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Numerical Modeling of Rock Mass Weakening, Bulking and Softening Associated with Cave Mining

Matthew Pierce, Ph.D., P.Eng.; Principal Engineer; Itasca Consulting Group, Inc.

Introduction

Caving mining methods have been employed successfully in the extraction of ore bodies since the late nineteenth century [Brown, E.T. (2003), "Block caving geomechanics." (The International Caving Study I, 1997-2000), University of Queensland, JKMRC Monograph Series in Mining and Mineral Processing, Vol. 3, JKMRC, Indooroopilly, Australia]. There are several different methods of cave mining, including block, panel, sublevel and inclined. In block/panel caving, an ore column of finite width, length and height is drawn from a horizontal array of drawpoints at its base. In order for the ore to flow freely into the drawpoints, the rock mass must be fragmented first -- i.e., disturbed to the point where it disintegrates into a frictional assembly of fully formed blocks that are susceptible to flow. This generally is accomplished by blasting and removing some of the rock at the base of the ore column, a process referred to as undercutting.

An extraction level is developed a safe distance below the undercut level. It generally is comprised of a number of parallel tunnels called extraction drifts that provide access to an array of trough-shaped openings called drawbells, which connect through to the fragmented rock above. The extraction drifts and drawbells are connected via short tunnel segments called draw drifts. Fragmented rock flows through the drawbells in a controlled manner, rilling out into the draw drifts where it can be extracted safely by machinery. The point of extraction (which lies within the draw drift) is referred to as the drawpoint.

Although development of the supporting infrastructure can result in high capital costs, cave mining is an attractive option for some ore bodies because of its low operating cost and high production rates. Some of the key challenges associated with caving are:

- To ensure that the rock mass caves continuously upwards with material draw (i.e., does not stall);
- To ensure that the rock mass fragments into block sizes small enough to flow through the drawbells into the drawpoints (or at least hang up low enough in the drawbell to blast); and
- To develop an array of drawbells and a schedule for draw that maximizes recovery of the ore while minimizing draw of waste material from outside the ore column (dilution).

Numerical models can be used to help address the first challenge, i.e., understanding the likelihood of achieving continuous caving. There are several key rock mass behaviors associated with caving that should be considered when attempting to model the process numerically, including the progressive failure and disintegration of the rock mass from an intact/jointed to a caved material and draw-induced bulking and associated modulus softening. A non-linear, strain softening, dilatancy model is generally required to capture these behaviors with continuum-based approaches. A number of guidelines for developing this approach are presented here based on experience in analyzing a number of caving case histories worldwide [Chitombo, G. and M.E. Pierce. (2012) "A Practical Guide on the Use of the MMT Tools and Methodologies - Block Panel and Sublevel Caving," Report to Mass Mining Technology Project] and [Sainsbury, B. (2012), "A Model for Cave Propagation and Subsidence Assessment in Jointed Rock Masses". Ph.D. Thesis, University of New South Wales].

Peak Strength, Residual Strength and Brittleness

During caving, the rock mass must accumulate sufficient damage during yield to completely disintegrate into a free-flowing assembly of fragments. This transition from peak to residual strength is at the core of the caving process and can be represented via strain-softening models. The Geologic Strength Index (GSI), Hoek-Brown intact parameter (m_i) and uniaxial compressive strength (UCS) parameters typically are used to estimate the peak strength of the rock mass. This is defined by the following equations (where Sigma 1 = major principal stress; Sigma 3 = minor principal stress; and m, s, and a all unnamed material constants):

$$\sigma_1 = \sigma_3 + UCS\left(m_b \frac{\sigma_3}{UCS} + s\right)^a$$

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TECH Note

Numerical Modeling of Rock Mass Weakening, Bulking and Softening Associated with Cave Mining (continued)

This equation is based on the following:

$$m_b = m_i \exp\left(\frac{GSI - 100}{28}\right)$$

$$s = \exp\left(\frac{GSI - 100}{9}\right)$$

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} \quad e^{-20/3}\right)$$

For further detail, see: Hoek, E., C. Carranza-Torres and B. Corkum. (2002) "Hoek-Brown Failure Criterion - 2002 Edition," in NARMS-TAC 2002: Mining and Tunnelling Innovation and Opportunity, Vol. 1, pp. 267-273, R. Hammah et al., Editors. Toronto: University of Toronto Press.

