

ANNOTATION

Dissertations for the degree of Doctor of Philosophy (PhD)
In the field of study 8D071 – “Engineering and Engineering Sciences”
Educational program 8D07102 – "Transport, transport equipment and technologies"

AMANBAEV SABIT SHAYAKHMETOVICH

THE DEVELOPMENT AND CALCULATION OF THE CONSTRUCTION OF MODULAR OVERPASS TAKING INTO ACCOUNT GROUND FOUNDATION PROPERTIES

Relevance of the dissertation work. In modern cities of the Republic of Kazakhstan, one of the most pressing transportation infrastructure issues is the reduced capacity of the street and road network during repairs and reconstruction of underground utilities. Large-scale renovations of heating, water, sewer, and electrical networks involve digging up road surfaces, digging trenches, and partially or completely restricting traffic. Under conditions of high traffic volume, this leads to congestion, increased travel times, increased fuel consumption, and a deteriorating environmental situation in cities.

This problem is especially acute in large cities, where a significant portion of utility lines run directly under roadways. During repairs, traffic flows are forced to be diverted to adjacent streets, which overloads the city's road network and reduces the efficiency of the overall transportation system. Additional complications arise from the length of repairs, which can last for several months.

One promising solution to this problem is the use of mobile modular overpasses, which allow traffic to flow over the repair zone without completely closing the road. These structures help maintain traffic flow along the main route, reduce congestion on bypass routes, and mitigate the socioeconomic losses associated with traffic congestion. Unlike fixed overpasses and interchanges, mobile overpasses can be quickly assembled, dismantled, and transported to the designated site.

Despite the existence of individual developments in mobile bridge and crossing systems, the design of modular mobile overpasses for urban conditions, the calculation of their supporting structures, undercarriage, and the interaction of supports with the ground have not been adequately studied. Comprehensive design methods for such structures, taking into account the specifics of their transport and operational modes, as well as assessment of the stress-strain state of the ground under loads from the overpass supports, are lacking.

In this regard, the development of a modular mobile overpass design, the study of its stress-strain state, the calculation of the interaction of supports with the ground base, as well as the creation of a methodology for calculating and designing such structures are relevant.

Purpose of the study consists of developing a design, creating a calculation methodology and designing a modular mobile overpass used during the repair of underground utility networks, taking into account the interaction with the soil base.

The achievement of the research objective was ensured by a step-by-step solution of the following problems:

- analytical review of the designs of temporary bridges, overpasses, various methods of their calculation and the interaction of supports with soil foundations;
- justification and selection of supporting structures of the inclined and orthogonal modules, as well as the chassis of the mobile overpass;
- research, calculation and design of the structure of the orthogonal module and axles of the chassis for strength, rigidity and stability;
- research, calculation and assessment of the strength of the soil massif from the load of the modular overpass supports;
- mathematical modeling in the Ansys software package of the “overpass support – soil foundation” system to verify the strength assessment of the soil mass;
- development of overpass installation methods and implementation of research results as a general calculation method.

The idea of the work. The goal is to maintain road capacity during underground repairs of utility networks by using a quickly erected mobile modular overpass.

Object of study: stress-strain state of the elements of the supporting structure of the overpass, its chassis and the force interaction of its supports with the ground base.

Subject of research: modular mobile overpass.

The dissertation examined the structural forces of the overpass's metal structures, the operation of the undercarriage, and the interaction of the supports with the ground. Research methods used included mechanical and mathematical modeling, analytical calculation of soil stresses, numerical modeling in ANSYS software, and a comparison of analytical and numerical results.

Scientific novelty consists of justifying the parameters of a structure that has the properties of an overpass (bridge) in the working position and a vehicle when moving, and is expressed in the following provisions:

- for the first time, a calculation scheme and mathematical model of a modular mobile overpass have been developed, taking into account its operation as a spatial prefabricated and disassemblable structure;
- dependencies have been established that link the stress-strain state of the elements of the supporting structure with the action of static and moving loads, taking into account the joint operation of the modules and their connections;
- an analytical dependence of the bending moments in the dangerous nodes of the longitudinal frame of an orthogonally oriented module on the ratio of the linear rigidities of the beam and racks was obtained ($n = i_2/i_1$); the nature of the redistribution of forces when changing the rigidity of the beam was identified, and the optimal range was determined $1,5 \leq i_2/i_1 \leq 2,0$, which ensures a reduction in maximum bending moments by 20–25% and a reduction in the metal content of the structure by 15–18%;
- calculated dependencies were obtained for determining the power work of the undercarriage of the overpass, taking into account the impact of the structure's own weight and dynamic loads during transportation;

