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Assessment of the Stress-Strain State of a Mountain Range

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Abstract: *The role of rock engineering in the design and operation of deep mines is discussed in detail. Critical issues are the rock fracturing around mining excavations, the support and control of the fractured rock, and the rock mechanics design of mine infrastructure and extraction (stoping) systems. Mining-induced landslide is a man-made geohazard that has drawn increasing public attention. Studies have shown that these landslides are generally triggered by a confluence of factors including underground mining, topographical and geological conditions. Progress of the science of rock mechanics in the areas related to these issues is highlighted and critically examined. Specific areas are the prediction and assessment of the mechanical properties of rock mass, the mechanics of controlling fractured rock around deep mining excavations and the resulting demands on support systems. Rock engineering aspects of stoping systems and the regional stress changes resulting from the extraction of large mineral bodies are discussed in detail. The progress in design concepts for open stopes and stopes with caving of the roof strata is illustrated.*

Keywords: Rock engineering, excavations, stress-strain state, mountain range, safe mining operations, mineral deposits, mining-induced fractures.

I. INTRODUCTION

The roof above the coal seam is allowed to collapse freely into the goaf upon extractions of the coal. This consequently results in an alteration to the stress state of the slope body, a sagging and bending of the overlying rock strata, a formation of tension cracks, and a subsidence of the ground surface. The value of energy-based design concepts for very deep mines exploiting tabular mineral deposits is shown. The tools are available. What is needed is the development of robust design criteria for mine infrastructure, excavations and support systems for dynamic and changing stress environments. The second critical issue is the lack of highly qualified rock engineering personnel on the mines. This has been recognized by the European mining industry through supporting a continued education programme in rock engineering for deep mines. This raises the question whether there is a need for a special issue on mining rock mechanics and rock engineering and if so what are the differences to rock mechanics and rock engineering in civil underground construction. A further point that needs clarification is increased emphasis on rock engineering compared to rock mechanics. Rock engineering is seen as the application of rock mechanics principles in the design, construction and support of underground structures. Within the context of this contribution, the discussion will be confined to the design and support of extraction (stoping) and service excavations in mines. Rock excavation by means of drilling and blasting and mechanical means will not be covered with the exception of caving of rock, i.e. rock breakage due to the effects of gravity.

Before discussing the main differences between mining and subsurface rock engineering, it is necessary to understand the purpose of the two branches of engineering. The sole purpose of mining is to provide society with those minerals and mineral products which are required for energy production, the provision of materials for the manufacturing, chemical, food and pharmaceutical industries and the construction industry. The main purpose of subsurface activities is the utilization of the underground space for establishing infrastructure-required public utilities for transport, water and electricity distribution, the use of underground space in urban areas for storage of goods, parking of vehicles, libraries, sporting facilities, etc. and military installations.

II. MATERIAL AND METHODS

In the case of mining, the purpose of creating underground excavations is to extract the minerals needed by society. In the case of civil subsurface structures, the purpose is to provide the infrastructure required by modern industrial society. Other important differences which have an influence on the rock engineering approach are the areas of ownership and financing. Since most mining companies are private sector enterprises, their financial success depends on the cost of operation and the revenue received from the sale of minerals. In the development stage of a new mine, the costly infrastructure required to prepare the mineral deposit for extraction has to be established. At the stage of mine development, no income from mineral sales is available to finance the infrastructure work. For this reason, the exploration of the geological situation is often confined to the mineral deposit and very little if any geotechnical information is collected to assist the mine planer. This results in a high design risk which to some extent can be counteracted by flexible mine design. Since the design and development of the underground infrastructure is usually carried out by the mining company changes can be implemented readily and there are no legal and contractual implications. In the case of civil subsurface construction work, the situation is quite different as there are a number of different organizations involved, namely the owner, the engineering consulting company and the contracting company. Any change in plan has financial and legal implications. For this reason, the degree of site and geological exploration tends to be much greater than is the case of mining. This is facilitated by the public funding situation. Another important difference is that civil underground structures are often used by and open to the public, whereas mining excavations are not open to the public. This has implications on design safety and excavation support design. The main objective of mining is to provide society with the mineral raw materials required by the building industry, the energy industry, the manufacturing and chemical industry, the agricultural sector and the transport and communication sector. The source of mineral raw materials is the mineral deposit. Mineral deposits are anomalies in the earth crust where physical, chemical, hydrological and biological processes have resulted in a concentration of valuable mineral matter. Mineral deposits are limited in size and number, and constitute a valuable and in most instances non-renewable resource. The locality, size, shape and mineral concentration of a deposit and its geological and geotechnical environment is determined by nature and is outside human control. This severely constrains the degree of freedom of the rock engineering design of mines.

