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Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

**Mining Research Laboratories**
**Laboratoires de recherche minière**

# ROCK MECHANICS, INSTRUMENTATION AND GEOTECHNICAL STUDIES

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# ROCK MECHANICS, INSTRUMENTATION AND GEOTECHNICAL STUDIES

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## ABSTRACT

The Canadian Mine Technology Laboratory (CMTL) can be broadly divided into four main sections; Numerical Modelling, Instrumentation Development, Rock Properties and Support Systems and Mine Methods and Equipment.

The major thrust in numerical modelling at CMTL is to adapt codes written for main frame computers to the personal computer environment. Several 2-D models including PCSAP2D, PCEPFE and PCMINTAB as well as a 3-D Boundary Element Application Package have already been developed.

Instrumentation is developed for both project specific reasons and as more generally applicable research tools. The latter includes CANMET's new strain monitoring system and fiber-optics camera as well as recent advancements in tomographic sensors and analysis. Recent rockburst activity has led to the development of the Sudbury Local Telemetered Network for the Sudbury basin to monitor natural and mine-induced seismic activity. In addition macroseismic networks have been installed in area mines for source location of rockburst activity.

A new backfill laboratory has been set up on the Laurentian University campus to study the physical and engineering properties of backfill materials and costs associated with their use underground. It will also supervise the seven MDA research projects currently underway.

The Rock Properties and Support Systems (RPSS) group has recently acquired an MTS 880 Rock Mechanics Test System, a computer-controlled, servo-hydraulic, stiff test frame. This provides a facility for advanced testing not possible with conventional equipment. In addition, the CANMET's Elliot Lake

Laboratory operates the largest test frame in Canada with a axial load capacity of 18,000 kN. Projects planned for the '89/'90 fiscal year include work on the underground burial of high level nuclear waste, surface crown pillars, small mine stability, evaporite mining and the development of data bases for technical advances in rock mechanics and mechanical rock properties.

The Mine Methods and Equipment group keeps abreast of developments in the mining industry throughout the world and disseminates the information through seminars, annual reviews and state-of-the-art papers. It also seeks to promote cooperation in the industry by maintaining a national information bank on current and developing mining technology and prevalent mine operational problems.

# ÉTUDES RELATIVES À LA MÉCANIQUE DES ROCHES, AUX INSTRUMENTS ET À LA GÉOTECHNIQUE

PAR

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## RÉSUMÉ

Le Laboratoire canadien de technologie minière (LCTM) peut dans les grandes lignes être divisé en quatre sections principales: Modélisation numérique, Mise au point d'instruments, Propriétés des roches et systèmes de soutènement, et Méthodes et matériel d'exploitation minière.

Les efforts en matière de modélisation numérique au LCTM visent principalement à adapter, en vue de leur utilisation sur des ordinateurs personnels, les programmes écrits pour être exécutés sur de gros ordinateurs. Plusieurs modèles bidimensionnels, notamment le PCSAP2D, le PCEPFE et le PCMINTAB, ainsi qu'un progiciel d'application à éléments limites tridimensionnel ont déjà été préparés.

Des instruments sont mis au point à des fins propres à certains projets et d'autres en tant qu'outils de recherche d'application plus générale. Ces derniers comprennent le nouveau système de surveillance des déformations et l'appareil photographique à fibres optiques de CANMET ainsi que les perfectionnements récents en matière de capteurs tomographiques et d'analyse. Suite aux coups de toit récents, on a mis en place le réseau de télémétrie de la région de Sudbury en vue de surveiller dans le bassin de Sudbury l'activité sismique naturelle ou provoquée par l'exploitation minière. De plus, des réseaux macrosismiques ont été installés dans les mines de la région pour permettre de repérer les sources de coups de toit.

Un nouveau laboratoire des matériaux de remblayage a été créé sur le campus de l'Université Laurentienne en vue de l'étude des propriétés physiques et mécaniques des matériaux de remlayage et des coûts rattachés à leur utilisation

dans les mines souterraines. Ce laboratoire supervisera aussi les sept projets de recherche réalisés dans le cadre des ententes sur l'exploitation minérale qui sont présentement en cours.

