Energy, Mines and Resources Canada / Énergie, Mines et Ressources Canada

CANMET

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

NUMERICAL MODELLING AND SURFACE CROWN PILLAR DESIGN

L. Closset and S. Vongpaisal

Mining Research Laboratories

October 1988

Presented at Seminar/Timmins Partner with the Ontario Mining Industry, November 22-23rd, 1988, and Published in the Proceedings.

MINING RESEARCH LABORATORIES
DIVISIONAL REPORT MRL 88-146 (OPJ)

CANMET

Partner
with the Ontario Mining Industry
Partenaire
de l'industrie minière Ontarienne

Numerical Modelling and Surface Crown Pillar design

L. Closset and S. Vongpaisal

Mining Research Laboratories, CANMET, EMR, Ottawa

ABSTRACT

Numerical modelling has, over the years, become more and more popular. This paper reviews the different major types of numerical techniques and outlines their applications in Surface Crown pillar design. It discusses accuracy and limitations and outlines briefly the development work and some applications realised by Canmet in this field during the last few years.

RÉSUMÉ

Les méthodes numériques sont, d'année en année, de plus en plus populaires. Cet article fait une revue rapide des grands types de simulation numériques et de leur applications pour la conception des piliers de surface. La précision et les limitations de ces méthodes est discutée et un bref sommaire du travail de développment et de quelques applications réalisés par Canmet est présenté.

Introduction

Numerical modelling is the numerical techniques, usually programmed on a computer, to approximate the resolution of a differential equation system over a finite or infinite domain. For mining purposes, it means computer programs able to calculate, with adequate accuracy, stress, strains and displacement inside a rock mass and around mining excavations and predict stability or instability of these excavations.

In the surface Crown pillar context, if we use the simplified flow chart design presented by Bètournay [1] (figure I), Numerical modelling is a tool used during the dimensioning processes. Its quality and its reliability are, clearly, highly dependent on the previous stages and particularly the quality of the geotechnical investigations and monitoring.

Numerical Modelling Methods

There are four different numerical methods used in mining engineering to simulate rock behavior around mining activities. We will review briefly their theoretical basis [3] and outline their capabilities and requirement.

The first and the most used is the Finite Element method (FEM)[2]. Developed during the fifties for structural engineering, this method has been rapidly extended to any field of engineering. The method is based principally on the division into elements ("discretization") of the body to simulate and the hypothesis that displacement inside each element can be determined using a known-function . The method is limited to continuous bodies but can simulate various type of materials and behaviors. Numerous programs exist, some are very general and can handle a very large variety of problems, some are specific to certain applications. Examples of the use of finite element in mine design are numerous and well documented. It is still the leading method specially when non-linear behavior has to be simulated.

The second, the Boundary Element method (BEM) and the third, the closely related Displacement Discontinuity method (DEM) are a little younger and originated in the sixties [4]. They actually cannot handle such a broad variety of problems, but their capabilities in simulating mining structures are well established. Instead of dividing the whole body to be simulated, it is only necessary to divide it at the boundaries. This feature reduces drastically the amount of computational power needed, especially for elastic infinite bodies. However there are still some problems of accuracy along the boundaries which limited the application in some mining purposes. These problems could be eliminated and there is no doubt that this technique will become more and more popular over the years, specially with the development of software which can handle large non-linear 3D mining models.

The fourth, the Discrete Element method, is even younger [5]. It is the only method dedicated to geotechnical problems. The body is divided into elements, each one is free to move independently from the others according to Newton's laws of motion and therefore the method can handle non-continuous bodies. Because joints are included at the beginning in the method, it seems very close to the real rock-mass structure. However, because it requires a lot of data with the resultant difficulty in acquisition and because there are only few programs available, only few mining cases have been published to date. This method will certainly become more popular ,and some new developments [6] appear to be very interesting.

Numerical modelling, surface crown pillar and accuracy

For modelling purpose, surface crown pillars cases do not differ from other mining cases. Meanwhile, users of numerical modelling package have to be sure that the programs can simulate adequately the rock-mass behavior of their problem.

One can say that numerical models are usually inaccurate and often do not represent the mining reality. The main sources of inaccuracy while using numerical techniques are the following :

1) Use of inadequate constitutive model

2) Use of inadequate or erroneous data

3) Inhomogeneity of rock mass

4) Incorrect model geometry - major structural feature omitted

5) insufficient number of elements or "discretization"

Errors due to causes 1,2,4,5 are usually user related. The inhomogeneity can be circumvented by using the 'properties lower bound' approach. Experienced users can estimated error 5 and compare it to the level of accuracy of their data. Generally, even with very coarse divisions, the errors due to this cause are far smaller than ones due to inhomogeneity of rock properties (item 3)

The best method to minimize all these problems is to perform back-analysis of known cases. This will develop practical experience and will, with the help of the software they are using, define more accurately the behavior and properties of the rock mass to be used in modelling.

Canmet and Numerical Modelling

Canmet and Mine Research Laboratory have been active for many years in the development and the use of numerical modelling. Table 1 shows a summary of all the programs that Canmet has developed, sponsored or purchased. Canmet is also sponsoring software development in universities for Discrete Element Method.

On the other hand, as more and more personal computers are available in mining industries, Canmet has started to transfer some programs on these systems. The following programs are now available for all mining industries at low cost :

- PCBEM - a 2D boundary element program
- PCMINTAB - a 3D displacement discontinuity program
- PCSAP2D - a 2D linear elastic finite element program
- PCEPFE - a 2D nonlinear finite element program

Canmet is organizing technology transfer workshops to teach the use of these products, and, if there is interest in the industry and with its help, will upgrade these products to match as much as possible the need of the mining community.

In the future, Canmet will continues its task of developing and transferring numerical modelling packages to the industry allowing safer and higher productivity for canadian mines.

Case studies

Canmet has not only developed numerical programs but have used them to analyse various problems in mining stability. We will review briefly now three case studies of surface pillar design which have been realised with the help of Canmet.

1) Niobec Mine

Niobec Mine is located in the Lac St-Jean area not far from the town of St-Honore. Since 1984, at the request of the mine, Canmet is studying [7] the stability of that mine. The orebody is covered by 55 meters of good quality limestone. The overburden thickness is limited to some 3 meters. The surrounding rock-mass is a carbonatite which contains vertical zones of niobium enrichment. Mining is taking place in vertical stopes which are up to 90 meters high with length up to 70 meters and 25 meters wide.(fig 2)

Numerical modelling of the mining sequence around the crown pillar area had been realized by Canmet staff. Because of the good condition of the rock mass and its few fractures, 3D finite element method had been used for that purpose. SAP3D program was the perfect tool for that work.. Four different geometries has been analysed with the help off that software. The principal goal was to assess the stability of different stopes and pillar located not far from the surface. Figure III-1 is showing the geometry of one models. Using the Drucker-Prager and Hoeck and Brown criteria, the results show that pillars and stopes will be generally stable even if some stopes are extended to very large dimension along the strike up to 250 meters.

Because of the large dimensions of the model, it had to be moved to the CRAY-1 system located in Dorval, Quebec. The processing of that particular model involved the solution of a system of some twenty-five thousand equations.

2) Selbaie Mine

Selbaie mine is located in Northwest of Quebec, about 80 kilometers west of the town of Joutel, not far from the Quebec-Ontario border. Here the type of crown pillar is completely different to case 1). The ore body dips at about 45 degrees and has a thickness between 6 and 35 meters. The mining is realized on about 350 meters length. The bedrock is covered by 45 meters of overburden. In the south part of the orebody the ore zone is heavily altered and a significant proportion of the ore had been transformed into clay-type materials.

