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The control of ground vibration from colliery blasting during the undermining of residential areas

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SYNOPSIS

Results from a study undertaken at a Transvaal colliery on the feasibility of undermining an urban development by conventional bord-and-pillar mining operations in the No. 4 Seam of the Highveld Coalfield are discussed. Surface ground vibrations above production sections were measured, analysed, and then compared with well-accepted guidelines so that the expected effects of vibration on inhabitants and surface structures could be determined. The measurement and scaling of ground vibration from blasting are outlined, and the effects on humans and structures are discussed.

It is concluded that residential areas can be safely undermined by conventional drilling and blasting techniques provided certain simple guidelines are followed.

SAMEVATTING

Die resultate word bespreek van 'n studie wat by 'n Transvaalse steenkoolmyn gemaak is om vas te stel of dit uitvoerbaar sal wees om 'n stedelike ontwikkeling te ondermyn deur middel van konvensionele pilaarmynboubedrywighede in Laag no. 4 van die Hoëveldsteenkoolveld. Oppervlakgrondtrillings bokant produksieafdelings is gemeet, ontleed en dan met aanvaarde riglyne vergelyk om die uitwerking te bepaal wat die trilling na verwagting op inwoners en bogrondse strukture sal hê. Grondtrilling weens skietwerk word in hooftrekke beskryf, en hoe dit gemeet en gegradeer word; en die uitwerking daarvan op mense en strukture word bespreek.

In die ondersoek is daar tot die gevolgtrekking gekom dat woongebiede veilig volgens konvensionele boor- en skiettegnieke ondermyn kan word, mits sekere eenvoudige riglyne gevolg word.

Introduction

Approximately 60 per cent of the coal mined by underground methods in the Republic of South Africa is produced by bord-and-pillar mining methods using conventional drilling and blasting. Significant portions of the coal reserves are overlain by inhabited areas, but a correctly planned underground mining operation is compatible with surface use.

A study was undertaken at a Transvaal Colliery in the lower No. 4 Seam of the Highveld Coalfield on the implications of shallow mining activities to surface structures and residents. An important consideration in the undermining of inhabited areas is the short-term effects of blast vibration on surface structures and inhabitants. Ground vibration, which is a side effect of all types of blasting, not only holds the potential of causing damage to structures but is also irritating to humans. The need to control vibration from blasting is becoming increasingly important as public awareness rises and as mining and residential areas converge.

The potential for damaging structures and disturbing residents is established from monitoring of the ground vibrations on the surface above conventional bord-and-pillar workings, in conjunction with available criteria. Practical means of minimizing the blast vibration levels are then identified. It is hoped that the findings of the study described here and the procedures followed will be useful to others concerned with coal-mining operations beneath dwellings.

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Blasting Practice in Collieries

Fig. 1 shows a typical drilling pattern, in which holes 38 mm in diameter are drilled horizontally into the coal face in rows of 3 to 4 and columns of 5 to 6, depending largely on the bord dimensions and the seam thickness.

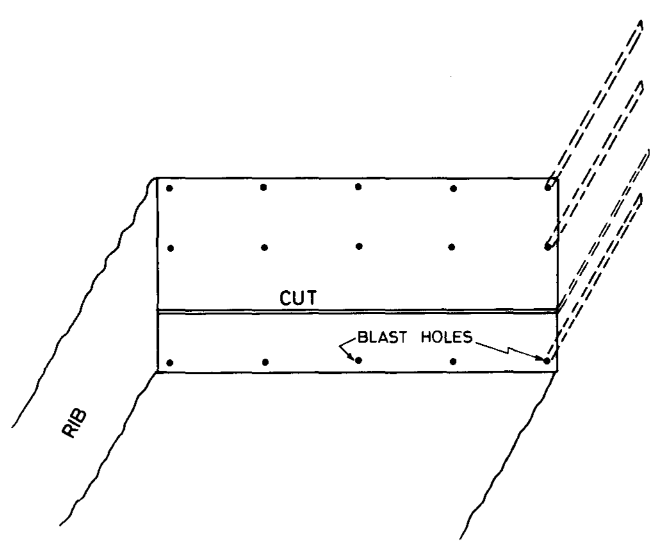

Fig. 1—A typical drilling pattern in collieries

Prior to drilling, a horizontal slot about 0,1 m wide is cut mechanically across the whole width of the face to a depth of 0,15 m beyond the intended depth of the blastholes. This cut eases breaking by providing displacement relief for the earliest firing holes. Thus, the amount of explosive required per hole is minimized, favouring blasting efficiencies and, moreover, reducing the risk of initiating methane and coal-dust explosions. Statutory requirements allow only permitted explosives to be used where there is a risk of methane or coal-dust explosions. These explosives are specially formulated to minimize the production of incendive particles and the flame of detonation, but there is a consequent reduction in strength. Inert materials are used to stem the blasthole after charging. By confining the explosive gases, stemming both reduces the likelihood of methane or coal-dust ignitions, and leads to a more efficient usage of the explosive energy. Explosives are initiated by electric detonators, of which six delay periods up to 150 ms (milliseconds) are available (Table I) for use in fiery coal mines.

TABLE I
RANGE OF ELECTRIC DETONATORS PERMITTED FOR USE IN FIERY COAL MINES

Delay number	Nominal delay period ms
0	Instantaneous
1	30
2	55
3	80
4	110
5	150

Description of Ground Vibration

Ground vibration is an undesirable but also unavoidable result of blasting. Controlling the magnitude of ground vibration is often a necessary consideration in blast design, since such vibration is capable of inducing damage to engineering structures, and is an irritant to humans. Only a small portion of the seismic energy generated by an explosive source is actually utilized in breaking and displacing the *in situ* rock. The remainder is propagated outwards from the charge in elastic waves, which change form as the waves and propagation medium interact. The vibration experienced at some distance from the blast normally comprises a complex combination of wave types that are difficult to separate in practice. Fortunately, this separation is not necessary in that the resultant vibration can be measured directly with seismic instrumentation. A discussion of the wave types comprising ground vibration is given by Green[1].

