solutions for semi-finite space. This solution is made in such a way that the boundary conditions on the surface are also satisfied, so when using MGE, you don't need to put finite elements on the surface of the half space. So R. Mindlin got the exact analytical solution of the E-field, which is generated by concentrated normal and tangential forces on the surface of a non-finite elastic field in a half space. The boundary condition was the absence of ground stress. σ

This problem is of great importance to soil mechanics, because it relates to the problem of the concentrated force in the middle of a semi-space applied to the middle of a non-finished array, which was solved by Aldlin in 1949. In formula 2.1, the p-Alendrin for the deformation "u" and the stress "p" are denoted by the symbol (*).



Rice. 2.1 Schematic diagram of concentrated force within the soil array (by R. Mandlin) for determining the sediment of the pals

Decision R. The compass allows for important factors such as the depth of load application and its transfer through the lateral surface of the foundation and in the lower plane of the foundation, the size of the foundation, the coefficient of lateral expansion of the foundation, the stress and strain in all active areas.

For vertical compressive stresses from the concentrated force P applied to the depth H, R. Mindlin (1949):

$$S_z \frac{P}{8\pi(1-\vartheta)}[-\frac{(1-2\vartheta)(z-h)}{R_1^3}+\frac{(1-2\vartheta)(z-h)}{R_2^3}-\frac{3(z-h)^3}{R_1^5}-\frac{3(3-4\vartheta)z(z+h)^2-3h(z+h)(5z-h)}{R_2^5}-\frac{30hz(z+h)^3}{R_2^7}]= \qquad (2.2)$$

ϑ - Poisson's coefficient;

$R_1 = ;\sqrt{(x-\bar{x})^2+(y-\bar{y})^2+(z-h)^2}$

$R_2 = \sqrt{(x-\bar{x})^2+(y-\bar{y})^2+(z+h)^2}$.

The ability to build accurate solutions for soil mechanics is limited. For this reason, there has been a long time since we realized the need for effective approximate numerical methods. The variability of the deformation process of the soil was studied by considering the integral equation of the force balance at the boundary of the foundation structure by numerical MgE [1, 3].

The proposed algorithm for solving the mixed problem is based on the numerical MGE. For soil, the solid environment model in the boundary state was adopted as a linear deformed and transient to a boundary (plastic) state according to the boundary equilibrium condition (flow) of the Messe-Schleicher-Botkin. The method of flexible solutions is implemented in the O.A. Illusion.

The mathematical implementation of the process of determining the VAT base by numerical MGE requires the finite element discretization of the boundary surface of the foundation and the active soil area, Fig. The nonlinear deformation problem is solved by an evolutionary algorithm based on the step-by-step O.A. method. Illusion. The next step used the data from the previous step. At each step of the load at the end of the iteration, the strain was determined and compared with the Messe-Schleicher-Botkin plasticity criterion. The ground work in the nonlinear stage was modeled by the dilatancy theory of the B.M. Nikolayevski-I.P. Fight [2, 4] using a dilatancy coefficient L (ρ), which depends on the density of the soil ρ.

The modern stage of soil mechanics (95% of soil deformation is irreversible) is characterized by an active transition to new calculation models that more fully reflect the real properties of the soil. These are models of plastic flow theory. The dispersion of the soil means that its state and properties at the moment depend on its previous loading history. The basis for building a soil model is the experimental information of the real soil behavior. And then, the model equations should not contradict the laws of conservation of motion, mass, energy.

The theory of plastic flow is written in differential equations:

$$\varepsilon_{ij}^{p} = \lambda \frac{\partial F}{\partial \sigma_{ij}} \mathrm{d} \qquad (2.3)$$

It is the change in the structure of the discrete soil under loads that makes the deformation problem of the soil nonlinear. And the prediction of the deformation of the foundation of buildings remains a priority problem of soil mechanics today, and the solution of this problem involves the delineation of the elastic and plastic states of the material, the formation of the initial conditions of plasticity. The properties of soils accumulating plastic residual deformation have aroused strong interest of researchers in plastic flow theory models that most fully reflect the behavior of a soil dispersion environment under load. Plasticity is a phenomenon that is characterized by a history of loading, so it is necessary to calculate the increase of plastic deformation during loading, and then find the total deformation.

2.3. Sea circles. Plasticity criteria

To investigate the behavior of a creek when the load acting on it changes, it is necessary to describe the deformation of the environment (t_E) and its stress state (t_S). In an isotropic environment, the orientation of the tension tensor plays no role and can be represented in three-dimensional principal stress space by the point P with the coordinates $\sigma._x$, σ_y, σ_z.

Tensor in a plane problem other than global tensor tensor T_S In the principal stress space, a more convenient method is also obtained based on the ellipsoid stress of the beam.So you have to take the ocean's input, which is the basis of all the practical calculations in soil mechanics, with the theory of plasticity. The advantage of applying stresses to the sea circles is that the points corresponding to the stresses acting on different sites are located on the same plane.

The sea showed that the area bounded by three perpendicular circles centered on the axis σ, Figure 2.2 These three circles define

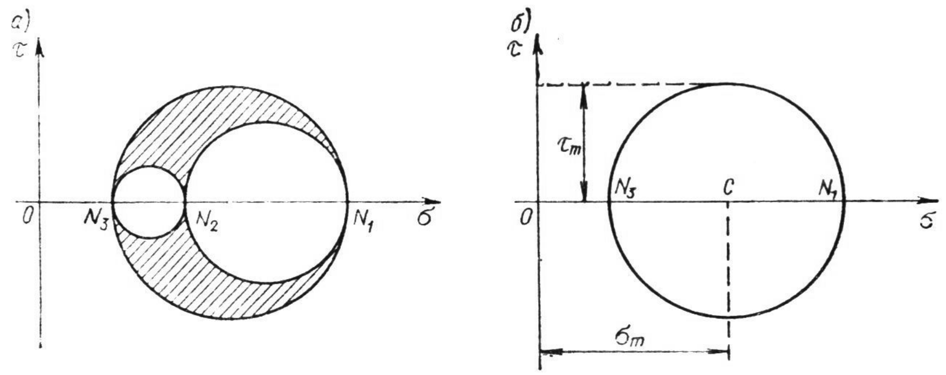


Figure 2.2 - Mohr's circles

Three main voltages σ_1, σ_2, σ_3 Which n points correspond to $_1$, N_2, N_3The largest circle is called the Mohr's circles. Its geometry depends only on the maximum and minimum principal stresses σ_1, σ_3 And it's not dependent on the intermediate head voltage σ_2 . The circle of the sea can also be characterized by the abscissa of its center $\sigma._m$ And radius τ_m (Figure 2.2 b).

