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COMPUTER SIMULATION OF A ROOM AND PILLAR MINING SYSTEM IN A CANADIAN POTASH MINE

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ABSTRACT

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, simulation models used in these deposits 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. A number of computer codes have been developed in Canada in recent years meeting these requirements.

This paper describes the use of one of these codes to predict the ground behaviour of a typical room and pillar mining section of a Western Canadian potash mine. Predicted ground behaviour, based on use of the code, was compared with actual behaviour through field measurements. The study provided good correlation between predicted and measured ground behaviour, and is an encouragement to greater use of modelling in mine stability studies related to mine design.

Key words: computer simulation, convergence, creep, finite element, viscoelastic

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SIMULATION SUR ORDINATEUR D'UN SYSTÉME D'EXPLOITATION PAR CHAMBRES ET PILIERS DANS UNE MINE CANADIENNE DE POTASSE

par

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RÉSUMÉ

La simulation sur ordinateur joue un rôle de plus en plus important dans l'évaluation de la stabilité structurale à court et à long termes des entrées de mine souterraine et dans les études de contrôle des terrains liées à la conception et à l'aménagement des mines. De telles simulations sont de plus en plus utilisées dans la conception des mines souterraines de sel et de potasse.

A cause de la nature viscoélastique du sel gemme, les modèles de simulation de ces gisements doivent tenir compte de leurs propriétés, qui varient dans de temps, pour prévoir correctement les obturations d'entrées de mine, les contraintes dans le terrain et la stabilité du terrain à partir de conditions prescrites de rupture. Plusieurs programmes informatique, mis au point au Canada au cours des dernières années, satisfont à ces conditions.

La présente communication décrit comment utiliser un de ces programmes pour prévoir le comportement du terrain dans un chantier d'exploitation par chambres et piliers d'une mine de potasse de l'Quest canadien. Le comportement du terrain, prévu au moyen du programmes, a été comparé au comportement réel établi à partir de measures prises sur le terrain. L'étude a montré que les comptements prévu et mesuré concordent bien, incitant les chercheurs à utiliser davantage la modélisation dans les études de stabilité des terrains liées à la conception des mines.

Mots clés: simulation sur ordinateur, convergence, fluage, élément fini, viscoélastique

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1.0 *INTRODUCTION*

Saskatchewan potash mines, by any standards, are comparatively efficient and safe. But present low ore extraction ratio, approximately 30% of ore in place, in terms of resource conservation is a major concern [1]. The potash industry has considerable economic incentive to increase present percentage extraction provided mine stabilities are not adversely affected. 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. In recent years, computer simulation codes have been developed which permit assessment of the short and long term stability of salt and potash mine openings, taking into consideration the viscoelastic behaviour of the formations.

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]. Recently in the U.S. Nuclear Waste Isolation programme, others have used various codes in evaluation of their capability for design of nuclear waste repository [3]. Because of the proprietary nature of the above codes, they are not available to mine operators in Canada.

The aim of this study was to validate a computer code, which has been developed for the Canadian potash mining industry, to assess the structural stability of underground openings in a potash mine. 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. A typical room and pillar mining section in a Canadian potash mine was used in this study.

2.0 THE MINE

2.1 *General Description*

The mine used in this study is located in the south-eastern Saskatch- ewan, 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. 1.

2.2 *Finite Element Representation*

As shown in Fig. 1, 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. 1. 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. 2 was generated by a 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. The overburden stresses were simulated by applying a distributed pressure of 21.6 MPa as shown in Fig. 1.

3.0 *COMPUTER PROGRAM*

The computer program GEOROC, used in this study, 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 [4]. 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 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.

