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BACKFILL RESEARCH IN CANADIAN MINES

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by

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ABSTRACT

The Canadian mining industry has been innovative in its approach to the use of backfill in underground mines. Outstanding advances have been made in the technologies of using cemented mill tailings and smelter slags. Present research is focussed on these, as well as on: densified and paste fills; cemented waste rock; frozen fills; fly ash substitutes; and post-consolidation.

In this paper, an overview is made of the history of the development of backfill technology in Canada, and of the work presently in progress. The needs of the industry for future research are also identified.

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Keywords

backfill, backfill history, Canada, cemented mill tailings, cemented waste rock, fly ash, frozen fills, mining, paste fills, research, underground mines,

RECHERCHE SUR LE REMBLAYAGE DANS LES MINES CANADIENNES

par

J.E. Udd*

RÉSUMÉ

L'industrie minière canadienne a été des plus innovatrices, dans son approche relativement à l'utilisation du remblai dans les mines souterraines. Des percées importantes ont été réalisées dans les technologies d'utilisation des remblais cimentés et des scories de fonderies. La recherche actuelle est présentement orientée sur ces types de remblai ainsi que sur les suivants: remblais denses; remblais rocheux cimentés; remblais congelés; substituts de cendres; remblais post-consolidés.

Dans le présent article, un aperçu est donné de l'historique du développement de la technologie du remblayage au Canada ainsi que des travaux en voie de cheminement. Les besoins de l'industrie, en recherche future, sont également identifiés.

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Mots-Clés
Canada, cendres, extraction, historique du remblayage, opérations souterraines, recherche, rejets d'usine cimentés, remblai, remblais congelés, remblais denses, remblais rocheux cimentés,

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INTRODUCTION

Waste rock from mining operations has been used to provide unit support and to fill openings for hundreds, if not thousands, of years. In the ancient greek silver mines at Laureion, pillars were constructed of stone to support the back(1). Agricola, in his classic work "De Re Metallica" refers to waste rock being thrown into the openings among the timber(2) - evidently not for support, but rather, for waste disposal purposes.

Pillars constructed of rock (sometimes quarried), or concrete, or timber, have been used continuously in mining up to present times. In a historical context, however, the use of waste rock or other materials in order to fill openings for support purposes is a relatively recent development - necessitated by large scale mining methods, and facilitated by modern milling practices.

The development of the flotation process late in the 19th century and early in the 20th had monumental implications for both mining and milling practices. The rapid application of flotation technology on a global scale was probably one of the driving forces in the transformation of the minerals industry from selective to mass production methods. The milling processes which were implemented in the present century produced, as waste, a material which is probably the cheapest and easiest to handle for purposes of filling mine openings.

Prior to the availability of mill tailings, waste rock or alluvial sands or gravels were commonly used for fills. Crushed smelter slag was sometimes used, depending on its availability. At the beginning of the century, the common mining methods involving fill were rill stoping, cut-and-fill, and shrinkage (with broken ore as temporary fill)(3).

The same technology, with several variations, was reported in the 1940's(4).

During the 1930's and 1940's, equipment was developed which led to very rapid improvements in mining practices. Notable amongst these were the introduction of scrapers in the 1930's and the development of tungsten-carbide bits after the Second World War(5). By the 1950's, trackless mining was being introduced.

Concurrently, in the long-established mines, mining had proceeded to greater depths. Both the local ground conditions and the sizes of the stopes being mined necessitated the use of fill for support. During the 1950's "sand" fill (hydraulic tailings) came into much more widespread use in Canadian mines, particularly in the massive deposits of the Sudbury Basin in which a conversion was being made from square set mining to cut-and-fill. Initially, "sand" fill was used to replace waste rock in filling the timber sets(6). Later, after the development of consolidated fills, it became possible to eliminate the labour-intensive and extremely costly square-set method almost entirely from Canadian practice. The word "almost" is used advisedly, for, as will be mentioned later, there is still one important operation at which square-setting is in use in 1988.

During the 1930's some notable work with backfill was conducted at the Horne Mine of Noranda Mines Ltd.(7). With the local geological materials being unsuitable for the backfill that was needed for pillar mining operations, experiments were conducted on reverberatory furnace slag to which had been added pyrrhotite tailings. The result was a very strong fill which has never been duplicated. This author recommends a reading of the paper listed in the references, by Patton(7), as a "classic" in the development of innovative fill technology.

