ANNOTATION

The dissertation by Kanat Tabynovich Alenov titled "**Study of the Stress-Strain State of Building Structures during Interaction with a Deformable Medium Reinforced with Structural Elements**", submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) in the educational program 8D07365 – "Construction".

Relevance of the Dissertation Research Topic. Modern urban development is characterized by the intensive construction of multi-story buildings. In many cases, especially when there is a shortage of available land plots in cities, buildings are erected on sites that were previously considered unsuitable for construction. This, in turn, necessitates the careful selection of engineering solutions to ensure high-quality geotechnical design of building foundations.

National construction standards in many countries recommend addressing such issues based on a techno-economic comparison of traditional and modern design methods.

Under these development conditions, the stability and reliability of multi-story buildings largely depend on the correct selection of a computational model that determines the stress-strain state of structural elements, foundations, and the underlying soil.

Currently, the design of foundations on natural soil in a number of countries, including Kazakhstan, is carried out in accordance with the EN 1997 standard. This standard requires the use of a soil model as the computational model, which describes the behavior of the foundation soil under the considered limit state.

Analytical and experimental studies of geotechnical structures are generally conducted using two of the most widely adopted models: the Coulomb–Mohr elastoplastic model and the Hardening Soil model, which is used for reinforced soils.

Construction design standards adapted to the requirements of the Eurocodes propose addressing the challenge of building on collapsible soils by reinforcing the geotechnical mass with vertical elements. This method improves the mechanical properties of the soil, increases its strength, and allows for efficient redistribution of loads transmitted to the foundation. Under such conditions, the soil foundation should be considered as an artificial geotechnical mass with enhanced properties formed by the presence of reinforcing elements.

In soil reinforcement methods used for the foundations of buildings and structures, vertical reinforcing elements made of cement-soil, gravel, sand, lime, and other materials are employed. These elements improve the mechanical, filtration, and anisotropic properties of the geotechnical mass, enhance its bearing capacity, and accelerate the consolidation process of the foundation during compaction.

Such a reinforced geotechnical mass is capable of withstanding uneven foundation deformations without sustaining damage, thereby enabling the construction and reconstruction of buildings and structures in complex engineering and geological conditions.

Currently, specialized integrated software such as MIDAS GTX and Plaxis 3D enables the modeling of soil reinforcement while accounting for the nonlinear properties of soil in solving geotechnical problems. This approach allows for a more accurate representation of the complex behavior of soil and its response to various types of loads, which in turn enhances the precision and reliability of design solutions.

Degree of Development of the Topic. Research addressing the interaction between structural elements and the soil foundation began with the simplified Winkler elastic foundation model. Based on this model, other calculation methods were subsequently developed, as presented in the works of N.P. Pasternak, V.Z. Vlasov, and N.N. Leontiev. The methodology for using the coefficient of subgrade reaction in the analysis of deformed structures is outlined in the studies of B.T. Korenev.

The effectiveness of applying elasticity theory for the analysis of structures on elastic foundations, using the relevant elasticity theory relations, has been examined in the works of N.A. Tsitovich, V.A. Florin, B.N. Zhemochkin, A.P. Sintsin, I.A. Simvulidi, M.M. Gorbunov-Posadov, T.K. Klein, and other researchers.

Significant contributions to the study of soft clay soils as foundations for buildings and structures have been made by foreign researchers such as K. Terzaghi, A. Skempton, A. Bishop, L. Shukla, B.I. Dalmatov, M.Yu. Abelev, A.A. Bartolomei, P.A. Konovalov, Yu.K. Zaretsky, Z.G. Ter-Martirosyan, and others.

Among Kazakhstani researchers who have made significant contributions to the development of geotechnical design and construction, notable scientific works include those of Zh.S. Erzhanov, Sh.M. Aitaliev, B.B. Teltaev, E.A. Isakhanov, A.Zh. Zhusupbekov, E.T. Besimbaev, V.A. Khomyakov, and other scholars.

In 1994, V.K. Fedorovich and S.G. Bezvolev proposed a methodology for calculating the stress-strain state of the pile zone and other vertically reinforced soil embankments. The technology of reinforcing the geotechnical mass with strengthening elements was substantiated in the works of O.A. Makovetsky and I.T. Mirsayapov.

Modern computational systems, based on methods for analyzing structures on elastic foundations, enable the consideration of the interaction between foundations and building elements, allow for accurate modeling of structural components, and ensure their efficient performance.

Nevertheless, there is a lack of adequate engineering methods for evaluating and verifying design solutions that take into account the specified physical and mechanical properties of geotechnical masses artificially improved with reinforcing elements. This issue highlights the need for further research and the development of methodologies to accurately assess the reliability and safety of structures when reinforcing or otherwise strengthening the foundation.

