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GROUND MOTION STUDIES IN A BACKFILLED STOPE AT WEST
DRIEFONTEIN
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Rock Engineering

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PREFACE

One of the major motivations for placing backfill has been the expectation that backfill should reduce the damaging effect of seismic waves on the stability of excavations. Previous studies by COMRO workers have shown that, in general, there is a reduction in damage in backfilled stopes to conventional stopes. The results given by Mr Goldbach confirm this conclusion and quantify the effect of backfill on the length of the hangingwall beam, which is subjected to vibration during the passage of a seismic wave and the vibration time and peak ground velocity. In effect the data explains why the hangingwall in backfilled stopes and gullies is more stable during seismic events than the hangingwall of unfilled stopes; this has important implications for the design of support systems in deep mines where seismic activity is likely to be encountered.

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SUMMARY

This report looks at the ground motion from 24 small magnitude seismic events recorded at various points inside a backfilled stope. The in-stope ground motion is compared to that recorded at an off-reef site. The seismic events are analysed according to peak ground velocity, spectral peaks and vibration times.

The results from this study, together with the results from previous work on ground motion analyses in backfilled and conventionally filled stopes, show how backfill can reduce the overall ground motion of seismic events.

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1 INTRODUCTION

Considerable research has been carried out into the *in situ* behaviour of backfill, investigating both confined compression and complete backfill rib behaviour. Examples of papers and reports that address these aspects of backfill are Squelch (1990), Gay *et al.* (1988), Grtunca *et al.* (1989) and Adams *et al.* (1991). The benefits of placing backfill have been reported in Adams and Grtunca (1990). Results of modelling of backfill were presented in Grtunca and Clark (1989) and computer simulations of the behaviour of a backfilled stope were recently presented to the mining industry.

However, an important area of backfill research that only recently has begun to draw considerable attention is the effect that backfill has on the frequency and size of seismic events. Hemp and Goldbach (1990) have shown that, on a regional scale, backfilled areas can, in the absence of complex geological features, experience more favourable seismic conditions compared to unfilled areas. The filled areas were shown to experience a smaller ratio of large to small events, whereby seismic energy was released in a greater number of small events and in fewer large events than in unfilled areas.

This report focuses on an analysis of ground motion from small magnitude seismic events recorded in a backfilled stope compared to that recorded off-reef. Section Two reviews previous work in this area, while Section Three describes the site and the portable seismic system that was installed for this project. Results are presented and discussed in Section Four and the findings on ground motion in a backfilled stope are summarized in Section Five. Current and ongoing research in this area are briefly discussed in Section Six.

2 REVIEW OF PAST WORK

In an effort to study the effect of conventional support on controlling the movement of fractured ground around deep-level stopes during seismic events, Spottiswoode and Churcher (1988) compared the ground motion of seismic events recorded in a conventionally supported (unfilled) stope with that recorded in a remote (i.e. off-reef) site.

In order to record in-stope ground motion, geophones were placed 10 m from the face on the roof and floor of a longwall panel where timber packs were used as supports. Geophones recording off-reef ground motion were mostly located in footwall drives (approximately 40 m below reef) and were part of the West Driefontein mine seismic network, although some were located hundreds of metres from reef. From an analysis of four seismic events, Spottiswoode and Churcher obtained the following results.

- Coda waves following the P- and S-waves in the stope were amplified compared to those recorded at the remote site.
- Dominant frequencies recorded at the remote site varied for each event and were therefore related to the source. However, a dominant frequency of 70 Hz was observed at the stope site and this frequency did not vary with event magnitude; it appeared to be a characteristic of the site and was therefore considered a 'site effect'. This site effect was explained by the resonance of a 30 m long unsupported stope beam.
- Larger peak ground motions were observed on the side of the stope that was closer to the source of the event. In other words, the stope was seen to cast a partial 'shadow' across the incoming rays, reducing the ground motion amplitudes at the side (hangingwall or footwall) opposite to that of the incoming rays.
- Differential movement between the roof and floor was found to generally exceed the average stope movement during seismic events. In other words, the stope hangingwall and footwall tended to move apart and together more freely than to move up and down in unison.
- Finally, peak ground velocities were found to be on average 2,5 times larger at the stope site than at the remote site for each event. This was explained by the fact that softer materials, i.e. the fracture zone around the stope, could amplify ground motion.

Based on these observations, it was determined that a conventionally supported stope transmits very little seismic energy, and Spottiswoode and Churcher (1988) showed that the use of backfill as stope support had the following implications.

- If backfill is placed close to the face, the length of unsupported stope beams will be reduced. This shorter beam, which is also stiffer, would then cause stope resonance to be shifted towards higher frequencies where, for damaging events, less seismic energy is present. Higher frequencies are also attenuated faster than lower frequencies.
- Backfill provides increased damping of seismic energy compared to timber support.

Adams *et al.* (1990) were the first to compare seismic ground motion in a backfilled stope with that recorded off-reef. These workers fixed geophones to the hangingwall of a backfilled stope, such that one geophone site had backfill on both sides and this site was classified as being totally filled; a second geophone

site in the stope had backfill only on one side and this site was classified as being partially filled. The off-reef geophone was located 20 m below reef. From an analysis of 22 seismic events, Adams *et al.* (1990) obtained the following results.