For plane problems there is one special plane where the principal stresses (maximum σ) are active. σ_1, and minimum σ_3) And what's perpendicular to the principal intermediate voltage $\sigma_{2.}$ Sea circle with diameter N $_3N_l$ (Fig. b) is thus the geometric position of points corresponding to the tension acting on the planes perpendicular to the specified particular planes. This is the sea circle.

The criteria for plasticity. Elastic-plastic bodies. In n-dimensional space, we can assume that there is an open elastic region bounded by some so-called boundary surface that belongs to this region and defined by the equation $F(\sigma_{ij}) = 0$, given the name of the plasticity criterion.When you see it. So p belongs to the elastic region, so the behavior of the body is elastic and then the real is the next matrix ratio

$$\varepsilon_{ij} = E \cdot \sigma_{ij}, \qquad (2.4)$$

Where is E-a square symmetric matrix of order n, which is called the elastic matrix.

If you want to. So when p goes to the boundary surface, plastic deformation occurs, and if it goes back to the elastic deformation area, the plastic deformation becomes residual.

When you see it. P is on the boundary surface $f(\sigma)_{ij}) = 0$, then there's plastic deformation. Using the principle of plastic work, the plastic deformation rate can be given as follows (2.3):

$$\varepsilon'_{ij} = \lambda\, \partial F / \partial \sigma_{ij},$$

λ-The ratio of the ratio, which depends on the point P, the value of which is unknown. That means the velocity vector of the deformation is directed normally to the boundary surface.

Criteria for the plasticity of the shell and cod

These boundary surface equations are dependent only on the stress state. They're not dependent on deformation or the speed of deformation.

If a elastic plastic body is isotropic, the plasticity criterion is independent of the axis of the coordinates and can be used in the principal stress space. In this case, the plasticity criterion looks as follows:

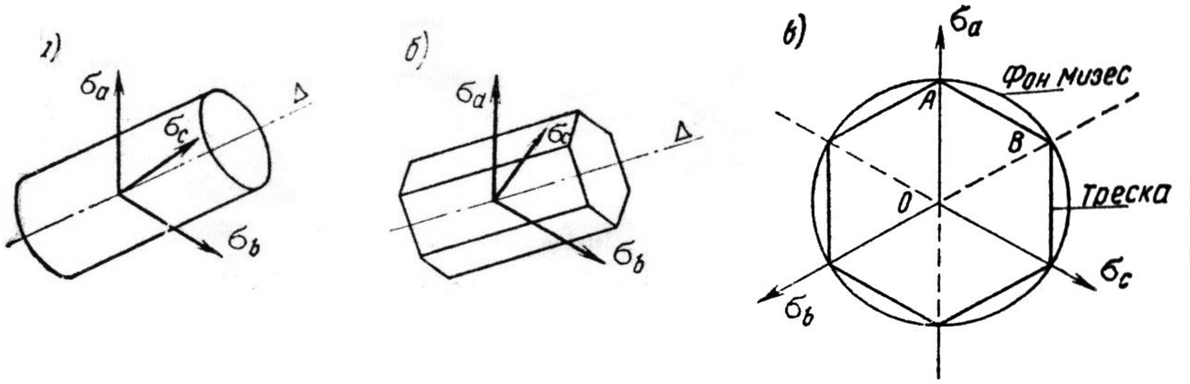
$$F(\sigma_1, \sigma_2, \sigma_3) = 0. \qquad (2.5)$$

The simplest is the Mizesse criterion.

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 - 2a^2 = 0. \qquad (2.6)$$

This criterion is only dependent on the intensity of the various deviators and not on the pressure of all sides. When the Mizesse criterion is applied, the plastic flow is at a constant volume.

The boundary surface of the meshes is a circular cylinder with forming parallel lines δ (σ) $_1$ = σ_2= σ $_3$). The intersection perpendicular to the cylinder is a circle with radius a$\sqrt{2/3}$, (Figure 2.3. c)



Rice. 2.3 - Plasticity criteria:
(a) the Mises criterion; (b) the Tresk criterion; C) Normal intersections of the Mises and Tresk criteria

The cod criterion is presented in a slightly different way. It includes the main voltages (maximum $\sigma_{min,}$ And minimum $S_{max,)},$ And the intermediate main tension doesn't matter.

$$\sigma_1 - \sigma_3 - 2b = 0. \qquad (2.7)$$

The cod boundary surface is a hexagonal prism, Figure 2.3 b. The side of the hexagon is equal to b$\sqrt{8/3}$b (Fig. 2.3, b)B. In this case, deformation is also carried out without changing the volume.

Coulomb's law. (1773p.) The boundary surface for most materials is fairly accurately described by equation (2.8), Figure 2.4

$$\tau = c + stgf \qquad (2.8)$$

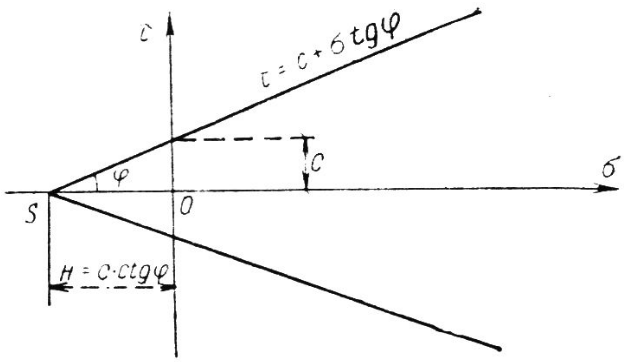
C - coupling, expressed in stress units,

φ-- the angle of the internal friction.

Figure 2.4 shows the boundary curve corresponding to equation (2.8). It consists of two beams coming out of the TCH. The S axis and the angle φ that forms with this axis. These two rays are usually called straight coulombs.

OS = H = c · ctg φ - is the resistance of the tensile material. When the adhesion is zero, the material is called a drop and the coulomb lines go through the start of the coordinates, and the criterion of destruction is written as:

$$\tau = \sigma tg\varphi \qquad (2.9)$$



Rice. 2.4 - Coulomb's Law

Coulomb's Law this is the simplest law of friction. Where the voltage slope is less, it's kept even. If the adhesion is not equal to zero, the material is called a bond. The linearity of Coulomb's law is, of course, just an approximation, but it's very productive.

The plastic criterion for the pendulum looks like

$$(\sigma_1 + \sigma_3)sin\varphi - (\sigma_1 - \sigma_3) + 2c \cdot cos\varphi = 0 \qquad . \qquad (2.10)$$

This expression can be given in another form:

$$\sigma_1 - \sigma_3\frac{1+sin\varphi}{1-sin\varphi} - c\frac{2cos\varphi}{1-sin\varphi} = 0. \qquad (2.11)$$

If you go to angle φ/2, then

$$\sigma_1 - \sigma_3 tg^2(\frac{\pi}{4} + \frac{\varphi}{2}) - 2ctg\,(\frac{\pi}{4} + \frac{\varphi}{2}) = 0. \qquad (2.12)$$

The corresponding boundary surface is a pyramid with the axis δ and the vertex with the coordinates (-H,-H,-H) where n = c · ctg φ, Figure 2.5. a.

