Fifth Australia-New Zealand
Conference on Geomechanics
Sydney, 22-23 August 1988

Predicting and Monitoring Stress and Deformation Behaviour of Backfill in Deep-Level Mining Excavations

I.H. CLARK
Head of Section, Chamber of Mines of South Africa Research Organisation
R.G. GURTUNCA
Principal Engineer, Chamber of Mines of South Africa Research Organisation
P.S. PIPER
Head of Section, Chamber of Mines of South Africa Research Organisation

SUMMARY Stress and closure have been measured in a deep-level South African gold mine with suitably developed instrumentation. The monitored data is compared to laboratory tests. A computer programme is successfully used to simulate the deformation behaviour of the backfill in laboratory tests and underground.

1 INTRODUCTION

Backfill is being placed in deep South African gold mines in an attempt to alleviate rockbursts and rockfalls. To assist with the design of mine layouts which incorporate backfill and to select the most suitable backfill system to minimize these problems, it is necessary to understand the behaviour of backfill and its influence on the rock mass behaviour. To obtain this understanding stress and closure are being monitored in backfilled stopes:

- to compare the in situ behaviour of different backfill materials, and
- to quantify the influence of the placement parameters on the deformation behaviour of backfill.

Additionally, laboratory testing is being carried out to approximate the stress and strain response of the backfill under similar conditions to those measured underground and secondly to provide input parameters for selected mathematical models that can be used for computer simulation. This paper summarizes the progress that has been made to date in these areas.

2. INSTRUMENTATION FOR IN SITU MONITORING

In order to define the in-situ stress and deformation behaviour of backfill, instrumentation is required to measure stope closure and stresses in three mutually perpendicular directions. Commercially available load cells can measure stresses in backfill but they were found to be unreliable at stresses greater than 5 MPa. No existing instrumentation appeared to be suitable for the measurement of stope closure. Instrumentation was therefore developed at the Chamber of Mines Research Organization capable of measuring stresses up to 100 MPa and deformations of 0,5 m (equivalent to strains of up to 50 per cent) in the backfill.

The hydraulic stress meters are placed to measure stress in three mutually perpendicular directions; the mechanical closure meter measures closure perpendicular to the rock surfaces and the backfill extensometer measures lateral deformations in the backfill paddock.

The instrumentation performed well during laboratory evaluation trials and to date units of the instrumentation installed in a backfill paddock underground, (in January 1987), are still performing reliably at stresses above 35 MPa and deformations in excess of 300 mm.

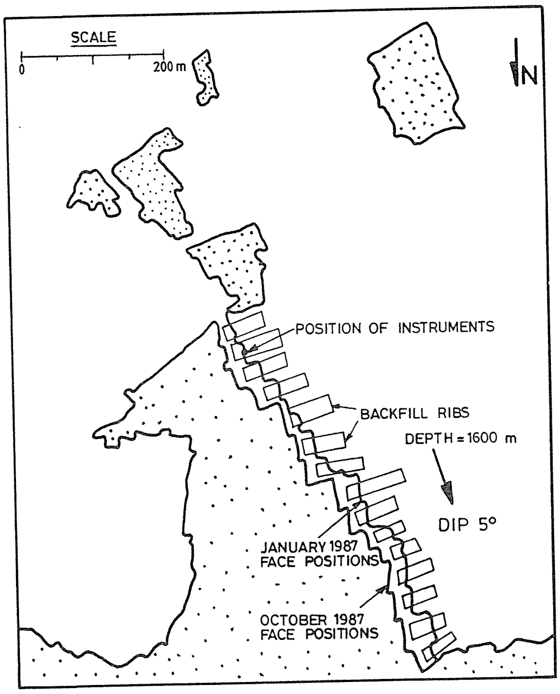

Figure 1 Extent of mining excavations around the backfill throughout the monitoring period

2.1 In situ Backfill Behaviour

The extent and layout of the mining excavations surrounding the backfill instrumentation site considered in this paper, at the time of installation in January 1987, and at the end of October 1987, are shown in Figure 1. The plan also shows the location of the instrument station comprising three stress meters and one closure meter. Since installation the mining face has advanced 22 meters and backfill has been placed at the same rate so that a constant (5-7m) distance between backfill and face was maintained throughout the monitoring period.