Residual strength typically is set to that of a bulked rockfill comprised of angular fragments (i.e., zero cohesion and a friction angle of 40-45°).

In the model, plastic shear strain is commonly used as a scale for damage accumulated during yield under compression and can be used to control the rate at which the rock mass strength degrades from peak to residual. The plastic shear strain required to go from peak to residual strength is referred to as the critical strain, and is effectively a brittleness parameter. Some generalizations may be made about rock mass brittleness. For example, a higher-quality rock mass (higher GSI) with greater solid rock volume participating in the failure process often will act in a more brittle fashion, thus having a lower critical strain value. Conversely, a lower-quality rock mass (lower GSI) with higher fracture frequency often will act in a more ductile fashion, thus having a larger value of the critical strain. An estimate of the relation between the critical strain and GSI was determined by a back-analysis of rock mass failure in caves and other openings as a part of the International Caving Study [Lorig, L. (2000) "Methodology and Guidelines for Numerical Modelling of Undercut and Extraction-Level Behaviour in Caving Mines," Report to International Caving Study (1997-2000)]. The estimate provides a starting point for describing the degree of strain-softening to be used in simulation of caving:

$$\textit{critical strain} = (12.5 - 0.125 \times GSI) / (100 \times d) \quad \text{where, } d = \text{zone size.}$$

The presence of zone size within this relation recognizes that the critical strain parameter is zone-size dependent in continuum models where shearing tends to be resolved in a band approximately one zone thick. Currently, work is underway to determine the full stress-strain response of a jointed rock mass more rigorously (and thus, the critical strain) by using the Synthetic Rock Mass (SRM) approach [Pierce, M., P. Cundall, D. Potyondy and D. Mas Ivars. (2007) "A Synthetic Rock Mass Model for Jointed Rock," in Rock Mechanics: Meeting Society's Challenges and Demands (1st Canada-U.S. Rock Mechanics Symposium, Vancouver, May 2007), Vol. 1: Fundamentals, New Technologies & New Ideas, pp. 341-349. E. Eberhardt et al., Editors. London: Taylor & Francis Group, 2007] and [Mas Ivars, D., M. E. Pierce, C. Darcel, J. Reyes Montes, D. O. Potyondy, R. P. Young and P. A. Cundall. (2011), "The Synthetic Rock Mass Approach for Jointed Rock Mass Modelling," Int. J. Rock Mech. Min. Sci., 48, 219-244].

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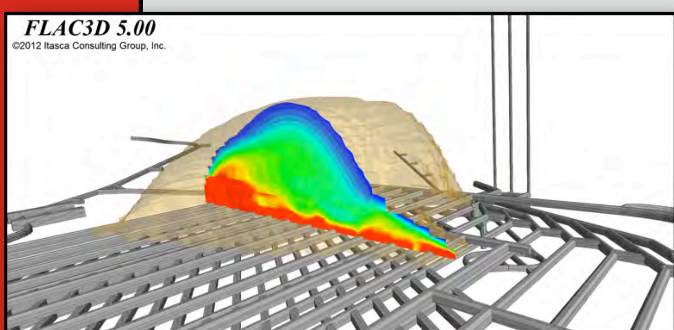
TECH Note

Numerical Modeling of Rock Mass Weakening, Bulking and Softening Associated with Cave Mining (continued)

Dilation and Bulking Limits

When a rock mass caves, it may bulk as a result of shearing-induced dilation (e.g., in the movement zone immediately above a drawpoint or at the perimeter of the cave where the rock is moving downward relative to a static boundary) or by failing in tension under the force of gravity (e.g., at the cave back). Thus, it is important to allow for dilatancy and irreversible volumetric expansion within the numerical model. Figure 1 shows non-uniform bulking within a continuum model of a cave as a consequence of the two bulking mechanisms acting simultaneously. In order to prevent zones from expanding to unrealistic levels during shear, the dilation angle must also be set to zero when the user-defined maximum bulking factor is reached. The maximum porosity of angular rockfill is typically in the range of 40 to 50%, which is equivalent to a bulking factor of 66 to 100% [Pierce, M. (2010) "A Model for Gravity Flow of Fragmented Rock in Block Caving Mines." Ph.D. Thesis, University of Queensland].



