Basic engineering principles in the design of sandwich-pack support

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SYNOPSIS

From a consideration of the functional requirements of a stope-support pack, simple design principles were developed. The material and dimensional properties of the different components of the pack were determined from a series of laboratory tests. The most important requirement for an adequate pack is that the cushioning layers of timber between the concrete brick layers should provide sufficient transverse reinforcement. The tendency of the compressed timber to creep is shown to be a serious limitation to pack performance and must therefore be an important consideration in the overall design of supports.

SAMEVATTING

'n Beskouing van die funksionele vereistes vir 'n steunpak vir afbouplekke het gelei tot die ontwikkeling van eenvoudige ontwerpbeginsels. Die materiaal- en afmetingseienskappe van die verskillende onderdele van die pak is aan die hand van 'n reeks laboratoriumtoetse bepaal. Die belangrikste vereiste vir 'n geskikte pak is dat die houtkussinglae tussen die betonlae voldoende dwarswapening moet verskaf. Daar word getoon dat die neiging van saamgeperste hout om te kruip 'n ernstige beperking op die werkverrigting van die pak is en gevolglik 'n belangrike oorweging by die hele ontwerp van stutte moet wees.

Introduction

Support packs constructed of timber and concrete have been used successfully and extensively in stoping since about 1966. The original sandwich pack gained wide acceptance because it represented a saving in materials and a considerable reduction in timber[1], and it is now generally recognized that a real improvement in hangingwall condition has resulted from its improved stiffness compared with that of timber packs. The reduced fire hazard is an additional benefit incidental to the general use of concrete in stope support.

Numerous variations of pack construction have been examined in hundreds of tests carried out within the industry under laboratory conditions[2]. In addition, the actual load generated in a stope pack in the working situation underground has been measured in a few instances. However, there has been no systematic investigation of the important engineering properties involved in the design of a sandwich pack. Failure to appreciate the essential purpose and limitations of the various components of a pack has led to much waste of effort, and possibly even to widespread use of basically unsuitable designs. On the other hand, a better understanding of the functional requirements has made it possible to improve the overall performance of packs and even effect savings in cost.

This paper attempts to distill from experience, as well as from deliberate experiment, the essential engineering principles that determine the behaviour of a timber–concrete stope pack. Although the experimental results are largely from tests on sandwich packs, the basic principles are valid for most types of concrete–timber combinations.

Functional Requirements

The main function of stope support is to prevent the separation of strata and the loosening of fractured rock over the working area immediately behind the stope face. An outline of the principles involved and a guide for determining the density of support are given by the 1976 High Level Committee on Rockbursts and Rockfalls[3].

A pack is essentially a passive form of support that needs to be compressed before it will generate any useful support load. Compression of a pack results from the elastic convergence of the stope or from the dead mass of separated strata or loosened fractured blocks of hangingwall above.

Convergence of the rock mass into the stope continues progressively and predictably as the stope advances, and normally presents no problem or threat to the workers. The other two effects are obviously undesirable and are specifically what the pack support is intended to prevent.

It follows that a pack must be as stiff as possible so that a small amount of convergence will generate a sufficiently large reaction or support load. Quantitatively, it will generally be very difficult to assess what support load is required, and it is also likely to vary from place to place. Qualitatively, it can be stated that the reaction should exceed the weight of that rock, which might become separated from the converging rock mass. Then, opening of bedding planes or other weaknesses cannot occur, and loosening of any fractured blocks will be limited.

It is important to appreciate that pack support can have no effect whatsoever on the amount or rate of convergence. Compression due to convergence will continue inexorably and must be accommodated by the pack.

Thus, there exists the somewhat paradoxical requirement that a *stope support must be very stiff and, at the same time, have an almost unrestricted ability to yield.* The load–compression characteristic of such an 'ideal' support is shown in Fig. 1, together with a synthesized curve showing the typical response of a sandwich pack and a skeleton timber pack.

The basic characteristic of timber packs (Curve III) is their relatively low initial rate of load acceptance, b–c in Fig. 1, followed much later by a rapid and sustained increase in reaction, d–e. The use of concrete components, which are virtually incompressible compared with timber, has the effect of improving the

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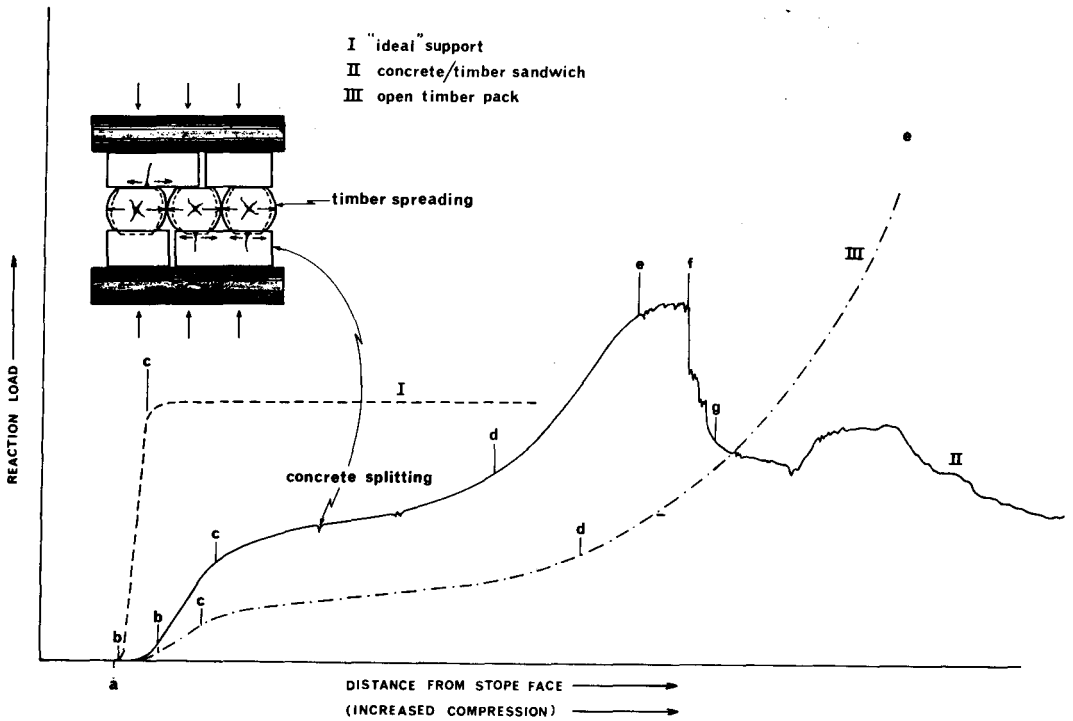

Fig. 1—Idealized load–compression characteristics of stope support

response of the sandwich pack (Curve II) some way towards the ideal characteristic of Curve I. The amount of stiffening is in direct proportion to the reduction in the compressible timber component, but the total yield before failure is considerably reduced.