Samples of freshly placed backfill (classified tailings) showed that there was very little porosity variation with time after placement and throughout the paddock (Clark, 1986). Underground sampling results show that the porosity is typically 48 to 50 per cent.

The three measured stresses are plotted against vertical strain in Figure 2. The results show that a vertical stress of 29 MPa was measured for a strain of 36 per cent while the stress in the dip direction reached 15 MPa at this same strain. The stress meter measuring strike stress was damaged and stopped functioning after 23 per cent strain (5 MPa).

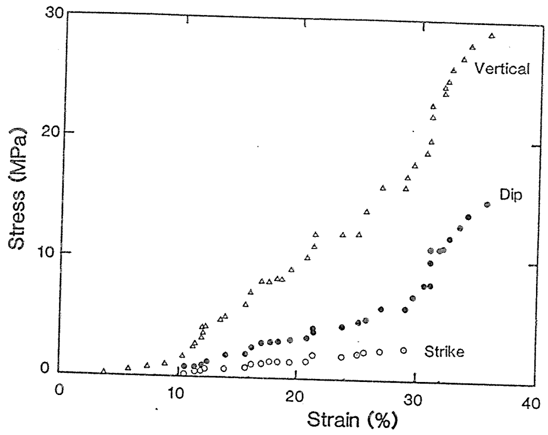

Figure 2 Monitored stresses in three principal directions

Measurements of the rock mass displacements outside the backfill indicated that no ride had taken place but that the closure was greater outside the backfill than measured by the closure meter inside the backfill, Figure 3. Similar closure results have been obtained at other sites and the reduced closure inside the backfill is attributed to the support provided by the backfill to the fractured and separated hangingwall rock, rather than instrumentation error. The stress and closure results are considered to be representative of the in situ behaviour of classified tailings backfill.

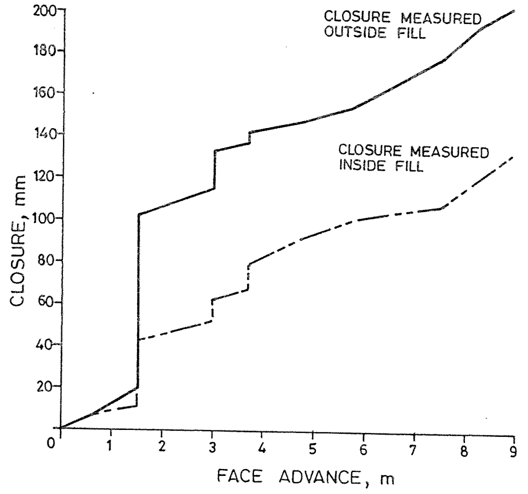

Figure 3 Comparison of stress-closure profiles obtained inside and outside backfill

3 LABORATORY TESTING

In the previous section, stress and strain data monitored in backfill placed in a tabular, deep-level mining excavation was presented. The ratio of the vertical stress to the mean of the dip and strike stresses is presented in Figure 4. Throughout the monitoring period the stress ratio (K_0) remained fairly constant. The simplest laboratory test which gives a constant stress ratio is the confined compression, or uniaxial strain test.

The laboratory established axial stress versus axial strain curve (refer to Figure 5) shows that the backfill is a compressible, strain hardening plastic material.

In order to quantify the effects of confining stress on the strength and deformation behaviour of backfills and to establish input parameters for the constitutive models, triaxial shear tests were performed.