The mining recovered slices of about 6 to 8 metres wide, leaving a 7.5 meters thick remnant pillar. These slices were backfilled as soon as possible after mining.

In the first phase, Canmet had funded and supervised a project carried out by Strata Engineering of Toronto [8], to verify the design prepared by mine staff. Numerical modelling, which was only a part of the study, had to deal with soil type material; backfill and overburden and a very soft and inhomogeneous rock. In this case, again the finite element method had been chosen. The results of this investigation showed that the mine design was safe and that it was not possible to mine wider slices in this area.

An interesting part of this study was the back-analysis of a major cave-in which occured few years ago. The comparison of this analysis and the real case showed that the numerical modelling was reliable in predicting the stability and the extension of the cave-in that occured in this type of material and has certainly reinforced the trust of the mine management team in modelling techniques.

In a second phase the mine had submitted an unsolicited proposal [9] to study the recovery of the 7.5 meters thick remnant pillar left under the overburden. The proposed method is to activate and control the cave-in of the overburden which is supposed to fall into the stopes as backfill (see figure 3). As there are some buildings located on the overburden surface close to the underground workings, the control of the caving, and therefore the surface subsidence, is certainly the key to the proposed mining method.

This work, once again realized by Strata Engineering, will use the same non-linear 3D finite element software to simulate the behavior of overburden caving. The first part of that study had shown that there is a possibility that the caving and the surface subsidence cannot be controlled. At present, the consultant is studying new data collected last summer.

3) Holt-McDermott Mine.

Holt-McDermott Mine is located in Northeastern Ontario, near the Quebec Border. For this project, Canmet staff have studied the stability of an excavation created near the surface in a fault zone embedded in a basaltic rock mass. Numerical modelling was complicated by the presence of a graphitic schist zone running parallel to the ore body [10]. Because of the lateral extension of the mine excavation 2D finite element method has been used to assess the stability of stope 0997 situated about 40 meters under the surface (figure 4). All the runs had been conducted on a personal computer. The results outlined different potential zones of failure in the vicinity of the surface crown pillar and the need for reinforcement and and the use of appropriate blasting techniques in that area.

Conclusions

Numerical modelling is a powerful tool for surface crown pillar design. But the quality of the results it gives is highly dependent on the quality of input data.

Canmet has been and will be extensively involved in numerical modelling development as well as its uses in mine excavation design. On the other hand, the access of less expensive computing power by the development and the reduced costs of micro and mini-computer allows Canmet to transfer the technology of computer modelling to every mine in Canada : a new goal.

Bibliography

1. Bétournay M.C., "A design philosophy for surface crown pillars of hard rock mines"; Division Report M&ET/MRL 86-139(J); CANMET, Energy, Mines and Ressources, Canada, December 1986

2. Zienkiewicz O.C., "The Finite Element Method"; McGraw-Hill, UK, 1977

3. Brady B.H.G, Brown E.T., "Rock Mechanics for Underground Mining" George Allen & Unwin, UK, 1985

4. Crouch S.L., Starfield A.M., " Boundary Element Methods in Solid Mechanics"; George Allen & Unwin, UK, 1983

5. Hart R., Cundall P.A. and Lemos J. " Formulation of a three-dimensional Distinct Element Model - Part II. Mechanical Calculations for Motion and Interaction of a system Composed of Many Polyhedral Blocks "; Int. J. Rock Mech. Min. Sci. & Geomech. Abst. Vol. 25, No 3, pp. 117-125,1988

6. Fortin M. and Gill D.E. "Analyse de stabilité par discrétisation et programmation linéaire appliquée aux piliers de surface"; in "Colloque : l'ingénérie des piliers de surfaces - Val d'Or 1986" ; Centre de Recherche minérales, Ministère de l'Énergie et des Ressources du Québec, Canada, 1987

7. Yu Y.S., Bétournay M.C., Larocque G.E. and Thivierge S. "Pillar and stope stability assessment of the Niobec Mine using the three-dimensional finite element techniques." mines"; Division Report M&ET/MRL 88-68(OP,J); CANMET, Energy, Mines and Ressources, Canada, July 1988

8. Weak rock mass model for support of surface crown pillar at Les Mines Selbaie, Contract Report # 15 SQ. 23440-5-9017, Canmet, Canada, 1987

9. Recovery of the surface crown pillar through the control caving method at Les Mines Selbaie, Contract Report # 035Q 23440 7-9195, Canmet Canada, 1988

10. Bétournay M.C., "Application of 2-D finite Element modelling to the 0997 near-surface stope, Holt-McDermott Mine" Division Report M&ET/MRL 88-82(TR); CANMET, Energy, Mines and Ressources, Canada, August 1988

MRL/CANMET NUMERICAL MODELLING CAPABILITIES

Canadian Mine Technology Laboratory

Table 1

MODELS	SAP2D	PCSAP2D	QUAD	EPFE	PCEPFE	DRUKPRA	NEAT	TEMPFE	NAOS	GEOROC	BMINES	NONSAP	SAP3D	BIT3D	PCBEM	BITEMJ	BEAP	BEAPDD	BEAPM	ENERBRAY	MINTAB	PCMINTAB
F.E.	x	x	x	x	x	x	x	x	x	x	x	x	x									
B.E.														x	x	x	x		x	x		
D.D.																		x	x		x	x
2 D	x	x	x	x	x	x	x	x	x	x	x				x	x				x		
3 D											x	x	x	x			x	x			x	x
Axisymmetric									x	x	x											
Static, linear	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x		x	x	x
Stress/displacement	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x		x	x	x
Temperature/heat flux								x														
Energy release																				x	x	x
Dynamic												x										
Non-linear			x	x	x	x	x			x	x	x				x						
Joints/faults			x								x					x			x			
Progressive failure				x	x																	
Transient										x	x											
Thermal stress	x	x									x											
Excavation	x	x	x	x	x	x	x			x	x		x								x	x
Backfill			x	x	x	x	x			x	x		x								x	x
Substructuring						x																
Restart			x			x	x			x	x					x					x	x
Pre-processor	x	x	?	x	x	x	x		x	x	x		x	x	x	x	?	?	?		x	x
Post-processor	x	x	?	x	x	x			x		x		x		x	x	?	?	?		x	x
Interactive		x			x										x		x	x	x			x
Documentation	g	g	?	g	g	f	f		g	g	g		f	f	f	f	f	?	?	f	g	g
Sources	1	1	*	1	1	1	1	1	1	1	2	3	1	4	1	5	*	*	*	1	1	1

Documentation: g - good; f - fair;

Sources: 1 - MRL/CANMET; 2 - U.S.B.M.; 3 - Univ. of California, Berkley; 4 - Dr. T.A. Cruse, Southwest Research Institute, San Antonio Tx. 5 - CSIRO; * - under development.