- the dependencies of the distribution of stresses in the soil foundation on the load parameters, the geometry of the supports and the distance to the edge of the trench were established;
- calculation ratios were obtained for assessing the local stability of the soil massif under the overpass supports, which make it possible to determine the maximum loads and safety factors;
- verification of analytical solutions for stresses in a soil massif was carried out based on numerical modeling in the ANSYS software package using the Mohr-Coulomb elastic-plastic soil model;

Scientific provisions submitted for defense:

- research results describing the joint operation of the supporting structure of a modular mobile overpass and its chassis in transport and operational positions;
- patterns of distribution of the stress-strain state of structural elements, taking into account the modular design and the action of transport loads;
- dependencies connecting the internal forces in the longitudinal frame of an orthogonally oriented module with the ratio of the rigidities of the beam and racks;
- patterns of formation of the stress state of the soil foundation under the overpass supports;
- results of the assessment of local stability of the soil massif and ultimate loads on the foundation;
- results of numerical modeling of the “overpass support – soil foundation” system in the ANSYS software package and their comparison with analytical solutions;
- a method for calculating and designing a modular mobile overpass, taking into account the conditions of transportation, installation and operation.

The author defends:

- a design of a modular mobile overpass consisting of supporting modules and a chassis;
- a calculation model of the overpass and justification for the selection of cross-sections of the supporting structure elements;
- design solutions and calculations of the chassis, including axle rotation mechanisms, wheel lifting and rotation, as well as axle parameters;
- results of indirect calculation of the running gear of the overpass based on the input of a dynamic coefficient;
- application of a calculation scheme for the interaction of overpass supports with the ground base and the use of the elastic-plastic model of the Mohr-Coulomb soil in numerical modeling;
- results of analytical and numerical study of the stress state of the soil foundation and assessment of its local stability;
- results of mathematical and numerical modeling of the structure and system “overpass support – soil foundation”;
- technological solutions for transportation, installation and dismantling of modular overpasses.

Practical significance. The work is determined by the development of a methodology for calculating and designing a modular mobile overpass, including the

justification of its design parameters, solutions for transportation, installation and organization of its operation.

The results of scientific research and development have been implemented in the activities of Gradient Project Institute LLP and are also used in the educational process of the Karaganda Technical University named after Abylkas Saginov in the training of students of the educational program 6B07106 – "Transport, Transport Equipment and Technologies" within the framework of the discipline "Organization and Road Traffic Safety".

Brief summary of the work.

The first chapter analyzes current traffic congestion issues arising during underground utility repairs. It examines existing mobile bridge and overpass designs equipped with moving mechanisms, as well as modern methods for calculating bridge structures and support-subgrade interactions. The research objectives and tasks are defined.

The second chapter develops the design of a modular mobile overpass and provides its technical justification. The scope of application, operating conditions, structural design of the overpass, and the design of its chassis are discussed.

The third chapter is devoted to the calculation of the structural elements of the orthogonally oriented module and the chassis axles. Strength, rigidity, and stability calculations are performed, the influence of the rigidity characteristics of the structural elements is investigated, and the loads on the chassis axles are determined.

Chapter four examines the interaction of the overpass supports with the underlying soil. An analytical determination of soil stresses is performed, and the strength and local stability of the soil under loads from the overpass supports are assessed.

Chapter five presents mathematical modeling of the overpass support-subgrade system using ANSYS software and compares the analytical and numerical results. The overpass installation and transportation technologies are discussed, and the main results and conclusions of the dissertation are presented.

Personal contribution of the author. The study involves analyzing scientific and technical literature on modular mobile overpasses, setting research goals and objectives, developing a structural design for the overpass, performing calculations, and designing an orthogonally oriented module and chassis, including determining axle parameters and wheel-lift mechanisms. The author conducted analytical and numerical modeling of the overpass support-subgrade system, assessing the stress-strain state and local soil stability, and developed solutions for the overpass's transportation, installation, and operation.

