UNIVERSITY OF PETROȘANI

DOCTORAL SCHOOL

DOCTORAL THESIS
SUMMARY

RESEARCH ON THE MODELING AND SIMULATION OF POWERED ROOF SUPPORT AND ITS INTERACTION WITH THE ROCK MASS USING COMPUTER SYSTEMS

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The advent of powered roof supports marked a technological leap in the evolution of longwall support equipment. Since their introduction, which facilitated the expansion of the longwall mining method, powered roof supports have undergone a continuous process of improving design and functional parameters, characterized by constructive diversification and an expanded range of applications to increasingly diverse deposit conditions.

The progress achieved so far in enhancing the design and functional parameters of mechanized supports, as well as the increased efficiency of individual supports, have considered requirements imposed, particularly by the increase in load-bearing capacity, the extension of the face length, the rise in working height, and the expansion of the height adjustment range.

In the field of mechanized support improvement, progress has been made based on theoretical, laboratory, and in-situ research regarding phenomena occurring in the massif because of mining operations, as well as the interaction process between the support and the rock.

Classical models of support-rock surrounding interaction exhibit serious deficiencies in explaining complex geomechanical phenomena related to longwall support and the interaction of mechanized support with surrounding rocks. Most of these models do not consider support parameters such as construction type and rigidity, nor the time-variable nature of the loads acting on it.

Existing models, inspired by the specific practical experience of certain local mining conditions, mostly refer to outdated support types whose current use is more limited. These models cannot encompass all decisive parameters for the design and selection of mechanized supports. Therefore, these models lack an appropriate level of generality, even if they are national standards or recommendations, and cannot provide a rational basis for choosing and designing powered roof supports used in different conditions.

The load-bearing capacity of supports has gradually increased with the use of hydraulic props with larger interior surfaces and the progressive increase in the working pressure of the hydraulic agent up to values of 45 MPa. This increase has been facilitated by the evolution of the quality of materials used and the technological progress of control, force, and sealing elements in hydraulics.

PRETENSION FORCES, initially limited to small values, can be adjusted over a wider range, up to 60% of the nominal load-bearing capacity. Choosing an optimal pretension force can reduce the total load on the support section to maintain stability in the immediate vicinity of the face. These trends indicate the need for further research to better understand the behavior of supports and their interaction with surrounding rocks and to provide data for the improved selection and use of mechanized supports.

An appropriate model for longwall powered roof supports and their interaction with surrounding rocks must consider the effects of both axial and flexural stiffness of the immediate roof and floor strata to analyze the development of loads acting on the section and the sensitivity of the section to pretension pressure.

As a result, new methods and tools are necessary to expand the investigation scope of rock-support interaction phenomena, considering the influence of support stiffness on surrounding rocks, the interdependence and reciprocal conditioning of the mechanized support section with the surrounding rock mass, transitioning from the flat section model to the spatial one, and using modern analysis methods such as the finite element method.

The aim of the doctoral thesis, titled "Research on Modeling and Simulation of Mechanized Support and Its Interaction with Rock Mass Using Advanced Computer Systems," is to contribute to understanding the interaction issues of support in general and powered roof supports in particular with the surrounding rocks through modern modeling and simulation methods using advanced computer systems.

The objective of the thesis is to create a comprehensive research tool with a general character that eliminates the existing segmentation in the theoretical, applied, and methodological aspects of this field.

The thesis is structured into an introduction, eight content chapters, and a final chapter of conclusions and original contributions.

In Chapter 1, titled "THE ROLE AND CONDITIONS IMPOSED ON MINING SUPPORTS DURING OPERATION IN LONGWALL MINING," presents the current state of knowledge in the field regarding the addressed issues. I highlighted that the research conducted so far has not led to the development of a unified and universally accepted theory on the phenomena that occur in the rock mass due to mining. However, significant progress has been made in understanding the deformation regime of rocks caused by mining and the specific interaction phenomena in the rock-support system.

In this context, the main determining factors influencing the manifestation of mining pressure in longwalls were reviewed, as well as the movement process of rocks along the longwall contour and the development of loads on support elements. In the final part of the chapter, I presented a synthesis, based on literature data, of the conditions that the longwall support system must meet to efficiently fulfill its function in mining technology.

Chapter 2, titled "THE PLACE AND ROLE OF SUPPORTS IN MINING TECHNOLOGIES," started by emphasizing the importance of support as a component or unit operation in underground coal mining technology in general, and specifically in longwall mining. I illustrated, with detailed graphic examples, the main exploitation technologies, both with individual support and mechanized support, to illustrate the variety of existing technical solutions and their influence on support equipment. A comprehensive classification based on various typological and functional criteria for powered roof supports was provided, using both schematic-functional representations and concrete examples of materialization.