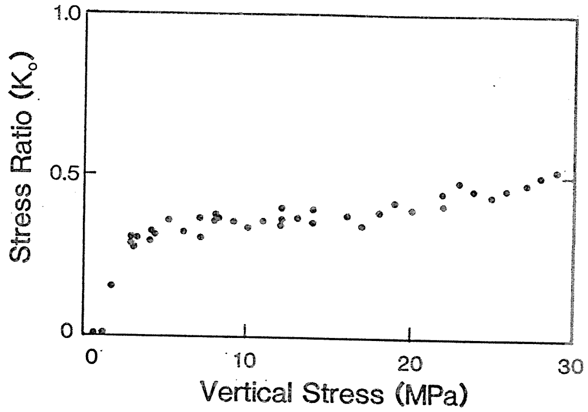

Figure 4 Stress ratio of monitored data as a function of the maximum principal stress

Conventional drained triaxial tests were carried out on cylindrical specimens of backfill, prepared to the same initial conditions as described for the confined compression tests, over a range of confining pressures relevant to the deep-level mining applications, viz. 0,1 to 32 MPa. The experimental results plotted in deviatoric - mean stress space are used to define the failure envelope for the backfill, (Clark, 1987).

The mean stress is defined as $J_1/3$,

where J_1 is the first invariant of stress

$$J_1 = (\sigma_1 + \sigma_2 + \sigma_3) \qquad (1)$$

The second invariant of deviatoric stress is defined as

$$J_{2D} = \frac{1}{6}\left[(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2\right] \qquad (2)$$

In equations (1) and (2), σ_1, σ_2 and σ_3 are the principal stresses (compression assumed positive).

4 COMPUTER MODELLING

The computer programme FLAC (Cundall, 1987), was used to simulate the deformation behaviour of classified tailings backfill. The constitutive law embedded in the programme is described in the following sections.

4.1 FLAC Programme

FLAC is a two-dimensional finite difference, dynamic relaxation programme which allows large strain and non-linear material behaviour to be modelled. In this paper the plasticity Cap model is used to model the non-linear behaviour of backfill.

4.1.1 The Cap model

The cap model (Sandler and Rubin, 1987) was developed to provide a mathematical description of the behaviour of geologic materials based on the classical theory of plasticity. It is considered to be an appropriate model for mining applications because it caters for most modes of behaviour observed in practice. These include elastic behaviour (linear and non-linear), shear failure and cap plasticity.

The model is defined by a fixed yield surface and a plastic strain rate vector which obeys an associated flow rule. The yield surface is represented in stress space by

$$\sqrt{J_{2D}} = A - \frac{C}{1 + BJ_1}$$

where A, B and C are material constants. For cohesionless materials parameters A and C are equal.

The shape of the cap is chosen to be elliptical for a wide range of geological materials. The position of the cap during loading is related to the plastic strain history (ε_v^p) through the hardening rule. The form of this behaviour is represented by the equation

$$\varepsilon_v^p = \frac{W\,p_A^2}{H^2 + p_A^2}$$

where W and H are material constants and p_A is the mean stress corresponding to the point where the cap intersects the yield surface. The parameter W reflects the compressibility of the material and H is related to the stress level at which most of the compaction is obtained. The choice of hardening rule parameters affect most significantly the K_0 or uniaxial stress-strain response while the cap shape describes the stress path.

5 LABORATORY VS FIELD RESULTS

The stress-strain curve obtained for the laboratory confined compression test and the underground monitored response are compared in Figure 5. There is close agreement between the two up to a vertical stress of 8 MPa. Beyond this stress level, although both continue to harden, they do so at different rates. Beyond 8 MPa the underground monitored curve shows step-wise increases in stress with increasing strain. This response indicates a stress controlled stick-and-slip type of deformation.

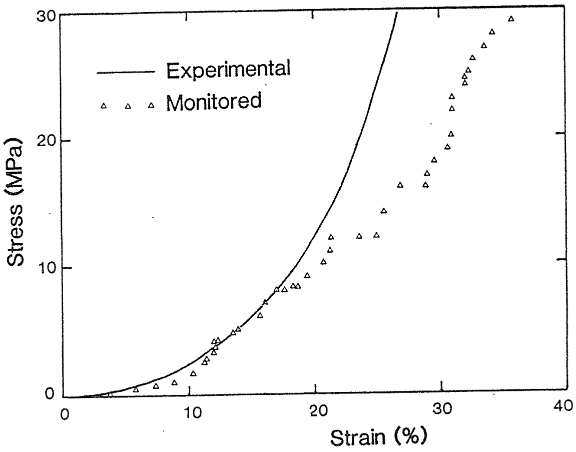

Figure 5 Comparison of the laboratory and underground monitored stress-strain

The most significant difference in the boundary conditions for these two curves is that the laboratory test is rigidly confined whereas the backfill underground is contained in a deformable confining paddock. The agreement between the laboratory curve and the underground monitored results is quite reasonable up to stresses of about 12 MPa.

