The design and testing of pipe-sticks for underground stope support

by P. J. J. VAN VUUREN*, B.Sc. (Eng.)

SYNOPSIS

Pipe-stick support in deep-level gold mines is first described and illustrated, a pipe-stick being a mine pole trimmed to the required size and sleeved by a pipe. An account is then given of an investigation into this form of support that involved load–compression tests in a 1000-ton press, tests in a rapid-loading machine simulating rock-burst conditions, a study of the load–compression behaviour of pipe-sticks installed underground, and a cost evaluation.

Pipe-stick support was found to be very effective on the face and to cost less than conventional matpacks.

SAMEVATTING

Pypstokbestutting in diepgoudmyne word eers beskryf en geïllustreer. 'n Pypstok is 'n mynpaal wat tot 'n vereiste grootte afgeskaaf word en omhul is deur 'n pyp. Daarna word daar verslag gedoen oor 'n ondersoek in verband met hierdie vorm van bestutting wat las-druktoetse in 'n 1000-ton pers, toetse in 'n snellaaimasjien wat rotsbarstoestande naboots, 'n studie van die gedrag van pypstokke wat ondergronds aangebring is onder belasting en samedrukking, asook 'n koste-evaluering behels het.

Daar is gevind dat pypstokbestutting baie doeltreffend is op die werksfront en minder as die konvensionele matpakke kos.

Introduction

The design of stope support for tabular orebodies in deep-level gold mines is very complex, and continuous research is being carried out to find the optimum support system to satisfy the great variety of parameters. Much of the research is centred around the *in situ* behaviour of stope support elements and the behaviour of the stoped-out area itself.

Towards the end of 1975, the Rock Mechanics Department of General Mining and Finance Corporation decided to initiate an experimental programme on pipe-stick support. Tests were undertaken at the C S I R laboratories, and installations were incorporated in a stope at Stilfontein Gold Mine under protected conditions, i.e. in between the matpacks forming the normal stope support, in order to establish the characteristics of pipe-stick support. The conclusions drawn from these tests were very encouraging, and it was decided that the experiment should be continued on a larger scale.

This paper describes this support system and its possible application in the gold-mining industry.

Stope Support Requirements

Stoping creates a slot in the rock, which disturbs the equilibrium and results in a redistribution of the weight of the superincumbent strata to the solid areas, where additional stresses are induced. Owing to structural weaknesses and stress fractures in the hangingwall rock, bed separation occurs, creating hazardous conditions in the stope[1, 2].

As stoping progresses, elastic and dilatation convergence takes place, the rate of convergence depending on the rate of face advance, depth of mining, strength of hangingwall rock, and type of support installed. Although the elastic convergence is virtually irresistible, it is possible to control the amount of convergence due to bed separation and maintain the integrity of the immediate hangingwall strata.

*General Mining and Finance Corporation Limited, Johannesburg.

The prime function of stope support is therefore to generate sufficient force very soon after installation to control the rate of bed separation and deformation of the immediate hangingwall within acceptable limits. Since the elastic convergence is irresistible, the support elements should have a yield characteristic that allows shortening whilst support is maintained.

It is well-known that the various types of stope support elements used in gold mines react differently when deformed[3–6]. Ideally, stope support should be very stiff initially so as to reach the design yield load with a minimum amount of compression, and should then yield at a constant load.

It is significant that a comparison of laboratory tests and underground *in situ* tests indicate a much lower load-bearing capacity for the latter, probably owing to the time-dependent reaction and decaying of the packs underground[7].

Features of Pipe-stick Support

Pipe-stick support consists of a mine-pole and a pipe forming a sleeve round the mine-pole (Fig. 1). When a mine-pole is installed with its long axis parallel to the direction of the loading force, it very rapidly reaches its maximum load-bearing capacity, i.e. within 2 per cent compression. After this point has been reached, failure commences and the support very soon becomes ineffective (Fig. 2).

When a stick is enclosed by a pipe, that pipe provides lateral restraint to the failing timber and therefore enables the support system to carry considerable load long after the stick has failed. The load-bearing capacity of a pipe-stick is higher than either that of the pipe or the stick. The pipe sleeve prevents destruction of the stick, whilst the stick gives stiffness to the pipe.

To allow for variation in stoping width, a short length of stick is left protruding at either end of the pipe. When load is applied, sufficient creep takes place to allow the stick to be pushed right into the pipe before failure occurs. The protruding stick enables the person instal-

