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The effect of loading history on stress generation due to inelastic deformations around deep-level tabular stopes

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SYNOPSIS

This paper demonstrates that the horizontal stresses induced by the creation of a tabular stope in a single mining step are always tensile at the centre of the stope span, but that compressive stresses are actively generated in hangingwalls and footwalls during sequential mining. A stress-distribution mechanism is introduced, and is used to explain the results for elastic behaviour, and for inelastic behaviour both during a single mining step and during multiple mining steps.

SAMEVATTING

Hierdie referaat toon dat die horisontale spannings wat deur die skepping van 'n tafelvormige afbouplek in 'n enkele mynboustap geïnduseer word, altyd trekspannings in die middel van die afbouplek se span is maar dat drukspannings aktief in die dakke en vloere ontwikkel word tydens opeenvolgende ontginning. Daar word 'n spanningsverspreidingsmeganisme bekend gestel en gebruik om die resultate vir elastiese gedrag, en vir onelastiese gedrag tydens sowel 'n enkele mynboustap as meervoudige mynboustappe te verduidelik.

Introduction

Analysis of the impact of underground excavations on the surrounding rock mass gained considerable impetus during the early 1960s when elasticity theory was applied to gold-mining problems by Salamon[1]. This approach to the modelling of the stress and displacement values induced by tabular mining was soon verified as appropriate at points in the rockmass remote from excavation surfaces. At the same time, it was recognized that large deviations from elastic results could be expected, particularly in the vicinity of a stope face.

More recently, attention has been directed to the detailed fracturing that arises ahead of and close to an advancing stope face, and that consequently becomes embedded in the immediate hangingwall and footwall regions of the stope[2-4]. A generalized conceptual model of such fracturing is shown in Fig. 1.

These studies have revealed a remarkable regularity of certain types of fracture, and suggest that it may be possible to apply numerical models to describe these phenomena. The fact that this has not as yet been achieved highlights a fundamental deficiency in the understanding of the underlying mechanisms connecting fracture formation and the accompanying re-distribution of stresses in stope boundary surfaces.

Elastic theory predicts that the tangential stress acting on the surface of a horizontal stope is given by[1]

$$\sigma_{xx}(x, 0) = -(1 - k)P_y \quad \text{(1)}$$

where x = direction of horizontal axis
y = direction of vertical axis
k = ratio of primitive horizontal to vertical stress
P_y = primitive vertical stress (MPa).

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Clearly, if the horizontal primitive stress is less than the vertical stress, the stress tangential to the stope hangingwall is strongly tensile; for example, if k = 0,5 and P_y = −54 MPa, σ_{xx} = 27 MPa (compressive stresses are regarded as negative in this paper).

It is important to note that σ_{xx} is directly proportional to the depth of the excavation, and that equation (1) applies to all the plane-strain stope configurations analysed by Salamon[1] in 1968 within zones where total closure does not occur. Since the predicted horizontal stress can exceed the tensile strength of the rock, it would be expected, on the basis of elasticity theory, that large extension fractures would open normal to the stope hangingwall and footwall, with concomitant instability of the fracture zone. This is not observed in practice, and it is evident that the horizontal stress is compressive. Some evidence[5] exists that, in certain cases, this may exceed 100 MPa in compression.

The explanation for the magnitude of horizontal compressive stress and for the inherent stability of the stope hangingwall is at present based on a number of conjectured hypotheses. These have been based largely on detailed observation of the fracture patterns that form in the vicinity of the advancing stope face[2,4,6]. It is basically inferred that slip on mining-induced fractures must be accompanied by dilation. It is postulated that this, in turn, is transmitted to the layers of rock formed by reef-parallel parting planes.

In this paper, it will be demonstrated that the horizontal stresses that are induced by the creation of a tabular stope in a single mining step are always tensile at the centre of the stope span for any realistic constitutive model. It will also be shown that active generation of compressive horizontal stresses in the hangingwall and footwall is possible when sequential mining steps are considered and inelastic deformations occur. A stress-distribution mechanism is introduced and used to explain the results

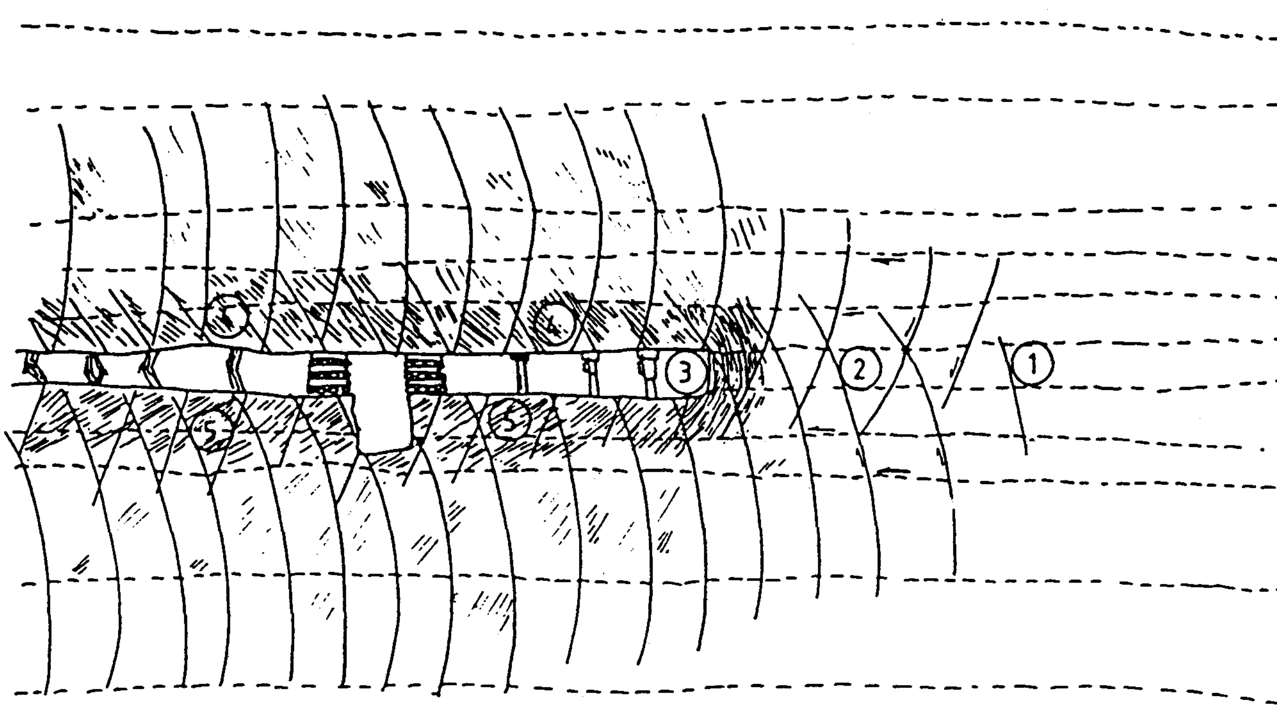


Fig. 1—A generalized conceptual model of fracturing (after Adams, Jager, and Roering[2])

from an elastic, a single-step inelastic, and a multiple-step inelastic approach. Proper insight into mechanisms determining the stress distribution in stopes is essential since this has a major influence on the direction and presence of fractures and the stability of stopes. It can be shown that preconditioning of the rockmass can be an important factor in the development of stresses, that support conditions can influence the stresses substantially and, finally, that the applied mining technique may also play a role. A discussion of these considerations is also included.