In an attempt to explain the deviation of the underground curve from the laboratory curve, the underground data was replotted to check if the stress path remained constant during the period of monitoring. The stress path under constant K_0 loading conditions precludes that the sample reaches a stress state which lies on the yield surface. However, complex local stress paths can be imposed in the backfill underground.

The underground monitored data is presented in Figure 6 as a plot of deviatoric vs mean stress. The plotted data trace the stress path followed during the monitoring period. This figure shows that the stress path underground remained fairly constant; however, the horizontal to vertical stress ratio increased from 0,30 initially to 0,50 when the vertical stress reached 29 MPa (Figure 4).

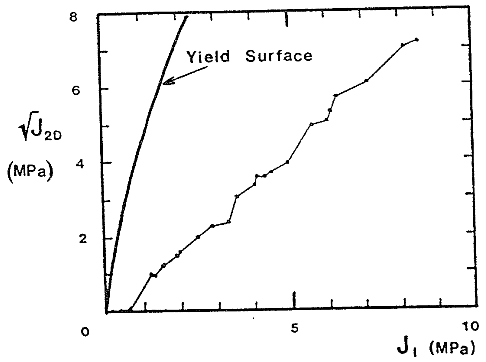

Figure 6 Stress path plot for underground monitored data

It is concluded that the major difference between the underground and laboratory stress-strain curves is the boundary conditions. In the laboratory confined compression test a state of failure is never reached whereas underground the backfill is not rigidly confined and some deformation takes place by local internal shearing.

6 COMPUTER SIMULATIONS

Numerical simulations are most often conducted for the following reasons:

- to develop an understanding of a physical process,
- to analyse a specific problem, and
- as a design tool.

In order to achieve realistic results and to minimise the assumptions surrounding a simulation, the input parameters must be determined accurately. In this paper the procedure followed was to test first the validity of the input parameters by simulating the stress-strain behaviour of backfill tested in the laboratory and subsequently, the ability of the programme to predict the in situ behaviour of backfill in a stope.

6.1 Predicted vs Experimental Response

The laboratory uniaxial strain test was modelled with FLAC using the experimentally derived cap model parameters.

The cap model prediction compares closely with the laboratory established response as shown in Figure 7.

Based on these results it was concluded that the cap model could be applied with reasonable confidence to the interpretation of in-stope behaviour of backfill.

6.2 Predicted vs In-Stope Response

A number of computer runs were performed to predict the in situ behaviour of backfill. Initially a rib of backfill with similar dimensions to an underground paddock was modelled. Thus, no lateral confinement was imposed and a centre of symmetry was set on the one edge. Loading was simulated by applying a constant velocity and a constant profile (rigid boundary) across the upper and lower surfaces. In Figure 8, the modelled stress-strain response determined at positions A and B (Figure 9) are compared to the underground results. It is interesting to note that a modelled unconfined response similar to the measured underground results can be obtained and that there is localised softening beyond a stress of 8 MPa. However, the fitting of the modelled curve to the monitored results depends on where the stresses are measured.

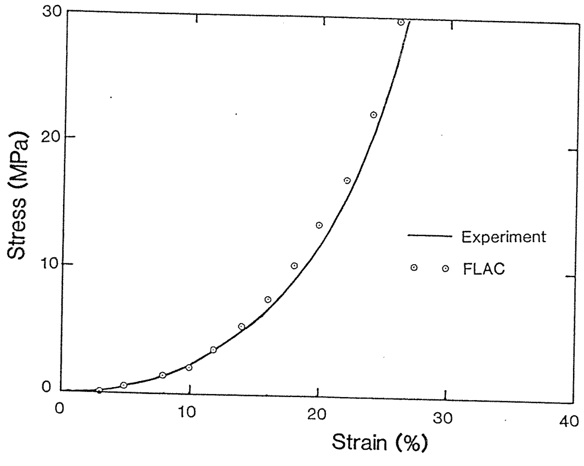

Figure 7 Comparison of the experimental and FLAC modelled uniaxial strain test

In order to better understand the results obtained from in situ monitoring, a more realistic stope model which uses consecutive mining steps with backfilling will have to be run.