Figure 2.5. b shows the intersection of the pyramid with one of the planes of symmetry (in this case, this is the plane defined by the axis σ_1And the line d). The points of the boundary surface of the plane correspond to the triaxial compression values in laboratory tests on a triaxial apparatus; Section A corresponds to a normal "triple compression" study (point A corresponds to a simple compression), Section SD corresponds to a stretch study and Section DE corresponds to a compression study.

Figure 2.5. B shows the intersection of the pyramid with the plane perpendicular to the line D. This intersection is an incorrect hexagon, and the ratio of the distance from the center of the figure to the corresponding surfaces

$$\frac{GF}{GE} = \frac{3-sin\varphi}{3+sin\varphi}. \qquad (2.13)$$

$\varphi = 0$, If that's the ratio is equal to 1, and the hexagon becomes right.

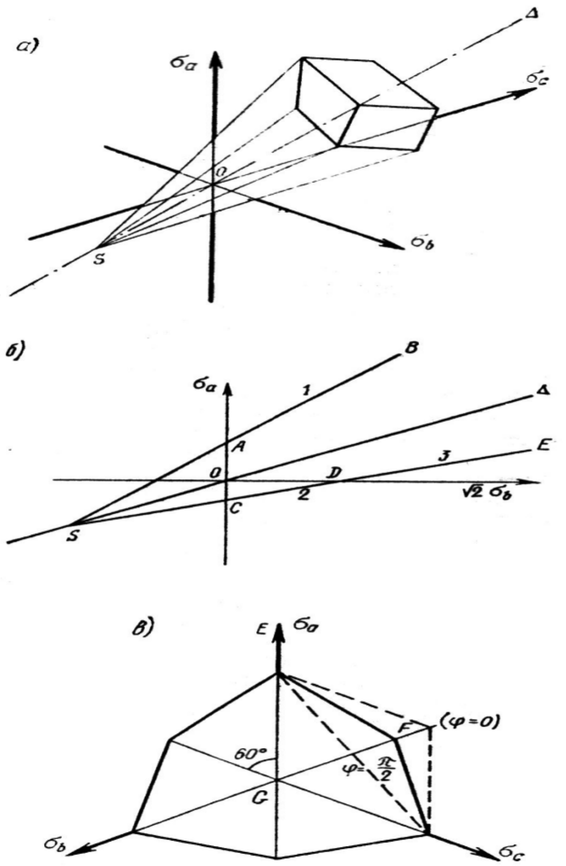


Figure 2. 5 Coulomb boundary surface (a) is a boundary surface in the form of a pyramid with a axis of symmetry δ; B)-Intersection of the boundary surface by the plane (o, σ_3, (d); C) is the intersection of the boundary surface with a plane perpendicular to the axis of symmetry D. Fig.A, σ_b, σ_c Matches S_1, σ_2, σ_3

2.3. Arrival condition of the Mizesa-Schleicher-Botkin plastic flow

Impact of load trajectory on VAT base. The solution of the mixed problem involves calculating the stresses and strain in both the elastic and plastic fields. In the elastic region, the strain is directly related to the full deformation by nonlinear or linear ratios. There is no uniform correlation between strain and strain in plastic areas and the incremental ratios of the increases in plastic deformation and strain should be used to determine the plastic component deformations, which should be integrated, tracing the deformation history from the moment the boundary state appears in the runoff environment. The load sequence, i.e. the load trajectory, will be automatically taken into account.

In the mixed problem method used in this paper, the determinative relationships between increases in plastic deformation and stresses were considered in the non-associated plastic flow law, using the ground velocity coefficient λ, which is an additional parameter of the non-associated model.

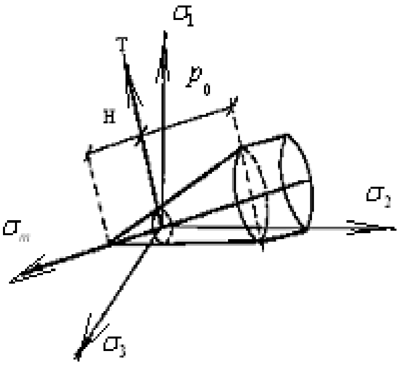
The Messe-Schleicher-Botkin model of the soil environment is based on the plastic flow theory and describes the physical nonlinear deformation of the soil foundation. These deformation models consist of elastic and plastic components, considering a mixed (elastic-plastic problem): ε

$$d\varepsilon_{ij} = d\varepsilon_{ij}{}^{e} + d\varepsilon_{ij}{}^{p}, \qquad \varepsilon_{ij} = \varepsilon^{e}{}_{ij} + \sum \varepsilon^{P}{}_{ij} + d\varepsilon^{P}{}_{ij}\,. \tag{2.14}$$

$d\varepsilon_{ij}{}^{e}$ $d\varepsilon_{ij}{}^{p}$ Where the increase in the elastic deformation of the soil, the increase in the plastic deformation of the soil.

$d\varepsilon_{ij}^{e}$ $d\varepsilon_{ij}^{p}$ $d\varepsilon_{ij}^{e}$ So the complete deformation is made up of two components: reverse (elastic) and irreversible. The work of increasing stresses is converted into elastic energy, while the work of increasing irreversible deformation dissipates $\sigma_{ij} \cdot d\varepsilon_{ij}^{p}$.

The non-associated plastic flow law is used to determine the increases in plastic deformation of the soil at work:



$$d\varepsilon_{ij}^{p} = d\lambda \frac{dF}{d\sigma_{ij}}, \quad F \neq f; \qquad (2.15)$$

Rice. 2.6. Mizesa-Schleicher-Botkin's plasticity criterion in Coordinates of main voltages

Where f is the plastic potential, the corresponding selection of f ensures the orientation of the plastic deformation growth vector in accordance with the experimental data, f is the function that determines the plastic condition (f = 0). $d\varepsilon_{ij}^{p}$

In most cases, the deformation of the soil is accompanied by a change in volume. It should be noted that the plastic state of the soil leads to its destruction as a result of displacement. The deformation that occurs here causes the ground particles to repackage.

