



DESCRIPTION OF THE ENGINEERING GEOLOGICAL CONDITIONS OF THE FERGANA REGION AND WIDELY DISTRIBUTED SOIL TYPES

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Abstract

The article proposes a “regional deformation prediction methodology based on cyclic loading and artificial intelligence” for predicting changes in some deformation parameters of soils under variable stresses. Loess, alluvial-proluvial and fine-grained soils widespread in the Fergana region are selected as the research object, and their physical and mechanical properties, wetting regime and deformation behavior under the influence of seismic and transport loads are comprehensively studied. First, laboratory tests are conducted under cyclic loading, and an experimental database on resilient modulus and permanent deformations is formed. Then, the parameters of the Cam-Clay type constitutive models are recalibrated based on regional soil properties, and the results obtained are integrated with a prediction model developed using artificial neural networks and other ML approaches. The proposed methodology allows for a high-accuracy prediction of deformation parameters, taking into account the effects of soil collapse potential, moisture and stress levels. This approach, adapted to the engineering-geological conditions of the Fergana region, is of practical importance for designing the foundations of residential and industrial structures, assessing the long-term stability of road and irrigation structures, and reducing regional geotechnical risks.



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Keywords: Soil deformation, alternating stresses, cyclic loading tests, resilient modulus, collapsing soils, Cam-Clay constitutive model, artificial neural networks, machine learning (ML), regional deformation prediction, soils of the Fergana region.

INTRODUCTION

A thorough study of the engineering-geological conditions of the Fergana region and the characteristics of the soil types widespread in this region serves as a necessary scientific and practical basis for assessing the deformation behavior of soils under variable stresses and reliably predicting some of their deformation indicators. The rapid development of industrial enterprises, highways and railways, irrigation and land reclamation systems, residential and social infrastructure in the region in recent decades has complicated the loading regime of soil layers and requires a more accurate study of their physical-mechanical and deformation parameters. In this regard, the geological stratification, the peculiarity of the relief, the regime of surface and groundwater, the level of seismic activity and the influence of anthropogenic factors characteristic of the Fergana Valley should be analyzed in an integrated manner.

The genesis, granulometric composition, porosity, moisture content, degree of compaction, tendency to compaction, ability to subsidence (prosegaemost) and swelling, shear and compression strength of the soils in this region are directly dependent not only on the conditions of their natural formation, but also on changes in the water regime, irrigation loads, transport vibration stresses and other dynamic influences. Loess-like soils, sandy and sandy-clay layers, alluvial-proluvial deposits, partially sandy and gypsum layers, which are widespread in the Fergana region, often create a complex engineering-geological situation and can cause uneven subsidence, subsidence-swelling, loosening, sliding and other undesirable deformation processes in the foundations of various structures. Therefore, it is of scientific and practical importance to determine the types of soils and their territorial distribution, and to describe typical soil models and their deformational properties for each geological and engineering region.

The division of the relief of the Fergana region into plain-ravine and foothill zones, the formation of soil layers in the areas of alluvial-delta plains, river



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terraces and proluvial-conical spreads leads to a significant difference in engineering-geological conditions. As a result, even in one district or small area, different engineering-geological elements, soil horizons of different densities and moisture content, uneven soil layers and groundwater levels at different depths can be found. It is emphasized that in such conditions, it is not enough to assess the deformation indicators of soil layers based only on laboratory tests, but an integrated approach is required with regional engineering-geological mapping, seismological, hydrogeological and geophysical data.

Under conditions of variable stresses – for example, in road foundations under the influence of traffic flows, in buildings with periodically changing industrial equipment, near hydraulic structures exposed to wave action – soil layers exhibit elastic-plastic and, in many cases, nonlinear behavior. Soil types with a relatively high content of dusty and fine fractions, which are found in the Fergana region, are subject to significant compaction, re-compaction, disruption of structural connections and, as a result, changes in deformation parameters over time under the influence of such stresses. Therefore, in the process of characterizing engineering-geological conditions, it is necessary to take into account not only the current state of the soil, but also its transition processes, the evolution of deformation parameters depending on the time factor.