In this paper, the influence of sliding on bedding planes is not examined in detail; the paper focuses specifically on high-angle fracturing.

Elastic Continuum Approach

In many design problems of a tabular mining layout, the stope is modelled as an excavation in an elastic continuum. The stress distribution around a parallel-sided panel has been analysed by Salamon[7] and is shown in Fig. 2. It can be seen from the diagram that a region of tensile horizontal stresses exists above and below the panel. It is also apparent that, in the solid regions adjacent to the unsupported span in the plane of the excavation, the vertical and shear stresses will be high.

If the primitive vertical stress before mining is P_y, it can be shown that the induced horizontal stress acting along the centreline above the panel is given by[1]

$$\sigma_{xx}(0, y) = \left\{ -1{,}0 + \frac{y(2l^2 + y^2)}{(l^2 + y^2)^{1{,}5}} \right\} P_y, \qquad (2)$$

where l = half span of the panel
y = vertical distance above the panel.

The total horizontal stress is given by the sum of the primitive horizontal stress, P_x, and σ_{xx}. It can be seen from equation (2) that, at the stope horizon, $y = 0$, the induced horizontal stress is equal to $-P_y$. If $P_x = kP_y$, the total horizontal stress is given by equation (1). More importantly, the induced horizontal stress at the centre of the stope surface is independent of the stope span, $2l$.

By use of Salamon's analysis, it can also be shown that

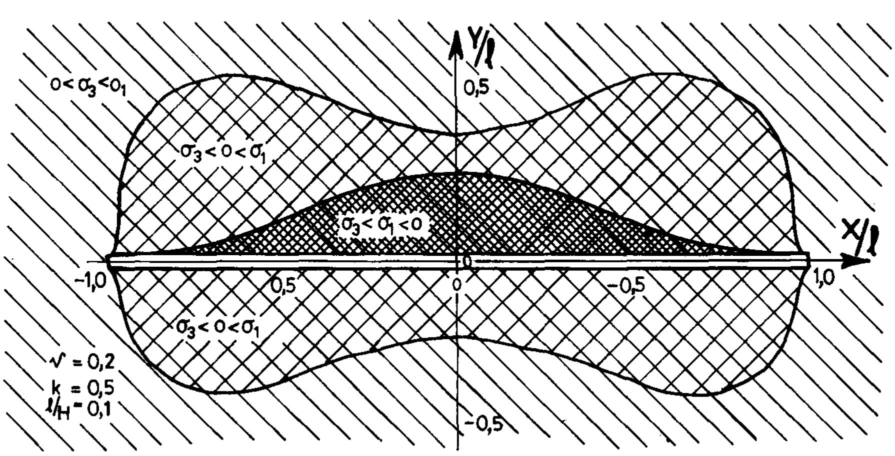


Fig. 2—Principal stresses around a stope in an elastic continuum (after Salamon[7])

the induced shear stress acting along the vertical plane at the edge of the panel, as shown in Fig. 3, is given by

$$\sigma_{xy}(l, y) = -P_y l^2 \cos\left\{\frac{3}{2}\left(\frac{\pi}{2} + \theta\right)\right\} y^{-0,5}(4l^2 + y^2)^{-0,75}, \quad (3)$$

where $\theta = \tan^{-1}(y/2l)$.

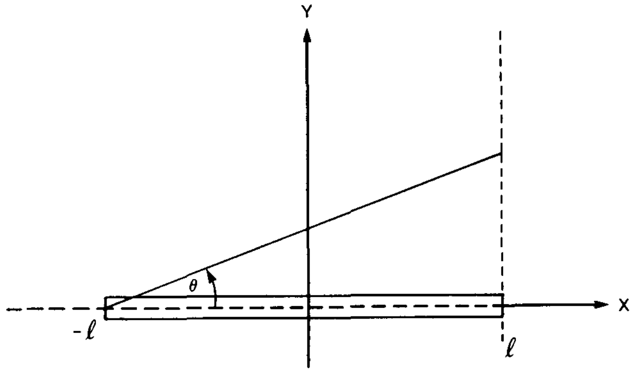


Fig. 3—The coordinate system used in equation (3)

The distributions of induced horizontal stress and shear stress corresponding to equations (2) and (3) are shown in Fig. 4.

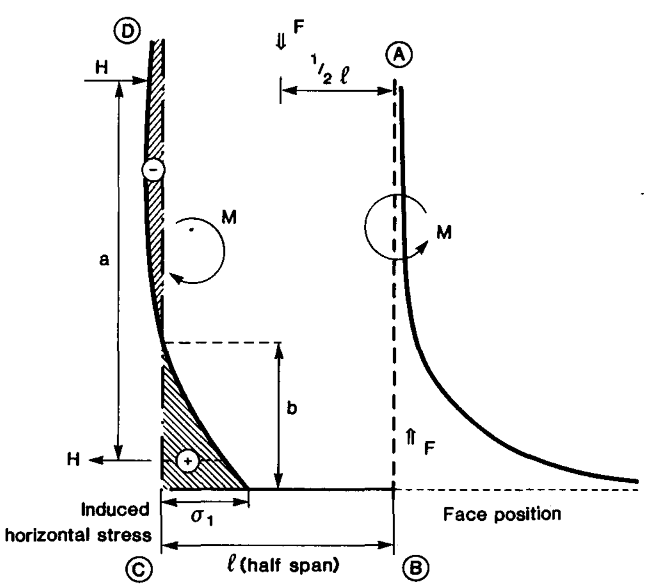


Fig. 4—The mechanism of balancing forces in an elastic continuum

In order to explain the distribution of stress around a parallel-sided panel in an elastic material, one can consider the tractions that arise on the boundaries of an imaginary rectangular solid region, ABCD, above the mined-out area. These are the tractions that would have to be imposed on the surfaces of ABCD were it to be detached and to remain in the same state of stress (Fig. 4).

In the primitive state before mining occurs, a uniform external traction is assumed to act on surface B–C. The total force acting on surface B–C per unit distance along the length of the panel in a vertical direction is

$$F = \gamma D l \ (MN/m), \quad (4)$$

where γ = body force per unit volume of rock (MN/m^3)
D = depth below surface (m)
l = stope half span (m).