A paper in the same volume(8), by the staff of Cominco's Sullivan Mine, at Kimberley, B.C., is also recommended reading because of the diversity of filling practices which are described. At the time of writing, in 1957, surface gravel, development waste, waste from caving, and concentrator float and sulphide tailings were all being used to provide the large tonnages necessary to fill open stopes prior to pillar recovery.

In the mines of the Sudbury Basin, in which many of the technical innovations in backfilling practice originated, the original practice was to fill shrinkage and cut-and-fill stopes with waste rock. In 1935, a mixture of sand and gravel, from overburden, were used for the first time at the Falconbridge mine(9). In the late 1940's and early 1950's the use of classified mill taillings was introduced.

In the cut-and-fill stopes of the mines of the Falconbridge organization, the practice was to use elm plank floors, for scraping purposes, on top of the sand fill. In the late 1950's, however, concrete working floors were laid when the fill was suitable for aggregate(9). A very key development, reported in 1959(10) was: "Recent experiments indicate that tailing fill and cement can be mixed on surface and delivered to a stope through the tailing fill system to produce an adequate mining floor when laid to a thickness of 4 inches".

At Inco, the use of Portland cement to stabilize sand fill was begun in 1960(11). After a period of extensive tests the technique was introduced into practice in the Frood mine in 1962. Subsequently, the use of cemented fill became standard practice in all of the mines of the Sudbury basin and throughout the Canadian industry.

The use of cemented fill has had a very great impact on Canadian mining practices. With its introduction in the Sudbury mines in the early 1960's, the immediate benefits realized were through improvements to cut-and-fill mining practices and pillar recovery operations. Square-set mining disappeared as cut-and-fill practices were applied to pillar mining. Also in Sudbury, the newly-developed backfill technology was closely associated with new mining methods: undercut-and-fill, at Inco(11), and post pillars, at Falconbridge(12). Subsequently, it has become possible to apply bulk mining methods, principally blasthole, in instances where more selective methods could have been used previously(13). The strengths of cemented fills, and their free standing properties, has enabled mine planners to increase level intervals and stope dimensions. Cemented backfill has been essential to the reductions in mining costs which have been achieved in the 1980's.

TABLE 1

Some Important Dates in Connection with Backfill in Canada

1903	-	first flotation plant in Canada, using the Elmore oil process, Le Roi Number 2 mine, Rossland, B.C. (Ref: History of Milling in Canada", 6th Commonwealth Mining & Metallurgy Congress Vol. "The Milling of Canadian Ores", 1957, p. 25).
1933	-	experiments with reverberatory furnace slag and pyrrhotite tailings at the Horne Mine, Noranda, Quebec(7).
1935	-	introduction of sand and gravel backfilling at Falconbridge Mine, Falconbridge, Ontario(9).
1948	-	replacement of waste rock by "sand" (tailings) fill at Frood Mine, Inco, Sudbury, Ontario(6).
1959	-	experimental use of cemented tailings for cut-and-fill stope floors at Falconbridge(10).
1960	-	tests on the addition of Portland cement to stabilize hydraulic fill at Inco(11).

VARIATIONS ON PRESENT BACKFILL PRACTICE AND KEY TECHNOLOGICAL ISSUES

During the twenty-five years, or so, that cemented backfills have been used in Canadian mines, there has been much experimentation to determine the optimum mixes for particular applications. Cement is expensive, and the cost implications from achieving even slight reductions in the quantities added are very large. In 1983, in Inco's mines in the Ontario Division alone, it was estimated that over two million tonnes of cemented backfill were placed underground in a normal operating year(14). The quantities being placed at present by the entire Canadian industry must be several times that amount.

No attempt is made in this paper to review all of the backfilling practices, or the variations thereon, which are in use in Canada. There are perhaps as many of these as there are individual mines. Numerous references can be found in the literature, particularly the "CIM Bulletin", very quickly.

