Horizontal stresses in the hangingwall of tabular stopes

by A.P. Squelch*

Synopsis

The question of what stress condition exists in the hangingwall of tabular stopes remains topical and largely unanswered. Limited field data exist to quantify the situation and provide calibration for investigative computer modelling exercises. Work conducted in 1989 and 1990 under a Chamber of Mines Research Organization (now the CSIR: Division of Mining Technology) programme of research into the behaviour and benefits of backfill may assist with this situation. The original work was motivated by the premise that the improved hangingwall stability in backfilled panels (identified by rockfall accident analyses) is due to a change in the hangingwall stress regime. Current, largely theoretical, studies into mechanisms of stope hangingwall behaviour and support interaction could benefit from considering these data.

Keywords: Backfill, horizontal stress, stope hangingwall, hangingwall stability, support interaction.

Introduction

A knowledge and understanding of the horizontal stresses that act in the hangingwall of tabular stopes is crucial for the meaningful design of stope support systems. The issue is as topical today as ever, which is evidenced in the reporting of, for example, recent research into hangingwall stability[1] and support design criteria[2]. The primary questions are as follows:

➤ are horizontal stresses tensile or compressive and

➤ what are their magnitudes and orientations?

Research carried out under the Chamber of Mines Research Organization (COMRO), now the CSIR: Division of Mining Technology, during 1989 and 1990 provides a rare opportunity to obtain an insight into these questions. Current research undertakings that require clarity on the issue of hangingwall stresses can benefit from revisiting the earlier information, via its publication in a widely read journal.

The original work formed part of COMRO research into the influence and benefits of backfill in South African gold mines. The relevant portion of the work was motivated by the idea that a change in the stress regime in the stope hangingwall due to the presence of backfill was the most likely way to explain the improved hangingwall stability identified by rockfall accident analyses[3]. It is still speculated as to the precise mechanisms that are responsible for generating horizontal compressive stresses in the hangingwall of tabular stopes, a condition that contradicts elastic theory. Various explanations are, however, given to account for the situation.

Stress regimes around tabular excavations

In most computer modelling of tabular excavations only the strike-parallel horizontal stress and vertical stress are predicted because of the 2D nature of many of the models used. Kirsten and Stacey[4] compared the stress regime around a tabular excavation in an elastic continuum with that in a non-elastic discontinuum. Elastic modelling, as is to be expected, predicts that:

➤ a biaxial (i.e. in vertical and strike directions) tensile zone exists over most of the excavation

➤ a small zone of tension-compression (again only in strike and vertical directions) exists near the stope face and

➤ the bulk of the surrounding rock mass overlying the immediate stope hangingwall is under biaxial compression.

Whereas, the non-elastic discontinuum modelling led Kirsten and Stacey[4] to note that:

➤ substantial horizontal clamping stresses are generated and

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- 'the beneficial effect of horizontal stresses in the fractured nether hangingwall is self evident'.

More recent inelastic studies of Kuijpers[5] and Kuijpers and Napier[6] examined mechanisms that could account for the generation of compressive horizontal stresses in the stope hangingwall. Explanations arising from this work include: ratchetting of vertical fractures resulting from the stepwise mining process; and the actions and interactions of beams in the stope hangingwall. These studies also identified aspects requiring further research; in particular the need for relevant underground measurements.

Commenting on the envelope of stress-induced fractures that surrounds a deep-level stope, Jager and Roberts[7] stated that 'The dilation of this fractured zone causes high compressive horizontal stresses in the stope hangingwall. These horizontal stresses clamp the fractured rock together, so that the hangingwall is to a large extent self supporting. However, because unfavourable orientation of fractures can occur in the immediate hangingwall it is inevitable that some unstable keystone blocks are present notwithstanding these horizontal stresses'. Further to this, Jager and Roberts[7] attributed the high rates of inelastic closure observed in deep-level stopes to the presence of high horizontal compressive stresses which produce a bending or buckling of the hangingwall and footwall strata into the stope. They also note, from work carried out by Legge[8], that bed separation is facilitated by a breakdown of cohesion on bedding surfaces due to the shearing on these surfaces that the horizontal stresses cause.

Hermann[9] found, in the *back area caving* situation, that some degree of horizontal stress relaxation occurred in the extensively fractured lower layers of the hangingwall and confirmed that this contributed to improved (face area) hangingwall conditions, a conclusion supported by the observations of Batty and Bell[10]. Hermann[9] further suggested that the higher, less severely broken, layers might contain higher compressive stresses because of the existence of some confinement. His measurements indicated that the magnitude of these compressive stresses might exceed 50 MPa.

It appears that backfill stabilizes the stope hangingwall by creating suitable horizontal clamping forces. Lubbe[11] attributed an observed increase in resistance to seismic shake-down to the existence of 'improved' horizontal clamping stresses in the immediate stope hangingwall. These clamping stresses being a result of increased back area loads because of the placement of backfill. Piper *et al.*[12] discussed both the potential and realized benefit of using backfill in reducing rockfall and rockburst damage. They attributed the success in reducing rockburst damage and the frequency of rockfalls to:

- induced horizontal stresses (clamping)
- shorter hangingwall beams, which are inherently more stable than the normal stope hangingwall and
- possible transmission of horizontal stresses in the backfill to the hangingwall.

