Western European Journal of Modern Experiments and Scientific Methods
Volume 3, Issue 5, May 2025
https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed

THEORETICAL FOUNDATIONS OF THE ISSUES OF STUDYING AND MODELING GEOTECHNICAL PROPERTIES OF SOILS

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Abstract: This article analyzes the experience and modern approaches to studying the geotechnical properties of soils in Central Asia, particularly in the Fergana Valley. The complex geological structure and natural conditions of the region significantly influence the physical and mechanical properties of soils, requiring their in-depth study. The article examines methods for determining the behavior of regional soils using foreign experience, advanced laboratory and field tests, geophysical methods, and artificial intelligence-based mathematical modeling technologies. The role of geotechnical monitoring in construction and operation processes is also emphasized. The research results demonstrate the importance of integrating modern scientific and practical approaches in the study of Central Asian soils, ensuring the safety of structures, and creating sustainable infrastructure.
Keywords: Soils, geotechnics, mathematical modeling, Central Asia, Fergana Valley, geological structure, laboratory tests, field tests, geophysical methods, geotechnical monitoring.

INTRODUCTION

In recent years, the acceleration of the urbanization process in the Republic of Uzbekistan, the accelerated implementation of large-scale infrastructure projects, the modernization of the transport and communication system, and the large-scale construction of modern industrial zones and residential areas have significantly increased the need and demand for the construction industry. At the same time, the success of construction processes directly depends on the correct assessment of the properties of underground layers - i.e., soils.

Soils are the natural foundation of any structure. Their physical and mechanical properties, strength, degree of deformation, water permeability, and other geotechnical indicators directly affect not only the stability of the structure, but also the duration of its operation and safety. Therefore, the in-depth study of the geotechnical properties of soils and their modeling using mathematical and computer technologies is one of the important scientific and technical problems that fully meets the requirements of today's scientific and technological progress.

The relevance of the topic lies in the fact that today in the territory of our republic, construction work is increasing in geologically complex zones with variable structural and mechanical state of soils. Especially when designing earthquake-resistant structures, there is a need to predict the behavior of soils in seismically active zones. This requires the introduction of modern methods of scientific modeling.

In the Decree of the President of the Republic of Uzbekistan "On the Development Strategy of New Uzbekistan for 2022-2026" (No. UP-60, January 28, 2022), special attention is paid to the introduction of scientific research and modern technologies in the field of construction, and the comprehensive study of underground infrastructure. Also, in Resolution No. PP-4423 "On Measures for Fundamental Reform of the Construction Industry and Increasing its Efficiency" (January 12, 2023), specific tasks are defined for the digitalization of soil environment assessment and engineering and geological surveys [1,2].

The main goal of this article is the systematic study of the geotechnical properties of soils, the creation of mathematical and computer models based on their physical and mechanical indicators, as well as the analysis of the possibility of assessing real geotechnical conditions based on these models.

Tasks:

1. Classification of the main types of soils and illumination of their geotechnical characteristics;
2. Analysis of laboratory and field methods for determining the physical and mechanical properties of soils;
3. Review of theoretical models and their mathematical expressions used in geotechnical modeling;
4. Simulation of the behavior of the soil environment using modern software tools (for example, Plaxis, GeoStudio);
5. Evaluation of the modeling results by comparing them with real geotechnical conditions.

The scientific significance of the research lies in the in-depth study of the possibilities of their representation in numerical and mathematical models, taking into account the complex physical structure of soils. This enriches the methodology of scientific analysis in the field of geotechnics and serves to propose new approaches.

Practical significance - reliable design of the foundation of structures, reduction of engineering errors, increasing the safety of construction and efficient use of land resources by correctly assessing the condition of the soil at construction sites. Such modeling plays an important role, especially in the construction of large engineering structures (bridges, hydroelectric power plants, subways, underground tunnels).

Based on the foregoing, approaches based on in-depth study and modeling of the geotechnical properties of soils are a necessary scientific basis for modern construction technologies, the development of geotechnical science, and the sustainable development of the country's infrastructure [3,4].