After stoping has taken place, the half span, l, is unsupported, and the total body force, F, must be supported by a resultant shear force, F, which acts on surface A–B, as shown in Fig. 4. The total active moment that is created by this shear force and the induced horizontal stresses along plane A–B must be balanced by a passive moment that can be generated only by horizontal stresses along C–D. (No shear stress acts on C–D since it is the centre line of a symmetric geometry.)

Moment M, which is created by the vertical forces only, is equal to $F \times l/2$ (Fig. 4). It can be seen from Fig. 4, and deduced from equation (2), that the distribution of horizontal stresses along C–D is such that a net horizontal force, H, acts in both directions. The moment due to the horizontal stresses along C–D can be expressed as $H \times a$, where a is the moment arm. The distribution of horizontal stresses along C–D will primarily be affected by the distribution of shear stresses along A–B. Although the horizontal stresses along A–B will influence the stress distribution along C–D as well, this effect is of second order and has been neglected. Numerical simulations have shown that this is a reasonable assumption. Therefore, this analysis focuses only on the effect of the shear-stress distribution along A–B.

Moment M will have a fixed value ($F \times l/2$) for a particular span size. The moment created by the horizontal stresses along C–D, as induced by the shear stresses along A–B, must therefore have the same value (M) to give a balanced situation. For the elastic situation, the shear-stress distribution along A–B and the total horizontal-stress distribution along C–D are as shown in Fig. 4. Any other distribution of shear stresses along A–B will induce a redistribution of horizontal stresses along C–D, but will not affect the value of M. The mechanism described here represents combined beam-and-arch behaviour.

If the redistribution of shear stresses along A–B is effected by slip on a narrow band of failed material, the induced stress at the centre of the panel can be represented by an integral relationship that involves the slip density at each point of the fracture. This relationship can be shown to be given by

$$\sigma_{xx}(0, 0) = \frac{E}{4\pi(1 - \nu^2)} \int_0^{\frac{\pi}{2}} \left(\frac{D_y}{l}\right) \sin 2\theta \, (1 - 2\cos 2\theta) \, d\theta, \quad (5)$$

where E is Young's modulus, ν is Poisson's ratio, and D_y represents the slip on the fracture and has a negative sign when it is in the direction shown in Fig. 3.

From equation (5) it is possible to deduce that the horizontal stress induced at the centre point by a distribution of shear dislocations will be independent of the stope span, $2l$, provided the shear discontinuity, D_y, remains geometrically similar and is scaled by the stope span. This can be shown to be true provided there is no total closure in the panel, and provided the primitive stress gradient is negligible.

Limited Stress Approach

A wide variety of constitutive laws is available to simulate the observed inelastic behaviour of rock. The constitutive models used in practical applications usually employ some (shear) failure criterion that allows excess stresses in highly stressed regions to be redistributed over neighbouring lower-stressed areas until the failure criterion is satisfied everywhere.

Typical results are shown in Fig. 5; the same beam or arch mechanism is operative in this situation, but the shear stresses along plane A–B are more smoothly distributed because they are bounded by a certain limit stress. Owing to the redistribution of these shear stresses, a larger area is subjected to induced shear stresses, and effectively a higher beam, or arch, is created. As the effective moment, M, in this situation is still equal to the effective moment in the elastic case, the induced (tensile) horizontal stresses along C–D will decrease substantially (Figs. 4 and 5).

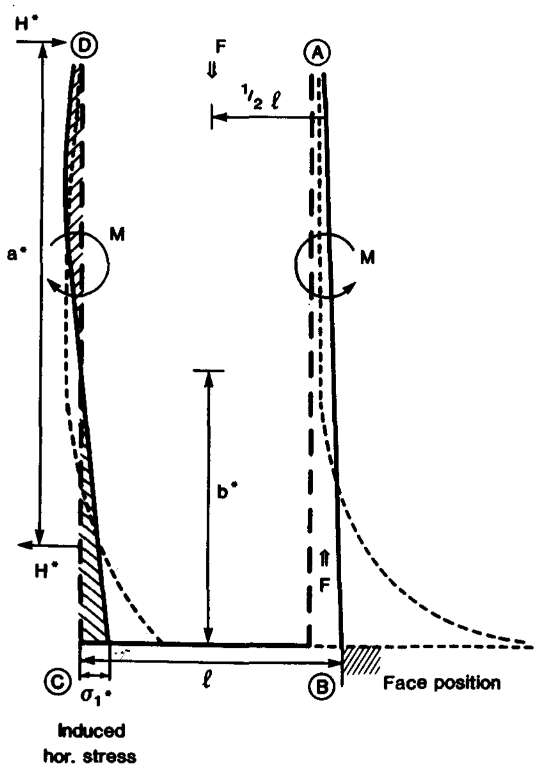


Fig. 5—The mechanism of balancing forces in an inelastic continuum (the dotted line indicates the elastic situation)

The induced vertical and horizontal stresses ahead of the stope face will decrease as well, because they are directly related to the shear stresses. To compare the effects on stress distribution of some constitutive laws, use is made of the basic model shown in Fig. 6. The geometry of the model simulates the excavation of a slit in a single step in a surrounding rockmass. The boundaries are sufficiently remote to avoid interaction effects. Two planes of symmetry allow the model to be reduced to a quarter of the simulated geometry. Before the slit is created, the surrounding rockmass is stressed by a vertical stress of -60 MPa and a horizontal stress of -30 MPa.

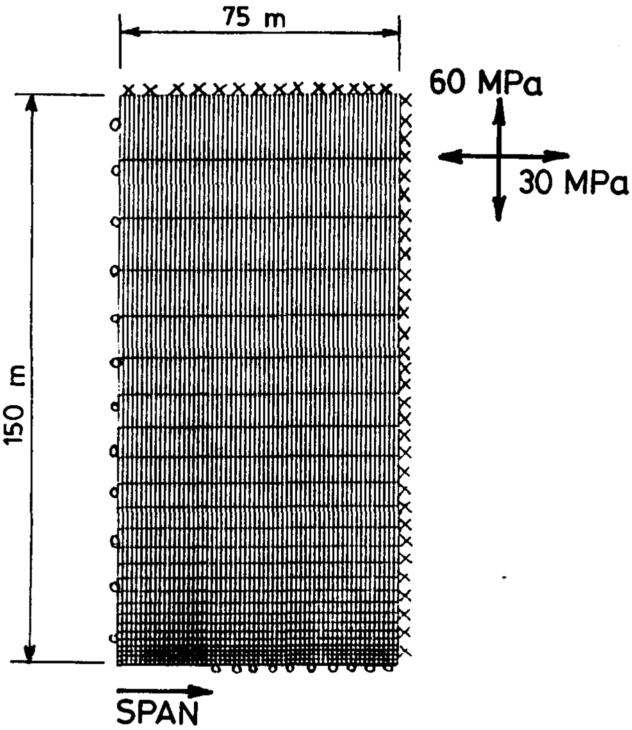


Fig. 6—The geometry used in the finite-difference computer models

Fig. 7 shows the resulting horizontal stresses along the slit for a variety of constitutive models, and Fig. 8 gives the resulting vertical displacements. Although the differences in the various results from Figs. 7 and 8 are quite distinct, none of them matches the extreme values that can be observed in underground situations[4–6]. If the constitutive models and the *in situ* data have some validity, the major deficiency of the modelling results may arise because the loading path (or stress history) has been disregarded. The commonly applied linear elastic models do not require consideration of a loading path since the principle of superposition is always valid if the excavation surfaces are stress free (no support reaction). When material failure occurs, plastic strains are generated and the superposition principle is no longer applicable since residual stresses and strains will be induced according to the actual loading or, in mining terms, excavation sequence. Although this is one of the basics of plasticity[18], it is ignored in many practical applications.