The character of ground vibration is fully described by measurements, in three mutually perpendicular directions, of the time history of the acceleration, the velocity, or the displacement at a point (particle) in the ground. These quantities are interrelated, as shown by the following expressions where A is acceleration, V is velocity, D is displacement, t is time, and f is the frequency of vibration:

$$A = \mathrm{d}/\mathrm{d}t\ V = \mathrm{d}^2/\mathrm{d}t^2\ D, \quad \text{.......................... (1)}$$

and for sinusoidal motion take the form

$$A = 2\pi f V = (2\pi f)^2 D. \quad \text{.............................. (2)}$$

In practice, it is generally easiest to measure either the velocity or the acceleration. Most commercial monitors of blast vibrations record particle velocity (i.e. velocity of ground movement), since the maximum or peak particle velocity (*PPV*) of ground movement is closely related to the potential for structural damage and to the level of human annoyance, as discussed later.

Scaling and Prediction of Ground Vibrations

The peak particle velocity, *PPV* (in millimetres per second, mm/s), experienced at some distance R (in metres, m) from an explosive source of mass M (in kilograms, kg) in rock is conveniently expressed in the form of a power law as follows:

$$PPV = \mathrm{a}\left(\frac{R}{M^{\mathrm{b}}}\right)^{\mathrm{c}}, \quad \text{...................................... (3)}$$

where a, b, and c are constants controlled mainly by the geology and the type of blasting. It is commonly accepted that an initiation time difference of 9 ms is required if constructive interference is to be avoided from neighbouring charges[2].

The quantity R/M^{b}, known as scaled distance, is a normalizing factor to account for changes in the mass of the charge and the propagation distance from source to reference point. Square-root scaling (b = 1/2) typifies the approach used in studies of surface blasting. Square-root scaling evolved from the consideration of cylindrical wave divergence (two-dimensional) such as a body wave close to a cylindrical charge or, at further distances, a surface wave. Similitude predicts that similar velocities should result from instances where the ratio of radial distance from a cylindrical hole, R, to the hole radius, r_h, are equal. Since the charge mass is proportional to the square of the hole radius, this distance ratio, or scaled distance, can be written $R/(M)^{1/2}$. Similarly, where three-dimensional wave divergence closely represents the real situation, cube-root scaling should apply. At great distances from a charge, where wave propagation is three-dimensional through an extended medium, cylindrical charges can be approximated as a spherical source. Here, the explosive mass varies with the cube of the equivalent spherical-charge radius, r_s. Hence, in this case similar, or scaled, distances are $R/(M)^{1/3}$.

In practical situations, other factors come into play such as the higher attenuation rate of high-frequency vibration components with propagation distance. The best scaling factor for use in a specific application is generally the one that provides the best statistical fit of the experimental data. Square-root scaling is normally used when propagation curves are being developed for the common situation of vibrations from surface blasting measured on the surface. Reports that cube-root scaling provided the best fit of experimental measurements for instances where wave divergence is approximately three-dimensional include those by Engineering Research Associates[3], Duvall and Atchison[4], Rupert and Clark[5], and Naismith[6]; the last two studies measured vibration in underground coal mines from surface mine blasting.

General propagation equations have been offered by

Dupont[7] and by Abraseys and Hendron[8]. However, since the absolute charge mass and distance, geology, and types of blasting vary widely, the propagation equation should be developed from measurements taken at the particular site of interest. When this is not possible, as when the mining of a new area is being planned, the findings of investigations under similar conditions will provide a reasonable approximation.

Structural Damage

The relationship between ground vibration from blasting and structural damage has long been the subject of extensive research by many investigators. The peak particle velocity of ground movement near structures has been identified as a simple, single-term criterion for the prediction of structural damage. The main reason for this is that, according to elastic theory for plane waves (Kolsky[9]), which are realistic approximations for blasting (Dowding[10]), the particle velocity, PV, is directly proportional to the strain, ϵ, namely,

$$PV = C_c\epsilon, \quad (4)$$

where C_c is the dilational wave velocity (sonic velocity) of the material. Therefore, increases in the particle velocity of ground movement correspond to increases in ground strain which, in turn, generally induce greater strains in structures. And, it is strain that ultimately causes cracking of structural elements. An early criterion for damage to structures was the energy criterion proposed by Crandell[11]. It is based on considerations of kinetic energy and the assumptions of simple harmonic motion, defined as

$$ER = A^2/f^2, \quad (5)$$

where ER is the energy ratio, A is the peak acceleration (in feet per second squared, ft/s^2), and f is the frequency of peak amplitude (in hertz, Hz). Nicholls *et al.*[12] point out that, although not used by Crandell, this equation is readily rewritten to express energy ratio as a function of velocity as follows:

$$ER = 4\pi^2V^2, \quad (6)$$

where the units for particle velocity are in feet per second (ft/s). In SI units, where V is in millimetres per second (mm/s) and A in metres per second squared (m/s^2), these equations take the form

$$ER = V^2/_{2353} = 10{,}8\,\frac{A^2}{f^2}. \quad (7)$$

The correlation between energy ratio and extent of structural damage cited by Crandell, and the particle velocity equivalents are given in Table II. The damage threshold of 84 mm/s proposed by Crandell is in close agreement with the threshold level of 71 mm/s cited by Langefors *et al.*[13]. This was later followed by the suggestion of 51 mm/s as a safe limit by Edwards and Northwood[14].