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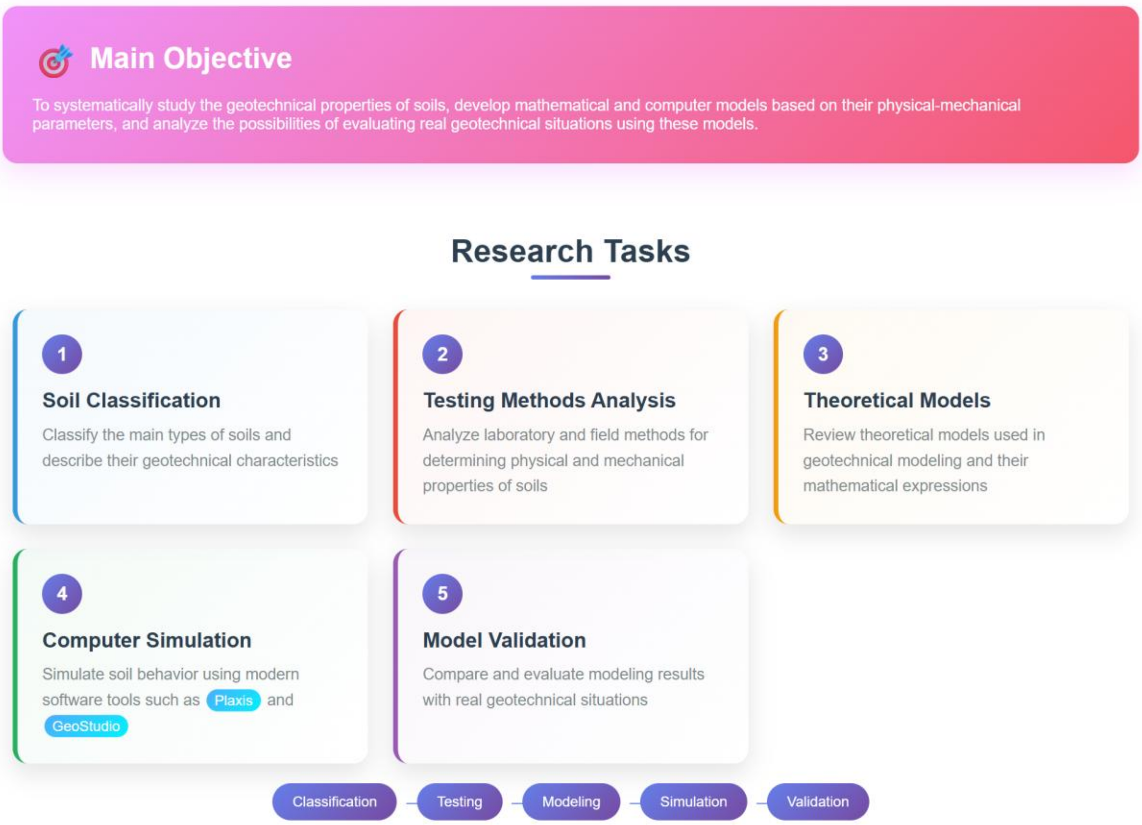

Figure 1. Purpose and objectives of the study

LITERATURE ANALYSIS

The study and modeling of the geotechnical properties of soils is one of the most relevant areas of modern geotechnical science. Because today, it is not enough to assess physical and mechanical processes occurring in the underground environment based solely on empirical methods. In this regard, along with scientific and technological progress, especially the development of digital technologies, the use of mathematical modeling, computer simulation, and geotechnical programs is becoming an important tool.

In the scientific literature, the theoretical foundations of soil mechanics were developed by Karl Terzaghi. His work "Soil Mechanics," published in 1925, laid the first scientific foundation for geotechnical science. Terzaghi's theory of effective stress, views on soil compression and filtration are still accepted as the main parameters in modern modeling algorithms. In recent years, such American scientists as T. W. Lambe, R. Whitman, Peck, Holtz have deepened this direction and proposed theoretical models for determining the elastic-plastic behavior of soils, strength limits, and deformation properties.