This research work comprehensively describes the engineering-geological conditions of the Fergana region, highlights the geological structure of the region, relief-morphological features, hydrogeological conditions, seismic zoning and the distribution of physical-geological processes. Also, the genesis, granulometric composition and solid phase properties of soil types common in the region are systematically analyzed in terms of their water-physical indicators, natural density and deformation stability. The engineering-geological data presented in this article will form the initial information base for laboratory, field and computational-experimental work to be carried out in subsequent articles to determine, model and predict certain deformation indicators of soils under variable stresses. As a result, the necessary engineering-geological foundations will be created for geotechnical approaches adapted to the conditions of the Fergana region, for determining the ranges of parameters characterizing the deformation behavior of soils and for predictive models based on them.



LITERATURE ANALYSIS

An analysis of the literature shows that foreign scientists have worked mainly in three major areas on the deformation behavior of soils under variable stresses and their prediction:

- (1) experimental study of resilient and permanent deformations of soils under cyclic/dynamic loading,
- (2) mathematical description of stress-strain relationships based on constitutive (equational) models,
- (3) forecasting subsidence and other deformation indicators using artificial intelligence and data-driven approaches.

In the first direction, the response of subgrade soils to repeated loading cycles under traffic loads has been the focus of much research. Seed et al. demonstrated in laboratory experiments how the resilient deformation of sandy soils under cyclic loading varies with loading rate and stress level, and developed important empirical relationships for subgrade soils subjected to train and road traffic. These approaches were later extended to assess the resilient modulus and permanent (residual) deformation using repeated load triaxial (RLT) tests. In modern research, the resilient modulus and permanent deformation of subgrade soils are considered to be key parameters affecting the performance of asphalt pavements; for example, Yang et al. provide a comprehensive review of the relationship between resilient modulus and permanent deformation by systematically analyzing existing empirical equations. In other works, the time-dependent change in the resilient modulus under the influence of liquid phase pressure, moisture and stress levels under cyclic loading, and the ranges of resilient modulus for fine-grained soils at different moisture and compaction stress levels have been determined. These results can serve as a methodological basis for assessing the resilient and permanent deformation behavior of soils under transport and seismic loads in the conditions of the Fergana region.

The second important direction is the description of the nonlinear elastoplastic behavior of soils based on constitutive models and critical state mechanics. In the Cam-Clay and Modified Cam-Clay (MCC) models, the soil state is expressed in terms of average stress, deviatoric stress, and specific volume, and the failure and large deformation processes are predicted using the critical state line. In recent



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years, a number of modifications of these models have been proposed, including models for structured soils, overconsolidated clay soils, and time-sensitive models. For example, in some studies, the stress–strain–time response of clay soils is described within the framework of the MCC model, taking into account the relaxation, consolidation, and compression paths over time. In other works, models based on critical states are reworked for structured soils, taking into account factors such as subloading, deviatoric hardening, and dilatancy. In recent years, a comprehensive review by Onyelowe et al. has systematically analyzed various constitutive models, their application limits, advantages and limitations related to soil type, moisture, loading regime, and other factors. Such approaches can also serve as a theoretical basis for calculating nonlinear behavior under variable stresses for soils in the Fergana region, but it is emphasized that they need to be parameterized according to regional soil characteristics.

In the foreign literature on the deformation behavior of loess-like soils and alluvial-proluvial deposits widespread in the Fergana region, the most relevant works are mainly on collapsible soils. It has been noted in many studies that in loess and other collapsible soils, as a result of wetting, liquid phase pressure and structural failure, sharp volumetric subsidence is observed, which poses a serious threat to building foundations and roads. The “state-of-the-art” review by Al-Rawas systematically summarizes the classification, subsidence mechanisms and assessment methods of collapsible soils. Jefferson and co-authors also show the relationship of collapse deformation with soil density, stress state and capillary forces, and explain the process of disruption of interparticle bonds and volumetric subsidence through a microstructural approach. Studies conducted in the conditions of the Loess Plateau of China provide important information on the assessment of the collapse potential of Malan loess in relation to multi-scale wetting deformation, pore size and clay fraction distribution. Also, recent reviews on methods for identifying collapsible soils and assessing the degree of collapse show the advantages and disadvantages of laboratory and field tests, as well as problems with empirical normative criteria. These results are very relevant for zoning loess-like and collapsible soils in the Fergana region, assessing their subsidence risk and predicting long-term deformation under variable loading conditions.