When switching from a new SDS to a complex SDS, there is a problem of formulating the conditions for switching to a elastic-plastic state. Generalizing the concept of the current limit for the nine-dimensional tension tensor space, the concept of the current surface F is introduced, which has the characteristic that when the voltage vector that represents the tension state at a point on that surface, the material goes into the plastic state. T_σ

$f(\sigma_{ij}) = 0$ $\qquad$ $f(\sigma_1, \sigma_2, \sigma_3) = 0$ $\qquad$ So you can give the surface of the flow:, or in three dimensions: (2.5). The selection of surface current is invariant to the selection of coordinate systems.

The Mizesa-Schleicher-Botkin criterion is used as the plastic flow condition F in the work. The condition f = 0 corresponds to the boundary condition where the function f takes the form (2.16):

$$\begin{cases} f = T + \sigma_{окт} \cdot tg\psi - \tau_S = 0 \quad при \quad \sigma_{окт} \leq p_0 \\ f = T + \rho_0 \cdot tg\psi - \tau_S = 0 \quad при \quad \sigma_{окт} > p_0 \end{cases}, \qquad (2.16)$$

This flow surface gives the ratio between $\sigma_{окт}$ (The first tensor of the tension T_σ) and T (First voltage deviation invariant D_σ) On the octahedral plane and together with the equations of equilibrium (2.1) provides the number of equations and the number of unknown ones for the model to lock.

2.5. Matrix formula for calculating MGE equation and its numerical realization

The two-dimensional problem (from the point of view of the field's suspension symmetry) is considered in the Master's thesis, and the computational integral equation (2.1) is converted into a discrete form, recording it for a number of elements of the side surface and the blade of the field. The points where an unknown function is searched are called nodes and they are located in the middle of each segment for the constant elements, Figure 2.8. The boundary of a foundation structure is broken down into N elements of which N_1 elements were set on the side surfaces of the fields, and N_2 elements are on the blade of the field. The values of the functions u (displacement) and q (voltage) were considered constant in the area of each element, and one of two unknown values (u or q) was known. The known values were U (move). According to this equation (2.1), we can give:

$$c \cdot u_i + \int_{\Gamma} u \cdot q^* d\Gamma = \int_{\Gamma} q \cdot u^* d\Gamma \quad , \tag{2.17}$$

As the point "i", we took the value of ξ for which there is a fundamental solution, that is, u (ξ) = u_i.

For constant elements, the boundary is always "smooth", so the coefficient of $_{And}$Same as c_1 = 1/2. Equation (2.17) is the relation in discrete form between the node "i" where the functional solution is given and all the "j" elements (including the element i = j) at the boundary.

The functions u and q, which are under the integral sign in equation (2.1), have constant values in the area of each element and can therefore be derived from an integral sign that gives:

$$\frac{1}{2}u_i + \sum_{j=1}^{N}\left(\int_{\Gamma_j} q^* d\Gamma\right)u_j = \sum_{j=1}^{N}\left(\int_{\Gamma_j} u^* d\Gamma\right)q_j \tag{2.18}$$

$\int q^* d\Gamma\, \widehat{H_{ij}} \int u^* d\Gamma = G_{ij}$ If you mark A (2.18) you can write:

$$\frac{1}{2}u_i + \sum_{j=1}^{N} \widehat{H_{ij}} \cdot u_j = \sum_{j=1}^{N} G_i \cdot q_j \tag{2.19}$$

Enter the mark: $H_{ij} \begin{cases} \widehat{H_{ij}} & i \neq j \\ \widehat{H_{ij}} + \frac{1}{2} & i = j \end{cases}$. = then the equation (2.19) will look like:.

$$\sum_{j=1}^{N} H_{ij} \cdot u_j = \sum_{j=1}^{N} G_{ij} \cdot q_j \quad (2.20)$$

The matrix representation of this equation: $H \cdot U = G \cdot q$

Transfer of the unknowns to the left gives

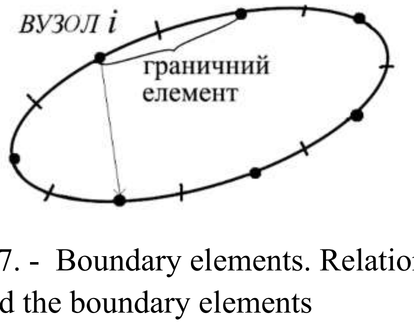
$$\mathbf{A \cdot Y = F}, \quad (2.21)$$

Where Y is the vector whose components are searched for unknown.

The integral equation (2.1) can be given a discrete form by writing it for a series of n elements. Consider a two-dimensional area, the boundary of which is divided into a series of boundary constants along the length of the elements (Fig. 2.9.). So let's assume that the functions u and q are constant over the length of each boundary element and equal to their value at the node of the element. The nodes are located in the middle of the boundary element.

So in general, u and q can change according to a linear or more complex law. Note that for each boundary element one of two functions (u or q) is known. Equation (2.21) can be written

$$c_i u_i + \int_{\Gamma} u q^* d\Gamma = \int_{\Gamma} q u^* d\Gamma . \quad (2.22)$$



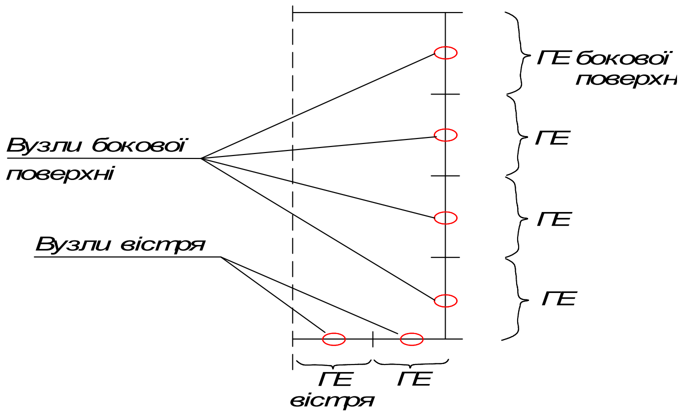
Rice. 2.7. - Boundary elements. Relationship between the fundamental solution at the boundary node and the boundary elements

Discrete form (2.22) for point i:

$$\frac{1}{2} u_i + \sum_{j=1}^{N} \int_{\Gamma_j} u q^* d\Gamma = \sum_{j=1}^{N} \int_{\Gamma_j} q u^* d\Gamma . \quad (2.23)$$

Equation (2.23) for each node "and" of the side surface and the field sparse gives a system of algebraic equations:

$$\begin{vmatrix} \hat{h}_{11} & \hat{h}_{12} & \dots & \hat{h}_{1n} \\ \hat{h}_{21} & \hat{h}_{22} & \dots & \hat{h}_{2n} \\ \dots & \dots & \dots & \dots \\ \hat{h}_{n1} & \hat{h}_{n2} & \dots & \hat{h}_{nn} \end{vmatrix} \times \begin{Bmatrix} U_1 \\ U_2 \\ \cdot \\ U_n \end{Bmatrix} = \begin{vmatrix} q_{11} & q_{12} & \dots & q_{1n} \\ q_{21} & q_{22} & \dots & q_{2n} \\ \dots & \dots & \dots & \dots \\ q_{n1} & q_{n2} & \dots & q_{nn} \end{vmatrix} \times \begin{Bmatrix} p_1 \\ p_2 \\ \cdot \\ p_n \end{Bmatrix} \quad (2.24)$$