In recent decades, digital methods have become particularly prominent in geotechnical modeling. In this regard, the **Hardening Soil** model, developed by A. Schanz, S. Vermeer, and W. Broere, serves to clarify the deformation behavior of various types of soils. This model takes into account the change in hardness parameters depending on the load, thereby allowing for more accurate modeling of relatively uncertain real geotechnical conditions. This model has been successfully implemented, especially in the PLAXIS program, and has yielded practical results in many large projects.

Cam-Clay and Modified Cam-Clay models are also widely used. They were proposed by A. Schofield and C. Wroth and are especially used in modeling the processes of compaction, the state of plasticity, and the phases of hardening of clay soils. This model, developed by the University of Cambridge, was subsequently integrated into applications such as GeoStudio, Abaqus, MIDAS GTS NX. These models allow for accurate representation of soil behavior under real load conditions.

Another important aspect of geotechnical modeling is related to the analysis of soil behavior in earthquake-resistant areas. In this regard, experimental studies conducted by the Japanese scientist Masayuki Hyodo are aimed at determining the melting properties of soils. In laboratory conditions, he applied seismic loads to sandy soils of different densities and modeled how their shear limits, strength, and deformation parameters changed. Such approaches are important in the design of earthquake-resistant structures [5,6].

A number of important scientific studies on these issues have also been conducted in local scientific schools. In Uzbekistan, in particular, in the laboratories of the Tashkent Architectural and Construction Institute, the Tashkent State Technical University, and the Research Institute of Geology, work is aimed at determining the natural physical and mechanical properties of soils, developing a calculation methodology based on them, as well as selecting parameters suitable for modeling. In the work carried out by Professor S.Kh. Nazarov, the compaction graphs, strength limits, and deformation properties of soils were experimentally studied. Associate Professor R. A. Ergashev conducted research on determining the degree of water saturation of various soil types and the influence of this state on deformability.

Also, the "Development Strategy of New Uzbekistan," approved by the Decree of the President of the Republic of Uzbekistan dated January 28, 2022 PF-60, defines specific tasks for the development of scientific and technical spheres, in particular, the introduction of modern technologies in the field of construction and geotechnics. Resolution No. PP-4423 , adopted on January 12, 2023, provides for strict measures to improve the quality of construction, deepen geotechnical analysis, and introduce digital construction technologies. This indicates an increased need for modeling in local scientific research and applied projects.

Analysis of foreign and domestic literature shows that the study of the geotechnical properties of soils, their analysis based on theoretical models and application in computer modeling is a scientifically substantiated and practically relevant area. While foreign research is aimed at improving theoretical modeling, domestic research is aimed at determining parameters corresponding to the natural state of soils and real construction conditions. The combination of these two approaches creates an important foundation for the design of modern, safe, and reliable facilities in our country [7].

RESULT AND DISCUSSION

Geotechnical properties of soils and their classification

Soils are solid and semi-solid layers naturally located on or under the earth's surface, the geotechnical properties of which are very important for the stability and strength of buildings and structures. These properties are closely related to the physical, mechanical, and chemical nature of the soils, on the basis of which the foundations of structures are designed and the safety of underground structures is ensured. Physical properties include granulometric

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composition, i.e., particle size and their ratios. For example, there are various fractions such as sand, gravel, clay, each of which has its own specific density, water absorption, and transfer coefficients. The degree of moisture and water saturation affect the soil's deformation and behavior under pressure.

Mechanical properties represent the reactions of soils under loads. Compressibility, i.e., reduction in volume under pressure, cutting strength, i.e., resistance to cutting force, elasticity, and plasticity, belong to this group. Also, the filtration coefficient determines the flow of water through the soil and is important in determining hydrogeological conditions. Some soils, especially sandy soils, can exhibit a melting state under seismic influences, which jeopardizes the stability of structures. Therefore, the tendency of soils to melt also requires special attention.

