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CORING OF SOFT SOIL-LIKE ROCK MATERIALS

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by

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ABSTRACT

A new coring technique is described for the sampling of highly altered rock. This and an innovative field survey method were developed to supply valid and representative data for numerical modelling of openings in the soil-like material. The results were not only reflective of in situ behaviour, but successful enough to be adopted for the sampling and modelling of other highly altered surface crown pillar masses, mining structures in need of better design methods.

KEYWORDS: altered rock, surface crown pillars, diamond drilling, core recovery, rock strength, failure mechanisms, mineral modelling, cave-in, back-analysis.

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CAROTTAGE DE MATÉRIAU MOU, RESSEMBLANT À UN SOL

par

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RÉSUMÉ

Une nouvelle technique de carottage est décrite pour l'échantillonage de roche hautement altérée. Celle-ci et une méthode innovative de relevés furent développées pour fournir à la modélisation d'ouvertures des données valides et représentatives pour ce matériau ressemblant à un sol. Les résultats s'avérèrent non seulement représentatifs du comportement en place mais assez réussis pour être adoptés pour l'échantillonage et la modélisation d'autres piliers de surface hautements altérés, des structures minières requérantes de meilleurs méthodes de conceptions.

MOTS CLÉS: roche altérée, piliers de surface, forage au diamant, récupération de carotte, résistance du roc, mécanisme de rupture, modélisation numérique, effondrement, rétro-analyse.

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INTRODUCTION

In Canadian hard rock mines, the stability of surface crown pillars (the rock mass separating the uppermost underground opening from surface) is a pressing problem (1). The safe design of such pillars requires an understanding of near surface conditions and material behaviour. Demands are growing for numerical modelling techniques to enable parametric and detailed design studies to be carried out. The results and implications of a near suface rock mass evaluation drilling program, excerpted from a CANMET sponsored and industry supported research study, are presented in this case history.

Rock mass characterization is often necessary and vital in advance of creating safe and economic underground openings. The traditional method has been, and continues to be, extraction of high quality rock cores for determination of rock quality and rock mass characterization, aided by in situ mapping during excavation, shaft sinking, and the like. In strong rocks, the traditional techniques of diamond core drilling are often satisfactory. However, in weaker rock masses, traditional techniques have lead to poor rock core recovery and even loss of core through wash outs and erosion during the drilling process.

SITE AND GEOLOGY

The minesite, Les Mines Selbaie, is a 1500 tonnes per day underground copper mine located some 80 km north of Joutel, Québec (figure 1).

The overburden at the mine site is thick and averages about 45 m, consisting primarily of fine grained very dense tills and till-like sediments. The native rock consists of a series of tuffs and breccias, bedded chert-pyrite and volcanoclastic debris occurring within a plutonic complex (2).

The ore zone (dipping about 50°) consists of quartz-sulphide vein systems up to 200 mm in width. These veins occur within several elongate lenses of heavily fractured rock, (as much as 30 m in width) caused by and lying above a major fault.

The enrichment of original ore values to depths of 200 m within the fault zone has been attributed to supergene alteration (3). Supergene alteration is made possible by descending meteoric waters through the fault zone. The chalcopyrite in this zone has been altered to sooty chalcocite, bornite, limonite and relatively high quantities of native copper, all of which occur within a sugary quartz and kaolin gangue. As a result, the rock mass is not only severly fractured, but is also surrounded by and/or consists of kaolinized and other gangue-like materials.

The richest ore values at the mine are found nearest the surface, at about the 50 to 60 m level immediately below the overburden. The uppermost working level of the mine is located at a depth of 55 m below prevailing ground surface. Mining safety regulations require a surface crown pillar thickness of 15 m or more. However, at this site, special dispensation has been received to reduce that thickness to 7.5 m based on the richness of ore values in this zone.

Some of the facilities at the mine site, primary ore processing facilities, office buildings, and a dormitory, are located above actively mined stopes.

SCOPE OF STUDY

The research study into modelling and verification of surface crown pillar behaviour in the weak rock mass at Les Mines Selbaie was divided into three phases: material characterization (drilling, sampling and laboratory testing), numerical modelling, and verification of predictions.

The first phase - drilling, sampling and laboratory testing - was completed in August 1986 (4), and the second phase, numerical modelling, was completed in late 1987 (5). Results of field verification are presently being evaluated.

