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An evaluation of yielding timber props as a support system in rockburst conditions

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SYNOPSIS

The support of stopes by means of yielding timber props, with or without hydraulic props, is common in the mining industry. This paper discusses the ability of these support systems to absorb energy during a rockburst, and further investigates their capability to withstand a range of ground velocities. It is found that the rate of stope closure prior to a rockburst strongly influences the behaviour of these support systems during the rockburst. It is recommended that hydraulic props be used in conjunction with yielding timber props in these conditions, and that yielding timber props with an increased yield range are desirable.

SAMEVATTING

Die stut van afbanplekke met meegeehoutstutte, met of sonder hidrauliese stutte, is algemeen in die mynboubedryf. Hierdie referaat bespreek die vermoë van hierdie stutstelsels om tydens in rotsbarsting energie te absorbeer en ondersoek ook hul vermoë om in reeks grondsnelhede te weerstaan. Daar is gevind dat die toedruktempo van die afbanplekke voor 'n rotsbarsting 'n sterk invloed uitoefen op die gedrag van hierdie stutstelsels tydens die rotsbarsting. Daar word aanbeveel dat hidrauliese stutte onder hierdie omstandighede saam met meegeestutte gebruik moet word, en dat meegeestutte met 'n groter meegeestut wenslik is.

Introduction

The use of yielding timber props such as profile props and pipesticks as stope support has proliferated in the mining industry in the past ten years. These support units are used in such diverse rock conditions as shallow stopes, where fracturing does not occur, and ultra-deep workings subject to rockbursts. As the depth of workings increases, the rate of stope closure, determined in millimetres per day or in millimetres per metre of face advance, also increases. Other factors such as excavation geometry, rock type, and overmining or undermining also influence the rate of stope closure, but this general rule holds. Yielding timber props have a limited yielding range and, when this is exceeded, they are unable to sustain any further significant load. They therefore have a finite ability to do work. Thus, the higher the rate of stope closure prior to a rockburst, the less the work capacity of the support system during the rockburst, which can lead to partial or complete failure of the support system.

This paper also discusses a combined support system in which the first three rows of yielding timber props are replaced by hydraulic props, which also have a limited yielding range and work capacity. Similarly for this support system, it is proposed that, the higher the rate of stope closure prior to a rockburst, the less the work capacity of the props during the rockburst, which can result in partial or complete failure of the support system.

Yielding Timber Props

Yielding timber props are used as stope support without hydraulic props at a number of locations in the mining industry. Fig. 1 shows a section of a stope supported by this support system. The working area of the stope extends from the face to the sixth line of support, where the sweeping line is situated.

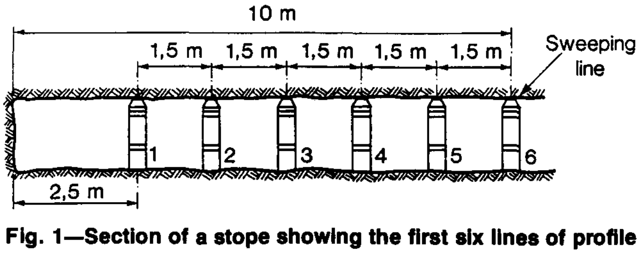

Fig. 1—Section of a stope showing the first six lines of profile props

The following assumptions are made here:

- the strike spacing of the yielding timber props is 1,5 m
- the dip spacing of the yielding timber props is 2,0 m
- the yield distance of the yielding timber props is 225 mm
- the face is advanced on a two-day cycle
- the area supported by one strike row of yielding timber props (including the face area) is 20 m^2.

Rates of Stope Closure

Rate of stope closure can be expressed in two ways: in millimetres per metre of face advance, or in millimetres per day. As the mining cycle can vary, the closure rate in terms of the latter unit is used here.

Rates of stope closure in the industry vary from minimal at shallow depth to 40 mm per day at great depth; this range is considered in the analysis below. For this purpose, the line of yielding timber props closest to the stope face is assumed just to have been installed and not yet to be subject to stope closure. The support units behind the first row will be subject to various amounts

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of closure depending on the rate of stope closure and the mining cycle.

Absorption of Energy

For the purpose of this analysis, the force-deformation behaviour of profile props 200 mm in diameter is used. The behaviour of this particular prop is typical of the various types of yielding timber props available, and the conclusions reached will therefore also apply to all these types of props.