Granulometric, physical, mechanical, and chemical criteria are used in soil classification. In granulometric classification, particles are divided into groups such as sand, gravel, and clay based on particle size. Geotechnical classification is carried out based on their physical and mechanical properties: from hard and strong layers to clayey and soft soils rich in organic matter. Plastic and elastic properties also influence the class of soils. At the same time, the water permeability coefficient and chemical composition are also additional criteria for their grouping. Proper classification and determination of soil properties are essential for improving the quality of foundations for construction projects, ensuring their stability and long-term operation. This is of great practical importance, especially in the implementation of construction projects in various geological conditions existing in different regions of Uzbekistan [8,9].

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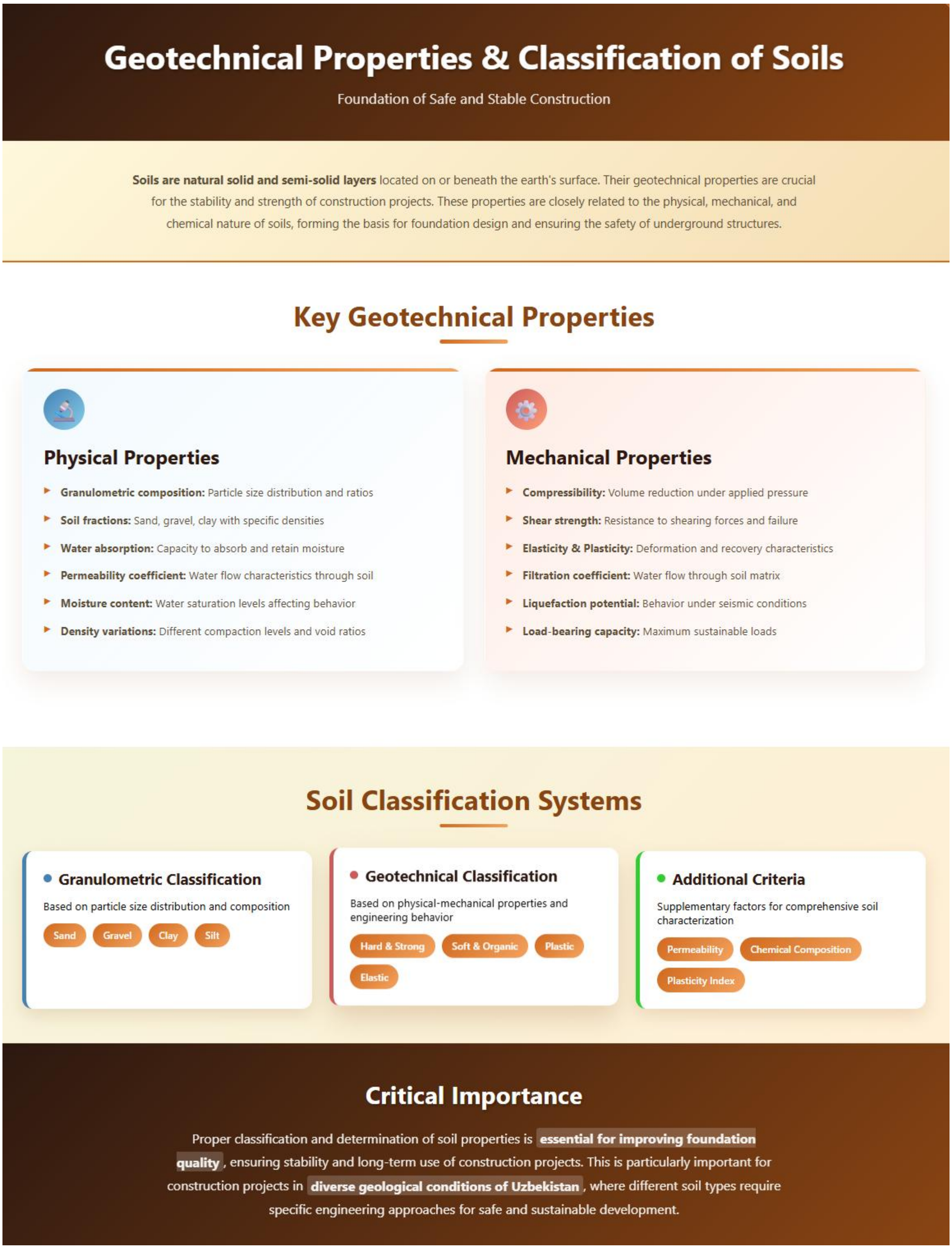