- Coda waves were again amplified in the stope relative to the off-reef coda, masking the arrival of the S-wave.
- Both the on-reef and the off-reef geophones recorded seismic events that had dominant frequencies in the range 200 - 400 Hz. This range did not vary with event magnitude. The off-reef site must therefore still have been too close to the stope, as it displayed similar resonant behaviour to the on-reef sites.
- At the partially filled site, peak ground velocities were measured in the horizontal direction, whereas at the totally filled site peak ground velocities were measured in the vertical direction. The off-reef peak ground velocities were always smaller (by a factor of two) than those measured on-reef for the same event and their orientation depended on the source location relative to the off-reef site.
- An examination of the phase relationships of waveforms from orthogonal geophones revealed that the first few cycles of the P-wave remained in-phase at the off-reef site, whereas they quickly became out-of-phase at the on-reef sites. The on-reef geophones were situated in fractured ground which caused a lot of scattering, resulting in out-of-phase behaviour.
- The duration of seismic vibration was found to be on average 16 ms off-reef, compared to 28 ms on-reef.

The following conclusions were made by Adams *et al.* (1990) about ground motion in a backfilled stope:

- Past work has shown the hangingwall in backfilled stopes to become clamped at around 3 MPa (Gürtunca *et al.*, 1989). Due to this binding of the stope beams, reduced internal reflections are expected and thus the coda should be minimised compared to a conventionally supported stope.
- The resonant frequencies in a backfilled stope (200 - 400 Hz) are higher than in a conventionally supported stope (70 Hz - Spottiswoode and Churcher, 1988), indicating that the length of unsupported stope beams has been reduced.
- The peak ground velocity observations can be explained by the fact that less backfilling causes less clamping of the hangingwall beam due to a larger tensile zone (Gürtunca and Clark, 1989). This larger tensile zone at the partially filled site means that horizontal seismic motion was possible, thus causing peak

ground velocities to be recorded on the horizontal geophone components. Conversely, a restricted tensile zone at the totally filled site causes seismic ground motions to be preferentially orientated in the vertical sense.

- With rigorous, well-placed backfilling, the integrity of the hangingwall rockmass is expected to be better preserved with fewer open fractures than in an unfilled stope, and thus increased in-phase behaviour of waveforms is expected.
- The closing of fractures, as well as the reduction of unsupported stope beam length, should reduce seismic vibration times considerably in a well-filled stope.
- Although amplification of seismic waves still occurs in backfilled stopes compared to an off-reef site, the amplification is expected to be less than in unfilled panels.

In an important area of research such as the understanding of ground motion in a backfilled stope, conclusions should not be based on the results from one site only. The work presented in this report is therefore essentially a repeat exercise of that done by Adams *et al.* (1990), at a different site, and the analysis is more quantitative.

3 SITE DESCRIPTION

The site chosen for this experiment was located on 26 level in the western portion of the 5W sub-shaft pillar area on West Driefontein gold mine at a depth of approximately 2 250 m below surface (see Figure 1). In all panels the internal permanent support was classified tailings backfill which had a placed porosity of approximately 47 per cent. The backfill was placed in conjunction with one row of rapid-yielding hydraulic props at the face and timber packs on both sides of the gullies. The average dip of the Carbon Leader Reef in this stope is 22° south and the stoping width is approximately 1 m. Mining proceeded in an easterly direction, and the mining area was bounded in the south by a NE-SW trending seismically active dyke, which has a throw of 45 m. This scenario was expected to generate adequate amounts of seismicity and increasing amounts of strong ground motion were expected as mining approached the dyke.

A COMRO designed Portable Seismic System (PSS) (Patrick *et al.*, 1990) was installed at the underground site. The system was commissioned in October 1990 and after approximately three months a sufficient number of seismic events had been recorded that were suitable for analysis.

Five triaxial sets of 4,5 Hz SM-6 geophones were installed underground. One triaxial set was installed at the end of a 10 m deep borehole drilled horizontally into the sidewall at an angle of 70° from the cross-cut (see Figure 1). Core

retrieved from the borehole revealed that the rock at the end of the hole was unfractured. Together with the fact that this point was about 60 m below reef, this meant that it was an ideal location to measure off-reef behaviour. An additional four triaxial geophone sets were installed in panel 4 in the stope to measure on-reef behaviour (see Figure 1). Two geophone sets were installed in a dip gully, one in the hangingwall and one in the footwall. A fourth set was installed in the footwall, 10 m inside backfill, and a fifth triaxial set was installed in the strike gully hangingwall close to the face. All in-stope geophones were mounted in aluminium holders, which were attached directly to the skin of the hangingwall or footwall. The face geophone set was moved forward as mining progressed, in order to monitor ground motion at the face. The purpose of this geophone layout was to examine the ground motion at various points inside a backfilled stope relative to off-reef ground motion.