Left. Figure 1. Contours of bulking factor inside of the predicted cave limits from a continuum model of caving. Bulking is highest near the undercut level and diminishes with elevation, trending toward zero near the upper limits of the cave. Rock mass modulus is updated continuously relative to the bulking factor shown here, resulting in rock mass softening and shedding of stresses to the surrounding rock mass and infrastructure.

Modulus Softening

The rock mass Young's modulus (E_{rm}) can be estimated from GSI and the intact modulus, E_i, using the following equation:

$$E_{rm} = E_i \left(0.02 + \frac{1}{1 + e^{((60-GSI)/11)}} \right)$$

Further detail is provided at Hoek, E., and M. Diederichs. (2006) "Empirical Estimation of Rock Mass Modulus," Int. J. Rock Mech. Min. Sci., 43, 203-215.

As a rock mass yields and then bulks via shear or tension under draw, it is expected to experience a significant drop in modulus. Representation of this drop is required in order to account for stress shedding away from the cave and into the surrounding rock mass. Laboratory testing has shown that the modulus of a fragmented rock assembly drops in a non-linear fashion with increased bulking, and that the rate of modulus change is a function of fragment shape and intact strength [Pappas, D.M. and C. Mark. (1993) "Behavior of Simulated Longwall Gob Material," Report of Investigations, 9458 USBMS]. The relations derived from this test work have been extrapolated and embedded within caving models to update the modulus continuously for each zone based on the user-defined intact rock uniaxial compressive strength (UCS), rock fragment shape and bulking factor.

Conclusions

Because of the extensive yielding and large-scale displacements involved, there are several material behaviors that must be considered within numerical simulations of caving that might not otherwise be relevant. These include the complete degradation of rock mass strength from peak to residual, bulking-associated modulus softening and the specification of a dilation shutoff at the bulking limit. The guidelines for consideration of these mechanisms presented here have been established and tested through the analysis of a large number of cave mines worldwide.

american rock mechanics association

San Francisco Symposium - What to Expect

350 technical papers

2 poster sessions

17 exhibitors

3 all-day workshops

4 special activities

44 technical sessions

4 keynote presentations

3 technical tours

1 beautiful city by the bay

ARMA Committees

ARMA Technical Committees: Call for Members

The ARMA Board of Directors decided to create Technical Committees. The mission of the Committees is to support and conduct activities that contribute to the development and dissemination of knowledge in rock mechanics and geomechanics, to engage ARMA members in technical activities, and to support the vision of ARMA. Committee activities include, but are not limited to:

- Planning and organizing technical sessions, specialty conferences, workshops and short courses;
- Soliciting, preparing and/or reviewing and editing papers, reports and manuals and guidelines of practice;
- Contributing to the ARMA Newsletter.

The first two committees to be established are: Committee on Induced Seismicity and Committee on Hydraulic Fracturing.

The *Committee on Induced Seismicity* will focus on technical aspects pertaining to seismic events associated with anthropogenic activities. Individuals interested in this committee should send an email to Erik Westman, ewestman@vt.edu, who will coordinate membership, facilitate the first meeting and conduct the election of officers.

The *Committee on Hydraulic Fracturing* will focus on all technical issues related to hydraulic fracturing. Individuals interested in working with this committee should send an email to John McLennan, jmclennan@egi.utah.edu, or Ahmad Ghassemi, ahmad.ghassemi@ou.edu, who will coordinate membership, facilitate the first meeting and conduct the election of officers.

If interested, please contact the committee coordinator(s) preferably by June 7. It is expected to have the first meeting of the technical committees in June during the ARMA Symposium.

Suggestions and/or expression of interest for creating and coordinating other technical committees should be sent to Antonio Bobet, bobet@purdue.edu.

ARMA Activities

New Activities Planned in San Francisco

Conference Dates: 23-26 June 2013

Location: Westin San Francisco Market Street Hotel, Third Avenue, San Francisco, California, USA

ARMA Future Leaders have developed two new initiatives for the Symposium. Prizes awarded in these events are generously contributed by Itasca Consulting Group. The new activities are:

Career Corner

A career corner with bulletin boards will be set up for students to post resumes and employers to post career opportunities. The event, conceived as an informal gathering, serves as the first step to connect students and potential employers. Volunteers from the Future Leaders group will be available during the two poster session times and on Monday, 24 June, from 6:00 to 6:30 p.m. to facilitate the communication, advise on resume writing and discuss career outlook.