The total response of the sandwich pack is also illustrated in Fig. 1. A small amount of the initial compression, a–b, is absorbed in 'bedding-in' and results in a negligible increase in load. This is followed by a period of relatively rigid linear load acceptance, b–c, to a stress level where crushing of the timber commences.

During this period, c–d, of progressive breakdown of the cell structure of the wood, some vertical splitting of the concrete bricks is likely to occur but without any loss in load. With the timber fibres completely compacted, a further rapid increase in load occurs to a stress level that is sufficiently high to cause massive crushing of the concrete, e–f. The resulting transverse bulking of the concrete fragments causes tensile failure of the crushed timber slabs with appreciable loss in load, f–g. The final reduced and erratic resistance to compression results purely from friction between the partly constrained pieces of concrete rubble and crushed timber.

The overall characteristic of the pack is determined by the complicated interaction of many factors. For various reasons, among which the inherent variability in the timber is probably dominant, it is not easy to isolate and examine the individual effect of all the factors. However, as a result of both *ad hoc* and deliberate experimental testing, the specific effects of the more important factors were established. These can be divided into three groups: the characteristics of the concrete brick, the characteristics of the timber and, finally, the design and constructional features. Unless otherwise specified, all the experimental data are based on 0,6 m by 0,6 m packs 1,2 m high tested in the 9000 kN testing machine of the Mine Equipment Research Unit of the C S I R.

Concrete Bricks

Of all the factors that affect the behaviour of a sandwich pack, those concerned with the concrete brick fall most completely within the control of the user. Provided that its limitations and functional requirements are properly understood, it should be comparatively easy to gain optimum benefit from the concrete component.

The manufacture of the concrete brick should obviously conform to accepted standards of concrete technology. The main determinant of cost is the amount of cement required to achieve the desired strength of brick. For economic as well as functional reasons, therefore, the question of strength demands careful consideration.

Failure of the pack is not simply a consequence of fracture of the concrete but results from the complex interaction of the timber and the concrete. Additional features such as the shape, size, and surface finish of the brick and the actual mode of failure of the concrete become relevant.

Strength

Determination of the support load required of the pack is the first step in deciding on the strength of the concrete to be specified for the manufacture of the brick. The basic assumption is that a pack is required to carry the weight of a column of rock whose base extends midway to the adjacent pack in each direction and whose height extends at least to the highest known geological weakness to which a fall might conceivably extend,

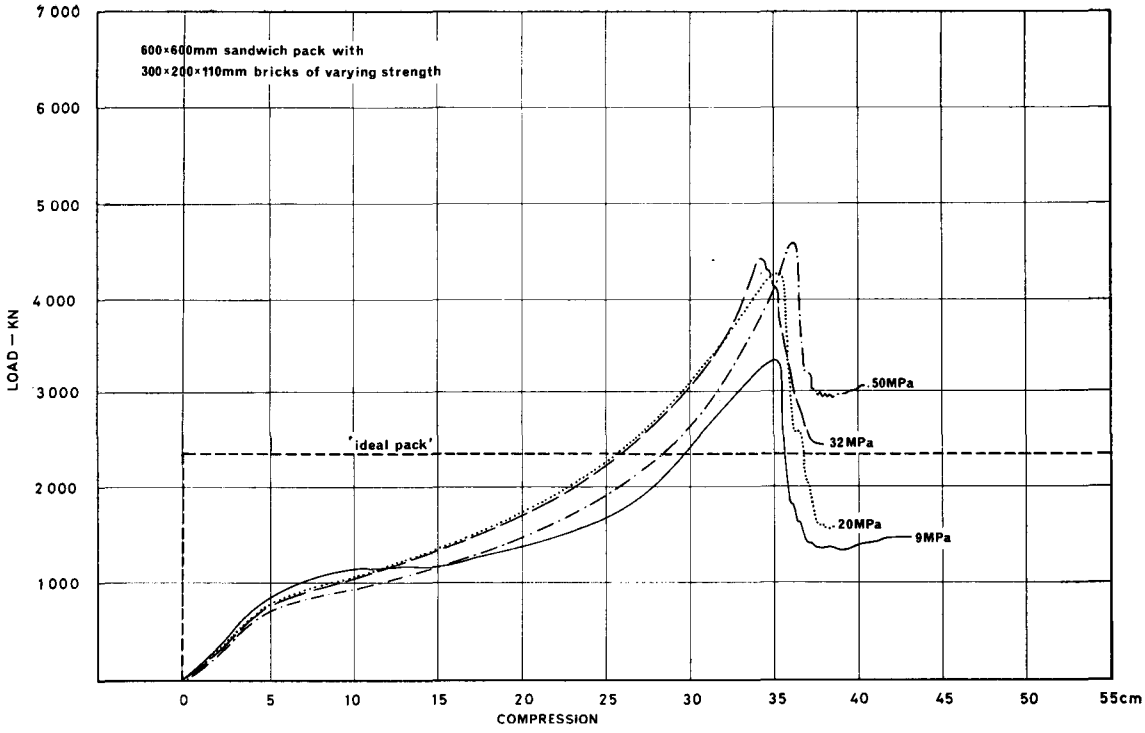

Fig. 2—The effect of concrete strength on pack characteristic

Simplified guidelines for the density of pack support are provided in Section 6.2 of the recommendations of the 1976 Committee on Rockbursts and Rockfalls.

For the purpose of example and to set a strength 'standard' that will be referred to elsewhere in this paper, it will be assumed that a 5 m thickness of strata is required to be supported before failure of the bricks occurs. The sandwich packs are 0,6 by 0,6 m in size and are spaced at 2,6 m centres:

Volume supported: $2{,}6 \times 2{,}6 \times 5 = 33{,}8\ m^3$

Load supported: $33{,}8 \times 2{,}7 \times 9{,}8 = 885$ kN (relative density of rock 2,7) $= 0{,}88$ MN.