Once a mineral deposit has been identified by exploration and assessed as being economically viable, the mining process commences. It comprises the development of necessary infrastructure to reach and prepare the mineral body for extraction, the selection of extraction method, extraction of mineral, and transport of mineral. In the case of deep mines, this usually requires the sinking and equipping of shafts, the development of mine tunnels from the shaft to the vicinity of the deposit (primary development), the development of mine tunnels close to or inside the mineral deposit to prepare it for extraction (secondary development) and the development of vertical infrastructure in the extraction area to facilitate mineral transport and ventilation (ore passes, ventilation shafts). The detailed layout depends on the geometry of the mineral body, the local geology and the system of extraction used. The latter is referred to as stoping system and the extraction excavation as stope.

There exists no universally accepted definition of deep mining. Most definitions of deep mining relate to the changes in mining conditions and mining difficulties associated with the increase in mining depth. The most noticeable effects of depth are the increase in the in situ rock stresses which result in damage to mining excavations and the increase in rock temperature which results in unfavourable environmental conditions and associated physiological stresses for the work force. Efforts to define deep mining in terms of a specific depth value have met with mixed success as the effect of depth on the rock pressure-related mining problems not only depends on the depth of mining but also on the strength of the rock mass.

III. RESULTS

The same applies to the effect of depth of mining on the thermal environment in deep mines which depends on the thermal properties of the rock mass. To illustrate these points, the effects of depth on mining conditions in “deep” coal and gold mines are compared. At a depth of 1000 m below surface, the vertical in situ rock stresses are very similar in the two mining situations, namely about 25 MPa in the case of the coal mines and 27 MPa in the case of the gold mines. However, due to the very much weaker rock formations found in coal mines, the rock pressure-related problems in the coal mines tend to be much more severe than those experienced by gold mines at the same mining depths. The thermal problems in the two mining industries are also very different because of the different thermal properties of the rock formations. In the case of the geologically much younger coal deposits, the temperature increase with depth is about, whereas in the case of the 3.500-million-year-old gold mining deposits in Southern Africa the rock temperature increase per 90 m depth is only about 1 °C. At the same mining depths, the virgin rock temperatures in the coal mines are, therefore, three times higher than those found in gold mines. These examples illustrate and explain the difficulties encountered in defining deep mining. In the case of the heat problems in deep mines, the depth at which the virgin rock temperature exceeds 30 °C would appear to be bench mark value as at such rock temperatures measures would have to be taken to cool the ventilating air to prevent heat stress problems. The uncertainty concerning magnitude of the pre-mining horizontal stresses constitutes a serious problem in the rock mechanics planning of new mines. It is hard to imagine architecture and construction without large-span shells of various applications and taking into consideration the requests of architects, the new achievements in numeral modeling of the surfaces and introduction of new groups of tailored surfaces, the appearance of new forms and types of thin-walled shell structures of this kind is inevitable. The bionic method of solving these tasks pushes the boundaries of these opportunities.