Object of the Study. The slab foundation of a multi-story residential building and the soil foundation (geotechnical mass). The interaction of the “building–foundation–soil” system reinforced with vertical reinforcing elements. Variable soil stiffness coefficient. Computational geomechanical models developed using the PLAXIS software package.

The aim of the dissertation is to investigate the stress-strain state of building structures in interaction with a deformable medium — the geotechnical mass reinforced with vertical reinforcing elements possessing specified physical and mechanical properties — as well as to enhance the stability and reliability of the building structures.

Main Research Tasks

To achieve the stated aim, the dissertation addresses the following tasks:

1 Development of a rationale for the interaction between building structures and the soil foundation, as well as for the reinforcement of the geotechnical mass with reinforcing elements in boreholes.

2 Justification for the use of the finite element method and the elastoplastic Hardening Soil model for determining the stress-strain state of slab foundations installed on a geotechnical mass reinforced with vertical reinforcing elements.

3 Modeling the interaction of the “building–foundation–soil” system on a reinforced foundation using the PLAXIS software package, as well as studying the dependence of this interaction on the variable soil stiffness coefficient by the finite element method.

4 Calculation of the stress-strain state and settlement of slab foundations on collapsible soils with the application of reinforcement of the geotechnical mass using vertical elements.

5 Determination of the relationship between the stiffness coefficient of the geotechnical mass and the number and length of vertical reinforcing elements installed in boreholes, as well as the assessment of their effectiveness based on numerical modeling.

Scientific Novelty of the Work:

1. A systematic and scientifically grounded justification has been developed for the effective interaction of building structures within a geotechnical mass reinforced with vertical reinforcing elements, which contributes to improving the reliability of buildings and structures. This finding offers new engineering solutions for the interaction between structural elements and soil foundations, as well as for enhancing their stability and reliability.
2. Geotechnical solutions for the construction of slab foundations on collapsible soils reinforced with vertical reinforcing elements installed in boreholes have been justified. These solutions improve the mechanical properties of the soil and ensure the stability of the stress-strain state of the foundations.
3. The conditions for applying the Hardening Soil model to predict the stress-strain state of slab foundations within a geotechnical mass reinforced with vertical reinforcing elements have been substantiated. The use of this model enables accurate calculation of the mechanical properties of the geotechnical mass.
4. Based on numerical experiments, the dependence of the equivalent deformation modulus of the soil on the reinforcement ratio of the geotechnical mass with reinforcing elements has been confirmed. This result provides a basis for making effective decisions in enhancing soil strength and in the structural design of foundations.
5. Numerical experiments have been conducted, demonstrating the dependence of the stiffness coefficient of the geotechnical mass on the number, length,

and spacing of vertical reinforcing elements. These dependencies provide valuable insights for optimizing construction projects.

6. The conditions for applying vertical reinforcement of the geotechnical mass to prevent foundation settlement on weak collapsible soils have been identified, along with the practical significance of this approach in reducing construction costs and shortening project timelines. These findings are supported by solutions implemented in specific construction projects and are adopted based on the conditions of each individual site.
7. Numerical modeling has demonstrated the feasibility of controlling the suitability of a geotechnical mass for the operation of a specific construction project through reinforcement with vertical reinforcing elements. This method enables the management of the foundation compaction process during construction.

The practical significance of this work lies in the development of an effective design model for slab foundations situated on weak collapsible soils, as well as in the ability to control foundation settlement through the reinforcement of the geotechnical mass with vertical reinforcing elements. The technology of reinforcing the geotechnical mass with vertical borehole elements contributes to reducing construction costs and shortening project timelines, while also enabling more efficient use of the geotechnical conditions at construction sites. This approach simplifies soil compaction or replacement processes, enhances building safety, and accelerates the construction schedule.

Conclusions Submitted for Defense:

1. Analysis and scientific-technical justification of the interaction between building structures and a geotechnical mass reinforced with vertical reinforcing elements.
2. A calculation and design methodology for assessing the stress-strain state of slab foundations located on weak collapsible geotechnical masses reinforced with vertical reinforcing elements.
3. Results of calculations and conditions for applying the Hardening Soil model to predict the stress-strain state of slab foundations.
4. Results of numerical experiments demonstrating the dependence of the equivalent deformation modulus of the geotechnical mass on reinforcement with vertical elements.
5. Design solutions for preventing the development of settlement processes in slab foundations through the reinforcement of the geotechnical mass with vertical reinforcing elements at a specific construction site.
6. Design outcomes confirming the effectiveness of the technology for installing vertical reinforcing elements in strengthening the geotechnical mass.

The reliability of the results is confirmed by the application of hypotheses accepted in the mechanics of deformable solids, as well as by the consistency of numerical calculation results obtained using the finite element method within the modern software package Plaxis.