Rice. 2.8. - Spatial surface and sparse field discretization by permanent boundary elements

Options found in the main diagonal:

$$h_{ii} = \hat{h}_{ii} + c_i. \qquad (2.25)$$

Matrix: $HU = GP$. (2.26)

The sequence of calculation of piles according to MBE:

1 Forming the input data defined by the geometry of the surface elements of the foundation.

2 Numerical integration using ordinary square Gaussian formulas to produce nuclei with singular weight functions (fundamental functions-solutions of R. Mandlin) to obtain matrices for a system of linear algebraic equations.

3 Write the equations for each of the subregions.

4 Solutions of SLAR for relatively unknown stress limits: tangent and normal σ. τ

5 Definition of bearing capacity of a foundation structure.

2.6. Conclusions on the section

The MGE emerged as a result of the further creative development of a wide range of numerical methods, combined under the general name "finite element theory." The boundary element method is based on the concept of the fundamental solution of the boundary problem, which corresponds to the source function given as the delta function of the hole.

Deformation research is essentially a geometric direction of analysis.
It's known as deformation theory.

– The stress theory is based on the equilibrium requirements.

-Physical equations are the mathematical idealization of the mechanism of material behavior.The mathematical apparatus of the MGE model is supplemented by experimental laws of deformation (dilatancy theory). In this case, unlike the soil solid model, it is assumed that displacement deformation depends not only on the deflector but also on the spherical stress tensor (which restrains them), and that individual deformation is related to both the spherical stress tensor and the deflection stress tensor (the deflector further thickens or clarifies the soil depending on porosity).

The distribution of stresses caused by concentrated loads applied in the middle of a half space was given by R. Aldlin in 1949, who received not only the stress but also the corresponding shifts from concentrated single loads applied in the middle of a half space. These solutions (fundamental solutions) correspond to half the soil (geomechanical problems, because the pressure from the foundation is applied not to the surface of the soil, but to some depths inside the soil array).

Section 3. Results of forecasting studies for MBE SDS of pile foundation

3.1. Statement of the task of determining the bearing capacity of the hanging piles 4.5-25

The problem of developing a foundation calculation model that ensures a sufficient degree of consistency between the calculation results and the reality and making the algorithms of this model simple to use with software complexes remains one of the current problems. The soil environment already undergoes irreversible deformation under moderate external loads and is part of a group of plastic bodies that are thickening.

Modern methods of calculating the foundation in soil mechanics allow us to estimate only their order. Using as the calculation pressure of a limit corresponding to the end of the linear section of the load-settlement graph usually leads to uneconomical solutions.

There is an unaccounted large area of research into the displacement deformation of the soil when it is in the plastic stage. At the same time, the reserves of the plate zone allow for an increase in the load on the foundation when the settlement of the elastic stage does not exceed the limit allowed for the construction.

The classical plastic flow theory and the dilatancy theory of granular environments of Prof. were used to obtain a reliable mathematical model of soil in the master's thesis. V.N. Nikolayevski, Prof. I.P. Boyka. In calculating the boundary state of a discrete soil environment, the dilantancy theory allows the plastic flow model to be modified, dictated by rheological experiments, and to model the boundary state of the soil with adequate experimental data. The significance of the results of the extensive study of the foundation [2, 3,] requires extensive introduction and further development in order to construct a theory of foundation calculation that is satisfactory to construction practice.

The numerical boundary element method (MBE) [1, 3, 18, 19] is used.

The basic equation is the integral equation (2.1) obtained by K. Brebbij [1], which is analogous to a system of 15 differential equations (static, geometric, physical):

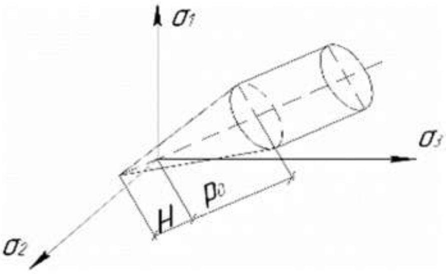
$$\left.\begin{array}{c} \sigma_{ij,j}+b_j=0 \\ \varepsilon_{ij}=\dfrac{1}{2}(u_{i,j}+u_{j,i}) \\ \sigma_{ij}=C_{ijkl}\varepsilon_{kl} \end{array}\right\} \Rightarrow C_{ij}(\xi)u_j(\xi)+\int_{\Gamma} p_{ij}^{*}(\xi,x)u_j(x)d\Gamma(x)=\int_{\Gamma} u_{ij}^{*}(\xi,x)p_j(x)d\Gamma(x),$$

Where u is the displacement vector at the boundary of the foundation structure;

P is the voltage vector at the boundary; -The core of the boundary equation (2.

u^* , p^*, σ^* 1)-the solution of R. Aldlin for the displacement, tension and stress derivative corresponding to the single explosive effect (p = 1) in the half space [1];

The Mizes-Schleicher-Botkin criteria are used in the work (Fig. 3.1):



Rice 3.1- Modified Messes-Schleicher-Botkin plastic criterion in principal stress coordinates

The surface f runoff for describing the nonlinear properties of soils gives the ratio between σ_m(I the stress tensor invariant) and T (II stress deviator invariant) on the octahedral plane and together with the equations of equilibrium provides the number of equations and the number of unknown (2.15):

$$\left| \begin{array}{ll} f = T + \sigma_m \cdot tg\psi - \tau_S & npu\ \sigma_m \le P_0 \\ f = T + P_0 \cdot tg\psi - \tau_S & npu\ \sigma_m > P_0 \end{array} \right.$$

where F is the flow condition,

σ_m - hydrostatic pressure;

T is the intensity of the voltage deviation;

ψ, c - the angle of internal friction and adhesion on the octahedral plane;

τ_s -an octahedral parameter similar to a clutch;

P_0 -The ground environment parameter, which is the transition from cone to cylinder.