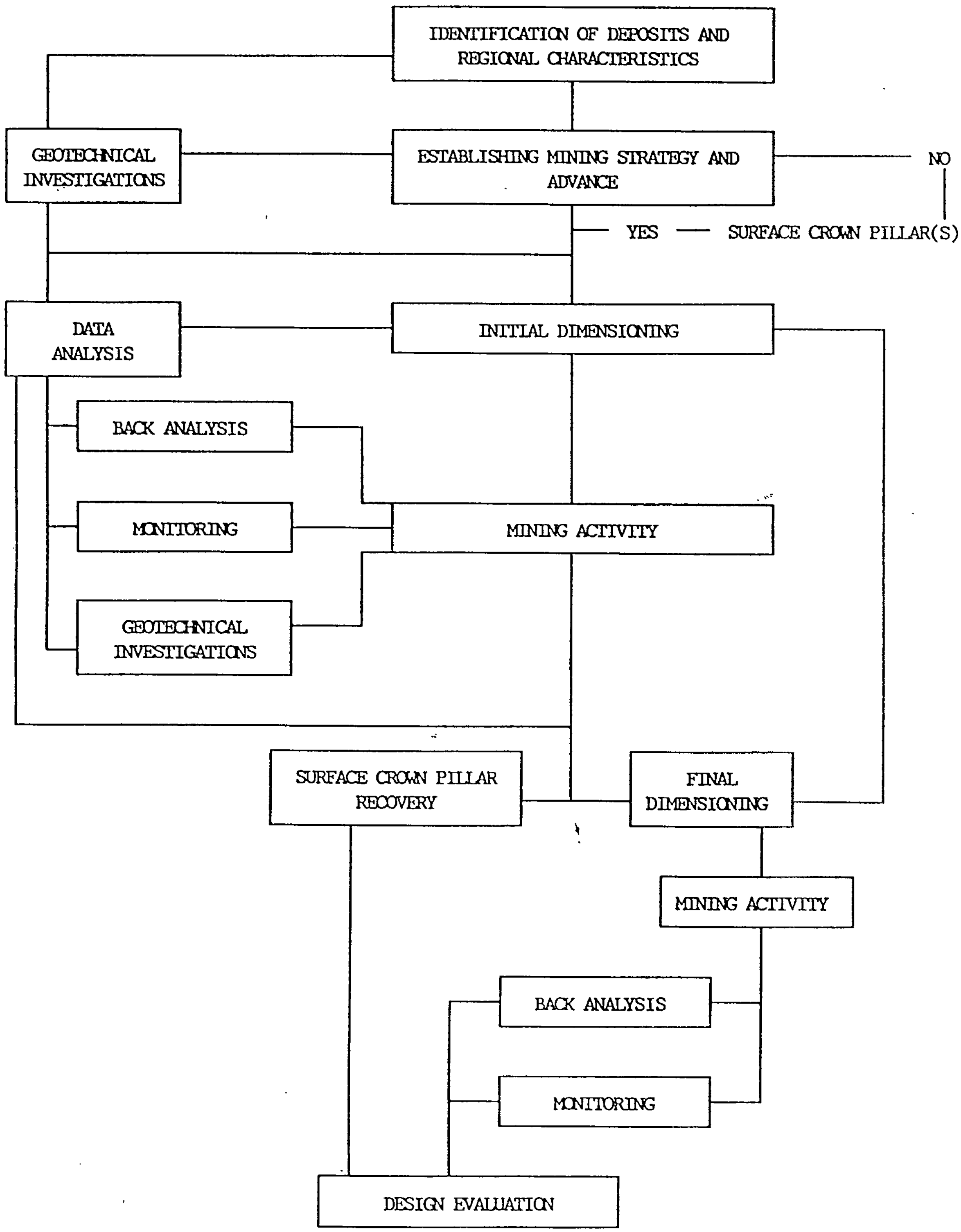
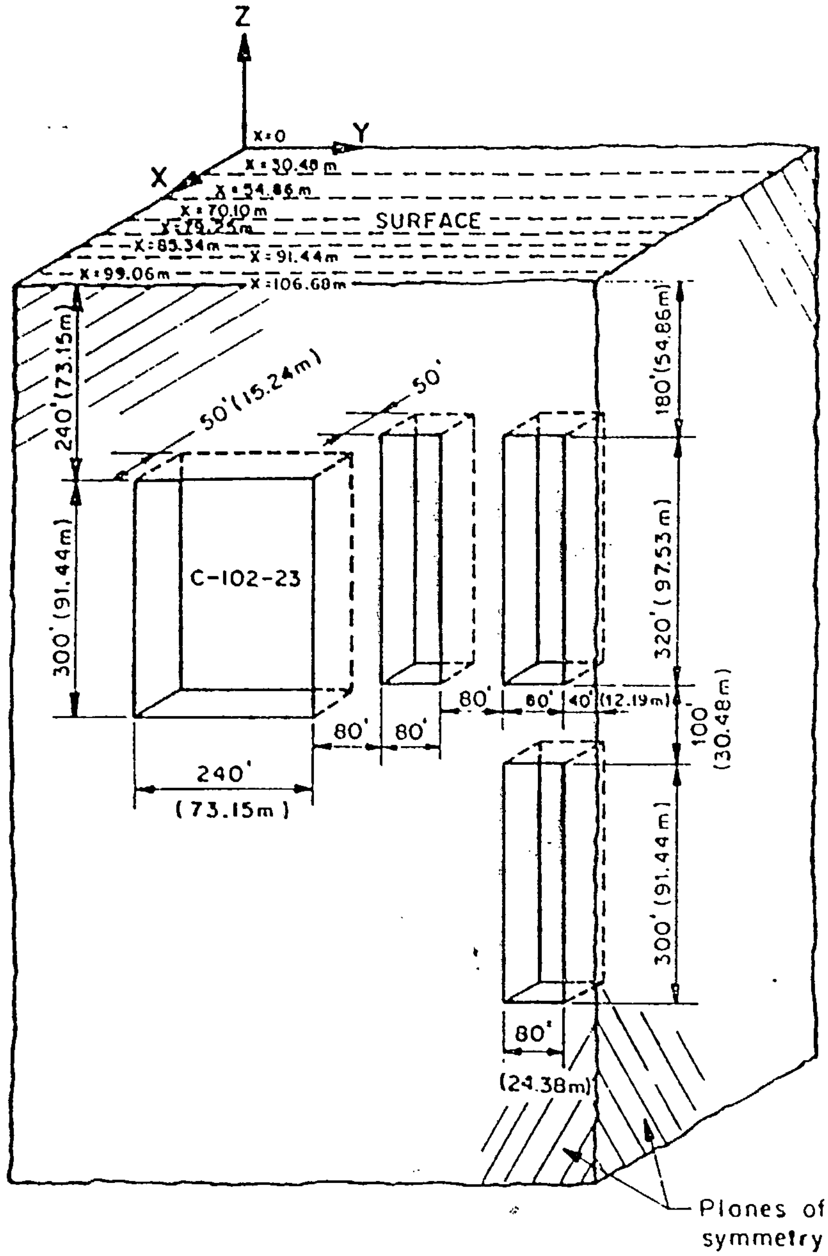


Figure 1. Simplified flow chart for crown pillar design (from Bétournay,1986)



An Isometric View of A 3D Mine Model
(Showning Quarter of the Structure to be Simulated)