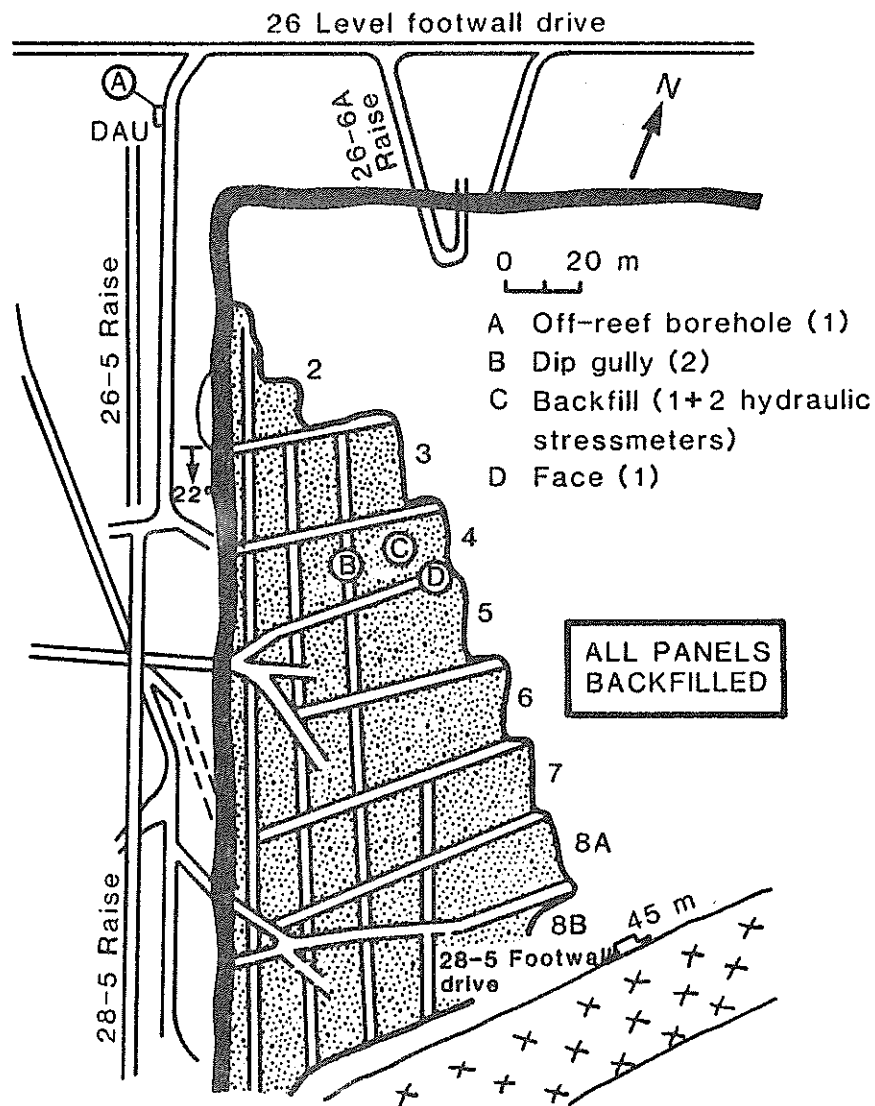


Figure 1 LOCATIONS OF THE GEOPHONE SITES IN THE BACKFILLED STOPE (THE NUMBER OF TRIAXIAL GEOPHONE SETS AT EACH SITE ARE SHOWN IN BRACKETS)

The four in-stope triaxial geophone sets were connected to four transducer stations located in an abandoned winchbed. The transducer stations amplified the seismic signals recorded by the geophones, and these amplified signals were then transmitted to the Data Acquisition Unit (DAU) via FM telemetry along twisted multiple pair telephone cable. The DAU was located in the stope cross-cut at the off-reef borehole site. The off-reef geophone set had its transducer station located next to the DAU. The events were digitally recorded by the DAU and were then sent via modems and telephone cable up the shaft to an IBM PC-AT compatible computer on surface.

Signals from each geophone were sampled at 10 000 samples per second. Anti-alias filters were set to 2 500 Hz. The off-reef signals were amplified by a gain of 100, whereas the in-stope signals were amplified only 20 times. The reason for this will become apparent later. The gains were set by changing a pair of jumpers in the amplifier section of the geophone interface cards located in the outstations.

Between November 1990 and February 1991 the PSS recorded approximately 1 500 seismic events. Twenty-four events that were well recorded were selected as a data base suitable for analysis. The event magnitudes, calculated from the off-reef signals were in the range -1,9 to 0,5 and the events located between 51 m and 369 m from the off-reef site. At an average hypocentral distance of 150m, a magnitude 0,5 event would have saturated the off-reef geophones. Locations were obtained from a software location algorithm by picking P- and S-wave arrivals on the off-reef signals and P-arrivals only on the in-stope signals, as amplified P-wave coda frequently masked the arrival of the S-waves on the in-stope signals. The algorithm uses the picked arrival times, the P-S time interval and calculated azimuths to obtain the hypocentral locations. Over the period of recording, hydraulic stressmeters, installed in the same backfill bag that contained the backfill geophone set, revealed that the vertical stress inside the fill had increased from 6 MPa to 25 MPa. The West Driefontein mine seismic network recorded 7 of the 24 events and the mine's locations compared favourably with those of the PSS. The average difference in location between the two networks was 50 m. The PSS has managed to locate events with an average location error of only 8 m.

4 RESULTS

Figure 2 shows the locations in plan of the 24 seismic events chosen for analysis. The face and geophone positions are indicated on the plan and the size of the crosses is proportional to the size of the events. The locations of these events are shown for a face parallel section and for a face perpendicular section in Figures 3 and 4, respectively. Figure 2 shows that about an equal number of events occurred ahead of the face and behind the face during the period of recording. Also, from Figure 3, it is apparent that approximately the same number of events

occurred above the reef and below the reef. However, on the face perpendicular section (Figure 4) it appears as if, ahead of the face, the events were generally located in the footwall, whereas behind the face the events were mainly located in the hangingwall. This pattern of event locations will be studied in greater detail in the future.