Fig. 1

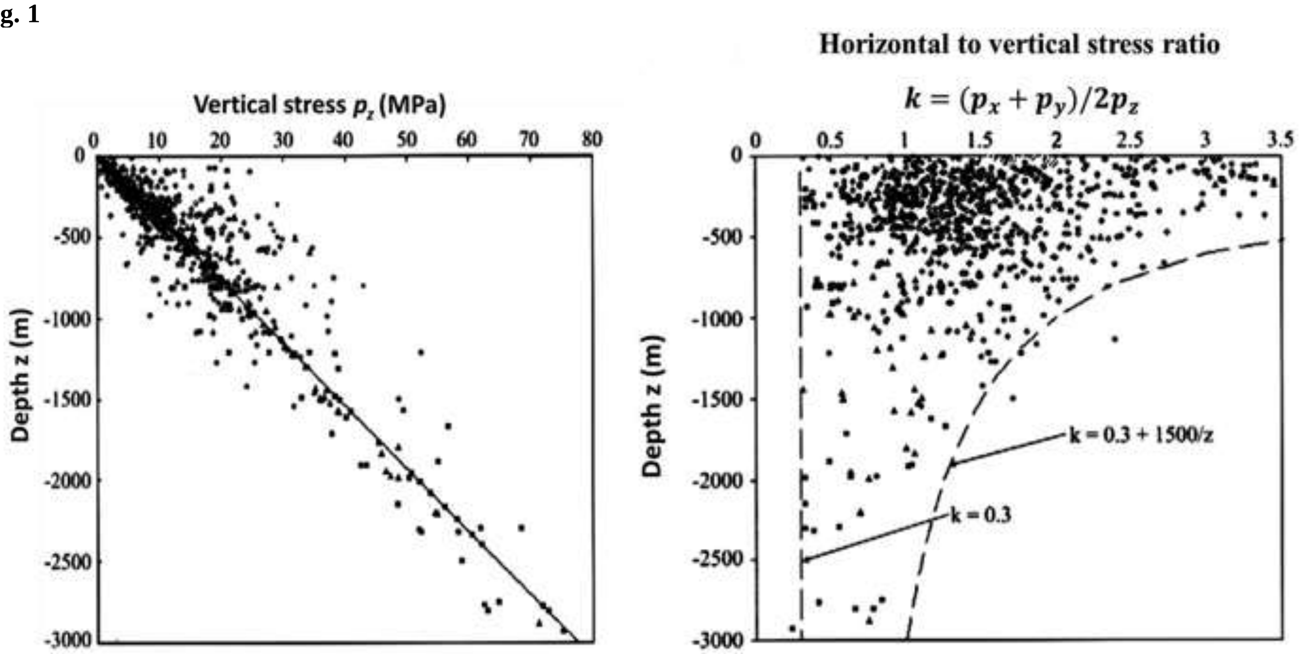

Fig. 1-Variation of measured in situ vertical stress, p_z, with depth below surface in different mining regions and ratio of measured average horizontal stresses to the vertical stress.

In addition excavations are required for necessary services such as pump chambers, refrigeration plants, hoist chambers, underground workshops and store rooms, and refuge chambers. Most of these excavations have to remain operational throughout the life of mine but at least throughout the operational life of mining sections. To ensure the stability of these excavations, careful planning is essential taking into considerations the stress changes throughout the operational life of the infrastructure.

Rock fracturing around excavations is governed by the type of rock, the degree of jointing of the rock mass, the magnitude of in situ rock stress and its orientation relative to the excavation, the geometry and size of excavation, and the orientation of jointing relative to the excavation walls. An aspect which is frequently neglected is the effect of rock layers of different geomechanical properties on rock fracturing. The extrusion of soft rock layers sandwiched between hard layers can induce tensile fractures in the hard and strong rock layers at comparatively low rock stresses and result in pre-mature failure of excavation walls due to rock spalling parallel to the excavation wall. In massive hard brittle rock, micro-crack formation in the direction of maximum compressive stress commences at about 40% of uniaxial compressive strength. These excavation wall parallel fractures form thin rock slabs and prevent mobilization of frictional forces in the low-confinement environment found in the vicinity of excavation wall and have negative influence on cohesion. In the case of softer ductile rock formations or heavily jointed rock masses, the above-mentioned phenomena are absent and rock fracturing around the excavation is caused by shear failure and the formation of extensive failure zones around the excavations.