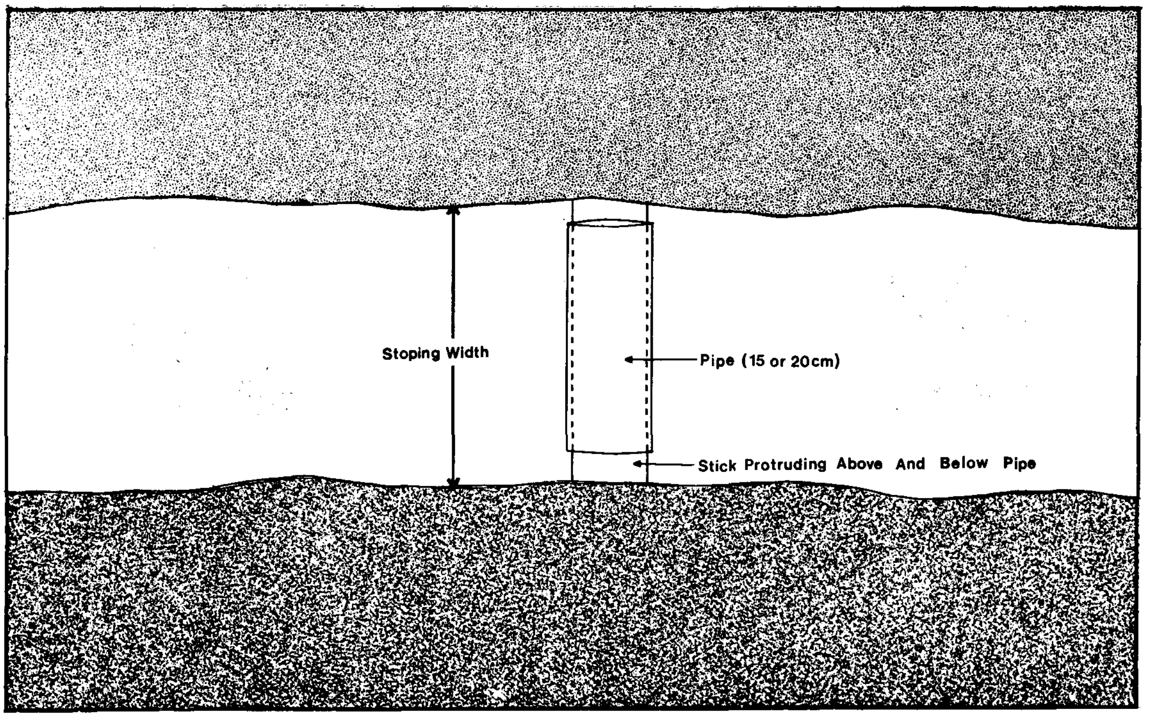

Fig. 1—A pipe-stick for stope support

ling the pipe-stick to cut off a short piece to suit the stoping width at the point of installation.

To highlight the differences in load–deformation behaviour, the load–percentage deformation characteristics of a matpack (60 cm by 60 cm saligna), a mine pole, and a pipe-stick are shown in Fig. 3.

The following conclusions can be drawn from Fig. 3.

(a) A mine pole reacts very rapidly, but, once its failure load has been reached, it soon becomes ineffective. It is therefore unsuitable as permanent support in stopes experiencing more than a few centimetres of elastic convergence.

(b) Pipe-sticks offer a higher maximum load than a similar stick, maintaining a considerable load during deformation. Once the maximum load has been reached, the slope of the load–deformation curve tends to be downwards. This behaviour may appear unstable, but, since it does not happen to all the pipe-sticks at the same time, the overall system is considered stable. The stiffness of the hangingwall also contributes considerably to an overall stable system.

(c) Matpacks offer very little support during the first 10 per cent of deformation and become superior to pipe-sticks only after about 20 per cent deformation. The initial stiffness is increased by wedging and prestressing[4, 5] but is eliminated in practice by uneven hangingwall or footwall and poor installation. Support is not given in the face where it is needed. Matpacks maintain the integrity of the hanging by preventing blocks from falling out by virtue of the area supported.