Figure 2. Geometry of Niobec numerical modelling

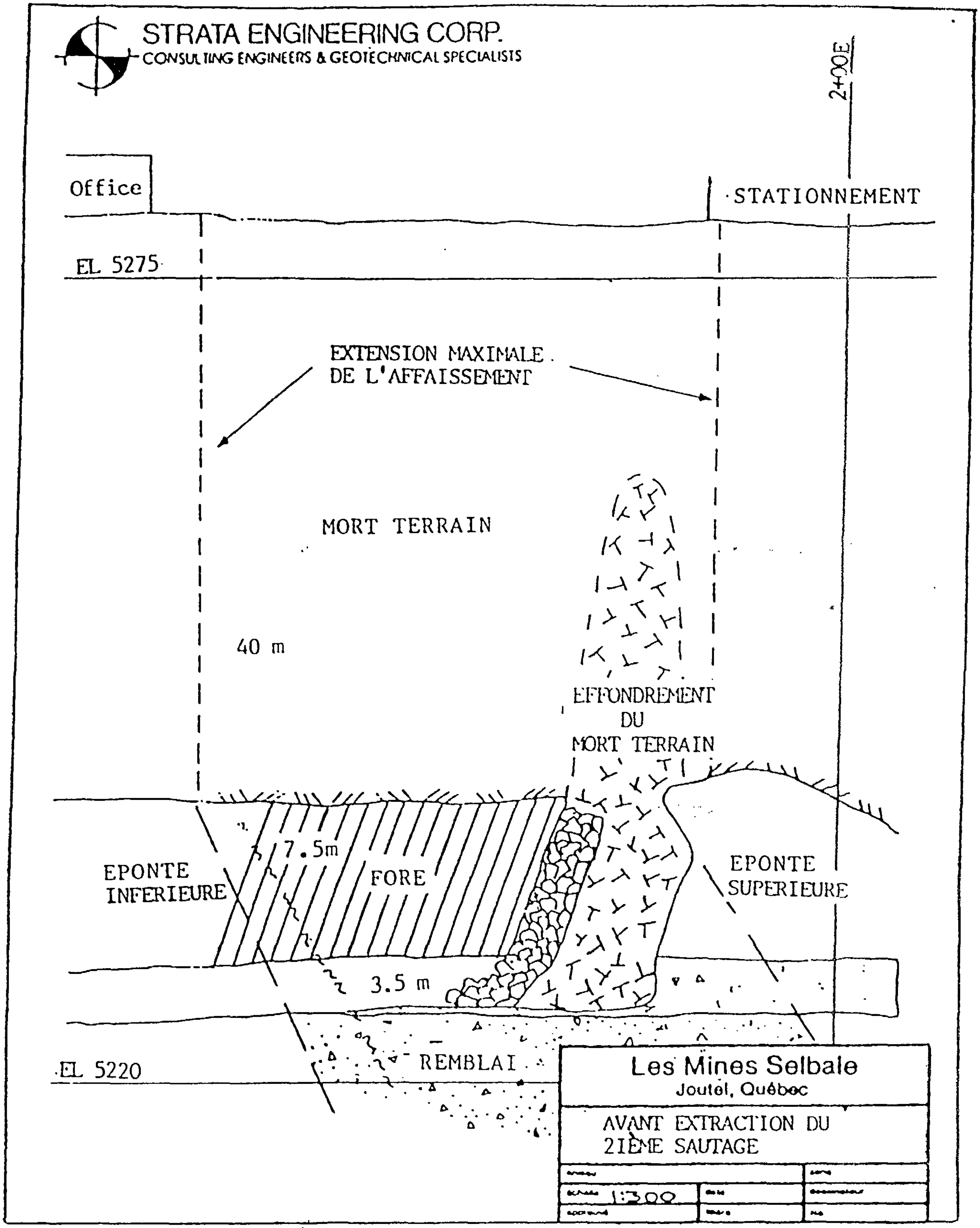


Figure 3. Proposed method for controlled caving of Selbaie mine crown pillar

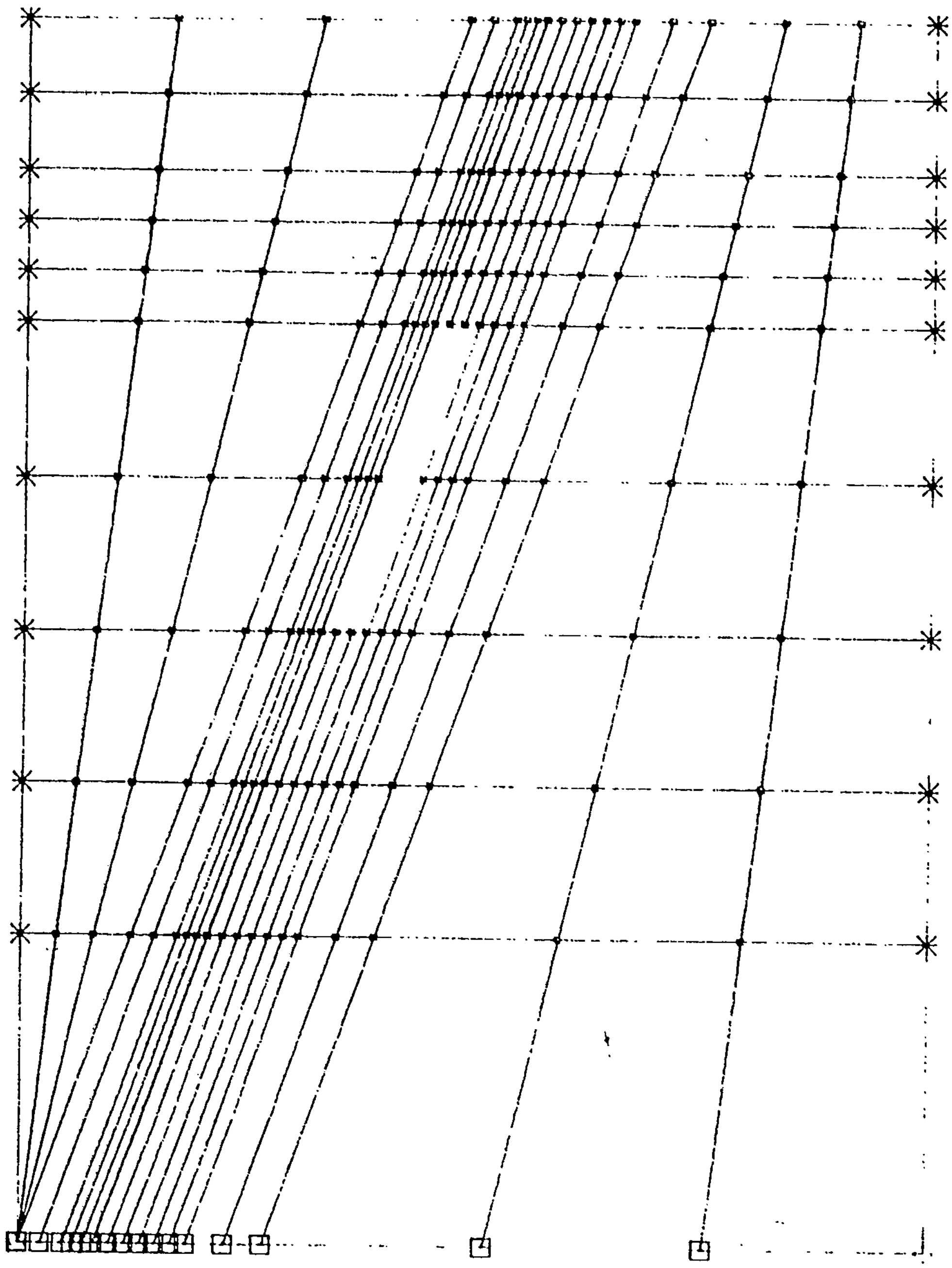


Figure 4. Mesh used for Holt Mc Dermott numerical modelling

Energy, Mines and Resources Canada / Énergie, Mines et Ressources Canada

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

MRL 88-146(OPJ)c.1

NUMERICAL MODELLING AND SURFACE CROWN PILLAR DESIGN

L. Closset and S. Vongpaisal

Mining Research Laboratories

October 1988

Presented at Seminar/Timmins Partner with the Ontario Mining Industry, November 22-23rd, 1988, and Published in the Proceedings.