Nonetheless, the following examples are to illustrate some of the present trends in backfill research in Canadian mines and some of the key technical issues. The list is not necessarily complete and reflects this writer's opinion only:

1) Optimizing the Use of Cement

The design of backfill as a source of support is now regarded as an important part of the process of mine design. In view of the costs of cement and additives, however, it is essential that there should be tight controls over the quantities used.

To date, these have been established as the result of trial and error. As but one, and only one, example, at the Strathcona Mine, of Falconbridge, the following ratios of cement to tailings were in use in 1983(13):

- 1:8 for containment plugs for blasthole stopes, for 0,3m floors in cut-and-fill stopes, and for 1,5m layers over timber sill mats above new mining horizons;

- 1:32 to 1:40 for bulk pours in cut-and-fill stopes;

- 1:16 to 1:40 for bulk pours in blasthole stopes.

For pours in stopes, the mixes selected depended on mining geometries and design calculations. No doubt similar approaches are followed by other mine operators.

2) Alternatives to Cemented Mill Tailings

Because of the cost of cement there are powerful economic incentives to find acceptable substitutes. In Canada, especially at the Kidd Creek Mine, at Timmins, Ontario, much work has been done on the use of cemented rockfill. Since 1982, it has been reported(15), ground blast furnace slag has been substituted for between 30% of 60% of the Portland cement previously used.

In theory, given an adequate and available supply of suitable waste rock, a cemented rock fill should not only be less expensive than cemented tailings but also substantially stronger and of a higher modulus. There are potential problems to be overcome in placement, however, in order to prevent zoning, segregation, and degradation of particles.

In Australia, considerable work has been done to assess the properties of "pozzolans" as potential substitutes for cemented backfills. Pozzolans are materials which can provide silica, which, in the presence of water and calcium hydroxide, react to form cemented hydrated calcium silicates. Potentially, smelter slags and fly ash are pozzolanic. According to work reported by Thomas, et al(16), some Canadian slags have demonstrated pozzolanic potential. Apart from the work at Kidd Creek, this writer is unaware of any large scale attempts in Canada, at present, to use smelter slag as a backfill. As mentioned earlier, the work at Noranda in the 1930's is a landmark(7) in this area.

3) Emplacement Systems and "total" Fill

Each of the several materials used for backfilling present unique problems from a materials handling point of view. Coarse, or large-sized fills, including waste rock, gravel, slag, and alluvial sand are usually placed either by waste passes which lead directly to the stope to be filled, or by mechanical means including hauling or conveying, or by a mixed-mode system. Such systems are expensive.

Mill tailings, on the other hand, are almost always developed hydraulically through systems comprised of boreholes and pipelines. The enormous advantage of using hydraulic fill is that the delivery systems are much less costly and are much more flexible. This flexibility is only useful in medium to large mines, however, in which bulk pours can be arranged and accommodated. For small operations the only alternative may be to place fill by small-scale very-expensive methods, possibly even still involving physical handling. Two of the research thrusts mentioned in this paper are directed to special applications: one in which very small quantities are needed; and the other a situation when only dry fill can be used because of the solubility of the waste material (salt).

Apart from the problem of integrating mine and mill production schedules so that adequate quantities of fill will be available when these are needed, there are five principal technical problems in using mill tailings for backfill. First, in order to achieve adequate percolation rates so that the water may be discharged and the fill stabilized as quickly as possible, the finest fractions of the tailings, or slimes, must be removed by classification. Second, mine pumping systems must be capable of handling the large quantities of water involved. Third, the percolation of water through the fill inevitably results in some leaching of the cement which may be mixed to bond it. Fourth, it is very difficult to reduce zoning and achieve a consistency of the poured mixes. Finally, hydraulically-placed mill-tailings can involve a lot of mess and resulting clean-up.

At present, research is underway which, hopefully, will result in improvements to practices in many of the problem areas. The technology of emplacing densified fill, if successfully developed to the scale at which it can be applied to large-stope bulk mining operations, will have a very large and rapid payback for the industry.

If, further, a technique can be developed by which all of a mill's tailings output, including slimes, can be safely disposed of underground, a major step will have been made towards solving one of the industry's important environmental problems.

4) Stabilization of Today's and Yesterday's Backfill

In our present practices, elaborate precautions must be taken to ensure that pours of liquid fills are adequately contained until drainage of water precludes any possible danger of liquefaction. Escaping backfill, or overburden, can cause tremendous damage and possible loss of life.