φ_m The displacement angle of the foundation (slope of the sea circle) in the model is determined by the formula:

$$\varphi_m = \varphi_f \pm \theta \quad , \qquad tg\theta = \frac{d\varepsilon_v}{d\gamma} = \Lambda \quad , \qquad (3.1)$$

Ed $_f$-The angle of the internal friction of the soil,

Λ -The dilatancy rate (an additional parameter of the uncorrelated plastic flow model) was analytically dependent on soil density ρ and critical soil density ρ^{cr} $\Lambda = \Lambda(\rho, \rho^{cr})$., in turn p^{cr}Depends on hydrostatic pressure σ_m, Options P_0 And minimum and maximum density

$$\rho^{cr} = f(\sigma_m, P_o, \rho_{\min}, \rho_{\max}).$$

Soil the variation of soil dilatancy processes was calculated according to the model of dilatancy environment by V. N. Nikolayevski, I. P. Boyka [2, 3]. The density of the soil is taken as the reinforcement parameter in the calculation model.

The value of the current value of the soil density at each step load was determined by the formula:

$$\rho_i = \rho_o / e^{\varepsilon_v}, \qquad (3.2)$$

where ε_v are volumetric strains, which were determined using the Genki strain measure:

$$\varepsilon_v = \ln V_i / V_0; \qquad (3.3)$$

ρ_i, V_i -current density and volume values on the load step ;

ρ_o, V_o -initial values.

3.2. Numerical implementation of the calculation of 4.5-25 per MBE

The behavior of the "field-foundation" system in work was studied by considering the change in properties of its elements, local component-input system parameters of their model 28. Ten of them are the physical-mechanical characteristics of the soil: E-deformation modulus; Poisson's coefficient; -soil density; -minimum soil density,-maximum soil density; C-Clutch; -angle of internal friction; w is soil moisture; -the degree of hay of the soil; -The magnitude of the stresses on the octahedral plane when the soil is still working as a total stress environment The 18 input parameters describe the geometry of the field and the pattern of the active base area . $\nu \rho \, \rho^{\min} \, \rho^{\max} \, \varphi \, S_r \, p_0$.

The richness of the soil foundation structure, which is determined by the genesis of the deposits, was taken into account by the weighted average characteristics of the soil.Unlike construction materials, the strength and deformation of a discrete soil environment are not characterized by minimum, but by average values of strength characteristics. The deformation and strength of the dispersion foundation is the result of the average soil properties in some areas.

Replacing geological parameters of a multiphase environment with equivalent quasi-homogeneous parameters is a fairly efficient approach in the calculation.

The mean values of the basic input physical-mechanical properties of the soils that are included in the calculation:

Deformation modulus E = 10 MPa,

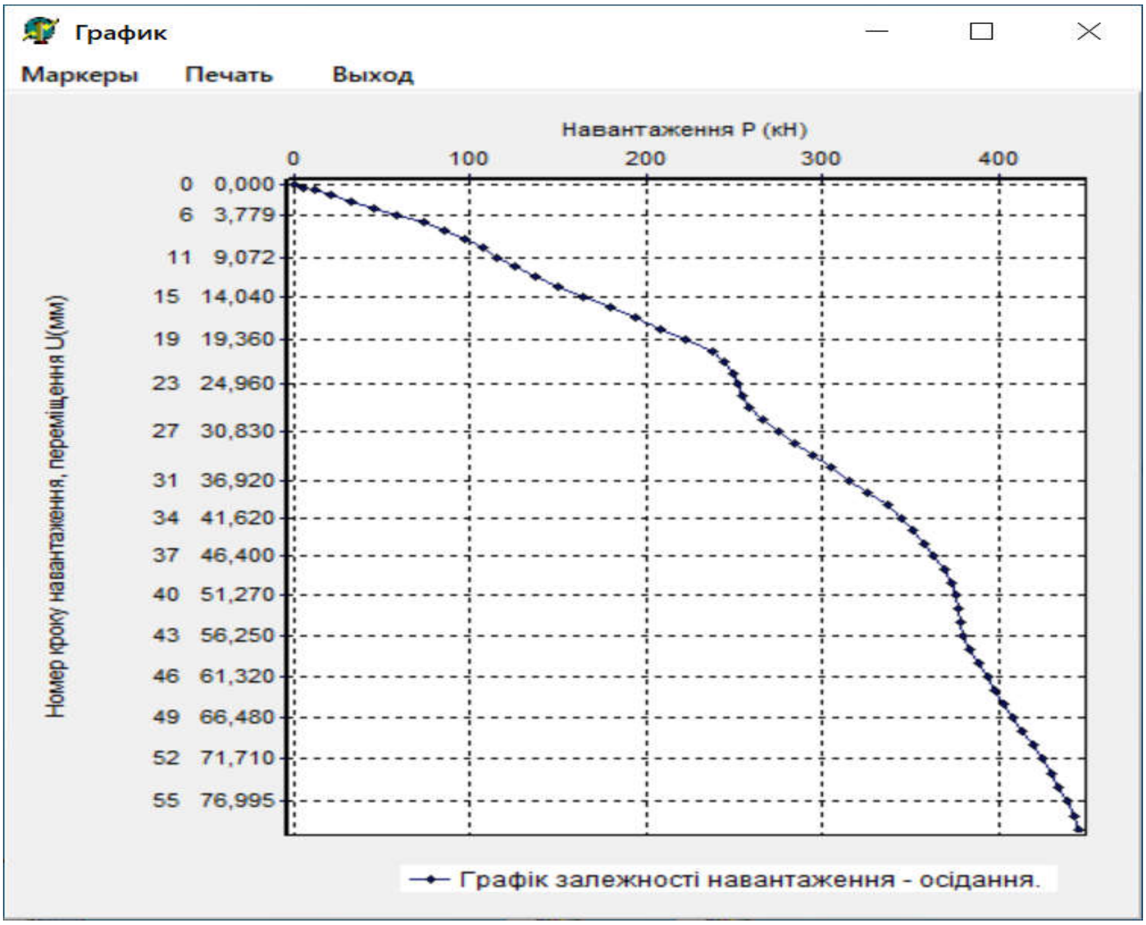
Poisson's coefficient = 0.35, ν

Soil density p = 1.818 g/cm^3,

Clustering C = 3.1 MPa,

The angle of internal friction is 1,534 radians. φ

Results of numerical prediction of the bearing capacity of the prism killing field with 4.5-25. It's served on rice 3.2.



Rice. 3.2 Pole carrying capacity 4.5-25 for MBE

3.3. Numerical study analysis of work fell from 4.5-25

According to the graph, the calculation range is 4.5-25 per the number of mge per graph. 3.1 The "p-S" dependence on the bearing capacity of a single field, calculated according to the standard formula (3.4) (340 kN) of displacement, is 4.16 cm. The calculated load allowed on the field, N = 340/1.4 = 243 kN, where the displacement is approximately 3 cm, the p-S dependence within these limits is almost linear, and the precipitation is approximately S = 3 cm, which is approximately the same as the precipitation of S4.5-25 obtained by the spherical elementary summation method s = 3 cm.

