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A rock-engineering monitoring programme at West Driefontein gold mine

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SYNOPSIS

This paper describes the results obtained from a rock-engineering monitoring programme carried out at West Driefontein gold mine, where dewatered and classified tailings have been used as backfills for local and regional support. The *in situ* behaviour of these backfills and the surrounding rockmass were determined, and it was found that the backfill used on this mine has provided significant regional support. The underground observations also showed less rockburst damage in backfilled panels than in unfilled panels, provided the backfill had been placed properly in the stopes.

SAMEVATTING

Hierdie referaat beskryf die resultate wat verkry is met 'n moniteerprogram vir rotsingenieurswese wat by die West Driefontein-goudmyn uitgevoer is waar ontwaterde en geklassifiseerde uitskot as terugvulling vir plaaslike en regionale steun gebruik is. Die *in situ*-gedrag van hierdie terugvullings en die omringende rotsmassa is bepaal en daar is gevind dat die terugvulling wat by hierdie myn gebruik is, beduidende regionale steun verleen het. Die ondergrondse waarnemings het ook minder skade as gevolg van rotsbarstings in panele met terugvulling as in panele sonder terugvulling getoon mits die terugvulling behoorlik in die afbouplekke geplaas is.

INTRODUCTION

The use of backfill as support was first introduced at West Driefontein gold mine in August 1981, with the objective of reducing seismicity and rockburst damage. Backfill consisting of dewatered and classified tailings was used in different sections of the mine, and COMRO (Chamber of Mines Research Organization) was involved in the backfill project; firstly, to measure the *in situ* performance of these backfill materials and the surrounding rockmass; and, secondly, to assess the effectiveness of the backfill in reducing rockburst damage. Gay *et al.*[1] reported the results of the monitoring programme obtained until 1986. This paper summarizes the results obtained after 1986 until the end of the monitoring programme in December 1989.

The *in situ* measurements of dewatered and classified tailings and the surrounding rockmass behaviour were carried out in three areas; namely, 3 Sub-shaft, 5 West Shaft Pillar, and 2 Shaft. A description of the underground sites is given in the following sections.

3 Sub-shaft

The location of the underground instrumentation site in 28-24 Carbon Leader Reef (CL) stope, close to the Number 3 Sub-shaft of West Driefontein gold mine, is shown in Fig. 1. The dip of the reef is approximately 22°, and the depth of mining is about 2000 m in the vicinity of the stope.

The location of backfill instrumentation and the extent of backfilling in the area are illustrated in Fig. 2. The mining and associated backfilling were located adjacent to a normal faulted dyke that traverses the mine property from northeast to southwest and passes through the 3 Sub-shaft pillar. Extraction of the reef on the west side of the dyke/s had been completed before mining on the east side of the fault began in 1986. The backfill utilized in the stopes was dewatered tailings, which had a porosity of approximately 44 per cent. Before the start of mining in 1986, no backfill had been placed in this section of the mine.

Three triaxial hydraulic stress meters for the measurement of stresses in three mutually perpendicular directions were installed in a 4 m wide paddock in panel 1W, as shown in Fig. 3. A Glötzl-type stress meter was also

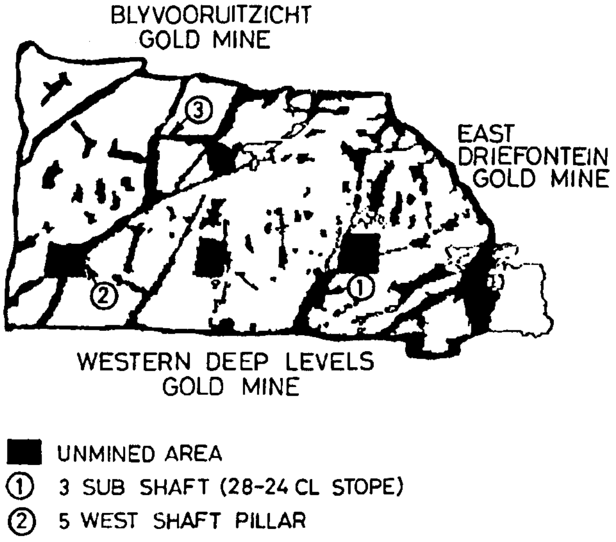

Fig. 1—Plan showing the location of the backfill monitoring sites at West Driefontein gold mine

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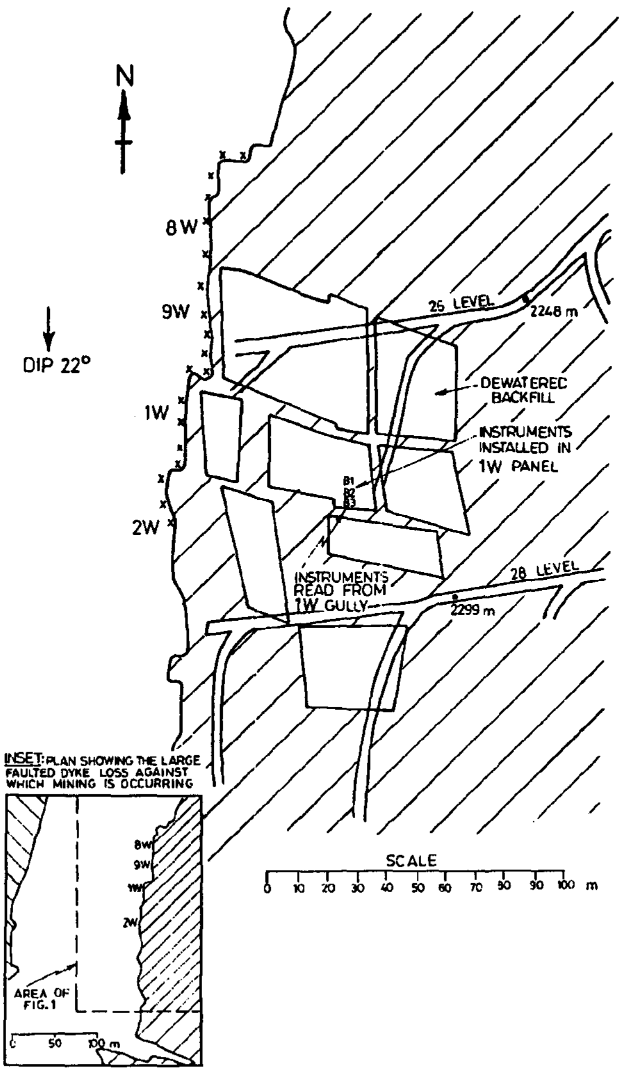

Fig. 2—Location of instrumentation in 28/20 Carbon Leader stope

installed to measure the vertical stress only. One orientation, referred to as the 'vertical stress', is actually meassured parallel to the reef plane normal to the axis of maximum closure. The other two stress meters are positioned to measure stresses in the strike and dip directions.

A mechanical closure meter was installed next to each station for measuring stress to indicate the closure in the backfill. Outside but adjacent to the instrumented backfilled paddock, on the up-dip side of the 1W and 9W strike gullies, closure ride stations (S1 and R1) were established to measure the closure in the gully vicinity (Fig. 3). The paddock that contained the instruments was 8 m from the face at the closest edge at the time of filling.