To safeguard against any possibilities of this occurring, elaborate bulkheads and fill fences are usually constructed across the lower accesses into stopes to be filled. Further, it is not uncommon for the initial pours of fill behind such barricades, to be enriched by additional cement in order to achieve much greater strengths. These structures are known as "fill plugs".

The use of densified fills may make the use of such elaborate and costly structures unnecessary. Before one can eliminate these with complete confidence, however, it will be necessary to establish that there is no liquefaction potential.

Because the techniques of hydraulic backfill have been developed only in the last forty years, or so, it is still possible to find cases when pillars in older parts of long-established mines are adjacent to stopes filled with unconsolidated sands, gravels, or waste rock. The challenge to the operator is to recover these pillars with complete safety and taking the greatest possible advantage of the most recent mining technology.

One of the present thrusts in the industry, then, is to determine the ways in which loose fill can be consolidated.

5) Use of Backfill in the North

In Canada's far north, the climate is such that an entirely different approach is needed for successful backfilling. Because of the cold, which is often intense, the handling of large quantities of water would cause enormous problems. Hence the handling of hydraulic fill is considered to pose almost insurmountable problems (from an economic point of view).

Water can be handled in small quantities, however, and under closely controlled and monitored circumstances. This has led to the development of a frozen backfill at Cominco's Polaris operation. Waste rock, quarried on surface, is sprayed with water as it is placed in completed stopes(17). Once frozen, it has been found that the adjacent panels can be mined quite successfully.

Mining in the north in the future will present many technical and operational challenges. Backfilling will be high on the list of priorities for research.

BACKFILL RESEARCH IN CANADA IN 1989

Principally as the result of a series of Mineral Development Agreements (MDAs) signed between the Canadian Federal Government and most of the provincial and territorial governments (of which there are 12), there has been a substantial increase from the mid 1980's onwards in the quantity and quality of mining research. Most of the projects which were approved through the MDA's were conceived by the industry to address its needs and were destined for delivery by the industry - often acting in partnership with governments, consultants, and academe. The "bottom line" is that a lot of research has moved from the laboratory into the mine, and from bench scale to field-demonstration scale.

Backfill research has been one of the important areas addressed in agreements between the federal government and three provincial governments; namely, Manitoba, Ontario and New Brunswick. In the mid 1980's, backfill research was also done in Saskatchewan through a specific federal program known as "START" (Short Term Assistance for Research and Technology).

All of the projects included in these programs are described briefly in this paper. Collectively, the various levels of government are probably committing about $1 million annually to backfill research. The industry, through its own in-kind contribution to MDA projects, is probably at least matching that amount and possibly expending twice as much.

Nor is the only research being done through the MDAs. Many individual mining companies are undoubtedly enhancing their practices and techniques through their own resources. Unfortunately, there is no simple way to ascertain the totality of the industrial effort. Recently(18), the Mining Research Directorate of the Ontario Mining Association estimated that about $100 million is now being expended annually on mining research in Canada. If that is the case, it is probably a fair guess to estimate that about 10% of that amount, or $10 million/annum, is being committed to backfill research.

The dimension of research does not end there, however, since research is also in progress in some Canadian universities. Both McGill and Queen's Universities, at Montreal, Quebec and Kingston, Ontario, respectively, have been associated with some of the MDA backfill projects. The Universities of Saskatchewan and Waterloo, at Saskatoon, Saskatchewan and Waterloo, Ontario, respectively, have also been involved with the potash backfill research.

There may be others also in the field, but the writer has not been made aware of these. Naturally, any omissions are regretted and, if there are some, the writer would appreciate being advised of this.

The following are brief descriptions of the projects presently in progress through the various MDAs.

"Evaluation of Methods for Delayed Backfill Consolidation" - Manitoba MDA

While the use of cemented and consolidated fills is now common, this has been a feature of Canadian mining practice for only about 30 years. Previously, unconsolidated alluvial sands, gravels, waste rocks, slags, and many combinations of these, were used. In many areas, depending upon the availability of mill tailings and other considerations, such is still the case.

