Geomechanics in Underground and Open Cut Mining

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I.- INTRODUCTION

My talk is intended to tell something of the history of the involvement of Geomechanics in mining, particularly in Australia.

During the 20th century, the growth in the development of the tools and machines used in mining, and the harnessing of greater and greater quantities of energy to these machines, together with the continued improvement in technology and materials used in blasting, has enabled the size and depth of excavations both surface and underground to be increased out of all proportion from those possible in the days of hand tools and manual labour.

As excavations have scaled up in size, it has become more and more important to understand the forces that cause the rocks, soils and minerals to remain in situ in the earth's crust without movement, to understand what change in circumstances will cause them to move, and when they do move what is the nature of the movement and the forces involved in the movement.

As these matters are better understood the mining engineer is better able to plan and design the sorts and size of openings he may make in the earth, specify the types and nature of drilling and excavation tools he requires for surface and underground excavation, and use with maximum economy the explosives required to loosen rocks for excavation. Conversely, as his understanding grows it will enable him to predict more accurately the stability and safety of ground and structures adjacent to mining operations, and to understand the longer term consequences of such operations on the surrounding country.

In development of large-scale mining enterprises in Australia, geomechanics research related to the huge Bougainville open-cut copper project, the brown coal developments of the S.E.C. of Victoria and work at the Snowy Mountains Authority and Mt. Isa Mines as well as other mines, has played a significant part in national development.

II.- HISTORY

The science of Geomechanics, by whatever name it might have been called, has always been a fundamental art or science in mining because of the very nature of the processes of excavating valuable minerals and rocks from the earth's crust. The miner has to determine the tools and application of forces necessary to excavate the opening, to judge or determine the stability of rocks or soils surrounding the opening with or without support, judge the effect of excavation in an area on adjacent openings or the adjacent natural surfaces. The breaking of rock, controlling of caving in underground operations, the flow of materials in caving operations and ore passes, the maintenance of permanent openings for haulage of ore, the support of ground are among the many matters that have been subjects of study as long as mining has been carried out.

The mining engineer up till the 1930's took less interest in the theories of soil properties and behaviour being developed, tending to devote his investigation to development of simple "rule of thumb" principles for excavation in soils or rocks, leaving it to the civil engineer to undertake the development of theories which became essential as earth and rock dams, foundations for structures, road construction etc. all increased in size throughout the world.

Since the 1950's there has been a marked increase in theoretical study amongst the mining companies and many universities and institutes throughout the world and in the time and effort spent in seeking to develop a greater depth of understanding of Geomechanics. Rock mechanics, until comparatively recently, has largely developed from somewhat empirical rules based on mining experience throughout the world.

In the 1950's more and more effort was put into investigation work aimed at developing a proper understanding of the mechanics of rocks and soils, structures and stability, in order to achieve the proper balance of economy and safety in mining operations. In Europe, America, South Africa and Australia, at a number of universities and institutes oriented towards mining, investigations started which were for the first time really geomechanics, seeking to bring together the theories of soil mechanics with the empiricism of rock mechanics.

As in all the applied sciences, the major efforts had in the first instances to be devoted towards observation and measurement of stress and movement. To date rock and soil mechanics theory has only been able to proceed as rapidly as the collection of reliable data of stress and movement will permit and the development of tools and techniques in these fields has been, and still is, fraught with problems.

The initial fundamental academic research work in geomechanics as related to mining was being undertaken in Australia at the Australian National University by Professor Jaeger and associates, working particularly in conjunction with the Snowy Mountains Authority and the coal mining industry. At the University of Melbourne work was being carried out under sponsorship of the State Electricity Commission of Victoria in connection with the large-scale open-cut brown mining.

Later the requirements of mining at Mt. Isa and Broken Hill led to further research being undertaken within companies and in the Universities of Queensland and New South Wales.

Since the mid-1960's geomechanics investigation work has gained in momentum in Australia. The C.R.A. group work, under the guidance of Professor Hoek, is establishing design criteria for the very-large-scale Bougainville Copper open-cut operations, where a whole variety of problems in relation to geomechanics are of very great significance; better slope design, overburden stripping and removal by sluicing, the design of the mine and plant in an earthquake area with live volcanoes comparatively nearby. In my own company the low-cost caving operation at the Mt. Charlotte mine of Gold Mines of Kalgoorlie has been based on investigations both in relation to the optimum drilling and blasting schedule to cave and break up the ore and also design for stopes and for drawing off the broken ore to obtain maximum recovery with minimum dilution. In mentioning the C.R.A. and Western Mining work, I have started to discuss in more detail the particular areas in mining where theoretical research into geomechanics has started to play a more significant part. Perhaps it is worthwhile at this stage to continue to look more closely into the specific fields where such research is and will prove of considerable use in mining.

I would group the geomechanics work into two main areas, what one might call micro-geomechanics, comprising work seeking to determine the way the grains, particles and components that make up rocks (or soils) of all types are held together and the way forces should be applied by tools and machines to break up the rock to facilitate the further steps involved in winning the ore. The second area, which could be named macro-geomechanics, consisting of work related to the evaluation of factors which affect the stability of rocks and soils, surface or underground. There are two aspects to this: firstly, the creation of unstable conditions to bring about the process of excavation and, secondly, the continuance of stable conditions either temporarily or permanently such as in the permanent batters and surrounds of large open cuts, the haulage shafts, drives, tunnels etc. in underground operations. In both these areas, the significance of the roles played by contained water either intersititial or pressure water in crevices still warrants further research. The two divisions of research naturally overlap and a proper understanding of what I have called micro-geomechanics is obviously necessary in the study of the macro field.