Fig. 2—A mine pole after maximum load had been reached

Support Pattern

The usual pattern is a row of packs installed on either

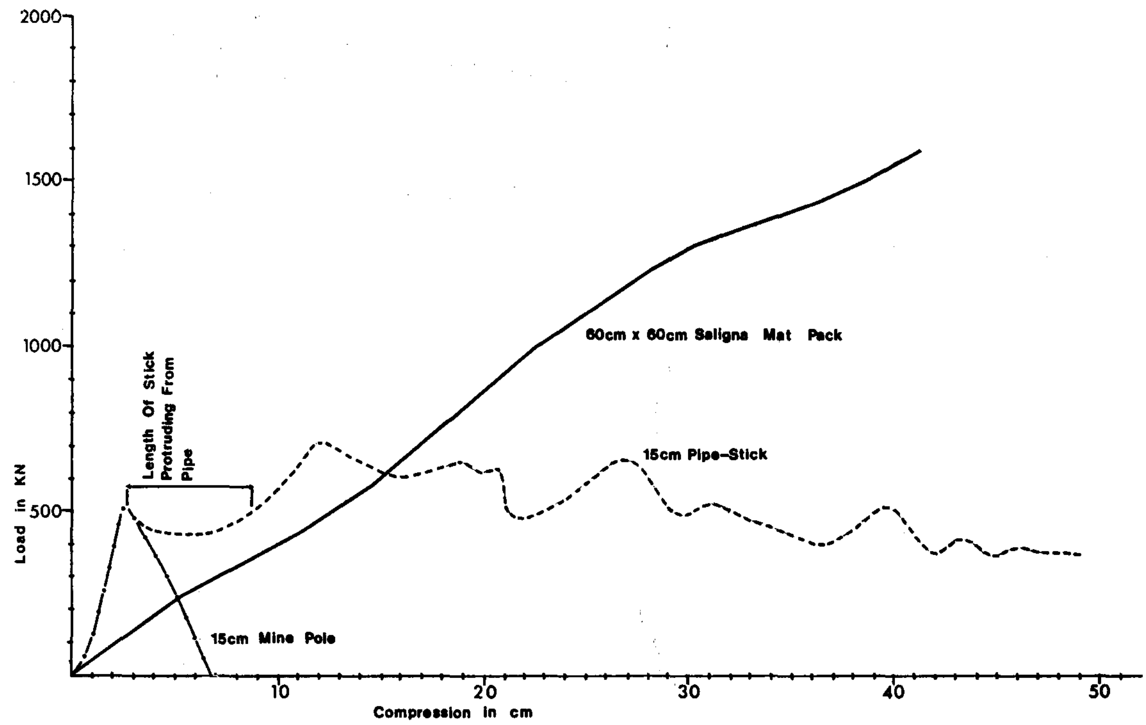

Fig. 3—A comparison between mine poles, pipe-sticks, and saligna matpacks

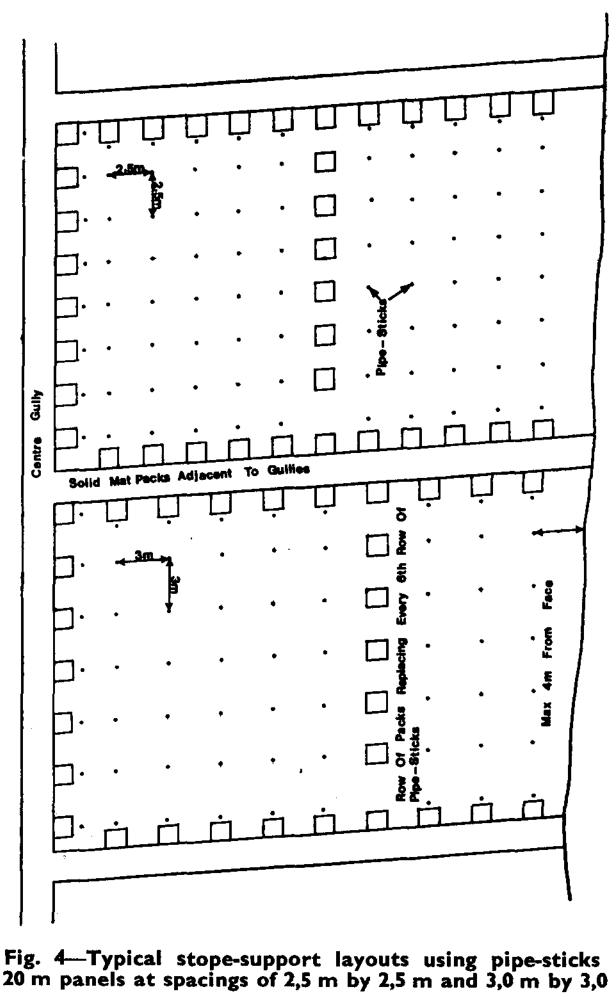

Fig. 4—Typical stope-support layouts using pipe-sticks in 20 m panels at spacings of 2,5 m by 2,5 m and 3,0 m by 3,0 m

side of dip and strike gullies, every sixth row of pipe-sticks often being replaced by a row of packs. The row of packs adjacent to gullies is considered essential because

(1) punching into the fractured footwall could render the support much less effective,
(2) dislodgement of the pipe-sticks at any stage could result in a collapse in the gully, with serious consequences, and
(3) the mat packs maintain the integrity of the gully hangingwall.

The replacement of pipe-sticks by packs in every sixth row is a precaution in the case of sudden failure along a parting plane over an extensive area, which would result in mass collapse and dislodgement of the pipe-sticks.

Fig. 4 illustrates typical stope-support layouts using pipe-sticks.

Manufacture of Pipe-sticks

The pipe-sticks being used at present have a diameter of 15 cm. They are manufactured in different lengths, which increase by 10 cm from 80 cm to 140 cm.

The pipes are cut to a suitable length, and matching sticks are cut to a length 20 cm larger than the pipe. Both are then painted the same colour, a different colour for each length. The stick is then placed in a lathe and trimmed to fit firmly into the pipe (Fig. 5). This lathe consists of two electric-motor driven discs with a number of TC cutters on the disc and a rotating spindle holding the stick. Once cut, the stick is pushed into the pipe with a long-travel piston ram so that it protrudes from the pipe by 10 cm on either side.

The capital requirements for a plant that is capable of producing 300 pipe-sticks per day are R35 000.

Advantages of Pipe-stick Support

(1) Owing to better load-compression characteristics up to 20 per cent compression, improved support close to the face is achieved. This results in better hangingwall control and safety on the working-face area.

(2) Friable hanging can be effectively supported by close spacing, and normal sticks can be used in conjunction with pipe-sticks. This method has been used effectively, resulting in better stoping-width control.

(3) Cleaning and sweeping operations have been made easier because of better utilization of the scrapers. Less rock is left behind between the supports.

(4) There is a considerable saving of transport and installation labour.

(5) Because less timber is used in the stopes, the fire hazard is reduced.

Disadvantages of Pipe-sticks

(a) The support density of pipe-sticks appears to be inadequate owing to their small cross-sectional dimensions compared with packs. Miners therefore install them at a greater density than that laid down, or change to timber packs when bad hangingwall conditions are encountered. This practice is very costly.