The area of greatest concern (in terms of rock- related accidents) in a stope is the face area[13], where the majority of labour is concentrated. The state of stress in this region has an influence on the occurrence of rockfalls and, therefore, injuries. If a different stress state exists in filled panels compared to unfilled panels, this may have a favourable or unfavourable influence on the occurrence of rockfalls. Quantifying the stress regime existing in the hangingwall of filled and unfilled panels was, therefore, identified as a key step in explaining the improved hangingwall conditions associated with backfilling.

Measurement procedure and site descriptions

Determining the horizontal stress regime in the hangingwall of backfilled and unfilled (i.e. conventionally supported) panels was accomplished by conducting so-called *doorstopper stress measurements*[15–17]. These (strain) measurements were undertaken at suitable sites on Vaal Reefs 2 and 5 Shafts and chosen on the basis that they provided comparable backfill and conventional mining environments.

Measurement procedure

The standard and well documented method of stress determination using CSIR *doorstopper* strain cells[14–18] was chosen for the investigation. This was because of:

- the availability of installation and measuring equipment
- the availability of expertise
- the relative simplicity of the technique
- the availability of a suitable computer program for data analysis and
- the fact that only a horizontal biaxial stress state was to be measured.

BX (i.e. 60 mm diameter) holes were drilled vertically into the hangingwall of gullies in selected panels, at positions ranging from 2 m to 4 m from the panel face (Figure 1). Drilling had to be carried out in the gullies, and not inside the panel, to accommodate the diamond drill machine.

Previous work[19] carried out by COMRO Rock Engineering at Vaal Reefs 2 Shaft indicated that the majority of rockfalls in stopes at Vaal Reefs were confined to the first 2 m of the hangingwall. Also, rockfalls of a thickness greater than 1 m tended to be associated with geological features, and therefore not of direct interest to the investigation. Hence, it was decided to limit the investigation to within the first 2.5 m of hangingwall strata.

Doorstopper strain cells were installed in vertical boreholes progressively from a depth of 0.7 m to a final depth of about 2.5 m (Figure 1). Owing to the fractured nature of the rock it was usually necessary to carry out the measurements in at least two holes (more than 0.5 m apart) in order to obtain results at reasonable intervals over the depth range 0.7 m to 2.5 m.

Description of underground sites

Sites were chosen to provide comparable backfill and conventional (scattered) mining situations and were located at the Vaal Reefs Gold Mine in the Klerksdorp mining district (Figure 2).

Suitable backfilled sites were found at 2 Shaft and comparable unfilled conventional sites at the adjacent 5 Shaft. The sites were selected on the basis that a large area had been mined out either using a conventional support

