CAPABILITIES, LIMITATIONS AND THE USE OF THE GEOROC COMPUTER PACKAGE

Y.S. Yu

Canadian Mine Technology Laboratory

August 1987

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ABSTRACT

Computer codes have been used by various researchers in modelling viscoelastic formations, with a good degree of success. Serata used a complex rheological model, REM (Rheological Element Model) code, to simulate mine openings [2]. Others, in the U.S. Nuclear Waste Isolation Programme, have evaluated the capability of various codes for the design of nuclear waste repository [3]. Because of the proprietary nature of the above codes, they are not available to mine operators in Canada. Consequently, in 1984, CANMET initiated a research project to develop a numerical modelling package for use in the design of underground potash mine openings. GEOROC is the resultant computer program; it was developed by RE/SPEC Ltd., of Calgary under contract to CANMET.

In recent years, computer simulation is playing an increasingly important role in evaluating the short and long term structural stability of underground mine openings, and in ground control studies related to mine design and layout. Such simulations are increasingly being used in the design of underground salt and potash mines.

Because of the viscoelastic nature of salt rock formations, simulation models must take into consideration their time dependent properties if they are to correctly predict opening closures, ground stresses, and ground stability based on prescribed failure criteria.

This presentation describes the capabilities, limitations and the use of computer code - GEOROC. A case history in which GEOROC is used to simulate a typical room and pillar mining section of a Western Canadian potash mine is provided. Predicted ground behaviour using the code is compared with actual behaviour as determined through field measurements. Results indicate that good correlation exits between predicted and measured ground behaviour, and is an encouragement to greater use of modelling in mine stability studies related to mine design.

POSSIBILITÉS, LIMITES ET UTILISATIONS DE LA COLLECTION DE PROGRAMMES GEOROC

par

Y.S. Yu

RÉSUMÉ

Des codes machine ont été utilisés avec un certain succès par les différents chercheurs au cours de la modélisation des formations viscoélastique. Serata a utilisé un modèle rhéologique complexe, soit le code REM (Rheological Element Model), dans le but de simuler les ouvertures de mines (2). Aux États-Unis, d'autres chercheurs du "Nuclear Waste Isolation Program" ont évalué le potentiel de plusieurs codes utilisés pour la conception des dépôts pour le déchets nucléaires (3). En raison des droits de propriété attachés aux codes susmentionnés, ils ne sont pas disponibles aux exploitants de mines au Canada. Par conséquent, en 1984, CANMET a entrepris un project de recherche dans le but de développer un programme de modélisation numérique utile à la conception des ouvertures de mines de potasse. GEOROC, le programme qui en est résulté, a été développé par RE/SPEC Ltd. de Calgary dans le cadre d'un contrat du CANMET.

Au cours des dernières années, la simulation sur ordinateur joue un rôle de plus en plus important dans le cadre de l'évaluation à court et à long termes de la stabilité structurale des ouvertures de mines souterraines, et des études sur le contrôle du sol se rattachant à la conception et à la planification des mines. L'emploi de ces programmes de simulation ne cesse d'augmenter dans le cadre des travaux de conception des mines souterraines de sel et de potasse.

En raison de la nature viscoélastique des formations de sel gemme, les propriétés qui dépendent du temps sont l'un des facteurs dont doivent tenir compte les modèls de simulation lorsqu'ils servent à prédire la fermeture des ouvertures de mines, les contraintes du sol ainsi que la stabilité du sol d'après des critères d'échec fixés.

Le présent rapport a donc pour but de décrire les possibilités, les limites et les utilisations du code GEOROC. Il présente de plus, l'historique d'un cas où GEOROC a servi à la simulation d'une galerie type et d'une section exploitée par piliers d'une mine de potasse de l'Ouest canadien. Une comparaison entre le comportement du sol prévu par le code et comportement réel du sol déterminé par des measures sur le terrain a été réalisée. Les résultats obtenus ont indiqué qu'il existe de bonnes corrélations entre le comportement du sol prévu par le code et celui mesuré sur le terrain. Enfin, ces résultats encouragent à faire une plus grande utilisation de la modélisation minière dans le cadre des études effectuées dans le domaine de la conception minière.

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1.0 INTRODUCTION

Computer codes have been used by various researchers in modelling viscoelastic formations, with a good degree of success. Serata used a complex rheological model, REM (Rheological Element Model) code, to simulate mine openings [1]. Others, in the U.S. Nuclear Waste Isolation programme, have evaluated the capabilities of various codes for the design of nuclear waste repository [2]. Because of the proprietary nature of the above codes, they are not available to mine operators in Canada. Consequently, CANMET initiated a research project, in 1984, to develop a numerical modelling package for use in the design of underground potash mine openings. GEOROC is the resultant computer program; it was developed by RE/SPEC Ltd., of Calgary under contract to CANMET [3]. In May 1986, two technology transfer workshops were organized to transfer GEOROC to the Canadian potash mining industry.

The potash industry has considerable economic incentive to increase the present percentage extraction rate provided mine stabilities are not adversely affected [4]. To assist them in the stability assessment of new mining configuration permitting higher extraction ratio, the potash industry is increasingly turning to the use of analytical techniques which have proven so beneficial to the hard rock mining industry in design studies.

Measurements of opening closure and stresses in pillars and abutments, in salt and potash mines, clearly indicate the creep behaviour of the formations involved. Computer simulation codes developed for the assessment of the short and long term stability of salt and potash mine openings, must take into consideration the viscoelastic behaviour of the formations.