5 West Shaft Pillar

The location of 5 West Shaft Pillar and of the underground monitoring site within the shaft pillar is shown in Fig. 1. The average depth of the stope is about 2000 m below the surface, and the panels dip south at about 20°.

Mining in the Shaft Pillar area was stopped in 1984 owing to increased seismicity, and was resumed in 1986 with the introduction of backfill to reduce seismicity and rockburst damage during the extraction of the Pillar. The position of the measuring stations and the extent of backfilling in 28-8c CL stope in the Shaft Pillar area are depicted in Fig. 4. The mining and backfilling took place in nine

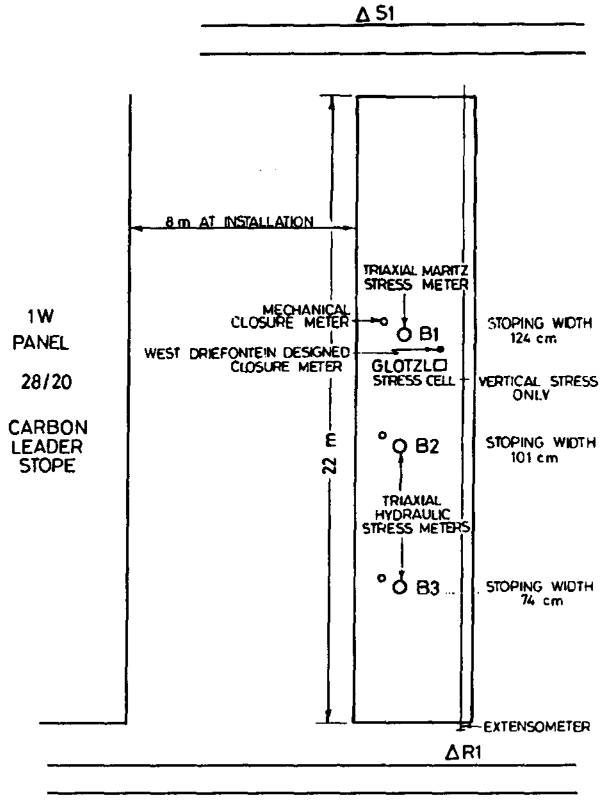

Fig. 3—Layout of instrumentation in backfill paddock in panel 1W

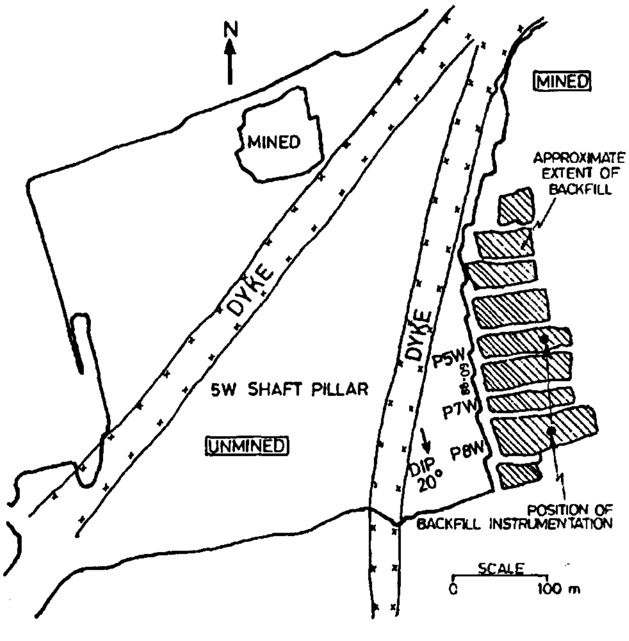

Fig. 4— Location of the instrumentation in 5 West Shaft Pillar area

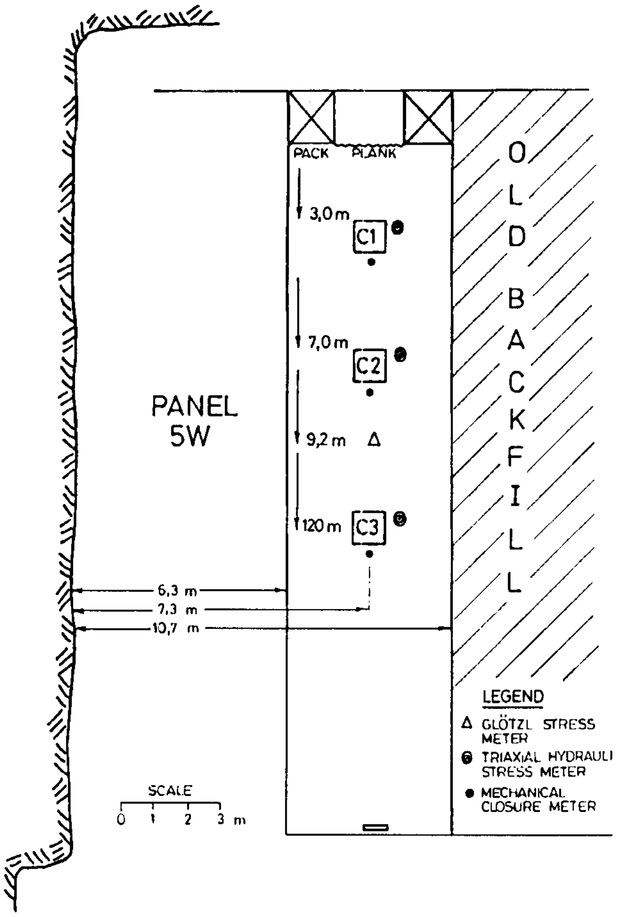

Fig. 5—Layout of the instrumentation in the backfill paddock in panel 5W

panels on the east side of the Pillar, advancing towards a seismically active dyke. Dewatered tailings with about 40 to 43 per cent porosity were used as backfill.

A triaxial station that had three Glötzl stress meters was installed in panel 8W (Fig. 4), and a mechanical closure meter was installed next to the stress meters. In panel 5W, three triaxial hydraulic stress meters and a vertical Glötzl stress meter were installed (Fig. 4). A mechanical closure meter was installed adjacent to each triaxial station in the panel. The layout of the instruments is shown in Fig. 5.

2 Shaft

Backfill instrumentation was installed in 14-14 CL stope west of the 2 Shaft protection pillar as shown in Fig. 1. The dip of the reef in this area is about 25°, and the depth of mining is approximately 1400 m. Classified tailings with a porosity of 46 per cent were used as the permanent support in the extraction of the water-barrier pillar west of 2 Shaft pillar. Four west-advancing panels were used to extract the highly stressed ground. The mining of the water barrier pillar proceeded with the bottom faces leading. In spite of the ground being an isolated remnant, almost all the reef was extracted from this contract.

Three triaxial hydraulic stress meters with a mechanical closure meter at each station were installed in panel 3W in 14-14 CL stope, as shown in Fig. 6. A closure ride station was installed up-dip of the instruments on the 2W gully shoulder.