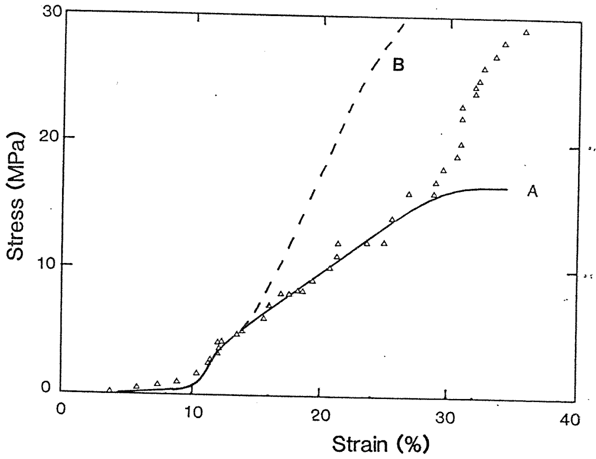

Figure 8 In situ modelled stress-strain response

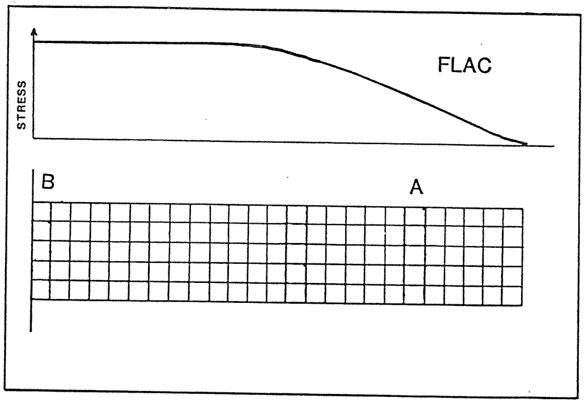

Figure 9 Variation of stress across a backfill panel

7 CONCLUSION

It has been shown that the stress and closure behaviour of a backfilled stope in a tabular deep-level mine can be measured with suitably developed instrumentation. The results obtained in-situ were then used to establish that the actual stress path being followed conforms to a constant stress ratio, K_0. This led to the selection of the confined compression test for approximating backfill behaviour under laboratory conditions. The confined compression test is the simplest test method which follows a constant K_0 stress path. Based on in-situ sampling of the placed backfill a sample was prepared to the same starting porosity (48%) and a stress-strain curve was established.

It was found that the laboratory stress-strain curve predicts the in-situ response accurately up to stresses of 12 MPa for the results presented in this paper. For higher stresses the monitored response appears to be softer. Using a plasticity based constitutive law (Cap model) and by considering the differences in boundary conditions, the behaviour of the backfill was accurately predicted.

It is concluded that a complex material model must be used for both the backfill and the surrounding rockmass, if realistic stress and closure predictions are to be made. However, the development and implementation of numerical simulation techniques must not be used to replace in situ measurement. The strongest application of numerical modelling will be to augment decision making processes. In the mining industry these will include the selection of a particular backfill material to meet a given mining objective and the design of mining layouts which include backfill.

8 ACKNOWLEDGEMENT

The content of this paper forms part of the research programme of the Chamber of Mines of South Africa.

9 REFERENCES

Clark, I.H. (1986). The properties of hydraulically placed backfill. Proc. Backfill Symposium, Johannesburg, Assoc. Mine Managers South Africa, in press.

Clark, I.H. (1987). The strength and deformation behaviour of backfill in tabular deep-level mining excavations. Ph.D. Thesis (in preparation).

Cundall, P. (1987). FLAC (Version 2.00). User Manual. Itasca Consulting Group, Inc., Minneapolis, Minnesota.

Sandler I.S. and Rubin, D. (1979). Cap and critical state models: Short course notes. Second Int. Conf. Constitutive Laws for Engng. Materials: THEORY and APPLICATION, Tucson, Arizona.