In this presentation, the capabilities, limitations and the use of GEOROC and its theoretical background are briefly discribed. A case history study which was used to validate the computer code and to assess the structural stability of underground openings in a potash mine is discussed. The validation study consisted of comparing theoretical code predictions with field measurements for the mine section being simulated. It was hoped that the study would provide an additional incentive for the use of numerical modelling in potash mine design and planning.

2.0 GEOROC COMPUTER PROGRAM

The computer program GEOROC was developed by RE/SPEC of Calgary, Alberta, under contract to the Canada Centre for Minerals and Energy Technology (Canmet), Energy, Mines and Resources Canada [3]. GEOROC, a finite element code, employs eight-noded isoparametric quadrilateral elements, and uses a frontal solution solver. It is a two-dimensional (plane and axisymmetric) structural analysis program which can analyze

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a wide range of underground mining problems involving complex shaped openings, varied mining sequences and support methods, including backfill. Elastic and/or viscoelastic materials with complex geologic stratification can be modelled. The GEOROC code is written in Fortran 77 for portability, and is currently running on a VAX 11/750 computer.

2.1 Capabilities and Limitations

The capabilities and limitations of the software can be summarized as follows:

(a) Geometry: Two dimensional plane stain, plane stress and axisymmetric.

(b) Material: Isotropic elastic and/or viscoelastic material properties. Each element in the mesh may have its material specified individually.

(c) Mining sequence: Initial and a number of sequential excavations including backfill can be simulated.

(d) Pressure loading: Pressure may be applied to the interior walls of the the excavations for simulation of support systems, and backfill, etc.

(e) Boundary conditions: Kinematic (displacement) constraints, external surface loading, and skewed boundary orientation relative to axes are incorporated.

(f) Initial stresses: Initial stresses are evaluated based on overburden specific weight and lateral earth pressure coefficient or based on body forces.

(g) Changes of properties: Mechanical properties may be changed during the analysis. This alteration is done when a user-specified closure has been reached or at user-specified times; it is intended for modelling backfill behaviour.

Several program limits are currently imposed due to the array sizes. They are:

(a) Number of sequential excavations $\leq$ 5.

(b) Number of elements along the periphery of excavation $\leq$ 50.

(c) Number of nodes at which output is requested $\leq$ 350.

(d) Number of elements at which output is requested $\leq$ 100.

In addition, this program has no restart capability.

2.2 Other Remarks

The GEOROC software package consists of the following programs:

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(a) GEOMESH - It is a mesh generator which follows very closely Zienkiewicz's concept of mapping via isoparametric shape functions. This pre-processor or mesh generator is quite flexible and allow a variety of complex meshes to be generated with relative ease. The mesh can be easily graded from very dense in the regions of concern to very sparse at the boundaries. In general, GEOMESH is quite adequate for modelling purpose.

(b) GEOROC - This is the main finite element program.

(c) Post-processor - A number of sub-programs, ALGEBRA, TPLOT and SPLOT were developed for post-processing. To run ALGEBRA, TPLOT or SPLOT, a third party software package, NCAR [5], must be available on the computer system. The use of these sub-programs is not interactive and 'user friendly'. This is, perhaps, one of the weak features of the GEOROC system.

2.3 Empirical Constitutive Creep Laws

A number of constitutive laws for rock salt have been applied in rock mechanics studies related to the design of underground storage structures in salt mines where stress, temperature and time are significant in terms of time-dependent deformation [6]. Senseny and Carter have carried out a comprehensive review of the constitutive laws available to describe salt creep [3]. Detailed discussion of the constitutive laws developed to describe salt/potash materials deformational behaviour is beyond the scope of this study. However, during the development of the GEOROC code, it was considered important that the code should permit modelling of both transient and steady state of these materials. Three empirical laws were incorporated within the GEOROC code, namely: the power law, the time-exponential law and the Norton power law. These laws were selected because they are simple and have received relatively wide use. Also, they require relatively few parameters to be defined, and there exists a relatively large base of case-histories and laboratory experiment data [3,6].

The three empirical laws incorporated into the GEOROC code are:

The power law:

$$\varepsilon = A s^m t^n$$

The exponential-time law:

$$\varepsilon = \varepsilon_{ss} t + \varepsilon_a [1 - exp(-B\varepsilon_{ss}t)] \qquad for \ \varepsilon_{ss} \geq \varepsilon^*$$
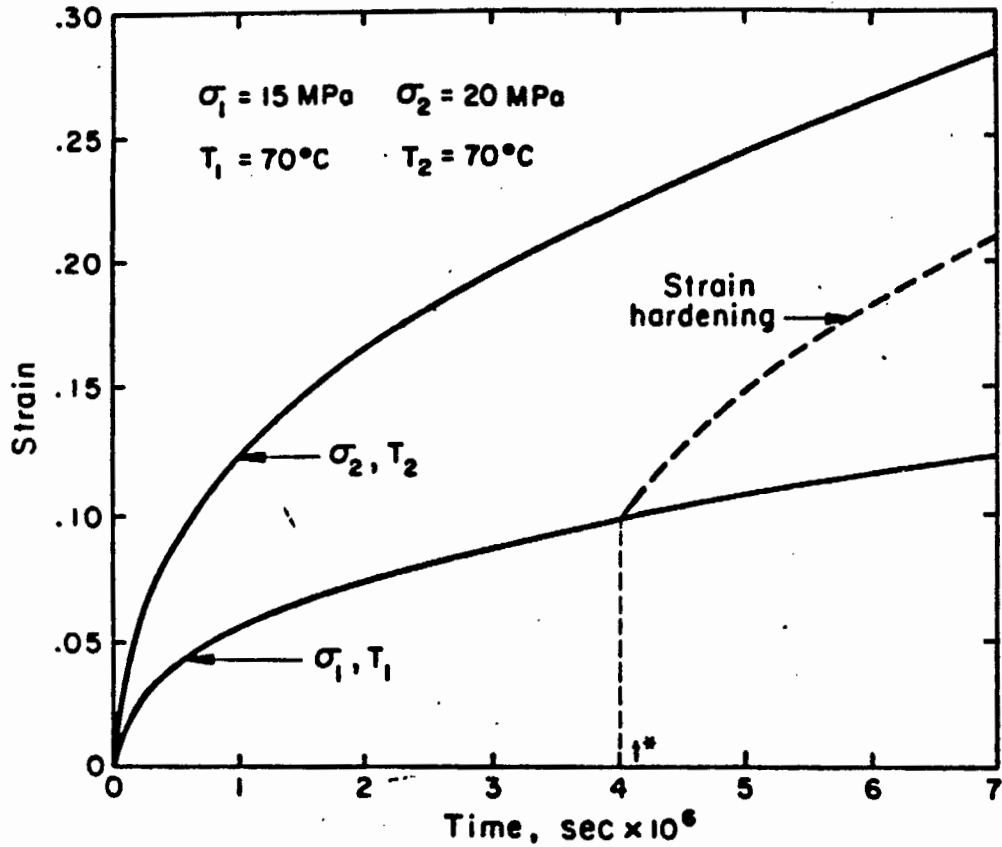
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Fig. 1 Typical creep strain vs time curve and strain-hardening strategies to account for creep strain under non-constant stress and temperature histories (After Fossum)

$$\varepsilon = \varepsilon_{ss}t + \varepsilon_a \varepsilon_{ss}/\varepsilon^*[1 - exp(-B\varepsilon * t)] \quad for \quad \varepsilon_{ss} < \varepsilon^*$$

The Norton power law:

$$\varepsilon_{ss} = As^m.$$

where ε = creep strain

s = deviatoric stress

t = time

$\varepsilon_{ss} = As^m$ (steady state strain rate)

ε^* = critical strain rate

A, B, m, n, ε_a = parameters to be determined experimentally.

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A typical creep strain vs time curve and strain-hardening strategies to account for creep strain under non-constant stress and temperature histories is shown in Fig. 1. The code allows for the nonlinear creep behaviour of materials by using an incremental procedure in which a successive series of linear solutions for each time step is carried out [3,7,8].

3.0   A CASE HISTORY STUDY

3.1   General Description of The Mine

The mine used in the case history study is located in the south-eastern Saskatchewan, Canada. In this area, the prairie evaporates consist of alternate beds of halite and sylvite, and are approximately 140m thick. The salt back averages 30m in thickness and overlies the 2.4 m thick potash seam being mined. The back is relatively free of clay seams, and Dawson Bay dolomite overlies the evaporates. The potash seam is at an approximate depth of 960 m and is mined using a long room and pillar mining system. Panel recovery averages 40% while overall mine recovery is around 35%. The geological setting and mining sequence for the section under study are shown in Fig. 2.

3.2   Finite Element Representation

As shown in Fig. 2, a panel of two rooms, was modelled. The rooms are located at a depth of about 960 m (3150 ft) in the prairie evaporate formation. The rooms are 25.9 m (85 ft) wide separated by a 37.2 m (122 ft) wide pillar. In practice, the 25.9 m rooms were mined in four individual passes. In this study, to reduce computer time, Room 1 was mined in four passes but Room 2 was mined in one pass (step 5). The mining sequence is indicated by numbers 1, 2, ... 5 in Fig. 2. The finite element model shown in Fig. 2 represents only one half of the model used in the study. Advantage could not be taken of mine symmetry to reduce the size of the model because of mining sequence asymmetry.

The finite element mesh shown in Fig. 3 was generated by GEOMESH - the mesh generator. It consisted of 504, 8-noded elements and 1605 nodes. Plane strain conditions were assumed.

No field stress measurements were available as basic input information for the study. It was assumed that the initial field stress conditions were due to gravitational loading which provided a gradient of 0.0226 MPa/m (1 psi/ft) under hydrostatic conditions. Overburden stresses were simulated by applying a distributed pressure of 21.6 MPa as shown in Fig. 2.