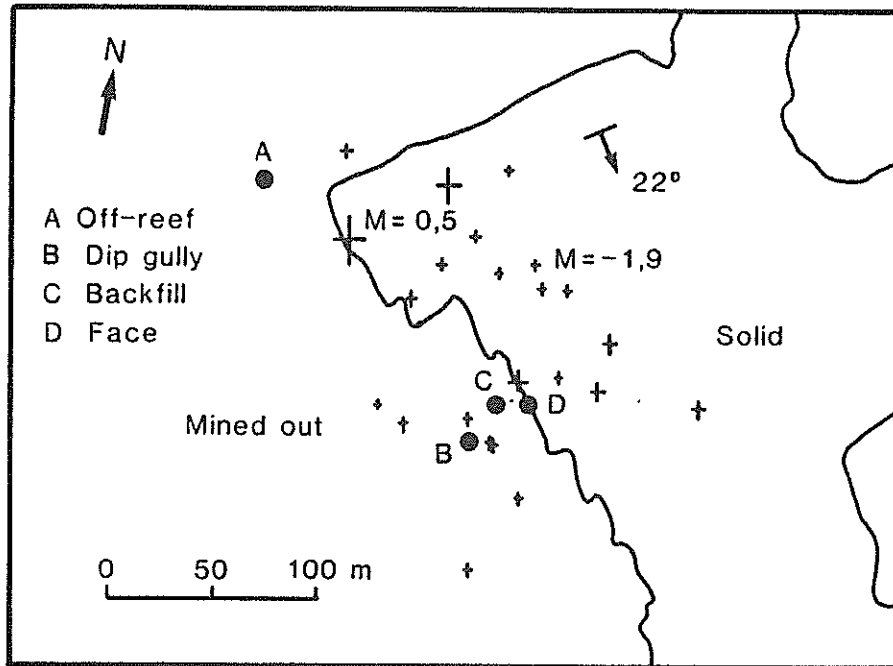


Figure 2 LOCATIONS OF SEISMIC EVENTS IN PLAN

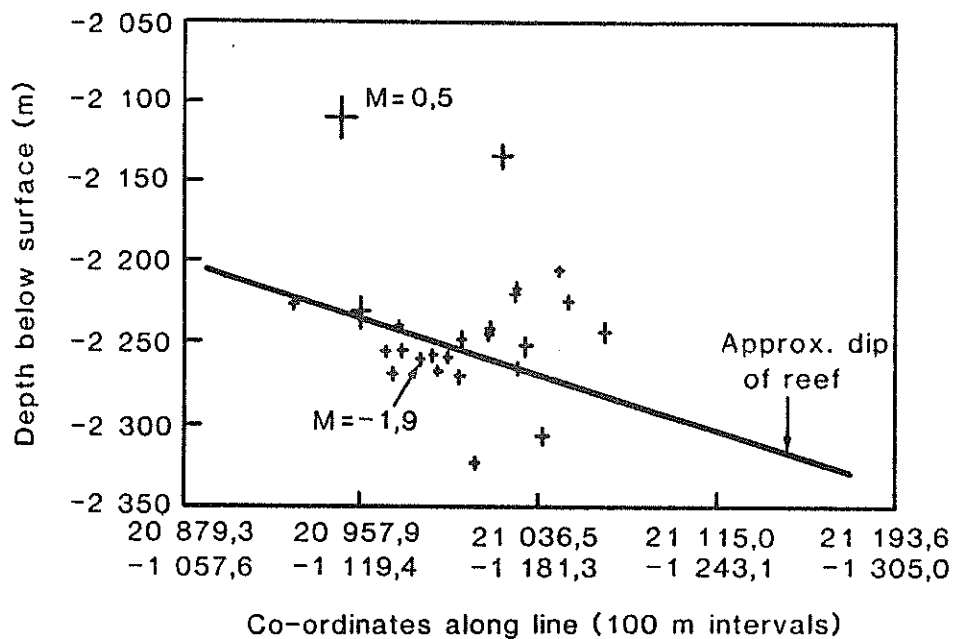


Figure 3 LOCATIONS OF SEISMIC EVENTS IN SECTION ALONG A FACE PARALLEL LINE

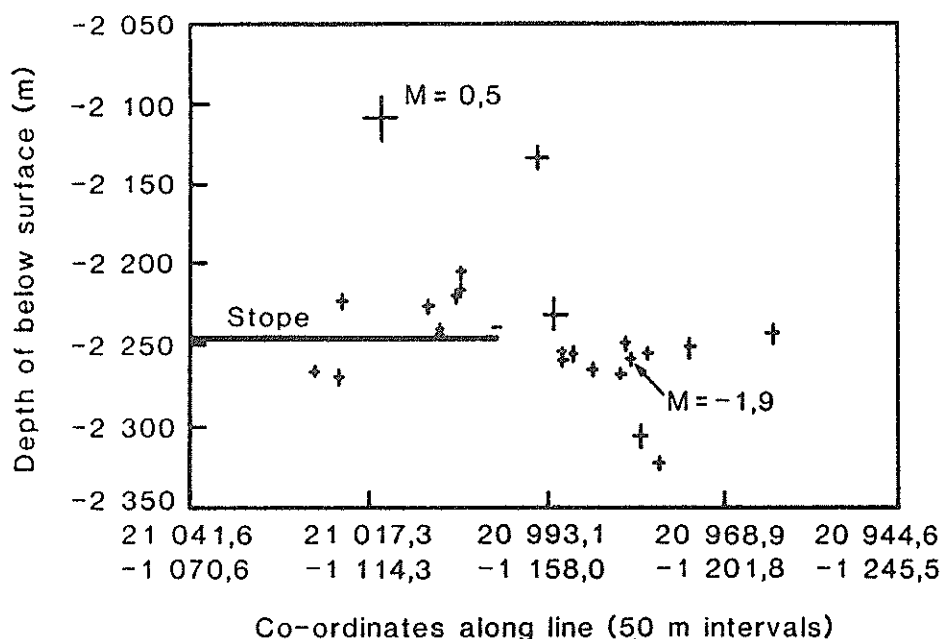


Figure 4 LOCATIONS OF SEISMIC EVENTS IN SECTION ALONG A FACE PERPENDICULAR LINE

The waveforms of the 24 seismic events were analysed according to:

- i) peak ground velocity
- ii) spectral peaks
- iii) vibration times

4.1 Peak ground velocity

Figure 5 is an example of the waveforms recorded for a magnitude -0,2 event that was located 185 m from the off-reef site. Note that, due to the high stresses generated inside backfill, two geophone components ceased to operate soon after installation. The mounting design has since been modified to make the geophone holders more robust in future installations. The peak ground velocity recorded off-reef for this event was 0,76 mm/s, whereas on-reef the peak ground velocity was 13,46 mm/s. The in-stope ground motion was therefore larger than that recorded off-reef. Even though the event was located much closer to the stope than to the off-reef site, the peak ground velocity is still larger by a factor of 7,18 than it is off-reef, once a correction has been made for the distance differential.