The scope of the first phase included drilling and sampling of both the overburden and the upper rock mass, down to the level of the surface crown pillar. The geographical remoteness of the site made it necessary to utilize the on-site, resident, production type drilling contractor, rather than experienced geotechnical drilling contractors.

The field work in the first phase included the coring of the weak soil-like rock mass at three borehole locations: MT-10, MT-11 and MT-12, Figure 2. The overburden drilling and sampling experiences are omitted from this paper. Since surface drill coring for rock mass characterization in remote locations is necessarily expensive, the scope of the study was expanded to rock mass characterization by means of underground scanline surveys, covered in a subsequent section of this paper. By correlating scanline results with those of laboratory tests on the recovered cores, it is hoped to reduce the requirements for additional high quality (and therefore expensive) rock coring for the design of future suface crown pillars. To this end, the study has proven to be successful, due mainly to excellent core recoveries made possible by a simple modification to the traditional rock coring techniques normally used in hard rock, production coring.

ROCK DRILLING AND CORING

All soil and rock drilling, sampling and coring was performed by resident drillers without the expense in either soil or rock drilling for special sampling purposes. The machine available at the mine site was a skid-mounted Inspiration III drill rig. The drilling program commenced on October 22 and ended on November 26, 1986, totalling approximately 165 m of soil and rock sampling/coring, for an average production rate of about 7 m/day, with variations of between 1 m/day to 15 m/day. A work-day averaged about 8 hours, from dawn to dusk, typical for that time of the year. At the end of the drilling program, the weather turned extremely cold, and daily production rates dropped dramatically due to frozen lines, pump and rig starting problems, and the like.

MT-11 was the first borehole to be drilled. Core recoveries were generally very poor (less than 30 per cent) due to an unusually weak and soil-like rock mass immediately below the overburden contact. The techniques used to recover cores included:

1. using a double tube bit on a triple tube core barrel;
2. alternating between face-discharge and standard bottom hole discharge bits;
3. double tube core barrel.

Only tap water was used as the drilling fluid in this borehole.

None of these variations in rock coring techniques had any significant influence on core recoveries. The recovered core pieces were from harder rock material.

The next borehole drilled was MT-10. The first few core runs met with the same lack of success as at MT-11. Subsequently, a small amount of Polydrill R, a polymer mud, was added, which improved the core recoveries from 30 per cent to 60 per cent, on average in a few of the core runs. In order to improve the recoveries even further, a variant of a technique first reportedly used in England (6) for very soft friable rocks was tried. The techniques of creating a foam at the bit are well known in the water well drilling industry (7).

An air compressor was connected by a T-Joint to the drill stem water swivel, and air pumped under pressure along with reduced water flow from the water supply pump was reduced. Immediate success was noted, not only in progress of the coring operation, but also in core recoveries. Average core recoveries increased to over 90 per cent in the weakest rock zones being drilled. Large cores of kaolinitic materials, finely disintegrated siliceous dacite tuff breccia in a clayey silt matrix, highly fractured sooty chalcocite and sounder rocks were all recovered intact from the double tube core barrel. The final weak soil-like rock core recovery in MT-10 was over 95 per cent subsequent to the use of compressed air.

The original terms of reference for this research program were to drill only boreholes MT-10 and MT-11. The huge success achieved at MT-10, for the first time in the mine's history of coring operations, prompted the initiation of an extra borehole, MT-12, to verify the validity of the compressed air injection technique.

Tri-coring to a depth of 30 m was done in MT-12 to save time. The dense nature of the overburden had prevented thus far obtaining decent and meaningful undisturbed samples of the soil immediately above the rock contact. Therefore, an attempt was made to try the air-water mixture technique for coring of the overburden materials. Unfortunately, the compressor broke down and the validity of the technique for coring dense, almost cohesionless, tills and similar finer grained soils could not be verified. When the borehole drilling reached the bedrock contact area, the compressor had been repaired, and excellent core recoveries were obtained until the compressor broke down once again, at which time core recoveries immediately dropped to values equivalent to those obtained earlier at MT-11.

The results of the rock coring operations, with and without introduction of air into the drill fluid stem, are summarized in Table 1, for various rock types in the surface crown pillar. Core recoveries in a weak, soil-like rock mass, can be improved if a polymer based drilling mud is used in conjunction with compressed air by drilling in an N-size double tube core barrel fitted with a face-centred discharge diamond bit.

Adding air to the drilling fluid permitted the use of less water for lubrication, cooling, and lifting of cuttings, and hence less erosion of the soil-like rock core, while keeping wear on the diamond bits to a minimum. Best results were obtained with a bit advance rate of about 2 m/hr, and a water/air pressure ratio of between 10 and 15.