Students participating in the career corner should bring hard copies of their resumes. All students who post their resumes will be automatically entered into a drawing for a raffle prize.

Employers interested in advertising openings and participating in this event, please send an email to Peter Smeallie (info@armarocks.org) by 10 June or simply bring hard copy material to post at the symposium.

Student Trivia Contest

A student trivia contest will be held on Monday starting at 6:30 p.m. Students are encouraged to form an interdisciplinary team with up to three members. The questions will cover a diverse range of technical areas, including civil, petroleum and mining engineering. The winners of the event will be announced at the banquet on Tuesday and could earn a cash prize of over $100.

FEATURED Article

My Career in Rock Mechanics

Charles Fairhurst, Professor Emeritus – University of Minnesota, Senior Consultant, Itasca Consulting Group; Minneapolis, Minnesota

Editor's Note: As a new initiative of the Publications Committee, we will ask some of the pioneers in the field of Rock Mechanics to tell their stories of how they started their careers in rock mechanics. This is the first part of Dr. Charles Fairhurst's story on his life before he started to develop the rock mechanics program at the University of Minnesota. The second part, on the development of the rock mechanics program at Minnesota from the late 1950's to more recent time, will be published in the next issue of the newsletter.

Part One: "But it is only for eighteen months"

As often the case with careers, my acquaintance with rock mechanics developed over a considerable period and involved several large elements of chance.

The first of five children, I was born on August 5, 1929, in Widnes, a town situated between Liverpool and Manchester in the 'Industrial North' of England. My birthplace is notable as the headquarters of the Imperial Chemical Industries (ICI) Heavy Chemicals Division.

The Great Depression, a period of severe unemployment, started barely three months after I was born and ended only with the start of World War II, in September 1939. Although my first 16 years covered a very difficult period in Britain, I was blessed with wonderful parents who ensured that our memories of these times are, for the large part, pleasant ones. My father, a coal miner, served also during the war on the local Rescue Brigade -- helping extricate people trapped in bombed buildings. My mother worked in a local munitions factory. I was charged with keeping my two brothers and two sisters under control until one parent was available to take over.

Liverpool was the main port for ships from the United States and other countries bringing essential military and food supplies to Britain. As a consequence, Liverpool was a target for German bombers. We were "treated" to loud anti-aircraft fire, aerial dogfights, bombs, occasional airplane crashes -- and a steady rain of shrapnel. My main task was to keep my brothers from dashing out from our air-raid shelter to pick up "souvenirs" to trade next day with their classmates.


Charles Fairhurst. Left, 1955; Right, 2012.

My father worked underground at Cronton Colliery, a mine on the southern tip of the Lancashire coal-field. My mother, from a tight-knit Irish family, loved my father, but had no interest in mining or mining communities, so we knew little of these places. From 1934 to 1941, I attended Holy Family School, a Catholic elementary school in the village of Cronton, with two teachers, two classrooms and about 40 pupils in total. Miss Hennin taught children from ages 5 to 8; Miss Mooney, the headmistress, taught everyone from 9 to 14.

A strict but remarkably talented teacher, Miss Mooney decided that I had "potential" and should prepare to take the Grammar School Entrance Examination.[1] For about a year, she required me to study at her home for two hours each evening.

[1] Later known as the 'eleven plus' examination. See http://en.wikipedia.org/wiki/Eleven_plus_exam

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FEATURED Article

My Career in Rock Mechanics (continued)

I passed the exam and entered the Wade Deacon Grammar School (Widnes)[2] in 1941. This proved to be a superb school with excellent teachers in the Arts and Sciences, preparing students for entrance to university. The School Certificate (Ordinary Level) was taken after five years. A small group of students were selected to enter the "Sixth Form" for a further two years of university preparation, and taking the Advanced School Certificate examination. Our second year, Sixth Form class (1947-48) consisted of just 7 students (5 boys and 2 girls) studying just four subjects -- Mathematics, Applied Mathematics, Physics and Chemistry. I asked to continue also with French, and was provided with a tutor -- a former Army major.