La section Propriétés de la roche et systèmes de soutènement (PRSS) a fait récemment l'acquisition d'un système d'essai en mécanique des roches MTS 880, un bâti d'essai rigide servohydraulique commandé par ordinateur. Ce système permet d'effectuer des essais poussés qui ne pouvaient être effectués avec le matériel classique. De plus, le laboratoire d'Elliot Lake, de CANMET, exploite le plus gros bâti d'essai au Canada, dont la capacité de charge axiale est de 18 000 kN. Les projets prévus pour l'année financière 89-90 comprennent des travaux portant sur l'enfouissement souterrain des déchets nucléaires hautement radioactifs, les piliers de surface, la stabilité des petites mines, l'exploitation de l'évaporite et l'élaboration de bases de données sur les progrès techniques relatifs à la mécanique des roches et aux propriétés mécaniques de la roche.

Les section Méthodes et matériel d'exploitation minière se tient au courant des perfectionnements réalisés dans l'industrie minière à travers le monde et diffuse l'information par le biais de séminaires, de revues annuelles et d'articles sur des techniques de pointe. Elle cherche également à favoriser la collaboration dans l'industrie en maintenant une banque d'informations nationale portant sur les méthodes d'exploitation actuelles et les méthodes en cours d'élaboration, ainsi que sur les problèmes d'exploitation minière dominants.

# INTRODUCTION

In the 60's, Marshall McLuhan coined the phrase 'global village' and while he was speaking of the effects of mass media, the 70's and 80's have witnessed the evolution of the global economy. Mining is a textbook example of the process. Mineral exports from South America, the Pacific rim and communist block countries are putting downward pressure on prices due, in large part, to cheaper labour costs and government subsidies. It seems unlikely that, in order to compete, Canadians will accept reduced wages or social benefits, nor should they. The industry, itself, must continue to become leaner and more efficient. Put simply, this means extracting the greatest amount of ore for the cheapest cost while maintaining adequate working conditions and levels of safety. It is here that the Mining Research Laboratories (MRL) Division of CANMET plays its most vital role.

Geological engineering and rock mechanics, in particular, are maturing sciences and their value in mine design is becoming increasingly recognized. Investigators at MRL, however, realized some years ago that a systemic approach to ground control was sorely needed. Research into structural geology, in situ stress measurement, and the effects of mine geometry has led to the publication of guidelines on such topics as multi-seam mining (6), stope and pillar design (7) and pit slope engineering (13) to name a few. The last ten years has witnessed tremendous growth in this area to the point where the former Rock Mechanics Laboratory has evolved into the Canadian Mine Technology Laboratory (CMTL) whose name reflects the wider scope of activities which it is presently involved in. The laboratory can now be broadly divided into four main groups which include: Numerical Modelling, Instrumentation Development, Rock Properties and Support Systems and Mine Methods and Equipment.

## Numerical Modelling

Numerical modelling is becoming an essential tool in minimizing the risk of development especially when companies are forced to draw the line between profit and loss with an ever sharper pencil. However, in a discipline where an understanding of the underlying principles seems to depend as much on experience and intuition as science, the job of modelling in predicting the effects of excavation appears difficult at best. Most algorithms used for ground movement simulation have, historically, required tremendous computing power. In fact, at CANMET, mainframes ranging from a VAX 11/750 and a CYBER 730 to a CRAY-1 super-computer are being used for their solution. More recently, high resolution SUN work stations have been employed to give realistic three dimensional imaging. The introduction of powerful desk top computers, however, is creating a revolution in the field of numerical modelling. Their capacity and affordability can put the predictive capabilities of extremely complex simulations in the hands of even the smallest mining operation. The major thrust in modelling at CMTL, therefore, is to adapt codes created for larger machines to the PC environment.