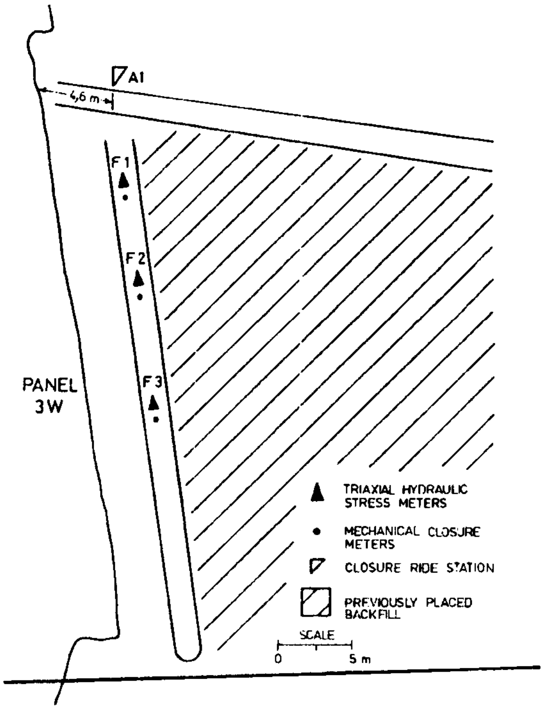

Fig. 6—Location of the instrumentation in the backfill paddock in panel 3W

RESULTS OF *IN SITU* MEASUREMENTS

Two types of backfill behaviour, namely confined-compression behaviour and complete backfill-rib behaviour, were monitored at West Driefontein gold mine.

The confined-compression behaviour of backfill is usually measured in the centre of a paddock, where the maximum confinement is likely to occur. Additional stress and closure meters are installed across the paddock to establish the change in backfill behaviour between different points in the paddock, giving the complete backfill-rib behaviour.

Confined Compression Behaviour

3 Sub-Shaft

The confined compression behaviour of the dewatered-tailings backfill was determined at three stations in panel 1W at 26-28/20 CL stope. Fig. 7 shows the in situ confined-compression behaviour of the backfill up to a vertical stress of 45 MPa at about 19 per cent strain. The measured strike and dip stresses are also plotted in Fig. 7. Also shown in the diagram is the good agreement between the in situ behaviour and the standard confined compression laboratory test result. The laboratory test curve used in the diagram is for a backfill sample with an initial porosity of 40 per cent, which is very close to the measured porosity of the fill in the paddock in which the instruments had been installed.

It can be seen from Fig. 7 that the ratio of horizontal dip and strike stresses to the vertical stress varies from about 0,3 at low stresses to 0,5 at higher stresses. This stress ratio is known[2] as the K_0, and many measurements show the K_0 ratio to vary between 0,3 and 0,6. Therefore, in order to simplify the subsequent diagrams, the horizontal

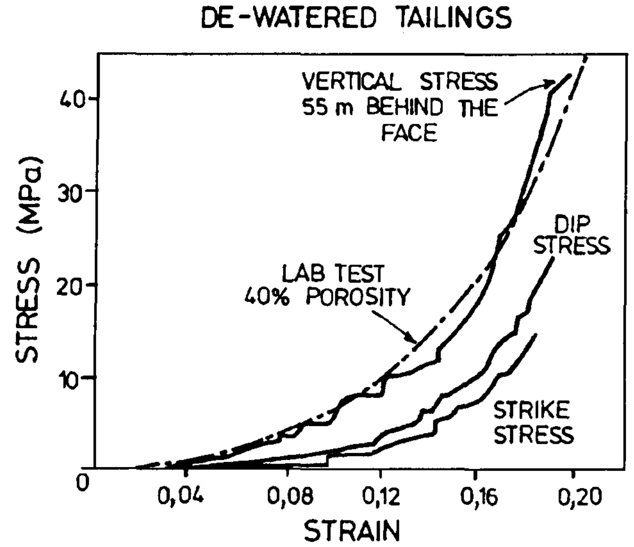

Fig. 7—Confined-compression behaviour of the dewatered-tailings backfill measured in panel 1W at 26–28/20 CL stope

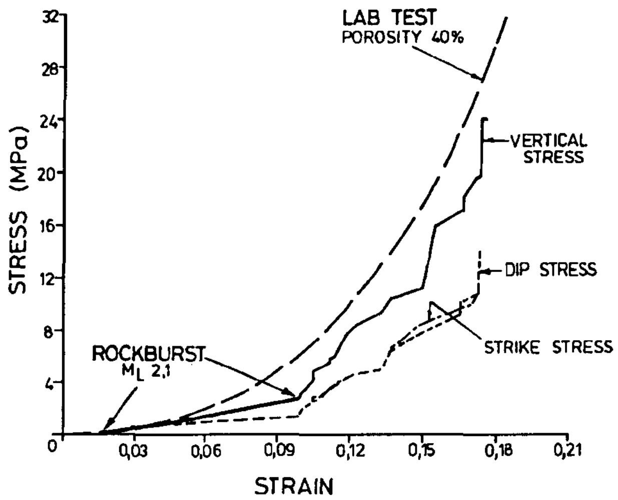

Fig. 9—Confined compression behaviour of the dewatered tailings backfill measured in panel 8W in 5 West Shaft Pillar

stresses are not always included.

Fig. 8 displays the vertical stresses measured at B1 (the Glötzl cell), B2, and B3 in panel 1W. As seen in the diagram, the vertical stresses measured at stations B2 and B3 followed similar paths until the B3 stress meter failed at 7 MPa and a strain of 9 per cent.

However, the backfill placed at station B1 and the Glötzl site showed a slightly softer response than at the other two stations. This is due to the different porosity (i.e. 43 to 44 per cent) of the backfill placed at these stations.

5 West Shaft

Three Glötzl type stress meters were installed to form a triaxial measuring station in the centre of panel 8W, as shown in Fig. 4. A mechanical closure meter was also installed next to the Glötzl stress meters. The stress–strain behaviour of the dewatered tailings measured in this panel is shown in Fig. 9. The maximum vertical, strike, and dip stresses are 24 MPa, 14 MPa, and 13 MPa respectively at 17 per cent strain. A laboratory-test confined-compression curve for a sample with 40 per cent porosity is included in Fig. 9 as a comparison between the *in situ* and the laboratory results. It is interesting to note that a rockburst took place in the stope during the measurements, and increased the stresses and closure by 2,2 MPa and 20 mm respectively. (Table I gives further details.)

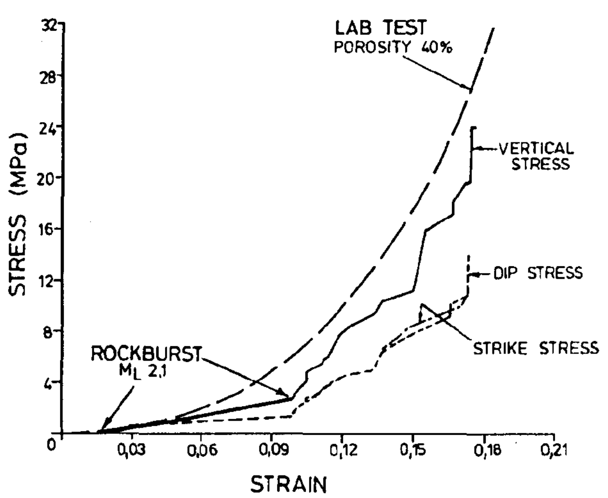

Fig. 8—Vertical backfill stresses measured at stations B1, (Glötzl cell), B2, and B3 in panel W1

Three triaxial hydraulic stress meters and a vertical Glötzl stress meter were installed in panel 5W at 28-8c CL stope, as shown in Fig. 5. A mechanical closure meter was also installed adjacent to each triaxial station in the panel. Fig. 10 shows the stress–strain behaviour of the backfill measured at station C3. The strike stress meter at this station did not record any stress. The dip stress meter operated up to a stress of 6 MPa at about 18,7 per cent strain. The last measurement of the vertical stress meter showed a stress of 27,5 MPa at 24,5 per cent strain. Also displayed in the diagram is the laboratory confined-compression curve for a sample with a porosity of 43 per cent.