Figure 2. Geotechnical properties of soils and their classification

Methods of studying the geotechnical properties of soils

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Various methods and techniques are used to determine the geotechnical properties of soils, as this process is important in ensuring the stability and safety of structures. Research methods mainly consist of laboratory tests, field (field) tests, modern geophysical methods, and geotechnical monitoring technologies, which complement each other and ensure a comprehensive approach.

Laboratory research methods play a key role in determining the physical and mechanical properties of the soil. Within the framework of these methods, such parameters as granulometry, density, moisture content, compressibility, cutting strength, and plasticity are determined. Soil reactions under various loads are studied using tests performed on special equipment - compression, hardness, cutting tests, and others. Laboratory methods are especially reliable in obtaining accurate and reproducible data, but they are limited to small samples.

Field tests are designed to study the behavior of soils in natural conditions. The most common field tests include standard consolidated cutting test (CU), triaxial compression test, and penetrometer tests. At the same time, such methods as QSI (Size Indices), CPT (Conical Penetrometry Test), and SPT (Standard Penetration Test) are also widely used as a series of in-situ tests. These tests allow measuring the density, compaction properties, resistance to cutting forces, and other parameters of soils directly in their natural state, therefore they are important for obtaining prompt and reliable information at the construction site.

Modern geophysical methods include technologies that help to determine the structure and physical parameters of underground layers non-invasively (without destroying the surface). Accurate data on soil density, moisture content, layer thickness, and other properties are obtained using techniques such as georadar, seismic tomography, electrical resistance measurements, and electromagnetic methods. These methods are especially convenient for rapid and large-scale study of large areas and are widely used in modern geotechnical design and analysis processes [10].

Geotechnical monitoring technologies allow for continuous monitoring of the soil condition during construction and subsequent operation. These technologies include inclinometers, piezometers, as well as remote sensors for measuring deformations. Monitoring systems analyze the data obtained in real time and determine changes in the pressure, displacement, and water state of soils, which is of great importance in preventing emergencies and ensuring the safety of the structure.

Thus, while laboratory tests allow for accurate and in-depth analysis when studying the geotechnical properties of soils, field tests help to verify them in their natural state. If modern geophysical methods are effective in the study of large territories, then geotechnical monitoring provides constant control over the safe and high-quality implementation of construction. The results obtained through a comprehensive approach are the basis for making scientifically based and practically reliable decisions [11].