Several two dimensional analysis packages have already been developed using a highly interactive, menu-driven approach. These user-friendly packages include CANMET's successful Structural Analysis Program (PCSAP2D), a program which performs static, linear, elastic analyses of two dimensional, plane or axisymmetric structures. Another 2-D package, the Elastic Plastic Finite Element (PCEPFE) program, incorporates a generalization of the Mohr-Coulomb failure criteria to allow for plastic deformations in failed material. Both programs utilize finite element techniques and can handle up to 2000 and 1400 elements, respectively, in the PC formats.

PCMINTAB, or Mining Simulator for Tabular Type ore bodies, is a software package developed using the displacement discontinuity technique. Dynamic dimensioning of the data array has allowed the grid to be expanded to 80 X 80, or 6400 elements. The program also takes into account the compressibility of pillars and includes a linear backfill element.

The Boundary Element Application Package (BEAP) is a three dimensional PC simulation developed as part of the Canada/Manitoba mineral development agreement. Its analysis of stresses and displacements employs a quadratic non-conforming element and the use of an iterative equation solution solver reduces the total CPU required for a large problem.

Expanded mainframe versions exist for the programs mentioned as well as several which are, as yet, too extensive to adapt to the PC world. Among these is SAP3D which is a structural analysis program for 3 dimensional geological systems. This static, linear elastic analysis requires over 25,000 equations for a realistic three dimensional mine setting and has been adapted to run on the CRAY-1 (15).

Instrumentation Development

While these codes have become easier to use and the simulations more realistic, a model can only be as good as its input data. It is the responsibility of the instrument development group to provide the necessary tools for both the field and laboratory investigator so that measured behaviour can be as representative of the rock mass as possible. The value of the group can be illustrated by CMTL's association with Atomic Energy of Canada Ltd. over the last ten years. AECL, as part of the Nuclear Fuel Waste Management Program (NFWMP), must study the effect of nuclear waste emplacement on the properties of the host rocks selected from possible repository sites. This means determining not only the usual strength and deformation characteristics but also how these might be expected to change under the high temperatures generated by decaying waste. CMTL has, consequently, developed high pressure/ high temperature technologies which permit measurements of deformation in the microstrain range (11) and permeabilities on the order of $10^{-12}$ m/sec (2), all in the most hostile of environments.

Elastic deformations usually associated with mining activity in hard rock are generally small and research in this area has suffered from a lack of rugged, reliable, and inexpensive instrumentation capable of measuring displacements in the microstrain range. Recently, CANMET has developed the strain monitoring system for just such applications.

Put simply, the system consists of a fine wire tensioned across a metal ring and vibrated by an integrated exciter unit. The entire module is wedged into a borehole with a specially designed hydraulic installing tool which provides sufficient force to ensure intimate contact with the borehole walls. The unit is subsequently stressed or destressed according to mining activity in the area. The difference in oscillation frequency as the wire tension changes can be directly related to ground movement in the plane of the wedges. While the method, itself, has been used for several years, the CMTL- developed unit has minimal hysteresis and a resolution on the order of 2 to 5 microstrain, or at least an order of magnitude better than previous models. A complementary data logger was also developed to accommodate four strain monitors and four thermistors. The logger is battery-operated and can be entirely sealed in the borehole with no external wiring. It takes readings every hour for a period of up to six months. A major advantage of the monitor and data logger system over strain gauge based instrumentation with similar resolutions is that the monitor can be recovered, recalibrated if necessary, and used again. Field trials of the equipment at the Niobec Mine, in Quebec, showed excellent correlation between mining operations and deformations observed in the instrumented holes. Further work is under way to adapt the cell for softer rock and, with suitable calibration, for stress as well as strain measurement.

A valuable tool for recent rock mass characterization programs conducted by CANMET is CMTL's new fiber-optics borehole camera. The technology was originally developed for the nuclear industry for inspecting reactor piping. It has subsequently been adapted by the instrumentation group to obtain a high resolution picture from a camera which is only 12mm in diameter. With a video cassette recorder hook-up, any size hole can be permanently logged including the exact location, approximate orientation and in situ aperture of the existing cracks. The camera is also useful for identifying suitable locations for the installation of monitoring equipment such as extensometers, piezometers or stress meters (8).