In fact, the on-reef peak ground velocity was always larger than the off-reef peak ground velocity. Typical off-reef peak ground velocities were in the range 0,1 mm/s - 3,8 mm/s, whereas on-reef the peak ground velocities were in the range 1,5 mm/s - 19,1 mm/s. The median value of amplification of in-stope to off-reef peak ground velocities (corrected for distance) was 6,6. Spottiswoode and Churcher (1988) and Adams *et al.* (1990) previously obtained on-reef peak ground

velocity amplifications of 2 to 2,5. The higher value of 6,6 obtained here is not considered to be excessive and is believed to occur partly as a result of amplification of seismic waves caused by a large degree of on-reef fracturing which is generally accepted to occur around deep-level stopes. However, another factor may have played a role. It is well known that the intermediate principal stress direction is parallel to the face (as evidenced by induced face parallel fractures). Seismic events occur due to the relaxation of such induced stresses. The off-reef site in this study was located on the seismic B-axis direction, which is parallel to the intermediate principal stress and is the direction of least radiated seismic energy (Spottiswoode, 1991). Therefore, the energy from seismic events recorded at the off-reef site may well have been underestimated, resulting in an exaggerated calculated on-reef to off-reef amplification of peak ground velocities. On the other hand, the lower values obtained by other authors may also be due to the fact that their off-reef sites were still close enough to mining to be affected by stope amplification. In Spottiswoode and Churcher (1988) and in Adams *et al.* (1990) the off-reef sites were 40 m and 20 m below reef, respectively; the off-reef site in this study is 60 m below reef and is most probably situated in true virgin ground. Therefore, the relative amplification of on-reef to off-reef peak ground velocities is expected to be higher in this study. However, amplification with distance from reef is not yet well understood. Note that, due to this on-reef amplification, the in-stope geophones were set to record at one-fifth of the gain of the off-reef geophones.

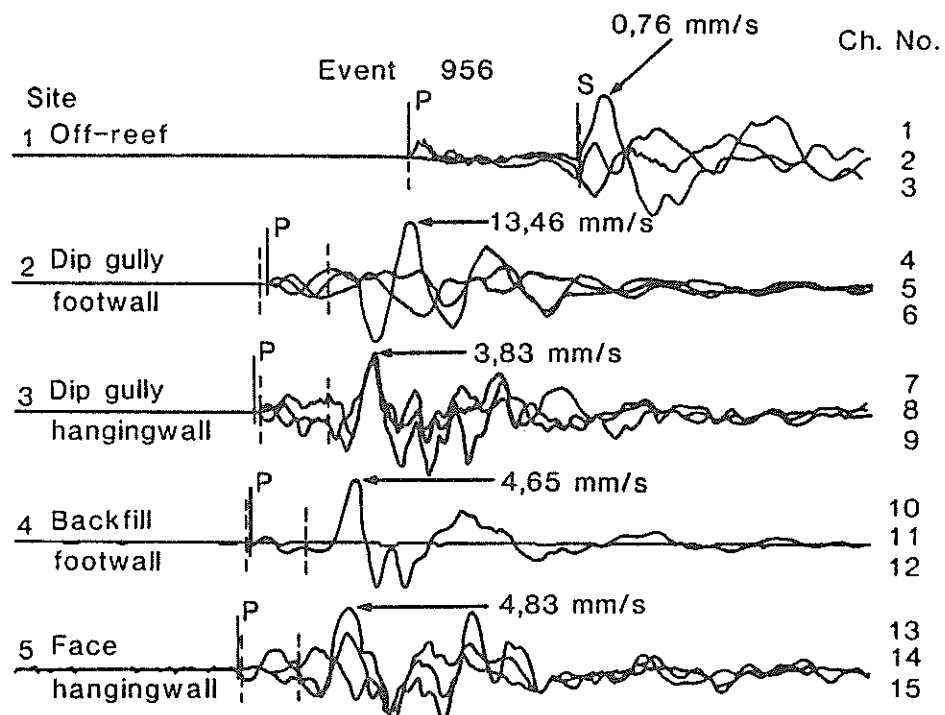


Figure 5 WAVEFORM TRACES RECORDED FOR A MAGNITUDE -0.2 EVENT, 185 M AWAY FROM THE OFF-REEF SITE

Further, it was found that at the off-reef site the peak ground velocities occurred on either of the horizontal geophone components for 80 per cent of the events. This was controlled by the angles of incidence of most events, i.e. the hypocentres of most events were located in roughly a horizontal plane with respect to the off-reef site, thus causing the peak energy to be recorded on the horizontal components. On-reef, however, peak ground velocities occurred on the vertical geophone components for two-thirds of the events, regardless of event location. This is explained by the fact that, during seismic excitation, the slope, which is essentially a planar interface, is free to move in the vertical sense, thus causing peak ground motions to be mainly recorded on the vertical components.

Comparing the peak ground motions at the various on-reef sites, it is apparent that, for half the time, peak ground motions were recorded at the dip gully footwall and the rest of the time at either the dip gully hangingwall or at the face. Peak ground velocities never occurred inside the backfill. These observations can be explained with the aid of Figure 6 and the following considerations. The gully shoulder is heavily fractured and unconfined and is therefore free to move during a seismic event; thus, the peak ground velocity occurred at this point in the slope for half of the events. The gully hangingwall, on the other hand, is clamped by horizontal stresses (Squelch, 1990) and is, therefore, less free to move. This confines the hangingwall during seismic vibrations and peak ground velocities were recorded less often at this point. The largest stresses are generated inside backfill (Gürtunca *et al.*, 1989) and therefore peak ground motions were never recorded at this point.