In the study, the power law was selected for modelling the time dependent behaviour of salt and potash materials. This law is commonly used to describe the transient creep which follows excavation. The power law was selected because it requires less input parameters than the exponential-time law.
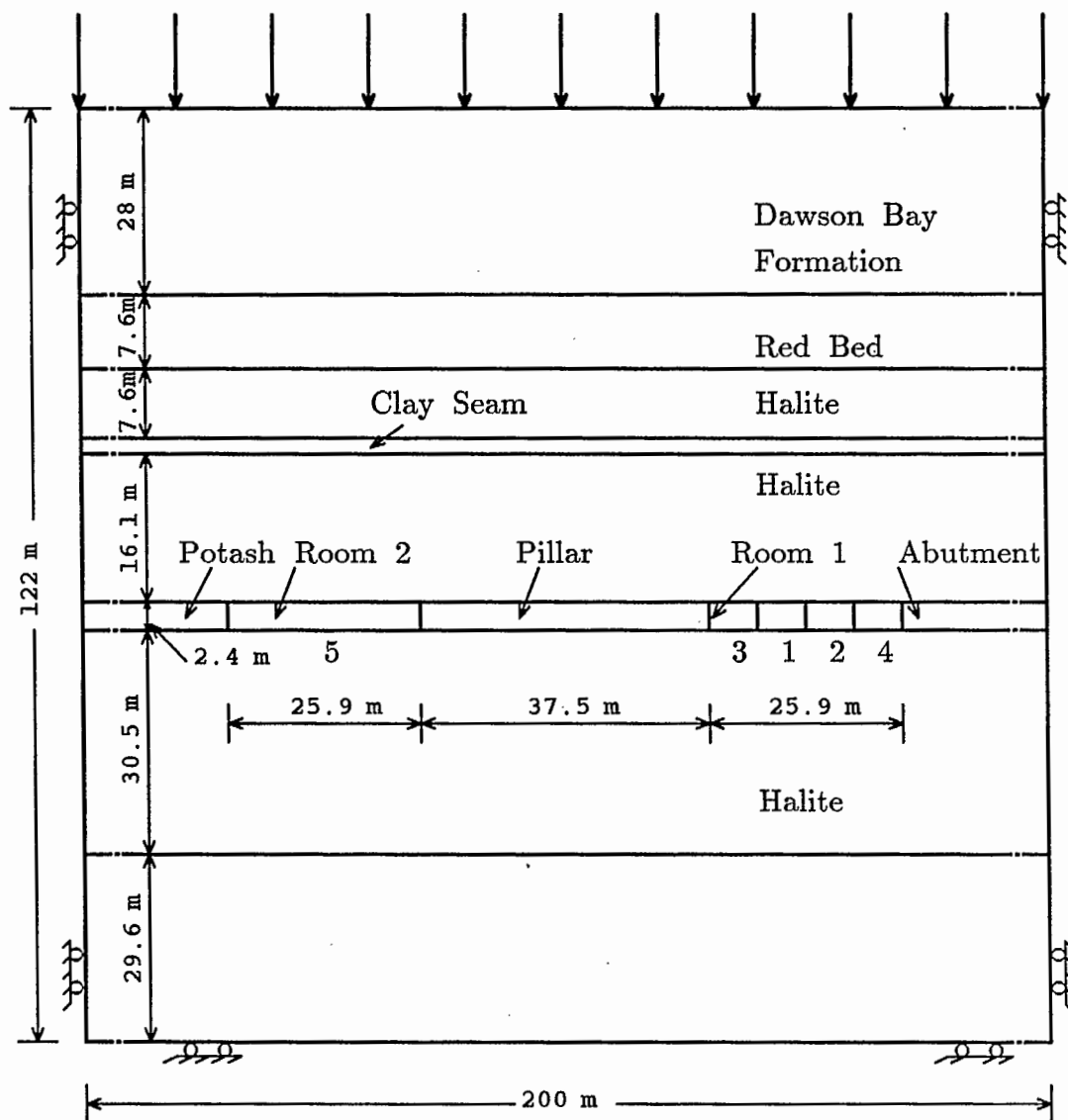
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Fig. 2 Diagram showing the geological settings, model dimensions,
mining sequences, and boundary conditions

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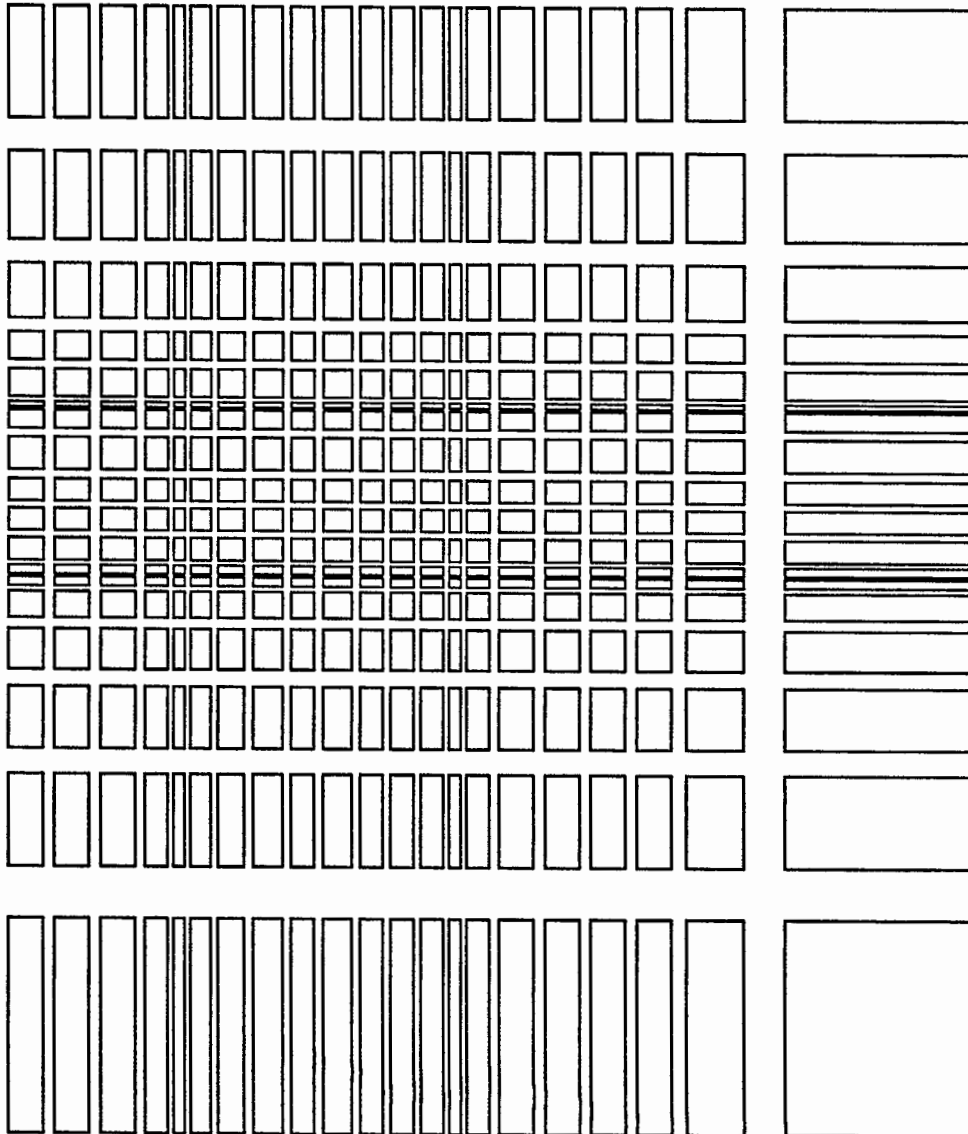
Fig. 3 Finite element mesh showing only one half of the structure