Perhaps I can illustrate this best by examples from my own experience which tell in themselves the story of the continuing and deepening involvement of geomechanics in open-cut mining in Australia.

Incidents involving substantial movements of massive coal blocks and overburden in and around the excavation areas had been a regular feature of open-cut mining operations in the Yallourn and Yallourn North open-cuts prior to 1950. The incidents underlined the need for greater understanding of the causes of these movements, particularly as it was proposed to take the new Morwell open-cut to a depth of over 400 ft. and future development of the huge Loy Yang field could involve multiple-seam mining to a depth of 1,000 ft. and more in unconsolidated or semi-consolidated sediments.

At the same time early in the 1950's, due to problems involved in reaching design outputs from new bucket-wheel excavators, there was a growing awareness of the limited knowledge and experience of German mining engineers and excavation manufacturers in relation to the effective design and utilisation of the bucket wheels for digging our local clay overburdens and coal. Rhineland overburden consisted of sands and fine gravels and their coal is friable with no pronounced planes of weakness in one direction or another.

A programme of research was instituted in the mid-1950's to provide proper bases to establish design criteria for the plans to mine the deep brown coal seams of the Latrobe Valley and also the most efficient way to dig with bucket-wheel excavators in our clay overburden and brown coal. I omitted to mention that just under the bottom of the 300-400 ft. Morwell coal there was known to be an almost artesian aquifer which would tend to lift the coal and probably promote serious movements, and which could cause flooding of the lower portions of the open-cut as the depths of working increased.

The research programme consisted of the following elements:

(i) The usual literature research and investigation of the possible existence of similar mining problems elsewhere. This led to the discovery that a great deal of similar work was in fact getting underway elsewhere in the world, in particular in the Bingham Canyon huge copper open-cut in Utah, U.S.A.- but more of interest to us was work undertaken at the University of Aachen in West Germany.

(ii) The development of a very comprehensive system to survey horizontal and vertical surface movement in and adjacent to the Yallourn and Morwell open-cuts and endeavours to observe and measure what movement occurred at depth in the coal adjacent to operations as excavation occurred, particularly at coal/clay interfaces.

(iii) Research into the physical characteristics of the brown coals of the Latrobe Valley at the University of Melbourne. Several papers by K. Rosengren, separately and collectively with Professor Trollope and E.T. Brown, detail the results of this work. Their paper, "The Mechanics of Brown Coal" published in Geotechnique in December, 1965, would possibly still be the classic paper in theory in this field.

(iv) Research into the development of instruments and techniques for determining movement stress and strain within the brown coal deposits before and during mining. Much of this work was carried out by Professor Newstead, now of the A.N.U., and at the Monash University under the direction of Professor I. Donald.

(v) Laboratory and field experimentation related to the resistance to cutting and fracture of brown coal and overburden in the process of digging by bucket-wheel excavators.

(vi) Operational research work on the application of digging forces and the methods of continuous digging with these excavators.

(vii) Investigations to establish the extent and recharge rate of the sub-artesian aquifer underlying the Morwell seam, to determine the measures that would need to be developed to minimize the effects of these aquifers on mining operations at depth.

Over the last six or seven years the planning of the development of the huge Bougainville open-cut copper project similarly led to a comprehensive programme of research under the overall guidance of Professor Hoek of the Imperial College, London.

III.- UNDERGROUND

In underground coal mining, the introduction of mechanised mining has created the need for application of geomechanics to the design of coal cutting machines and design and support of mine openings. Roof bolting techniques, the use of temporary roof supports and greater control of roof caving as operations proceed has led to use of larger openings, greater economies from bigger machines and also higher extraction percentages. In Australia the work done on arch support and roof bolting theory and application by the Snowy Mountains Authority and Professor Jaeger and associates at the A.N.U. undoubtedly has been of considerable benefit throughout both coal and metalliferous mining.

I think the applications for geomechanics in underground metal mining can once again be best illustrated by an example with which I have some familiarity.

Operations at the Mt. Charlotte mine in Kalgoorlie, with guidance from the Mining Engineering Department of the University of Melbourne, have utilised the results of geomechanics research and theory in several aspects.

Firstly, in the design of the stopes and supporting pillars so that maximum extraction of ore is achieved without prejudicing either the safety of operations or involving excessive overbreaking of surrounding rock which would produce dilution of the ore. Secondly, the location of draw points so that the ore can be drawn from the stopes, achieving maximum recovery without flow problems or dilution by waste rock or filling from the caved area.

The cut-and-fill method which was developed using thorough geomechanics studies and planning has resulted in a very-low-cost operation permitting until recently the profitable extraction of low-grade gold ore which would not be otherwise possible.

The planning of the operations are based on determination of the characteristics of the ore-bearing rocks and the development of mathematical models to simulate the mining operation.

Measurement of the inherent stresses in the rock showed that the field stress along the strike of the ore body was of the order of 2,500 p.s.i. as compared with 1,500 p.s.i. across the ore body.

The design of the stope and supporting pillar were undertaken in such a way as to avoid high stress concentration, minimize the possible danger of the roof failure and poor ground conditions in the North and South ends of the ore body.

In conclusion, I am conscious that this paper does not tell anywhere near adequately the story of geomechanics in mining in our national development, nor have I mentioned or done justice to the initiative and efforts of many people involed - work at North Broken Hill, the coal mining industry, and elsewhere.