When the necessary overlap of timber is taken into account, the cross-sectional area of the pack is 0,25 m². Therefore, the average stress in the pack is

$$\frac{0{,}88}{0{,}25} = 3{,}5 \text{ MPa.}$$

Even with well-slabbed chock pieces, the real area of contact between timber and concrete is probably less than one-half the nominal area and the desired brick strength must be at least 8 MPa. The fact that brick of such low strength could not be expected to survive normal underground handling suggests that the design procedure is somewhat oversimplified. Nevertheless, the

TABLE I
LOAD-COMPRESSION VARIANCE OF REPEATED TESTS

Compression	'Weak' bricks (15 MPa)			'Strong' bricks (31 MPa)		
	Load	S.D.		Load	S.D.	
cm	kN	kN	%	kN	kN	%
2,5	459	91	19	389	81	20,5
5,0	707	78	11	589	39	6,6
7,5	812	108	13	695	24	3,4
10,0	902	104	11,5	758	45	5,9
15,0	1009	114	11,2	892	45	5,0
20	1127	122	10,8	1060	68	6,4
25	1324	244	17	1227	90	7,3
30	1610	295	18	1512	81	5,3
35	1952	342	17,5	1964	79	4,0
40	2414	381	15,7	2671	118	4,4
45	2828	361	12,7	3720	232	6,2
50	2659	496	18,6	2855	251	8,8
55	2673	139	5,2	1689	314	18,5
60	3468	216	6,2	2525	664	26,3
65	4026	83	2,1	3272	600	18,3

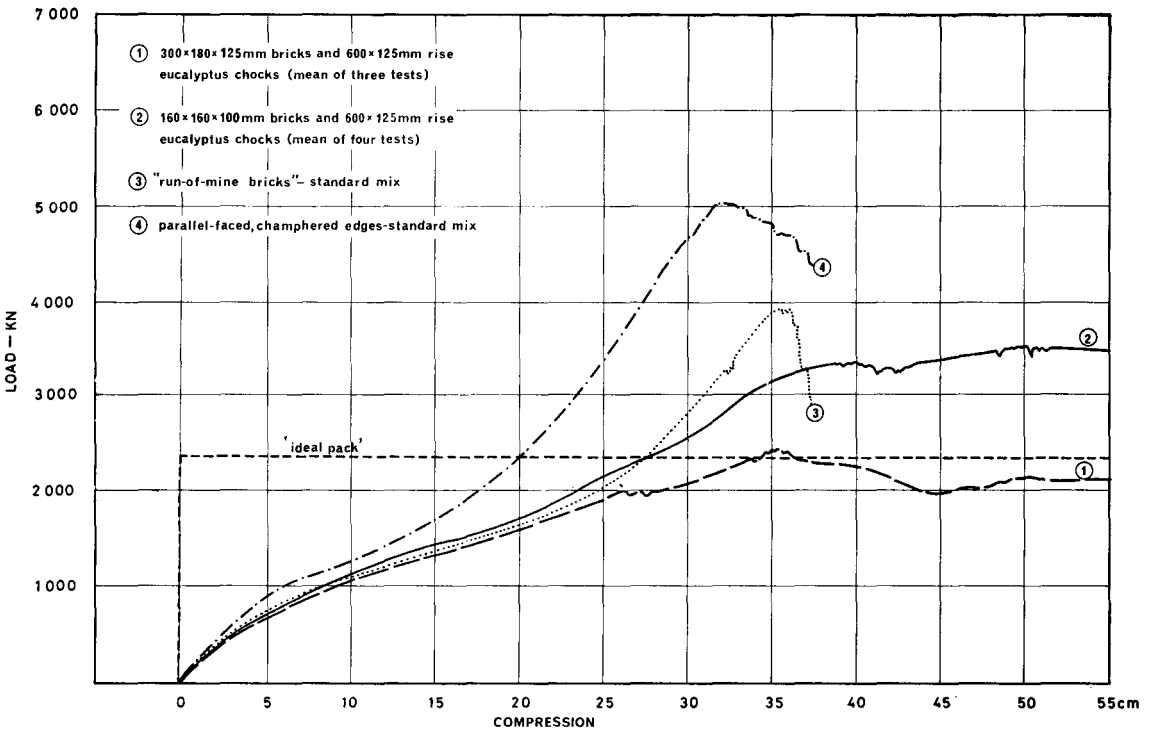

Fig. 3—The effect of brick height and surface finish on pack characteristic

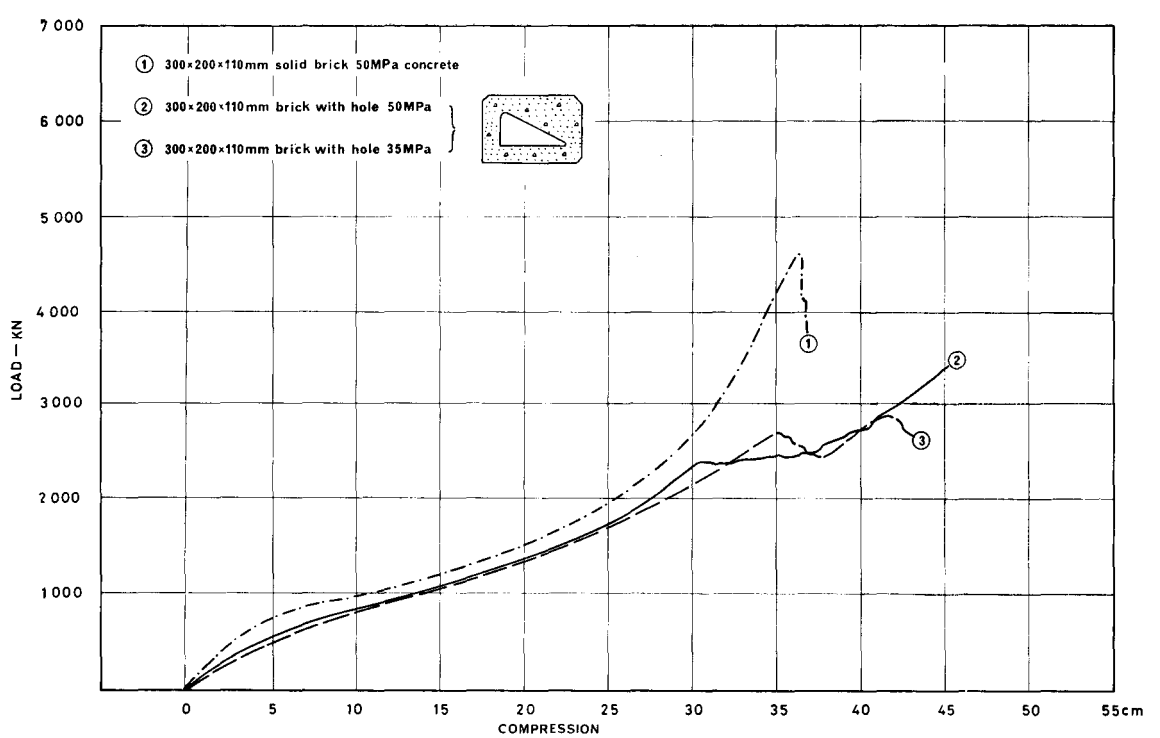

Fig. 4—The effect on pack characteristic of different failure modes of concrete

relatively small effect of brick strength on overall pack characteristic, under laboratory conditions, is shown in Fig. 2.

This somewhat surprising feature was also confirmed in a carefully controlled series of tests that compared three packs made of standard 'strong' E.R.P.M. bricks (31 MPa) with three packs built of weaker (15 MPa) bricks. The 125 mm rise chocks were specially selected for uniformity of shape and appearance from a normal mine consignment of saligna. The strength of the bricks was determined by the Portland Cement Institute on standard 100 mm cubes that were cut from bricks taken from the batches used in the respective tests.