Thus, it is not uncommon presently for a mining engineer to have to contend with the problem of mining pillars between stopes filled with unconsolidated fill. The alternatives which are available to stabilize such loose fills include pressure grouting and the percolation of cemented mixtures by gravity.

In this project, which was the subject of a contract in the amount of $100,000 to the Hudson Bay Mining and Smelting Company Ltd., a review was to be made of the cost effectiveness of the methods which are available for delayed consolidation of backfills. This was to have been followed by field trials using preferred methods and the establishment of predictability criteria. There would also have been the development of theoretical models and the correlation of field results with these. The major objective is to develop practical techniques for the in-situ consolidations of fills.

At an advanced stage of the work, however, the company was unable to proceed further with the field experimentation because of the lack of a suitable experimental stope in the Flin Flon area.

The following two reports were produced on those portions of the project which were completed:

(a) "Stabilization of Soils and Backfill - A Review of Mining and Civil Applications".

(b) "Laboratory Investigations of HBMS Smelter Slag, Progress Report No. 1".

"In-Situ Determination of Dewatered Tailing Fill Properties" Projects - Ontario MDA

The most common backfilling method is to emplace mill tailings in the form of a slurry. On curing, the water which is used to transport the solid particles to the stopes must be pumped from the mine as the fill consolidates and ages. Cement, added to increase the strength of the fill, is leached away as the water percolates downwards.

The successful use of higher-density paste-type fills would offer a number of improvements to mine operators. First, with much less water being used, there would be significant reductions in pumping costs and cement losses. Second, because of the increased retention of cement and higher density, the fill would attain higher strengths more rapidly. Third, this, in turn, would simplify the methods which are used to design the structures used to contain the fills (i.e., bulkheads and fill fences). Fourth, there would be an improvement in the handling of slimes and in costs of clean-up underground.

Two projects, involving alternative technologies are now nearing completion in the province of Ontario:

(a) At Inco, in the Sudbury basin, work has been in progress for some time at the Levack Mine to design a system which will permit the delivery of high-density fills directly through pipelines. A CANMET contract, in the amount of $112,000, is in place to accelerate this work.

At Inco a surface mixing plant and a gravitational system is used to deliver the paste fill to a test stope. The initial results, at depths at less than 1,200 feet, have been very successful. Monitoring instrumentation has been installed and the trial stope filled. Mining is in progress.

Based on the early successes, and even before completion of the project, consideration has been given to extending the technology to openings at greater depths.

The Inco Project is now nearing completion. A draft final report has been received and is being reviewed by CANMET staff.

Some of the significant findings from the report are as follows:

(i) The strengths of paste fill samples were found to be about double those of samples of hydraulic backfill with similar cement contents.

(ii) The uniaxial compressive strengths of paste-fill samples recovered in-situ were about 80% higher than those of laboratory-prepared samples.

(b) At Dome Mines Ltd. an alternative approach to the delivery of paste fill is being investigated. Through a CANMET contract, in the amount of $152,580, the company is evaluating the potential use of a device known as the "tailspinner". Operating much like a centrifuge, the tailspinner receives liquid backfills at normal pulp densities (about 60% solids by weight). On delivery, the water is spun from the fill and removed. An extruded paste is emplaced.

At Dome, in-situ monitoring of fill behaviour is now in progress. Laboratory studies of the behaviour of paste fill are complete and a report has been received from McGill University, the sub-contractor on the project. A debriefing seminar on this aspect of the work will be held when the final report becomes available for general distribution.

A draft final report for the Dome project is now being prepared. A series of accidents at the mine during 1988, however, prevented access to the experimental stope for several months. These delayed the completion of this project, as well as another entitled "Liquefaction Potential of Dense Backfill". The final report from Dome was expected by the end of 1988.

Falconbridge Limited, another sub-contractor on this project, has also submitted a draft final report on a survey of World Paste Fill Practices. The Falconbridge research group is currently assessing the feasibility of using paste fill for some of their mining operations.

"In-Situ Monitoring and Computer Modelling of a Cemented Sill Mat and Confines During Tertiary Pillar Recovery" - Ontario MDA

In cut-and-fill mining, the intervening pillars between previously-mined stopes are recovered during secondary extraction. Sill pillars, between the mining blocks and the levels, are recovered during a final, or tertiary, stage. The entire process of extracting all of the ore between levels may involve several years.