Nicholls *et al.*[12], after a thorough analysis of numerous investigations conducted by the U.S. Bureau of Mines (USBM) and others, confirmed that particle velocity in the ground near structures should not exceed 51 mm/s in any of three mutually perpendicular directions if the probability of damage to the structure is to be small (less than 5 per cent). USBM investigators[15], in a recent study of response to ground vibration for 76 different structures, took cognizance, in constructing the frequency-dependent particle-velocity criteria shown in Fig. 2, of the interplay between the frequency of ground vibration and the natural frequency of the structure.

TABLE II
ENERGY RATIO AND STRUCTURAL DAMAGE ACCORDING TO CANDELL[11]

Energy ratio	Particle velocity equivalent, mm/s	Structural damage
<3	<84	No damage
3	84	Damage threshold
3–6	84–168	Caution zone
>6	>168	Danger zone

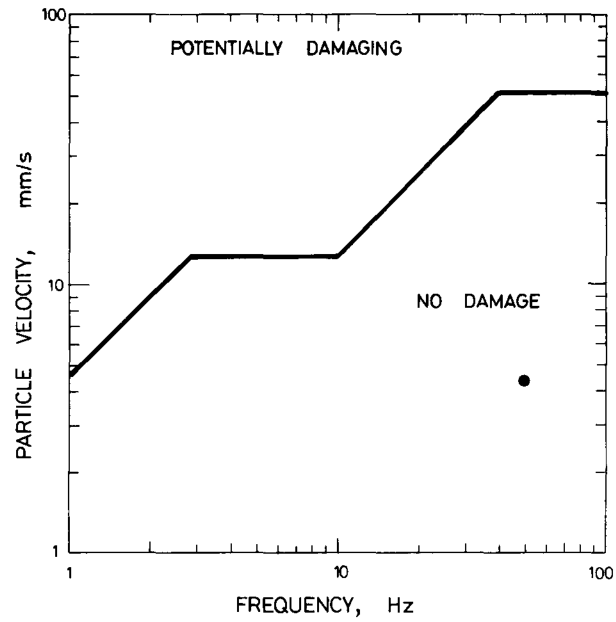

Fig. 2—Frequency-dependent limits of particle velocity for the avoidance of structural damage (after Siskend *et al.*[15])

Because the ground displacement increases appreciably as the frequency falls below 40 Hz at constant velocity, these criteria recommend PPV levels of less than 51 mm/s when the dominant frequency of the ground vibration falls below 40 Hz. Furthermore, ground-vibration frequencies below 40 Hz are approaching structure resonances, normally within the 4 to 12 Hz bandwidth[15], at which stage the structure response will be highest. These latest USBM criteria are obviously more conservative than a constant velocity limit of 51 mm/s.

Other recent studies have also emphasized that the actual response of a structure, as opposed to the ground motion near the structure, should be used as the limiting factor. To this end, the SDF (single degree of freedom) computational approach, adopted from studies of building response to earthquakes, is claimed by Dowding[10] to be the most accurate. The SDF methodology is too lengthy for detailed discussion here; briefly, it takes account of structure characteristics (mass, stiffness, vibration damping) together with ground vibration time history in the calculation of structure response. Dowding reports that the SDF model provides a closer correlation to structure response and damage than does the peak particle velocity of ground movement near the structure. In its present form, however, this method is too complex and time-consuming for general application. For current needs, the recent criteria proposed by the USBM, illustrated in Fig. 2, provide conservative safe blasting limits for the avoidance of structural damage.

Human Response

The level of vibration perceived by humans is considerably lower than that required to induce structural damage. Many studies have been undertaken on the human response to mechanical vibration, but most of these were concerned with protracted vibration, which does not closely represent the transient nature of ground vibration. A summary of research into human response to vibration was compiled recently by Siskend *et al.*[15]. Essentially, there is no information to indicate the reaction of people to blasting-induced vibration while in their homes. Most studies have subjected humans to vibration in a laboratory environment, and the duration of vibration was found to be directly related to its undesirability.

Results from the classic study of human tolerance to vibrating motion by Reiher and Meister[16] and from a more recent investigation by Wiss and Parmelee[17] were used in the construction of Fig. 3 (data taken from Table 15 of Siskend *et al.*[15]), which relates human perception to vibration levels and exposure time. The Reiher and Meister study used exposure times of 300 s, while pulses of 0,5 to 5 s were used by Wiss and Parmelee.

Human reaction was found to be independent of frequency when expressed in terms of frequency times displacement, i.e. velocity. Fig. 3 shows that humans become less sensitive to vibration as the exposure time decreases. The left portion of Fig. 3 is of most direct interest since, judged by the range of firing times for detonators used in collieries (Table I), the duration of vibration will normally be less than a quarter of a second.

One important factor not addressed by scientific studies is the effect of the frequency of occurrence of the vibratory event. In most surface mining and construction operations, blasting usually takes place less than once a day to, at most, only a few times a day. However, in the typical underground case of two adjacent colliery sections, mining on two shifts involves blasting approximately 24 times a day. In this case, even low vibration levels may prove objectionable to humans in view of the intermittent nature and high frequency of the blasting. Thus, it is logical to expect that decreasing human sensitivity to shorter duration of vibration will be countered to some extent by an increased frequency of such events. Dowding[10] refers to experience with dynamic soil compaction, where frequent ground motion (every 2 to 5 minutes) of 2,5 mm/s caused extreme annoyance to residents. He postulates that, when events occur as often as ten times a day, human response will approach the levels determined in the study by Reiher and Meister[16]. These levels are equivalent to the 300 s values of Fig. 3, where the velocities of 2,5 mm/s are already within the strongly perceptible range.