Table 1. Material Properties of the Geological Formations used in Modelling study

Items	Halite (roof)	Halite (floor)	Potash	Clay Seam	Red Beds	Dawson Bay Formation
E (MPa)	5,060	5,336	3,268	1,455	14,546	33,011
ν	0.46	0.46	0.46	0.44	0.27	0.28
γ (Kg/m³)	2,200	2,200	2,700	2,200	2,300	2,700
A	$.26 \times 10^{-10}$	$.26 \times 10^{-10}$	$.26 \times 10^{-10}$	$.26 \times 10^{-10}$	n/a	n/a
m	7.0	7.0	7.5	7.0	n/a	n/a
n	.39	.39	.39	.39	n/a	n/a

E, ν and γ are Young's modulus, Poisson's ratio and density, respectively.
A, m and n are the parameters used for the power law in GEOROC.

The modulus of deformation, E, Poisson's ratio, ν, and density, γ, were determined in laboratory tests. The parameters A, m and n were chosen from the limited information available on them in the literature [3,6]. The material properties used are shown in Table 1.

3.3 Results

In this study, a typical room and pillar mining section in a Canadian potash mine was simulated at the time of machine excavation passes 1, 2, 3 and 4 in Room 1: 0.007, 14, 27 and 46 days, respectively, relative to reference excavation commencement. In practice, each pass takes a few days to complete, however, for simplicity, the mining of a pass was assumed to be instantaneous at the indicated time. Room No. 2 was excavated as one pass 127 days after excavation commenced in Room 1. The study was run for a period of 750 days. The following study results were extracted from a paper presented at the International Conference on Computational Plasticity, April 1987 [9].

3.3.1 *Room Convergence*

Measurements of room closure is of great practical interest in potash mining. For the mine section simulated, convergence measurements were taken at the centre of each pass following mining. An initial reading was taken after the completion of the excavation.

The total closure for all four passes in Room 1, calculated from GEOROC, are plotted in Figs. 4a, 4b, 5, and 6. The corresponding field measurements for each pass are plotted on the same figures for direct comparison. As indicated by these graphs, the measured and predicted room closures are in reasonably good agreement, measured closures are slightly lower than calculated closures. This is possibly due to the creep deformation which has occurred in 'the time' lag between the initial measurement and the time of excavation.

It should also be noted that the calculated roof sag, which accounts for more than 60% of total room closure, is consistent with field observations.

3.3.2 *Pillar and Abutment Stresses*

In potash mines, hydraulic borehole pressure cells are usually installed in pillars and/or abutments to monitor stress changes [10]. In this study, following the completion of all four passes in Room 1, boreholes were drilled into the pillars and/or abutments, more or less horizontally, for pressure cell installations. The cells, installed at pre-determined depths, were pressurized into place.

Fig. 7 shows calculated and measured abutment stress changes for a cell located 4.5 m from the the wall of Room 1 for a period up to 750 days after excavation. This cell was pressurized initially to about 14 MPa. The pressure dropped to about 10.2 MPa shortly after installation, and gradually increased to the predicted level. Creep would seem to stabilize about one year after excavation. As expected, both measured and calculated stresses were slightly higher than the virgin ground stress, 24 MPa. At greater distance from the mined openings, it is anticipated virgin ground stresses would be realized.

The measured stress changes, at about 3.5 m into the center pillar of Room 1, is shown in Fig. 8. The preset initial pressure, for this cell, was low; however, the pressure reading increased steadily and approached the predicted level about two years after installation. The change of stress vs time would appear to slow down after completion of the first year of mining. Both the measured and predicted stresses were approximately 30% higher than the virgin ground stress, which is not considered unreasonable for such a location in the center pillar.