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The third major block is the prediction of ground deformation using artificial intelligence (ANN, ML) and data-driven approaches. A comprehensive review by Shahin shows that artificial neural networks have been successfully used to model foundation bearing capacity, ground behavior, settlement of structures, slope stability, tunnel and underground structures, liquefaction, soil permeability, and many other geotechnical problems. For the prediction of foundation settlement, Nejad and co-authors developed ANN models based on SPT and CPT data and demonstrated the high accuracy and stability of neural networks compared to traditional empirical methods. Neural networks and hybrid models have also been used to predict ground settlement during tunnel excavation, proving that it is possible to relatively accurately model the complex stress-strain processes that occur during deep excavation. In recent years, ANN-based settlement and deformation predictions for gypsum and other special soil types have been developed, demonstrating good agreement between actual and predicted values. However, it is emphasized that these studies also strongly depend on the quality and size of the database, and on the proper organization of the training and validation process.

Studies that combine the above three areas are also emerging: for example, studies aimed at characterizing the permanent deformation of subgrade soils in combination with water regime and suction based on repeated load triaxial tests, and then generalizing these results through empirical or ML models. Carvalho Everton et al. analyze the rutting mechanisms, moisture and suction effects using RLT tests for different types of sandy soils, and propose a model aimed at assessing the long-term stability of pavement foundations. On the other hand, Yang et al. systematically highlight the possibilities and limitations of ML methods in assessing the resilient modulus and permanent deformation, and emphasize the need to integrate them with traditional tests. These approaches provide a methodological basis for connecting experimental data to ML or constitutive models when predicting certain deformation parameters of soils under variable stresses in the Fergana region - for example, when assessing the long-term settlement and deformation risk for road foundations, residential buildings and industrial structures.



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Critically, the common drawback of many models developed in foreign literature is that they are often calibrated for a specific region, soil type and loading conditions and cannot be fully transferred to other geological and engineering conditions. The parameters of the Cam-Clay and MCC models, empirical criteria for collapsing soils, and the training range of ANN models are adapted to a specific database. Therefore, for loess, alluvial-proluvial and other common soils of the Fergana region, it is necessary not to directly apply these models, but to recalibrate them based on laboratory and field experiments, adjust the parameters to the regional range, and, if necessary, introduce new additional coefficients and corrections. Also, although most foreign works cover seismically active regions and conditions of intensive transport loads, factors such as irrigated plains, seasonal changes in groundwater levels, irrigation loads and salinity have not been studied very extensively. For the Fergana region, these factors may be the main factors determining the deformation behavior of soils over time.

In general, research conducted by foreign scientists has created a strong theoretical-experimental and computational base for studying and predicting soil deformation under variable stresses: various laboratory methods for assessing resilient and permanent deformations under cyclic loads, elastoplastic models based on critical states, microstructural analysis of collapsing soils, solutions for predicting subsidence and deformation using ANN and ML methods. However, the specific engineering-geological, hydrogeological and anthropogenic conditions of the Fergana region require adapting these scientific approaches at the regional level, forming a database of local soils and re-determining model parameters. In this sense, this dissertation study relies on foreign experience, but is distinguished by the fact that it offers a new, regionally adapted methodology aimed at predicting certain deformation indicators under variable stresses on the example of soils widespread in the Fergana region.

RESULTS AND DISCUSSION

An analysis of foreign literature has shown that research on the deformation behavior of soils under variable stresses covers three main blocks: laboratory and field experiments under cyclic (dynamic) loading, mathematical description of stress-strain relationships based on constitutive (elasto-plastic) models, and



prediction of settlement and other deformation indicators using artificial intelligence and data-driven approaches. According to the results of the analysis, each of these areas, while having its own advantages, also exhibits certain limitations for a region with complex engineering and geological conditions such as the Fergana region.