In rock mechanics studies, a number of constitutive laws for salt were applied in the design of underground storage structures in salt mines where combination of stress, temperature and time are significant in terms of time-dependent deformation [5]. Senseny and Carter also presented comprehensive reviews of constitutive laws for salt creep [4]. Detailed discussion of the constitutive laws for salt/potash materials is beyond the scope of this study. However, during the development of the GEOROC code, it was considered

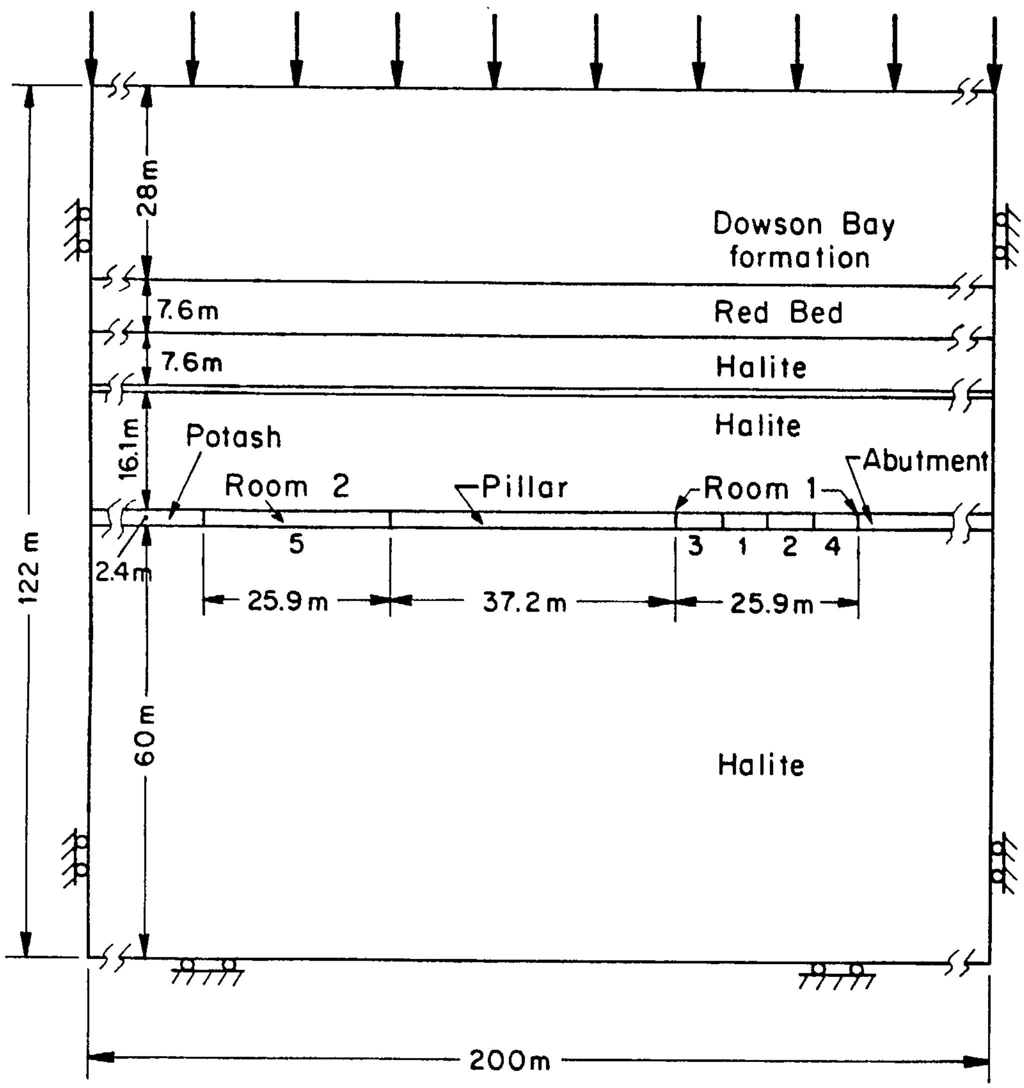

Fig. 1 Diagram showing the geological settings, model dimensions, mining sequences, and boundary conditions