3.3.3 *Abutment Pillar Expansion*

Extensometers are usually used to monitor the roof, floor, pillar and abutment expansion. The movement monitored at a distance of approximately 2 m into the abutment of Room 1 is shown in Fig. 9. The measured displacements (towards the opening) were consistently lower than the calculated displacements. A possible explanation is that by the time the extensometers were installed, significant creep had already occurred.
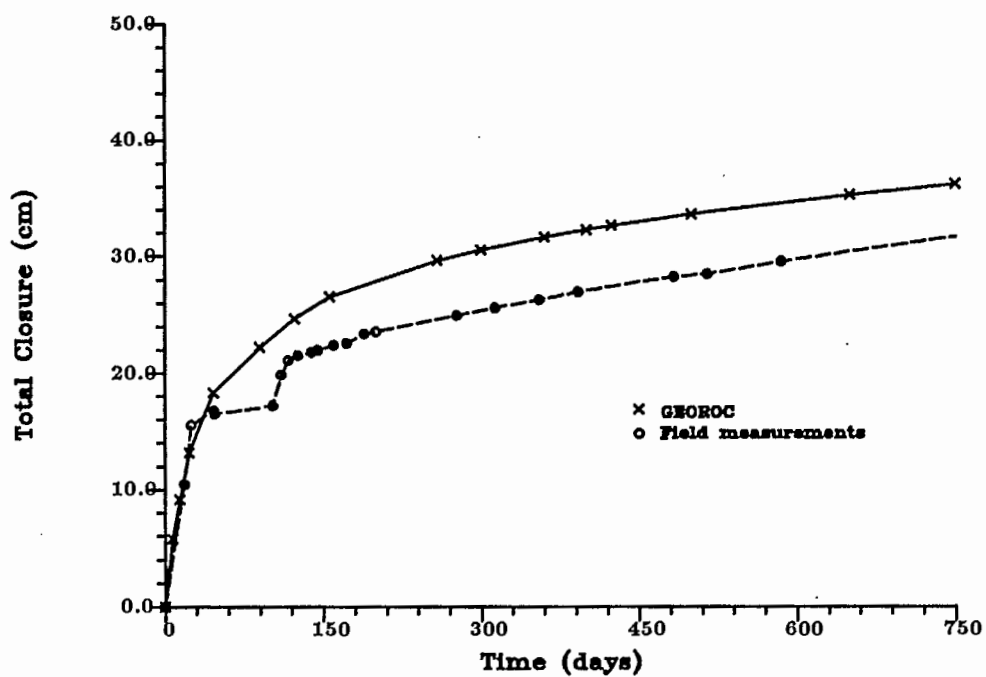
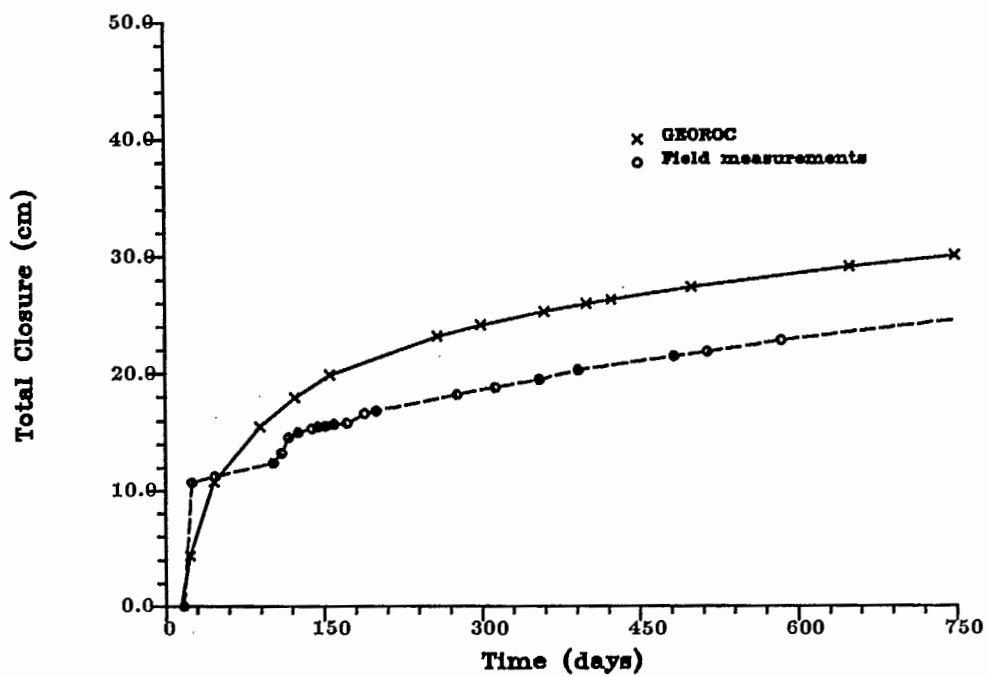Fig. 4a Total closure at the center of room 1 — 1st pass