The generation of residual stresses will be demonstrated in the following section.

Incremental Stress Development under Limited Stress Conditions

During mining operations, highly stressed regions are continuously excavated and high stresses are induced at new locations. If the removal of highly stressed rock is regarded as an unloading operation, the development of residual 'locked-in' stresses can be demonstrated.

Fig. 9 shows the induced vertical-stress distribution in front of a stope. The integrated function represents the total vertical reaction, which is equal to the original traction acting on B–C before mining commenced. The

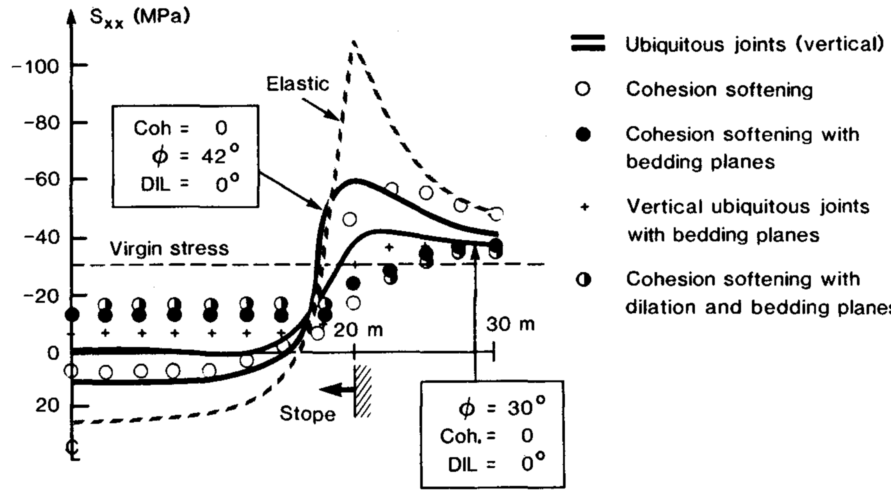


Fig. 7—Horizontal stress along the stope skin for different constitutive models

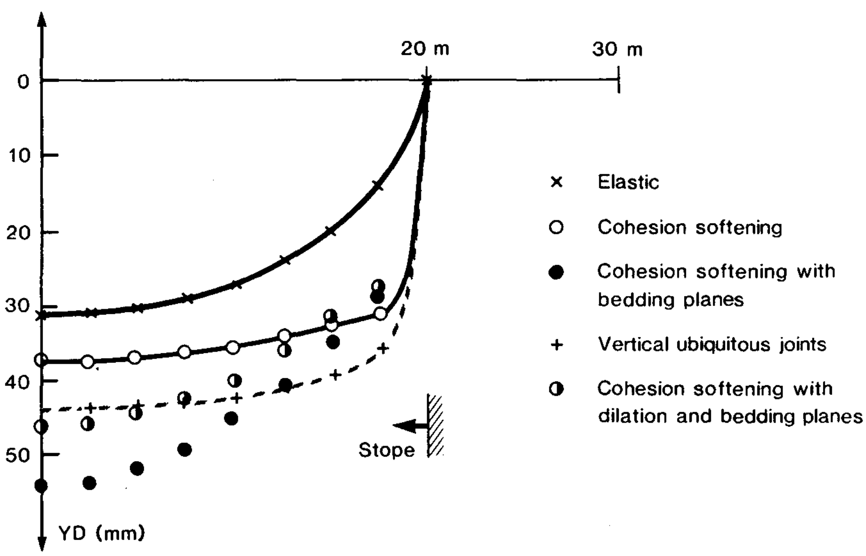


Fig. 8—Vertical displacement (closure profile) of the stope for different constitutive models

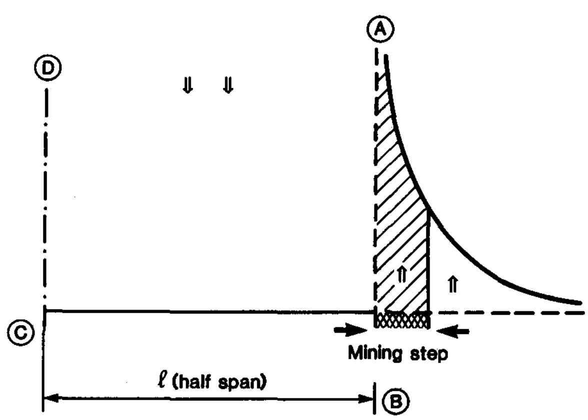


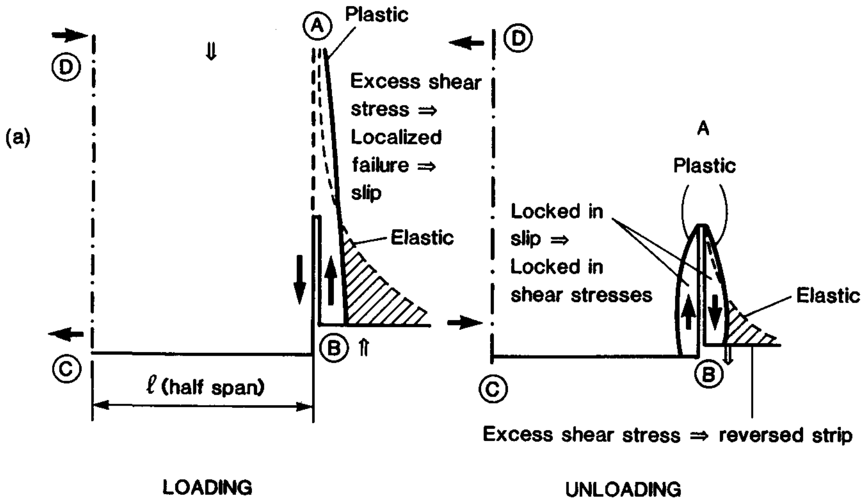
Fig. 9—Induced vertical stress along the horizontal centreline (the shaded area represents the part that becomes unloaded as a result of mining)

removed (shaded) area represents a certain percentage of the total vertical reaction. This percentage is equal to the percentage of unloading due to a single mining step. It is clear from Fig. 9 how the ratio of the mining-step size to the total mined-out area affects the percentage of unloading.