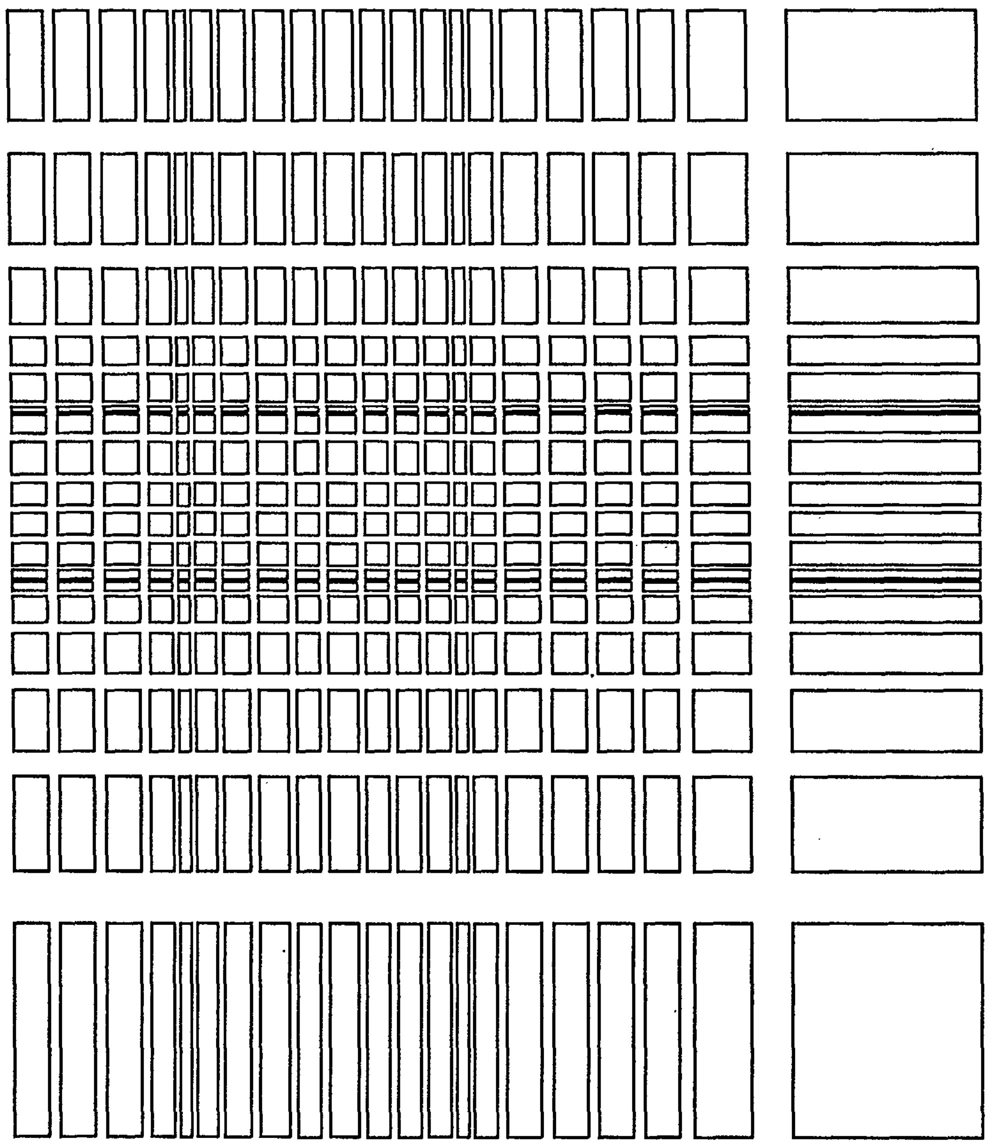

Fig. 2 Finite element mesh showing only one half of the structure

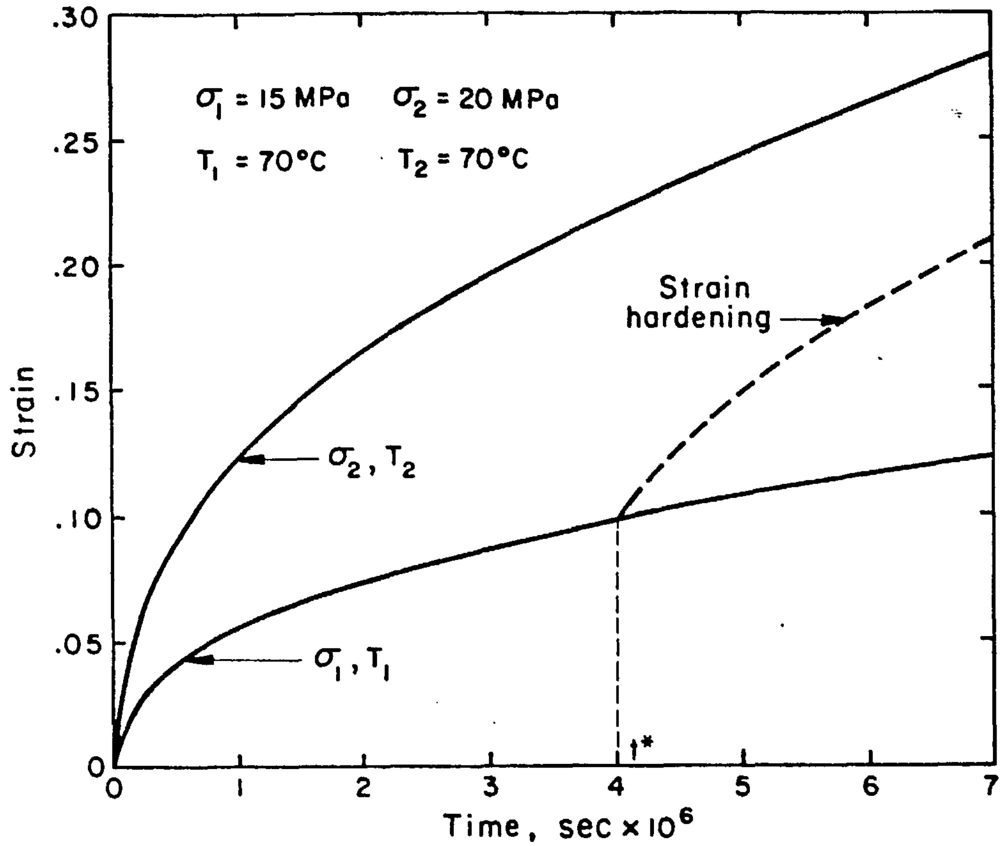

Fig. 3 Typical creep strain vs time curve and strain-hardening strategies to account for creep strain under non-constant stress and temperature histories (After Fossum)

important that the code should be able to model both transient and steady state creep of salt/potash materials. Three empirical laws were recommended and incorporated within the GEOROC code, namely: the power law, the time-exponential law and the Norton power law. These laws have been selected because they are simple and have received relatively wide use. They require relatively few parameters to be defined, and therefore, there is a relatively large data-base of case-histories and laboratory experiment data [4,5].

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 law is expressed as follows:

$$\varepsilon = As^m t^n,$$

where ε is effective creep strain, s is effective stress, and t is time since loading. A, m and n are experimentally determined parameters. Since ambient temperature in a potash mine is constant, the impact of temperature on material properties has been incorporated into parameter A. A typical creep strain vs time curve is shown in Fig. 3.

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/m^3)	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	6.5	6.5	7.5	6.5	n/a	n/a
n	3.9	3.9	3.9	3.9	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 code allows for the nonlinear creep behaviour of the materials in this study by using an incremental procedure in which a successive series of linear solutions for each time step is carried out [4,6,7].

The GEOROC code is written in Fortran 77 for portability, and is currently running on a VAX 11/750 computer.

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 [4,5]. The material properties used are shown in Table 1.

4.0 *RESULTS*

In this study, a typical room and pillar mining section in a Canadian potash mine was simulated, and machine passes 1, 2, 3 and 4 in Room 1 were excavated at 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.

4.1 *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 with measured closures being slightly lower than calculated closures. This is possibly due to the crrep 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.

4.2 *Pillar and Abutment Stresses*

In potash mines, hydraulic borehole pressure cells are usually installed in pillars and/or abutments to monitor stress changes [8]. 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 of 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.