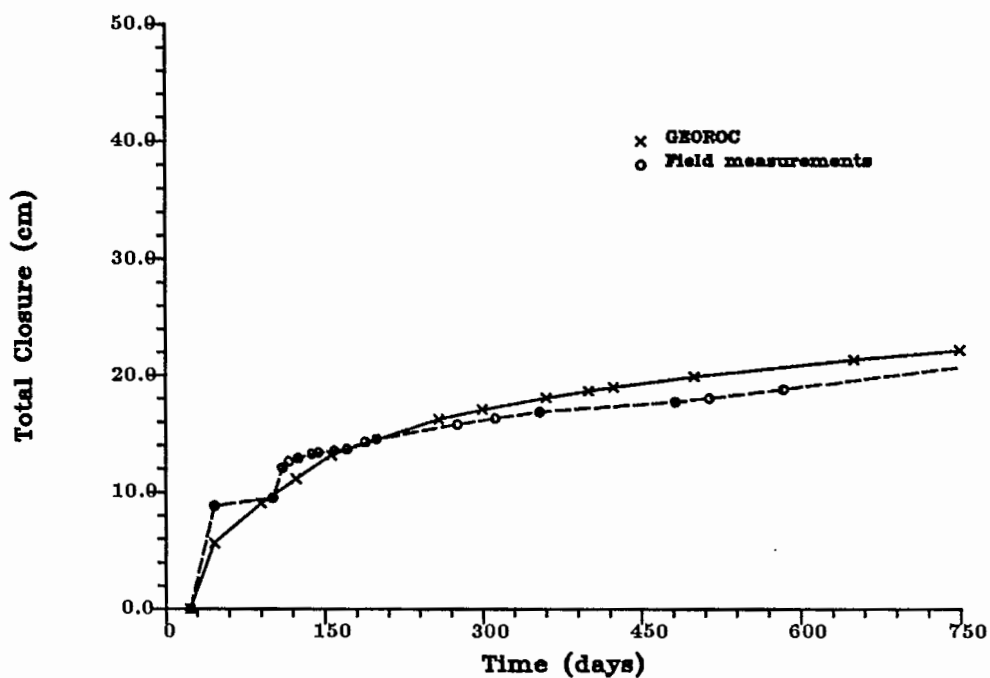Fig. 4b Total closure vs time — 2nd pass
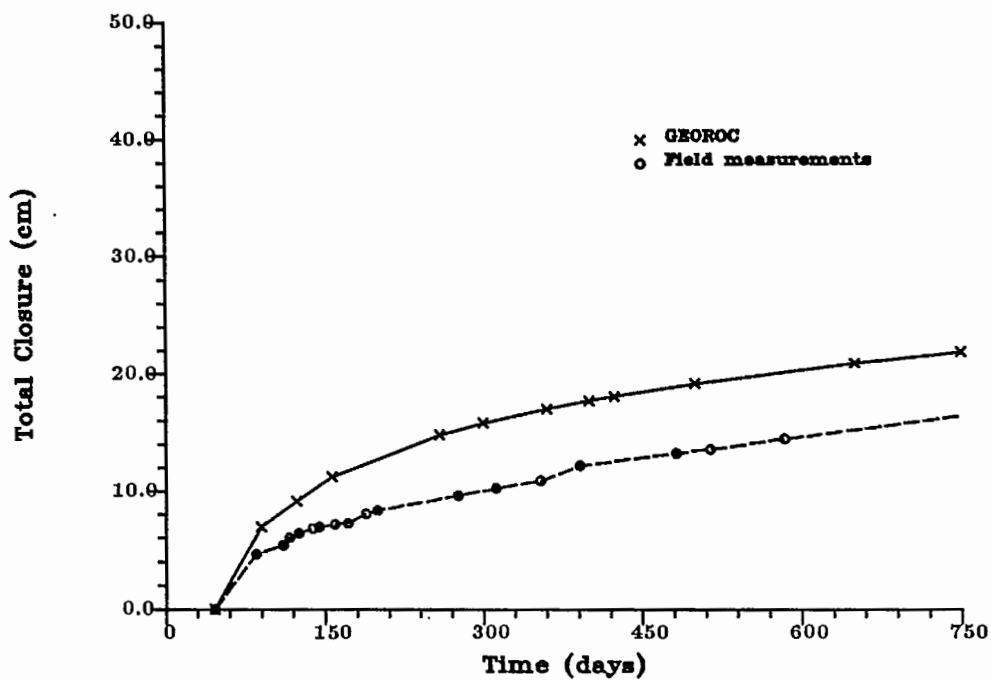
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Fig. 5 Total closure vs time — 3rd pass

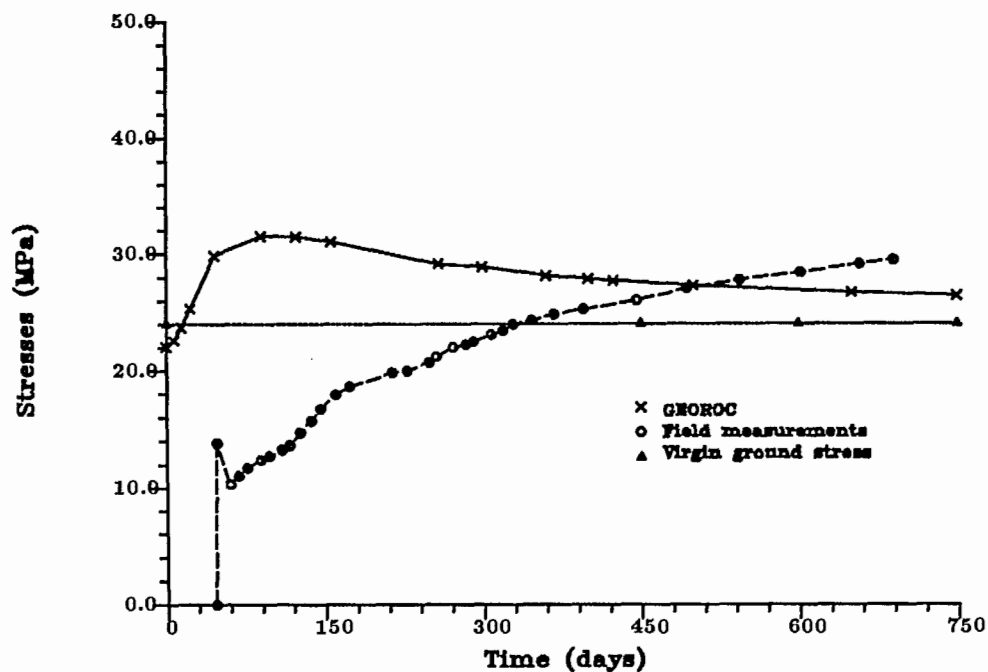**Fig. 6 Total closure vs time — 4th pass**