Fig. 2 shows the force-deformation curves for profile props at two deformation rates. Curve 1 was determined experimentally underground for a closure rate of 20 mm per day. Curve 2 is the calculated force-deformation curve that would be applicable during a rockburst at a deformation rate of 1 m/s. The loading rate adjustment described by Roberts, Jager, and Riemann[1] was used in the determination of curve 2. The large difference in the force for any given deformation is an effect of the different loading rates. When this curve was compared with force-deformation curves obtained in the Terratek rapid-testing machine at rates of 1 m/s, it was found to be similar.

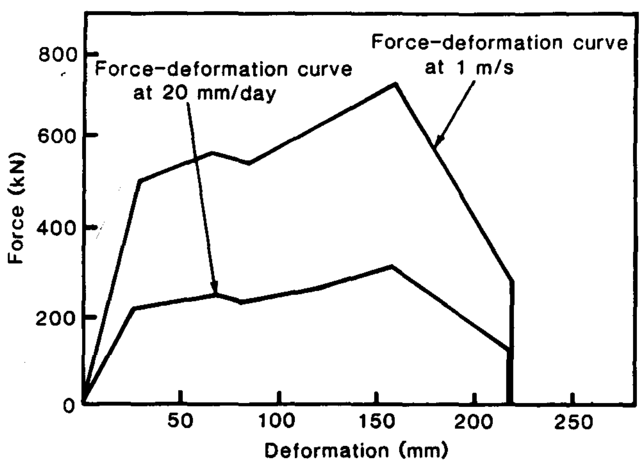

Fig. 2—Force-deformation curves for a profile prop at various deformation rates

The area under curves 1 and 2 can be used to calculate the work done by the props at the two loading rates. At a deformation rate of 1 m/s, a yielding timber prop is able to absorb 122 kJ of energy, but this will apply only to the props in the row closest to the stope face where no closure has occurred. The yielding timber props in the second to sixth line will have a smaller capacity to absorb energy since a portion of their yieldability will have been reduced by closure. The amount will depend upon the rate of stope closure, the blasting cycle, and the position of the support unit behind the stope face.

For example, a two-day cycle and a closure rate of 20 mm per day will result in 40 mm of stope closure on props in the second line of support, 80 mm on the third line, and 120 mm, 160 mm, and 200 mm on the fourth, fifth, and sixth lines respectively (Fig. 3). If a rockburst now occurs and the support is deformed at a rate of 1 m/s, then these yielding timber props will be able to absorb 122 kJ of energy in the first row, and 108 kJ, 85 kJ, 59 kJ, 33 kJ, and 9 kJ in the second, third, fourth, fifth, and sixth rows respectively. This is determined by the remaining area under the 1 m/s force-deformation curve as defined by the position of the support units behind the stope face (Fig. 3).

Table I shows how the energy-absorbing ability of these support units, during rapid deformation, in rows 2 to 6 decreases for various rates of stope closure. This is shown graphically in Fig. 4, where the energy available to be absorbed is plotted against the support unit position behind the stope face for various rates of stope closure.

Fig. 4 shows that, at closure rates in excess of 20 mm per day, the sixth line of support has no further ability to yield. It is therefore unable to absorb energy, and will fail if subjected to further closure or to a rockburst. Similarly, at a closure rate of 30 mm per day, the fourth, fifth, and sixth lines of support will be unable to accommodate any further deformation and will fail if a rockburst occurs. In general, therefore, with increasing stope-closure rates and increasing distance from the stope face, this stope-support system has a decreasing ability to absorb energy.

Combined Support System

Many yielding timber-prop support systems are used

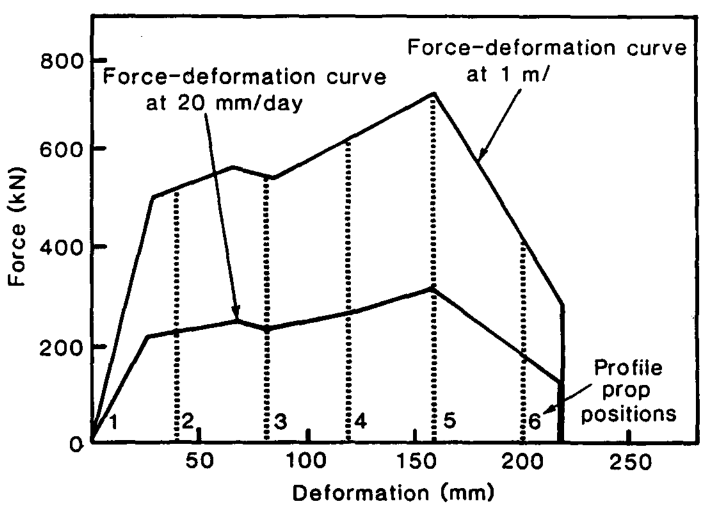

Fig. 3—Positions of profile props in relation to the force-deformation curve for a closure rate of 20 mm per day