In the conclusion of the chapter, I analyzed the influence of the temporal succession of operations (cutting with the shearer, section movement) on the performance of complex mechanized longwall mining, establishing calculation relationships that allow the constructive, dimensional, and functional correlation of mechanized support with other components of the mechanized complex, namely the shearer and the scraper conveyor.

Chapter 3, titled "INTERACTION OF POWERED ROOF SUPPORTS WITH SURROUNDING ROCKS," addresses the issue of the interaction of powered roof supports with surrounding rocks in a unified approach, starting from information in the literature and incorporating personal considerations and developments. Given the conceptual and phenomenological nature of existing studies, their shortcomings, and the character of theoretical developments dependent on simplifying assumptions and local conditions, a general conceptual model was presented. This model forms the basis for most mentioned approaches, albeit with slight differences, and is suitable for further developments.

Continuing with a synthesized presentation, I used a unified graphic to illustrate the main models of the interaction of powered roof supports with surrounding rocks, including some normative models used in mining practices in various countries. I highlighted a common feature of these models: the static nature of the support-rock surrounding interaction, which considers the maximum estimated values of parameters describing the process based on the principle that the load on the support section is the result of the weight of a compact or fragmented rock block detached from the roof of the stratum.

Conceptually, I presented, with graphic examples and mathematical relationships, the most comprehensive theory regarding the distribution of normal stresses based on the influence zones of longwall mining on the rock mass. Furthermore, the static and kinematic characteristics of the mechanized support section were mentioned, an aspect that is less addressed in the literature. This aspect is not correlated with the interaction problem between mechanized support and surrounding rocks, emphasizing the main parameters defining the performance of a mechanized support section.

In this context, I redefined some characteristics of mechanized support that have been less considered or deficiently described in the interaction process between support and rock, namely, rigidity and load-bearing capacity, as well as factors influencing them. Factors such as the distribution of support pressure along the length of the beam or base are crucial in determining the behavior of both the support and the surrounding rocks.

Based on this, load-bearing calculation methods were reformulated and tabularly presented the load-bearing characteristics of the main types of known mechanized supports. In the final part of the chapter, I introduced a new method for evaluating the performance of mechanized support correlated with roof stability, namely the mass response curve method. This method provides a convenient means of analyzing the behavior of the support-rock system.

Chapter 4, titled "FINITE ELEMENT METHOD, DISCRETE FINITE ELEMENT METHOD," focuses on the modeling and simulation tools used in the subsequent developments of the thesis by addressing the use of the finite element method as a modern engineering problem-solving tool. The fundamental concepts of the method were presented, along with the steps required for creating the mathematical model and the model with finite elements. The computer applications utilizing this method, such as SOLIDWORKS for dynamic models of the interaction between mechanized support and rocks in the massif and the Irazu application employing the discrete finite element method, were introduced.

In Chapter 5, titled "VIRTUAL MODEL OF MECHANIZED SUPPORT FOR SIMULATION," the creation of a simplified virtual model of a mechanized support section of type SMA-2 was discussed. This support, equipped with a four-bar linkage mechanism generating a lemniscate and a corner cylinder, is designed for both roof support and protection of the working space in longwall mining. The virtual model details were thoroughly presented in SOLIDWORKS, and throughout the chapter, the construction of component parts and their assembly within the virtual support were described.

Chapter 6, titled "STUDY OF THE KINEMATICS OF THE RAISE-LOWER MECHANISM OF THE MECHANIZED SUPPORT MODEL," was dedicated to the theoretical and applied analysis of the geometry and kinematics of the four-bar mechanism ensuring longitudinal stability of modern support sections. The first part of the chapter theoretically presented the geometry of generating the lemniscate curve using the SOLIDWORKS application and the parametric equations of the lemniscate. Subsequently, the kinematic analysis of the four-bar mechanism with geometric parameters suitable for its use as a guiding mechanism for the beam of the mechanized support was conducted. Using SOLIDWORKS for trajectory generation and the Excel utility for plotting curves based on coordinates extracted from SOLIDWORKS, graphical representations of the trajectories described by various points on the linkage, assimilated constructively with the shield of the support, were presented.

Based on the model presented in Chapter 5, a study of the kinematics of a mechanized support section of type SMA-2 was conducted using the capabilities of the SOLIDWORKS application. This study resulted in obtaining the trajectory of the shield tip and the beam tip of the mechanized support model. Analyzing the shape of the beam tip trajectory, concluded that it is not a straight line parallel to a vertical plane (the face of the longwall) but rather a curve with a large radius of curvature. This curve satisfies the technological requirement that the movement of the beam tip be nearly vertical and quasi-linear.

Using the trajectory data of the beam tip in the Excel application, the root mean square deviation of the abscissa values of the curve relative to the abscissa value of the vertical line, located halfway between the minimum and maximum abscissa values of the trajectory, was calculated. Analyzing the values of this calculated deviation compared to those obtained through analytical methods demonstrated the usefulness and relevance of the proposed kinematic analysis method.