In the literature, first of all, there was a predominance of works devoted to resilient (recovery) and permanent (residual) deformations of soils under cyclic loading. In most of them, repeated load triaxial tests were conducted for sandy and sandy soils, and in some cases, for soils with clay and mixed granulometric composition, and the range of resilient modulus (M_r) and permanent relative deformations were determined. The generalized data show that for well-compacted coarse-grained soils, the resilient modulus usually varies in the range of 150–300 MPa, and for soils with fine and dusty particles - in the range of 50–150 MPa, while permanent (residual) axial deformations are recorded in the range of 1–6%, depending on the number of loading cycles and the level of stress. It is also confirmed in almost all studies that an increase in the degree of water saturation tends to significantly reduce the resilient modulus and increase permanent deformation. This situation directly corresponds to the conditions of the Fergana region, where irrigation and groundwater levels are high, and indicates the need to pay special attention to the moisture parameter when assessing the load-bearing capacity of soils and the risk of long-term subsidence [15,16].

If the generalized statistical data on foreign studies are conditionally presented in the form of Table 1, it becomes clear how the resilient modulus and the range of permanent deformations differ depending on the type of soil and loading conditions.

Table 1. Resilient modulus and permanent deformation ranges of soils under cyclic loading (generalized data)

Soil type	Humidity condition	Resilient modulus, M_r (MPa)	Permanent relative deformation, ϵ_p (%)
Coarse-grained, dense	Optimal humidity	200–300	1–2
Coarse-grained, moist	High humidity	120–200	2–4
Sandy / sandy	Optimal humidity	100–180	2–3
Sandy/sandy, moist	High humidity	60–120	3–5
Fine-grained (clay mixture)	Moderately humid/wet	50–120	3–6



As can be seen from Table 1, an increase in humidity, especially in soils with a high fine and dust fraction, leads to a significant decrease in the Mr value and an increase in permanent deformations. In loess-like, alluvial-proluvial and fine-grained soil types typical of irrigated areas, which are widespread in the Fergana region, a change in the water regime as a result of irrigation loads can itself be a major factor reducing the resilient modulus and increasing the risk of subsidence. In this sense, the ranges noted in foreign literature can serve as initial comparative criteria for regional tests, but the need to recalibrate these values in Fergana conditions, although debatable, is seen as a methodological necessity.

The second major trend is constitutive models, particularly those based on critical state mechanics, such as Cam-Clay and Modified Cam-Clay (MCC), which are widely used as an effective approach to mathematically represent the stress–strain–volume change relationship. According to the literature review, many works based on these models show that they can better represent nonlinear elastoplastic behavior, especially in over-compacted clay soils, and more accurately describe the consolidation and volumetric shrinkage processes. However, statistical analysis shows that in most papers, a large number of laboratory tests are required to determine the model parameters, and the average distribution of the parameters also has a rather wide range. For example, for clay soils studied in different regions, the slope coefficient M of the critical state line is usually in the range of 0.8–1.4, while the parameters λ and κ , which characterize the initial loose state, vary in the ranges of 0.05–0.25 and 0.01–0.08, respectively. This dispersion indicates that it is difficult to directly transfer the MCC model to soils of other regions, and that separate calibration and parameter identification are necessary for each region. MCC or other elastoplastic models can also be used for soils of the Fergana region, but here it is necessary to determine the parameters by integrating seasonal changes in moisture content, rewetting due to irrigation, and seismic loads [17,18].

In the literature review, a separate block of studies on collapsing soils - loess and loess-like deposits - stands out. Most of these works analyze volumetric settlements measured in a compression chamber under various vertical pressures and wetting conditions, express the collapse potential (Ic) in percent and divide it into categories such as "insignificant", "small", "medium", "severe" and "very



serious" collapse. Generalized statistical data show that for loess-like soils, when the collapse potential is 1–3%, it can usually be accepted without structural measures, when it is in the range of 3–6%, structural and technological measures are necessary, and when it is 6–10% and higher, the area is assessed as a region with a high risk of collapse. This can be conditionally expressed in the form of Table 2.