No other work is available on human response to events lasting less than 0,5 s or to multiple events. Therefore, indisputable conclusions cannot be drawn about the potential of human annoyance from colliery blasting. A compromise between these opposing interests involves the adoption as a guide of the perception levels shown at the 5 s exposure time in Fig. 3. Based on the criterion that strongly perceptible vibration is objectionable and annoying, the particle velocity should be maintained at less than 10 mm/s if it is to remain below the strongly perceptible threshold. Where practical, levels of less than 7 mm/s and, better yet, 3 mm/s are desirable since these correlate with the mean response and threshold limit of distinct

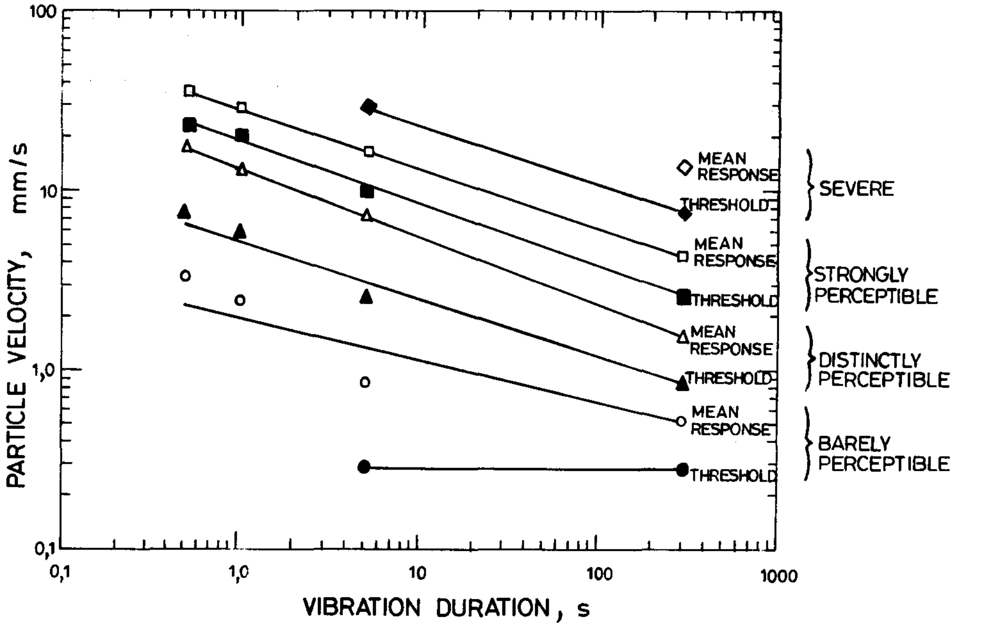

Fig. 3—Human perception of vibration

perception, below which the potential for human annoyance will be small.

Case Study of Ground Vibration

A programme of blast-vibration monitoring was conducted at a Transvaal colliery to quantify the levels expected when mining extended to the ground beneath a nearby urban development. The distance separating the residential area and the nearest mine workings was 1,2 km, and these workings were chosen as the monitoring site. An examination of the geological fence diagram of the monitored site in Fig. 4 and the cross-section of the proposed site given in Fig. 5 shows that the areas are geologically similar except for the dolerite intrusions beneath the residential area.

Fig. 6 gives plan and section views of the positioning of two separate triaxial geophone packages of a Sinco (Slope Indicator Company) type S-2 vibration monitor in relation to the underground workings. The dynamic response of this system is flat (± 10 per cent) in terms of particle velocity between 6 and 150 Hz. In each geophone package, one of the transducers sensed vertical motion, while the other two sensed horizontal motion. The common blasthole pattern and initiation timing during the monitored period are depicted in Fig. 7.

Explosive charges comprised 0,8 kg of Ajax per hole. The blast locations and number of headings per blast, which varied from 1 to 3, are shown in Fig. 6. The particle-velocity waveforms were recorded from 13 of the production blasts during the day shift of two consecutive days, providing a total of 26 relationships between vibration levels, propagation distance, and charge mass. These data were fitted by means of regression analysis to give the propagation equation

$$PPV = 4176\ (R/M^{1/3})^{-1,85}, \quad \text{.........................} \quad (8)$$

which is plotted with the data points shown in Fig. 8. Curve-fitting and statistical techniques are covered in detail by Olson *et al.*[18] and by Issac and Bubb[19].