MINING RESEARCH LABORATORIES
DIVISIONAL REPORT MRL 88-146 (OPJ)

CANMET

Partner
with the Ontario Mining Industry
Partenaire
de l'industrie minière Ontarienne

Numerical Modelling and Surface Crown Pillar design

L. Closset and S. Vongpaisal

Mining Research Laboratories, CANMET, EMR, Ottawa

ABSTRACT

Numerical modelling has, over the years, become more and more popular. This paper reviews the different major types of numerical techniques and outlines their applications in Surface Crown pillar design. It discusses accuracy and limitations and outlines briefly the development work and some applications realised by Canmet in this field during the last few years.

RÉSUMÉ

Les méthodes numériques sont, d'année en année, de plus en plus populaires. Cet article fait une revue rapide des grands types de simulation numériques et de leur applications pour la conception des piliers de surface. La précision et les limitations de ces méthodes est discutée et un bref sommaire du travail de développment et de quelques applications réalisés par Canmet est présenté.

Introduction

Numerical modelling is the numerical techniques, usually programmed on a computer, to approximate the resolution of a differential equation system over a finite or infinite domain. For mining purposes, it means computer programs able to calculate, with adequate accuracy, stress, strains and displacement inside a rock mass and around mining excavations and predict stability or instability of these excavations.

In the surface Crown pillar context, if we use the simplified flow chart design presented by Bétournay [1] (figure I), Numerical modelling is a tool used during the dimensioning processes. Its quality and its reliability are, clearly, highly dependent on the previous stages and particularly the quality of the geotechnical investigations and monitoring.

Numerical Modelling Methods

There are four different numerical methods used in mining engineering to simulate rock behavior around mining activities. We will review briefly their theoretical basis [3] and outline their capabilities and requirement.

The first and the most used is the Finite Element method (FEM)[2]. Developed during the fifties for structural engineering, this method has been rapidly extended to any field of engineering. The method is based principally on the division into elements ("discretization") of the body to simulate and the hypothesis that displacement inside each element can be determined using a known-function . The method is limited to continuous bodies but can simulate various type of materials and behaviors. Numerous programs exist, some are very general and can handle a very large variety of problems, some are specific to certain applications. Examples of the use of finite element in mine design are numerous and well documented. It is still the leading method specially when non-linear behavior has to be simulated.

The second, the Boundary Element method (BEM) and the third, the closely related Displacement Discontinuity method (DEM) are a little younger and originated in the sixties [4]. They actually cannot handle such a broad variety of problems, but their capabilities in simulating mining structures are well established. Instead of dividing the whole body to be simulated, it is only necessary to divide it at the boundaries. This feature reduces drastically the amount of computational power needed, especially for elastic infinite bodies. However there are still some problems of accuracy along the boundaries which limited the application in some mining purposes. These problems could be eliminated and there is no doubt that this technique will become more and more popular over the years, specially with the development of software which can handle large non-linear 3D mining models.

The fourth, the Discrete Element method, is even younger [5]. It is the only method dedicated to geotechnical problems. The body is divided into elements, each one is free to move independently from the others according to Newton's laws of motion and therefore the method can handle non-continuous bodies. Because joints are included at the beginning in the method, it seems very close to the real rock-mass structure. However, because it requires a lot of data with the resultant difficulty in acquisition and because there are only few programs available, only few mining cases have been published to date. This method will certainly become more popular ,and some new developments [6] appear to be very interesting.

Numerical modelling, surface crown pillar and accuracy

For modelling purpose, surface crown pillars cases do not differ from other mining cases. Meanwhile, users of numerical modelling package have to be sure that the programs can simulate adequately the rock-mass behavior of their problem.

One can say that numerical models are usually inaccurate and often do not represent the mining reality. The main sources of inaccuracy while using numerical techniques are the following :

1) Use of inadequate constitutive model

2) Use of inadequate or erroneous data

3) Inhomogeneity of rock mass

4) Incorrect model geometry - major structural feature omitted

5) insufficient number of elements or "discretization"

Errors due to causes 1,2,4,5 are usually user related. The inhomogeneity can be circumvented by using the 'properties lower bound' approach. Experienced users can estimated error 5 and compare it to the level of accuracy of their data. Generally, even with very coarse divisions, the errors due to this cause are far smaller than ones due to inhomogeneity of rock properties (item 3)

The best method to minimize all these problems is to perform back-analysis of known cases. This will develop practical experience and will, with the help of the software they are using, define more accurately the behavior and properties of the rock mass to be used in modelling.

Canmet and Numerical Modelling

Canmet and Mine Research Laboratory have been active for many years in the development and the use of numerical modelling. Table 1 shows a summary of all the programs that Canmet has developed, sponsored or purchased. Canmet is also sponsoring software development in universities for Discrete Element Method.

On the other hand, as more and more personal computers are available in mining industries, Canmet has started to transfer some programs on these systems. The following programs are now available for all mining industries at low cost :

- PCBEM - a 2D boundary element program
- PCMINTAB - a 3D displacement discontinuity program
- PCSAP2D - a 2D linear elastic finite element program
- PCEPFE - a 2D nonlinear finite element program

Canmet is organizing technology transfer workshops to teach the use of these products, and, if there is interest in the industry and with its help, will upgrade these products to match as much as possible the need of the mining community.

In the future, Canmet will continues its task of developing and transferring numerical modelling packages to the industry allowing safer and higher productivity for canadian mines.

Case studies

Canmet has not only developed numerical programs but have used them to analyse various problems in mining stability. We will review briefly now three case studies of surface pillar design which have been realised with the help of Canmet.

1) Niobec Mine

Niobec Mine is located in the Lac St-Jean area not far from the town of St-Honore. Since 1984, at the request of the mine, Canmet is studying [7] the stability of that mine. The orebody is covered by 55 meters of good quality limestone. The overburden thickness is limited to some 3 meters. The surrounding rock-mass is a carbonatite which contains vertical zones of niobium enrichment. Mining is taking place in vertical stopes which are up to 90 meters high with length up to 70 meters and 25 meters wide.(fig 2)

Numerical modelling of the mining sequence around the crown pillar area had been realized by Canmet staff. Because of the good condition of the rock mass and its few fractures, 3D finite element method had been used for that purpose. SAP3D program was the perfect tool for that work.. Four different geometries has been analysed with the help off that software. The principal goal was to assess the stability of different stopes and pillar located not far from the surface. Figure III-1 is showing the geometry of one models. Using the Drucker-Prager and Hoeck and Brown criteria, the results show that pillars and stopes will be generally stable even if some stopes are extended to very large dimension along the strike up to 250 meters.

Because of the large dimensions of the model, it had to be moved to the CRAY-1 system located in Dorval, Quebec. The processing of that particular model involved the solution of a system of some twenty-five thousand equations.

2) Selbaie Mine

Selbaie mine is located in Northwest of Quebec, about 80 kilometers west of the town of Joutel, not far from the Quebec-Ontario border. Here the type of crown pillar is completely different to case 1). The ore body dips at about 45 degrees and has a thickness between 6 and 35 meters. The mining is realized on about 350 meters length. The bedrock is covered by 45 meters of overburden. In the south part of the orebody the ore zone is heavily altered and a significant proportion of the ore had been transformed into clay-type materials.