The results are given in Table I, and the averaged curves are shown in Fig. 12. Although the peak strength was slightly lower, the subsequent loss in load was distinctly less for the pack constructed of the weaker bricks. The negligible effect of concrete strength on pack performance is also evident in Fig. 4.

Dimensional Factors

Shape of Brick

A convenient way to improve pack stiffness by increasing the concrete component is to increase the height of the concrete brick. Because of the greater free surface available between the reinforcing timber layers, the concrete spalls and fails earlier and at considerably lower loads. This effect is displayed in Fig. 3 for bricks 125 mm high (Curve 1) and bricks 100 mm high (Curve 2).

There is some indication that bricks of smaller transverse dimension yield a stronger pack than that provided by the same area of larger bricks. The smaller bricks probably accommodate irregularities in the timber surface where larger units would be subjected to bending stresses. For the same reason, square bricks are slightly better than rectangular bricks.

Uniformity and Surface Finish

To avoid point-loading, which can cause premature fracture of the concrete, the bricks must be perfectly regular prisms with the loaded faces, in particular, plane and parallel.

Projecting pieces of large aggregate in the concrete can weaken the timber by penetrating and cutting the fibres. Crushed stone of 10 to 12 mm maximum size, when used in a suitable brickmaking machine, provides a sufficiently smooth surface finish and regularity of shape. Rounded or chamfered edges where possible on the brick are beneficial.

The effect of improved shape and surface finish is shown by Curves 3 and 4 in Fig. 3.

Mode of Failure of Concrete

The indication in Fig. 12 that the stronger bricks gave rise to more abrupt pack failure with more pronounced loss of load suggested that the mode of failure of the concrete was important in avoiding this effect and prolonging the useful life of the pack. The strong concrete broke up into relatively large sharp fragments, which caused the timber pieces to fail in tension with dramatic loss in load. On the other hand, small aggregate relatively weakly bound together permits a pervasive crumbling failure that does not destroy the timber so readily.

Increasing the unloaded-surface area by moulding the bricks with various shapes of hole promotes this effect (Fig. 4).

An almost 'ductile' failure was obtained in a vertically perforated brick made from an air-entrained, small-aggregate concrete (Fig. 5).

Timber Characteristics

Of the many sources of variability in performance inherent in the timber component of a pack, most are completely beyond the control of the user. In principle at least, the species of timber can be specified and, within limits, the dimensions of the chock. It is imperative that the width of the slabbed surfaces and, more particularly, the rise, should be maintained within close tolerances if the optimum performance is to be attained.

The basic engineering properties of timber that are most important are the tensile strength in the fibre direction and the 'strength' and compressive modulus across the grain. These properties are influenced by indeterminate and uncontrollable factors such as age, growth rate, and moisture content, but they are primarily dependent on the species of timber.

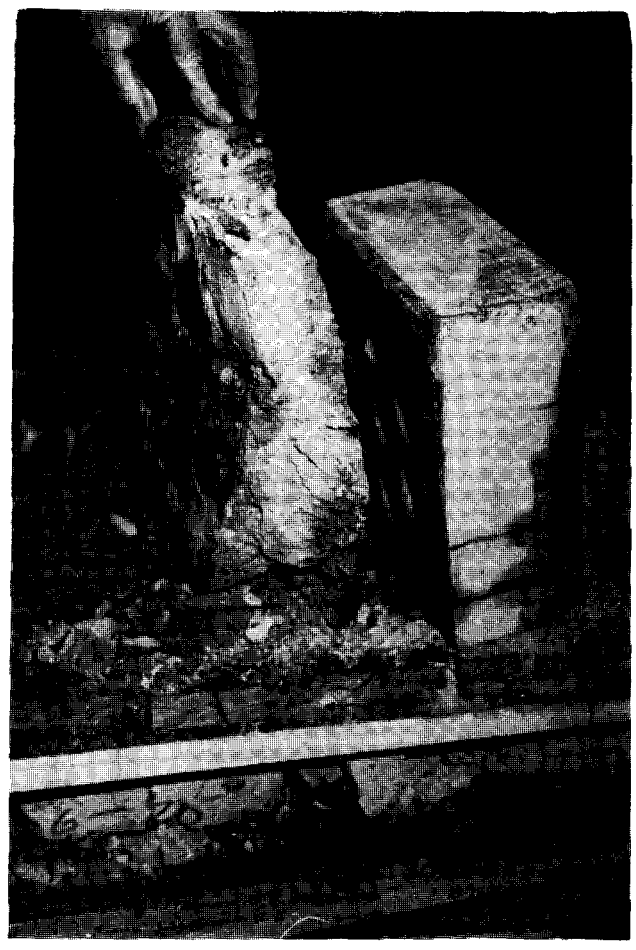

Fig. 5—Pervasive, 'ductile' failure of low-strength, air-entrained concrete brick of lowered aspect ratio

Inherent Variability

The relatively small standard deviation (mean 11,2 per cent) listed in Table I gives an indication of the maximum uniformity in behaviour possible in selected timber. A variation in pack load of about 20 per cent standard deviation is more likely with timber of nominally the same dimension and species[4].

Where timber of the same species is obtained from different sources, the variability in pack performance will be much greater.

Tensile Strength

Careful observation of a destructive test of a sandwich pack reveals that the function of the timber layer is not only to accommodate stope convergence by yielding but, equally important, to provide transverse reinforcement to the pack.

Because of its very anisotropic nature, the timber has a somewhat ambivalent effect in this regard. As it crushes during the yielding phase (c–e in Fig. 1), the timber spreads at right angles to its fibre direction — an exaggerated Poisson effect. This actually promotes initial failure of the concrete by pulling the brick apart to cause the characteristic vertical split indicated in Fig. 1.

Later, when large concrete fragments expand laterally, the very high tensile strength and modulus (see Addendum A) bind the pack together and prevent the pieces from abjectly slumping into the angle of repose. The overriding importance of this effect can be dramatically illustrated when a sandwich pack is tested with the fibres in the successive layers of timber all pointing in the same direction.