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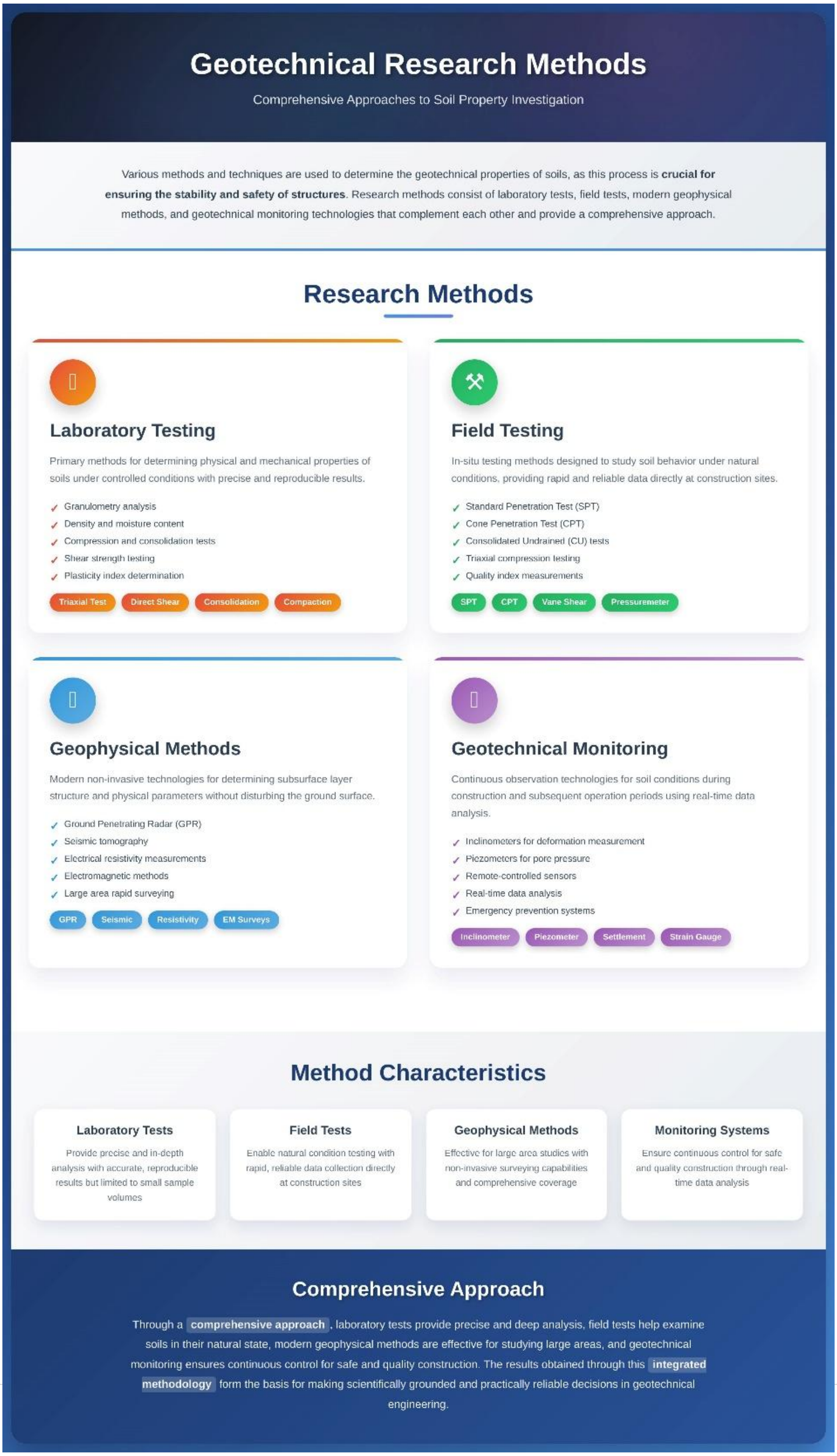

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Figure 3. Methods of studying the geotechnical properties of soils

Theory of mathematical modeling of soil properties

The theoretical foundations of mathematical modeling are widely used for in-depth study of the geotechnical properties of soils and forecasting their complex behavior. These approaches are of decisive importance in solving practical problems by creating mathematical equations and models expressing the mechanical and deformation properties of soils.

Among classical mathematical models, the Mohr-Coulomb model is the most widespread, which is used to express the cutting strength of soils. Based on this model, the maximum value of the shear force is taken as the sum of the angle of internal friction and the binding forces. Mohr-Coulomb theory, due to its simplicity and practical applicability, is the main model in many geotechnical calculations, but it does not fully cover such complex mechanical properties of soils as plasticity and compaction. Accordingly, a more complex and realistic Cam-Clay model has been developed, which is especially suitable for clayey and loamy soils. The Cam-Clay model mathematically expresses the hardening of soils in a consolidated state, taking into account compression and plasticity processes [8].