4.3 *Abutment Pillar Expansion*

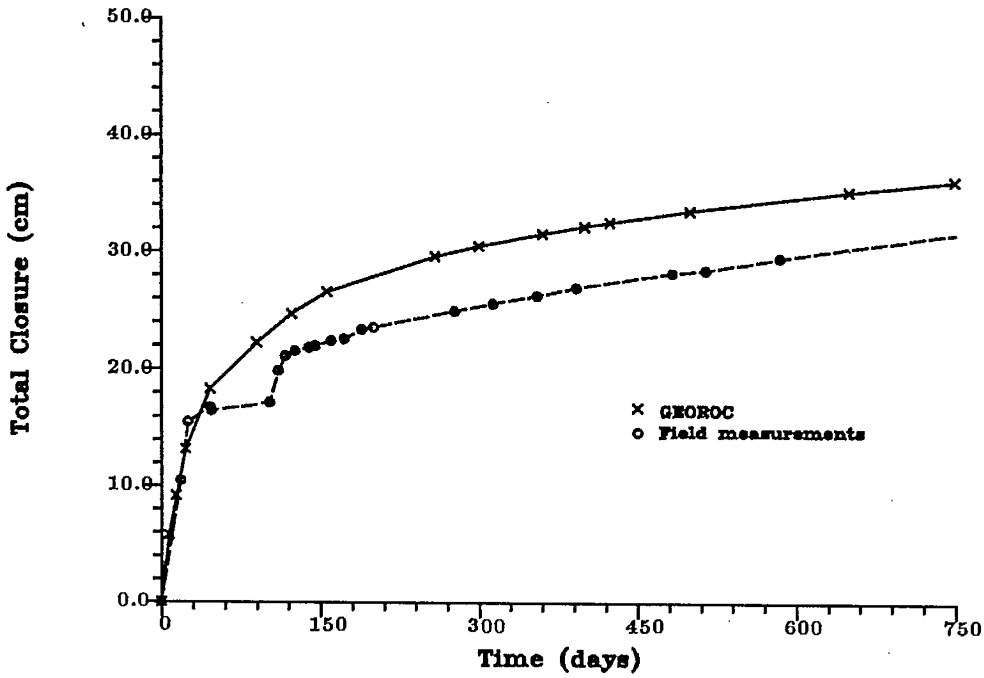

Fig. 4a Total closure at the center of room 1 – 1st pass

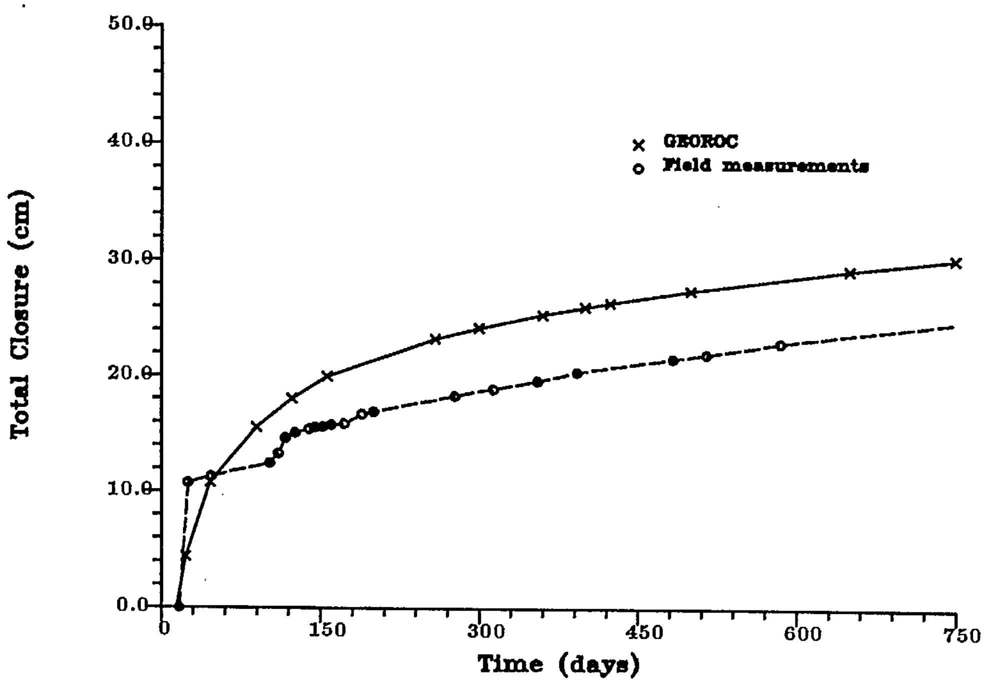

Fig. 4b Total closure vs time – 2nd pass

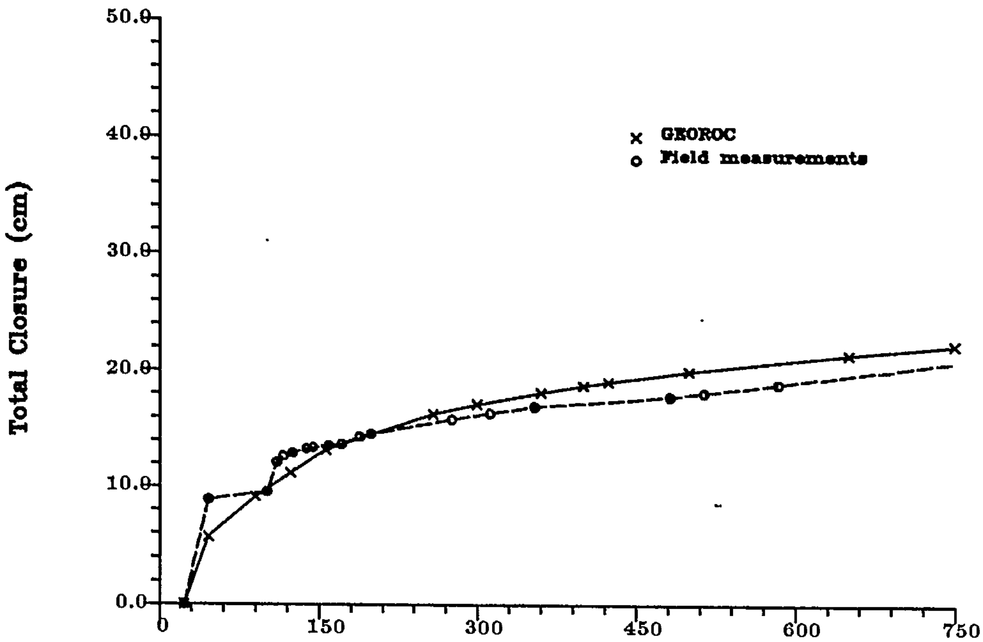