During this process, however, mining practices and economic conditions are constantly changing. The results can be great departures from original plans and large variations between the properties of fills in contiguous openings.

In order to provide increased confidence in both design methodology and extractive practices, a project, involving both in-situ monitoring of ground conditions during the extraction of sill pillars and computer modelling for predictive and back-analytical purposes, was initiated with Falconbridge Ltd. The contract, under the Canada/Ontario MDA is valued at $154,720.

At the time of writing, the project has been completed and a draft final report is being reviewed.

Some of the significant findings of the research are:

(i) The results of computer simulations indicated a close correlation between the behaviour of in-situ fill and that predicted by the computer model.

(ii) The computer model has now been used to evaluate sill mats, other than at the trial area, at Falconbridge's Strathcona Mine.

A debriefing session will be held as soon as the final report becomes available for release.

"Use of Cemented Fills for Controlling Violent Failure in Pillars" - Ontario MDA

In the room-and-pillar mines in the near-horizontal tabular uranium deposits of Elliot Lake backfill was not considered to be necessary since the vast mined out areas remained quite stable. Commencing about 1985, however, there was much increased rockbursting and failures of the rib pillars in the area near the boundary pillar between the Denison and the Rio Algom mining operations. The area affected was more-or-less in the centre of the previously mined part of the ore-bearing conglomerate reef.

Experience has shown that the area affected by rockbursting in a room and pillar mining operation can grow rapidly and become extensive. The only practical remedial action may be to pour backfill around the pillars. This seems to be a method of increasing the post-yield strengths of pillars and, consequently, of limiting the growth of the failure zones.

To study the use of tailings backfill as a means of stabilizing an area which is in the process of fracturing, a project, with a contract value of $610,000, was initiated with Denison Mines Ltd. In this research, the stabilities of pillars are being monitored as a selected area is backfilled. Monitoring involves both stress measurement and microseismic techniques. A microseismic system, belonging to CANMET, has been installed in the designated area of the mine for the purpose of the study.

The research is now well-advanced, with the previously-mined stopes of the test panel area having been filled with about 120,000 tons of deslimed tailings consolidated with iron ore blast furnace slag. The area immediately up-dip from the backfill area has been seismically active - with local rockbursting pillar spalling and heaving of the floor. Because of this, the microseismic system was redeployed to provide better coverage of the active area. Denison Mines also decided to expand the area that would be filled as the backfilled panel is less seismically active than the surrounding area.

"In-situ Properties of Backfill Alternatives
in Ontario Mines" - Ontario MDA

In spite of the fact that a wide range of materials has been used as backfills in mines (i.e., alluvial sand, waste rock, mill tailings, slags, and mixtures of these), very little is known concerning the relative merits or demerits of these. There is a need to determine the properties of various backfill alternatives and to establish general engineering specifications.

To accomplish this, a contract, in the amount of $470,000 was signed with Falconbridge Ltd. Much of the work is being carried out at the Kidd Creek operations, at Timmins, Ontario.

In the research, which commenced in 1987, various types of backfill are being emplaced in openings which have been surrounded by monitoring instrumentation. The results of this large-scale comparative study should permit a quantification of the support characteristics of fills. Further, the relationships between laboratory and field properties, once established, will permit the establishment of specifications.

At present, both laboratory testing of various binder alternatives (including slags and flyash) and physical modelling trials are proceeding according to schedules. The installation of instrumentation and field trials are also underway. Laboratory trials on copper slag and fly-ash binders, as well as field trials involving layered fill, Reiss Lime, Slag and Monolithic Packing Materials have been completed. Field Instrumentation trials are continuing at Kidd Creek Mines. Additional trials are planned.

An evaluation of anhydrides as binder alternatives is also being carried out by McGill University under sub-contract. A report on this was expected by January 31, 1989.

It is now anticipated that the entire project will be completed early in 1990. The results should be reliable specifications for various filling materials. Additionally, less expensive alternatives to present methods and approaches may result.

"3-D Numerical Models for Simulation of
Bulk Mining at Depth" - Ontario MDA

During the past decade, especially, there have been rapid advances in the analytical tools which are available to rock mechanics specialists. Numerical modelling techniques have taken the place of experimental stress analysis and are now used for engineering design purposes.