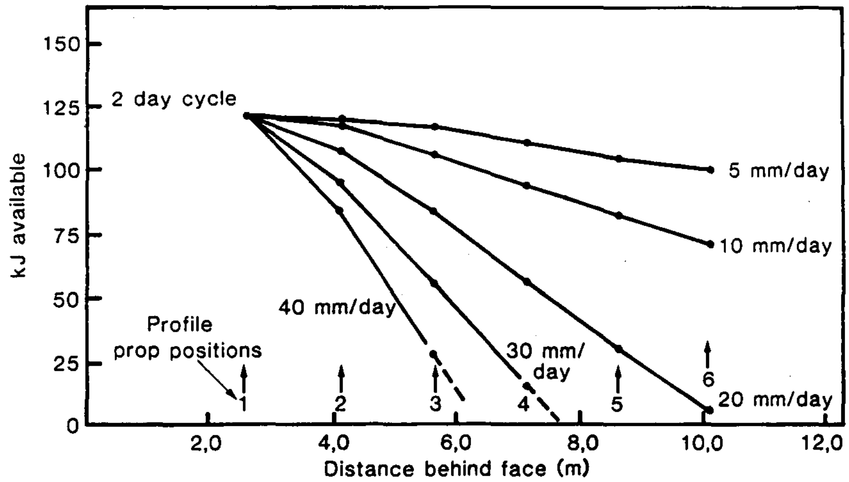

Fig. 4—Ability of the profile-prop support system to absorb energy as a function of the distance behind the stope face for various closure rates

TABLE I
THE ENERGY-ABSORBING ABILITY OF PROFILE PROPS AT A DEFORMATION RATE OF 1 m/s FOR VARIOUS DISTANCES BEHIND THE STOPE FACE AND VARIOUS CLOSURE RATES

Closure mm/day	Position of profile prop											
	1		2		3		4		5		6	
	kJ	Def	kJ	Def	kJ	Def	kJ	Def	kJ	Def	kJ	Def
0	121	0	121	0	121	0	121	0	121	0	121	0
5	121	0	120	10	118	20	112	30	107	40	102	50
10	121	0	118	20	107	40	96	60	85	80	73	100
20	121	0	107	40	85	80	59	120	32	160	8	200
30	121	0	96	60	59	120	18	160	0	240	0	300
40	121	0	85	80	32	160	0	240	0	320	0	400

Def = deformation

with three rows of hydraulic props. These are installed in front of the timber support as indicated in Fig. 5.

The following further assumptions are made:

- strike spacing of the hydraulic props is 1,5 m
- dip spacing of the hydraulic props is 2,0 m
- the yielding distance of the hydraulic props is 350 mm.

The dip rows of hydraulic props are numbered from 1 to 3 from the face back, and the dip rows of yielding timber props are numbered from 4 to 6. The spacings of the hydraulic props are identical to the profile-prop example discussed above.

Fig. 6 shows a typical force–deformation curve for a hydraulic prop, and it is assumed that any loading-rate effect will be small and can be ignored. The stroke of the hydraulic prop is 350 mm, and a 400 kN hydraulic-prop unit is able to absorb 138 kJ of energy. As in the example above, this applies to the props in the row closest to the stope face (row 1), where stope closure has not yet acted. In reality, it is unlikely that all the props will be installed with their full stroke available but, for the purpose of this analysis, it is assumed that this is the case. The props in the second and third line will have a reduced capacity for energy absorption because a portion of their stroke will have been reduced by stope closure, the amount depending upon the rate of stope closure and the blasting cycle.