UNDERGROUND SCANLINE SURVEYS

For realistic modelling of the surface crown pillar, it was necessary to carry out detailed underground surveys of the orebody formation. Three scanline surveys were carried out at the 55 m level, shown in Figure 2. Detailed photomosaics were taken along each scanline. All contracts, faults and joints greater than 500 mm in dimension were noted, along with continuity, orientation, joint resistance factors, and infilling type. Pocket penetrometer tests were carried out along with torvane shear tests on the soil-like components of the scanned lines.

The visible rock mass was classified in accordance with the ranking scheme shown in Table 2. A rank of 1 to 6 was chosen to represent the rock-line material, and a rank of 7 to 11 to represent the soil-like material. This simple classification, aided by the scanline survey results and correlated with laboratory test results on the recovered cores, gave an excellent overall representation of the rock mass characteristic, and in particular, the relative proportion of soil-like rock volume to the total volume of rock (last column of Table 2).

The orebody rock consists of moderately to highly kaolinized Dacitic Tuff Breccia with zones and seams of limonization, silty clay infillings, finely ground sooty chalcocite and native copper. Kaolinization is particularly extensive in the ore-enriched zones, and increases in intensity towards the surface.

The degree of kaolinization varies from a bleached tuff breccia to pure kaolinitic clay. In the worst areas this altered rock mass can be described as soft, soil-like with small irregularly spaced remnant rock pieces.

LABORATORY TESTING

Several types of laboratory tests were carried out on the different types of rock materials recovered from the coring operations, as well as on bulk samples obtained from the 55 m level during the scanline surveys. These included: index property testing (moisture content, Atterberg limits, unit weights, grain size distribution) of both the soil-like rock and joint infill materials, slake durability, point load, Schmidt rebound hammer, both unconfined and triaxial type compression tests (on those specimens which could be lifted intact from the core box), as well as direct shear tests on both undisturbed and reconstituted samples.

A protocol for storage and handling of the fragile rock samples was developed during the field work at the mine site, and proved to be invaluable in preservation of the integrity of the samples both in storage and upon subsequent transportation by vehicle to the laboratory across a distance of over 1000 km.

The results of the point load and Schmidt tests were converted to approximate compressive strength values (8)(9). The correlation between the ranking of Table 2 and compressive strengths derived by various test methods is shown on Figure 3. A statistical method using the Hoek and Brown failure criterion for rock (10) was used to approximate the material constants for the failure envelope derived from triaxial tests. The modulii of deformation for the rock-like materials were determined using correlations with the Schmidt hammer R values and the stress-strain curves from unconfined compression tests. The tangential modulus of deformation was approximated from calibration curves developed for the Schmidt hammer rebound number (9). The stress-strain curves from unconfined compression tests were used to determine the tangential and secant modulii of deformation at 50 per cent of peak strength.

Some key results of the laboratory testing program are given in Table 3.

APPLICATIONS TO NUMERICAL MODELLING

The ability to extract cores from soil-like rock formations near the orebody-overburden contact zone, laboratory tests and correlations with scanline information, enabled the construction of a numerical model for the prediction of surface crown pillar stability. In essence it was concluded from the first phase of the study that the crown pillar rock formation comprised approximately 70 per cent rock-like materials and 30 per cent soil-like materials. Probex pressuremeter/dilatometer tests were carried out in boreholes MT-11 and MT-12 to obtain in situ values of the deformation modulii in both the overburden and the orebody. Prior information was already available on in situ stresses obtained by overcoring with a CSIRO hollow inclusion triaxial strain cell (11).

To assist with realistic modelling, the Mine was asked for their proposed or preferred method of mining the surface crown pillar. The stope size beneath the surface crown pillar is generally 22 m long in the strike direction. In weaker ground, this width is cut in half along the strike direction. In the weakest ground (soil-like rock mass), the surface crown pillar is mined in 5.5 m wide panels. The mine is totally depressurized with respect to ground water.