The mining recovered slices of about 6 to 8 metres wide, leaving a 7.5 meters thick remnant pillar. These slices were backfilled as soon as possible after mining.

In the first phase, Canmet had funded and supervised a project carried out by Strata Engineering of Toronto [8], to verify the design prepared by mine staff. Numerical modelling, which was only a part of the study, had to deal with soil type material; backfill and overburden and a very soft and inhomogeneous rock. In this case, again the finite element method had been chosen. The results of this investigation showed that the mine design was safe and that it was not possible to mine wider slices in this area.

An interesting part of this study was the back-analysis of a major cave-in which occured few years ago. The comparison of this analysis and the real case showed that the numerical modelling was reliable in predicting the stability and the extension of the cave-in that occured in this type of material and has certainly reinforced the trust of the mine management team in modelling techniques.

In a second phase the mine had submitted an unsolicited proposal [9] to study the recovery of the 7.5 meters thick remnant pillar left under the overburden. The proposed method is to activate and control the cave-in of the overburden which is supposed to fall into the stopes as backfill (see figure 3). As there are some buildings located on the overburden surface close to the underground workings, the control of the caving, and therefore the surface subsidence, is certainly the key to the proposed mining method.

This work, once again realized by Strata Engineering, will use the same non-linear 3D finite element software to simulate the behavior of overburden caving. The first part of that study had shown that there is a possibility that the caving and the surface subsidence cannot be controlled. At present, the consultant is studying new data collected last summer.

3) Holt-McDermott Mine.

Holt-McDermott Mine is located in Northeastern Ontario, near the Quebec Border. For this project, Canmet staff have studied the stability of an excavation created near the surface in a fault zone embedded in a basaltic rock mass. Numerical modelling was complicated by the presence of a graphitic schist zone running parallel to the ore body [10]. Because of the lateral extension of the mine excavation 2D finite element method has been used to assess the stability of stope 0997 situated about 40 meters under the surface (figure 4). All the runs had been conducted on a personal computer. The results outlined different potential zones of failure in the vicinity of the surface crown pillar and the need for reinforcement and and the use of appropriate blasting techniques in that area.

Conclusions

Numerical modelling is a powerful tool for surface crown pillar design. But the quality of the results it gives is highly dependent on the quality of input data.

Canmet has been and will be extensively involved in numerical modelling development as well as its uses in mine excavation design. On the other hand, the access of less expensive computing power by the development and the reduced costs of micro and mini-computer allows Canmet to transfer the technology of computer modelling to every mine in Canada : a new goal.

Bibliography

1. Bétournay M.C., "A design philosophy for surface crown pillars of hard rock mines"; Division Report M&ET/MRL 86-139(J); CANMET, Energy, Mines and Ressources, Canada, December 1986

2. Zienkiewicz O.C., "The Finite Element Method"; McGraw-Hill, UK, 1977

3. Brady B.H.G, Brown E.T., "Rock Mechanics for Underground Mining" George Allen & Unwin, UK, 1985

4. Crouch S.L., Starfield A.M., " Boundary Element Methods in Solid Mechanics"; George Allen & Unwin, UK, 1983

5. Hart R., Cundall P.A. and Lemos J. " Formulation of a three-dimensional Distinct Element Model - Part II. Mechanical Calculations for Motion and Interaction of a system Composed of Many Polyhedral Blocks "; Int. J. Rock Mech. Min. Sci. & Geomech. Abst. Vol. 25, No 3, pp. 117-125,1988

6. Fortin M. and Gill D.E. "Analyse de stabilité par discrétisation et programmation linéaire appliquée aux piliers de surface"; in "Colloque : l'ingénérie des piliers de surfaces - Val d'Or 1986" ; Centre de Recherche minérales, Ministère de l'Énergie et des Ressources du Québec, Canada, 1987

7. Yu Y.S., Bétournay M.C., Larocque G.E. and Thivierge S. "Pillar and stope stability assessment of the Niobec Mine using the three-dimensional finite element techniques." mines"; Division Report M&ET/MRL 88-68(OP,J); CANMET, Energy, Mines and Ressources, Canada, July 1988

8. Weak rock mass model for support of surface crown pillar at Les Mines Selbaie, Contract Report # 15 SQ. 23440-5-9017, Canmet, Canada, 1987

9. Recovery of the surface crown pillar through the control caving method at Les Mines Selbaie, Contract Report # 035Q 23440 7-9195, Canmet Canada, 1988

10. Bétournay M.C., "Application of 2-D finite Element modelling to the 0997 near-surface stope, Holt-McDermott Mine" Division Report M&ET/MRL 88-82(TR); CANMET, Energy, Mines and Ressources, Canada, August 1988

Table 1

MRL/CANMET NUMERICAL MODELLING CAPABILITIES

Canadian Mine Technology Laboratory

MODELS	SAP2D	PCSAP2D	QUAD	EPFE	PCEPFE	DRUKPRA	NEAT	TEMPFE	NAOS	GEOROC	BMINES	NONSAP	SAP3D	BIT3D	PCBEM	BITEMJ	BEAP	BEAPDD	BEAPM	ENERBRAY	MINTAB	PCMINTAB
F.E.	x	x	x	x	x	x	x	x	x	x	x	x	x									
B.E.														x	x	x	x		x	x		
D.D.																		x	x		x	x
2 D	x	x	x	x	x	x	x	x	x	x	x				x	x				x		
3 D											x	x	x	x			x	x			x	x
Axisymmetric									x	x	x											
Static, linear	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x		x	x	x
Stress/displacement	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x		x	x	x
Temperature/heat flux								x														
Energy release																				x	x	x
Dynamic												x										
Non-linear			x	x	x	x	x			x	x	x				x						
Joints/faults			x								x					x			x			
Progressive failure				x	x																	
Transient										x	x											
Thermal stress	x	x									x											
Excavation	x	x	x	x	x	x	x			x	x		x								x	x
Backfill			x	x	x	x	x			x	x		x								x	x
Substructuring						x																
Restart			x			x	x			x	x					x					x	x
Pre-processor	x	x	?	x	x	x	x		x	x	x		x	x	x	x	?	?	?		x	x
Post-processor	x	x	?	x	x	x			x		x		x		x	x	?	?	?		x	x
Interactive		x			x										x		x	x	x			x
Documentation	g	g	?	g	g	f	f		g	g	g		f	f	f	f	f	?	?	f	g	g
Sources	1	1	*	1	1	1	1	1	1	1	2	3	1	4	1	5	*	*	*	1	1	1

Documentation: g - good; f - fair;
Sources: 1 - MRL/CANMET; 2 - U.S.B.M.; 3 - Univ. of California, Berkley; 4 - Dr. T.A. Cruse, Southwest Research Institute, San Antonio Tx. 5 - CSIRO; * - under development.