(b) Pipe-sticks are unsuitable for use adjacent to gullies. A different design is required there to ensure effectiveness until total closure is reached. The dislodgement of pipe-sticks can result in a collapse over the gully.

(c) The angle of installation is critical, being the main cause of instability. This should be emphasized in the training and supervision of miners.

(d) The maximum stoping width for the stability of a particular diameter of pipe-stick limits its application to narrow reefs.

(e) The negative slope of the load-deformation curve beyond the yield point, and the fact that the maximum load is much less than for mat packs, may place pipe-sticks in disfavour.

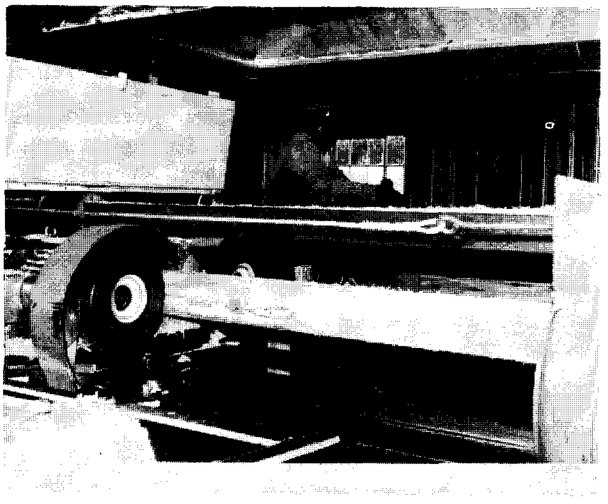

Fig. 5—Manufacturing pipe-sticks

Economic Evaluation

An accurate economic evaluation needs to include a detailed analysis of the transport, labour, face advance, centares per labourer, required spacing, actual spacing, and material cost. The following conclusions were drawn from such an evaluation.

(i) This support system has a potential for reducing the stope timber by approximately 50 per cent overall.

(ii) In view of the considerable reduction in the volume of pack material required, the use of pipe-sticks would effect substantial savings in transport, labour, and shaft time. This would result in a large direct saving, with improved delivery of other material required for production. The volume of material required is only 10 per cent of that for matpacks, and the installation time is 20 per cent.

(iii) Pipe-stick panels have a potential increase in productivity of 10 to 15 per cent over those with conventional support. Other improvements such as sweepings, regular blasting, and better face support result in consistently high face advance.

The following is a cost comparison made in 1977 for a stoping width of 1 m.

	Unit cost	2000 units per month
Pipe-sticks	R	R
Cost of 15 cm pipe (new)	9,00	18 000
Cost of 1,5 m at 15 cm pole (50% wastage)	1,00	2 000
Machining costs	,50	1 000
Shaft and haulage transport costs	,50	1 000
Stope transport and installation costs	,60	1 200
	R11,60	R23 200
Solid matpacks (60 cm by 60 cm)		
10 mats per pack at 87c each	8,70	17 400
Wedges	,50	1 000
Shaft and haulage transport	3,00	6 000
Stope transport and installation	2,50	5 000
	R14,70	R29 400
Paired matpacks (110 cm by 110 cm)		
20 pairs per pack at 83c each	16,60	33 200
Wedges	,50	1 000
Shaft and haulage transport	5,50	11 000
Stope transport and installation	4,60	9 200
	R27,20	R54 400

These costs apply only to the number of matpacks that are actually replaced by pipe-sticks, which indicates that, even when pipe-sticks are spaced at a greater density (about 30 per cent greater), they remain economically viable. The use of reject or secondhand pipes would effect an additional saving of about R6000 per month.

Comparative costs per centare mined are represented graphically in Fig. 6. These are based on the above costs and are for a typical mine using one of the support patterns shown in Fig. 4.

Test Results and Deductions

A series of load–compression tests were conducted in a 1000-ton press at the C S I R. The effect of variations in components was tested on a large variety of pipe-sticks, and load–deformation graphs were plotted and the behaviour and mode of failure of these elements observed. In addition, pipe-sticks were tested at the Chamber of Mines Research Laboratory on a rapid-loading machine simulating rock-burst conditions. Finally, pipe-sticks equipped with load cells were installed underground to monitor load–compression behaviour over a period of time.

The following deductions were drawn from these tests.

(*a*) *Diameter*

The load-bearing capacity of a pipe-stick of 20 cm diameter is about 25 per cent greater than that of a pipe-stick of 15 cm diameter. A 20 cm pipe-stick would also be more stable at higher stoping widths. On the other hand, the 15 cm pipe-stick is more economical and easier to handle, and is therefore preferable for low stoping widths. The critical width-to-height ratio limits the use of 15 cm pipe-sticks to a length of 140 cm. Beyond that length, the frequency of failure due to bending becomes too high. Fig. 7 is a typical load–deformation graph for a pipe-stick of 20 cm diameter and a pipe-stick of 15 cm diameter with a similar wall thickness.