The school encouraged students to study Arts or Sciences at Oxford and Cambridge. Study of Engineering was considered to be of lower caliber, and was not encouraged.

Although the war had ended in 1945, National Service (18 months duration) was still required of all able-bodied 18 year-old boys[3]. At about the age of 15, I had enrolled in the local (Widnes) Air Training Corps (ATC) to prepare for service as a pilot in the Royal Air Force. The ATC Commanding Officer was one of my Mathematics teachers. He allowed me to assist him by teaching the Aerial Navigation course at night. We also attended summer camp and were able to fly in Lancaster Bomber planes. Very exciting for a 17-18 year-old!

Having completed the "A (Advanced) Level" School Certificate Examination in Summer 1948, I took the Medical Examination in order to begin the required period of "National Service." I indicated preference to serve as a pilot in the Royal Air Force.

I was called for an interview by two RAF officers. After quizzing me about my knowledge of physics, I was informed that, although I had passed the medical exam, I was not eligible for flying duties because my eye-sight was not of the required standard. *"You seem to know some physics, so we are going to assign you to become a Radar Mechanic."*

I was devastated. "*I don't want to be a radar mechanic,*" I protested. "*You don't have any alternative,*" the officer replied. "*National service is still required.*" I was informed that I would receive instructions to report to a local RAF base in a few days. They "waved me away" and summoned the next person for interview.

One of my classmates, who had also been in the ATC, but had changed his mind about the Air Force when his older brother, a Meteor jet pilot, was killed just at the end of the war, told me that he planned to do his national service in the Mines[4].

I went to the recruiting officer for the Mining option, and told him that, if he could get my order to report to the Air Force reversed, I would enroll in the Mining Service.

A few days later, a letter arrived from the National Coal Board, telling me to report to the Manager of Cronton Colliery, who would assign me to a course of training. It was the mine where my father was now an underground official.

When I told my parents of my action, they were furious. My father, in particular, felt that I was throwing everything away. I recalled the scene in the 1941 classic movie "How Green Was My Valley?" when the Welsh coal miner, Gwilym Morgan, learns that his youngest son, Huw, who has done well in school, has decided to take a job in the mine "*But Huw is a scholar. Why take brains down a coal mine?*"

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[2] There were actually 'two schools in one,' the Boys School and the Girls School. Each year had two boys' classes and two girls' classes (each class of about 35 students). Although students were allowed some leeway to move between classes, the Boys School placed extra emphasis on the Sciences and the Girls School emphasized the Arts.

[3] Sixth Form students were granted deferment to allow them to complete their studies.

[4] Britain had expanded the National Service obligation to include Mining and Agriculture in addition to the classical military services. As an island nation, adequate supplies of energy (coal) and food were considered an essential part of the War Effort.

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FEATURED Article

My Career in Rock Mechanics (continued)

Keeping their sons away from a life in mining was a fundamental goal of many mining families in Britain. *"But it's only for eighteen months,"* I countered, *"and I can stay at home!"* Only slightly placated, my parents eventually conceded.

I duly reported to Mr. Clark, the Manager of Cronton Colliery in early summer, 1948. Apparently my arrival was an answer to his prayers. The Ventilation Engineer had submitted his resignation, unexpectedly, a few days earlier. Scanning my high school record, the manager smiled and said, *"I see that you have studied physics." "Yes, sir,"* I replied, *"Good. You can spend the next two weeks learning the ropes from Joe. From then on, you will be my Ventilation Engineer."*

Nationalization of British coal mines had been considered in the 1930's, but was deferred when war broke out. With the surprising defeat of Winston Churchill's Conservative government in 1945, the Labour Party, under Clement Atlee, moved quickly to establish the National Coal Board (NCB), with a mandate to upgrade the mines. The headquarters was at Hobart House, London. A large staff of industrial managers was assembled - many with no previous connections to the mining industry. Dr. Jacob Bronowski, a renowned mathematician and Renaissance man[5], born in Poland, was appointed Director of Research. Mining Research Centers were established at Isleworth, near London, and at Stoke Orchard in Gloucestershire (well away from the coalfields). A program was introduced to award 100 lucrative scholarships per year to encourage students to study Mining Engineering.