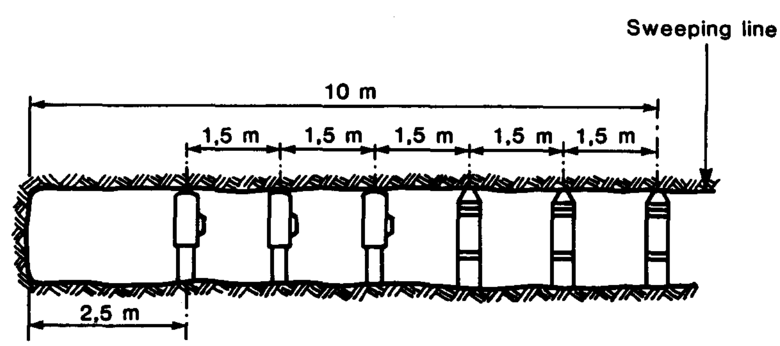

Fig. 5—Section of a stope with three rows of hydraulic props and three rows of profile props

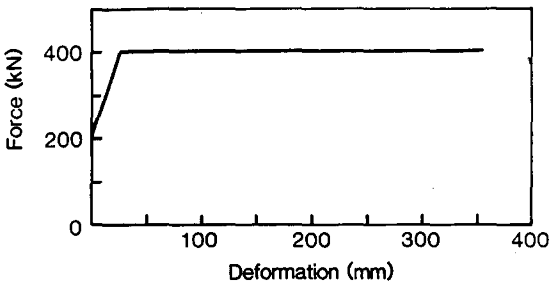

Fig. 6—Force-deformation curve for a 400 kN hydraulic prop

timber prop for various rates of stope closure.

Consideration of Fig. 7 shows that, as closure acts on the support units, their ability to absorb energy decreases. However, because the hydraulic props are removed from row 3 to be moved forward and the yielding timber props are installed in row 4, these units have not been subjected to the full amount of stope closure that would occur between rows 1 and 6. Therefore, the support system still shows a drop in ability to absorb energy with increasing rate of stope closure, but this is far less marked than in the previous example, where the support system consisted only of yielding timber props.

The yielding timber props are installed behind the

Effects of Ground Velocity

DEFORMATION RATE OF 1 m/s FOR VARIOUS DISTANCES BEHIND THE STOPE FACE AND VARIOUS CLOSURE RATES

Closure mm/day	Position of hydraulic prop						Position of profile prop					
	1		2		3		4		5		6	
	kJ	Def	kJ	Def	kJ	Def	kJ	Def	kJ	Def	kJ	Def
0	137	0	137	0	137	0	121	0	121	0	121	0
5	137	0	137	10	131	20	121	0	120	10	118	20
10	137	0	131	20	124	40	121	0	118	20	107	40
20	137	0	124	40	108	80	121	0	107	40	85	80
30	137	0	116	60	92	120	121	0	96	60	59	120
40	137	0	108	80	76	160	121	0	84	80	32	160

Def = deformation

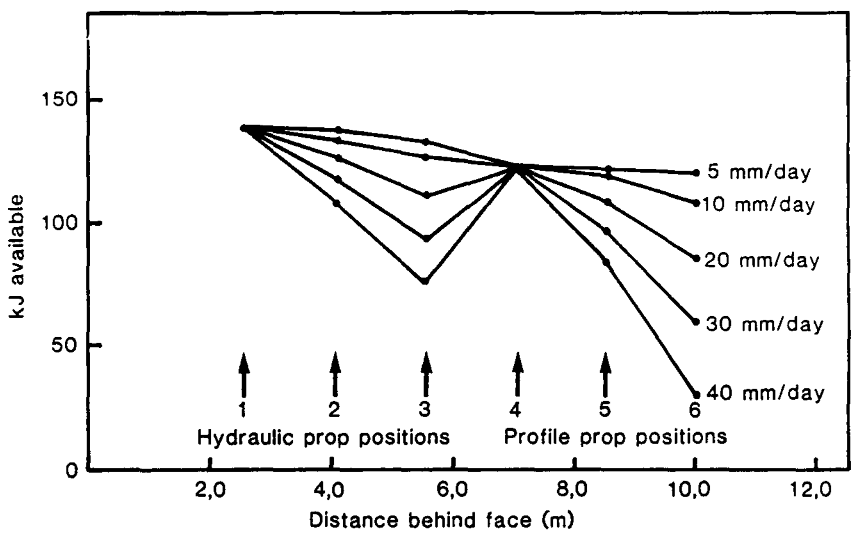

Fig. 7—Measure of the ability of a support system to absorb energy as a function of the distance behind the stope face for various closure rates

tional assumptions are made:

- the area supported by each support unit (including the face area) is 3,3 m^2
- each support unit supports a block of 3,3 m^2 bounded by vertical fractures with zero cohesion that are parallel and at right-angles to the stope face respectively
- the height of each of these blocks is 3,0 m
- the volume of each block is 9,9 m^3
- the mass of each block is 27 225 kg.