The vertical stress–strain curves obtained from stations C1, C2, and C3 are plotted in Fig. 11. The laboratory con-

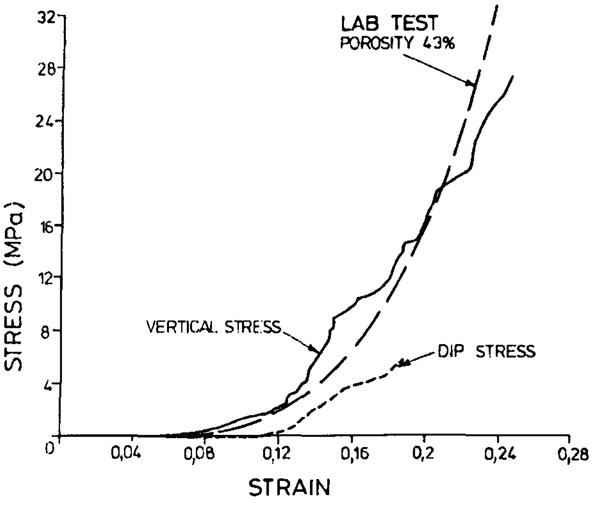

Fig. 10—Confined compression behaviour of the dewatered tailings backfill measured in panel 5W in 5 West Shaft Pillar area

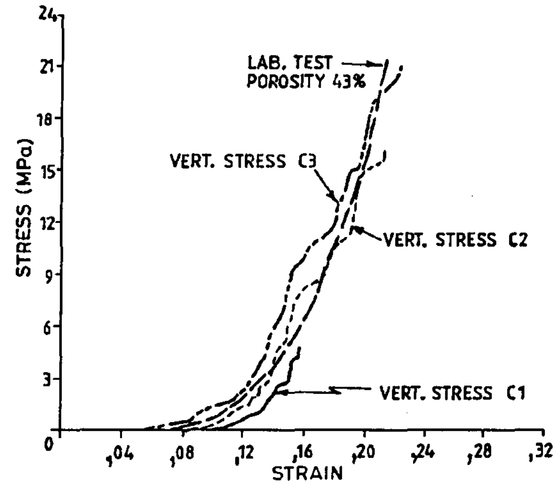

Fig. 11—Vertical backfill stresses measured at different points in the backfill paddock in panel 5W

fined-compression stress–strain curve for a sample with 43 per cent porosity is also included in the diagram.

2 Shaft

Three stations to measure closure and stress in backfill were installed in panel 3W at 14-14 CL stope as shown in Fig. 6. Two of the mechanical closure meters installed at stations F2 and F3 unfortunately operated to only about 70 mm of closure. Subsequently, the closure measurements from the closure meter at station F1 were used until the meter failed at 140 mm of closure. However, the results from the closure and ride stations were utilized for the calculation of strains.

Further problems were experienced with the confinement of the backfill instrumentation at this site. A dip gully was left about 3 m ahead of the instruments, and consequently only partial confinement could be provided for the instruments towards the face. Moreover, the malfunctioning of the closure meters and the lack of proper confinement of the backfill instrumentation in panel 3W affected the results obtained from the instruments. Therefore, only the confined-compression stress–strain behaviour of the backfill placed at station F3 is presented, as shown in Fig. 12. The maximum vertical, strike, and dip stresses measured at this station were 16,5 MPa, 9 MPa, and 8,1 MPa respectively at about 19 per cent strain. A laboratory confined-compression curve for a sample with 46 per cent porosity (i.e. the *in situ* porosity of the backfill material) is included in Fig. 12.

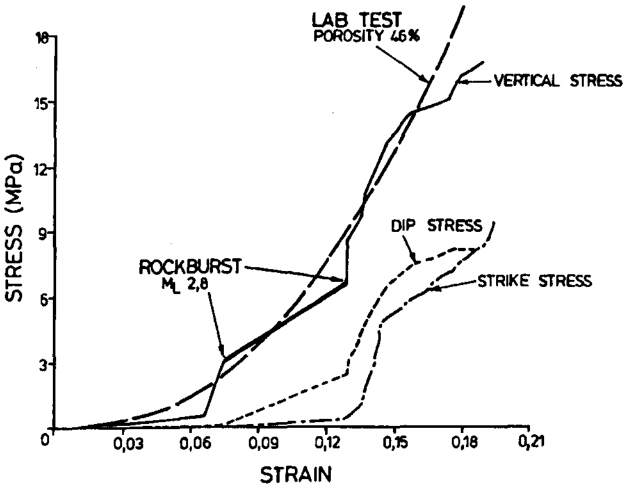

Fig. 12—Confined-compression behaviour of classified-tailings backfill measured at 2 Shaft

A rockburst occurred in the 14-14 CL stope during the monitoring programme, and this was recorded by the stress and closure meters in panel 3W. Details of this rockburst are listed in Table I.

Complete Backfill-rib Behaviour

The complete backfill-rib behaviour of the dewatered tailings backfill was determined in the 3 Sub-shaft and 5 West Shaft Pillar areas. Because of the problems explained in the previous section, the complete backfill-rib behaviour of the classified tailings could not be fully determined successfully at 2 Shaft.

The measurements obtained from the mechanical closure meters installed inside the backfill, and from the closure ride stations outside the backfill, are shown in Fig. 13. From these two diagrams, it is possible to see the development of closures outside the backfill relative to those inside the backfill. The curves shown in the diagrams indicate the closure measured at each closure meter on the same day. The corresponding backfill stresses at some stations are given in brackets in Fig. 13. Also shown in the diagram is the development of closure profiles with respect to distance to face. The first closure profile at the

TABLE I
THE STRESS-STRAIN RESPONSE OF BACKFILL TO ROCKBURSTS AT WEST DRIEFONTEIN GOLD MINE

Backfill type	Distance to face at the time of the event m	Closure increase measured mm	Vertical stress before the event MPa	Stress increase measured MPa	Work done kJ/m^2	Magnitude of the event M_L
Dewatered tailings 40% porosity (5 West)	18	20	0,6	2,2	34	2,1
Classified tailings	9	Stn F1 46	0,18	0,11	10	
46% porosity		Stn F2 46	2,5	6,3	260	2,8
(2 Shaft)		Stn F3 46	3,0	3,5	219	

top (i.e. 5 West Shaft Pillar) shows the measurements taken when the face was 9 m from the instruments. The lower curve showing the maximum closure at each station was plotted after the face had reached a position 38 m from the instruments. Equivalent face advance distances for Fig. 13b (3 Sub-shaft) are 13,5 m and 54 m respectively.