Modern constitutive models are aimed at more accurate modeling of soil behavior, which are developed based on experiments and practical observations. These models take into account the elastic, plastic, and viscoelastic properties of soils, and also describe their complex reactions to melting, pressure, and deformation. These models allow taking into account the variable parameters of soils under various conditions, while adapting them for multidimensional calculations.

With the development of modern computer technologies, the finite element method (FEM) has become widely used in mathematical modeling of soils. With the help of FEM, the interaction of earth layers and structures, the propagation of deformations and stresses are analyzed with high accuracy even in complex geometric shapes. This method allows simulating the physical parameters of soils using digital models, which serves to reduce errors in design and construction processes. Through FEM modeling, complex mechanical processes in underground conditions, including phenomena such as probing, compression, and splitting, are demonstrated at a high level.

In recent years, artificial intelligence (AI) technologies, especially machine learning and neural networks, have provided revolutionary approaches in geotechnical modeling. These methods, studying from large databases, show high accuracy and flexibility in predicting complex behavior of soils compared to traditional models. Machine learning algorithms, such as regression, classification, and in-depth study, are effectively used for the automatic determination of physical parameters of soils and prediction of their behavior in new conditions. Neural networks allow modeling complex connections based on many interconnected parameters, which gives more perfect results compared to classical approaches.

Thus, in the mathematical modeling of the geotechnical properties of soils, classical theories and modern calculation methods are used in harmony. Approaches from traditional models to advanced artificial intelligence technologies contribute to the development of more accurate, effective, and reliable solutions in the field of geotechnics. This is an important foundation for practical projects and scientific research [3].

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Figure 4. Theory of mathematical modeling of soil properties

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Regional studies of soils, in particular, developments in the territory of Central Asia, were carried out taking into account the specific geological and climatic conditions of this geographical location. The properties of the soils located in this area and their various layers are an important issue that requires in-depth study for sustainable and effective construction. Research conducted in the Central Asian region, especially in the territories of Uzbekistan, Kazakhstan, and Kyrgyzstan, is aimed at determining the physical and mechanical properties of soils, where natural conditions and the composition of the soil layer are unique.

The Fergana Valley is one of the regions with the most complex geological structure in this region. The soils of this valley are mainly composed of layers of clay, sand, and gravel, the properties of which vary significantly from place to place. In terms of geological structure, the Fergana Valley influences phenomena related to tectonic activity and water resources, which directly affects the mice, density, permeability, and deformation properties of soils. Therefore, geotechnical research in various regions of the valley requires a special approach and special methods.

Foreign experience and modern approaches open up new opportunities in the field of regional geotechnics. Developed geotechnical methods in the countries of Europe, North America, and Asia, including advanced laboratory tests, field research, artificial intelligence-based modeling, and modern monitoring technologies, contribute to a deeper and more accurate analysis of the properties of the soils of Central Asia. This is of great importance in increasing the efficiency and ensuring the safety of construction and infrastructure projects in the region. At the same time, along with foreign approaches, scientific research is being actively conducted, taking into account local geological and climatic conditions, which contributes to a deeper understanding of the specifics of regional soils [5].

CONCLUSION

The study of the geotechnical properties of soils in the Central Asian region, in particular in the Fergana Valley, has important scientific and practical significance. The geological structure of this territory is complex, and the presence of significant differences in the physical and mechanical properties of the soils requires special attention when planning construction and infrastructure projects. Soil horizons of the Fergana Valley are formed under the influence of many natural factors, including tectonic activity and variability of water resources, which leads to changes in such soil parameters as density, permeability, and deformation resistance. Therefore, in addition to traditional approaches, there is a need to apply complex and modern methods in the study of regional soils.