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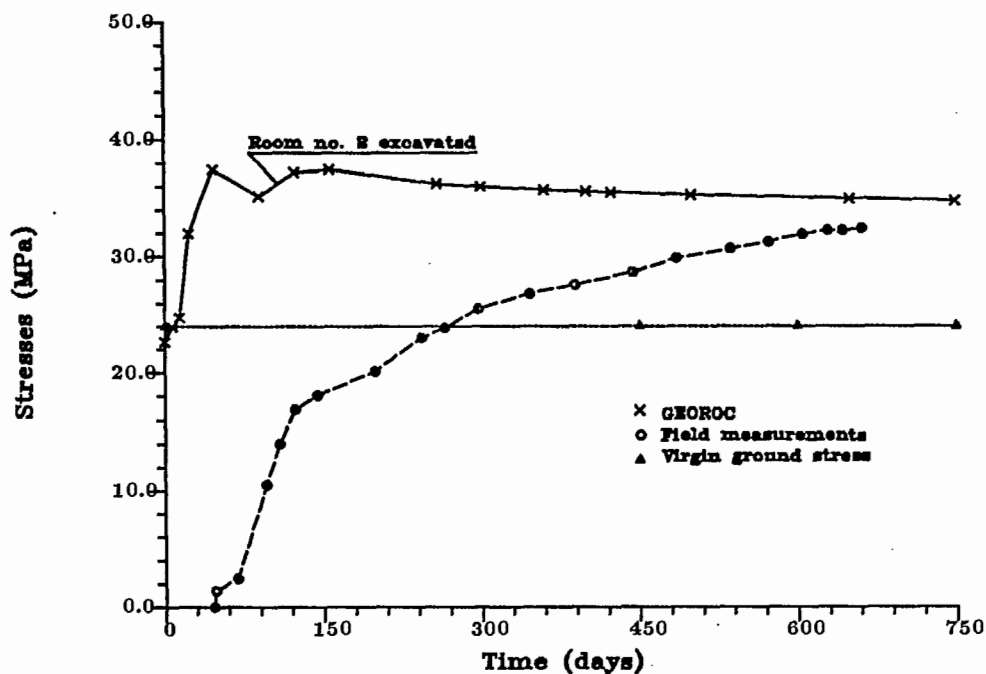**Fig. 7 Abutment stresses — 5.5m from the opening**

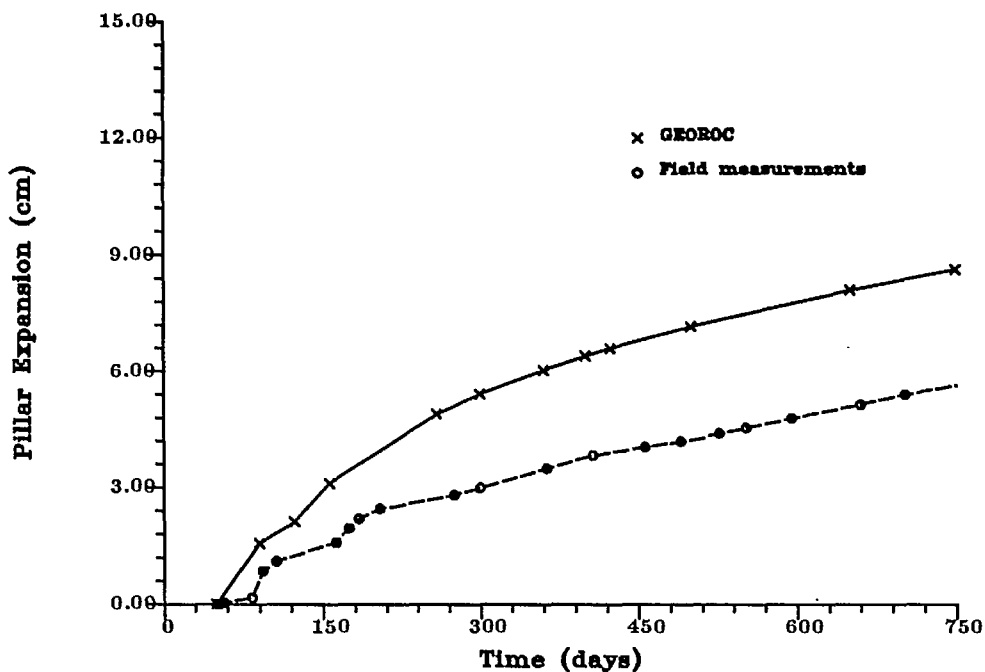**Fig. 8 Pillar stresses — 3.5m from the opening**

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Fig. 9 Abutment pillar expansion — 2m from the opening

4.0 *CONCLUSIONS*

GEOROC is a versatile and useful tool which has a wide range of potential applications in potash rock mechanics and mine design. However, a number of improvements can be made to make GEOROC program more 'user friendly'; a better post-processor should be incorporated.

Room closures and stresses predicted on the basis of mine simulation using the GEOROC code were in good agreement with stresses and closures measured in the test mine section simulated. The study supports the view that the use of quantitative analytic studies based on the use of computer modelling codes such as GEOROC, combined with a good instrumentation program, can be a valuable tool to mining engineers assessing the short and long term stability of potash mines. Mine modelling with such codes can also be used for field instrumentation placement to optimize data acquisition.

It is believed that computer modelling will become an even more valuable tool for salt rock mining as the viscoelastic behaviour of salt and potash materials become better known, through additional research. Back analysis of well-documented field data is another rational approach to establish a realistic database for salt rock.

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5.0 *ACKNOWLEDGEMENT*

6.0 *REFERENCE*

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