(*b*) *Wall thickness*

The thickness of the pipe walls has a great effect on

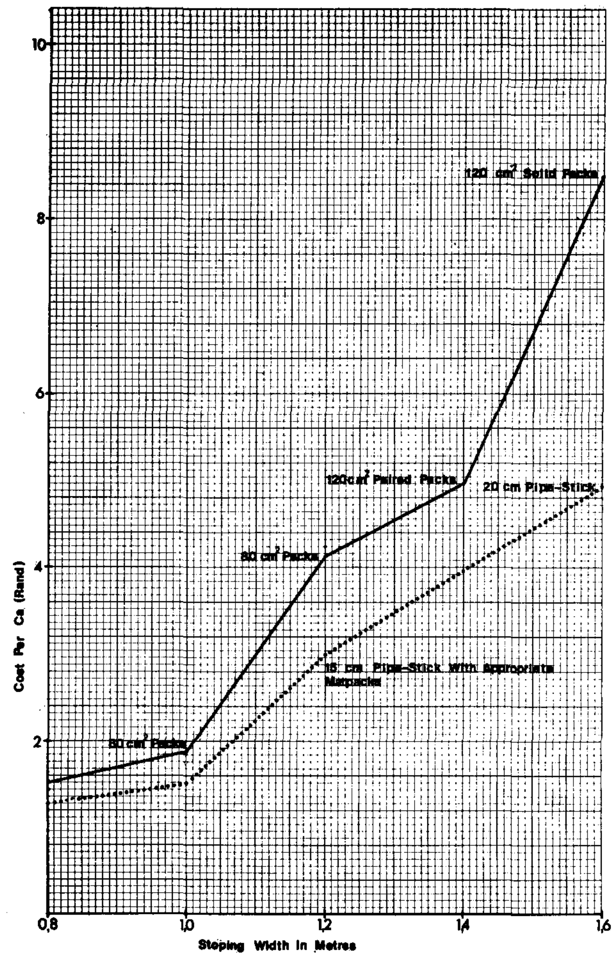

Fig. 6—Comparative costs of matpack and pipe-stick support

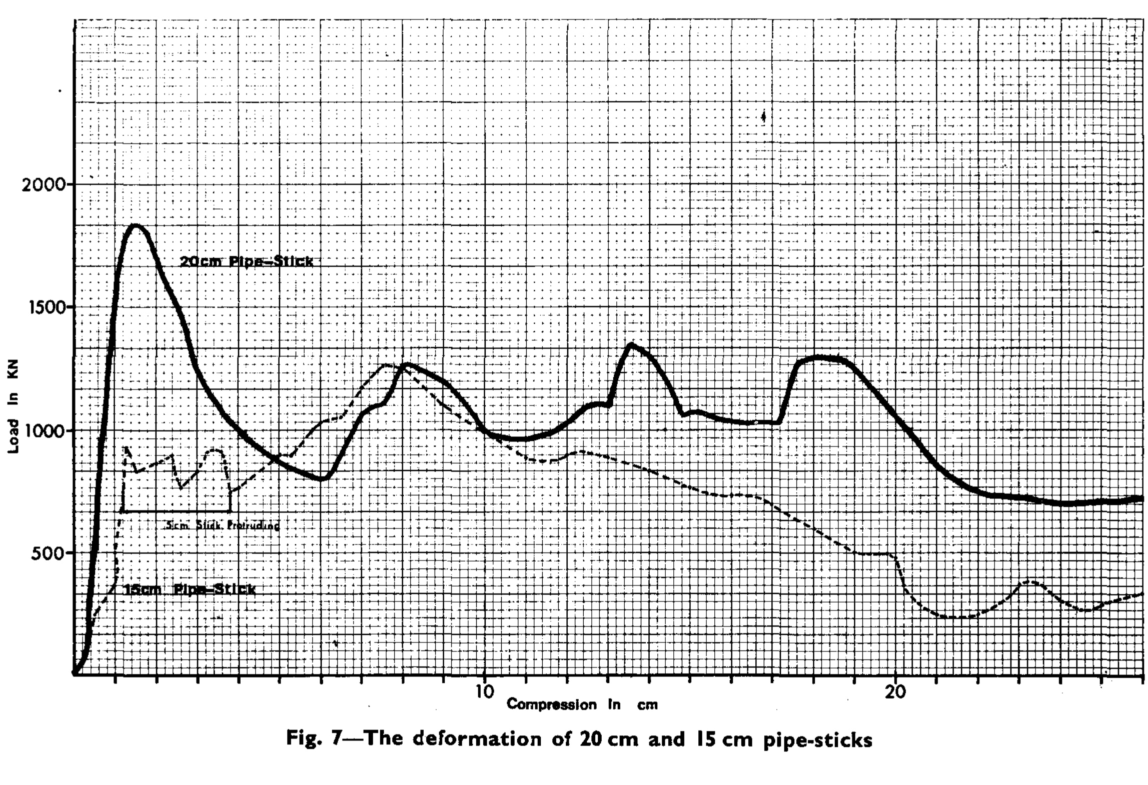

Fig. 7—The deformation of 20 cm and 15 cm pipe-sticks

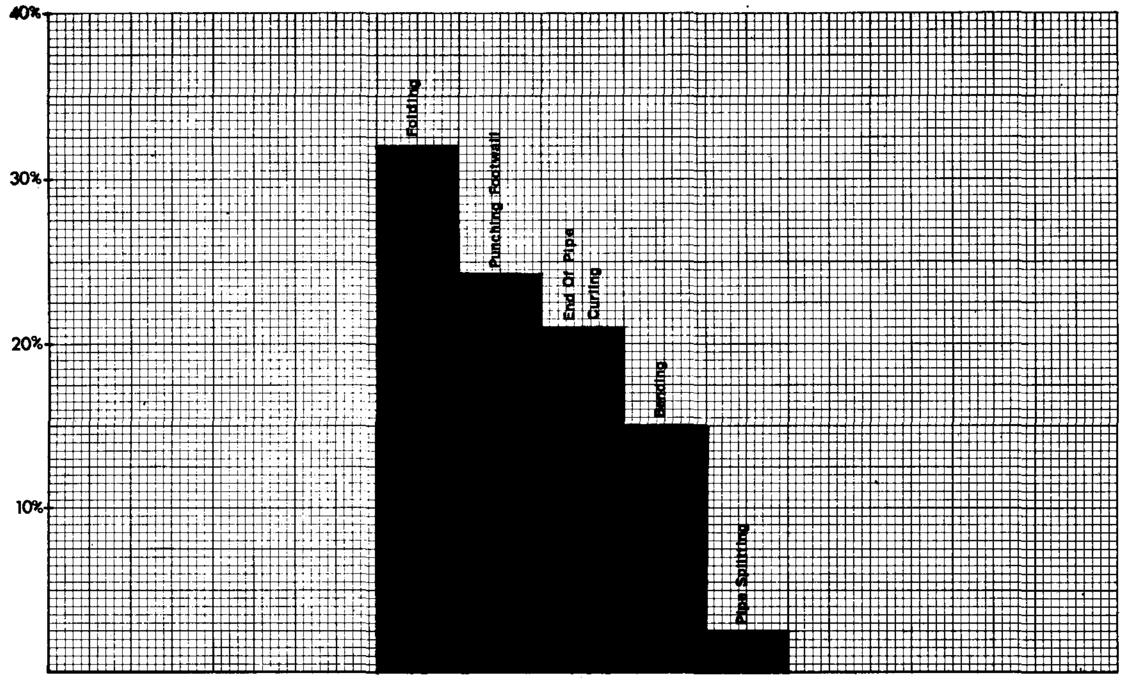

Fig. 8—The distribution of the various modes of failure

their load-bearing capacity. The selection of wall thickness enables a designer to vary the maximum load-bearing capacity between about 800 kN and 1500 kN. The cost of piping increases rapidly with increased wall thickness. It is recommended that piping with a wall thickness of less than 4 mm (thin) should not be used for pipe-sticks. Pipes with a wall thickness of about 5 mm are considered most suitable.

(c) *Stick protrusion*
When the end of the stick protrudes from the pipe, the initial load rises to the maximum strength of the stick and then decreases while the stick is compressed into the pipe. When the hanging and footwall come into contact with the pipe, it starts to carry load as well, and the total strength of the element is experienced. Fig. 7 shows typical load–deformation behaviour. If the stick protrudes too far, the end of the stick snaps at the initial peak on the graph, the load drops off immediately, and in many cases the pipe-stick is dislodged. It has been established that the maximum allowable length of protrusion is approximately 10 cm at each end of the pipe.