The author's personal contribution includes the formulation of the dissertation's goals and objectives, the collection and synthesis of research materials, the conduct of numerical and experimental studies, the interpretation of obtained results, the formulation of key findings and conclusions, as well as the preparation of scientific articles related to the dissertation topic.

Publications Based on the Research Results

During the course of the research, 14 scientific articles were published in both domestic and international scientific journals, as well as presented at international scientific-theoretical and practical conferences. These include:

- 2 articles in journals indexed in the Web of Science and Scopus databases;
- 5 articles in publications recommended by the Committee for Control in the Field of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan;
- 1 article submitted for publication and accompanied by the corresponding confirmation;
- 1 article in the proceedings of an international scientific conference;
- 2 articles at international scientific-theoretical and scientific-practical conferences;
- and 4 articles in other scientific journals.

Publicity of the Work

The quantity and scope of publications on the research topic comply with the requirements of the "Rules for Awarding Academic Degrees." The results, key findings, and conclusions of the dissertation are reflected and published in 14 scientific articles, of which:

- 5 articles (including 1 article with confirmed publication certification) have been published in scientific journals recommended by the Committee for Quality Assurance in Education and Science of the Republic of Kazakhstan.

Publications in International Peer-Reviewed Scientific Journals Indexed in Scopus/Web of Science

1. Bessimbayev Y. T., Bissenov K.A., Shadkam A.S., Niyetbay S.E., Moldamuratov Zh.N. *Modelling and Efficiency Assessment of Vertically Reinforced Slab Foundation of Multi-Storey Building* (Article). NANOTECHNOLOGIES IN CONSTRUCTION — A Scientific Internet-Journal, 2025, Vol. 17, No. 2, pp. 151–172. Percentile 49%. ISSN 2075-8545.

2. Loktev D., Loktev A., Stepanov R., Pevzner V. *An Aggregated Method for Determining Railway Defects and Obstacle Parameters* (Conference materials). IOP Conference Series: Materials Science and Engineering, Vol. 317, Issue 1, 2018. DOI: 10.1088/1757-899X/317/1/012021. Scopus, General Engineering – 25th percentile.

Articles in Journals Recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Education and Science of the Republic of Kazakhstan

3. Dzhanmuldaev B. Application of a Mathematical Method in Solving Boundary Problems of Natural Vibrations of a Rectangular Viscoelastic Plate Located under the Surface of a Deformable Medium (Article). Vestnik of L. N. Gumilyov Eurasian National University, 2015, No. 6 (109), Astana: ENU, pp. 22–28. ISSN 1028-9364.

4. Limiting Case of the Approximate Equation of Transverse Vibration of a Flat Plate Considering the Influence of Temperature (article). *Bulletin of the L. N. Gumilyov Eurasian National University*, 2017, No. 2 (117), Astana: ENU, pp. 43–46. ISSN 1028-9364. B. Dzhanmuldáev.

5. General formulation of flat element oscillation below the deformable medium surface by reference to temperature (Article). Bulletinof L.N. Gumilyov Eurasian National University. Technical science and technology series.№4(125)/2018. C 8-16. IRSTI 624.044:69.058.2. Dzhanmuldayev B.D

6. Approval accountability revenue of the disabled control contracts developed under the defined central building construction (Article Vestnik of Kazakh Leading Academy of Architecture and Civil Engineering 2019.№3 (73). - C 145-152. DzhanmuldayevB.D

7. Design Of A Slab Foundation With Vertically Reinforcing Elements. (Article) QazBSQABulletin. N1 (95), C 127- 143 2025. Construction. ISSN1680-080X(print) Bessimbayev E.T., Shadkam A.S., Niyetbay S.E

Articles published in other scientific journals and publications

8. Dynamic Calculation of Constructions Taking into Account Vertical Movements of Supports (article). Bulletin of Korkyt Ata University, Kyzylorda. Republican Scientific and Methodological Journal, No. 1 (52), 2019. ISSN 1607-2782. Zhanmuldayev B. D., Loktev A. A.

9. Transverse Vibrations of a Slab Section in the Substructure of a Ballastless Track (article). World of Transport, Vol. 17, No. 2, pp. 72–78, 2019. Dzhanmuldáev B., Loktev A., Fazilova Z.T.

10. Development of a Linear Theory for the Dynamic Behavior of Structural Elements in the Form of Plates Located Beneath the Surface of a Deformable Medium (article). Science and World: International Scientific Journal, No. 5 (21), 2015, Vol. 1, pp. 46–53. ISSN 2308-4804. Dzhanmuldáev B.

11. Nonlinear Vibrations of an Isotropic Plate in a Deformable Medium (article). International Scientific Journal “Young Scientist”, No. 5.2 (109.2), 2016. Dzhanmuldáev B.