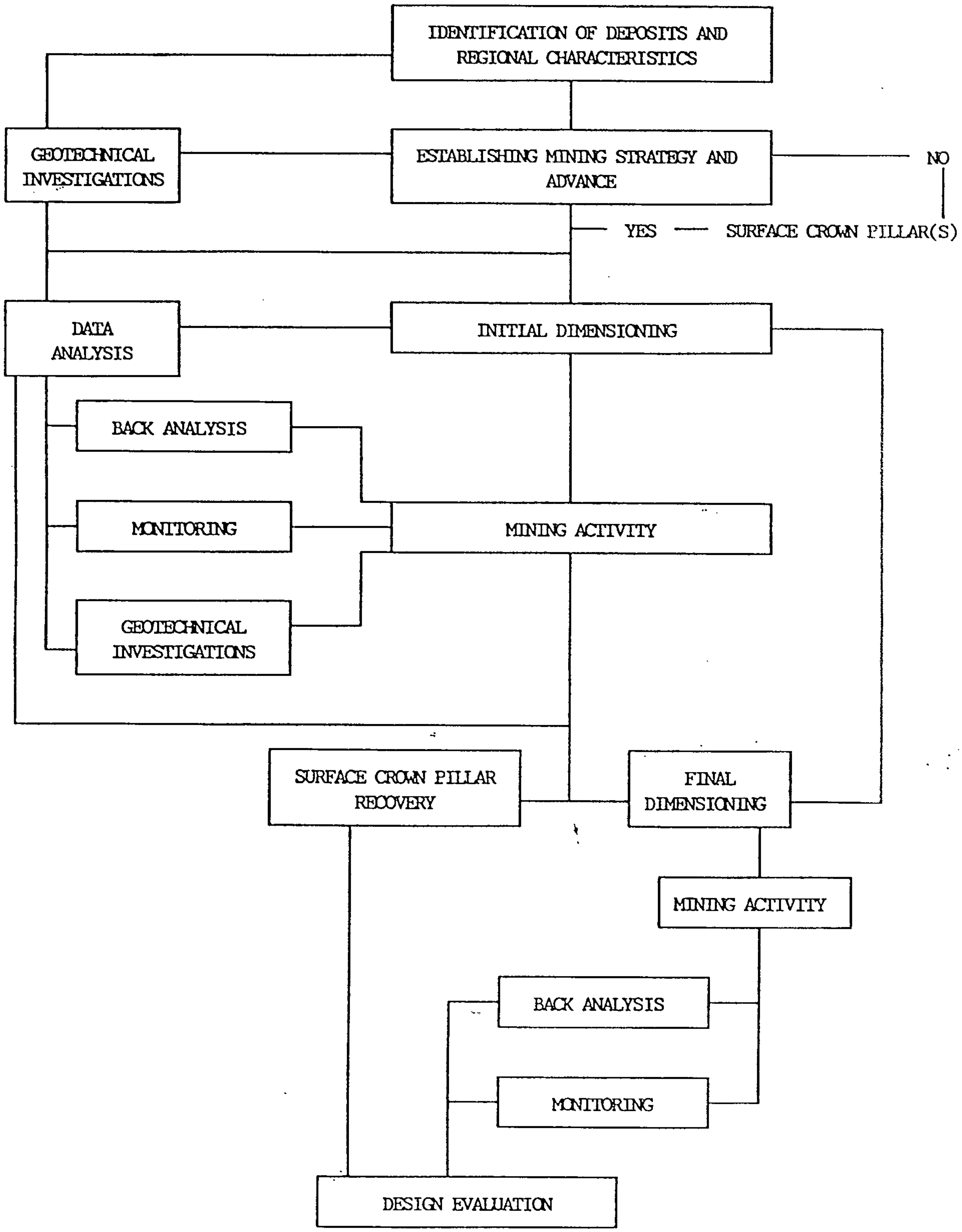
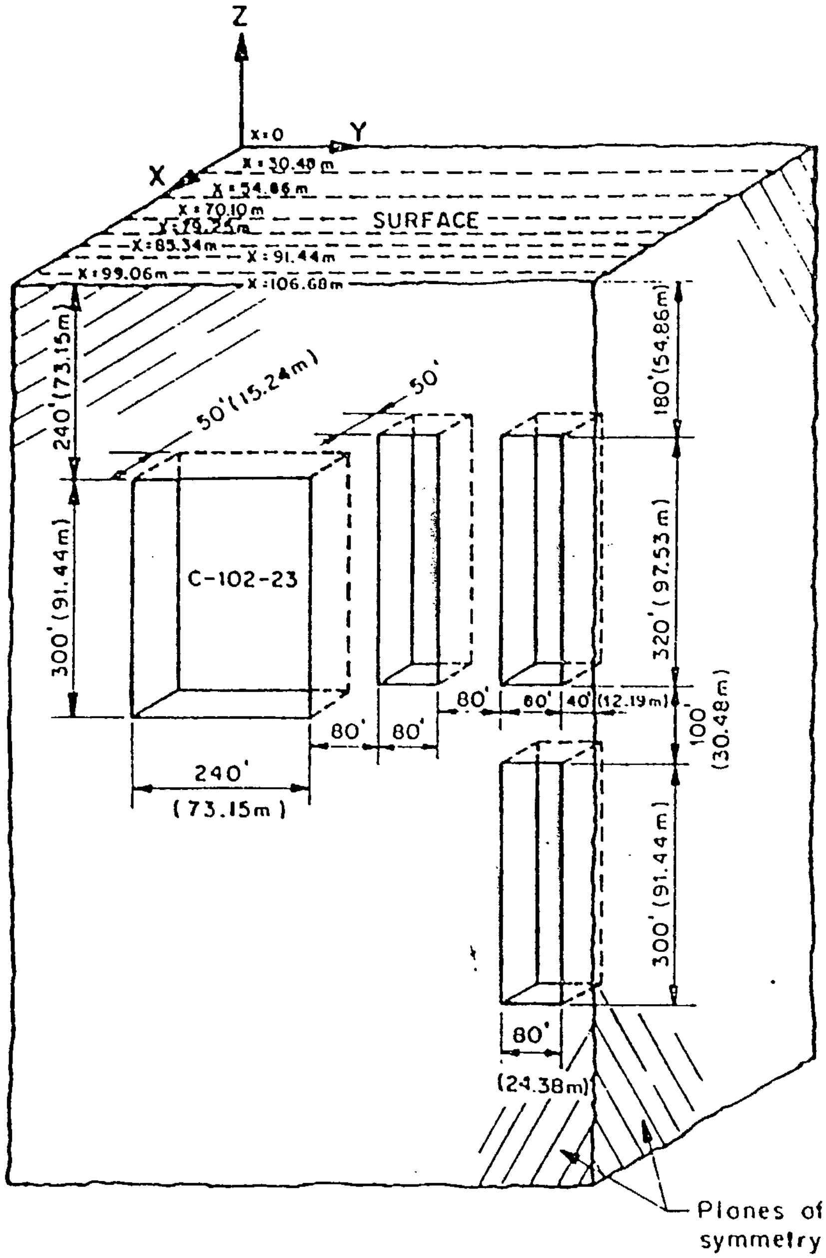


Figure 1. Simplified flow chart for crown pillar design (from Bétournay,1986)



An Isometric View of A 3D Mine Model
(Showning Quarter of the Structure to be Simulated)