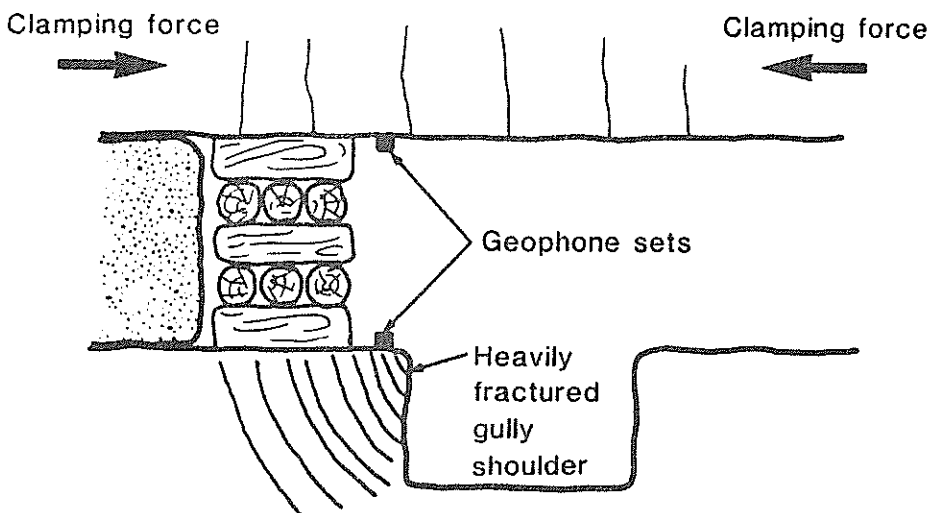


Figure 6 CROSS-SECTION THROUGH THE DIP GULLY THAT WAS INSTRUMENTED IN THE HANGINGWALL AND FOOTWALL

A final point worth mentioning in this section is to illustrate how well the peak ground velocities recorded at the off-reef site correlate with the magnitude of the events. McGarr *et al.* (1981) found the following relationship to be true:

$$\text{LOG}[Rv] = cM + d$$

where R = hypocentral distance

v = peak ground velocity

M = magnitude

c,d = slope and intercept of the straight line, respectively

This equation is valid for far field situations only. The 24 seismic events in this data set have source radii varying from 1,5 m to 10 m. Hypocentral distances from the off-reef site, however, have been calculated at between 51 m and 369 m; this means that the far field situation applies in this study. Assuming scaling laws for South African mine tremors, c and d have been found to be 0,50 and 2,81, respectively, for R in metres and v in mm/s (Spottiswoode, 1984). McGarr *et al.* (1981) calculated $c = 0,57$ and $d = 2,95$ for ERPM data, when R is measured in metres and v in mm/s.

Plotting LOG[Rv] versus magnitude calculated from radiated energy measured at the off-reef site for the seismic events in this data set yields a straight line with $c = 0,70$ and $d = 2,33$ (see Figure 7). These values are close to 0,50 and 2,81; the steeper slope obtained in this study probably results from an underestimation of magnitudes for the smallest events, due to attenuation. Nevertheless, the peak ground velocities correlate well with event magnitude.

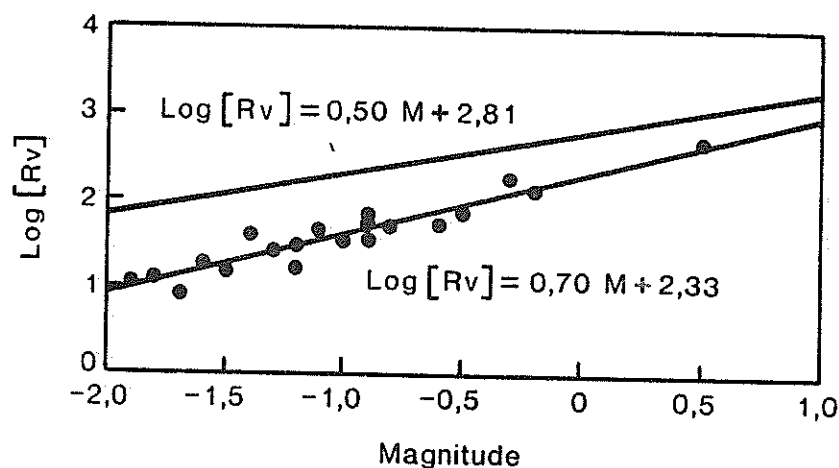


Figure 7 PLOT OF LOG[Rv] VS. MAGNITUDE (FROM ENERGY MEASURED OFF-REEF) FOR THE 24 SEISMIC EVENTS

4.2 Spectral peaks

An amplitude spectrum can be obtained by analysing the amplitudes of the various frequency components that constitute a seismogram (or part thereof) and then plotting the amplitude versus frequency on a log-log scale. For a seismic trace of ground velocity, such as that generated by a geophone, the amplitude spectrum look essentially like an inverted 'V'. The peak of the inverted 'V' is known as the corner frequency and the spectrum should have slopes of +1 and -1 below and above the corner frequency, respectively (see Figure 8). A true corner frequency, however, is related to the size of an event and is, therefore, a source term. Because the fracturing around a stope can modify the seismic signature of an event, the resultant peak in a spectral analysis may no longer be related to the source of that event. Therefore, in order to avoid confusion, and to apply a more general term, the peak in the amplitude spectra will in this analysis be referred to as a dominant frequency or a spectral peak.