CMTL's instrumentation group is also working with Paul Young, of Queen's University, to develop new techniques associated with downhole tomography. The possibility of characterizing underground structures according to the variation and attenuation of seismic waves has been the subject of study for many years. An understanding of the actual mechanisms affecting wave transmission such as ray bending, however, have only recently been incorporated in the interpretation of seismic surveys. This, coupled with the advent of increasingly powerful computer hardware, has enabled new algorithms which include algebraic reconstruction techniques and direct inversion to dramatically increase resolution. The next step in the evolution in geotomography, then, is to go from two to three dimensional imaging. In the short term, this will serve to provide better interpolation between diamond drill holes in characterizing a rock mass. In the longer term, refinement of tomographic techniques could result in more accurate and cost effective techniques of determining the design parameters required for effective mine design (14).

Talk of the development of geotomography and seismic interpretation leads to another important program being carried out at MRL's Elliot Lake Laboratory. In 1984, an unusually high level of rockburst activity in a short period attracted attention from the public, the mining industry, and government agencies. In light of this activity, a formal research project was announced in June 1985. Its goals were to develop capabilities in rockburst monitoring, analysis and prevention.

To achieve these goals, the Sudbury Local Telemetered Network was developed to enlarge the eastern Canada seismograph network, which is operated by the Geophysics Division of the Geological Survey of Canada (EMR). Its three one-component stations located around the Sudbury Basin improve the source location of northern Ontario natural and mining-induced seismicity. Other seismological stations at Elliot Lake, Kirkland Lake and Red Lake also augment rockburst detection. Data are transmitted to CANMET's Elliot Lake Laboratory and to the Geophysics Division of the GSC (EMR), in Ottawa.

New macroseismic networks had been designed to study smaller scale mining seismicity. Each network incorporates five triaxial sensors which permit recording of complete waveforms for analyses of source location, rockburst mechanisms and correlation of damage due to vibration levels. Three systems installed to date are working well, with another four planned for installation this summer.

While systems such as these provide means of detection for rockburst activity, development of prevention techniques must be considered as being of equal importance. Methods under study include special mine designs to deal with local strain, pillar, and fault-slip bursts, destress blasting and special support systems. What may be a key component in prevention is the development of new backfill procedures to reduce the severity and amount of liberated energy resulting from rockburst activity. In addition, the industry will benefit from studies on backfill and how it relates to artificial support methods and systems used in surface and underground mines (12).

This will require a new approach in terms of how backfill is perceived in the mining cycle. One recommendation gaining favor is to view backfill as a structural material which must be applied advantageously for resource recovery. In this regard, backfill design, transportation, placement and monitoring must incorporate numerical, laboratory and field components into engineering design studies to ensure safe and economical operations (3).

As part of the Canada/Provincial Mineral Development Agreements (MDA's), seven research projects on mine backfill are already being carried out under CANMET's supervision by various mining companies in the provinces of Ontario and Manitoba. The Sudbury Backfill Laboratory was also established on the Laurentian University campus, in 1987, as a field office of MRL. It is dedicated to the study of the physical and engineering properties of backfill materials and the costs associated with their use underground. A short term objective of the lab is to compile a summary report on typical backfill practices currently used in

Canadian mines complete with quality control methods, in situ instrumentation and monitoring techniques.

It is expected that the research activities of the Sudbury Laboratory, in conjunction with the results of the Canada/Ontario MDA research projects on backfill, will contribute to the eventual development of guidelines which will result in an expanded, safer, and more economical use of backfill by the mining industry (1).

Rock Properties and Support Systems

In the past, the mining industry around the world has not been criticized for over engineering the design and implementation of their operations. The rock mechanics division, if indeed one existed, was probably a small group huddled in one corner of engineering. That day is fast coming to a close as the upper parts of ore bodies in several mining regions are becoming depleted. Companies are having to proceed deeper and into areas whose stability is threatened by extremely high and complex stress fields. Consequently, failure envelopes must be more precisely defined-to the point where even the support capabilities of failed material should be taken into consideration. The Rock Properties and Support Systems group at CMTL has grown steadily over the last ten years to meet this increased need for more detailed and specialized information.