Information about publications and work approval. The main results of the dissertation research are reflected in nine scientific publications in Russian and English. These include two articles in international journals indexed in Scopus and Web of Science, as well as four articles published in journals recommended by the Committee for the Study of Higher Education of the Ministry of Higher Education of the Republic of Kazakhstan.

The results of the work were presented at international scientific conferences, where two abstracts were published. One certificate of state registration of copyright rights was received, confirming the intellectual property.

In the article “Research of the Stress-Strain State of a Mobile Overpass Structure” by Alexandr Ganyukov and Sabit S. Amanbayev, published in the journal “Communications – Scientific Letters of the University of Zilina” (indexed in the Scopus database; percentile in the direction of “Transport” – 37th, in the direction of “Engineering (mechanical engineering)” – 44th; <https://doi.org/10.26552/com.C.2026.010>), the results of the study of the stress-strain state of the spatial frame of the orthogonally oriented overpass module are presented, critical forces and relationships between bending moments and the rigidity of the structural elements are determined.

In the article “Optimization of Mobile Overpass Support Placement Considering the Nonlinear Properties of the Soil Foundation” by Alexandr Ganyukov, Adil Kadyrov, Aliya Kukeshova, Aidar Zhumabekov, Kirill Sinelnikov, Sabit Amanbayev and Akbope Karsakova, published in the journal “Applied Sciences” (indexed in the Web of Science database, quartile Q2 in the field of “Engineering (mechanical engineering)”; in the Scopus database – quartile Q1, percentile in the field of “Engineering (mechanical engineering)” – 79; <https://doi.org/10.3390/app16042075>), the results of optimization of the placement of supports of a mobile overpass are presented taking into account the nonlinear properties of the soil base and a numerical calculation method is developed in ANSYS.

In the article “Development of methods for installing a modular overpass” by A.A. Ganyukov, A.S. Kadyrov, S.Sh. Amanbaev, published in the Republican journal “Proceedings of the University” (https://doi.org/10.52209/1609-1825_2022_2_217), recommended by SHEQAC, presents the results of the development of technologies for the installation of a modular mobile overpass, including the crane method and the “sliding” method.

In the article “Study of the operation and calculation of the structural elements of the undercarriage of a modular overpass” by the authors S.Sh. Amanbaev and Sh.M. Suyunbaev, published in the journal “Proceedings of the University” (https://doi.org/10.52209/1609-1825_2022_4_286), the results of the calculation of the undercarriage elements of the modular overpass are presented with the determination of the axle loads and the selection of the cross-sections of the structure.

In the article “Development of a modular overpass used in the repair of urban utility networks” by A.A. Ganyukov and S.Sh. Amanbaev, published in the journal “Proceedings of the University” (https://doi.org/10.52209/1609-1825_2023_3_291), the results of the development of the design of a modular mobile overpass and the analytical calculation of the supporting elements of an orthogonally oriented module are presented.

In the article “Development of Mobile Communal Overpasses Applied During Repairing of Urban Communal Networks” by A.S. Kadyrov, A.A. Ganyukov, S.Sh. Amanbayev and A.A. Bogdanova, published in the journal “Material and Mechanical Engineering Technology” (https://doi.org/10.52209/2706-977X_2023_3_1),

recommended by SHEQAC, presents the results of the development of design solutions and calculation methods for mobile modular and single-span overpasses.

The thesis "Use of Modular Mobile Overpasses to Eliminate Traffic Congestion During Urban Utility Network Repairs" by A.A. Ganyukov and S.Sh. Amanbaev, published in the proceedings of the International Scientific and Practical Conference "XV Saginovsky Readings. Integration of Education, Science, and Production" (Karaganda, June 16–17, 2023), examines the use of mobile overpasses to reduce traffic congestion during utility network repairs.

The thesis "Modular Mobile Overpass as a New Type of Transport Equipment" by S.Sh. Amanbaev and A.A. Ganyukov, published in the proceedings of the XII International Scientific and Practical Conference "Innovative Technologies and Engineering" (Temirtau, October 19–20, 2023), presents the results of a study of the design of a modular mobile overpass and its interaction with the ground base.

Volume and structure of work. The dissertation consists of an introduction, 5 sections, and a conclusion, set out on 190 pages of typewritten text, which are explained by 81 figures, 25 tables, a list of references from 147 titles, and 7 appendices.

Research results and main conclusions.

The dissertation contains new scientifically based results, the use of which provides a solution to an important applied problem of creating a modular mobile overpass.