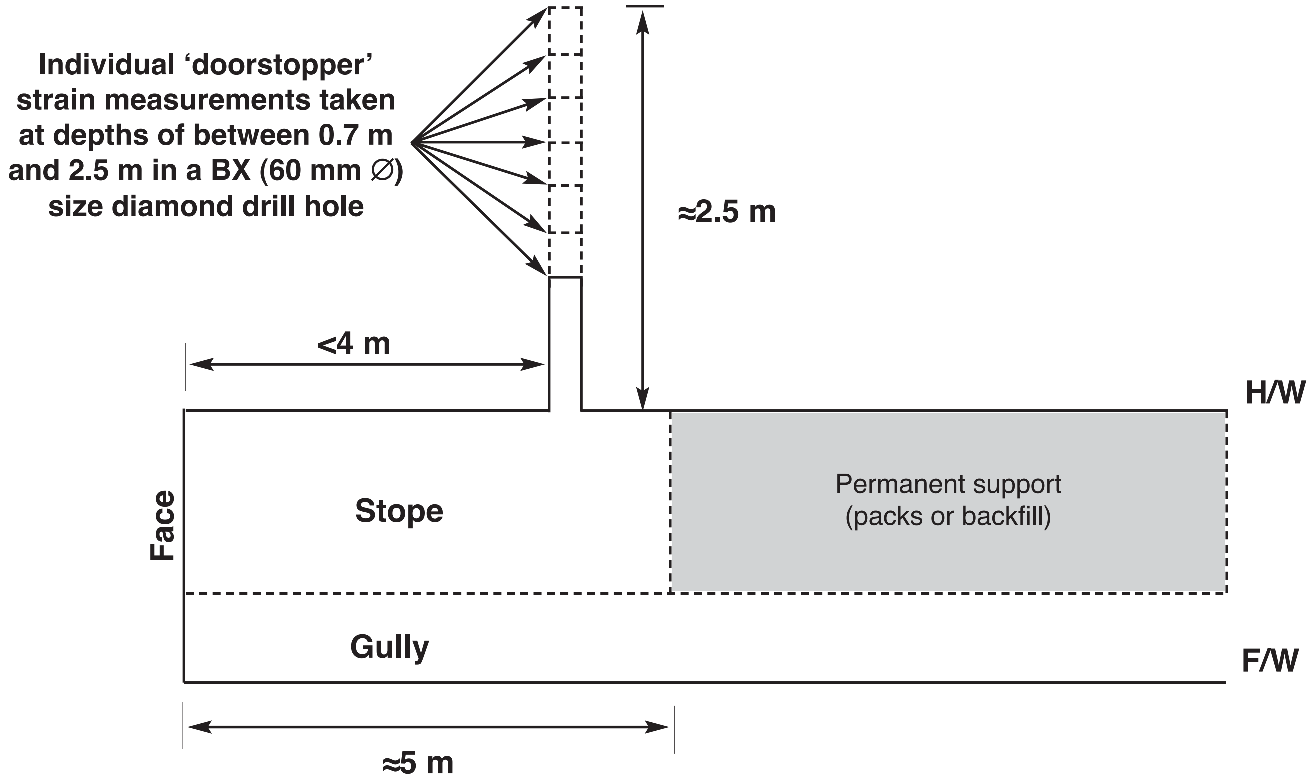

Figure 1—Schematic of 'doorstopper' measurement borehole

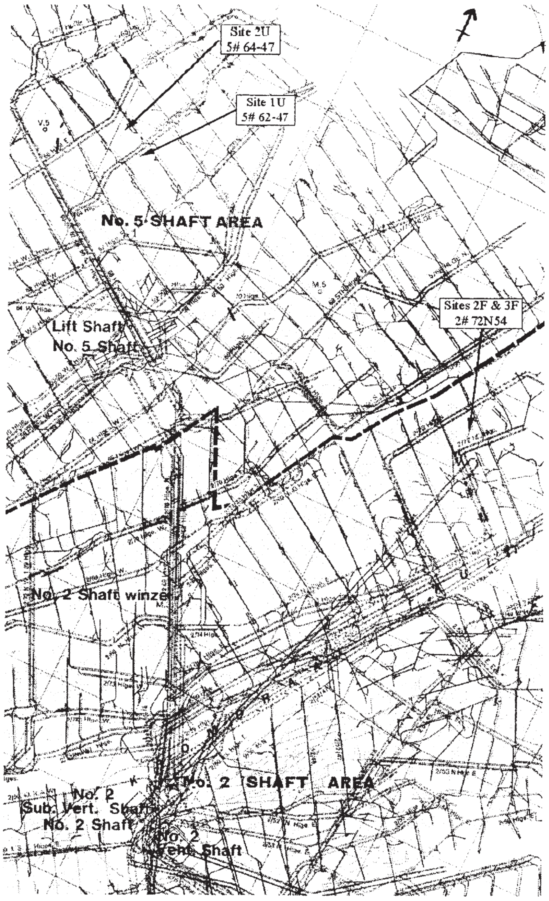

Figure 2—General location plan of measuring sites at Vaal Reefs 2 and 5 Shafts

system (i.e. packs) or using backfill, and that the mining situations were as similar as possible. Panels selected were in stopes mined out to their limits on both sides of the centre raise. Layouts of the unfilled sites are given in Figure 3 and Figure 4, and backfilled sites in Figure 5. Additional details about the sites, e.g. depth and dip, are given in Table I.

Hangingwall stresses

In keeping with the purpose of the original investigation, results are split into those from unfilled (conventional) panels and those from filled (backfill) panels. Strain gauge readings were processed using COMRO *doorstopper* analysis software to calculate maximum and minimum horizontal stresses and their respective orientations.

The analysis software makes use of standard strain transformation formulae to convert *doorstopper* strain gauge readings into maximum and minimum strains and stresses in a (horizontal) plane perpendicular to the axis of the instrumented borehole[15–17]. These formulae also require the input of values for Young's modulus and Poisson's ratio of the instrumented rock. Samples of the borehole cores were, therefore, sent for laboratory testing to determine these properties. Several sets of strain readings at each site were rejected after computation showed unacceptably large gauge checksums (error assessments) and variations in individual orientations.

In the following Tables of results:

- compressive stresses are shown as positive
- tensile stresses are shown as negative
- orientation of the major horizontal stress is given as an angle on the horizontal plane, where positive denotes