The only immediate visible changes at the mines were large notice boards erected at the entrance to the mine property announcing that the National Coal Board intended to bring about significant improvement to the mines and to working conditions.

The Underground Manager, my immediate supervisor, had worked in the mines under private ownership, and was not convinced that Nationalization would bring improvement. One day, smiling, he said to me, *"Charles, have you noticed the new sign telling us that the National Coal Board intends to be a model employer? Well, I was puzzled – so I looked up the definition of 'model' in the dictionary, and now it makes sense. It says 'model –a small imitation of the real thing.'"*

I have never forgotten this definition of a model.

Soon after my arrival at Cronton, I was contacted by NCB Divisional Headquarters in Manchester, and invited to apply for an NCB Fellowship to allow me to study for a degree in Mining Engineering. Oxford and Cambridge did not offer degrees in Mining, so I could not obey the wishes of my teachers at the Wade Deacon Grammar School. The nearest university that offered a degree in Mining Engineering was Sheffield University. I decided to apply and was accepted. The Department Head, Professor I.C.F. Statham, informed me that I should enter at the start of Academic Year 1949-50. By then, I would have completed just over one year of underground work in a mine. This was a pre-requisite for enrollment in Mining Engineering at the University.

My A-Level studies at Wade Deacon Grammar allowed me to be admitted to the Honours undergraduate Mining program. I was able to supplement the Mining courses with courses in the Department of Electrical Engineering, majoring in Power Systems. At the time that I was about to graduate in June 1952 with a B.Eng (Honours) First Class, I was invited by Dr. Robert Shepherd[6], a Senior Lecturer in Mining Engineering, to continue for a Ph.D. The National Coal Board had agreed to continue my NCB Scholarship to make this possible. Dr. Shepherd wanted me to conduct research on Rotary-Percussive Drilling of Hard Rock. I accepted. My Ph.D. was awarded in June 1955.

The NCB scholarship required me to follow a program of Directed Practical Training (DPT) during at least part of each break. This DPT program was intended to ensure that NCB Scholars would become familiar with all key practical phases of underground coal mining in some 3-4 years of training. Together with a Mining Engineering degree, this qualified trainees to take the Certified Colliery Managers examination (similar to Professional Registration).

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[5] His BBC series "The Ascent of Man" has been suggested as the inspiration for Carl Sagan's TV Series "Cosmos" in the 1980's.

[6] Dr. Shepherd had recently joined the staff, having worked previously at the NCB's Mining Research establishment at Isleworth –and earlier in the Explosives Division of Imperial Chemical Industries.

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FEATURED Article

My Career in Rock Mechanics (continued)

This early post-WWII period was one of rapid changes in mining, featuring rock bolting, hydraulic face supports, mechanized self-advancing coal extraction systems, and other innovations. Developments in the German mining industry -- horizon mining and armored cutter/conveyors[7] -- also contributed considerably. James Anderton, Production Manager of the St. Helens Area, North-Western Division of the NCB, and my DPT studies supervisor was the inventor of the Anderton Shearer Loader -- a major innovation in coal mining that was adopted widely.[8]

One of a group of five DPT students, I visited mines in the Ruhr in the summer of 1951, learning a great deal of the advances made by German mining engineers.

Unknown to me at the time, Professor E.P. Pfleider, head of the School of Mines and Metallurgy, University of Minnesota in Minneapolis, was concerned by the difficulties of drilling taconite (a very hard "flinty" iron ore, with a mixture of hematite, magnetite, quartz and chert) in the open–pit mines of Northern Minnesota. At the time, the only method that could drill taconite for blasting was to use jet-piercing, in which oxygen and kerosene are directed to the bottom of the drill hole and ignited to produce an intense jet flame that causes the rock to break by "spalling" to create a blast-hole. The university organized Annual Symposia on Drilling (and later Drilling and Blasting) to discuss ways to improve the drilling process. In 1955, Dr. Robert Shepherd, my Ph.D. thesis advisor, and his NCB colleague Dr. E.W. Inett, then conducting research on drilling of hard rock at Isleworth, were each invited to present a paper at the Fifth Annual Symposium on Drilling and Blasting, October 13-15, 1955, at the University of Minnesota.