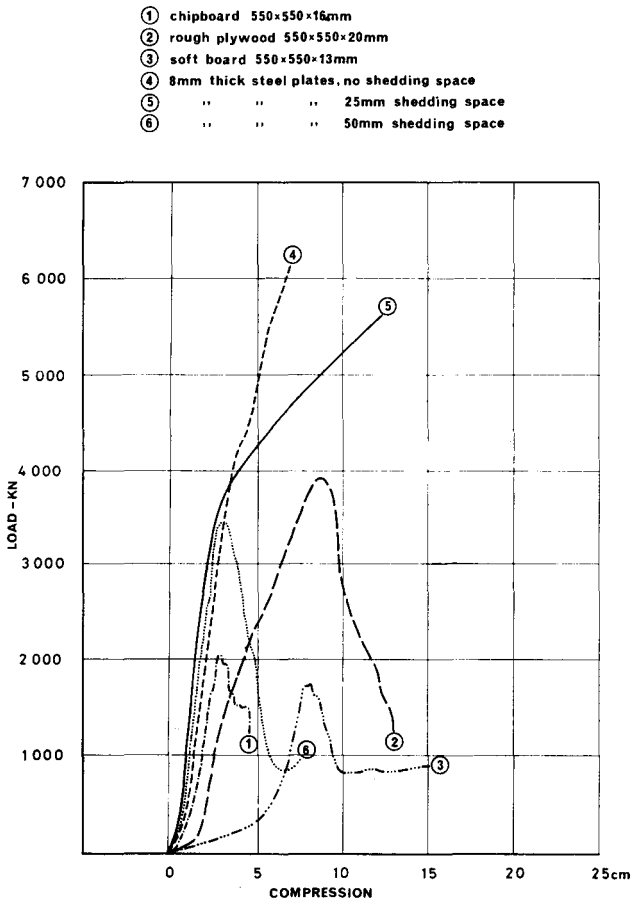

Fig. 6—The effect of varying transverse reinforcement on pack characteristic

The need for transverse strength in all directions in the cushioning material was examined more explicitly in a series of tests conducted with various 'synthetic' materials. Packs were built with 250 by 250 by 120 mm bricks of 10 MPa strength, interlayered between sheets of chipboard, plywood, and softboard, and their load–compression characteristics were plotted (curves 1, 2, and 3 respectively in Fig. 6).

Determinations of the tensile strengths of these materials and of various timbers were made in the Timber Research Institute of the C S I R (Addendum A). From these values, the total tensile strength across a complete layer of 'cushioning' material can be calculated. These strengths are listed in Table II.

TABLE II
TRANSVERSE STRENGTH OF INTERLAYERING MATERIAL

Material	Cross-sectional dimensions mm	Average tensile strength MPa	Average modulus of elongation GPa	Total tensile strength kN
Softboard	500 × 13	0,93	0,2	6
Chipboard	500 × 16	9,15	2,6	120
Plywood	500 × 21	37,22	9,3	390
S.A. Pine	500 × 30	50,00	12,5	750
Saligna	500 × 30	66,90	13,2	1000
Wattle	500 × 30	91,70	10,8	1370
White gum	500 × 30	93,21	23,7	1400

Total Strength Requirement

Although the 'synthetic' boards of reconstituted timber materials are more or less isotropic and ideal for eliminating point contacts and stress concentration between bricks, their total strength is inadequate in all cases (Fig. 6). In the continued effort to find the minimum reinforcing necessary for a 600 by 600 mm sandwich pack, a further series of tests was conducted using planks of various timber species (Fig. 7). The planks were of varied widths but all were nominally 30 mm thick.

Two layers of planks, crossed at right angles, made up one 60 mm thickness of timber between each successive layer of bricks. Special samples for the tensile test were cut from the planks and tested at the Timber Research Institute (Addendum A). The total transverse strength appeared to be inadequate in only one instance (Curve 7 in Fig. 7), where abrupt failure of the pine planks caused a pronounced loss of load after 20 cm of compression. Initial failure occurred much sooner in the other, stiffer packs, but the pervasive crumbling of the weaker bricks allowed continued yield to 50 per cent and more without loss of load.

From these tests the total transverse tensile strength requirement for a 0,6 by 0,6 m sandwich pack appears to be between 750 and 1000 kN (Table II).

It must be remembered that the 'cushioning' layer has invariably been compressed, usually in excess of 50 per cent, before major failure of the pack commences. Thus,

the actual transverse strength at that stage may be somewhat less than it was at the start. One test carried out by the C S I R on a saligna chock that had been compressed by 40 per cent across the grain showed that its tensile strength in the fibre direction was virtually unimpaired.

Across-grain Compression

A series of laboratory stress–strain tests were carried out on planed timber specimens of the same shape as the slabbed chocks and one-quarter the size.

For small deformations, the timber behaved linearly both parallel to and perpendicular to the fibre direction. The calculated compressive modulus across grain was 190 MPa for white gum and 60 MPa for saligna. Measured on the same testing machine, the concrete at 24 GPa was found to be 200 to 400 times stiffer. Thus, the initial stiffness of a pack is determined by the compression characteristic of the timber alone, the strain in the concrete being negligibly small.

On this basis, the measured deformation of the packs in Fig. 7 give estimates of the compressive moduli for the various timber species (Table III). Although somewhat lower, these effective moduli are of the same order as those measured in the small specimens.

TABLE III
EFFECT OF TIMBER SPECIES ON COMPRESSIVE MODULUS OF PACK

Species	Compressive modulus, E_c MPa	'Strength' at 50% compression MPa
Gum	120	18
Wattle	100	16
Pine	50	11
Saligna	40	12

During compression of the pack from about 5 to 25 per cent, the timber is crushed well beyond its elastic limit, and differences in 'strength' of the basic cell structure of the different species will determine the second-stage stiffness of the packs. Compressive 'strength' is not a singular value that can be measured and defined. An indication of the resistance at 50 per cent compression calculated from Fig. 7 is given in Table III. These values compare reasonably well with the 'strengths' of 17 MPa and 24 MPa measured for the small specimens of saligna and white gum at the same degree of compression.

Creep

For some time it has been recognized that laboratory testing subjects a pack, in an hour or less, to a degree of compression that normally requires months to occur in the underground situation, and that this limits the quantitative validity of the results.

More recently, measurements in actual underground packs on E.R.P.M. and on Western Deep Levels[5] showed that load-shedding due to timber creep is a major factor in determining the support capability in a pack.

The results of the E.R.P.M. observation are detailed in Fig. 8. It should be noted that the height of the underground pack (870 mm) is less than normal, and that it was particularly neatly constructed and unusually well blocked (Fig. 9). These factors would tend to make it relatively stiffer than the average pack. Despite these advantages, the actual support load generated at any stage during the first 20 per cent of compression was