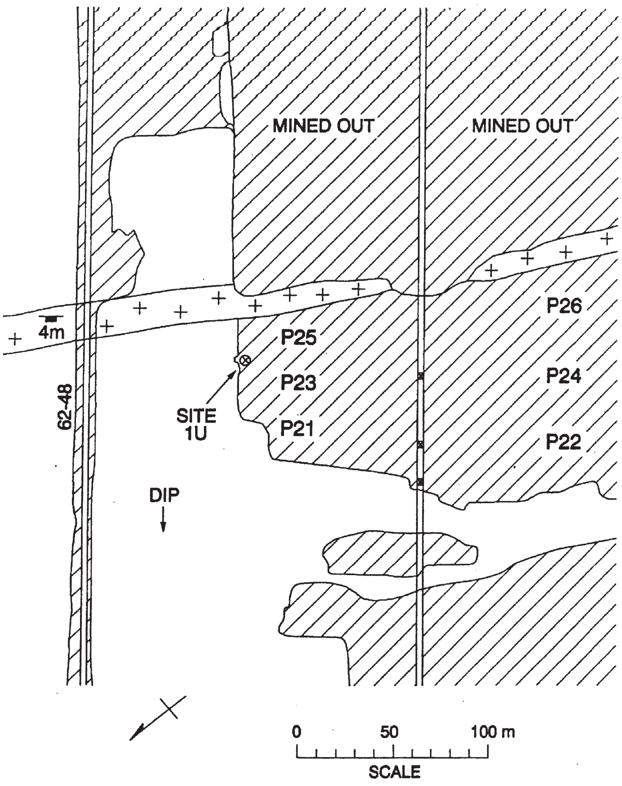

Figure 3—Location plan of unfilled site 1U in 62–47 stope, Vaal Reefs 5 Shaft

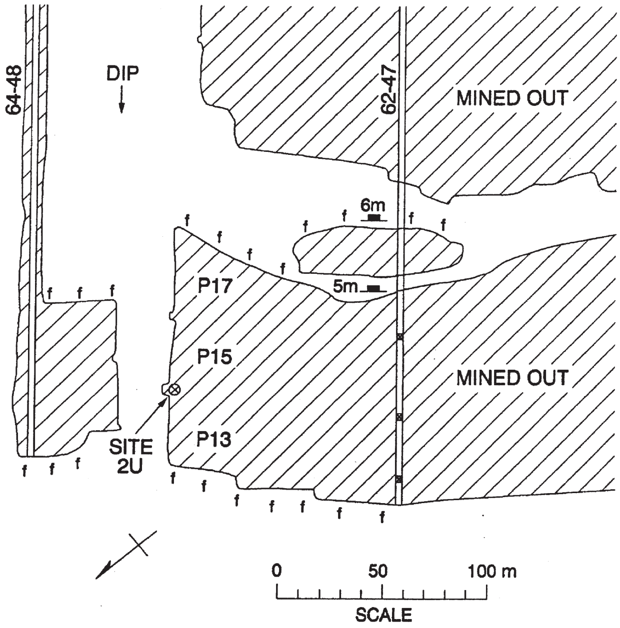

Figure 4—Location plan of unfilled site 2U in 64–47 stope, Vaal Reefs 5 Shaft

an anti-clockwise direction from the dip direction of the stope (cf. Figure 6) and

- Young's modulus (E) is taken as 68 GPa and Poisson's ratio (Ω) taken as 0.22. These are average values taken from laboratory tests carried out on core samples from the relevant boreholes.

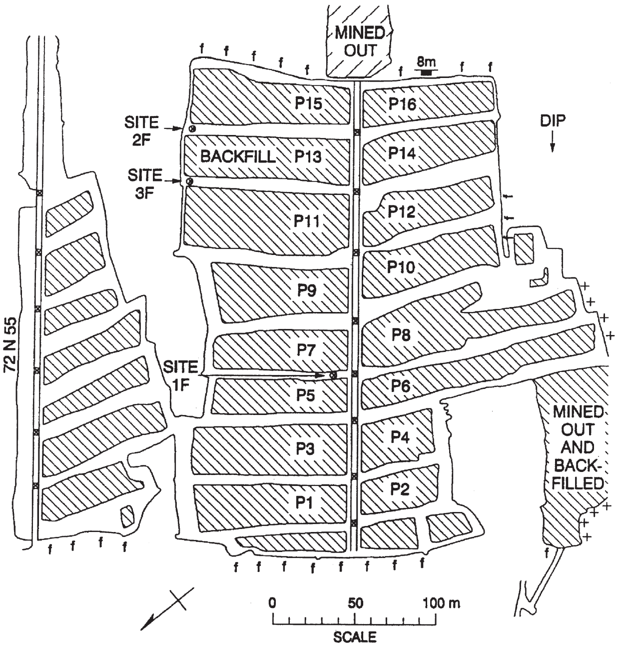

Figure 5—Location plan of filled sites 2F and 3F in 72N54 stope, Vaal Reefs 2 Shaft

Table I

Additional details relating to underground sites at Vaal Reefs mine

Site name	Shaft no.	Stope & panel no.	Type of site	Depth below surface	Reef type	Reef Dip
1U	5	62-47 P25	Unfilled	1860 m	Vaal reef	10°
2U	5	62-47 P15	Unfilled	1900 m	Vaal reef	10°
2F	2	72N54 P15	Filled	2100 m	Vaal reef	10°
3F	2	72N54 P13	Filled	2105 m	Vaal reef	10°

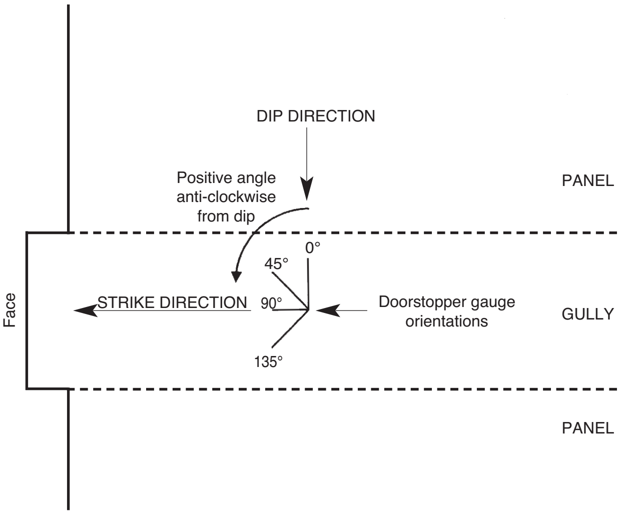

Figure 6—Schematic of *doorstopper* strain gauge orientations and horizontal angle sign convention

Unfilled panels

Results from the two unfilled sites, Site 1U (Figure 3) and

Site 2U (Figure 4) at 5 Shaft, are combined in order to give a generalized indication of the horizontal stress state in the gully hangingwall approximately 4 m back from the stope face. Individual strain gauge readings and the computed stresses and strains are given in Table II and Table III, respectively.