As will be seen from an examination of the natural scat-

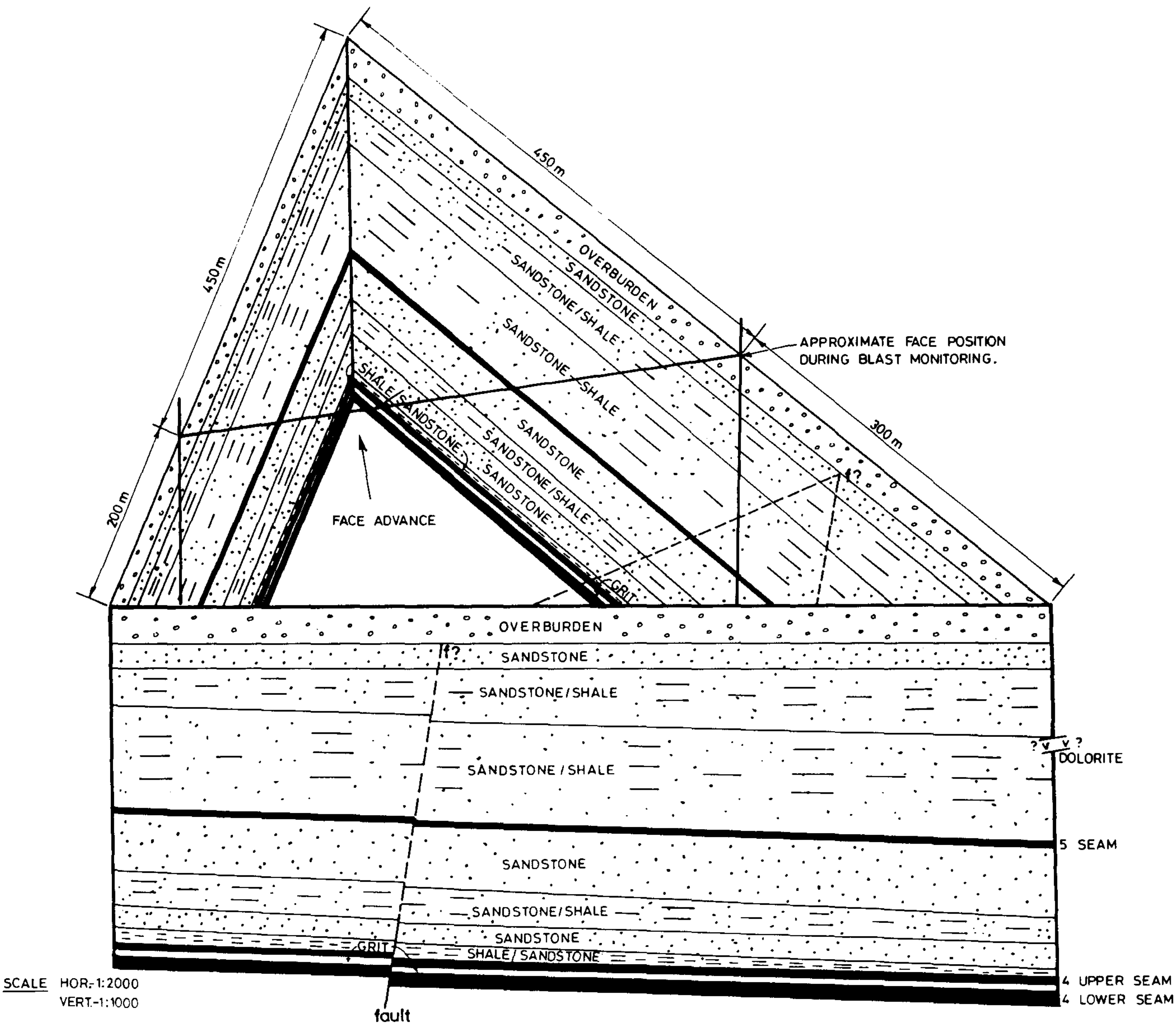

Fig. 4—Geological fence diagram of a site

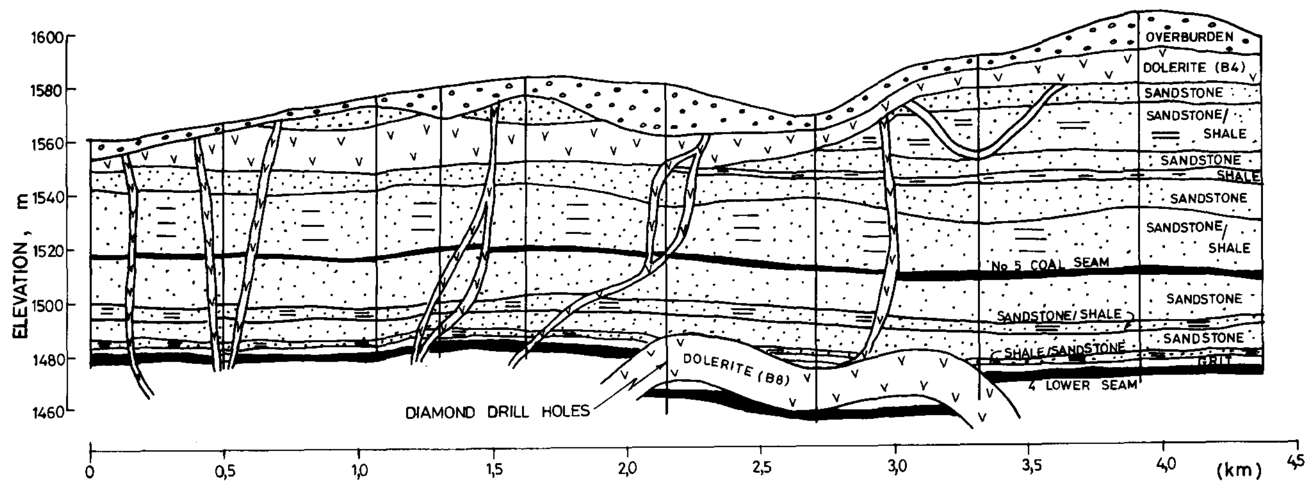

Fig. 5—Geological cross-section of the site to be undermined

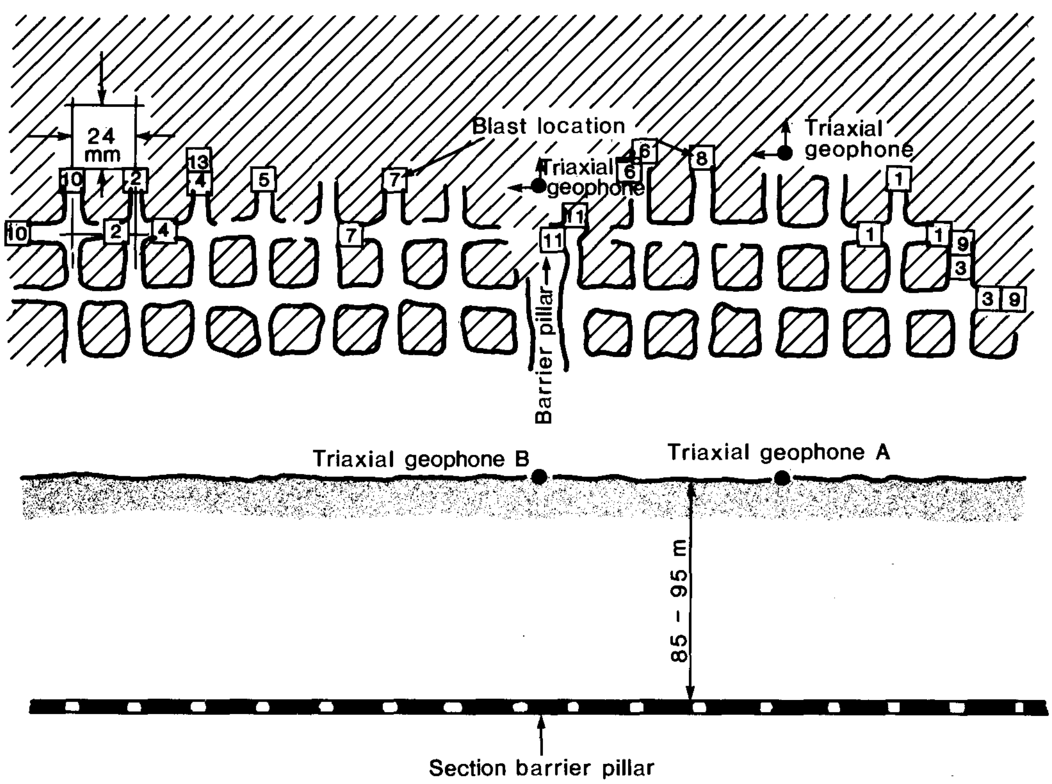

Fig. 6—Location of geophones in relation to underground blasting

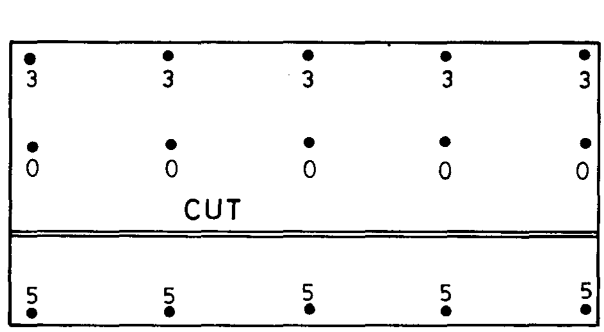

Fig. 7—Drilling pattern and initiation timing of monitored blasts

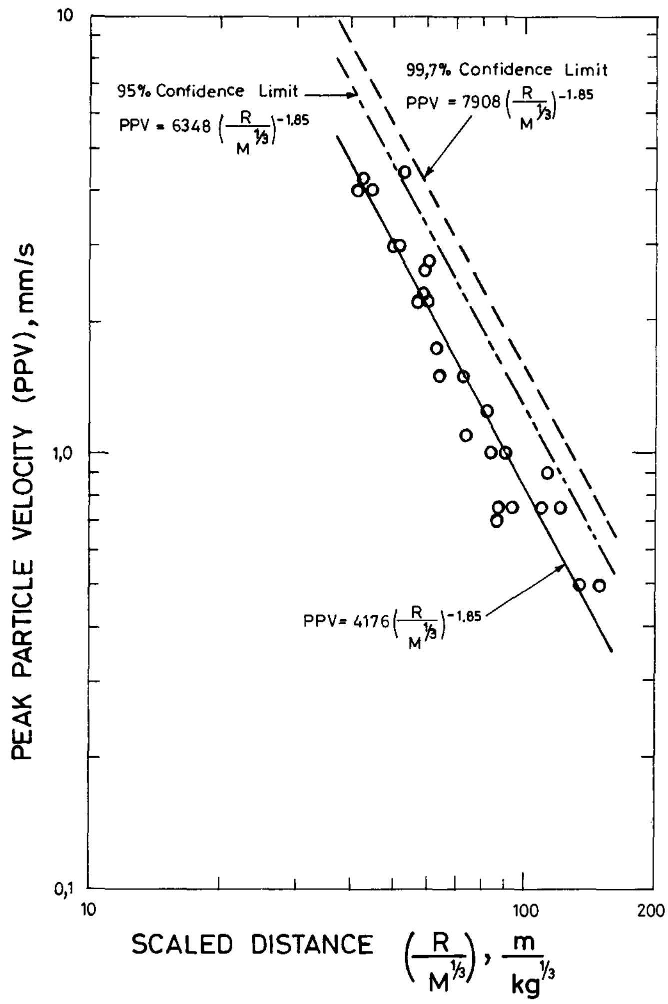

Fig. 8—Relationship between peak particle velocity and scaled distance for the monitored blasts

ter of data points in Fig. 8, this equation represents only average values, and the 95 per cent and 99,7 per cent confidence levels are therefore also displayed. As equation (8) indicates, cube-root scaling matched the points more closely than square-root scaling. This is to be expected from the earlier discussion of charge scaling, when one considers the three-dimensional divergence of body waves from underground blasting as they propagate towards the surface. Seismograms exhibited a dominant frequency of between 50 and 100 Hz, and the largest peak particle velocity measured was 4,4 mm/s. The darkened circle in Fig. 2 corresponds to a peak particle velocity of 4,4 mm/s, with a frequency of 50 Hz, and is well below the safe blasting limit. Vibration levels should be highest when a three-heading blast is directly below the point of interest on the surface. According to equation (8), and on the assumption of a total charge mass per delay of 12 kg (4 kg/delay/heading) and an overburden thickness of 90 m, a peak particle velocity of 4,7 mm/s is predicted (8,9 mm/s for the 99,7 per cent confidence limit). It was therefore concluded that current blasting procedures do not endanger the integrity of surface structures. A considerably greater charge mass per delay and/or a smaller overburden thickness are necessary before structural damage is of concern.