The numerical model chosen was a multi-dimensional finite element program capable of accepting Mohr-Coulomb type elements, with a 'birth' and 'death' option for each element. Two dimensional modelling was found to be inadequate, and all subsequent modelling was three dimensional. The failure mechanism adopted, based on the authors' previous experience and research (12), was as follows. The soil-like mass is held together around an opening by negative pore pressure, induced by the creation of the opening. With time this condition dissipates at the boundary leading to tensile failure, a mechanism which progresses upward. In order to accommodate tensile failure, gravitational forces were applied in ten computational steps, enabling the analysis to be halted to eliminate all tensile failed elements (by changing the status of the failed elements into unborn elements). The analysis was continued until full gravity loading was reached. The remnant rock pieces of the altered rock mass were too small to affect the stability as failure mechanism of the soil-like material.

A schematic of the model layout is shown in Figure 4 for back calculations of a 1983 cave-in which occurred in Stope 4 at Les Mines Selbaie. Approximately 9,000 tonnes of material was involved. The cave-in commenced at the 100 m level and progressed upward to the 60 m level in a total period of about 6 to 8 months. A comparison of the predicted versus actual failure surfaces is given in Figures 5a and 5b.

The good agreement reflects favourably on the choice of rock mass characteristics used in the numerical model, and proves the worthiness of good field data to predict or substatiate observations of geotechnical behaviour.

CONCLUSIONS

The successful prediction of an actual cave-in by numerical modelling techniques based on high quality field information and understanding of material behaviour shows the feasibility of designing surface crown pillars in weak, altered rock masses.

This case history shows that quality objectives for field geotechnical data can be met using ordinary, available mine site machines, tools and personnel despite site remoteness or drill-crew inexperience. In this study, the lack of core recovery using standard rock coring techniques arose due to the presence of a soil-like rock mass in the surface crown pillar below the overburden. The problem was overcome by the introduction of compressed air at the water swivel to allow reduction of water pressure and flow, so as to minimize core erosion and washouts, while at the same time allowing the lifting up of cuttings and prevention of premature diamond bit wear. The coring and scanline survey methods used are new techniques to obtain geotechnical parameters from materials hitherto difficult to quantify.

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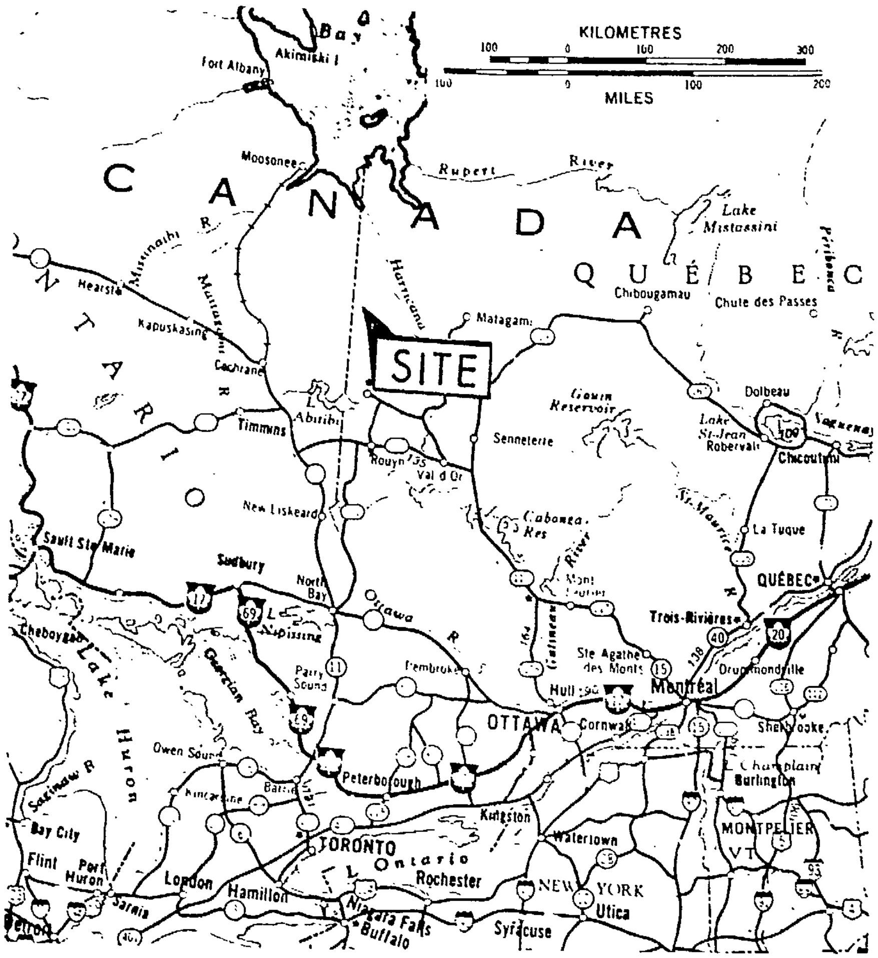