Filled panels

Results from the two filled sites, Site 2F (Figure 5) and Site 3F (Figure 5) at 2 Shaft, are combined in order to give a generalized indication of the horizontal stress state in the gully hangingwall approximately 4 m back from the stope face. Individual strain gauge readings and the computed stresses and strains are given in Table IV and Table V, respectively.

Discussion

The results obtained from filled and unfilled panels at Vaal Reefs (presented graphically in Figure 7 and Figure 8) provide a good indication of the reason for the improved hangingwall conditions observed in backfilled panels versus conventionally supported panels[3].

In the unfilled situation the maximum horizontal stress is compressive, at an average level of 8.3 MPa and the minimum horizontal stress is in general tensile, at an average level of -1.9 MPa. In the filled situation both the maximum and minimum horizontal stresses are generally compressive, at an average level of 13.1 MPa and 5.8 MPa respectively. Thus, the average levels of maximum and minimum stress in the filled panels (Figure 7) are 4.8 MPa and 7.7 MPa higher, respectively, than those in the unfilled panels (Figure 8).

Maximum horizontal stresses in the unfilled cases tend to follow well-defined orientations with respect to the stope face, i.e. midway between dip and strike (Figure 9). Each orientation set is associated with a different measurement site and possibly, therefore, related to an as yet unidentified site effect. In the filled cases the orientations are much more variable and not well defined with respect to the stope face (Figure 10). Other factors potentially responsible for variations in results are: fracturing in the hangingwall and vagaries of the measuring technique, e.g. quality of cement bond, small strain relief values, hot and moist environment etc. To offset these, results that were obviously erroneous were discarded at the initial analysis stage and only those with acceptable checksum values were retained for the final computation stage.

Although an estimated ±5 degree error may exist in the stress orientations given relative to the stope face (owing to difficulties in determining the exact physical orientation of each 'doorstopper'), it appears that there is a general consistency in the individual stress magnitude levels for each case. Indicating that, despite the small final sample size, a valid interpretation can be made with respect to the difference in hangingwall horizontal stress regime at the filled and unfilled sites. The interpretation is that a biaxial compressive state of horizontal stress exists, in general, in the hangingwall of filled panels and that this is significantly different from the more tensile situation prevailing in unfilled panels.

Table II

Combined strain gauge readings from unfilled panels

Site and test no.	Depth into h/w (m)	Strain gauge 1 0°	Strain gauge 2 45°	Strain gauge 3 90°	Strain gauge 4 135°	Strain gauge checksum	% error
1U3-1	0.700	19	-2	16	44	7	17%
2U4-1	0.710	-52	65	63	-72	18	14%
2U3-1	1.010	-4	177	25	-158	2	1%
2U1-1	1.380	67	133	-5	-41	30	24%
2U1-2	1.665	114	178	137	84	11	4%
2U4-4	1.890	61	175	-40	-146	8	9%
2U4-5	2.160	44	137	54	-54	15	10%
1U2-3	2.170	290	-127	-24	474	81	18%

Table III

Combined stress and strain results from unfilled panels

Site and test no.	Depth into h/w (m)	Maximum horizontal		Orientation* (deg°)	Minimum horizontal	
		Strain (μs)	Stress (MPa)		Strain (μs)	Stress (MPa)
1U3-1	0.700	30	2.1	-43	-3	0.3
2U4-1	0.710	65	3.6	45	-64	-3.5
2U3-1	1.010	128	7.3	48	-113	-6.1
2U1-1	1.380	95	6.2	34	-40	-1.4
2U1-2	1.665	127	9.9	52	57	6.1
2U4-4	1.890	130	7.5	36	-111	-5.9
2U4-5	2.160	101	6.7	47	-36	-1.0
1U2-3	2.170	354	23.2	-31	-134	-4.0

*positive = anti-clockwise from dip (cf. Figure 6)

Table IV

Combined strain gauge readings from filled panels

Site and test no.	Depth into h/w (m)	Strain gauge 1 0°	Strain gauge 2 45°	Strain gauge 3 90°	Strain gauge 4 135°	Strain gauge checksum	% error
3F1-1	0.805	213	150	52	108	7	3%
3F1-3	1.205	76	97	128	101	6	3%
3F1-4	1.430	245	23	74	292	4	1%
3F1-5	1.660	225	158	116	172	11	3%
2F1-5	1.760	77	-5	-67	5	10	13%
2F1-6	2.130	196	72	114	214	24	8%
3F1-7	2.155	520	365	203	324	34	5%

Table V

Combined stress and strain results from filled panels

Site and test no.	Depth into h/w (m)	Maximum horizontal		Orientation* (deg°)	Minimum horizontal	
		Strain (μs)	Stress (MPa)		Strain (μs)	Stress (MPa)
3F1-1	0.805	153	11.5	-13	34	4.8
3F1-3	1.205	91	7.3	62	53	5.2
3F1-4	1.430	228	16.3	-59	-1	3.5
3F1-5	1.660	160	12.7	-24	81	8.3
2F1-5	1.760	54	3.0	-2	-50	-2.7
2F1-6	2.130	166	12.6	-75	48	6.0
3F1-7	2.155	368	28.5	14	138	15.7