Fig. 10(a) shows a loading and a (partial) unloading cycle, and demonstrates how, during unloading, residual stresses are locked into the material. During loading, plastic strains are generated in the failed area, which may be a localized shear plane (fracture), but which could be represented as a zone of failure without affecting the basic concept.

Unfailed material is destressed during unloading and tends to expand in order to relax. Full relaxation would be obtained if the plastic strains, or the dislocations along the failure zone, disappeared completely. However, in the same way as resistance (limit stress) has to be overcome to induce these plastic strains during loading, resistance has to be overcome to remove these plastic strains during unloading. The resistance now acts to oppose unloading, and residual shear stresses are locked into the material. This process repeats itself at each mining step in the area that, in the previous mining step, underwent plastic deformations due to excess loading.

When the mechanism, introduced in Fig. 4 for the elastic situation, is used again to analyse the effects of the locked-in residual shear stresses on horizontal stress distribution, some interesting observations can be made.



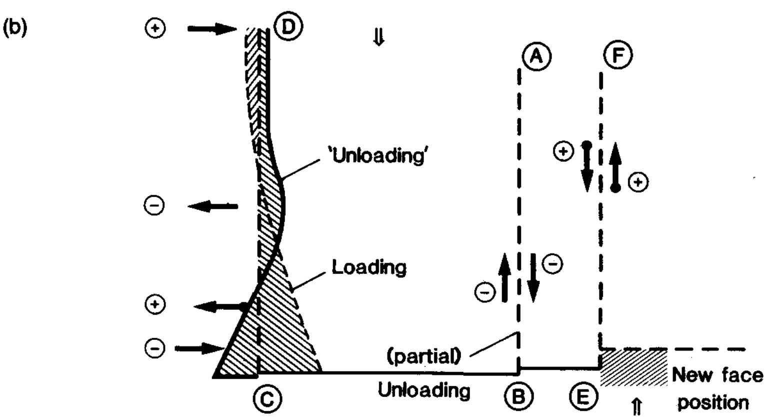


Fig. 10(a)—Restricted relaxation of shear stresses along a failure plane inducing residual shear stresses of an opposite sign

Fig. 10(b)—Residual shear stresses along A–B causing the 'unloading' distribution of horizontal stresses along C–D, and active shear stresses along E–F causing the 'loading' distribution of horizontal stresses along C–D

The locked-in residual shear stresses, which act in the opposite direction from the shear stresses that are generated during loading, will induce opposite moments, which subsequently induce horizontal stresses as shown in Fig. 10(b). As is the case in the previous situations for which the mechanism has been used, the induced horizontal stresses at the centre of the panel are independent of the span size but are proportional to the shear-stress distribution along the vertical plane E–F at the previous stope face. The residual shear forces locked in at each mining step depend on the percentage of unloading, which is related to the ratio of mining-step size to total stope span. Obviously, the limit stress, which is controlled by the relevant constitutive model, is also a major factor in the establishment of residual shear forces.

The implication of these observations is that horizontal stresses, which are locked in and cumulative, are generated at each effective mining step. These stresses act in an opposite direction from the stresses that are induced initially by the shear stresses acting along the vertical plane through the current stope face position (A–B). The stress increments decrease with each mining step as the percentage of unloading decreases. Fig. 11 shows the horizontal stress at the hangingwall skin at midspan (point C in Fig. 10) against the number of mining steps for a particular constitutive law with zero cohesion and a friction angle of 30 degrees on the joints. It should be noted that only the number of mining steps is relevant, and not the mining-step size. This implies that the same horizontal stress will be generated for a given number of mining steps irrespective of the step size.

As can be appreciated from Fig. 11, large horizontal stresses can be generated after a series of loading and unloading cycles. It must be emphasized that no constitutive model allows for an effective *generation* of stresses in a single-step analysis. In Fig. 7, for instance, analysis of a a single mining step using a wide variety of constitutive models indicates that the virgin stress at the hangingwall skin can be approached very closely owing to the smoothing effect of stress redistribution when limit stress levels are exceeded and plastic strains are subsequently induced. However, the virgin horizontal stress will never be reached. When incremental loading is included, locked-in, reversed stresses are generated, and the virgin horizontal stress can be exceeded. A completely different stress pattern will thus be obtained.

Fig. 12 illustrates the effects of locked-in stresses in terms of the stope closure profile corresponding to one, three, and five mining steps. These results were obtained with a displacement-discontinuity boundary element program[9]. Vertical fractures were allowed to develop at the stope face until the excess shear stress was reduced to zero.

As already emphasized, any model that is capable of simulating inelastic behaviour would show similar results and Fig. 12 is therefore typical. (This has been confirmed with FLAC and the finite-element code ABAQUS.)

A few interesting features arise from Fig. 12. When the

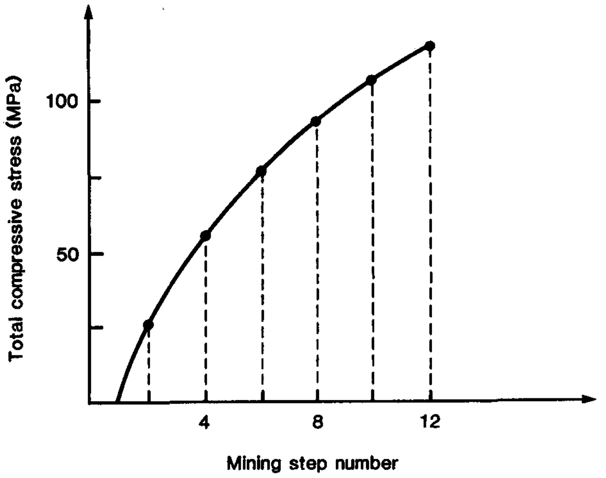


Fig. 11—Effect of mining sequence on the generation of horizontal stress in the hangingwall skin of a stope at midspan

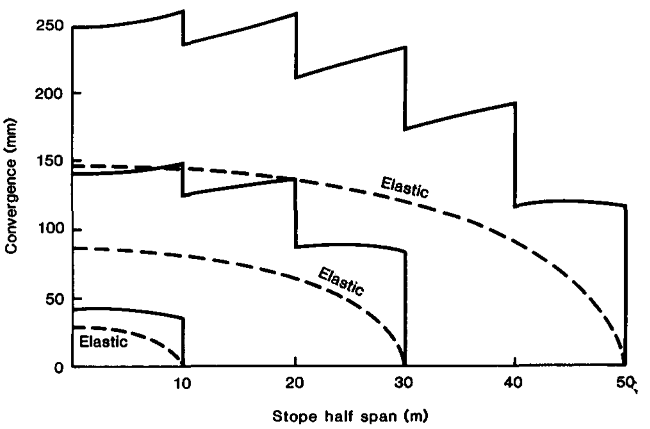


Fig. 12—Vertical displacement of a stope hangingwall after various mining steps

results of a single step are compared with those of a multiple step, it can be seen that multiple stepping leads to a reversed curvature in the closure profile as compared with an elastic analysis. After a number of mining steps, the closure profile near the centre of the stope indicates that the tangential stress is compressive.