Fig. 5 Total closure vs time – 3rd pass

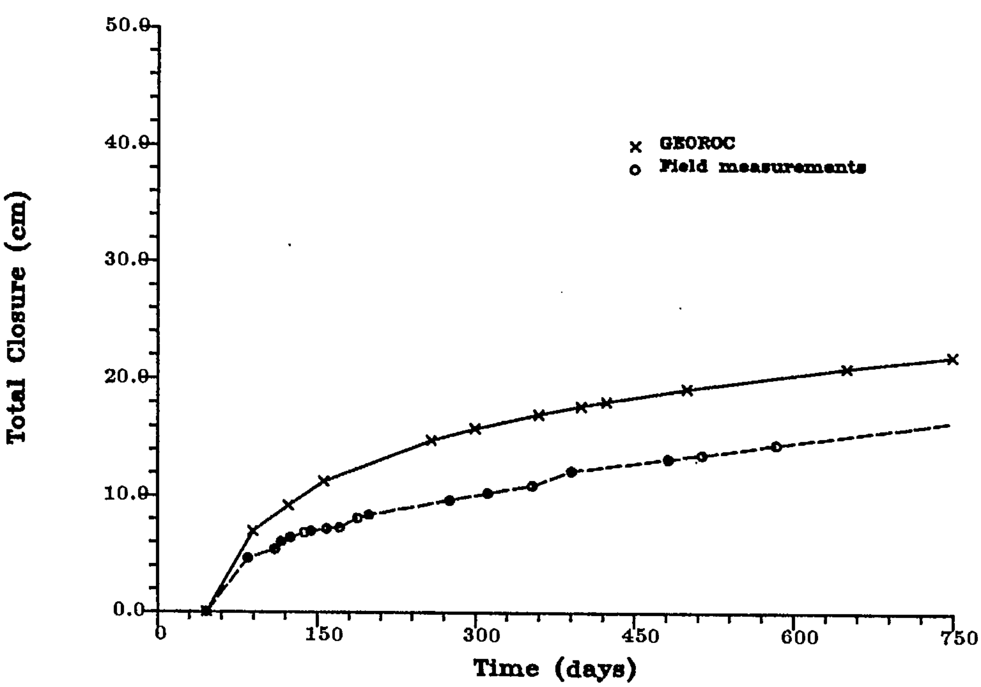

Fig. 6 Total closure vs time – 4th pass

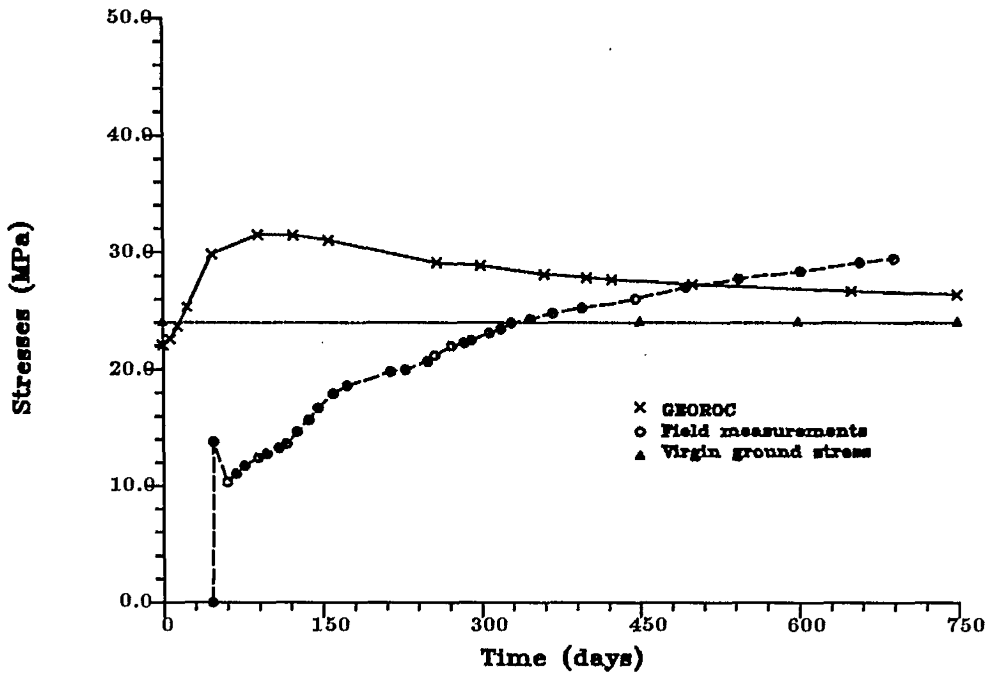

Fig. 7 Abutment stresses – 5.5m from the opening