Figure 1. Location of Les Mines Selbaie

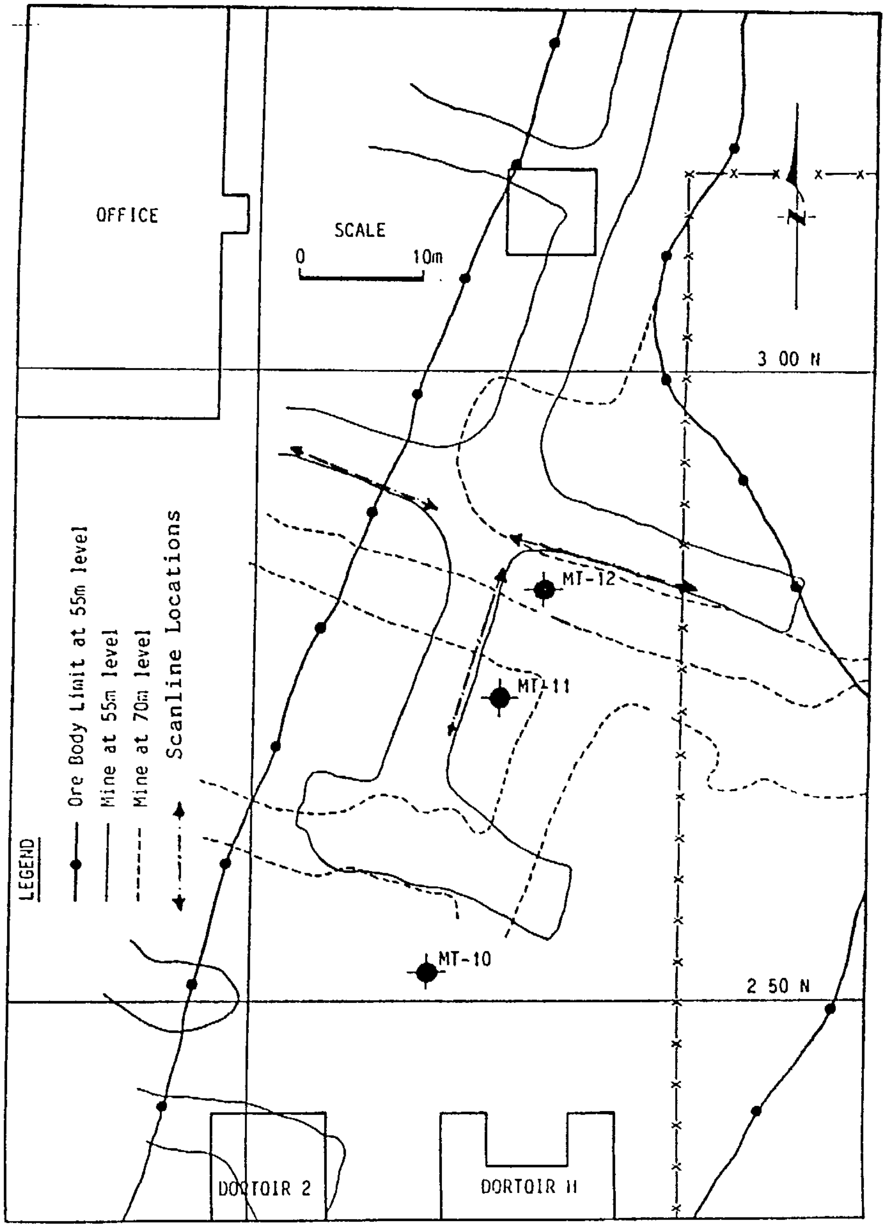


Figure 2. Borehole and Scanline Locations (4).