*positive = anti-clockwise from dip (cf. Figure 6)

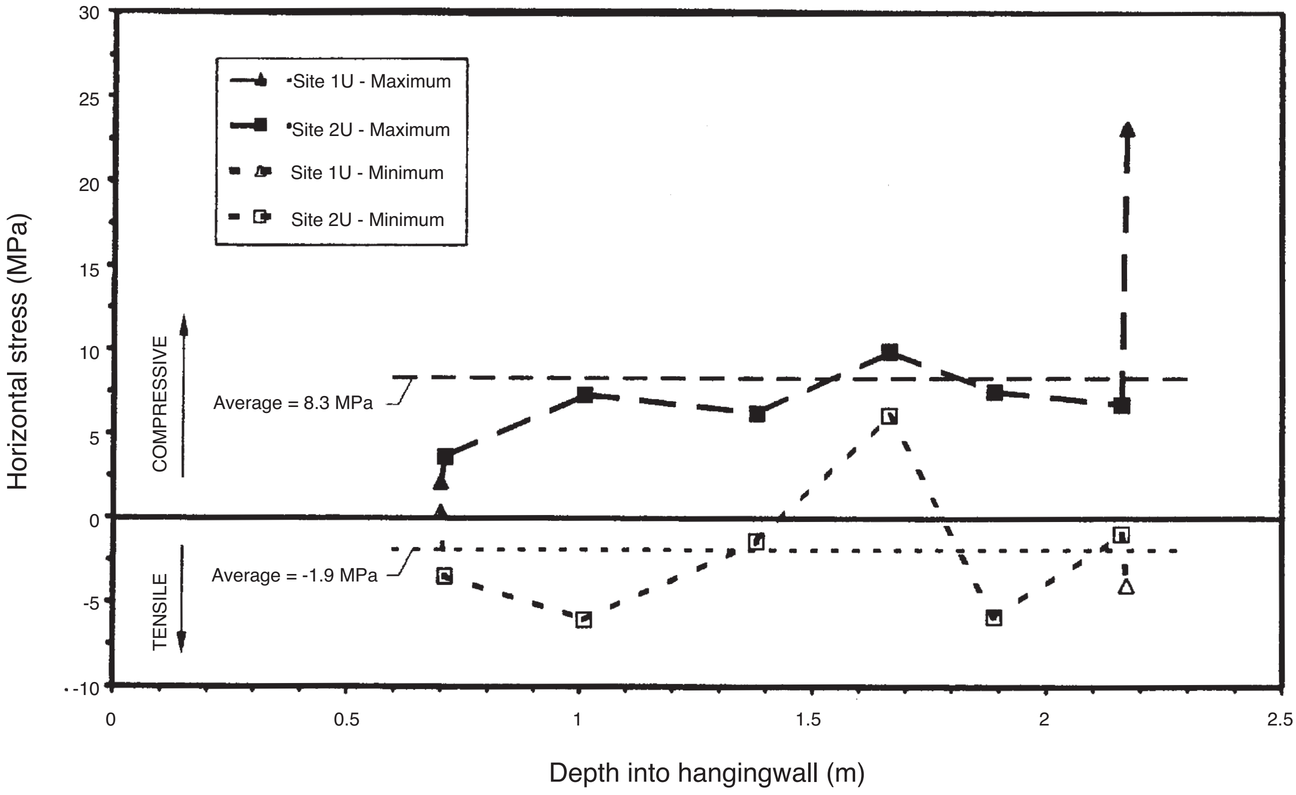

Figure 7—Maximum and minimum horizontal hangingwall stresses: unfilled panels

Elastic modelling tools predict tensile horizontal stresses in the immediate stope hangingwall. However, these numerical solutions need to be reconsidered in light of the presented field results, which represent a quantification of the actual *in situ* stresses. Numerical modules are, therefore, required to have mechanisms that represent compressive horizontal stresses under these conditions. Such models could then be used to investigate reasons for the increase in horizontal stress recorded in filled panels compared to unfilled panels.