It is also assumed that, during a rockburst, the blocks supported by the stope-support units are accelerated to a specific ground velocity. The higher the ground velocity imparted to these individual blocks, the larger the amount of energy required to be absorbed by the support unit to bring that block to rest.

Each support unit will have a different amount of yield left, depending on its position behind the stope face and the amount of closure it has experienced. Therefore, for any given support unit, a critical ground velocity will be attained by the defined block that would require the prop to use its total remaining energy-absorbing ability to bring the block to rest. Above the critical ground velocity, the support unit would not be able to absorb the required amount of energy, and it would fail.

Therefore, if the energy available to be absorbed by each support unit (E_A) is calculated, this can be equated to the kinetic and potential-energy components associated with the moving block on the assumption that the support unit is just about to bring the block to rest at the limit of the support unit's yield range:

$$E_A = 1/2\, mv^2 + mgh,$$

where E_A = the energy-absorbing ability of the support unit at any given time, which will be specific to each support unit and will depend on its position behind the stope face and on the stope closure rate;

m = the mass of the block supported by one support unit = 3,0 · 3,3 · 2,75 · 1000 = 27 225 kg;

v = the critical velocity at which the energy-absorbing ability of the support unit will just be exceeded;

h = the distance of yieldability left in the support unit after stope closure has acted upon it; for example, for the profile prop, 0,225 m minus the stope closure in metres.

$$\text{Therefore } v = \sqrt{\frac{E_A - mgh}{1/2\, m}}.$$

The values of E_A for different values of h were calculated for this critical ground velocity, and are given in Table III and shown graphically in Fig. 8. An example of the calculation is given in the Addendum.

Consideration of Fig. 8 shows that, with increasing rates of stope closure and with increasing distance behind the stope face, the ground velocity required to exceed the energy-absorbing ability of the support unit decreases.

For example, at a closure rate of 20 mm per day, the yielding timber prop in row 6 can withstand a ground velocity not exceeding 0,4 m/s. At a closure rate of 10 mm per day, the same support unit is able to withstand a ground velocity not exceeding 1,7 m/s. Therefore, stopes with high closure rates prior to a rockburst are more vulnerable to lower ground velocities than stopes with lower closure rates prior to a rockburst.

TABLE III

THE VELOCITY AT WHICH PROFILE PROPS WILL FAIL FOR VARIOUS DISTANCES BEHIND THE STOPE FACE AND VARIOUS CLOSURE RATES

Closure rate mm/day	Energy available (E_A) kJ	Yieldability left (h) m	Prop position	Velocity (v) m/s
0	121	225	1 to 6	2,13
5	121	225	1	2,13
	120	215	2	2,15
	118	205	3	2,16
	112	195	4	2,11
	107	185	5	2,06
	102	175	6	2,02
10	121	225	1	2,13
	118	205	2	2,16
	107	185	3	2,06
	96	165	4	1,96
	85	145	5	1,85
	73	125	6	1,71
20	121	225	1	2,13
	107	185	2	2,06
	85	145	3	1,85
	59	105	4	1,51
	32	65	5	1,05
	8	25	6	0,37
30	121	225	1	2,13
	96	165	2	1,96
	59	105	3	1,51
	18	45	4	0,69
	0	0	5	0
	0	0	6	0
40	121	225	1	2,13
	85	145	2	1,85
	32	65	3	1,05
	0	0	4	0
	0	0	5	0
	0	0	6	0

Combined Support System

A similar analysis can be carried out for the system of yielding timber props and hydraulic prop support. The values of E_A for different values of h are calculated to determine the critical ground velocity at which the hydraulic props and profile props will fail. This is given in Table IV and shown graphically in Fig. 9. The combined system consisting of yielding timber props and hydraulic props is clearly able to withstand higher ground velocities than the yielding timber-prop support system discussed earlier. This is not due to any inherent superiority displayed by the hydraulic props, but to the fact that the profile props are installed in the fourth row, and not the first row, and have therefore been subject to less deformation than if they had been installed in row 1. This also applies to the hydraulic props, which are moved from row 3 to row 1 as the face advances.