Chapter 7, titled "DYNAMIC MODELS OF THE INTERACTION BETWEEN MECHANIZED SUPPORT AND SURROUNDING ROCKS," which contains some of the main personal contributions from this doctoral thesis, is dedicated to presenting models of the interaction between mechanized support and surrounding rocks. These models were developed using the most current computer tools, and they are original and pertinent, leading to new results and interpretations.

In the first part of the chapter, a model of the interaction between longwall support and surrounding rocks was presented. This model allows for the consideration of complex phenomena characterizing this process, considering various factors such as the functional, constructive, stiffness, and geometric characteristics of the support equipment, as well as technological processes specific to the mining method concerning the influence of longwall operations. The model is based on an assumed relationship between convergence and support capacity and uses two measurable parameters at the level of hydraulic shields or support sections, namely the pressure in the hydraulic shields and the sliding or closing of the individual shield (or mechanized support section).

Furthermore, a conceptual model of the interaction of the mechanized support section, in terms of the deformation of the base and the beam as a result of their contact deformation with the floor and the roof of the longwall, was presented. In contrast to classical models that consider both the beam and the base as non-deformable, the presented model explains the nonlinear and non-uniform nature of the contact pressure distribution on the base and beam. This is highlighted by the flexibility of the beam and the base of the section.

Using the virtual simplified model of mechanized support SMA-2, created, and presented in previous chapters, various simulation variants were performed under static load on the support section, with and without considering the influence of the roof and floor of the longwall.

Thus, the effect of the virtual roof and floor on the stress and deformation of the beam and base of the mechanized support section was highlighted. Two operating regimes of the virtual section were analyzed. In the first regime, it was considered that the section model takes over the support load due to the roof pressure on the beam, and the hydraulic pillar is a passive element. In the second regime, the pre-tensioning regime was analyzed, where the hydraulic pillar is an active element that raises the beam under the effect of hydraulic pressure.

Differences and similarities between the two operating regimes of the support section can thus be highlighted. The analysis of the results of the mentioned regimes emphasizes that the differences recorded in the maximum values of stresses and deformations, as well as their positions on the beam and base, are insignificant. The influence of roof and floor deformation on the stresses and deformations of the beam and base was also analyzed in both previously presented operating regimes, highlighting the role of elastic deformation (subsidence) of the roof and floor.

Given the increasing attention in recent literature to dynamic phenomena (roof falls) where support is subjected to impact from falling blocks directly on the support beam, at the end of the chapter, a simulation of this phenomenon was conducted based on the same virtual model of the support section using the random vibration component of the SOLIDWORKS package. The analysis of the characteristic time response figures of the mechanized section model reveals the appearance of an oscillatory regime lasting approximately one second for displacement, velocity, and acceleration in the direction Y, with a rapid damping of the amplitude.

In Chapter 8, titled "SIMULATION OF THE ROOF COLLAPSE MECHANISM IN COAL EXPLOITATION WITH UNDERMINED BENCHES IN FRONTAL LONGWALL MINING," we analyzed the effect of the continued movement of the beam of the mechanized support section after establishing contact with the rock mass on the coal in the roof and bench of a heading.

The significance of the analyses in this chapter lies in the applicability of the complex procedure used for the dynamic study of the behavior of support and surrounding rocks, especially in the case of the undercutting extraction method, and for illustrating and validating the support loading assumptions presented in previous chapters.

The absolute novelty, supported using a unique combination of computer applications in simulation, lies in visualizing phenomena that could only be presented through significant screenshots in the thesis. Moreover, by appropriately adjusting parameters and detailing the procedures used, these simulations provide a useful research tool to advance the study of dynamic phenomena related to mechanized heading, combining the characteristics of mechanized support and surrounding rocks.

In the first part of the chapter, we theoretically analyzed the effect of mining pressure on the support of front benches with undermined coal based on a geomechanical model of these types of headings, presenting the assumptions on which it is based and the corresponding calculation relationships.

Based on a model of the heading with undermined benches and mechanized support, we conducted a simulation in the Irazu application. SOLIDWORKS was used to create the geometry model subjected to simulation in a format accepted by the Irazu application. The latter was used to create the actual model, establish the material properties, set boundary conditions and simulation parameters, and perform calculations and highlight results. ParaView was used to process and visualize the results of the calculations performed with the Irazu application.

The advanced imaging used for visualizing simulation results, highlighting the effect of the base on the heading when the section continues to rise after making contact with the rock, the evolution of the heading regarding stresses, deformations, rock displacements, energy variation associated with the fracturing phenomenon, and others represent an advancement in the study of dynamic phenomena related to mechanized heading through modeling and simulation of complex phenomena.