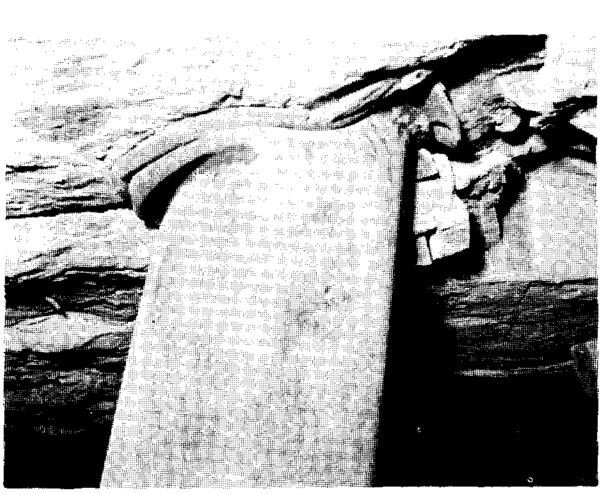

Fig. 9—Deformation of a pipe-stick after yielding load was reached

(d) *Distortion*
As the pipe-stick is compressed, it yields by distorting in various ways (Fig. 8). The ideal mode of distortion is the formation of a series of consecutive folds from one or both ends of the pipe (Fig. 9). The wavy nature of the graphs indicates this behaviour, each downward turn in the graph signifying the start of a new fold.

(e) *Combinations of pipes and sticks*
By the use of various combinations of pipes and sticks, the ultimate load-bearing capacity can be greatly increased. However, the necessity for greater load-bearing capacity and the increased cost are questionable at this stage. Mention must be made also of the possible danger of punching of the support into the foot and hangingwall strata. When a 15 cm pipe was inserted with a stick into a 20 cm pipe, a maximum load of 3840 kN was achieved (Fig. 10).

(f) *Rapid compression*
At the Chamber of Mines Research Laboratories, when pipe-sticks were tested under shock-load conditions, the mode of yielding was found to be similar to that experienced in the slow compression tests. From the result of these tests, it can be deduced that pipe-sticks would stand up reasonably well against seismic events.