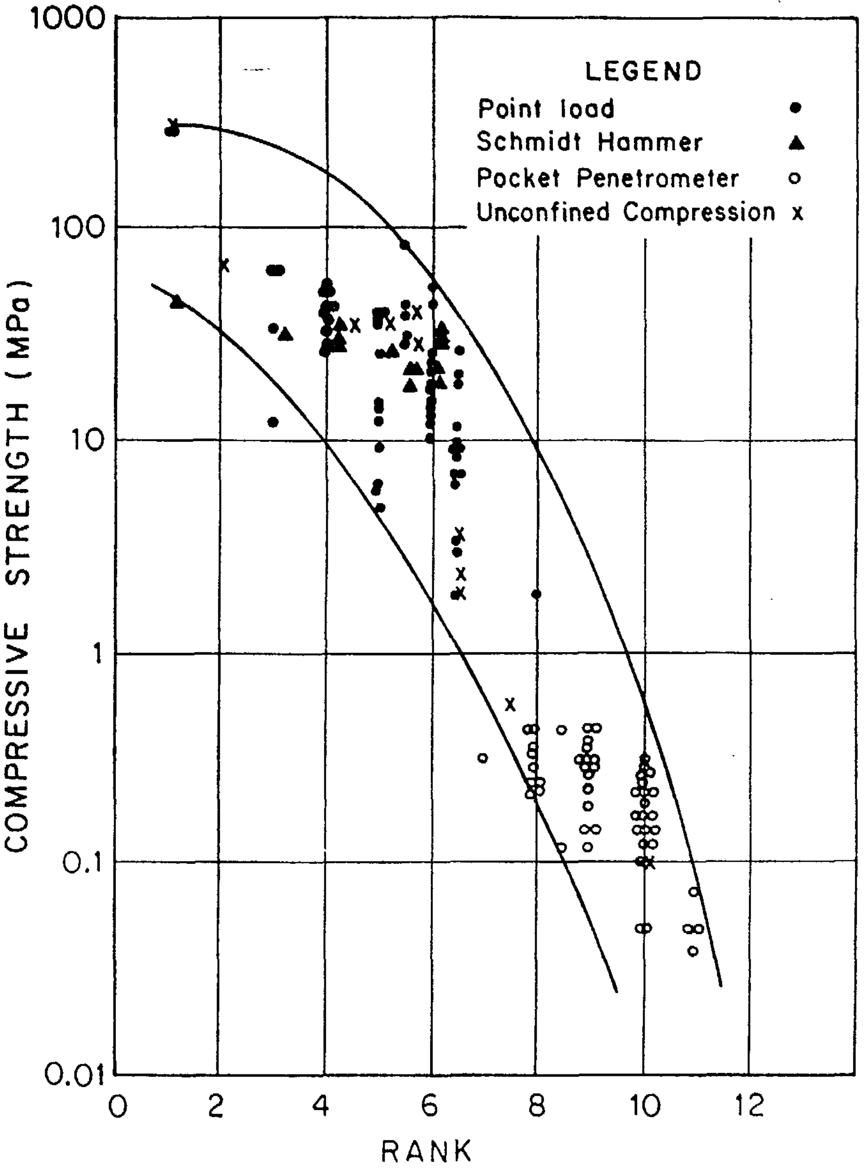


Figure 3. Unconfined Compressive Strength Versus Rank of Material From Scanline Surveys (4).