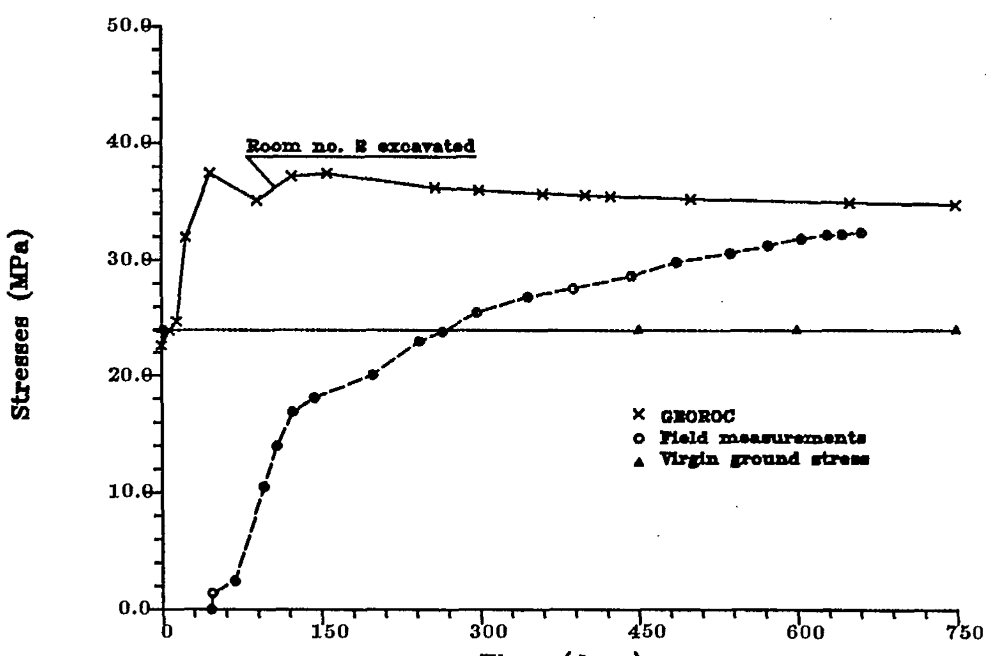

Fig. 8 Pillar stresses – 3.5m from the opening

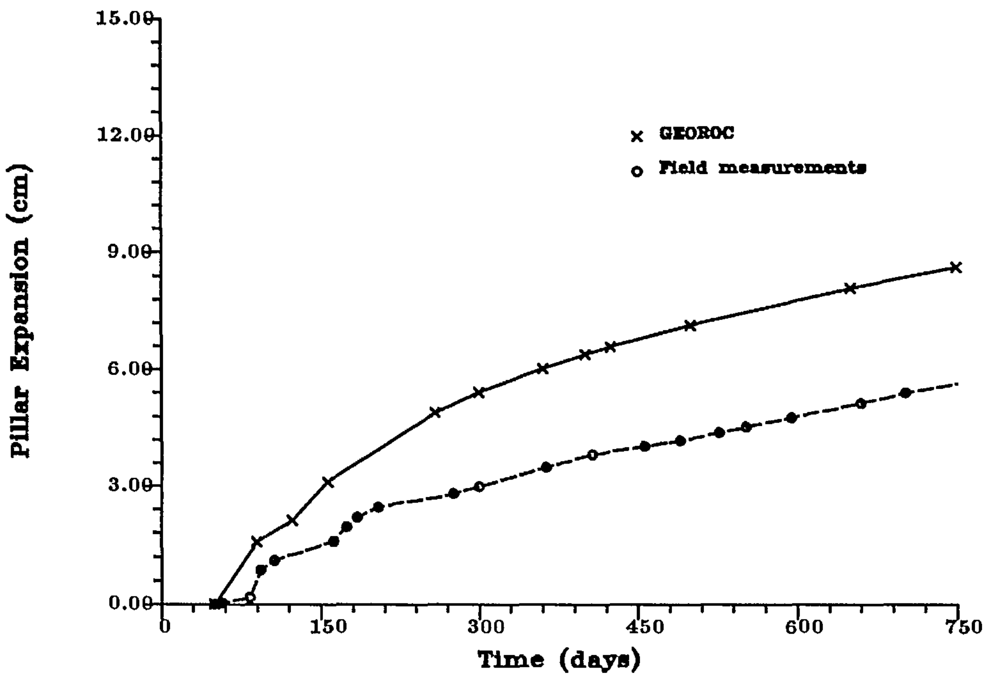

Fig. 9 Abutment pillar expansion – 2m from the opening

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, a significant creep had already occurred.

5.0 *CONCLUSIONS*

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 to more accurately establish the viscoelastic properties of salt rock.

6.0 *ACKNOWLEDGEMENT*

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