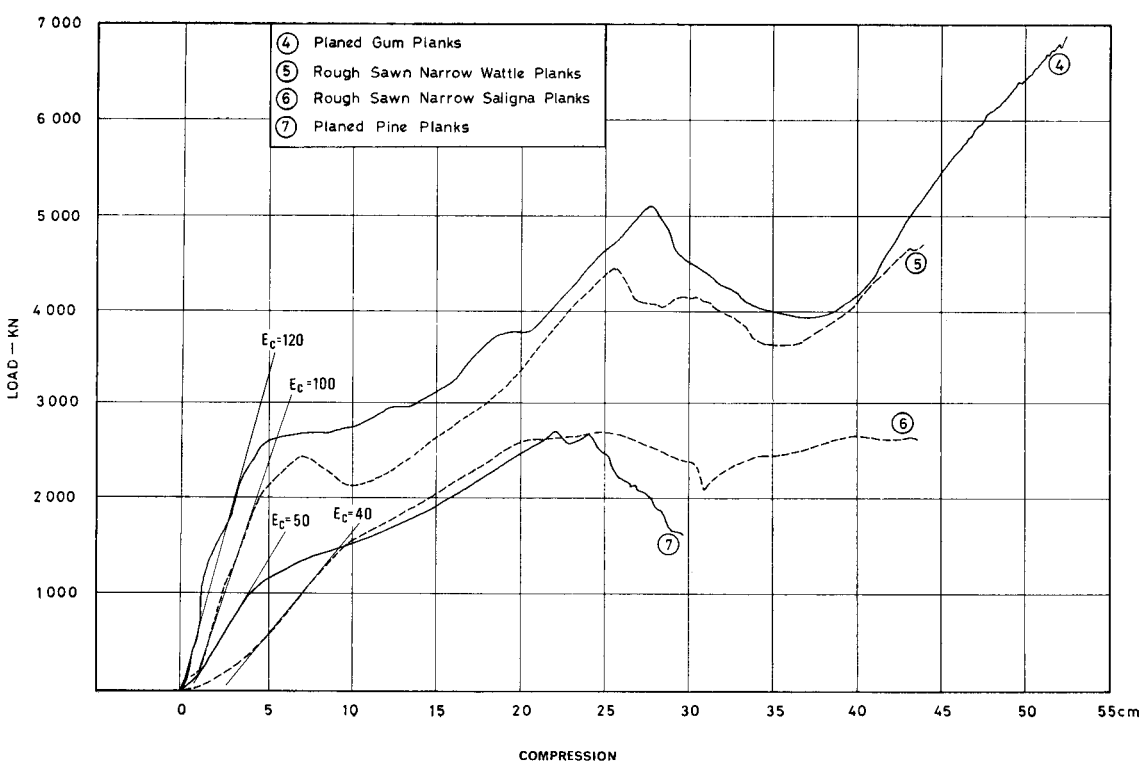

Fig. 7—The characteristics of sandwich packs constructed with planks of various timber species

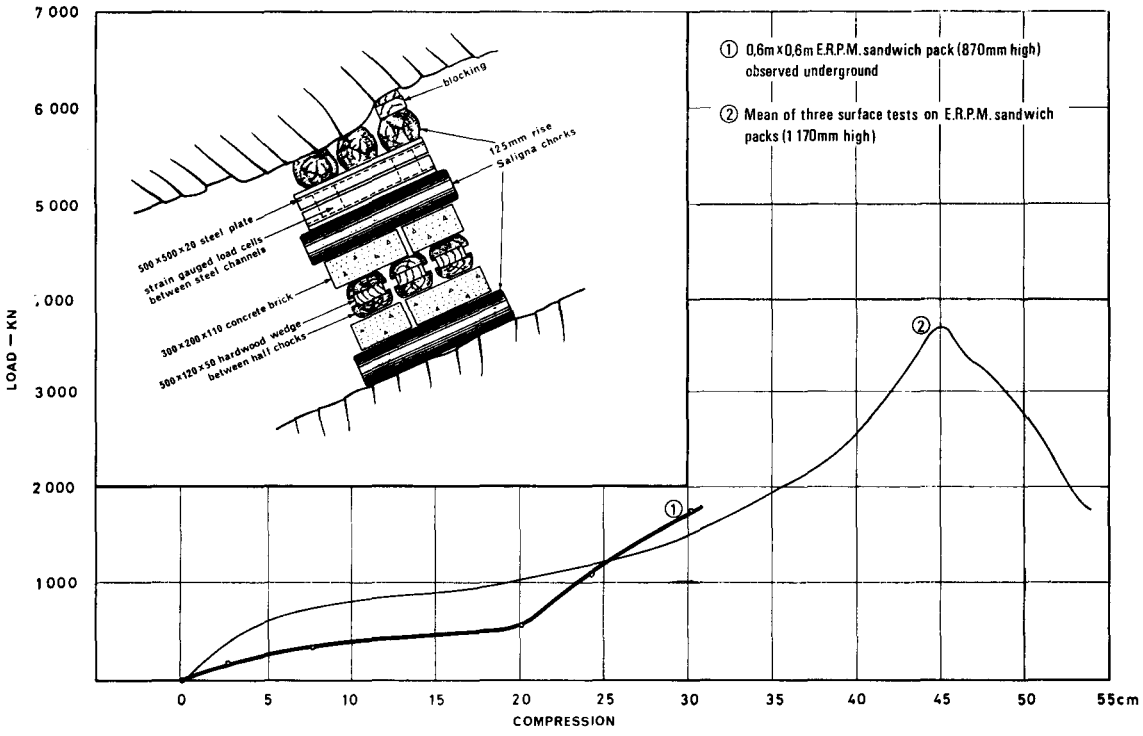

Fig. 8—Comparison between laboratory-determined and *in situ* pack characteristic

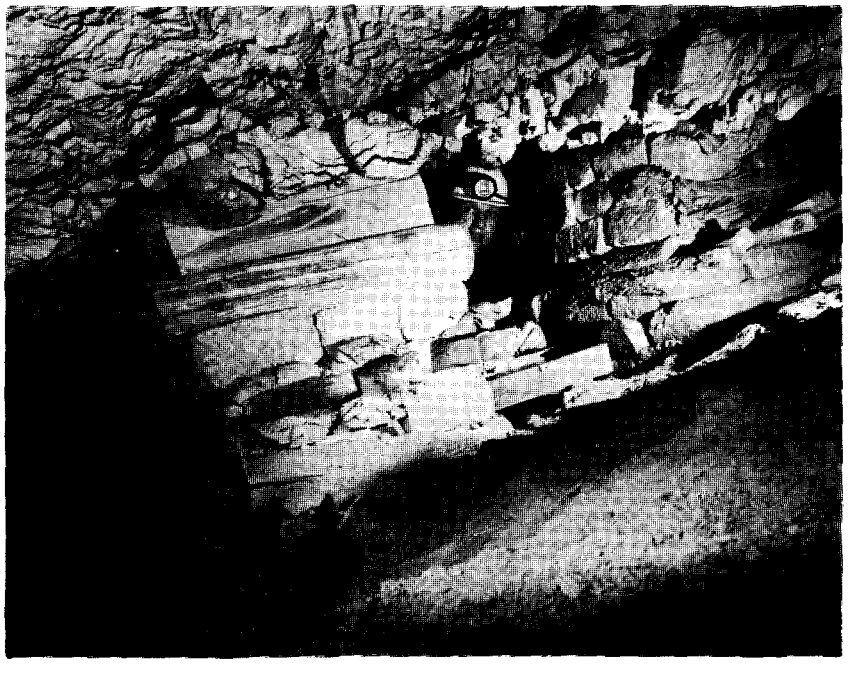

Fig. 9—Load-cell pack and standard sandwich pack 8,5 m from stope face, 20 per cent compressed