It can also be seen that the first mining step (loading step), corresponding to a half span of 10 m, causes an initial dislocation of about 40 mm, which is decreased in the next step (unloading step) to about 30 mm because of reversed movement along the discontinuity. However, each subsequent mining step does not affect the movement along this discontinuity any more, and a permanent dislocation becomes 'locked in'. These dislocations or plastic strains induce locked-in reversed shear stresses along the discontinuity since reversed movement, and consequently unloading, is restricted. The reversed shear stresses lead to opposite bending moments, and subsequently to compressive stresses in the hangingwall and footwall.

Discussion

It has been demonstrated that the loading history can have a very large influence on stress distribution in a parallel-sided panel in strata where bedding movements are minimal, when the span is enlarged progressively. To obtain a realistic insight into the actual situation around a deep-level stope, where rock failure is a common phenomenon, the loading history or mining sequence must be considered. The most striking effect of locked-in shear stresses is the potential for a build-up of compressive horizontal stresses of large magnitude in stope hangingwalls and footwalls. Evidence of the assumed existence of such high stresses is shown in Fig. 13, which is a photograph showing horizontal fractures in a stope hangingwall. These horizontal fractures are fairly common, and are thought to be caused by mining-induced horizontal stresses of a magnitude sufficient to cleave the rock material. The buckling of the hangingwall or footwall may also be explained by the existence of high horizontal stresses.

Fig. 13—Vertical section of a stope hangingwall that was exposed after a fall of rock; the horizontal fractures are assumed to have been caused by mining-induced compressive horizontal stresses (after Turner[10])

A positive effect of the existence of compressive horizontal stresses of a moderate magnitude is the provision of hangingwall stability. Without a compressive clamping force, especially in a fractured hangingwall, unstable conditions would prevail. If the mechanism for the build-up of horizontal stresses as discussed in this paper is correct, it should be possible to control the magnitude of the horizontal stresses by preconditioning of the rock, or by support of the rock, or by the applied

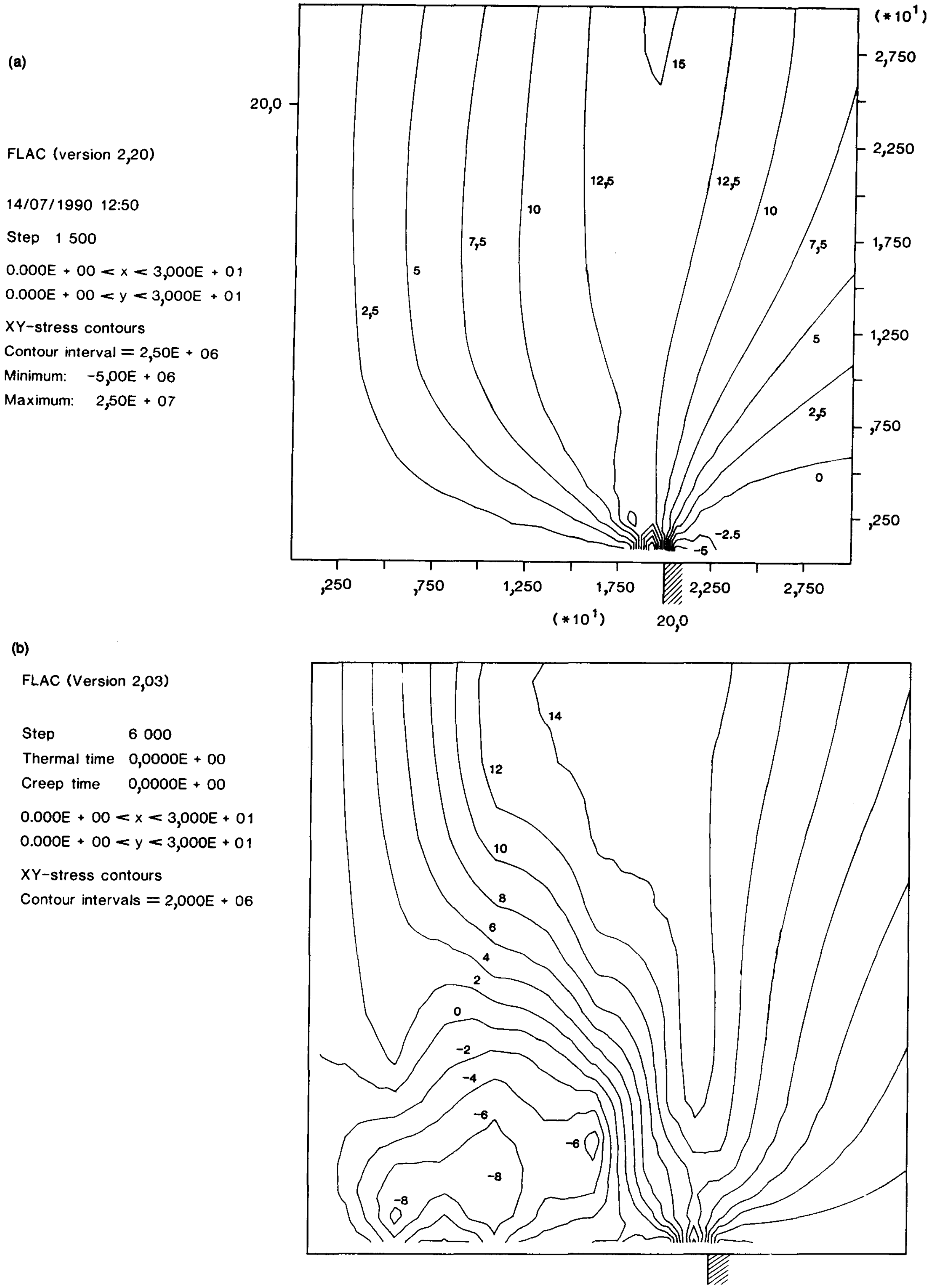


Fig. 14—Shear stress distribution (a) after 1 mining step and (b) after 4 mining steps