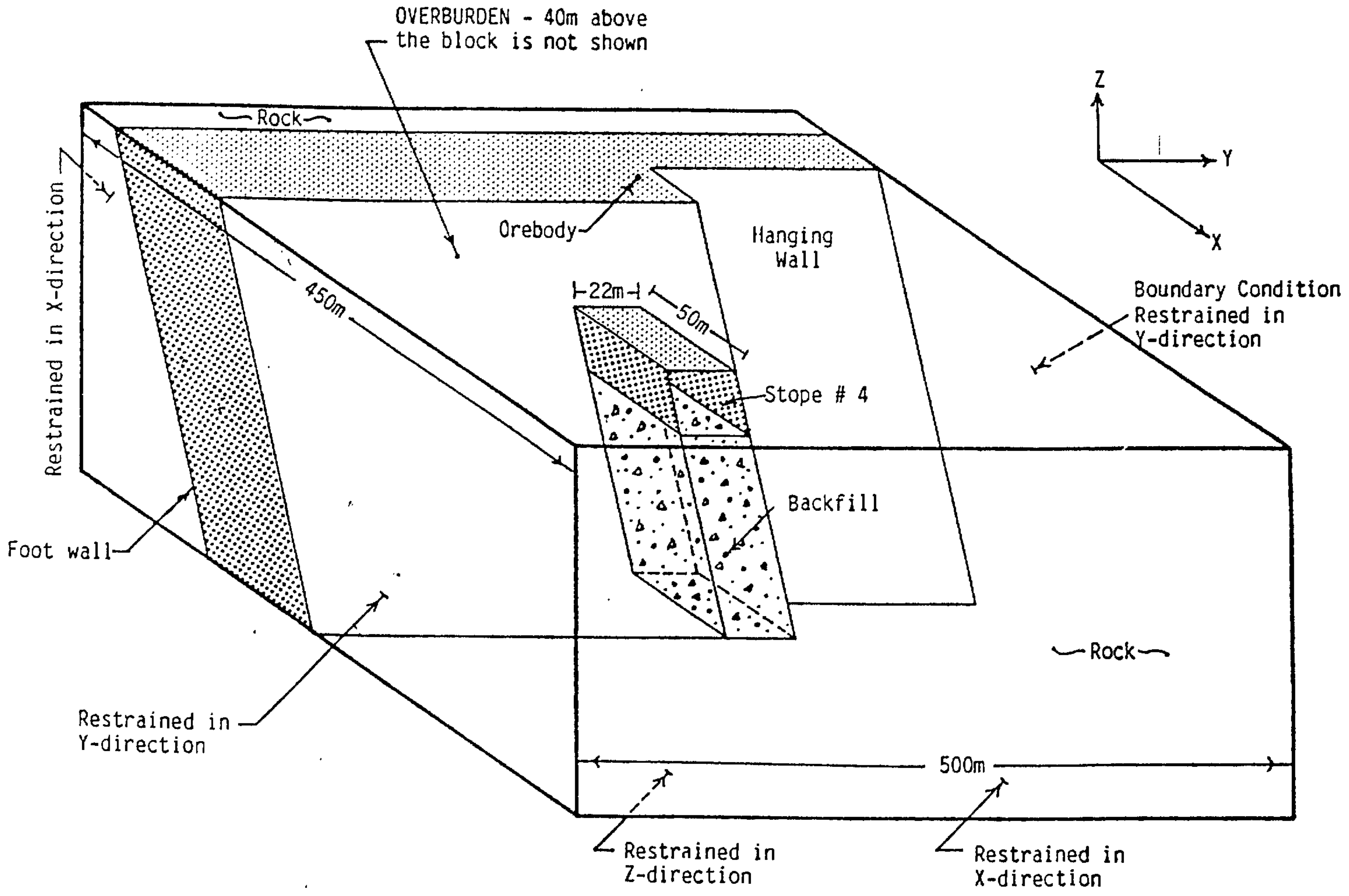
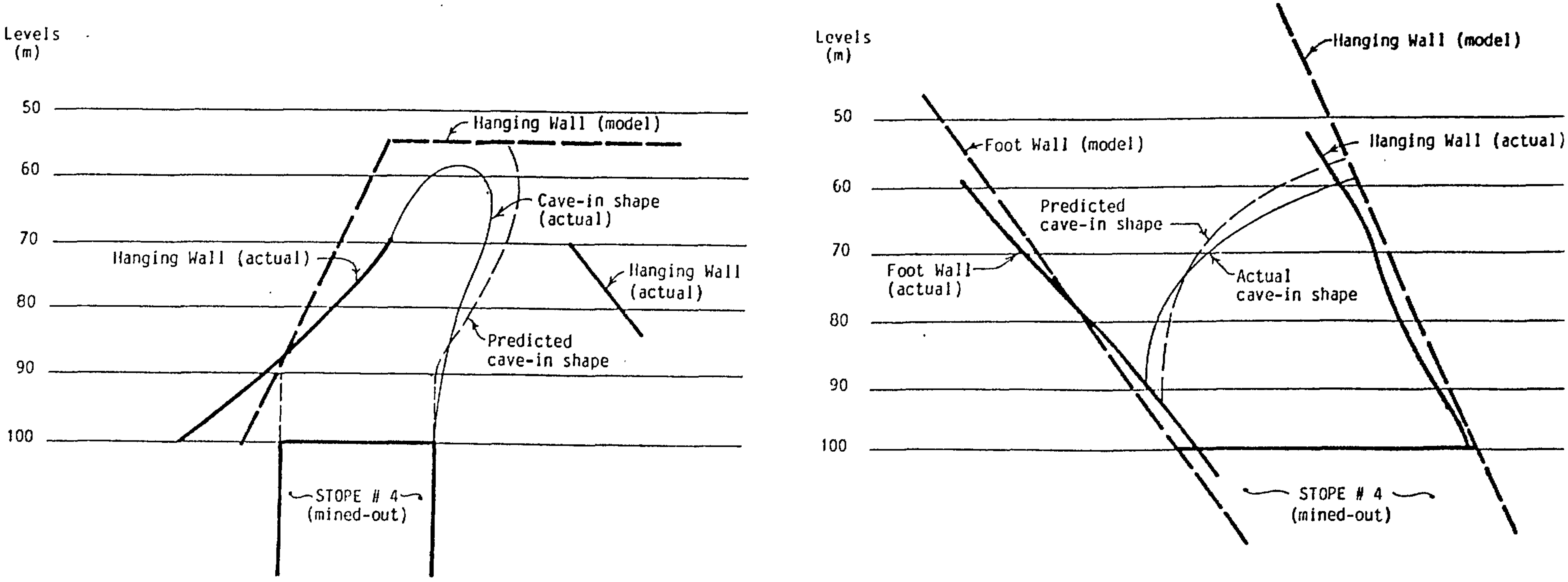