The numerical modelling of fracture and failure processes around deep excavations in rock requires a good understanding of rock and rock mass behaviour under different geological and rock stress conditions. The choice of rock failure criterion and appropriate constitutive model is critical for the result of numerical analysis. As pointed out the Hoek–Brown general failure criterion which is an empirical formulation for estimating the confinement–strength relationship of jointed rock masses with no preferred failure directions has found wide acceptance. For rock masses which have only one or two well-defined joint sets, this failure criterion should not be applied. Instead, the effects of jointing should be assessed using discrete models with appropriate values for cohesion and friction of the joint surfaces. The limitations of the Hoek–Brown general rock failure criterion for modelling rock failure around excavations in massive brittle and hard rock masses have been mentioned already.

The problem encountered with this and other more advanced constitutive models of rock mass behaviour is the determination of realistic model parameters for the post-failure region. Further advance in numerical modelling of rock and rock mass failure will depend on the quantification of the model parameters. Part of the problem is that the traditional way of testing the effect of confinement on rock behaviour in conventional hydraulic cells constitutes an unrealistic loading situation as it resembles a loading system with zero lateral stiffness unlike the real situation where the rock dilation is resisted by the stiffness of the surrounding rock mass.

Considerable progress has been made in the past 50 years in the science of rock mechanics. This is particularly in the areas of understanding of rock fracture processes, the support of rock structures based on rock reinforcement concepts, the development of numerical methods for structural analysis, the monitoring of mine seismicity and the development of semi-empirical design concepts are concerned. The effect of confining pressure on strength was investigated via computational model. The study on multiphase concrete materials under stress was especially complicated; the relationships between the internal stresses generated on specimens were analyzed in this article.

IV. DISCUSSIONS

What is lacking to some extent is the application of the newly gained knowledge and understanding of mine design and mine operation. There are two main reasons for this. The first is a lack of practical rock engineering hand books for mine operators and rock mechanics personnel working on mines. The second reason is the lack of rock engineering courses at universities. In most instances, the emphasis of the courses is on rock mechanics and fundamental rock mechanics issues. As a result, university graduates are ill prepared as far as finding solutions to the most pressing rock engineering problems encountered by the mines are concerned. The training of mining personnel in the area of applied rock engineering has been identified by the European mining industry as one of the most urgent needs. Once the width of remnant has reached a dimension of about 30 m, it may be opportune to change the direction of mining in such a way that the active mining face advances perpendicular to the strike direction of the mining-induced shear fractures thereby minimizing the potential of triggering sudden shear movement over large areas of the mining-induced rock fractures.

V. CONCLUSIONS

Under the auspices of the European Raw Materials Initiative, a continued education programme in rock engineering for deep mines was recently established to address this need. Open issues that will have to be addressed are the more extensive use of geophysical tools and methods to predict and monitor rock conditions in mines and the development of practical and reliable criteria and tools for designing rock structures and assessing support needs. From an operational point of view, there is a need to give rock engineering the right place in the mining hierarchy to ensure the safe and economic operation of deep mines. These have to be well supported and of adequate cross section to enable access to the remnant even in the event of severe rock pressure damage. Extraction of the remnant should start from the inside and progress towards the periphery of the remnant. Experience in extracting high stress-remnant areas in tabular mining situations shows that extensive steeply dipping shear fractures can develop along the advancing stope face. These mining-induced fractures are preferred discontinuities for the occurrence of rock bursts.

VI. ACKNOWLEDGEMENTS

Among various factors affecting the strength of axis-stressed concrete specimens, ambient pressure is one of the key factors. It is challenging to investigate the effect of aspect ratio of concrete strength using computed tomography (CT) due to the limitation of loading equipment.

In deep mines, the most important mining excavation is the shaft. The shaft provides access to the mineral body; it is required for the transport of men, material and equipment into and out of the mine and mined mineral from underground to the surface. In addition, shafts are required for the supply of the underground workings with air, water, energy, cooling agents and pumping of water from underground to the surface. In the immediate vicinity of shafts are numerous excavations required for the safe and efficient operation of a deep mine. . The state of internal stress and growth of crack of axis-stressed concrete specimens, as well as the changing mechanism of specimen strength under different ambient pressure values, were investigated.

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