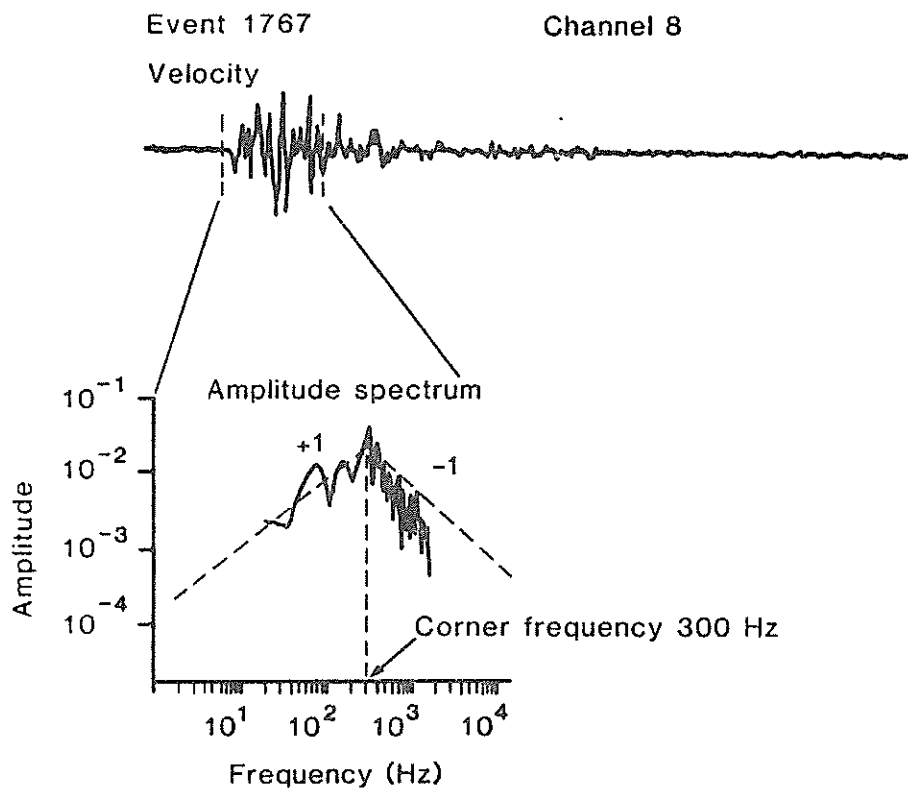


Figure 8 EXAMPLE OF AN AMPLITUDE SPECTRUM

An analysis of the seismograms recorded at the off-reef site shows that spectral peaks for the 24 events varied between 130 Hz and 900 Hz. The peaks were proportional to the size of the individual events and can therefore be considered to be true source-dependent corner frequencies.

In seismic source studies the following relationship holds true:

$$\text{LOG}f_0 = rM + s$$

where f_0 = corner frequency in Hz

M = magnitude

r, s = slope and intercept of the straight line, respectively

From corner frequency analyses by Spottiswoode (1984) for mine tremors on Blyvooruitzicht gold mine, r and s have been found to be $-0,50$ and $2,30$, respectively (assuming source scaling laws).

Plotting $\text{LOG}f_0$ (corrected for path attenuation) versus magnitude for the off-reef data yields a reasonably well-correlated straight line with $r = -0,37$ and $s = 2,06$ (see Figure 9). These values are close to $-0,50$ and $2,30$ for r and s , respectively, corroborating the argument that the off-reef spectral peaks are source-dependent.

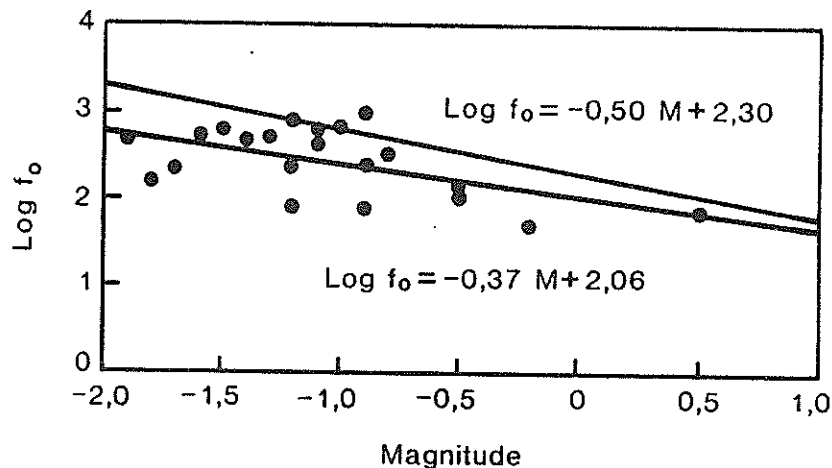


Figure 9 PLOT OF LOG[SPECTRAL PEAK] VS. MAGNITUDE (FROM ENERGY MEASURED OFF-REEF) FOR THE 24 SEISMIC EVENTS

The amplitude spectra of the signals recorded inside backfill yielded similar variable spectral peaks in the range 100 Hz to 760 Hz. It can be deduced from this that, because of the high stresses generated inside backfill and the stiff response of backfill, this position resembled 'solid rock' behaviour similar to the off-reef site.

However, all other in-stope sites yielded spectral peaks that were confined to a narrow bands of frequencies; the dip gully footwall signals generated spectral peaks between 100 Hz and 300 Hz, the dip gully hangingwall between 200 Hz and 500 Hz and the face between 130 Hz and 350 Hz. The spectral peaks consistently

fell into these narrow ranges, regardless of the size of the events. This narrow band frequency response must be a function of the stope and is therefore considered to be a site effect.