Foreign experience and advanced technologies, including laboratory and field tests, modern geophysical research methods, as well as modeling technologies based on artificial intelligence, allow for a more accurate and complete analysis of the complex properties of regional soils. This, in turn, contributes to the development of more reliable and safe solutions in the design of structures. In particular, methods of artificial intelligence and machine learning show high accuracy and efficiency in predicting the behavior of soils, which creates new innovative opportunities in the field of geotechnics.

The application of geotechnical monitoring technologies allows for constant monitoring of the condition of soils during construction and operation, which is important for preventing emergencies and ensuring the long-term stability of structures. Research conducted in Central

Asia not only creates a scientific basis adapted to local conditions, but also makes a significant contribution to the development of the region in the field of geotechnics, integrating with advanced approaches on a global scale.

Therefore, the development of experience in the study of regional soils and the widespread introduction of modern methods is an important factor not only in ensuring geological safety, but also in increasing economic efficiency. This process contributes to the development of sustainable infrastructure, industry, and the social sphere in Uzbekistan and neighboring countries, strengthening the competitiveness of countries in the global economic arena. As a result, the continuation of scientific and practical work on in-depth study and modeling of the geotechnical properties of soils will remain an important factor in the sustainable development of Central Asia and the creation of a safe construction infrastructure.

REFERENCES

1. Ogli Y. S. S. LEGAL STATUS OF AGRICULTURAL LAND //Eurasian Journal of Technology and Innovation. – 2024. – T. 2. – №. 5. – С. 105-113.
2. Yokubov S. DEVELOPMENT OF AGRICULTURAL CARDS USING ARCGIS AND PANORAMA TECHNOLOGIES //Innovations in Science and Technologies. – 2024. – T. 1. – №. 1. – С. 101-107.
3. Khakimova K., Yokubov S. CREATION AND MAINTENANCE OF STATE CADASTERS IN THEREPUBLIC OF UZBEKISTAN //Innovations in Science and Technologies. – 2024. – T. 1. – №. 1. – С. 85-93.
4. Yokubov S. SCIENTIFIC AND THEORETICAL FOUNDATIONS FOR THEDEVELOPMENT OF MAPS OF THE LEGAL STATUS OF STATE LANDCADASTERS IN THE TERRITORY USING GIS TECHNOLOGIES //Innovations in Science and Technologies. – 2024. – T. 1. – №. 1. – С. 80-84.
5. Yusufovich G. Y. Shavkat o ‘g ‘li SY CARTOGRAPHIC RESOURCES USED IN THE CREATION OF ELECTRONIC AGRICULTURAL MAPS OF FERGANA REGION //Finland International Scientific Journal of Education, Social Science & Humanities. – 2023. – T. 11. – №. 3. – С. 1001-1009.
6. Abduvakhabovich A. A. Shavkat o’g’li, SY Improving the Method of Mapping Agriculture Using Remote Sensing Data //Finl. Int. Sci. J. Educ. Soc. Sci. Humanit. – 2023. – T. 11. – С. 1093-1100.
7. Yusufovich G. Y. et al. The use of remote sensing technologies in the design of maps of agricultural land //Texas Journal of Agriculture and Biological Sciences. – 2023. – T. 23. – С. 17-21.
8. Eshnazarov D. et al. Describing the administrative border of Koshtepa district on an electronic digital map and creating a web map //E3S Web of Conferences. – EDP Sciences, 2023. – T. 452. – С. 03009.
9. Khakimova K. et al. Application of GIS technologies for improving the content of the tourist map of Fergana province, Uzbekistan //E3S Web of Conferences. – EDP Sciences, 2023. – T. 386. – С. 04003.
10. Khakimova K., Yokubov S. Creation of agricultural electronic maps using geoinnovation methods and technologies //Science and innovation. – 2023. – T. 2. – №. D1. – С. 64-71.

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https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed

11. Xakimova K. et al. Theoretical and methodological issues of creating the "ECO FERGANA" mobile application of tourist objects and resources of Fergana region //E3S Web of Conferences. – EDP Sciences, 2023. – T. 452. – C. 05025.