Table 2. Descriptive ranges of collapse potential (I_c) for loess and loess-like soils

Collapse potential, I_c (%)	Collapse rate	Engineering interpretation
< 1	Unimportant	There is almost no risk of collapse.
1 – 3	Small	The usual constructive measures are sufficient.
3 – 6	Average	Special measures are required
6 – 10	Seriously	Deep optimization of foundation solutions is necessary
> 10	Very serious	The area is dangerous; deep structural and technological measures are needed

Examples given in foreign literature show that in some regions, I_c for loess layers reaches values of 8–12% and higher, which has led to many deformation problems, such as uneven settlement of foundations, cracking of road surfaces, and sagging of stairs and walls. In some foreign regions close to the relief and construction conditions of the Fergana Valley, a sharp increase in collapse potential was also noted as a result of irrigation, filtration flows, and groundwater elevation. These facts justify the need to separate loess-like and collapsing soils in the Fergana region as a separate engineering-geological region, determine their collapse potential based on laboratory and field tests, and predict long-term subsidence under conditions of variable stresses.

The third area – research on predicting soil deformation using artificial intelligence and data-driven models – is one of the most promising areas in terms of results. According to the literature review, artificial neural networks (ANN), support vector machines (SVM), random forest and other ML algorithms have been widely used to predict foundation settlement, subgrade deformation, rutting under the pavement and subsidence of collapsing soils. In comparative statistical analysis, it is often noted that the root mean square error (RMSE) of the prediction



for traditional empirical equations is relatively high – for example, conditionally in the range of 20–30%, in ANN models this indicator is often reduced to 10–15%; it is also noted that the explained variance (R^2) is around 0.6–0.75 in empirical models, while in neural network models it reaches 0.85–0.95. These results can be represented in the form of conditional Table 3.

Table 3. Comparative performance of empirical and ANN models in predicting ground deformation (generalized)

Model type	RMSE (relative, %)	R^2 (proportion of variance explained)	Note
Empirical equations	20–30	0.60–0.75	Simpler, but less accurate
ANN (ML) models	10–15	0.85–0.95	More complex, but higher forecast accuracy

The summarized indicators presented in Table 3 clearly demonstrate the advantages of artificial intelligence approaches: when the database is large enough and of high quality, ML models can predict soil subsidence and deformation with significantly greater accuracy compared to traditional analytical formulas. However, as noted in the literature review, the main limitation of such models is the high demand for training data, the limited spatial and geological distribution of data, as well as the “black box” nature of the model, which often complicates the physical interpretation of the results. Thus, ML methods can be used in the conditions of the Fergana region, but they, on the one hand, require a large database, supported by local laboratory and field tests, and on the other hand, are expected to give the most effective results when used in integration with classical geotechnical models [19,20].

As a general conclusion, it can be said that in foreign literature a large amount of scientific experience has been accumulated in studying the deformation behavior of soils under variable stresses: it is possible to form a fairly complete picture of the range of resilient and permanent deformations under cyclic loads, the collapse potential of loess and collapsing soils, the statistical dispersion of the parameters of elastoplastic constitutive models, as well as the forecast accuracy of artificial intelligence models. At the same time, the analysis showed that most of these

results are adapted to specific regions and soil types, and cannot be fully transferred to a region with strong irrigation, high seismic activity, and a wide distribution of loess-like and alluvial-proluvial soils, such as the Fergana region. Therefore, it is advisable not to directly apply the statistical ranges and model solutions presented in the literature, but to accept them as a methodological basis and recalibrate them based on the results of special laboratory and field tests on the soils of the Fergana region. The next stages of this research plan to develop an improved model and methodology for predicting certain soil deformation parameters under variable stresses, taking into account foreign experience, but adapted to the geological and hydrogeological characteristics of the Fergana region.