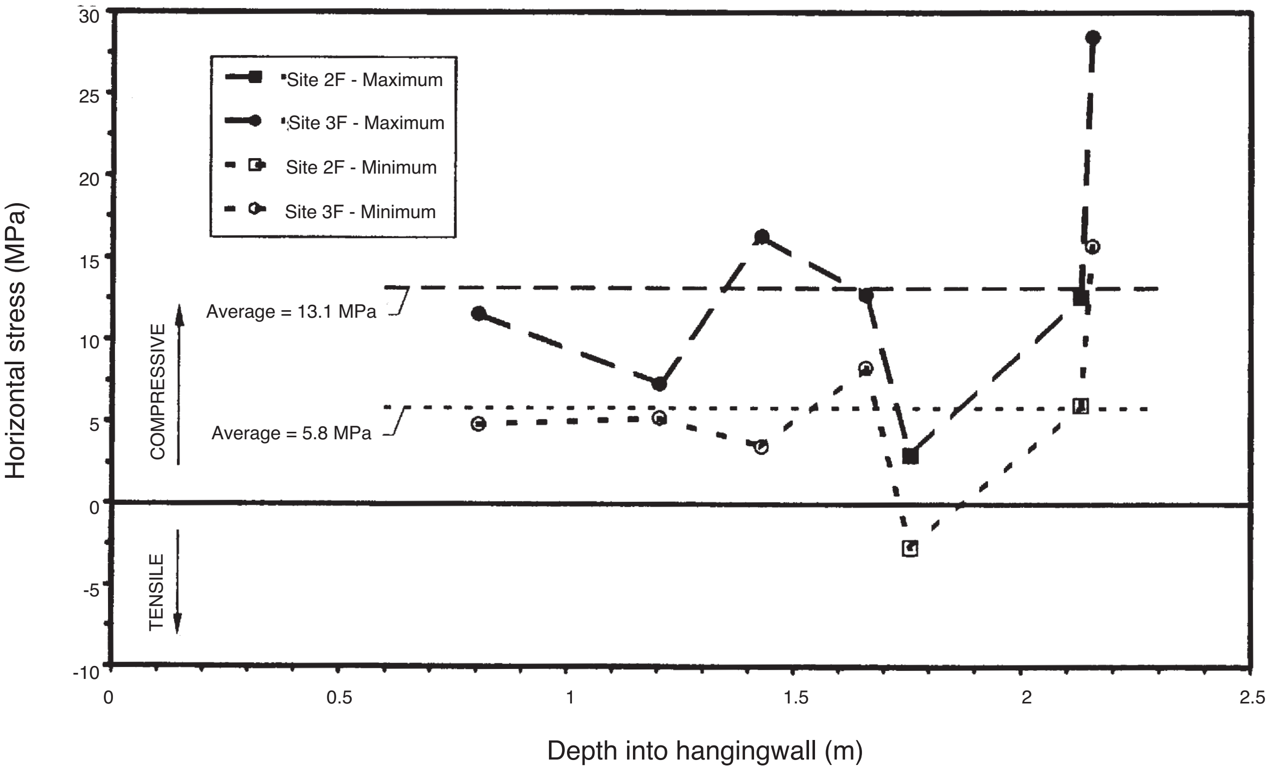

Figure 8—Maximum and minimum horizontal hangingwall stresses: filled panels

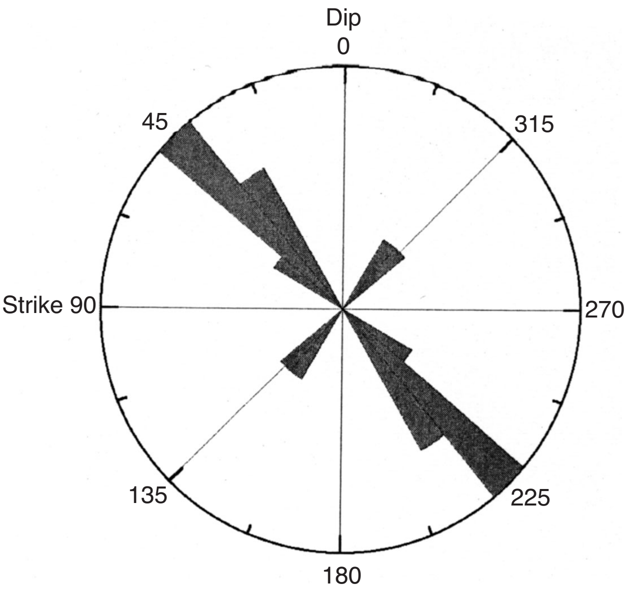

Figure 9—Maximum horizontal stress orientations: unfilled panels

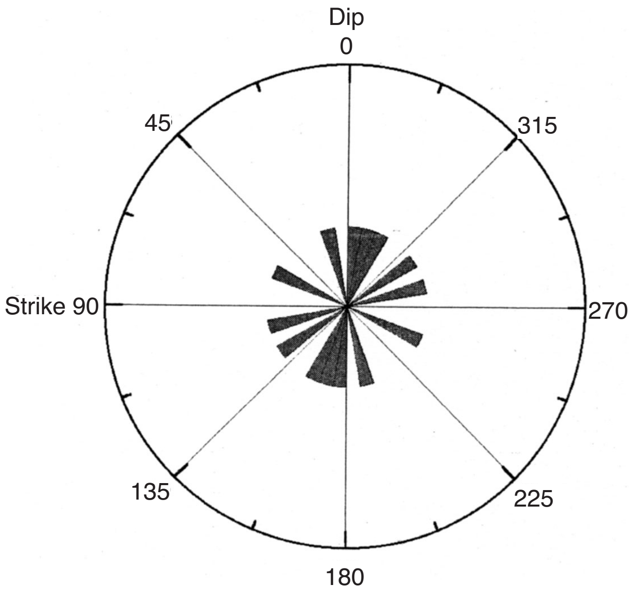

Figure 10—Maximum horizontal stress orientations: filled panels

The biaxial compressive state of horizontal stress recorded in the backfill (filled) panels provides an explanation for backfill's beneficial influence on rockfalls and hangingwall conditions. In addition, these results also provide valuable field data of relevance to the more generic problem of understanding and modelling the mechanisms of stope hangingwall behaviour and support interaction. These topics are being addressed largely from a theoretical perspective and by making a number of assumptions[1,2]. Benefit could, therefore, be obtained from considering actual field data in these endeavours[6,20], which also highlights the need for further strain relief measurements to be undertaken.