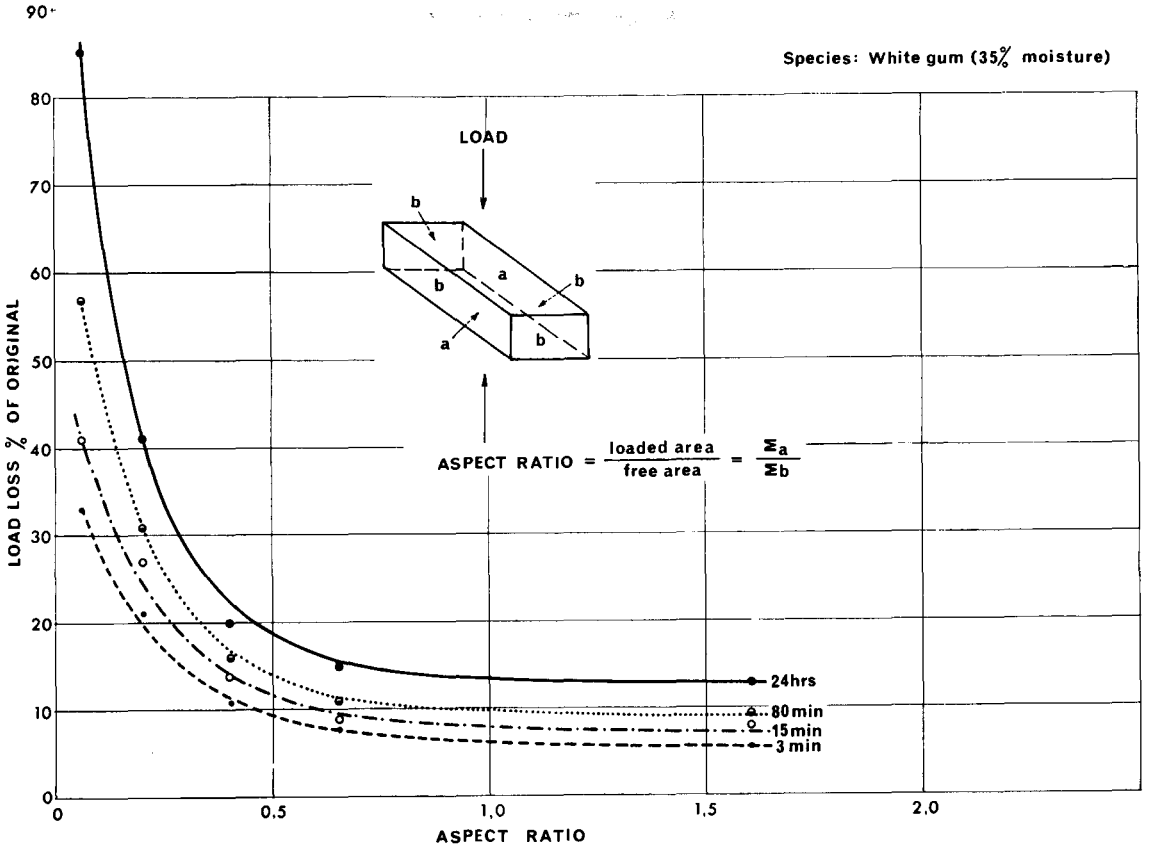

Fig. 10—The influence of aspect ratio on timber creep

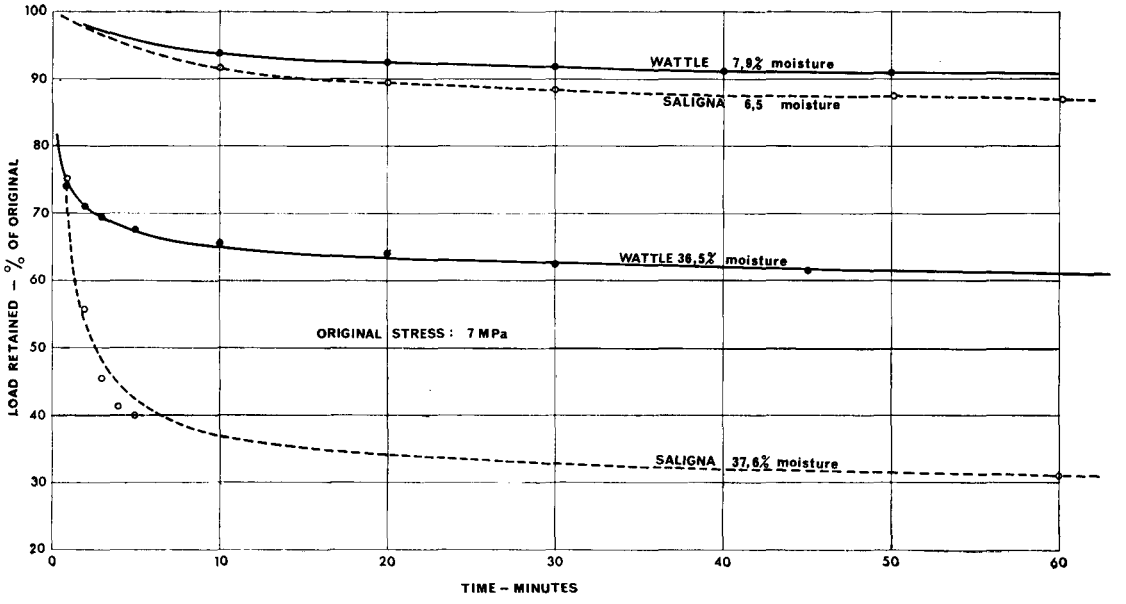

Fig. 11—Creep in timber as a function of species and moisture content

only one-half that anticipated from the surface test of the standard E.R.P.M. pack. If allowance were made for the greater height (1170 mm), the anticipated performance would be almost three times greater than was realized.

The experiments at Western Deep Levels showed the capability of underground packs to be only one-third to one-fifth of that determined in the laboratory for equivalent packs. This effect is so serious that considerable effort is justified to try to reduce the effect of creep.

Since the shape and species of the timber component can be controlled to some extent, it seemed advisable to determine the effect that these two factors might have on the rate of creep. Small specimens of planed timber were loaded for varying periods of time in a screw-type mechanical loading frame, and the decay in load was observed by means of a steel 'proving' ring.

The cross-sectional shape of the timber component is described in terms of 'aspect-ratio', and its effect on creep is shown in Fig. 10. At an aspect ratio of 0,4, which is typical for a chock piece, the effect of timber species and of moisture content is shown in Fig. 11.

It is well known that the creep rate of any material increases exponentially with increase in stress. Thus, it would appear that the specification and structural design of a pack intended to minimize loss of load must give major consideration to the following factors.

(a) Stress intensity: an increase in contact area will reduce the stress intensity and associated creep.
(b) Aspect ratio of timber component: this should be increased to reduce creep.
(c) Timber species: the denser types of timber should be specified.