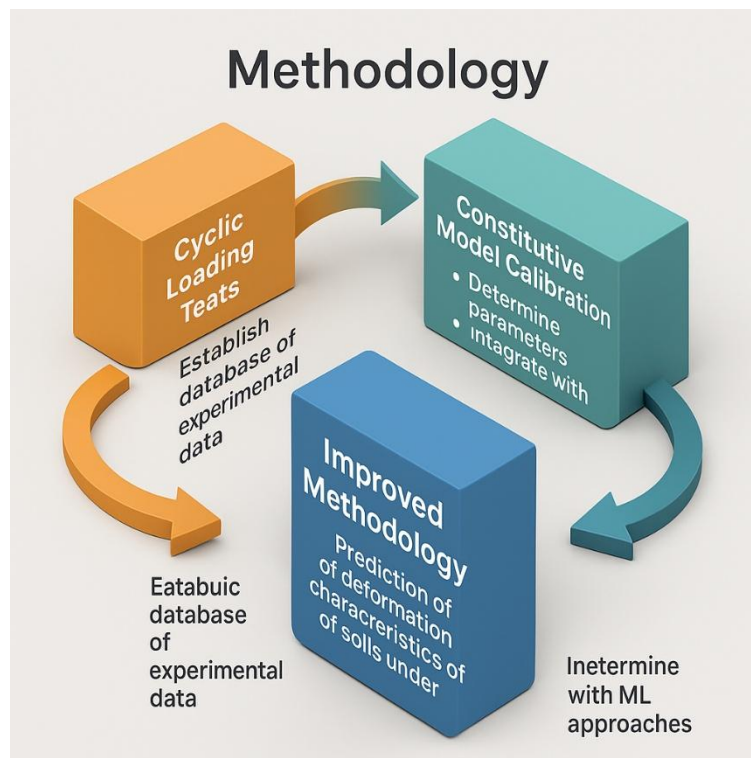


Figure 1. Regional Deformation Prediction Methodology Based on Cyclic Loading and AI.



CONCLUSION

The analysis of this literature showed that foreign scientific schools have created a strong theoretical and experimental base for studying the deformation behavior of soils under variable stresses. Methods for estimating the resilient modulus and permanent deformations under cyclic loading, elastoplastic constitutive models such as Cam-Clay and MCC, criteria for determining the collapse potential for loess and collapsing soils, and forecasting approaches based on artificial neural networks and other ML algorithms allow us to interpret the stress-strain relationship of soils as a multifactorial, nonlinear process. Statistical data clearly demonstrate the superiority of the ranges of resilient modulus, collapse potential levels, and accuracy of ML models, confirming the existence of a solid methodological basis for modern geotechnical analysis and design.

However, during the analysis, it was found that although these approaches were developed at a global level, the parameters and empirical ranges obtained from them are strictly tied to specific regions and soil types, and their direct application to irrigated plains, loess and alluvial-proluvial soils, and regions with sharply changing groundwater regimes may lead to certain errors and uncertainties. In particular, the parameters of the MCC model, the recommended threshold values for collapse potential, as well as the database used for training ANN models are not suitable for the conditions of the Fergana region and require recalibration and adaptation to the regional range.

Therefore, the relevance of this study is determined not by the repetition of foreign experience, but by the adaptation of the theoretical and practical approaches developed in it to the example of soil types widespread in the Fergana region, the development of a regional model and methodology for predicting certain deformation indicators under conditions of variable stresses. For this, it is planned to form an experimental database on cyclic loadings based on the results of local laboratory and field tests, determine the parameters of constitutional models and integrate them with ML approaches. As a result, it is expected to create an improved methodology that takes into account the engineering-geological and hydrogeological features of the Fergana region, can be used in practical design processes, and reliably predicts the deformation indicators of soils under conditions of variable stresses.