Brief conclusions based on the results of the dissertation research:

1. The conducted research made it possible to develop a design for a modular mobile overpass to ensure traffic movement during the repair of underground engineering and utility networks;
2. An analytical review of temporary bridge structures, mobile crossings and methods for calculating the interaction of supports with the ground base was carried out, confirming the relevance of developing a modular overpass;
3. A design concept for a modular overpass has been developed, including orthogonal and inclined modules, as well as a chassis for transporting the structure;
4. Research and calculations of the load-bearing structures of the overpass for strength, rigidity and stability were carried out, and rational parameters of the main elements were determined;
5. Analytical dependencies of the stress-strain state of an orthogonally oriented module were obtained and the influence of the rigidity of the elements on the redistribution of forces was established;
6. Calculation and research of the operation of the overpass chassis was carried out taking into account static and dynamic loads during transportation;
7. A calculation scheme for the interaction of the "overpass support – soil foundation" system has been developed, which makes it possible to assess the stress state of the soil;
8. The dependencies of stress distribution in the soil foundation were obtained and an assessment of the local stability of the soil massif under the overpass supports was performed;

9. Numerical modeling of the “overpass support – soil foundation” system was carried out in the ANSYS software package using the Mohr-Coulomb elastic-plastic soil model and a comparison was made with analytical solutions;

10. Technological solutions have been developed for the transportation, installation and dismantling of the modular overpass, including the crane method and the sliding method;

11. A methodology for calculating and designing a modular mobile overpass has been developed, taking into account the conditions of transportation, installation and operation.

Evaluation of the implementation of the assigned tasks. As a result of the research, the following problems were fully solved:

- an analytical review of the designs of temporary bridges, mobile and quickly deployable overpasses, as well as methods for their calculation and the interaction of supports with soil foundations, was carried out, which made it possible to substantiate the relevance of developing a modular mobile overpass;

- the choice of supporting structures for inclined and orthogonally oriented modules has been substantiated, and a design scheme for the running gear of the modular overpass has been developed;

- research, calculation and design of the structure of the orthogonal module and chassis axles for strength, rigidity and stability were carried out, the design parameters of the main elements were determined and working drawings of the structure were developed;

- research, calculation and assessment of the strength of the soil massif under the action of loads of the modular overpass supports were carried out, the patterns of stress distribution were determined and an assessment of the local stability of the soil foundation was carried out;

- mathematical modeling of the “overpass support – soil foundation” system was carried out in the ANSYS software package, verification of analytical solutions was performed and the reliability of the obtained calculation results was confirmed;

- methods for transporting, installing and dismantling a modular overpass were developed, installation equipment was selected and the research results were implemented in the form of a general methodology for calculating and designing a modular mobile overpass.

Development of practical recommendations for the application of the obtained results. The developed methodology for calculating and designing a modular mobile overpass can be recommended to engineering and technical personnel in the transportation, construction, and mechanical engineering industries, as well as to design and research organizations. The results of the research and numerical modeling can be used in the calculation, design, installation, and operation of modular mobile overpasses.

Assessment of technical and economic efficiency of implementation. A feasibility study confirmed the high efficiency of the single-lane modular mobile overpass. Capital expenditure per unit is 68–78 million tenge. The net present value over 15 years reaches 320–480 million tenge, with an internal rate of return of 34–42%, a payback period of 6–11 months, and a profitability index of 2.8–3.6. The

overpass significantly reduces the time required for detour closures, significantly reduces the economic impact of congestion, and ensures uninterrupted traffic flow. The implementation of mobile overpasses is an economically feasible and highly effective solution, providing significant budget savings.

Assessment of the scientific and technical level of the completed work:

– for the first time, a study was carried out on the design of a modular mobile overpass intended for use in conditions of repair of urban utility networks; design solutions for orthogonal and inclined modules were developed, and the operation of the supporting structure and running gear of the overpass was also studied;

– studies of the stress-strain state of the structural elements were conducted, the chassis was calculated taking into account static and dynamic loads during transportation, and rational parameters of the main elements were determined;

– a calculation scheme for the interaction of the “overpass support – soil foundation” system was developed, an assessment of the strength of the soil massif was carried out, and mathematical modeling was carried out in the ANSYS software package with verification of analytical solutions;

– technological solutions for the transportation, installation and dismantling of a modular mobile overpass have been developed.