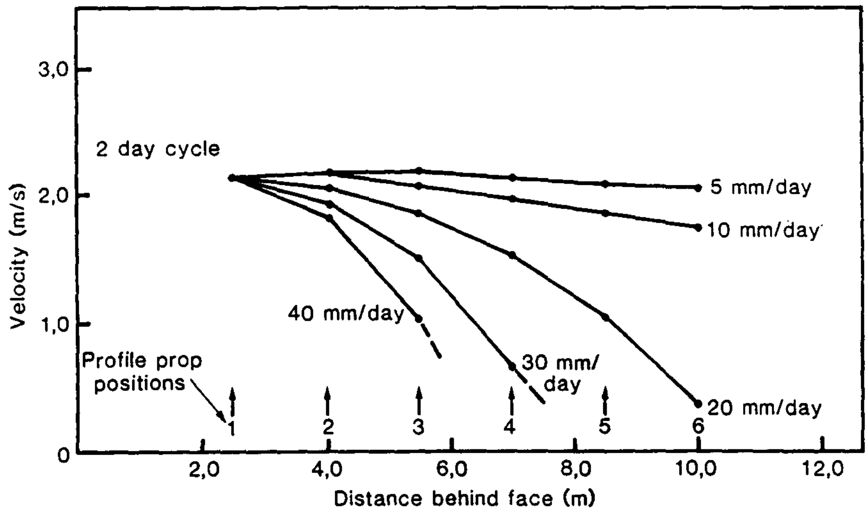

Fig. 8—Minimum ground velocity that will cause profile props to fail for different distances behind the stope face at various closure rates

TABLE IV
THE VELOCITY AT WHICH HYDRAULIC PROPS-PROFILE PROPS WILL FAIL FOR VARIOUS DISTANCES BEHIND THE STOPE FACE AND VARIOUS CLOSURE RATES

Closure rate mm/day	Energy available (E_A) kJ	Yieldability left (h) m	Prop position	Velocity (v) m/s
5	137	350	1	1,80
	135	340	2	1,81
	131	320	3	1,84
	121	225	4	2,13
	120	215	5	2,15
	118	205	6	2,16
10	137	350	1	1,80
	131	330	2	1,84
	124	310	3	1,73
	121	225	4	2,13
	118	205	5	2,16
	107	185	6	2,06
20	137	350	1	1,80
	124	310	2	1,73
	108	270	3	1,62
	121	225	4	2,13
	107	185	5	2,06
	85	145	6	1,85
30	137	350	1	1,80
	116	290	2	1,68
	92	230	3	1,49
	121	225	4	2,13
	96	165	5	1,96
	59	105	6	1,51
40	137	350	1	1,80
	108	270	2	1,62
	76	190	3	1,36
	121	225	4	2,13
	85	145	5	1,85
	32	65	6	1,05

Discussion

Approximately 30 per cent of gold-mine stopes are supported by means of yielding timber props such as pipesticks, profile props, and wedge props. Many of these yielding timber-prop support systems are used in mines with high closure rates and rockburst activity. If the absorption of energy is an important criterion in limiting rockburst damage, then cognizance should be taken of the results of the above analyses, namely that, with increasing rates of stope closure, much of the energy-absorbing ability of these support units is dissipated by stope closure, and their ability to absorb further energy, during a rockburst for example, is reduced.

A similar but less-marked trend is seen where a combination of yielding timber props and hydraulic props is used as a support system. This is because the profile props are installed in the fourth row, and not the first row, and have therefore been subject to less deformation, and also because the hydraulic props have been moved forward from row 3 to row 1 and in the process recover their yieldability. Therefore, because of the mechanics of placement, this support system has a larger capacity to absorb energy.

With respect to the critical ground velocity, similar trends are seen; the vulnerability to failure of individual units increases with the stope-closure rate and distance behind the stope face for yielding timber-prop support systems. For the same reason as above, the units making up the combined system consisting of yielding timber props and hydraulic props will fail only at higher critical ground velocities.

If it is perceived that the reduced energy-absorbing ability of these support units due to high rates of stope closure is a problem, then the solution is to increase the total energy-absorbing ability of the units. It is not desirable to do this by increasing the yield force since this will be dissipated by the stope closure; instead, the yield range of the support units should be increased. If the yield range of the support units described in the above analysis were increased substantially and the yield force held constant, then the energy-absorbing ability of the units would be increased for any rate of stope closure.