Conclusions

The horizontal stresses in the immediate (up to 2.5 m) hangingwall of the face area of backfilled panels on the Vaal reef are generally compressive, whereas in comparable unfilled panels tensile horizontal stresses are more evident. In addition, the average level of horizontal stresses is higher in the backfilled panels than in the unfilled panels for this particular geotechnical area. These findings provide an explanation for backfill's favourable influence on rockfalls and hangingwall conditions in the given geotechnical area.

The data presented, in addition to serving its original purpose, is also of relevance to the more generic research that is currently taking place into mechanisms of stope hangingwall behaviour and support interaction. It is hoped, therefore, that the publishing of these results will contribute to an increased level of understanding, a renewed interest in numerical modelling studies and a stimulus for further field measurements in these areas.

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References

1. Daehnke, A., Salamon, M.D.G., and Roberts, M.K.C. Quantifying stable hangingwall spans between support units. *J. S. Afr. Inst. Min. Metall.*, vol. 100, no. 6. 2000. pp. 375–388.
2. Daehnke, A., Van Zyl, M., and Roberts, M.K.C. Review and application of stope support design criteria. *J. S. Afr. Inst. Min. Metall.*, vol. 101, no. 3. 2001. pp. 135–164.
3. Squelch, A.P. and Gürtunca, R.G. Reduction in rockfall accidents and rockburst damage in backfilled stopes. *Proceedings of Mine Safety and Health Congress*. Chamber of Mines of South Africa, Johannesburg. 1991. pp. 229–242.
4. Kirsten, H.A.D. and Stacey, T.R. Stress-displacement behaviour of the fractured rock around a deep tabular stope of limited span. *J. S. Afr. Inst. Min. Metall.*, vol. 89, no. 2. 1989. pp. 47–58.
5. Kuijpers, J.S. Identification of inelastic deformation mechanisms around deep level mining stopes and their application to improvements of mining techniques. Ph.D. thesis, University of the Witswatersrand, Johannesburg. 1998.
6. Kuijpers, J.S. and Napier, J.A.L. The effect of loading history on stress generation due to inelastic deformations around deep-level tabular stopes. *J. S. Afr. Inst. Min. Metall.*, vol. 91, no. 6. 1991. pp. 183–194.
7. Jager, A.J. and Roberts, M.K.C. Support systems in productive excavations. *GOLD 100. Proceedings of International Conference on Gold*, vol. 1: Gold Mining Technology. SAIMM, Johannesburg. 1986. pp. 289–300.
8. Legge, N.B. Rock deformation in the vicinity of deep gold mine longwall stopes and its relation to fracture. Ph.D. thesis, University of Wales, Cardiff. 1984.
9. Hermann, D.A. Fracture control in the hangingwall and the interaction between the support system and the overlying strata. M.Sc. dissertation, University of the Witswatersrand, Johannesburg. 1987.
10. Batty, G.B. and Bell, J.H.C. Stope caving. *Assoc. Mine Managers S. Afr., Papers and Discussions*, vol. 1. 1945. pp. 421–432.
11. Lubbe, J. Using classified tailings as a means of stope support in the VCR at Western Deep Levels Limited—West Mine. *Assoc. Mine Managers S. Afr. Circular.* \. 2/90. 1990. pp. 1–18.
12. Piper, P.S., Jager, A.J., and Morris, A.N. Backfill—A means to alleviate the rockburst and rockfall hazard. *Proceedings of Mine Safety and Health Congress.* Chamber of Mines of South Africa, Johannesburg. 1987. pp. 460–483.
13. Roberts, M.K.C. and Jager, A.J. An analysis of falls of ground and rockburst fatalities. *Proceedings of Mine Safety and Health Congress.* Chamber of Mines of South Africa, Johannesburg. 1991. pp. 181–200.
14. CSIR. Thirteenth report on the measurement of stress in the ground surrounding mining excavations: Some stress measurements in hard rock using stress relief techniques. Contract Report No. C Meg 543, CSIR, Pretoria. 1963.
15. Leeman, E.R. The measurement of stress in rock. Part I: The principles of rock stress measurements. *J. S. Afr. Inst. Min. Metall.*, vol. 65. no. 2. 1964a. pp. 45–81.
16. Leeman, E.R. The measurement of stress in rock. Part II: Borehole rock stress measuring instruments. *J. S. Afr. Inst. Min. Metall.*, vol. 65. no. 2. 1964b. pp. 82–114.
17. Leeman, E.R. The measurement of stress in rock. Part III: The results of some rock stress investigations. *J. S. Afr. Inst. Min. Metall.*, vol. 65. no. 4. 1964c. pp. 254–284.
18. Pallister, G.F. The measurement of virgin rock stresses. Reference Report No. 5/69, Chamber of Mines of South Africa, Johannesburg. 1969.
19. Castelyn, F.J. Unpublished internal report. Chamber of Mines Research Organization, Johannesburg. 1989.
20. Napier, J.A.L. Personal communication. 2001.

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