In January of 1987, CMTL commissioned an MTS 880 Rock Mechanics Test System, a computer-controlled, servo-hydraulic compression machine. This 4500 kN, stiff frame press is equipped with a triaxial cell capable of generating confining and pore water pressures of 140 MPa at working temperatures up to 200° C. Computer-controlled servo-hydraulics makes it possible to extract more information from a single sample by enabling the operator to quickly and accurately increase confining pressure when failure is imminent. Conversely, the press can extract energy from the system at the point of failure and avoid the violent break usually caused by stored strain energy in softer machines. This allows us to go beyond the peak failure load and to determine residual strength values, again, for any range of confining pressures. The most remarkable aspect of the machine is that any instrumentation which produces an analogue signal can be used to control the rate of loading. This enables the investigator to utilize unconventional properties such as acoustic emission or volumetric strain as a control mode. The possibilities are still being explored but the machine's applications appear to be limited only by the skill of the programmer/operator and the imagination of the scientist (5).

CANMET also operates the largest capacity press available in Canada. The 18000 kN machine is located in our Elliot Lake Laboratories where it has been used for several years to test large sample sizes not normally associated with regular rock mechanics laboratory work.

Several projects are included under the umbrella of the Rock Properties and Support Systems group. As mentioned earlier, the longest standing among these involves our association with AECL and the NFWMP. Initially, work involved laboratory classification of plutons being considered for AECL's underground research laboratory (URL). This included high temperature/high pressure triaxial work applied to permeability, velocity, shear and compression testing. Sinking of the URL shaft in the Lac du Bonnet pluton near Pinawa, Manitoba is currently providing an invaluable opportunity to link properties determined in the lab with behaviour observed on an in situ scale. The coming year will include; studies of scale and loading rate effects on uniaxial mechanical properties, characterization of anomalous rock types in the area of the shaft, high temperature uniaxial testing for inclusion in the Hoek and Brown analyses of the Pinawa granite, high temperature/high pressure triaxial testing of samples from the newly-developed 420m level and, finally, ambient temperature triaxial testing with pore water pressure. If and when the concept of deep burial of high level nuclear waste is approved, CMTL will likely play a large role in the actual repository site selection phase (9,10).

A topic which has remained largely unresearched until recently involves the stability of surface crown pillars. The horizontal nature of crown pillar support makes their design using deep level compression pillar formulations inappropriate. Also, the number of factors influencing their behaviour such as geological setting, the degree of rock/soil interaction, groundwater movement etc. indicates the complexity of the subject. Attacking the problem, therefore, requires a diverse cross-section of disciplines, something with which CMTL has considerable experience.

The three main technical elements of the program include; obtaining applicable existing geotechnical information, preparing case studies and, the major thrust of the study, identifying and quantifying the factors affecting stability. By defining the extent of the problem and identifying the failure mechanics, new monitoring equipment specific to surface crown pillars can be developed. This has already lead to the new geotomographic data gathering techniques for 3-D imaging mentioned earlier. Armed with the resulting data, new probabilistic, deterministic, and empirical design methods will follow, finally culminating in the publishing of a design handbook. It is hoped that the final product will provide necessary, relevant information for the safe and economic dimensioning, recovery and stabilization of surface crown pillars (4).

A similar project involves work on the stability of small mines and will result in the development of an expert system to deal with special conditions arising from different extraction techniques which stress the rock mass to its geomechanical limit and/or simply from extraction in bad ground. The resulting documentation should enable mine planners to evaluate stope and pillar layouts, progression of mining, application of ground support against potential site specific ground control problems and to present the effects of various alternatives (10).

In 1983, the Short-Term Aid in Research and Technology or START program was introduced by Energy, Mines and Resources, Canada to assist the Canadian potash mining industry. One of the objectives of this initiative was to increase potash recovery over the current levels of between 28% and 38%. Studies were conducted in the areas of ground control, safety and productivity including predicting mine opening stability, subsidence, performance of backfill, blast design and development of mine services software.