It is suggested that the strong fracturing around the stope, as well as beam resonance of the stope, are responsible for the observed spectral peaks. The length of beam that would resonate at the above frequencies has been calculated to be approximately 10 m. This is roughly the distance behind the face at which the placed backfill is taking load and effectively 'closes' the hangingwall and footwall. Spottiswoode and Churcher (1988) previously calculated a resonating beam length of 30 m for a conventionally supported stope (30 m was also roughly the distance at which stope closure had taken place). Backfill has therefore reduced the length of a stope beam that is able to resonate during seismic events. As mentioned before, this is desirable as higher resonant frequencies contain less seismic energy for big events. The resonant frequencies obtained here are in agreement with those obtained by Adams *et al.* (1990). The fact that the dip gully footwall resonated at approximately half the frequencies of the dip gully hangingwall can again be attributed to the relatively unconfined, heavily fractured gully shoulder, whereas the hangingwall is clamped by horizontal stresses and will therefore resonate at higher frequencies.

4.3 Vibration times

The vibration times were measured off the seismograms and were defined as the time taken for the signal at a particular site to decay to one-fifth of its peak value. The value of one-fifth was chosen to represent the amplitude of seismic signal after which the main arrivals had passed and only smaller amplitude reflected waves were recorded. In general, vibration times depended on the size and location of the events; a large, distant event would vibrate longer than a smaller, closer event. The vibration times recorded at the off-reef site and at the face varied between 20 ms and 70 ms. However, vibration times at the dip gully site were found to be reduced by 30 per cent compared to those recorded at the face for two-thirds of the events. Adams *et al.* (1991) have shown that the vertical stresses in a backfilled stope are smallest at the face and increase towards the back areas. This increase in stress has the effect of closing up fractures, causing fewer reflections of seismic waves, and therefore the dip gully site would be expected to yield reduced vibration times compared to the face.

Of all the in-stope sites, the backfill geophones recorded the shortest vibration times (15 ms - 40 ms) for 80 per cent of the events. This is brought about by the increased stiffness of the rock surrounding the backfill due to large vertical stresses, providing for efficient transmission of seismic energy in the shortest vibration times.

The vibration times obtained in this study are similar to the 28 ms obtained by Adams *et al.* (1990) for a backfilled stope. Although Adams *et al.* (1990) used a different definition to calculate vibration times, the value of 28 ms did not change appreciably, when the one-fifth amplitude criterion of this study was applied to their data. Spottiswoode and Churcher (1988) did not calculate vibration times for seismic events (which were of similar magnitude to the ones in this study) recorded in a conventionally supported stope. However, when applying the method of measuring vibration times used in this study to their data, one obtains vibration times of 130 ms - 170 ms. The longer vibration times are a result of the longer unsupported beam length of unfilled stopes, which takes longer to come to rest after seismic excitation. Therefore, an unfilled stope is less stable and is likely to cause more damage than a backfilled stope, as the vibration times of seismic events are four times longer in an unfilled stope.

5 SUMMARY

In general, the research into ground motion in backfilled stopes so far has shown that backfill reduces the overall ground motion of seismic events.

In particular,

- a comparison of the peak ground motions recorded at various points inside a backfilled stope has shown that peak ground velocities never occurred inside backfill.
- a spectral analysis of seismic events has shown that backfill has reduced the length of unsupported stope beams from 30 m for a conventionally supported stope to 10 m. A shorter beam is stiffer and, during seismic excitation, this means that the stope will resonate at higher frequencies, where, for damaging events, less seismic energy is present. In addition, higher frequencies are attenuated faster than lower frequencies.
- the reduced beam length, together with the closing of fractures in the rock surrounding the stope, due to high backfill stresses, provides for efficient transmission of seismic energy. As a result, the shortest vibration times were recorded inside backfill compared to other points inside the stope. Comparing the vibration times obtained in this study for a backfilled stope with those for an unfilled stope, one notices that seismic events are dissipated four times more quickly in a backfilled stope than in an unfilled stope.
- from the above three points, it can be concluded that the hangingwall in backfilled stopes is more stable than in unfilled stopes. As a result, a backfilled stope vibrates at less damaging frequencies during a seismic event and for a much shorter time than a conventionally supported stope.

6 ONGOING RESEARCH

Even though the work presented here is in general agreement with previous work by Adams *et al.* (1990), unequivocal answers regarding the transmission of seismic energy in a backfilled stope compared to an unfilled stope have not yet been obtained. So far, the backfilled and unfilled cases have been evaluated separately at different sites. The difference in stopes, site geometries and seismic events makes it difficult to draw conclusions about the benefits a backfilled stope might have over a conventionally supported stope when subjected to a seismic event. Furthermore, past studies have only treated small, non-damaging seismic events. Strong ground motion from damaging seismic events ($M > 1$) has not been considered to date. Because of the above, research into the seismic response of back-filled stopes has been extended into two areas.

Firstly, the site reported on here at West Driefontein gold mine has been re-instrumented with accelerometers. With geophones the study was limited to seismic events with magnitudes less than 0,5. Using accelerometers, the seismic response of the backfilled stope can be studied for the all-important damaging events. As mining progresses eastward towards the NE-SW trending dyke intersecting the shaft pillar, an increasing number of large events is expected to occur, thus making this site ideal for the study of strong ground motion in a backfilled stope.

Secondly, a new site on 81 level at Western Deep Levels south shaft is being instrumented with a PSS. Two triaxial accelerometer sets will be installed in filled panels (one in the hangingwall and one in the footwall), and a further two triaxial accelerometer sets will be installed in conventionally supported panels adjacent to the filled ones (one in the hangingwall and one in the footwall). Again, mining progresses eastward towards a seismically active NE-SW trending dyke. The proposed layout of transducers will enable the study of the relative response of the hangingwall and footwall of filled and unfilled panels in the same stope subjected to the same seismic event. The in-stope ground motion will be related to that recorded off-reef by a fifth triaxial accelerometer set installed in a borehole at a remote site.

The results of both these studies will be presented early in 1992.

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