Figure 4. Numerical Model Layout, to Simulate Stope 4 Cave-in (5).



(a) (b)

Figure 5. Numerical Model Prediction of Stope 4 Failure vs. Actual Failure (a) Along Strike, (b) Normal to Strike (5).

ROCK TYPE	WITHOUT AIR PRESSURE			WITH 0.14 MPa AIR PRESSURE		
	Optimum Range Water Pressure (MPa)	Optimum Range Penetration Rate (mm/sec)	Average Recovery **	Optimum Range Water Pressure (MPa)	Optimum Range Penetration Rate (mm/sec)	Average Recovery **
Slightly Kaolinized Dacite Tuff Breccia	3.4 - 7.0	0.6 - 2.0	100	1.7 - 7.0	0.4 - 3.0	100
Moderately Kaolinized Dacite Tuff Breccia	2.8 - 3.5	0.6 - 1.3	95	1.7 - 7.0	0.4 - 1.0	98
Highly Kaolinized Dacite Tuff Breccia	2.5 - 3.0	0.6 - 1.3	70	1.7 - 2.5	0.4 - 0.6	90
Pieces of Rock in Silty Clay to Clayey Silt matrix, finely fractured sooty chalcacite	2.5 - 3.0	0.6 - 1.3	60	1.7 - 2.5	0.4 - 0.6	95

** Must use Face-Centred Discharge Bits and POLYDRILL® to obtain these Recoveries.

Table 1. Rock Coring Results With or Without Air Pressure (4).

RANK	CHARACTERIZATION	FIELO METHOO OF DETERMINING RELATIVE STRENGTH	AVERAGE VOLUME (%)
1	Very Strong	> 1 hammer blow to break	9.7
2	Strong	1 hammer blow to break	17.4
3	Moderately Strong	5 mm indentations with pick	12.4
4	Moderately Weak	Cannot be cut by hand	6.3
5	Weak	Crumbles under firm blows with pick	14.1
6	Very Weak	Broken in hand with difficulty	9.4
7	Very Stiff	Indented by fingernail	6.6
8	Stiff	Cannot be moulded in fingers	5.7
9	Firm	Difficult to mould in fingers	7.2
10	Soft	Easily moulded in fingers	10.4
11	Very Soft	Can be squeezed between fingers	0.8

Table 2. Rock Mass Ranking Scheme and Average Volume of Each Rock Type, Underground Scanline Surveys (4).

Property Tested		Competent Rock	Soil-Like Rock	Kaolin Zones
Moisture Content	(%)		5 - 25 (12)	15 - 24 (18)
Liquid Limit	(%)		28 - 35	18 - 25
Plastic Limit	(%)		20 - 23	15 - 18
Plasticity index	(%)		8 - 12	3 - 7
Gravel Size (>4.75 mm)	(%)		20 - 67	
Sand Size (<2.0 mm)	(%)		25 - 56	
Silt & Clay (<75µm)	(%)		6 - 13	
Unit Weight - General	(kN/m3)	24 - 30	19 - 26	
Unit Weight - Chalcocite	(kN/m3)		26 - 40 (33)	
Slake Durability, I2	(%)		69 - 98	
Compressive Strength:				
Point Load (I 50)	(MPa)	106 - 288	3 - 48	
Schmidt Hammer R	(MPa)		30	
Unconfined Compression	(MPa)			0.1 - 0.6
Angle Internal Friction,ø	(°)		41	33
Cohesion intercept,c	(kPa)		45	5
Modulus of Deformation:				
Unconfined Compression	(GPa)	12 - 32	1 - 10	
Point Load	(GPa)	(28)	12 - 24	

Note: Numbers in brackets refer to average values

Table 3. Summary of Laboratory Test Results (4).