ROCK MECHANICS APPLIED TO OIL SHALE MINING

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INTRODUCTION

When oil shale mining becomes an economic reality, probably within the next 5-15 years, we can be absolutely certain of at least one characteristic of the mining operation; it will be on a *very* large scale. Any operation of such a scale, concerned with the mining of such vast tonnages of rock, should profit by knowing all it can about that rock, how to break it, and how to support it most economically.

Rock in general is extremely variable as to different types, and even within a single type it is likely to vary radically in its characteristics from place to place in the same mine. Therefore, it is essential to analyze the properties or behavior of rock from a statistical approach on a multitude of reasonably accurate observations or measurements, rather than on a very few of great precision, but of doubtful significance.

Mines in general are as variable as the rocks in which they are found, and the genesis of their particular ore bodies. Oil shale mines in particular, however, are likely to be surprisingly similar in many ways because of the general uniformity of the oil shale and the remarkable expanse and thickness of the deposits.

Oil shale is a relatively strong rock, reasonably elastic, but not inclined to be brittle. Therefore, it should be expected to exhibit a fair amount of slow measurable deformation prior to failure in the field.

STATE OF THE ART

Rock mechanics as a distinct new discipline has come a long way since its inception about 15-20 years ago. The results of mathematical and photoelastic solutions to problems of stress concentration and distribution around and between mine openings, in a medium such as rock, are rather widely known and understood by mining people now, where only a handful of specialists discussed these things 15 years ago.

However, for want of factual quantitative field data, most of the development of rock mechanics to date has been based on reasonable assumptions and laboratory model studies. There is nothing wrong with such an approach

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when no other is feasible, but it is my opinion that such studies have come to a point of diminishing return, and we should now put the emphasis on the collection of quantitative factual data in the field.

The very act of collecting such data is very helpful to operating personnel in better understanding their mine structure situation, and theoretical analysis of such data will be based on realistic fact.

Rock mechanics instrumentation should be designed to permit the gathering of the maximum of significant quantitative data with the minimum of cost in equipment and personnel, and the minimum of interference with normal productive operations. Such instrumentation is by no means a "cure-all" for ground support problems, but it does provide the engineer with a very useful new precision tool which will permit him to detect and predict rock movement, stabilization, and/or failure long before the usual sounding bar and "eye-ball" experience technique can do so. Measurements taken over a period of time in a given mine lead to a valuable new form of "quantitative" experience, which might be called a sort of "micro-behavior" of the rock structure.

These rock mechanics data and experience have two major uses and values. First, many forms of failure predictions and warning systems can be based on precise deformation measurements. Such warnings permit the safe removal of men and equipment *before* rock failure, or the provision of support or reinforcement in time to be *added* to the strength of the rock instead of taking the full load on the supports *after* the rock has failed.

Second, quantitative data of this nature must inevitably lead to more efficient designs for rock bolting patterns, room and pillar dimensions, caving plans, opening shape, size, and orientation considerations, etc.

INSTRUMENTATION AVAILABLE

In 1950, rock mechanics instrumentation was practically unknown. By 1955, a few items had been described by Potts and others in England, and by 1960 a few were reported in the United States. The first commercially available instruments were probably those by Maihak in Germany, and the "Seismetron" in the United States, about 1958, but nothing became available commercially in quantity in this country until as recently as 1963. Now, only three years later, at least three firms in this country offer many types of instrumentation on an "off-the-shelf" basis, and a rather complete range of types is available.

CONVERGENCE EXTENSOMETERS

The simple measurements of convergence within an underground opening, or along its walls, can be very useful. Telescoping tube or rod extensometers are probably the most common type. The main tubes are preferably of Invar for temperature stability. The actual precise reading may be by simple sliding scale or a dial gage for greater accuracy and ease of reading. The accuracy is .001 to .002 of an inch, and all such instruments measure between metal stations anchored permanently in the rock.

Tape extensometers are useful for vertical measurements greater than about 25 to 30 feet, and for inclined or horizontal spans over 8 to 10 feet. Tension on the tape is by a calibrated spring or a fixed weight. The least reading is usually on the order of .005 to .010 inch, and accuracy somewhat less, especially for long spans and/or with strong air currents. These units have been used up to about 80 feet.

BOREHOLE EXTENSOMETERS

Borehole extensometers measure the change in length of a borehole, along its own axis. Most units detect the relative displacement of a reference point anchored in the collar of the borehole with respect to one or more anchors at various depths within the borehole.

The single position unit has but one anchor at depth and one at the collar. The connecting link may be a tensioned steel wire or a simple rod or bolt. Readout at the collar may be mechanical by a sliding depth gage, a depth micrometer, or a dial gage; or electronic by strain gages, potentiometers, linear differential transformers, etc. The electronic readouts are more accurate and can be remotely monitored when required, but they are far more expensive and subject to damage or failure than the mechanical types.