(g) *Underground test*
Load cells were installed on the top of two pipe-

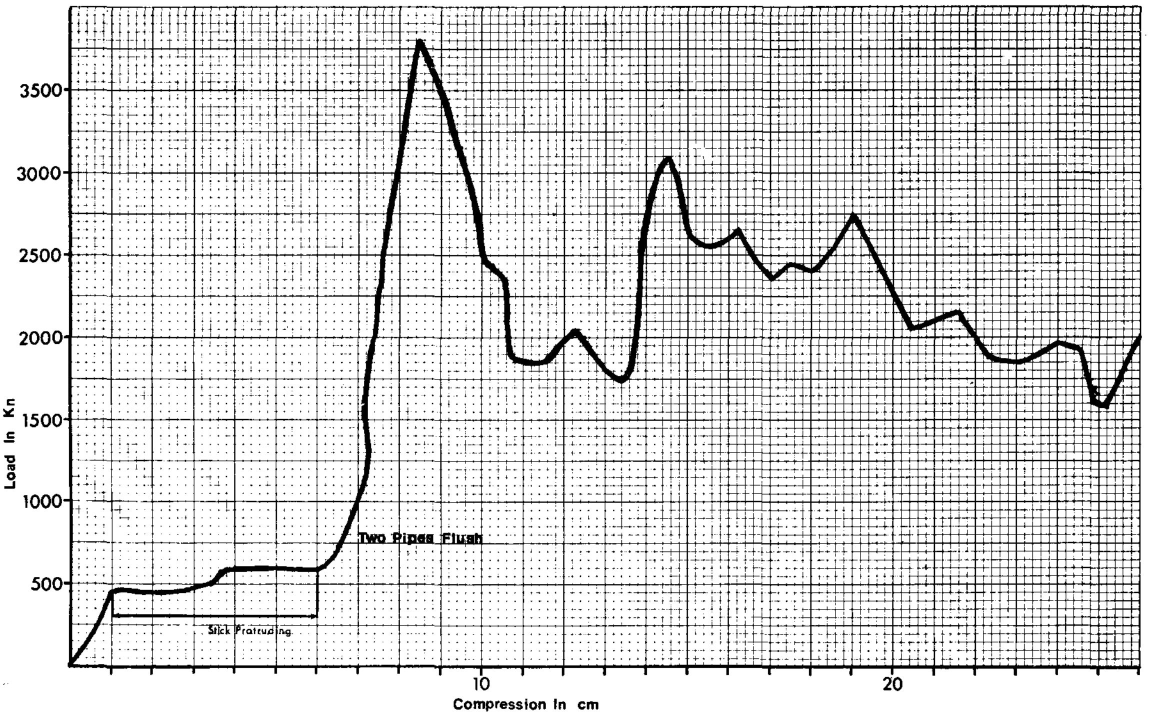

Fig. 10—Loading attainable with double pipes

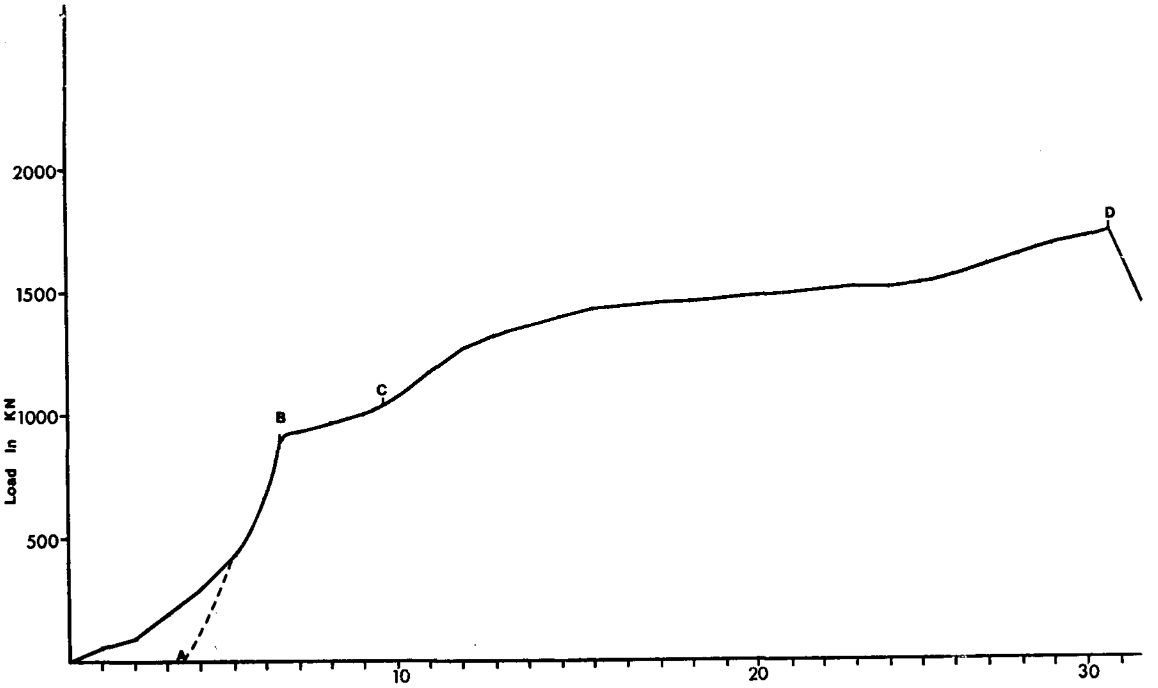

Fig 11—Results of strain-gauge test on an *in situ* pipe-stick

sticks in a stope at Stilfontein and monitored over a period of 6 weeks. Fig. 11 represents the results of one of these load cells installed 7 m from the face and monitored until it was 42 m from the face, at which stage 38 per cent closure had occurred. The initial flat portion of the graph is due to the load cell and bottom of the stick having to make solid contact with the uneven hangingwall and footwall. The test was terminated when the load cell eventually failed, shown by the downward trend at the end of the graph. The maximum load of 1300 kN obtained agrees very well with that found in the tests done at the C S I R. The flat section of the graph from C to D on the underground installation, which is absent in the laboratory tests, suggests time-dependent failure and creep, which occur underground but not under 'rapid' loading conditions such as in the laboratory. Deformation, tilting, and failure mode were recorded. At the end of the test, the total tilt was 20°.

Performance in Practice

During the first installation period, 21 pipe-sticks were installed in 23-23B stope at Stilfontein Gold Mine in January 1976. This stope was examined regularly, and the behaviour of all the pipe-sticks was recorded until closure was greater than 50 per cent. Similarly, a stope (28-49) at Buffelsfontein Gold Mine where pipe-sticks were being used as support in four panels was visited regularly over a period of six months (March to September 1977). Other stopes were examined whenever the opportunity arose, some salient features being observed.

During these visits, the following valuable information was obtained with respect to the behaviour and effectiveness of pipe-sticks.

(i) Pipe-sticks can yield in a number of ways such as curling, folding, splitting, or punching into the footwall. Under all these modes of yielding, the pipe-sticks deform in a stable manner and maintain a reasonable supporting load.

(ii) Some pipe-sticks bend and then lose their load, but an insignificant number of these appear in the vicinity of the working face. This mode of failure normally occurs about 15 m from the face, where it is not of great importance provided it is restricted to individual supports.

(iii) The failure of pipe-sticks is negligible up to 30 per cent convergence (i.e. 0,3 m) in low stoping widths. When the convergence increases beyond 30 per cent, a sharp increase in failure is observed. At a convergence of more than 50 per cent, the majority of pipe-sticks become ineffective.

(iv) Pipe-sticks installed ahead of the blasting barricade are not damaged and, if securely installed, are not easily blasted out.