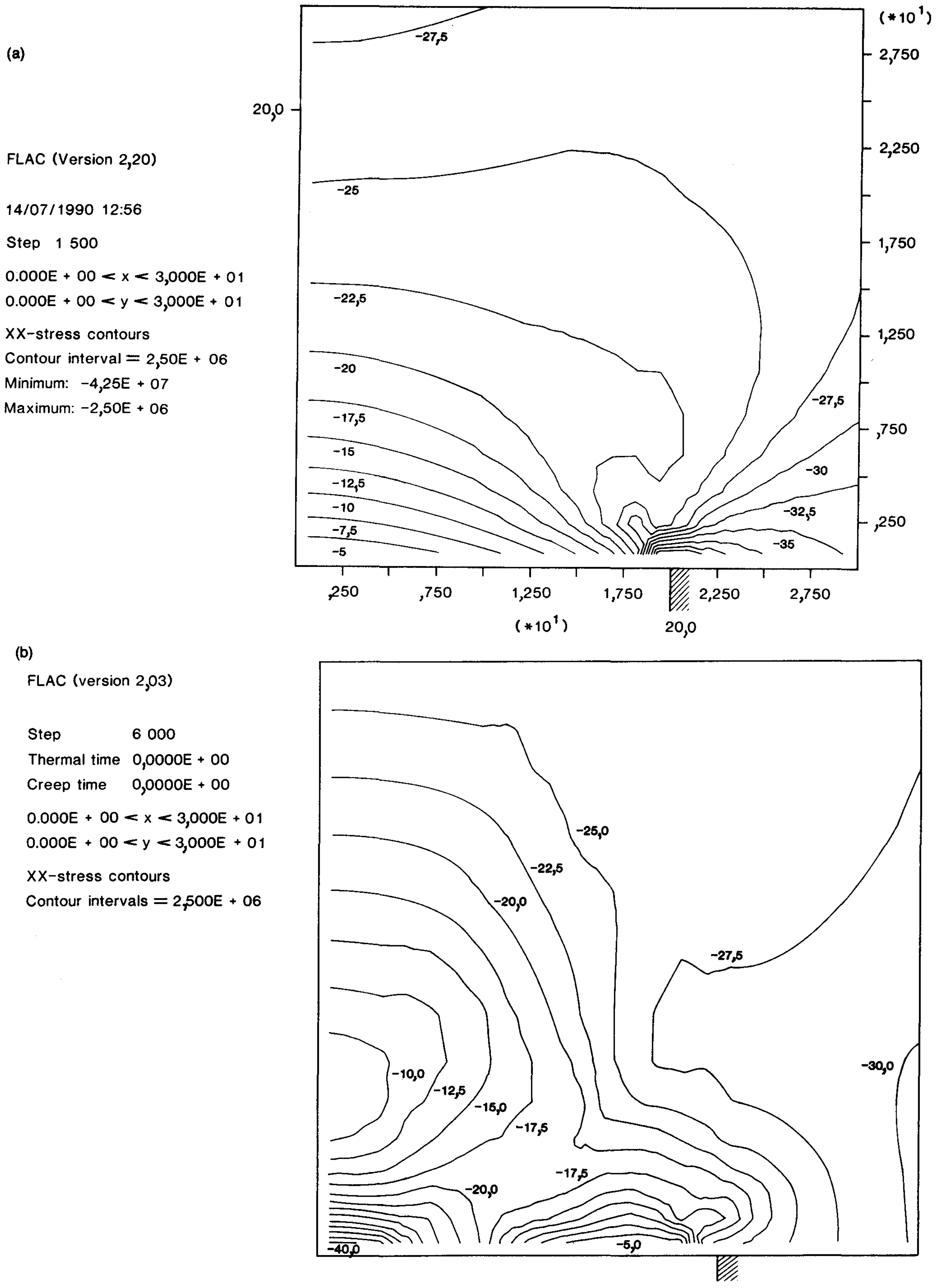


Fig. 15—Horizontal stress distribution (a) after 1 mining step and (b) after 4 mining steps

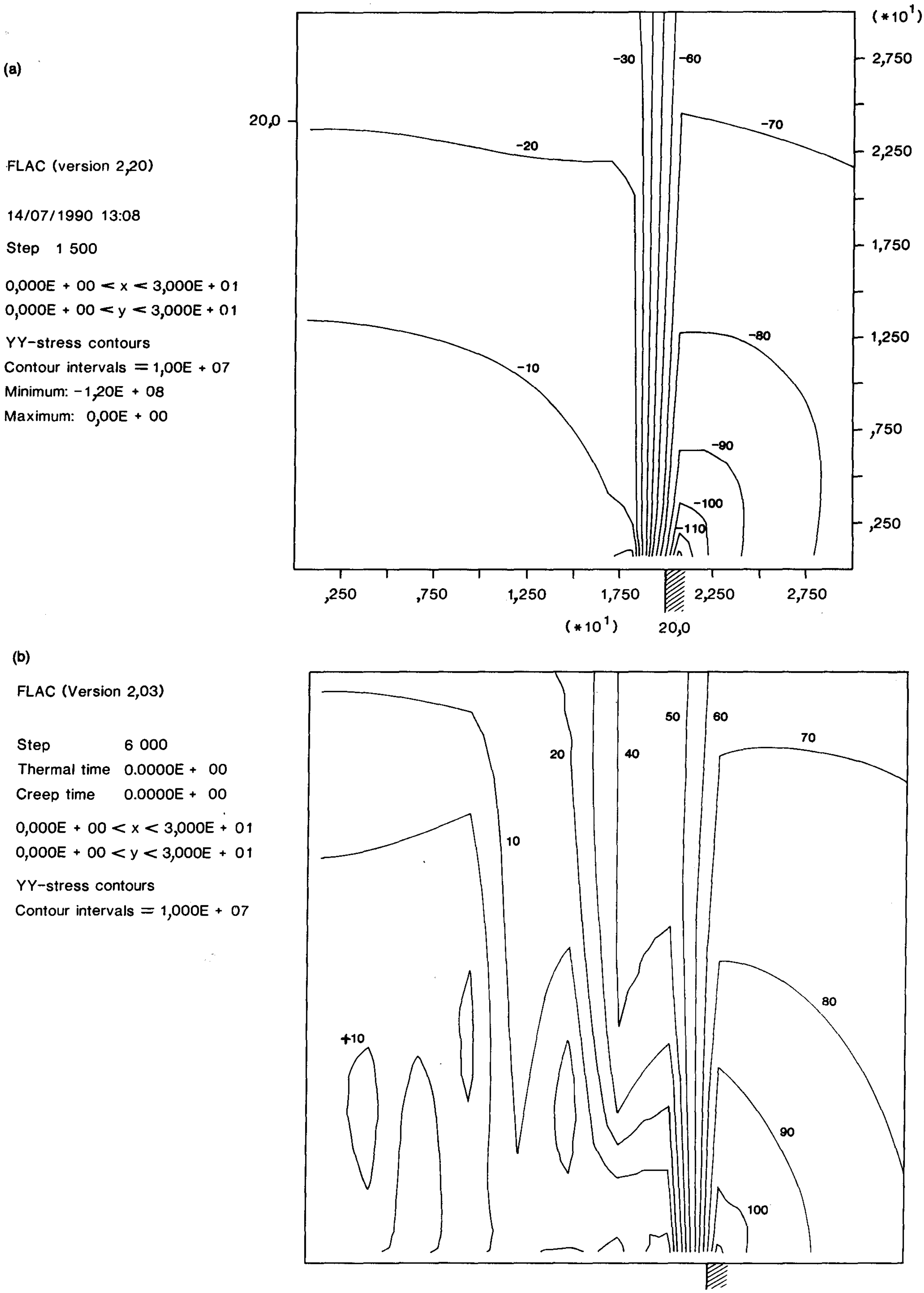


Fig. 16—Vertical stress distribution (a) after 1 mining step and (b) after 4 mining steps

excavation technique. A discussion of these practical applications requires a brief analysis of the actual situation, as shown in Fig. 1.