The program provided a much needed study of potash production and the industry has responded well. However, worthwhile recommendations resulting from the project require further study. These include monitoring excavation behaviour in potash under controlled conditions and development of numerical modelling capabilities relating to new mining layouts including backfill and subsidence models. The final objective will be a new and more efficient approach to mining Saskatchewan (10).

The past 25 years has seen a tremendous increase in information available on technical advances in rock mechanics related to mine design and methods. The sheer volume of work, however, has made it difficult to assimilate even a small portion of it by traditional literature searches. The introduction of "expert" or "knowledge-based" computer systems has made it possible to harvest the wealth of such information and store it in a database.

The Rock Mechanics Expert System program will develop an expert system prototype in 1989 to be utilized in solving mining engineering problems and in improving mine safety and productivity. The exercise in developing the system will also have the added benefits of providing a state-of-the-art review of current mining methods and the standardization of reporting on site-specific geotechnical data (9).

On a related topic, a data base is also being set up this year to summarize the mechanical properties of rock types studied under the various programs conducted at CMTL. Included in the summary will be: rock type, geographical location, tensile and uniaxial compressive strengths, as well as results from Hoek and Brown and Mohr-Coulomb failure analyses for both the intact and residual cases. The data base will be compiled using results acquired since 1980 and will be updated yearly as new data are obtained.

Mine Methods and Equipment

CMTL, as a part of it's responsibility, must keep abreast of developments in the industry throughout the world. Because of the diversity of topics relating to mining, CMTL's Mine Methods and Equipment group is divided into four categories of activities.

The Mine Methods and Evaluation section develops and evaluates mineability and mine operational economic criteria for hard rock mining in Canada and prepares, annually, estimates of planned and projected production capabilities of uranium mines. The unit has recently published a ventilation network program for use on PC's. This has already been used successfully in hard rock mines in Canada. It also annually estimates reasonably assured reserves and cut-off grades for uranium deposits based on three levels of pricing.

The Advanced Mine Equipment Technology section attempts to assess the potential impacts of worldwide developments in new mining equipment and other advanced technologies such as automation and robotics. The group also characterizes the dust produced in hard rock mines and the measures used to control it, as well as generally demonstrating the capabilities of environmental monitoring systems. CMTL distributes this information through annual reviews of mining equipment and state-of-the-art reports.

The Canadian Mining Technology Coordination section promotes cooperation among the various mining sectors and attempts to improve efficiency within the industry by maintaining a national information bank on current and developing mining technology and reporting on prevalent mine operational problems. The chief vehicle for getting this information to the industry at large is the "Index of Mining Technology Projects". The index is updated annually and has been received very well with some 1400 copies of the 1988 edition (the fourth) currently in print. The "Index" is available as CANMET Special Report SP88-17.

The Materials Handling and Operations Research section is developing new concepts in materials handling which will provide improvements in productivity and safety for both underground and open pit environments. The overall thrust of the program is to develop a system for computer-aided mine design and planning. This will hopefully manifest itself in the increased use of numerical modelling and in optimizing mine equipment utilization. For example, a recent study involving the automation and robotization of open pit mine haulage trucks visualizes possible savings of $150,000 to $200,000 per unit (9).

Mining in Canada, as elsewhere, has always been governed by the boom/bust mentality and, unfortunately, monies available for R&D tend to follow the course of commodities pricing. It was partially this behaviour which made the stabilizing influence of the original Mines Branch necessary. If we are to remain competitive in a world suddenly peopled by cheap labour and heavy government subsidies elsewhere, our edge must be in design and implementation. Now, more than ever, the art of mining and ground control, in particular, must be pushed to its technological limits. The Mining Research Laboratories of CANMET has positioned themselves to answer the needs of the mining industry both today and tomorrow. Whether in modelling, instrumentation, characterization or design, the state-of-the-art is employed at CMTL and, to paraphrase one of our more senior managers, 'We are open for business'.

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