The multiple position borehole extensometer works on exactly the same principle as the single position unit except there may be four, six, or eight anchors at various depths in the hole. The connecting links must be either wires or very small rods because of space limitations, and all displacements are referenced to a single plate or anchor at the collar.

LOAD CELLS

Load cells are of many different types, with many different sensing systems, but basically they all measure change of load from one time to a subsequent time, after initial installation. They may measure the load on pillars, tunnel sets, single props, rock bolts, etc. Borehole load cells may be inserted at depth in the rock, and may measure load changes in two or three directions in a plane normal to the longitudinal axis of the hole.

ABSOLUTE ROCK STRESS

Whereas the *change* in stress on the rock *subsequent* to the installation of a load cell may be a relatively straight forward determination, the absolute state of stress at a given time is much more difficult to measure. Several different methods have been tried, using various measuring techniques, but all utilize the principle of stress relief. The most realistic methods operate at some depth in the rock to eliminate the influence of the access opening itself on the stress field. A borehole deformation gage, preferably one which measures at least three diameters simultaneously, is first inserted in a preliminary small hole, perhaps 1½ inch diameter. After initial readings are obtained, a larger bit, usually 6-inch diameter, is used to over-core and thus stress relieve the rock around the gage. The changes in borehole diameter, measured with great precision during and after over-coring, are used to calculate the magnitude and direction of the absolute rock stress in the plane normal to the borehole.

WARNING LIGHTS OR ALARMS

Several relatively simple and inexpensive devices have been developed to continuously monitor a rock structure for incipient movement or instability, and flash a red warning light at the first sign of any movement. The same type of device could be rigged to ring a bell at a remote location or shut off power to a section if so desired. The basic sensing device is an inexpensive micro-switch sensitive to a motion of .001 to .002 of an inch. These devices have been used to warn of convergence in a stope during noisy loading operations, and to detect possible separation in a laminated roof during drilling on top of a 170-foot-high pillar.

EXAMPLES OF APPLIED ROCK MECHANICS

PILLAR RECOVERY

In the lead mines of southeast Missouri, one system of pillar recovery was developed which involved pattern bolting the entire roof, and then removing alternate rows of pillars. Thus, where unbolted spans of 25 to 40 feet had been the rule, bolted spans of 60, 70, and even up to 100 feet were formed. Experience in *that specific mine* and *rock* indicated that stope convergences of ¼ to ½ inch tended to stabilize and be safe, whereas in two instances measurements of ¾ and about 2 inches were followed by continuing convergence and early collapse.

LIMESTONE MINES

Several underground limestone mines in Iowa have the problem of determining safe room spans, the effectiveness of various bolting patterns, and they mine a product of low unit value and very competitive price. A systematic program of convergence measurements, in various room widths, and with bolting patterns of varying densities, should give quantitative experience from which to determine an optimum room width and bolting density.

As an example of the effect of bolt spacing on the unit cost of bolting per ton of rock mined, consider bolting on patterns of 4, 5, 6, or 7 foot spacing, a cost per bolt of $5 in place, and a room 24 feet high producing about 2 tons per square foot of mined area. The unit costs of bolting per ton of ore are:

4 ft centers: 16 sq ft per bolt, $5 ÷ 16 x 2 = $ .16 per ton
5 ft centers: 25 sq ft per bolt, $5 ÷ 25 x 2 = $ .10 per ton
6 ft centers: 36 sq ft per bolt, $5 ÷ 36 x 2 = $ .07 per ton
7 ft centers: 49 sq ft per bolt, $5 ÷ 49 x 2 = $ .05 per ton

If a program of measurements permits a mine to progress safely from a 5- to a 6- or 7-foot bolting pattern, very substantial savings can be realized to justify the cost of the investigation.

LARGE CHAMBER STABILITY

During planning and excavation of the large chambers for the NORAD installation at Colorado Springs, many decisions were based on considerations of rock mechanics. The orientation of the major chambers was chosen so as to assure the optimum stability with reference to the directions of major jointing. Pre-splitting was observed to be more effective in one direction than another, probably due to absolute rock stress variations. Borehole extensometers were used to monitor areas of weak rock for stability. Excavation was continued only so long as stability was indicated. When motion was detected, excavation stopped and bolting was resumed until stability was restored.

At Morrow Point Dam on the Gunnison River, the excavation of a large underground powerhouse chamber is being monitored in the same way, and precise taping is also being used to check for stability.

STRAIGHT CREEK TUNNEL STUDIES

A program of instrumentation carried out during the driving of the pilot bore for the Straight Creek Tunnel at Loveland Pass yielded much valuable data on tunnel support loads and their variations as the tunnel is advanced. When fully analyzed this promises to lead to significant economics in the specification of tunnel supports.

The above examples are only meant to provide a small cross section of the types of programs being pursued. Most of the major mining companies around the world either have programs of rock mechanics studies actually operating, or they are planning to organize such studies at this time.

SUGGESTIONS FOR INVESTIGATION

Several specific areas of investigation appear worthy of discussion with respect to the mining of oil shale.