The computing requirements for the larger models, however, can be far beyond the capabilities of most organizations. For this reason "mine wide" models are very rare and are mostly the property of large international-scale consulting organizations.

There is a need, both to advance the technology which is available and to investigate ways in which it can be transferred to smaller scale computers. By doing so, it would become available to the smaller organizations which do not presently possess the specialized skills necessary.

In order to develop a sophisticated three-dimensional model, applicable on a very broad scale, and suitable for simulating a wide variety of mining conditions including non-elastic and post-failure behaviour of a rock mass, a contract in the amount of $1,000,000 was signed with Inco Ltd. The company will not only develop the highly sophisticated model but will also calibrate it and refine it by making frequent reference to actual in-situ conditions and measurements.

The project is progressing according to schedule and within budget.

A review of bulk mining at depth was completed in June, 1988, and it is anticipated that a report will be available shortly. Two interim progress reports for the first year of the project (1986/87), were available for general distribution late in 1988. The reports treat the numerical modelling and the instrumentation aspects of the work.

Two interim progress reports, covering work completed during the second year, (1987/1988) are expected shortly. One will cover numerical modelling while the second concerns instrumentation.

Simultaneously, the development of a two-dimensional plasticity model, capable of simulating the failure zones around excavations and localized shearing, is nearly completed. The development of a three-dimensional plasticity model will commence in 1989 and will require about 18 months to complete. A technology transfer seminar/workshop on the two-dimensional plasticity model will take place in the spring or summer of 1989. The final details will be established after consultations with the contractor.

"Liquefaction Potential of Dense Backfill"
- Ontario MDA

One of the greatest concerns of any mine operator using mill tailings as a backfilling material relates to its liquefaction potential. Fine-grained materials, with a high moisture content, can liquefy under dynamic loading conditions. In a worst case scenario, a seismic disturbance could cause the fill in a recently-filled stope to liquefy, break the bulkheads due to the resulting sudden increasing pressure, and to flood out into the openings below. The results, as at Belmoral (but with overburden rather than fill) could be catastrophic.

In order to define the engineering parameters involved, and to study such behaviour of fill, and particularly densified fill, a contract in the amount of $125,250, was signed with Dome Mines Ltd. The objectives were to study the liquefaction potential of dense backfill, and to develop procedures for determining the safe limits for various types of fill materials.

The project is now nearly complete. A draft final report is being prepared by Dome and was expected to be completed by the end of 1988. A report on the Laboratory and field tests has been received from McGill University, the sub-contractor on the project. This report is currently being reviewed by CANMET staff.

The results of the research should assist the industry in establishing safe limits for evaluating the liquefaction potential of dense backfills.

"Use of Backfill in New Brunswick Potash Mines"
- New Brunswick MDA

Potash mining in Canada is essentially a "one-pass" type of operation. Rooms are mined in a series of passes using highly mechanized boring machines. The rate of advance is very rapid and total extraction of mineral probably averages about 40%. The intervening pillars between rooms are not mined, nor is backfill used. The present economics of potash mining are said to preclude the use of fill. The extraction ratio is low by design in order to provide long-term stability both of the rooms and of the overlying strata.

In the long-run, however, the low extraction ratio will result in a loss of reserves.

A second problem is that the potash is interbedded with salt. Because of contamination with other minerals this salt is not usable for any purpose.. After separation during milling, therefore, it is transported to storage piles on the surface. In the future the ultimate disposal of the waste salt will pose a number of environmental concerns.

The project in New Brunswick was designed to address both of these concerns. Under a $214,740 contract with the federal government the Denison Potacan Potash Company is evaluating the stabilizing effect of waste salt as a backfill in mined openings.

In the first phase of the work, completed in 1987, a study was made of the engineering properties of waste salt backfill, and of the effects of additives on strength. The costs and benefits of alternative stowing procedures have been assessed. Finally, using numerical methods of stress analysis, determinations were made of the effects of backfilling upon convergence and the creep of mine openings. The results have shown that at least ten years are required before backfill provides roof support.

A debriefing session for the first phase of the project was held on September 4, 1987.