It was suggested earlier that human response levels at the 5-second exposure time in Fig. 3 should be used as a guide. Despite the measured duration of vibration being from 200 to 250 ms, the reduced levels of human tolerance at an exposure time of 5 seconds are used in an attempt to account for the effects of the high frequency of blasting. At this exposure time, Fig. 3 shows that velocity levels of 0,3 to 1,5 mm/s are perceptible, and it is therefore impracticable for blasting to proceed entirely unnoticed. Average vibration levels from normal blasting practice lie within the distinctly perceptible range, and it is therefore prudent to reduce the vibration levels if practicable. This can be done by an increase in the scaled distance. But, since the distance separating blasting and surface locations is fixed, a reduction in vibration levels must derive from a decrease in the charge per time delay. For the obvious reason of retarding breakage, few miners would be agreeable to decreasing the mass of the explosive charge per hole below 0,8 kg. However a reduction in charge mass per delay can be achieved without adversely affecting the breakage if the available series of delay detonators is utilized and the number of headings blasted at one time is reduced. This is illustrated in Table III, which compares the peak particle velocities calculated from equation (8) for cases of 1 to 3 headings per blast with a maximum of between 3 to 10 holes per delays per heading.

TABLE III
COMPARISON OF PEAK PARTICLE VELOCITIES FOR VARIOUS INITIATION TIMINGS AND HEADINGS PER BLAST

Maximum number of holes per delay per heading	*PPV*, mm/s*		
	Number of headings per blast		
	1	2	3
3	1,7	2,7	3,4
4	2,1	3,2	4,1
5	2,4	3,7	4,7
8	3,2	4,9	6,3
10	3,7	5,6	7,2

* $PPV = 4176\,(R/M^{1/3})^{-1,85}$, $R = 90$ m, explosive charge = 0,8 kg per hole

A 15-hole drilling pattern allows as little as 2 to 3 holes per delay while, at the other extreme, as also found in practice, as many as 10 holes per delay, i.e. two rows of holes, are sometimes used. It is seen that vibration levels from 3 holes per delay will be less than half of those produced by 10 holes per delay. Furthermore, a double-heading blast with 3 holes per delay will produce average vibration levels that are only slightly higher than single-heading blasts with 5 holes per delay. It should be noted that single- and double-heading blasts with a maximum of 3 holes per delay will result in an average peak particle velocity of 1,7 and 2,7 mm/s respectively, both of which are below the distinctly perceptible threshold.

An alternative timing pattern with a maximum of 3 holes per delay is given in Fig. 9. In addition to substantial reductions in vibration levels, the use of this timing pattern will enhance the displacement relief for rib holes by firing these on a later delay than others in the row.

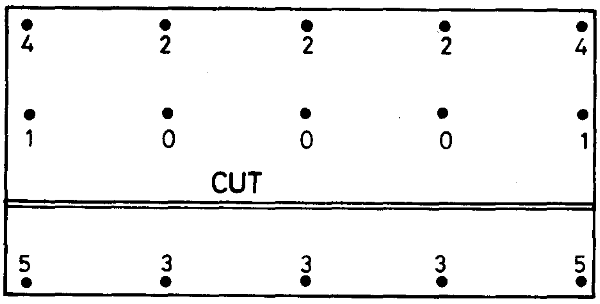

Fig. 9—Alternative initiation timing to minimize vibration levels and enhance breaking for rib holes

Consequently, this practice will also promote maximum advance per blast. Furthermore, the extent of blast damage to pillars, and their subsequent spalling will also be reduced.

Discussion and Conclusions

According to the predictive relationship for ground vibration levels developed by this study, and to widely accepted safe blasting limits, vibration from typical underground colliery blasting in South Africa will not damage surface structures above most mine workings. The lowest dominant frequency measured in this study was approximately 50 Hz, at which Fig. 2 indicates a vibration damage threshold of 50 mm/s. With a 99,7 per cent confidence limit for the predictive equation, a level of 50 mm/s would be reached only when the overburden thickness is reduced to 45 m for the extreme case of a blast consisting of 3 headings with 10 holes each on the same initiation time delay (maximum charge per delay of 24 kg). Therefore, measures to avoid damage to surface structures may need to be considered when the overburden thickness is less than about 50 m.

The limiting factor in most instances will be the vibration levels tolerated by surface inhabitants. It is difficult to predict human response to vibration of this type since no quantitative information is available on the effects of multiple events during the course of a day, and research is needed in this area. The distinctly perceptible vibration, together with the intermittent and high frequency of blasting from the continual mining activities, may be disturbing to surface residents. It is therefore desirable to keep vibration levels as low as practicable by utilizing the available range of delay detonators which, in turn, minimizes the mass of explosive charge per delay. It has been demonstrated that this approach will produce minimal vibration levels without inhibiting normal mining operations. An added benefit is that the higher degree of displacement relief for rib holes will ease breaking, and will promote maximum advance while minimizing blast damage to pillars.

Approximately 70 per cent of the coal from underground mines in South Africa is produced from the Highveld and Witbank areas, where blasting procedures, overburden thickness and, to a limited extent, geological features are generally similar to those of this study. Therefore, the predictive equation for the ground vibration levels developed in this study should be a close approximation for most collieries in these areas. The largest unknown in the application of the predictive equation in general cases is the effect of changes in geology.

As the high rates of face advance in most collieries are about 100 m per month, vibration will be noticeable at any given surface location only for a period of three to four months. To verify the actual vibration levels when residential areas are being undermined, it is recommended that a brief vibration-monitoring programme should be conducted. This would afford a ready check on the propagation equation proposed here, and would identify any significant influence introduced from changes in subsurface geology.

There are no statutory limits in South Africa on the level of ground vibration from blasting. It is proposed that the approach outlined in this paper should be used in future instances where the undermining of residential areas is considered. The author is not aware of other studies pertaining to surface ground vibration induced by underground colliery blasting under South African conditions. The equation developed here to express the propagation of ground vibrations can be used as a close approximation to the expected levels. For most collieries in South Africa, blasting can be conducted so as not to interfere with surface use.