International Scientific and Practical Conferences

12. Evaluation of the Effectiveness of Geomass Reinforcement with Vertical Reinforcing Elements in Bored Piles (article). (Satpayev Readings — 2025). Artificial Intelligence in Engineering and Industrial Systems: Proceedings of the International Scientific and Practical Conference on Process Optimization and Automation Solutions, April 12, 2025, Volume II, pp. 361–368.

ISBN 978-601-323-574-5, ISBN 978-601-323-576-9. Maulenov G., Besimbaev E., Shadkham A., Kaipova A.

13. Formulation of the General Problem of Vibrations of a Flat Element Located Beneath the Surface of a Deformable Medium, Taking into Account Temperature (article). International Scientific Journal "Young Scientist", No. 20.1 (79.1), 2014. III International Scientific Conference "Modern Science and Innovations", Bolashak University, Kyzylorda, Kazakhstan, December 2014, pp. 1–3. Dzhanmuldáev B.

14. Dynamic Interaction of Flat Isotropic Elements with a Deformable Medium Taking into Account Temperature: Analysis of the Approximate Equation of Vertical Oscillations of a Plate Beneath a Layer (article). XVI International Scientific and Practical Conference "Key Issues in Modern Science – 2020", April 15–22, 2020, Sofia, "Byal GRAD-BG OOD", 2020, Volume 6. Dzhanmuldáev B.

Main Scientific and Practical Results of the Dissertation Work:

1. A scientific and technical framework has been systematized and developed for the effective interaction between structural constructions and a geotechnical mass reinforced with strengthening elements.
As a result of the research, theoretical principles have been formulated regarding the stability of an elastic foundation, the deformational displacements of soil, and the dependence of mass stability on the variability of the soil stiffness coefficient.

2. An analysis of simple models of geotechnical soil media has been conducted, and the applicability of their mathematical models has been justified depending on the structural condition of the soil. Based on a comparative characterization of soil models, the capabilities to determine settlement, internal shear deformations, and the stress state of the geotechnical mass have been established. The advantages of applying the Hardening Soil model have been substantiated.

3. The deformation behavior patterns of the geotechnical mass reinforced with vertical reinforcing elements have been theoretically justified depending on the physical and mechanical properties of the soil and reinforcing elements, their quantity and size, as well as the lateral pressure between them. A theoretical foundation has been developed for considering the stress-strain state of the geotechnical mass reinforced with reinforcing elements as a model of a transversely isotropic layer.

4. As a result of the research, the function of the reinforced mass between the vertically installed reinforcing element and the slab foundation has been substantiated as a spatial axisymmetric problem that facilitates effective redistribution of loads from the building onto the reinforcing elements. It has been established that a subgrade layer thickness of 50–60 cm is sufficient for distributing the building load onto the reinforcing elements in a conical pattern.

5. In designing the deformation behavior of the geotechnical mass reinforced with reinforcing elements, the effective modulus of deformation E_{eff} of the transformed soil zone is used. This effective deformation modulus E_{eff} is the primary parameter determining the quantity of reinforcing elements and their placement.

6. Using the Hardening Soil model, a relationship was established between the soil reinforcement volume (%) and the stiffness coefficient of the reinforced mass. An increase in the reinforcement volume leads to a growth in the stiffness coefficient of the mass.

7. Numerical modeling of the interaction between vertical reinforcing elements and soil demonstrated the advantage of installing reinforcing elements in expanded (reamed) boreholes. During the reaming process, additional soil densification occurs around the borehole walls, which increases the frictional force between the reinforcing element and the soil, thereby enhancing the bearing capacity of the reinforced mass.

8. During the simulation of the settlement of a multi-storey residential building and the assessment of the stress-strain state of the slab foundation, the appropriateness of applying the Hardening Soil model for determining the stress-strain state of the slab foundation and reinforcing elements was substantiated. It was found that compared to the widely used Coulomb-Mohr model, the calculated values of the Hardening Soil model are approximately 20% lower, indicating its higher accuracy and adequacy.

9. The technical possibilities of installing reinforcing elements in reamed boreholes were considered, and conclusions were drawn about its effectiveness in terms of strengthening the geotechnical mass, technical and economic feasibility, and technological optimality. The advantages of this method compared to traditional technologies are justified based on the current level of engineering and technology, allowing a significant reduction in the time required for foundation reinforcement works and lowering earthwork costs.

Structure and Volume of the Work.

The dissertation consists of an introduction, four chapters, and a conclusion, totaling 149 pages. The work is illustrated with 111 figures, contains 13 tables, and includes a bibliography of 119 references.

Conclusion of the Dissertation.

The dissertation covers significant scientific research based on new theoretical and experimental results, as well as design solutions for a specific project. The work is devoted to the study of the stress-strain state of structural constructions and their interaction with a deformable geotechnical mass **reinforced by vertical reinforcing elements. It also aims to improve the stability and reliability of structural constructions.**