Fig. 14 shows graphs of the stresses at the three stations inside the backfill at various strains. The strains are indicated in brackets next to each vertical stress profile. To complete the stress profiles in the two diagrams, some of the points are estimated and connected to the other points with broken lines.

Closure Measurements

Closure measurements were carried out along gullies and inside panels at three monitoring sites at West Driefontein gold mine. The object of these measurements was to determine the closure rates in backfilled and unfilled stopes.

The development of closure profiles measured in backfilled and unfilled panels with respect to distance to face is shown in Fig. 15. The closure stations were installed about 3 m behind the face, and were monitored for about 40 to 50 m of face advance. However, at some of the stations that were installed more than 3 m from the face, the initial closure had to be estimated.

Fig. 15 indicates that the closure profiles measured at 5 West Shaft Pillar and 3 Sub-shaft were similar, but the closure rates at 2 Shaft were somewhat lower than at the other two sites. The average closure rates for the backfilled panels were calculated for 27 m of face advance (i.e. up to 30 m distance to face) or 216 days of measurement after their installation. This gave closure rates of 10,4 mm/m or 1,3 mm per day inside the backfill, and 14,1 mm/m or 1,76 mm per day along the gullies at 3 Sub-shaft and 5 West Shaft Pillar. At 2 Shaft, however, the closure rate was lower at 7,8 mm/m or 0,97 mm per day. The closure rates in the unfilled panels were 29,3 mm/m or 5,7 mm per day.

Control of Rockburst Damage

One of the major reasons for the use of backfill at West Driefontein gold mine is to reduce rockburst damage. Some of the visits made to rockburst sites in backfilled and unfilled stopes at this mine were described by Gay *et al* .[1] The observations made during further visits are summarized in Table II.

DISCUSSION

Confined-compression Behaviour

Figs. 7 to 10 and 12 clearly show that there is a good agreement between the *in situ* and the laboratory confined-compression curves. The porosity of the samples used to obtain the laboratory curves, however, varied between 40 and 44 per cent for the dewatered-tailings backfill and were about 46 per cent for classified-tailings backfill. The porosity values of both types of backfill were very close to the average *in situ* porosity of the backfill samples taken from the paddocks where the instruments were installed. The ratio of horizontal stress (i.e. dip and strike stresses) to

Fig. 13 (a)

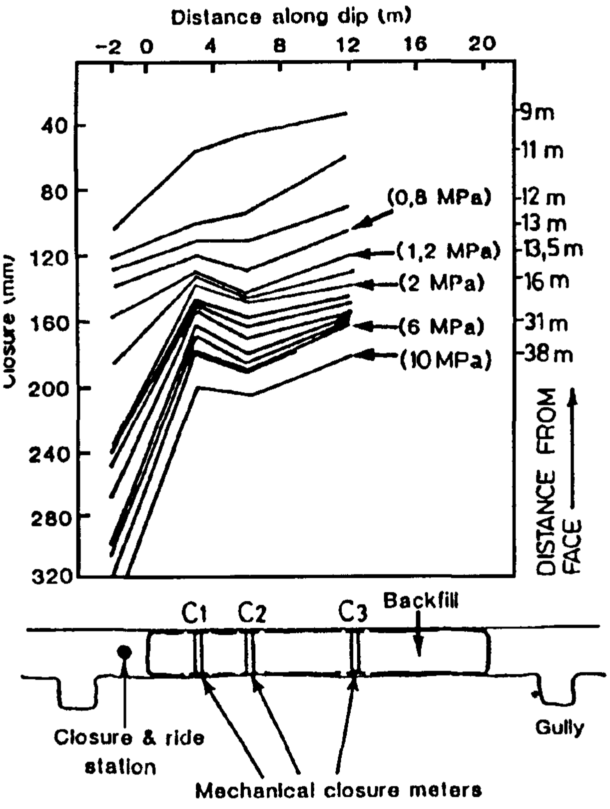

Fig. 13 (b)

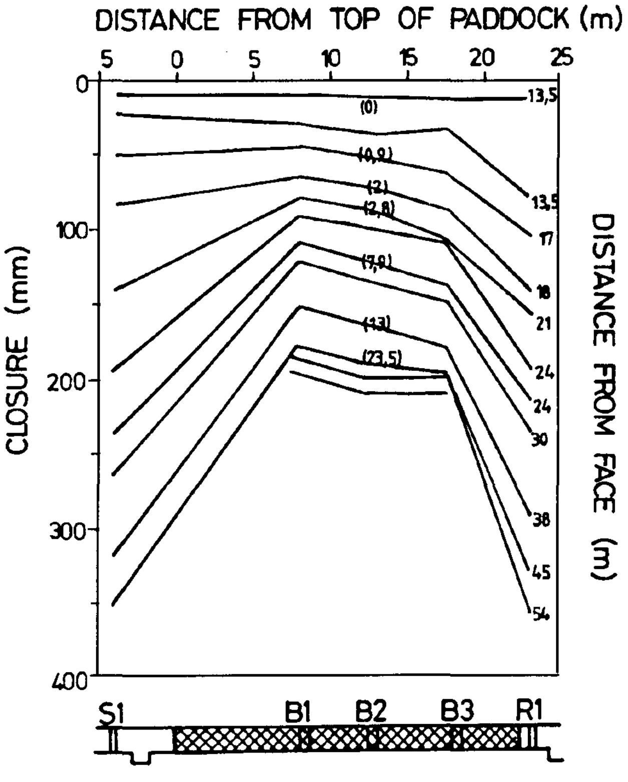

Fig. 13 —Distribution of closure across a backfill paddock in (a) 5 West Shaft Pillar and (b) 3 Sub-shaft areas

Fig. 14 (a)

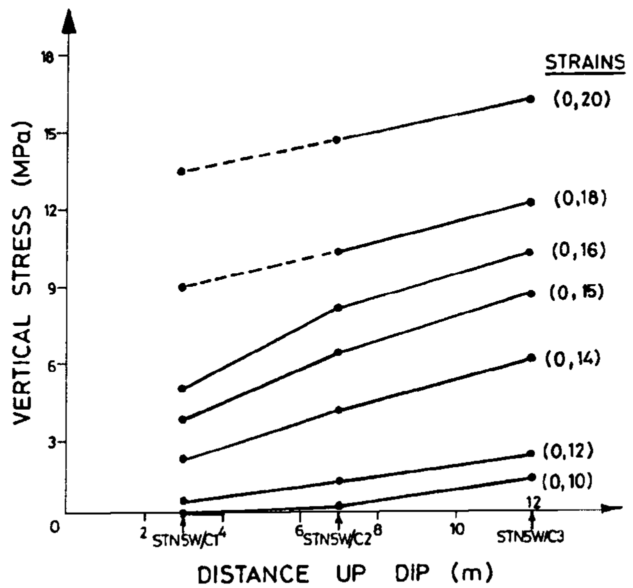

Fig. 14 (b)