Discussing his desire to develop a research program on drilling of hard rock, Professor Pfleider invited Dr. Inett to accept an appointment in the School of Mines to begin this research. As I understood it, Dr. Inett declined the invitation. Professor Pfleider then asked Dr. Shepherd whether he knew of any other colleagues who may be suited for this task.

Dr. Shepherd suggested that Pfleider contact me.

A short time later, I received a letter from Professor Pfleider, offering me a two-year post-doctoral appointment (at $6,000 per year) in the School of Mines and Metallurgy.

Although intriguing, the offer posed a dilemma. By accepting the NCB scholarship, I had a "gentleman's agreement" to work for the Coal Board for a number of years equal to the number for which I had received scholarship support. I had worked for somewhat less than four years in total, and so had a "deficit" of two years. I sent a letter to the NCB Regional Office in Manchester explaining the situation. A few days later I was invited to Manchester for a discussion. Although the meeting was cordial, no decision was reached.

A short time later, I was working underground when I received a message from the Manager informing me that I should come to the surface immediately. A car was waiting to take me to Manchester. When I emerged from the cage, I saw that it was no ordinary car but a Rolls Royce with a uniformed chauffeur. Standing there covered in coal dust from head to toe, looking for all the world like a stand-in for Al Jolson, I asked, *"Is it okay if I have a shower first?"*

The meeting went over much the same ground. I pointed out that it was an interesting offer but only for two years; could I not return to the NCB after this period? I noted also that quite a number of my NCB student colleagues had simply left for "hard rock" mining companies in South Africa, Rhodesia and other places overseas without even discussing their decisions with the NCB. Again it was a very cordial discussion, but the Board, understandably, was concerned about losing the talented and now experienced personnel that they had developed. Eventually, it was agreed that I would reimburse the NCB for what it considered a reasonable financial sum to cover the balance of time that remained on the agreement if I decided not to return to NCB employment after my two year appointment in Minnesota.[9]

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[7] The steel belt systems used to deliver baggage at airports were developed initially by German engineers for use in coal mines – a response to a shortage of rubber during WWII. Part of the postwar settlement imposed on Germany by the Allies was a loss of the right to patent war-time industrial innovations. British, French, Russian and U.S. companies moved quickly to seize advantage of these opportunities.

[8] See http://en.wikipedia.org/wiki/Anderton_Shearer_Loader.

[9] I contacted the NCB later, after I decided to remain in Minnesota, and received a letter in which the Board proposed that I reimburse them a very nominal sum, after which the matter would be considered closed. Throughout my entire interaction with the National Coal Board, I had the highest regard for the organization, and continue to thank them for starting me on a most fulfilling career.

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american rock mechanics association

FEATURED Article

My Career in Rock Mechanics (continued)

I contacted Professor Pfleider to accept his offer. He replied, providing details of the appointment. Armed with my British passport, Professor Pleader's letter, and a large X-ray of my chest, I visited the U.S. Consulate in Liverpool. I was interviewed for no more than 20 minutes, given the necessary visa, and left. It seems that, at this time, anyone from the United Kingdom (and probably from other countries as well) who had a Ph.D. in a scientific or engineering discipline was welcomed with open arms.

And so it was that, in July 1956, I booked my flight on a Boeing Stratocruiser from Manchester to Minneapolis, Minnesota. The plane made stops in Reykjavik, Gander, and Boston - where I transferred to a smaller plane stopping at Milwaukee and, finally, Minneapolis. I was met at the airport by Professor Don Yardley from the school. A great gentleman, Don drove me to his home, where I spent several days, before finding an apartment on University and Eighth Avenue, near the Campus.

Professor Pfleider and his colleagues were very welcoming and I settled in quickly. A short time after my arrival, "Gene" mentioned that Professor Howard Hartman, who taught the undergraduate courses in Mine Ventilation and Mine Plant Engineering (underground transportation and hoisting systems), had accepted an appointment at the Pennsylvania State University. Would I be able to take over responsibility for these courses, while still developing research in drilling of hard rock? The latter task was now a little less urgent; Hughes Tool Company had developed a roller cone drill with more robust bearings that was able to drill the taconite more economically. Gradually, I settled in -- teaching the courses and developing the drilling laboratory.