Immediately ahead of the stope face is an area of highly fractured, deformed rock that is partially destressed. Further ahead of the stope face, stresses will increase owing to larger confinement of the fractured rock material. Unfractured rock may be encountered only at distances greater than 10 m ahead of the stope face. Fracture no. 1 in Fig. 1 indicates a sheared fracture that developed in the unfractured rock during a previous mining step. The stress levels at that particular position can be presumed to just exceed the failure criterion for shearing. The position at which these shear dislocations occur will be referred to as the effective stope face since this is the position where failure is initiated.

Among the practical implications of the mechanism generating the horizontal stress is the use of preconditioning to relieve high stresses at the stope face. Preconditioning may involve blasting and/or fluid injection. When the blasting or fluid injection is performed near the sheared fractures ahead of the stope face, there are two different possibilities. If the active, loaded fracture, which is located at the effective face, is opened by the blast or fluid injection, the shear strength will decrease and the shear stress along the fracture will have to be redistributed over a larger area, causing lower induced tensile stresses in the hangingwall and footwall (Fig. 5). The fracture will consequently grow. If the passive or unloading fractures, which are located between the actual face and the effective face, are opened, further relaxation is allowed along these fractures and the negative, locked-in shear stresses are reduced, thus causing lower induced compressive horizontal stresses in the hangingwall and footwall (Fig. 10). A proper combination of these two possibilities may result in stable hangingwall conditions without the build-up of excessive compressive horizontal stresses, but with the maintenance of moderate stresses.

If the shearing of the fractures can be completely prevented by some form of support, then no generation of compressive horizontal stresses is possible and the elastic situation prevails. If shearing cannot be prevented, then only preconditioning and applied excavation techniques can be effective in reducing a build-up of excessive horizontal stresses.

It has been shown that the build-up of horizontal stresses in the stope skin is essentially related to the number of mining steps, and not to the size of the mining steps (the sheared fractures are spaced according to the mining-step size). If the distances between the sheared fractures can in reality be influenced by the applied mining technique, then a proper control over the build-up of horizontal stress is available. This may be of great practical importance. In mechanized mining, for instance, very small mining steps are involved. If a sheared fracture develops at each of these mining steps, a very rapid build-up of horizontal stresses can be expected. In reality, however, there will be a minimum distance between subsequent sheared fractures because the criterion for slip on an existing fracture will most likely allow for lower stresses than the criterion that controls the initiation of sheared fractures. In other words, after a sheared fracture has been formed and the stresses have been redistributed according to the slip criterion, additional stresses have to be generated before a new fracture can be initiated. A certain minimum mining step is required to provide these additional stresses.

Finally, the fact that a potentially more realistic situation is simulated by consideration of the loading history provides the modeller with more realistic results for design purposes. Examples of stress contours are given in Figs. 14 to 16, which show comparative stress distributions around a single stope that was excavated in one mining step and four mining steps respectively. In Fig. 14(b) negative shear stresses above the excavation indicate the presence of residual locked-in reversed shear stresses, as discussed previously. The rest of the area is hardly influenced by the loading history, as can be seen from Fig. 14(a). Fig. 15(b) shows the presence of moderate compressive horizontal stresses in the area immediately above the excavation. These compressive stresses are directly associated with the negative shear stresses shown in Fig. 14(b). Fig. 15(a), the single-step results, does not show such compressive stresses. Finally, in Fig. 16, which shows the vertical stress distributions, it can be seen that the residual stresses also influence the vertical stresses. This is due to the fact that the negative locked-in shear stresses along the vertically oriented failure zones (dislocations) induce tensile vertical stresses in the adjacent area towards the centre of the stope. In Fig. 16(b) tensile stresses with a magnitude of 10 MPa can be observed. Fig. 16(a) does not indicate the presence of such tensile vertical stresses.

Conclusions

It can be concluded that

- the loading history or mining sequence has to be considered in situations where inelastic behaviour takes place—the principle of superposition is not applicable
- residual stresses can affect the complete stress field considerably
- the mechanism presented for the generation of high compressive stresses in hangingwalls and footwalls may, in principle, provide a more realistic simulation of the actual stress distribution near tabular stopes
- the number of theoretical or effective mining steps is of primary importance
- preconditioning and support effects can be assessed with more appropriate stope stress distributions.

The shortcomings of this study, which need to be addressed in future research, include the facts that no distinction was made between the failure and the post-failure criterion, and that stoping width and geological inhomogeneities were neglected. The influence of stoping width is of special importance in the analysis of local (post-failure) conditions in the area between the stope face and the unfractured rock. Geological inhomogeneities will affect the general stress pattern. The influence of bedding planes, which has been addressed only in single-step analyses, should also be studied in multiple-step analyses. Finally, a back analysis, which would consist of relevant underground measurements, should be made.

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Cokemaking

Sponsored and organized by the Ironmaking and Steelmaking Division of The Institute of Metals and supported by the European Cokemaking Committee and major international institutions of the coal mining and ironmaking industry, the 2nd International Cokemaking Congress will be held from 28th to 30th September, 1992, at the Queen Elizabeth II Conference Centre, London.

Intended to provide cokemakers from around the world with the opportunity to update themselves with the latest technologies, as well as an international forum for discussion, the Congress will concentrate on important developments in cokemaking over the past five years, including newly designed ovens, regulations concerning environmental pollution and, in view of the threat of global warming, the importance of energy conservation.

The subjects for discussion will include the following:

- *Research* — Carbonization mechanisms; coking pressures; laboratory and pilot-plant procedures and equipment; coal selection; future carbonization processes; mathematical modelling
- *Coke quality* — Blast-furnace requirements at high injection rates; high-temperature properties and tests; requirements for foundries and other uses
- *Operation and design* — Tall/wide ovens and reactors; coke-oven machines; heating, automation, and process control; repair techniques; byproduct-plant operation; training and organization of management and staff
- *Environment* — Health in the work place; pollution control on new and existing plant; effect of environmental control on battery life; production and treatment of waste products.

A substantial programme of technical visits to plants throughout Europe is being arranged, and an exhibition of cokemaking supplies, equipment, and technology will run in conjunction with the Congress.

Like the previous cokemaking congress, which was held in Essen, Germany, in 1987, the 2nd Congress is expected to attract a wide range of international delegates.

Further information concerning the Congress and Exhibition is available from

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