At the time of writing, a second phase of the work, at a cost of $199,130 was in progress. This aspect of the project was scheduled for completion by the end of March, 1989. To date: the instrumentation around a trial stope has been installed; computer modelling to identify suitable mining geometries and permissible ground reactions for mining long secondary stopes in pillars; and laboratory determinations of the properties of highly consolidated fills, are in progress.

A third phase, at a contracted value of $150,500, was also in progress and scheduled for completion in June, 1989. In this phase, CANMET is contributing $63,370 to the work while the company is contributing the remainder. A microseismic monitoring system, to identify the reactions of the hanging wall to mining, will be installed after an evaluation of presently-available technology has been completed. A comparison will also be made of the outputs resulting from computer simulations of a standard mining sequence using both the GEOROC and VISCOT codes.

Backfill Projects - Saskatchewan MDA

The federally-funded mining research which has taken place in recent years in the Saskatchewan potash mines can be divided into two phases. In the first of these, which preceded the Mineral Development Agreements by about two years (i.e., 1983 to 1985), approximately $443,000 was committed to mining research through the START (Short-Term Assistance for Research and Technology) program.

Two of these projects related directly to possible uses of backfill in Saskatchewan potash mines. The first project entitled "Determination of Engineering Properties of Waste Salt for Backfilling Underground Potash Mines", was the subject of a $25,250 contract with the firm RE/SPEC Ltd. The second, called "A Field Test Program to Evaluate the Use of Waste Salt Backfill in Saskatchewan Potash Mines" was the subject of a $120,000 contract with Central Canada Potash. Both projects were concluded in the mid 1980's and the information derived from them has provided valuable background data for the work presently in progress in New Brunswick. The details may be found in the Proceedings of a CANMET seminar which was held in Saskatoon(18).

"Pneumatic Backfill System for Small Deposits"
- A Project Originally Planned for the Yukon Territory

For almost half a century a substantial proportion of Canada's silver production was derived from deposits worked by United Keno Hill Mines, Limited, near Elsa, in the Yukon Territory. The deposits, of which there are many in the area, are generally small, high-grade and surrounded by weak wall rocks. Mining was small-scale and labour-intensive. The mines at Elsa were probably the last in the country in which square set mining was still employed.

Because of the small stopes, low production, and high costs, however, the future viability of mining in the district was threatened. With silver prices having remained static for several years, it follows that given ever-increasing costs, profitability could only be improved through increasing productivities and reducing unit costs. The only effective way to do this, in the long-term, was to replace square set mining with the less expensive cut-and-fill technique.

At Elsa, however, exceptional impediments to making such a conversion were caused by the small sizes of the individual stopes and mines. Not only would conventional pipeline fill delivery systems be too expensive but also the exceptionally small quantities required from time to time at a large number of geographically dispersed locations would present unsurmoutable operating problems. The capital and operating expenditures needed to cope with the water accompanying hydraulic fill would also be severe. The same is probably true for many small mining operations.

With these constraints as background, it was proposed to make field trials of a new pneumatic small-scale and portable fill delivery system. In concept, fill would be delivered to the machine in a relatively "dry" form. Cement would be added at the machine and water injected as a spray at the nozzle as the fill is blown into the stope. The proposed research would have brought the concept through to a fully operating technique under sub-arctic conditions.

The project was proposed jointly by the company and CANMET for possible inclusion in the second round of an MDA between the federal and Yukon territorial governments. Unfortunately, continuing financial losses forced the closure of the operation very early this year (1989). The project, because of a general applicability to small-scale mining operations, remains as a high-priority item for future work.

SUMMARY

In this paper, the author has attempted to capture the flavour and the excitement of the backfill research which is currently in progress in Canada. Because of the funding which has been available through various jurisdictions of government, Canada is becoming an important player internationally in backfill research. All of the projects now underway are designed to discover better ways in which backfill can be designed and used and then emplaced for support purposes. The view of backfilling in Canada has matured from one of it being a problem of waste disposal and providing a mining floor, to that of accepting that properly engineered backfill is an essential part of mine design and long-term mine stability.

As the approach has matured, the research has taken a more innovative tack. The field-scale comparative studies of fill alternatives and the mine-scale field-validated predictive models, for example, are projects of which any country would be proud. Truly, these, and the others described, are on the leading edge of backfill technology.

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