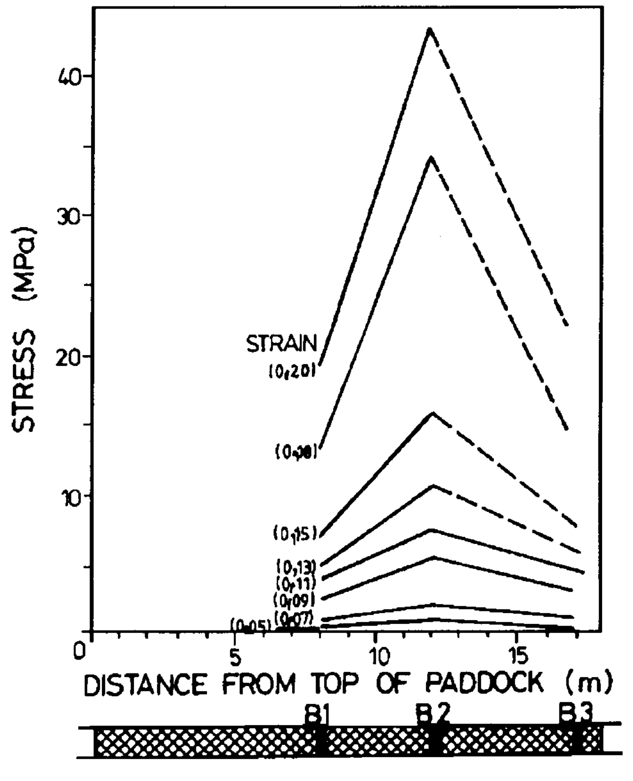

Fig. 14 —Distribution of vertical stress at various strains across the backfill paddock at (a) 5 West Shaft Pillar and (b) 3 Sub-shaft areas

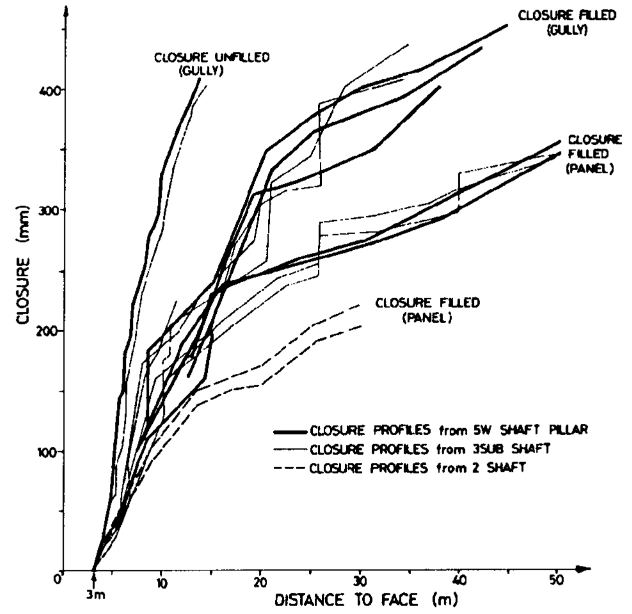

Fig. 15 —Closure profiles measured in backfilled and unfilled panels; the gully closure profiles at 2 Shaft are similar to those in the other backfilled gully areas

vertical stress measured at a point in backfill — the *K* ratio —varied with respect to time at each measuring station at 3 Sub-shaft and 5 West Shaft Pillar, is shown in Fig. 16. The *K* ratios of stations B1 and B3 (i.e. 3 Sub-shaft) increased to as high as 2 and then decreased to around 0,5 in the first 90 days of measuring. The vertical and horizontal stresses were less than 1 MPa at that time. The reading from the low-range stress meters may not have been particularly accurate, which may account for the high initial *K* ratios at those stations. The *K* ratios at other stations increased from zero and levelled off to relatively constant values of between 0,4 and 0,6. This final value of the stress ratio is defined as the K_0 ratio.

Fig. 16 indicates that, in all the triaxial loading conditions for about the first 200 days of measuring, there were variations in the *K* ratio. Later, it become almost uniform, indicating that the increase in horizontal and vertical stresses was equal and that K_0 loading conditions applied. This also implies that the lateral displacements in the backfill were zero or very small. The stress measurements show that constant K_0 ratios occurred in the backfill when the vertical stresses reached 6 to 7 MPa. Clark[3] observed the same behaviour in classified-tailings backfill, and concluded that a variation in K_0 occurs over the stress range 0 to 10 MPa, and that, above 10 MPa, the stress ratios stabilize at fairly constant values.

The relationship between deviator stress and strain is shown in Fig. 17. The deviator stress is the difference between vertical and horizontal stresses measured at a point, and is also known as shear stress. Fig. 17 shows that the deviator stresses measured at the stations in 3 Subshaft and 5 West Shaft Pillar demonstrated similar behaviour.

Clark[3] discussed the deformation behaviour of the two curves for station B2 in detail and identified four distinct

TABLE II
ROCKBURSTS IN BACKFILLED AND UNFILLED STOPES

Date	Seismic event	Area	Backfilled panels	Remarks
Mar 86	M_L 2,1 142 m below the reef	5A longwall	4 panels were affected. The event caused relatively minor damage. Only in one area with a structural weakness (fault) significant damage occurred	Gullies in the protection of filled ground remained open and apparently unchanged. Thickness of rockfalls varied between 0,3 and 3 m
Mar 87	M_L 2,52 M_L 1,06 in footwall	5 West Shaft	8 panels were affected. The events caused damage in one panel where the fill-to-face distance was more then 10 m	Damage in the strike gully of the panel occurred where the fill-to-face distance was more than 10 m. Rockfalls extended to the greenbar
Feb 88	M_L 1,74	5W Shaft pillar area close to a dyke in footwall	No damage in backfilled panels. Face-to-fill distances were about 5 to 6 m. Good face area support	Two footwall excavations were damaged. Sidewall movements resulted in extreme narrowing of the tunnels
Jun 88	M_L 0,56 Very close to the faces	14/18 Carbon Leader	Little damage was observed in backfilled panels.	No damage in the gullies
	M_L 1,56 Occurred 2 days after the first event		Backfill was close to the face, and good face area support was installed	
Aug 88	M_L 3,3 Close to the stope face	5 West Shaft	Little damage in the backfilled panels with close fill-to-face distances. Extensive damage where the fill-to-face distances were around 10 to 15 m	Damage in the strike gullies of the panels where fill-to-face distances exceeded 7 to 8 m. Most of the fallen rock was smaller than 0,3 m in thickness

stages of deformation. These are indicated in Fig. 17. Although, Clark gives a detailed description of these deformation stages, certain points deserve some discussion here.

Shrinkage due to the consolidation of backfill is a problem that is observed in most backfilled stopes but can be avoided by improved techniques of backfill placement. Fig. 16 shows that the triaxial and K_o compression stages follow shrinkage and that, throughout these stages, the backfill material is actually partially confined, the effective confinement increasing with the placement of new backfill ribs ahead of the backfill instrumentation. By contrast, Clark[3] defined breakdown and structural-collapse stresses that are the transition points between triaxial compression, line failure, and zone failure. He suggested that the backfill particles start fracturing at the breakdown stress, and that shear planes develop in the backfill during line failure. However, during the current work, small shear planes in the backfill were observed at a site where a tunnel was excavated through the backfill. The maximum deviator stress measured in the backfill before the tunnel was excavated was about 2 to 2,5 MPa. This stress level is too small to cause line failure, and it implies that shear planes start in the backfill during the triaxial-compression, partial-confinement stage.