If the preceding analyses are correct, it would be expected that a failure of the yielding timber-prop support system during a rockburst would occur from the back of the stope towards the stope face. Evidence showing this phenomenon should be sought to establish the validity of the above analyses.

Similar calculations can be made for pack or backfill support systems. It is apparent that they have a large ability to absorb energy and, if this is considered an important criterion for a given stoping situation, these support systems should be considered.

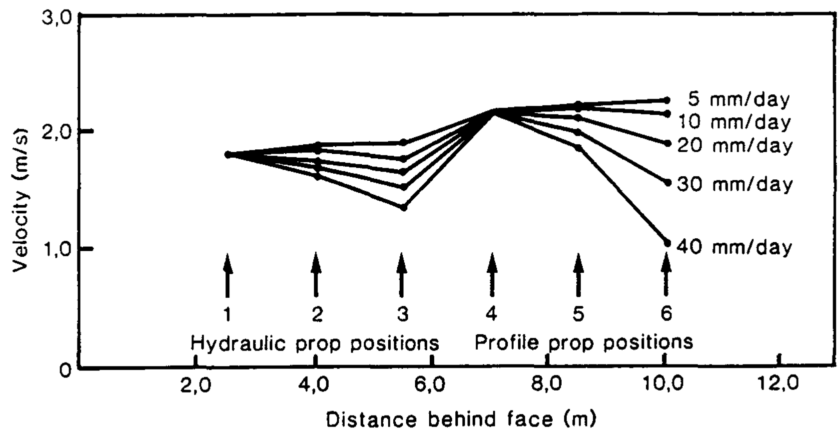

Fig. 9—Minimum ground velocity that will cause a support system to fail for different distances behind the stope face at various closure rates

It is of interest to note that, where yielding timber support systems are used and stope-closure rates of 10 mm to 20 mm per day occur, there is effectively no back-area support further than 10 to 20 m behind the stope face, all the units having failed at that distance. It is estimated that 10 to 15 per cent of the industry is mining with no effective back-area support except gully packs.

Conclusions

(a) The results of the above analyses show that stopes with high closure rates that are likely to experience rockburst damage should not be supported by yielding timber props only. Integration with hydraulic props provides a support system with a higher energy-absorbing ability.

(b) Yielding timber props with an increased yielding range would have a higher energy-absorbing ability than the examples considered above, and the development of such support units should be undertaken by manufacturers.

(c) Direct evidence of the failure of these support systems after rockbursts should be sought in the field.

Acknowledgement

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Reference

1. Roberts, M.K.C., Jager, A.J., and Riemann, K.P. The performance characteristics of timber props. Johannesburg, Chamber of Mines, *Research Report* no. 35/87. 1987.

Addendum: Example of the Calculations

The following is an example of the calculations to determine the energy absorbed by a support unit subjected to rapid stope closure during a rockburst.

Consider a profile prop that has been subjected to a stope closure of 120 mm. The amount of yield left is 105 mm, determined from the total yieldability of the support unit (225 mm) minus the closure that the support unit has been subjected to (120 mm).

For the purpose of this analysis, the assumptions made in the text are repeated:

- the area supported by each support unit (including the face area) is 3,3 m^2
- each support unit supports a block of 3,3 m^2 bounded by vertical fractures with zero cohesion that are parallel and at right-angles to the stope face respectively
- the height of each of these blocks is 3,0 m
- the volume of each block is 9,9 m^3
- the mass of each block is 27 225 kg.

If a rockburst occurs after the yielding timber prop has been deformed by stope closure, the subsequent deformation is rapid. Therefore, from Fig. 2, the energy available to be absorbed by the prop during the rockburst is 59 kJ.

Therefore, as $E_A = 1/2\,mv^2 + mgh$, v is the critical velocity at which the energy-absorbing ability of the support unit wil be exceeded, and h is the amount of yieldability left in the support unit after stope closure has acted upon it, prior to the rockburst.

$$\text{Therefore, } v = \sqrt{\frac{E_A - mgh}{1/2\,m}}$$

$$v = \sqrt{\frac{59\,100 - 27\,225 \cdot 9{,}81 \cdot 0{,}105}{13\,612{,}5}}$$

$$v = \sqrt{2{,}28}$$

$$v = 1{,}51 \text{ m/s.}$$