REFERENCES

1. Ti KS, Huat BBK, Noorzaei J., Jaafar MS, Sew GS A review of basic soil constitutive models for geotechnical application // *Electronic Journal of Geotechnical Engineering*. - 2009. - Vol. 14. – P. 1–18.
2. Onyelowe KC, Ebid AM, Sujatha ER, Fazel-Mojtahedi F., Golaghaei-Darzi A., Kontoni DP.N., Nooralddin-Othman N. Extensive overview of soil constitutive relations and applications for geotechnical engineering problems // *Heliyon*. - 2023. - Vol. 9, No. 3. – Art. e14465.
3. Al-Rawas AA State-of-the-Art-Review of Collapsible Soils // *Sultan Qaboos University Journal for Science*. - 2000. - Vol. 5, No. 2. – P. 115–135.
4. Lee P., Vanapalli S., Lee T. Review of collapse triggering mechanism of collapsible soils due to wetting // *Journal of Rock Mechanics and Geotechnical Engineering*. - 2016. - Vol. 8, No. 2. – P. 256–274.
5. Lawton EC, Fragaszy RJ, Hetherington MD Review of wetting-induced collapse in compacted soil // *Journal of Geotechnical Engineering*. - 1992. - Vol. 118, No. 9. – P. 1376–1394.
6. Houston S., Houston W., Zapata C., Lawrence C. Geotechnical engineering practice for collapsible soils // *Geotechnical and Geological Engineering*. - 2001. - Vol. 19, No. 3–4. – P. 333–355.
7. Mahmood MS, Abraham MJ A review of collapsible soils behavior and prediction // *IOP Conference Series: Materials Science and Engineering*. - 2021. - Vol. 1094. - Art. 012044.
8. Nouaouria M., Guenfoud M., Lafifi B. Engineering properties of loess in Algeria // *Engineering Geology*. - 2008. - Vol. 99, No. 1–2. – P. 85–90. [OUCI](#)
9. Shahin MA, Jaksa MB, Maier HR Artificial neural network applications in geotechnical engineering // *Australian Geomechanics*. - 2001. - Vol. 36, No. 1. – P. 49–62.
10. Shahin MA, Jaksa MB, Maier HR State of the art of artificial neural networks in geotechnical engineering // *Electronic Journal of Geotechnical Engineering*. - 2008. - Vol. 8. – P. 1–26.
11. Shahin MA, Jaksa MB, Maier HR Recent advances and future challenges for artificial neural networks in geotechnical engineering applications //



-
- Advances in Artificial Neural Systems. - 2009. - Vol. 2009. – Art. 308239 (9 p.).
12. Qian Y., Han J., Pokharel SK, Parsons RL Determination of resilient modulus of subgrade using cyclic plate loading tests // Geo-Frontiers 2011: Advances in Geotechnical Engineering. – Dallas, TX, USA, 13–16 March 2011. – GSP No. 211. – P. 4743–4751.
 13. Tamošiūnas T., Skuodis Š. Predictive stress modeling of resilient modulus in sandy subgrade soils // Infrastructures. - 2023. - Vol. 8, No. 2. – Art. 29.
 14. Sas W., Głuchowski A., Soból E., Bąkowski J., Szymański A. Analysis of the multistage cyclic loading test on resilient modulus value // Annals of Warsaw University of Life Sciences – SGGW. Land Reclamation. - 2016. - Vol. 48. – P. 53–65.
 15. Wani KMNS, Showkat R. Soil constitutive models and their application in geotechnical engineering: A review // International Journal of Engineering Research & Technology. - 2018. - Vol. 7, No. 4. – P. 129–134.
 16. Rakhimjanovna K. K. et al. THEORETICAL FOUNDATIONS OF THE ISSUES OF STUDYING AND MODELING GEOTECHNICAL PROPERTIES OF SOILS //Western European Journal of Modern Experiments and Scientific Methods. – 2025. – T. 3. – №. 05. – C. 54-66.
 17. Rakhimjonovna K. K. et al. PROBLEMS AND SOLUTIONS IN PROVIDING GEOINFORMATION OF THE STATE LAND CADASTRE //Western European Journal of Modern Experiments and Scientific Methods. – 2024. – T. 2. – №. 11. – C. 1-6.
 18. Khakimova K. et al. Design of an optimal irrigation system taking into account the characteristics of the earth using simulation-optimization models //E3S Web of Conferences. – EDP Sciences, 2024. – T. 590. – C. 02008.
 19. Musaev I. et al. Enhancing Sustainable Agriculture through Crop Diversification in Uzbekistan //E3S Web of Conferences. – EDP Sciences, 2024. – T. 590. – C. 06005.
 20. Khakimova K., Yokubov S. CREATION AND MAINTENANCE OF STATE CADASTERS IN THEREPUBLIC OF UZBEKISTAN //Innovations in Science and Technologies. – 2024. – T. 1. – №. 1. – C. 85-93.
-