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References

1. GREEN, R.E. Vibration damage from blasts and tremors. *Proceedings of the South African National Group on Rock Mechanics Conference Monitoring for Safety in Geotechnical Engineering.* 1984. pp. 89–104.
2. DICK, R.A., FLETCHER, L.R., and D'ANDREA, D.V. Explosives and blasting procedures manual. U.S. Bureau of Mines, *Report IC* 8925, 1983.
3. ENGINEERING RESEARCH ASSOCIATES, Inc. *Underground explosion test program final report, volume II: Rock,* prepared for U.S. Army Corps of Engineers, Sacramento District, Contract DA-040167.
4. DUVALL, W.I., and ATCHISON, T.C. Rock breakage by explosives. U.S. Bureau of Mines, *Report RI* 5356, 1957.
5. RUPERT, G.B., and CLARK, G.B. Criteria for the proximity of surface blasting to underground coal mines. *Proceedings, 18th U.S. Symposium on Rock Mechanics.* Jun. 1977. pp. 3C3–1 to 3C3–10.
6. NAISMITH, W.A. The influence of large scale surface blasting on the stability of underground coal mines. *First International Congress on Rockbursts and Seismicity in Mines.* GAY, N.C., and WAINWRIGHT, E.H. (eds.). The South African Institute of Mining and Metallurgy, 1982.
7. DU PONT, E.I. De Nemours and Co. *Blasters handbook.* 16th edition, Delaware, 1977.
8. AMBRASEYS, N.N., and HENDRON, A.J. Jr. Dynamic behaviour of rock masses. *Rock mechanics in engineering practice.* Stagg, K.G., and Zieniewicz, O.C. (eds.), New York, John Wiley, 1968. Chap. 7.
9. KOLSKY, H. *Stress waves in solids.* New York, Dover, 1963.
10. DOWDING, C.H. *Blast vibration monitoring and control.* New Jersey, Prentice-Hall, 1985.
11. CRANDELL, F.J. Ground vibration due to blasting and its effect upon structures. *J. Boston Soc. Civ. Engrs,* Apr. 1949. pp. 222–245.
12. NICHOLLS, H.R., JOHNSON, C.F., and DUVALL, W.I. Blasting vibrations and their effects on structures. U.S. Bureau of Mines, *Bulletin* 656, 1971.
13. LANGEFORS, U., KIHLSTRÖM, B., and WESTERBERG, H. Ground vibrations in blasting. *Water Power,* Feb. 1958. pp. 335–338, 390–395, 421–424.
14. EDWARDS, A.T., and NORTHWOOD, T.D. Experimental studies of the effects of blasting on structures. *The Engineer,* vol. 210. Sep. 1960. pp. 538–546.

15. SISKEND, D.E., STAGG, M.S., KOPP, J.W., and DOWDING, C.H. Structure response and damage produced by ground vibration from surface mine blasting. U.S. Bureau of Mines, *Report RI* 8507, 1980.
16. REIHER, H., and MEISTER, F.J. Die empfindlichkeit des menschen gegen erschuetterungen (Sensitivity of human beings to vibration). *Forschung auf den Gebert des Ingenieurwesens, Berlin,* vol. 2. Feb. 1931. pp. 381–386.
17. WISS, J.F., and PARMELEE, R.A. Human perception of transient vibration. *J. Structural Div. Amer. Soc. Civ. Engrs,* vol. 100. Apr. 1974. pp. 773–787.
18. OLSON, J.J., DICK, R.A., CONDON, J.L., HENDRICKSON, A.D., and FOGELSON, D.E. Mine roof vibrations from underground blasting. U.S. Bureau of Mines, *Report RI* 7330, 1970.
19. ISSAC, I.D., and BUBB, C. *A study of blast vibrations.* Part I, Tunnels and Tunnelling. Jul. 1981. pp. 35–41.

Bulk handling

The Bulk Handling Workshop 1987, entitled 'Operation and Maintenance of Bulk Handling Systems' and sponsored by The Institution of Engineers, Australia, will be held in Adelaide (Australia) on 3rd and 4th November, 1987.

The Workshop aims to bring together practising engineers involved in the operation and maintenance of bulk-handling equipment. Emphasis will be placed on the techniques and experience of the operational control of equipment, and on condition monitoring and total life maintenance of bulk-handling systems.

The Workshop will be informal in structure with similar-interest papers grouped together for presentation at working sessions. The following topics will be dealt with:

- Coal mining and transportation
- Grain handling
- Superphosphate manufacturing
- Timber handling
- Mining, transportation, and processing of metalliferous ores
- Quarrying
- Sugar
- Cement manufacturing.

All correspondence relating to the Workshop should be addressed to

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New ministry

The announcement by the State President, Mr P.W. Botha, of the establishment of a new Ministry of Economic Affairs and Technology has been welcomed by the Federation of Societies of Professional Engineers (FSPE). This is the realization of a long-standing ideal of the whole engineering profession, and will result in organizations that make use of high technology, like the CSIR, Mintek, AEC, and the SABS, being brought closer together. The engineering profession is vitally involved in these organizations.

FSPE played an active role, with is constituent societies and the Engineers' Association of South Africa, in forming the Interim Council of the S.A. Engineering Association, whose aim it is to establish an umbrella body uniting the whole engineering community. It is pleasing that the Minister who is responsible for this new portfolio, Mr D.W. Steyn, and the Deputy Minister, Mr G.S. Bartlett, are both engineers.

The Federation heartily endorses the statement made by Professor Roy Marcus, Chairman of the Interim Council, that this step will undoubtedly lead to the increased development, creation of more work opportunities, and increased competitiveness of South Africa's export products in international markets. Professor Marcus congratulated Minister Steyn on his increased responsibility and mentioned that, under his leadership, pioneering work will have to be done to achieve these ideals. He assured Minister Steyn and Deputy Minister Barlett of the enthusiastic support of engineers in their effort to straighten out the economy and technology of the State.