(v) A seismic event with a Richter magnitude of 3,7 occurred at Buffelsfontein Gold Mine during July 1977. The epicentre was in the vicinity of a stope that was supported on pipe-sticks at that time. The pipe-sticks withstood the shock of this event very well. They deformed in the normal manner, and only a few supports that were leaning over at the time were dislodged. The hangingwall was undamaged by the pipe-sticks.

(vi) A large number of panels have been stoped out successfully on pipe-sticks to date. Trouble experienced could be traced back to either poor installation or to geological reasons.

Problems Encountered

A number of problems have been encountered, some of which have been solved; others are inherent in the system and will require continuous attention.

(a) By far the major problem, and often the cause of early failure due to dislodgement, is the angle of installation. The pipe-stick must be installed accurately at right-angles to the hangingwall; otherwise, convergence of hangingwall and footwall forces the pipe-stick over until it is dislodged. Correct training and strict supervision are essential to ensure that pipe-sticks are installed at the correct angle.

(b) The end of the stick snaps when it protrudes too far from the end of the pipe. This has been overcome by limiting the protruding end of the stick to 10 cm on each side, by securing the pipe in position with a nail, or by deforming the end of the pipe slightly.

(c) When broken ground near dykes and faults is encountered, part of the hanging is often lost. Although pipe-sticks appear to be a better support in this case because of their stiffness, it is found that production personnel tend to favour matpacks.

(d) Lack of adaptability by stope workers is initially one of the major problems. Owing to the apparently less-dense installation, people feel unsafe in the stopes. The tendency is then to install pipe-sticks at a greater density or to revert to conventional support at the slightest change of conditions.

Conclusions

1. The steep load–deformation curve prior to yield and the constant load characteristics after yield mean that pipe-sticks are a very effective face support.
2. When it is necessary to keep the stope open for a distance greater than 40 m from the face, pipe-sticks are not suitable owing to their low ultimate loading characteristic.
3. Pipe-sticks reacted favourably to simulated rock-burst conditions, and successfully stood up during a large seismic event at Buffelsfontein Gold Mine.
4. The overall cost and labour-saving features make the use of pipe-stick support very attractive.
5. Good supervision and correct installation are essential if ineffective support and early dislodgement are to be avoided.

References

1. Wiggel, R. R. The effects of different support methods on strata behaviour around stoping excavations. S. Afr. Inst. Min. Metall., Symposium on Rock Mechanics and Strata Control in Mines, Apr. 1963–Jun. 1965. pp. 1-35.
2. More O'Ferrall, R. C., and Kersten, R. W. Stress and