OPTIMUM ROOM AND PILLAR DIMENSIONS

Recommendations for room and pillar dimensions to date have been based largely on laboratory tests on rock samples and model studies. With the recent developments in instrumentation, it should now be possible to make actual full size field studies of stresses, deformations, and their distributions and thus accumulate the most realistic data possible on which to base our designs. Such studies might conceivably lead to much smaller pillars than have heretofore been considered advisable.

When more is known about the mode and rate of failure of oil shale in situ, a retreating system of mining with very small "yieldable pillars" may become feasible.

ROCK BOLTING THEORY

Rock bolting is bound to have an important place in any system of underground mining for oil shale. Although millions of bolts are placed every year, we still know very little about the true theory of rock bolting and what makes it work. We need to study the mechanics of bolting and the stress distribution and re-distribution in the roof *during* and after the bolting operation. For example, there is evidence to suggest that as bolted spans are widened to the critical point, and under certain types of loading, the abutment bolting near the walls may become more essential than that in the center of the span.

OPEN PIT MINING

Extremely large scale surface mining, perhaps with wheel excavators, seems to be a possibility for at least some of the oil shale. Individual machines of this type may cost millions of dollars, and one dreads to even contemplate having such a machine caught by a sudden slide.

Pit stability should be fairly easy to monitor by long span strain meters laid out on the benches and rigged to trigger alarms. Long range multiple position borehole extensometers installed at various heights in the slopes should aid in a study of the mechanics of slope failure and how to predict it.

CONCLUSION

No mining method can be designed for optimum economy without quantitative data upon which to base the planning, and on the scale of operation envisaged for oil shale, the difference between optimum design and merely workable design could prove to be enormous. With the present state of the art of rock mechanics and the instrumentation now available, there is no reason why we cannot base our oil shale mining plans on realistic quantitative rock mechanics data.

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DISCUSSION

QUESTION: I wonder if you could give us some of your thoughts on what size rooms and pillars you might expect to see in a commercial mining operation in the oil shale and whether you would think that there would be additional supports needed besides the pillars? Could you give us some idea what to expect the cost per ton would be for mining the oil shale?

REED: There are a lot of people here who know more about the cost than I do, so I will just back off on that one entirely. As to what is the optimum room size and pillar size, I know approximately what is being used or what has been used to date. I only point out that if it were up to me, I'd want to get in there with some measurements and try some different sizes and base my final decision on a little experience on the ground; not a couple of days looking or testing a few pieces in the laboratory. That's the sort of thing I recommend. It doesn't make any difference if it is oil shale, or limestone, or what, I still feel that you have to get a feeling for what you're working with *on the ground* over a period of time. I highly recommend an in-house capability, by the use of instrumentation, however simple, by the people actually working on the ground; and a series of tests. Surely you are talking in terms of 30-, 40-, 50-foot spans. It could be 70 or 80 feet. I wouldn't hazard a guess as to what the limit is. I would say there might be reasons for considering smaller rooms and smaller pillars with the same extraction ration, if you follow me, because you would then get less deformation in the roof, and that may be the critical thing—not how big the pillar is to hold up the load, but what happens to the roof; does it break up the pillars, flexing the pillar or doing something like this because of excessive deformation?

As to additional supports, I believe we must accept the basic idea that no artificial support other than rock bolt *reinforcement* of the roof could ever be eonomic in the size of openings being contemplated.

QUESTION: Have your studies included anything about the responsiveness of oil shale to hydraulic fracturing?

REED: No, I'm sorry.

QUESTION: You mentioned the problem of open pit mining and burying a multimillion dollar machine. We are confronted with this in coal mining all the time. I wonder if you would care to comment on possibilities of strain gages along the sides of open pits where the mineral is unconsolidated, as being able to predict slides?

REED: Yes, the reason this came to my mind is because I saw some very large pits with wheel excavators working in a lignite or brown coal deposit in Australia last year. In fact, they were just patching one of these machines back together again after it had been caught in a slide, so I think it was rather on their mind! It strikes me that you could do this. Obviously the sort of stuff you are talking about, and the stuff I was looking at, in which you could even see the decayed wood, was hardly coal. It would have a very low modulus, and therefore, I would assume at least, that it is going to move quite a bit before it finally lets go. A large span strain gage keeping track of this sort of thing wouldn't have to be very sensitive to pick up several inches of movement, or change in length over a span of 50 or 100 feet. I don't know how to do it exactly, but I think it is certainly worth trying. You can set up things like this with an anchor or a steel stake, and some kind of a tensioning device, with a weight, perhaps, so it would be under constant tension. You might want to set such a device so that when it moves an inch or so it rings a bell or something like that. I think the principle is there; and I don't see any reason why it won't work.

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Returning to the University of California at Berkeley in February 1951 to do graduate work and accept an appointment as Lecturer in Mining and Research Engineering he received the M.S. degree in Mining in 1952 in the specialized field of mine opening support and rock mechanics. and the Ph.D. in 1955 in the same field.

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