Figure 2. Geometry of Niobec numerical modelling

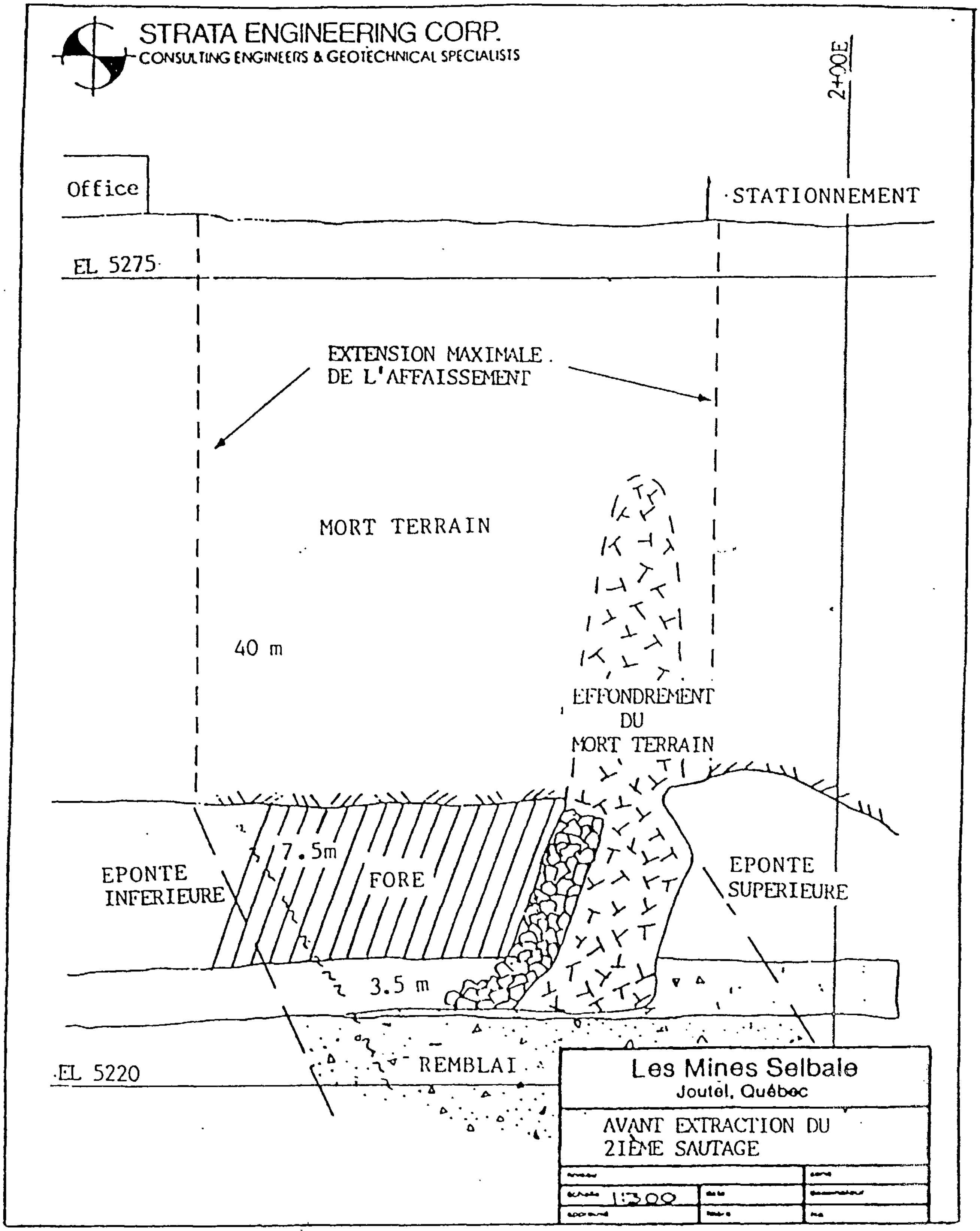


Figure 3. Proposed method for controlled caving of Selbaie mine crown pillar

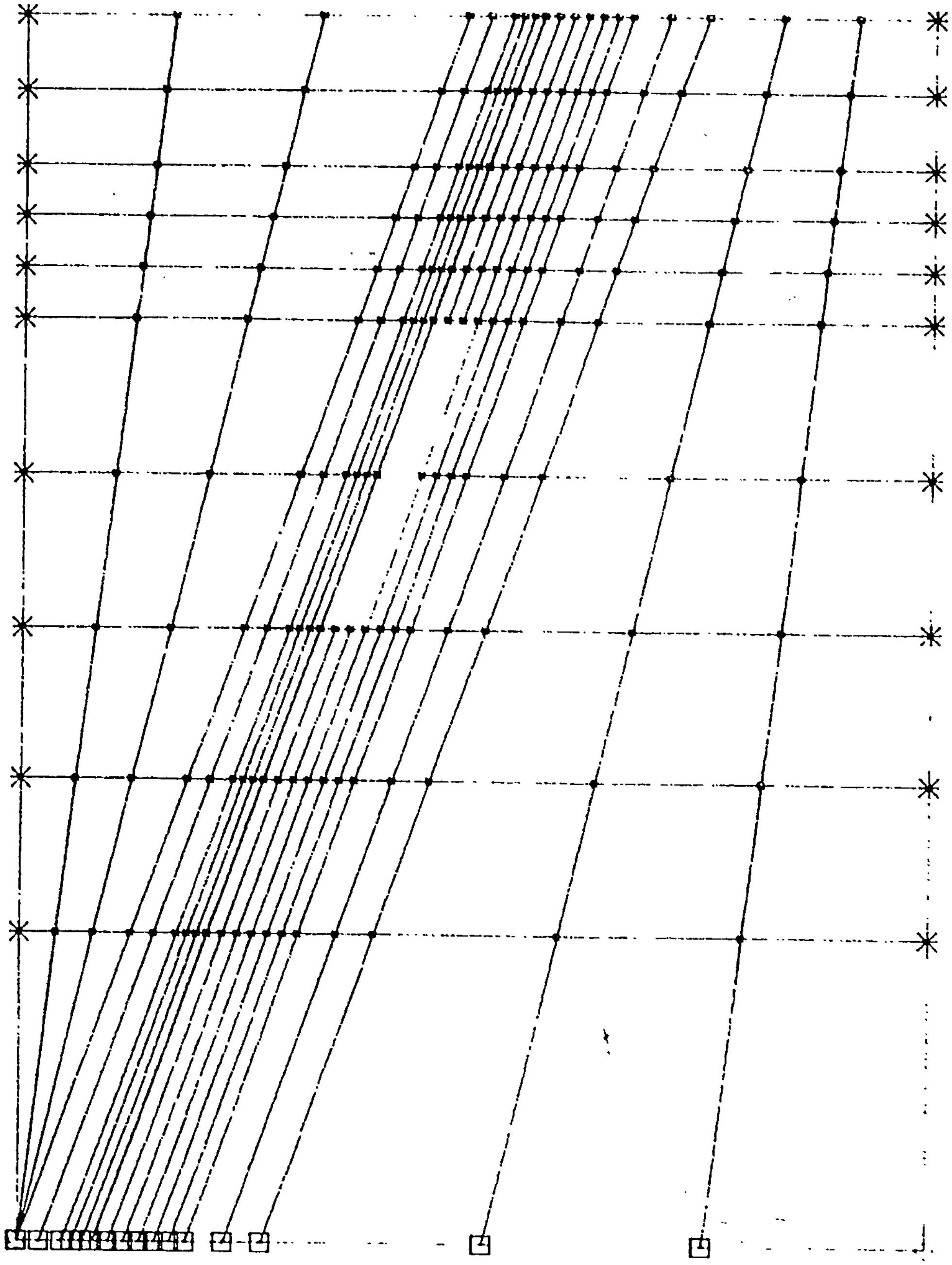


Figure 4. Mesh used for Holt Mc Dermott numerical modelling