In June, 1956, one month before my arrival at the University of Minnesota, the First U.S. Symposium on Rock Mechanics was held at the Colorado School of Mines. This initial meeting was co-sponsored by the University of Minnesota and Pennsylvania State University. Professor Lute Parkinson of CSM, Professor Pfleider and Professor Hartman were the main co-coordinators -- with Prof. Pfleider clearly a driving force.[10]

The U.S. Bureau of Mines had an active program of both fundamental and applied research in mining rock mechanics, led by Dr. Leonard Obert and his colleague Dr. Wilbur Duvall together with Drs. Louis Panek, Robert Merrill, Thomas Atchison and others. The U.S. Army Corps of Engineers, led by Ken Lane, and U.S. Bureau of Reclamation were also studying rock mechanics applied to Civil Engineering. Professor George B. Clark, University of Missouri-Rolla and Professor Phillip Bucky at Columbia University were also conducting research on rock mechanics related to mining.

At lunch with the mining faculty group in Spring 1956, Pfleider mentioned that he had been trying hard to find someone to teach courses and develop graduate research in rock mechanics. Turning to me, he started to say, "*I was wondering whether*…" I replied, "*Yes,*" reading his mind and leaping at the chance. He completed his thought. *"It would be much easier for me to find someone to teach Mine Ventilation and Mine Plant Engineering -- and let you develop rock mechanics."*

I was given a free hand to develop the program as I wished.

Another major development of 1957 is revealed by the photograph below. Soon after my arrival, I had joined the Newman Center on campus -- a Catholic social organization similar to one with which I had been associated at Sheffield University. Some months later, at a Newman group party at a home on Lake Minnetonka, I met Margaret Lloyd, a graduate student in English Literature at the university. Our friendship developed and, in September of that year, we were married. Some 56 years and 7 children later, we are fortunate and happy to be together, enjoying each other. Margaret became a central part of the rock mechanics "family" that developed over the following half century or so.

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[10] Development of taconite mining on the Iron Range of Northern Minnesota had led the School of Mines and Metallurgy to introduce an Annual Drilling Symposium in 1951. The first Symposium was held in Hibbing, with subsequent Symposia at the Continuing Education Center on the Minneapolis Campus. Until 1954, the meetings were predominantly "local meetings" with most attendees from the Upper Great Lakes region. Pfleider became Head of the School of Mines and Metallurgy in 1954. The 1955 Symposium included Prof. Fritsche from the University of Aachen, Drs. Shepherd and Inett from the UK, and others. He wanted U.S. mining universities to be abreast of international research.

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FEATURED Article

My Career in Rock Mechanics (continued)

Above: Marriage to Margaret Ann Lloyd, September 7, 1957.

It was now clear that any return to the NCB was very unlikely. Professor Pfleider had already changed my status from Post-Doctoral Associate to Assistant Professor. I could remain permanently, if my performance was judged to be satisfactory.

I contacted the NCB and, as noted earlier, an agreement was arrived at amicably.

Now I was free to concentrate on trying to establish a graduate program in rock mechanics at the University of Minnesota. This proved to be quite an adventure.

To be continued in the next ARMA e-Newsletter.

Rock Mechanics/Geomechanics Faculty Position at the University of Wisconsin-Madison

The University of Wisconsin-Madison is searching for a faculty member with expertise in rock mechanics/geomechanics to complement the faculty in Geological Engineering (www.gle.wisc.edu). This is a full-time tenured or tenure-track position and is open at all ranks. Applicants are expected to develop internationally recognized research programs, contribute to scholarly work in Geological Engineering, undertake instruction in undergraduate and graduate classes, and engage in professional service. The successful candidate is expected to develop interactions with other faculty on the University of Wisconsin-Madison campus including those within the College of Engineering, the Department of Geoscience, and Wisconsin State Agencies such as the Wisconsin Geological and Natural History Survey. The University of Wisconsin-Madison is an equal opportunity/affirmative action employer that promotes excellence through diversity and encourages all qualified individuals to apply. Unless confidentiality is requested in writing, information regarding the applicants must be released upon request. Applications and inquires can be directed to Professor Craig H. Benson, Chair, at chbenson@wisc.edu or (608) 262-7242.