A further problem is the identification of the location of these breakdown and structural-collapse stresses along the deviator stress–strain curves. Fig. 17 gives five deviator stress–strain curves in addition to the B2 curves used by Clark, and it is very difficult to identify points at which there is an increase in deviator stress with no strain increase from which breakdown and structural-collapse stresses can be determined.

The authors of the present paper believe that it would be more appropriate to define two stages of backfill compression than the four suggested by Clark. These two stages, which are indicated in Fig. 16, represent states of partially confined and fully confined compression. If it is assumed that the time boundary between the two stages is about 200 days, the corresponding deviator stress–strain values would be about 5 to 7 MPa and 12 to 14 per cent strain respectively. However, these deviator stress and strain values might change for different measurements, and it is not possible to identify this point on a stress–strain curve. Therefore, it would be a better approach to use the variation in K with respect to time or strain etc. to locate the transition boundary from partially confined compression to fully confined compression.

For example, in Fig. 16 the variations in K ratio with respect to time at station F3, 2 Shaft (i.e. classified tailings) show similar behaviour to the other K curves in the diagram, becoming approximately constant at a ratio of 0,5. However, the transition point from partially confined compression to fully K_o confined compression is around 160 days for the classified tailings, compared with 200 days for the dewatered tailings. This transition point at 160 days corresponds to about 16 per cent strain and 8 MPa vertical stress in the classified-tailings backfill.

Complete Backfill-rib Behaviour

As indicated previously, Fig. 13 shows the distribution of closure across the two backfill paddocks at 3 Sub-shaft and 5 West Shaft Pillar. In this diagram, it can be seen that the closure measured inside the fill was 40 to 50 per cent less than that measured at the closure stations outside the fill adjacent to the gully. However, the initial closure at all the stations developed more or less equally up to the point where the vertical stress in the backfill reached 1 MPa.

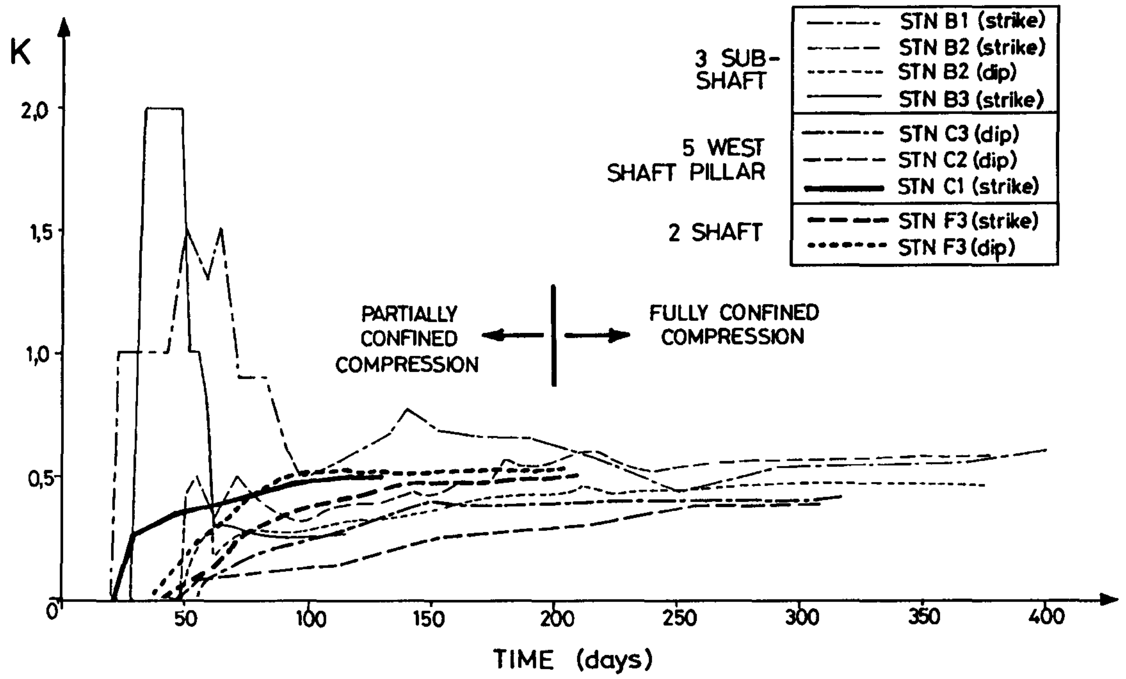

Fig. 16—The variation of *in situ* K ratio with respect to time

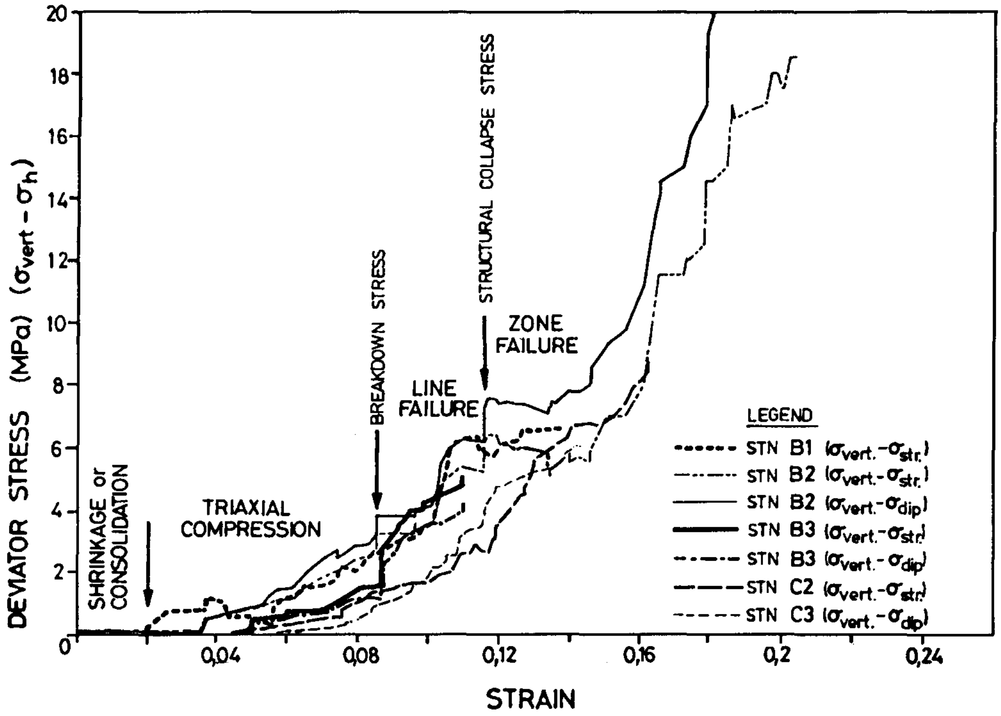

Fig. 17—Relationship between deviator stress and strain

Subsequently, the closure inside the panel was restricted, while the stations in the gully continued to be displaced at a relatively high rate until a stress of 3 to 4 MPa was developed in the fill. The closure differential between the gully and the panel developed mainly during this period. At higher backfill stresses, the amount of closure developing inside and outside the fill was fairly similar. This behaviour of the rockmass in response to the stress development in the fill indicates that large inelastic movements (i.e. bed separations and dilations) may take place in the vicinity of the gullies only when the stress in the backfill is less than 3 to 4 MPa. At higher stresses, the strata become clamped and the inelastic deformation is significantly reduced. The clamped beam bridges across the gully, and closes almost uniformly over the filled panel and unfilled gully area and converges into the excavation as a single structure.

