ANNOTATION
Dissertation for the degree of Doctor of Philosophy (PhD)
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GEOMECHANICAL SUBSTANTIATION OF THE PARAMETERS OF ENGINEERED EXCAVATIONS IN A LAYERED ROCK MASS

Relevance of this study. The development of the mining industry necessitates the continuous improvement of methods and technologies to ensure the stability of underground excavations. A key factor influencing the safety and efficiency of underground mining operations is the proper selection and justification of support parameters, particularly under complex geological conditions.

Failure to account for rock heterogeneity leads to a significant idealization of excavation and support conditions for excavations, thereby reducing the reliability of engineering decisions. This approach considerably undermines the completeness and accuracy of data used to assess the stability conditions of such excavations. Assessing the heterogeneity of multi layered rock strata is of considerable practical importance for addressing support-related challenges, particularly in relation to the structural and strength variability of the rock mass.

A layered rock mass is characterized by anisotropy of mechanical properties, a complex stress-strain state, and a high probability of stability loss under the influence of rock pressure. Under such conditions, the application of traditional methods for support design and calculation may lead to significant errors, which negatively affect the safety of mining operations.

Numerous studies conducted in recent years have focused on the investigation of stress–strain behavior and failure mechanisms in layered rock masses, taking into account various bedding angles, degrees of fracturing, and variability in physical and mechanical properties. Through physical modeling and numerical analysis using advanced software packages such as RS2, FLAC3D, UDEC, and others, it has been demonstrated that changes in layering geometry and interlayer contact properties have a significant impact on stress distribution and the formation of failure zones around excavations.

Modern numerical modeling methods, including the use of the RS2 software package, enable detailed analysis of the interaction between support elements and the surrounding rock mass, taking into account key geomechanical factors such as the dip angle of layers, the factor of safety, and the parameters of the inelastic deformation zone (IDZ).

Thus, the relevance of this study lies in the need for a scientific justification of the stability of mine excavations in heterogeneous layered rock masses, as well as the development of practical recommendations for the design and optimization of support parameters, taking into account real geomechanical conditions of operation.

The aim of this dissertation is to identify the patterns of stress–strain state evolution in the rock mass surrounding man-made openings excavated in a layered

rock structure and to develop recommendations for selecting the types and parameters of support systems.

To achieve this aim, the following objectives were defined:

– to conduct a review analysis of the problem and existing research on the stability of man-made excavations in anisotropic rock masses;

– to analyze the geomechanical conditions of layered rock formations and their impact on the stability of excavations;

– to conduct laboratory experiments to determine the effect of the layer dip angle on the strength of rock samples;

– to investigate the stress–strain state of the rock mass considering various layer dip angles;

– to perform a numerical analysis to establish the relationship between layer dip angles and the stress–strain state in the surrounding rock mass of mine excavations;

– to develop a methodology for selecting and optimizing support parameters, including rod supports, cable anchors combined with shotcrete and metal mesh;

– to model the interaction between the support system and the rock mass, and assess the factor of safety;

– to develop practical recommendations for supporting mine excavations in layered rock mass conditions.

The idea of the study is to develop technological schemes for supporting mine excavations, regulating the types and parameters of support for excavations in layered rock masses, considering the Geological Strength Index (GSI) and the geotechnical conditions of the deposit.

The object of the study is mine excavations excavated in a layered rock mass, where the thickness of the layers does not exceed two times the height (2h) of the excavation.

Research Methods. In the course of the dissertation, a set of research methods was employed, including an analytical review of modern concepts regarding the mechanical behavior of layered rock masses, the analysis of models for the strength properties of anisotropic rocks and their failure criteria; experimental studies aimed at determining the strength characteristics of rocks, including the modulus of elasticity, uniaxial compressive strength, and deformation properties; numerical modeling of the stress–strain state of the rock mass and fracture zones surrounding mine excavations using the RS2 software package, taking into account the layer dip angle, layer thickness, and geomechanical characteristics; comparative analysis of the influence of various geological and geomechanical factors on the stability of mine excavations; and the geomechanical zoning method used to classify the mass by stability and substantiate optimal support parameters.

The defended scientific provisions:

As the dip angle of the rock layers increases, the configuration of the inelastic deformation zone changes, under steeply dipping conditions, a significant expansion of the inelastic deformation zone is observed in the sidewalls of the excavation.

A ratio of excavation width to individual layer thickness equal to or greater than 1 indicates a significant influence of the structural features of the rock mass on the stress–strain state of the rock in the vicinity of the excavation.

The influence zone of closely spaced excavations becomes evident at distances equal to or less than three times the excavation width, where an expansion of the inelastic deformation zone occurs.

Scientific Novelty of the Dissertation:

– the formation characteristics of inelastic deformation zones around mine workings were determined, taking into account the inclination angles of geological layers. This made it possible to scientifically explain the asymmetric distribution of rock failure zones relative to the excavation axis;

– based on advanced numerical modeling, new patterns of formation and spatial distribution of inelastic deformation zones in layered rock masses were revealed, considering the distance between adjacent excavations and the thickness of geological layers. These findings clarified the influence of folded geological structures on the deformation processes around mine workings;

– scientifically grounded and original recommendations were developed for the selection of support systems and parameters for mine workings, based on the rock mass stability category, dip angles of layers, and specific geological conditions.

The practical significance of the study lies in the applicability of the obtained results for the design and optimization of mine support systems, which will enhance the safety of underground operations, reduce material costs, and increase the service life of the support structures.

The influence of rock layer dip angles on the stress–strain state of the rock mass has been substantiated through a comparative analysis of simulated stresses and strains, as well as the results of laboratory tests on rock samples.

The prediction of the influence of closely spaced excavations has been confirmed by calculations of critical distances between them, derived from numerical modeling and correlated with laboratory test results. It has been established that at distances equal to or less than three times the excavation width, there is a significant increase in the inelastic deformation zone, which is consistent with actual operational data from mine excavations.

Implementation of the Research Results in Industry:

The scientific and applied results of the dissertation have been implemented in the practice of design and operation of mine excavations. The developed recommendations make it possible to determine the optimal support design based on a set of geotechnical solutions aimed at improving the stability of mine excavations in layered rock masses, taking into account stability categories and the mining and geological conditions of the rock mass.

Author's Personal Contribution: The author's personal contribution includes the formulation of research objectives, the performance of laboratory experiments, and the analysis of the obtained results; the execution of comprehensive studies aimed at identifying the features of inelastic deformation zone formation around mine excavations with consideration of rock layer dip angles; and the development of practical recommendations for selecting the types and

parameters of mine support systems under complex geological conditions, taking into account the anisotropy and mechanical behavior of layered rock masses.

Approbation of this study:

The main findings and results of the research were presented at international scientific and practical conferences: «Innovations in Science and Practice» Ufa, Russia, 2023; «Integration of Science, Education, and Production – the Foundation for Implementing the Nation's Plan» Karaganda, 2021; and the XV Saginov Readings: «Integration of Education, Science, and Production», Karaganda, 2023.

Publication of the work: The main findings of the research are presented in 14 published works, including 2 articles in journals indexed in the Scopus database, 4 articles published in journals from the list recommended by the Committee for Quality Assurance in the Field of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, 3 conference abstracts, 1 utility model patent, and 4 certificates of registration in the state register of rights to copyright-protected intellectual property.

Structure and volume of the work: the dissertation consists of an introduction, four chapters, a conclusion, a list of references, and appendices. The manuscript comprises 107 pages and includes 54 figures, 22 tables, 74 references, and 4 appendices.