The critical pressure value, the pressure from which the first two phases of the ground stress state (Figure 3.2),

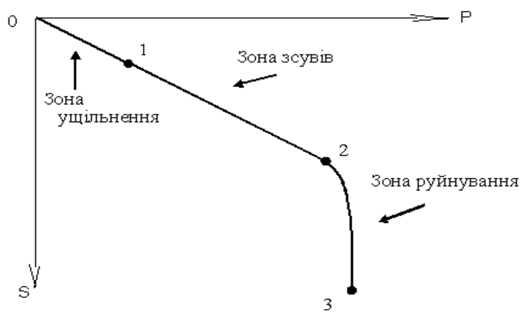


Figure 3.3.- Standard Load-Sediment Test Curve $s = f(P)$

And where the boundary equilibrium zone is only generated under the edge of the distributed load, Figure 3.2, is defined according to the standard documents:

P_{CR}= [(d $\pi \cdot \gamma_d$+ c · ctg + z$\varphi_{max}\gamma)\varphi \frac{\pi}{2} + \varphi$·/(ctg-)] + d · γ_d (3.4)

where γ_d- the weight of the soil above the foundation floor,

γ, φ, c-respectively, is the weight of the soil, the angle of internal friction and the adhesion of the soil lying under the foundation,

z_{max}-the maximum extent of the boundary equilibrium in the soil.

The current regulations allow the development of the displacement zone to a depth not exceeding a quarter of the width of the sole of the foundation, i.e. $_{max}$= 0.25 b.

Receiving from $_{max}$= 0.25 b and based on (3.4), the value of the critical load on the foundation soil used in practical calculations to determine the calculated soil resistance according to the applicable regulations:

P = M γ · b · + M γ_q· d · γ_d+ M_c· c (3.5)

Where M γ = 0.25 pi/(CTGP/2), M $\varphi + \varphi_q$= 1 + π/(CTGP/2), $\varphi + \varphi$

M_c· $\varphi\varphi + \varphi$= π ctg/(CTGP/2).

The design standards require that the stress at the bottom of the foundation be limited by the calculation of the foundation soil slope, as this is a condition for applying the linearly deformed environment model to the soil that allows for reliable settlement.

Thus, the comparison of the results of the calculation of the behavior under load field C4.5-25 by the numerical MBE and the calculation of the normative documents are almost identical.

3.4 Conclusions on the research part

- Developing the scientific basis for calculating the dispersion soil using the elastic-plastic dilatancy model is a current direction of modern foundation construction.
- The plastic flow theory adequately reflects the nature of soil deformation in a wide range of loads, and the solution of the nonlinear VAT prediction problem of fuel foundation has both scientific and practical value.
- The floor foundation allows for a building to have a reasonable settlement.

-The elastic-plastic soil model uses the Messe-Schleicher-Botkin strength condition and the unassociated plastic flow law and is an effective nonlinear model that allows the calculation method to assess the impact of previously defined and recorded areas of foundation deformation on settlement of buildings and the strength in the foundation and to take into account their presence in design.

This can increase the bearing capacity of the foundation compared to the traditional calculation.

-Any building is an interference with the natural state of the soil.

-Predicting the behavior of the soil under load requires the development of mathematical models that allow numerical analysis.

-Construction is one of the main sectors of the national economy of any country, it provides for the creation, expansion and reconstruction of existing core funds.

Construction is the locomotive for the development of all sectors of the country, for the increase in productivity, for the increase in material welfare.

Section 4. Technical part

Calculation of aggregate concrete marching

The width of the march is 1.35 m, the height above 2.8 m, and the inclination angle of the march is 30^0 ,

Grade 15 x 30 cm Grade 25 concrete, grade frame reinforcement

A300C, grid-VR-1.

Calculation data for concrete:

Heavy class B25 concrete:

R_b= 14.5 MPa; R_{bt}= 1.05 MPa; C_{b2}= 0, 9; R_{bn}= 18.5 MPa; R_{btn}= 1.6 MPa;

$E_b = 27 \cdot 10^3$MPA;

A300C steel fixture:

R_s= 280 MPa; R_{sw}= 215 MPa; $E_s = 2{,}1 \cdot 10^5$MPA.

Preliminary determination of the dimensions of the cross-section of the march.

We take the plate thickness h_f = 30 mm (in the section between the steps), the height of the ribs h = 170 mm, the thickness of the ribs b_r = 80 mm.

We change the gingival cross-section to the estimated tee -shaped one with a shelf in the compressed zone with a height of:

rib width $b = 2 \cdot b_r = 2 \cdot 8 = 16$ cm;

shelf width $b_f = 12 \cdot h_f + b = 12 \cdot 3 + 16 = 52$ cm.

4.1 Definition of loads and effort

Own Marks Weight g^n= 3, 6 kH/m^2 horizontal projection. Temporary normative load p^n= 3 kH/m^2, reliability coefficient under load γ_f= 1, 2; Long duration of active load p^n_{ld}= 1 kH/m ^{2}.

Calculated load per 1 m march length:

$q = (3.6 \cdot 1{,}1 + 3 \cdot 1{,}\ 2)\ 1{,}\ 35 = 10{,}\ 3$ kH/m.

Calculated critical moment in the middle of the march:

$M = q \cdot l^2/(8 \cdot \cos 30^o) = 10{,}3 \cdot 3^2/(8 \cdot \cos 30^o) = 13, 3$ kH.

Negative force from the calculated load on the support:

$q = q \cdot 1/(2 \cdot \cos 30^o) = 10.3 \cdot 3/(2 \cdot \cos 30^o) = 17, 8$ kH.

4.2. Predetermining the marching section dimensions

Let's take the plate thickness h_f= 30mm (at the intersection of the steps), height of the ribs H = 170mm, thickness of the ribs b_r= 80 mm.

Change the right-hand section to the calculation of the bracket with the bracket in the compressed area height:

Edge width $b = 2 \cdot b_r = 2.8 = 16$ cm; Shelf width

$b_f = 12 \cdot h_f + b = 12 \cdot 3 + 16 = 52$ cm.

4.3. Selecting the area of the longitudinal reinforcement section

$R_b \cdot c_{b2} \cdot b_f \cdot h_f \cdot (h_o - 0.5\, h_f) = 14.5 \cdot 100 \cdot 0.9 \cdot 52.3 \cdot (14.5 - 0.5 \cdot 3) =$ 2640,000 h · cm > M = 1330,000 h · cm, so the neutral axis is going through the shelf, so we're going to do the reinforcement calculation using the formulas for rectangular cross sections with width b_f= 52 cm.