The vertical backfill stresses measured at each station at the 3 Sub-shaft and 5 West Shaft Pillar sites are plotted at various strains in Fig. 14. This diagram shows that, at similar strains, the vertical stresses in the backfill were different across the paddock, and that minimum backfill stress occurred at the edge of the backfill paddock, becoming higher towards the centre of the paddock. For further discussion of this issue, measurements of backfill stress from both diagrams in Fig. 14 were replotted against the distance of the station from the centre of the paddock, as shown in Fig. 18. This reveals the consistency of the measurements taken at two different sites, there being good agreement between them. The stress profiles display a peak in the centre of the paddock, with the vertical stresses decreasing rapidly towards the edges of the paddock. Moreover, the vertical stress decreases more towards the up-dip side of the paddocks than on their down-dip side. This occurs because of the shrinkage and beaching of the backfill material on the up-dip side, causing the backfill to be relatively less confined.

It was previously proposed[4] that vertical backfill stresses are at a minimum at the edge of a backfill rib and become higher and uniform towards the centre of the paddock. However, the measurements specifically carried out to determine backfill-rib behaviour have revealed that the vertical stresses do not become uniform over the central area of the paddock but form a peak in the centre of the paddock as depicted in Fig. 18. This type of backfill-rib behaviour for comminuted waste and classified types of backfill materials has also been observed by Adams and Gürtunca[5] and by Squelch [6].

Closure Measurements

As explained previously, the closure rates measured at 3 Sub-shaft and 5 West Shaft Pillar are higher than those measured at 2 Shaft. Although all three sites had similar mining geometries and spans, the depth at the dewatered-tailings sites is about 600 m more than at the classified-tailings site. This clearly demonstrates the importance of the depth of mining on the rate of closure.

It is clear from Fig. 15, which shows the closure profiles measured at all three sites, that the backfill reduces the closure considerably more than in unfilled gullies. Gürtunca *et al.*[4] argued that the integrity of the hanging-wall beam might be achieved if the closure, and hence the differential movements of key blocks in the rockmass, were reduced. However, this argument of a reduction in rockfalls due to less closure in backfilled stopes has yet to be proved.

Control of Rockburst Damage

Underground observations (Table II) showed that rockburst damage was minimal in the backfilled panels provided the fill-to-face distances were about 5 to 6 m and the face area was supported adequately. The packs were extensively damaged during two rockbursts (i.e. March 1987 and August 1988) in panels where the fill-to-face distances exceeded 10 m.

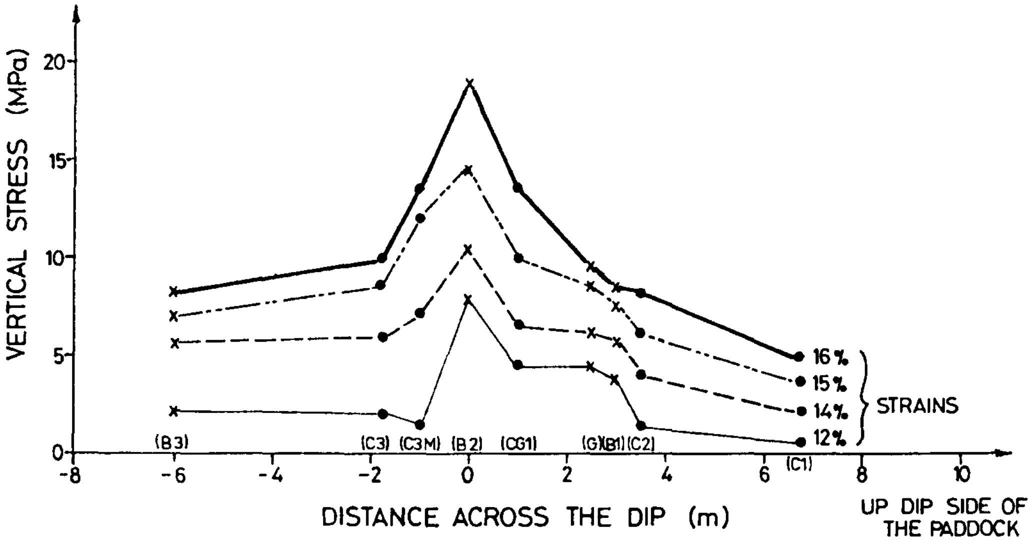

Fig. 18—Distribution of vertical stress at various strains across a backfill paddock (the results illustrated in Fig.14 were superimposed to produce this diagram)

In general, the gullies were in good condition following the rockbursts, but some gullies where the fill-to-face distances were more than 5 to 6 m were damaged as a result of rockfalls 0,1 m and 0,3 m into the hangingwall. The thickness of the rockfall was about 3 m in one case, but this rockfall was associated with a fault plane in the area.

Gay *et al.*[1] also concluded that, in general, stopes that had been backfilled survive rockbursts better than do conventionally supported stopes. They explained this as being primarily due to the greater areal support provided by the backfill, but also to the effectively greater stiffness of backfill than of conventional pack support.

In addition, backfill has a considerable ability to absorb seismically generated energy. Table I shows that the work done by backfill during rockbursts can be as high as 260 kJ/m^2. It was calculated by Jager *et al.*[7] that the average work done by a timber-pack system close to the stope face is about 43 kJ/m^2 for 300 mm rapid closure. This shows that backfill materials offer more resistance to the closure induced by a seismic event than that of conventional support units such as timber packs.

SUMMARY AND CONCLUSIONS

The rock-engineering monitoring programme at West Driefontein gold mine on the *in situ* behaviour of backfill and the surrounding rockmass, and on the effectiveness of backfill to reduce rockburst damage produced the following results.

(1) The confined-compression stress–strain behaviour of the dewatered-tailings and classified-tailings backfills used on this mine were established.

(2) There was good correlation between the *in situ* and the standard laboratory measurements.

(3) Only the complete backfill-rib behaviour of the dewatered tailings could be established, and it was found that the maximum and minimum closure takes place in the gullies and near the centre of the filled panel respectively. However it was also found that the minimum stress occurs at the edge of the backfill paddock, and the stresses form a peak in the centre of the paddock at similar strains.

(4) The closure rates are significantly lower in filled stopes than in unfilled stopes.

(5) The seismically induced rockburst damage in backfilled panels is less than that in unfilled panels, indicating that backfill has the potential to provide significant benefits in both regional and local support.

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Zinc and lead

An international symposium on the extraction and applications of zinc and lead (Zinc & Lead '95) will be held in Sendai, Japan, from 22nd to 24th May, 1995. The Symposium is co-sponsored by the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) and the Mining and Materials Processing Institute of Japan (MMIJ).

The Symposium will highlight zinc and lead technologies for the 21st century, with emphasis on mineral processing, hydrometallurgy, pyrometallurgy, recycling, secondary materials, and applications. The intent is to bring together industry and the academic community to discuss zinc and lead technologies, as well as the environmental and marketplace challenges facing these metals. The programme will be complemented by technical tours to Japan's leading zinc and lead processors.

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