By $\alpha_m = m\, c_n/(R_b \cdot c_{b2} \cdot b_f \cdot h_o^2) = 1330000 \cdot 0{,}95/(14{,}5 \cdot 0{,}9 \cdot 52 \cdot 14{,}5^2 \cdot 100) = 0{,}089$
So we find 0.973, $\chi = 0.095$.

Then you need the area of the armature intersection

$A_s = (M \cdot \gamma_n)/(\cdot\, h_o \cdot R_s) = (1330{,}000 \cdot 0.95)/(0.973 \cdot 14.5 \cdot 280 \cdot 100) = 3.26$ cm ^{2}
So we take 2 14 A300C, and we take $2.\emptyset_s = 3.08$ cm ^{2}(-4.5% allowed).

Section 5. Safety of work

Safety at work is of economic importance in society,

Determines the effectiveness of the improvement and promotion measures

The social importance of job security is an economic expression of the social importance of job security.

The security of work is politically important because security Safe and safe working conditions are an integral part of the state Policies, one of the most important functions of central and local governments Executive and Social Security Fund Accidents at work and occupational diseases.

This section addresses the issues of occupational safety and security related to Fire protection and sanitary conditions.

5.1. Fire Protection

Evacuation of the occupants of the building is done by a staircase from the top of the building. The internal fire extinguishing is provided by a fire stand that runs through all the floors and is located in the general floor corridors. Parking spaces should have 8 pieces of fire shields per 1 floor, and OHP-10 fire extinguishers should be available in shops.

Fire alarm is foreseen with the installation of PPS-3 in shops and parking spaces, ventilation systems are foreseen when fire alarm is turned off.

The wiring will be done by wires in steel pipes, cables, cable wires, cable wires in brackets. It also provides for the establishment of a fire alarm system and evacuation management system.

System will provide:

- Sound transmission;
- Broadcasting of fire verbal messages;
- Sending fire location, roads messages in individual building areas

Evacuations and actions that ensure personal safety.

The technical equipment of the system consists of a set of sound amplifiers, and a set of tape recorders, speakers, and the devices for controlling them.

5.2. Sanitary conditions and requirements

Temperature, relative humidity, air velocity in the living room should be at optimal levels. A water combustion system is planned to maintain the air temperature at the cold time of the year. The heat medium for the combustion systems is hot water with parameters T = 95 ° C, T_2= 70 °C.

Rooms have natural side lighting through windows, and artificial lighting with electric incandescent lamps, and in parking spaces, shops and entertainment centers, lighting is done with fluorescent lamps.

Natural lighting is regulated by the natural lighting ratio, which is different for different rooms.

The main source of noise is road transport. To reduce the sound pressure level to a standard, metal-plastic windows are used, and the design reduces the penetration of noise and dust into the room.

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ПРОТОКОЛ
ПЕРЕВІРКИ КВАЛІФІКАЦІЙНОЇ РОБОТИ НА
НАЯВНІСТЬ ТЕКСТОВИХ ЗАПОЗИЧЕНЬ

Назва роботи: Інженерна оцінка несучої спроможності паль за методом граничних елементів

Тип роботи: Магістерська кваліфікаційна робота
(БДР, МКР)

Підрозділ кафедра БМГА, ФБЦЕІ
(кафедра, факультет)

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- [ ] 3. Виявлені у роботі запозичення є недобросовісними і мають ознаки плагіату та/або в ній містяться навмисні спотворення тексту, що вказують на спроби приховування недобросовісних запозичень.

Особа, відповідальна за перевірку ________ (підпис) Блащук Н.В. (прізвище, ініціали)

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Автор роботи ________ (підпис) Пан Жуйцзя (прізвище, ініціали)

Керівник роботи ________ (підпис) Моргун А.С. (прізвище, ініціали)

RESPONSE

supervisor of the master's qualification work

M.Sc. **Pang Rui Jia**

on the topic "**ENGINEERING ASSESSMENT OF BEARING CAPACITY OF PILE BY THE BOUNDARY ELEMENT METHOD**"

In MQW, a topical issue of geomechanics and foundation construction was considered - improvement of methods for determining the bearing capacity of pile foundations of deep laying of high-rise buildings, which work in the non-linear stage of dependence between stresses and deformations in order to predict their safe behavior.

MQW meets the given task.

The level of disclosure of issues of non-linear operation of soil foundations of hanging piles corresponds to the modern level of designing their operation under load.

The results of numerical studies of the operation of the foundation pile according to MGE with the use of R. Mindlin's solutions correspond to the experimental data *studies confirm the effectiveness* of the procedures carried out under the MGE.

MQW was produced as part of the scientific research work of the Department of Construction, Urban Economy and Architecture of the FBEC of the VNTU.

The main provisions, results and conclusions of the MKR are reflected in the abstracts of reports at the 55th conference of VNTU "Youth in Science" - 2024, VNTU, where the test was held.

The master's degree student meets the quality of training requirements for masters of higher education and the possibility of awarding him the master's qualification.

MQW is qualitatively executed and meets the requirements of current standards, there is a possibility of implementing its results in construction practice.

MQW deserves a "good" rating.

Head of the master's program
qualification work

_Prof. café BMGA FBCEI
dtn., professor

(position, scientific degree, academic title) ______ A.S. Morgun

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
ФАКУЛЬТЕТ БУДІВНИЦТВА, ЦИВІЛЬНОЇ ТА ЕКОЛОГІЧНОЇ ІНЖЕНЕРІЇ

OPPONENT'S FEEDBACK

for master's qualification work

M.Sc. **Pang Rui Jia**

on the topic "**ENGINEERING ASSESSMENT OF BEARING CAPACITY OF PILE BY THE BOUNDARY ELEMENT METHOD**"

The MQW topic corresponds to the approved topic and task.

The topic is devoted to the topical issue of foundation construction - improvement of methods for solving the problem of nonlinear behavior under the load of pile foundations of high-rise buildings for the possibility of predicting their bearing capacity.

In the MQW, an adequate calculation model was used to study the operation of pile foundations using the modern numerical method of boundary elements (BEM) using modern computer technologies, an analysis of materials developed in soil mechanics was carried out, taking into account the characteristics of behavior under the load of a dispersed soil medium, its dilatational properties.

The application of numerical MGE to the solutions of practical problems of geomechanics, the process of foundation settlement and permissible loads on them is justified by theoretical explanations, supported and illustrated by numerical calculation data, since the need to solve problems related to the assessment of soil strength and deformability is dictated by the needs of engineering practice .

MQW is qualitatively executed and meets the requirements of current standards, there is a possibility of its implementation in construction practice.

MQW deserves a "good" rating.

Opponent

Assoc. café THP__FBCEI

Assoc., ctn____________________________

(position, scientific degree, academic title) (signature) N.M. Slobodian

(initials, last name)