Design and Construction

Main Design Factors

The preceding discussion and results have implied or shown explicitly that, in general terms, the main considerations involved in the structural design of concrete pack support are as follows.

(1) The stiffness of the pack is *increased* by decreasing the net vertical height of the timber and by increasing the contact area.
(2) The liability to creep is *decreased* by decreasing the vertical content of timber and by increasing its area.
(3) The ability to yield without abrupt failure *decreases* with decreased timber content.
(4) The mode of failure of the concrete brick can be improved by a reduction in cement content, aggregate size, density, and aspect ratio.
(5) The need for 'binding' together of the fractured concrete is vitally important and imposes a very considerable strength requirement on the transverse reinforcing. This reinforcement must apply through both the width and the depth of the pack.

It is interesting to note that attempts by the National Coal Board to find substitutes for pack timber failed in many instances, for the same reasons of inadequate transverse reinforcing[6].

Constructional Features

The considerations mentioned above determine the strength and dimensions of the components of the pack. The manner in which these components are assembled can have important effects on the strength and stability of the pack.

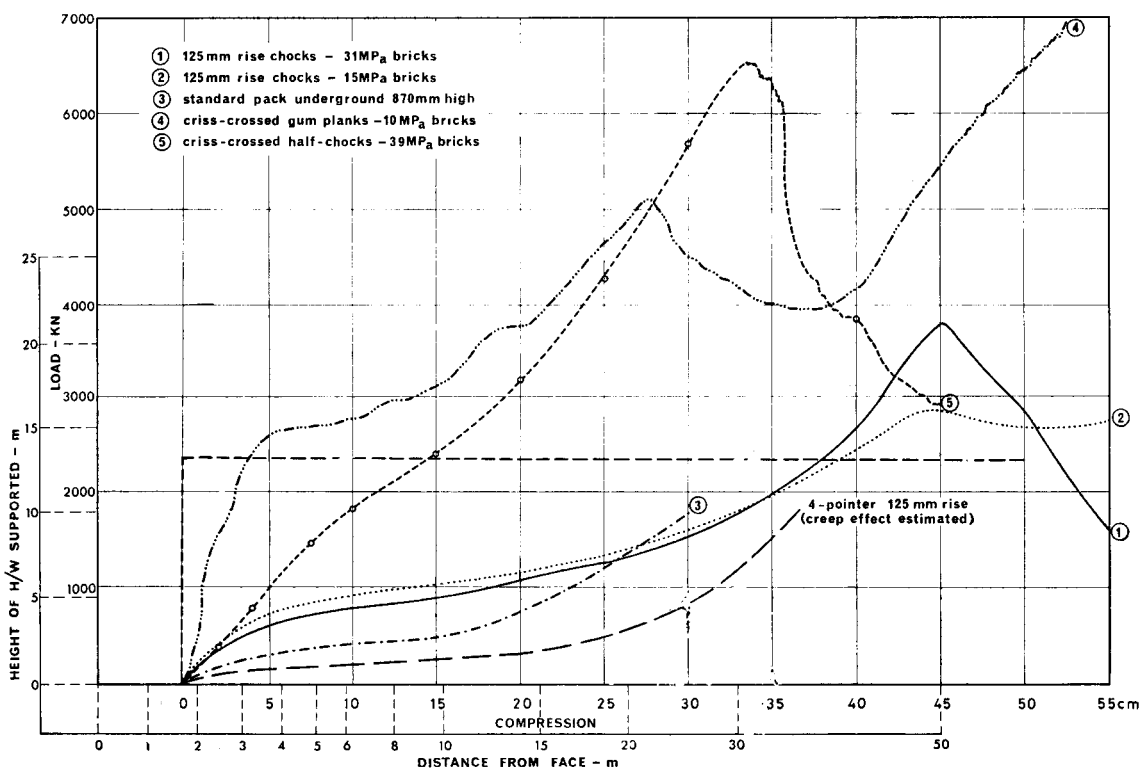

Fig. 12—The effect of constructional design on pack performance

Alternating Fibre Direction

The need to have transverse tensile strength in both directions in the pack has been mentioned. This is normally achieved by strict alternation of the direction of successive layers of chocks. A marked improvement is achieved by alternation of the fibre direction within each layer of timber. The effect of splitting 125 mm chocks and criss-crossing the half-slabs between each course of bricks is shown in Fig. 12.

Overlap

In all pack construction it is established practice for the ends of the timber to overhang the edges of the orthogonal timber above and below. In sandwich packs, an overlap of the *ends* of the timber with respect to the concrete edges is also recommended.

On the other hand, if the *sides* of the timber overhang the edge of the concrete, a weakness may result. The sharp edge of the brick can cut in along the grain of the timber piece and cleave off a large segment of the chock, which may roll out and possibly break away a large fragment of the brick above.

Shedding Space

Decreasing the 'aspect-ratio' of the concrete by forming large holes through each brick appears to favourably modify the mode of failure of small-aggregate concrete (Fig. 5). Alternatively, to leave a shedding space between adjacent bricks is a more practicable way of avoiding the higher transverse stresses that would arise as larger triaxial stresses build up before failure of the confined concrete occurs.

This effect is well illustrated by the tests in Fig. 6, where steel plates 8 mm thick were used between brick layers to effectively provide infinite transverse reinforcement. The maximum load that can be developed by a layer of four 250 mm square bricks of 10 MPa strength should be about 2500 kN. Where 50 mm of shedding space was provided in Test 6, the four bricks behaved almost independently and the maximum load was 3400 kN.

As the shedding space was reduced to 25 mm and then to zero, the failing concrete layer bulked into a state of confined triaxial stress, which increased its 'strength' very considerably. With the more than adequate lateral reinforcement provided by the steel plates, the maximum load in the pack increased uncontrollably (Tests 4 and 5 in Fig. 6). In the practical situation, the lateral stresses would, at some stage, have exceeded the limited transverse strength of the timber layer and the pack would have suffered dramatic losses of load.

Wedging and Blocking

The difficulty of forming a good contact between the topmost layer of the pack and the often extremely irregular surface of the hangingwall is probably the major cause of 'softening' a pack and so appreciably reducing the capability of stope support.

Ineffective wedging causes similar losses of load by creating high stress concentrations over small areas of contact. In addition, wedging usually introduces a weakness that will cause premature localized failure in the pack, particularly if it is near mid-height where the pack is naturally least constrained and most prone to buckling. The best location for the wedges in a sandwich pack is in the layer of timber above the lowest layer of bricks.

In all the packs tested other than those of Fig. 6, the E.R.P.M. standard wedging method was incorporated (see Addendum B).

It is possible to achieve pre-loading of 150 kN with this arrangement of wedges (Fig. 13a), but it is more likely that only a fraction of this is normally achieved underground. A certain amount of the wedging load will be lost in any case as a result of creep (Fig. 13b).

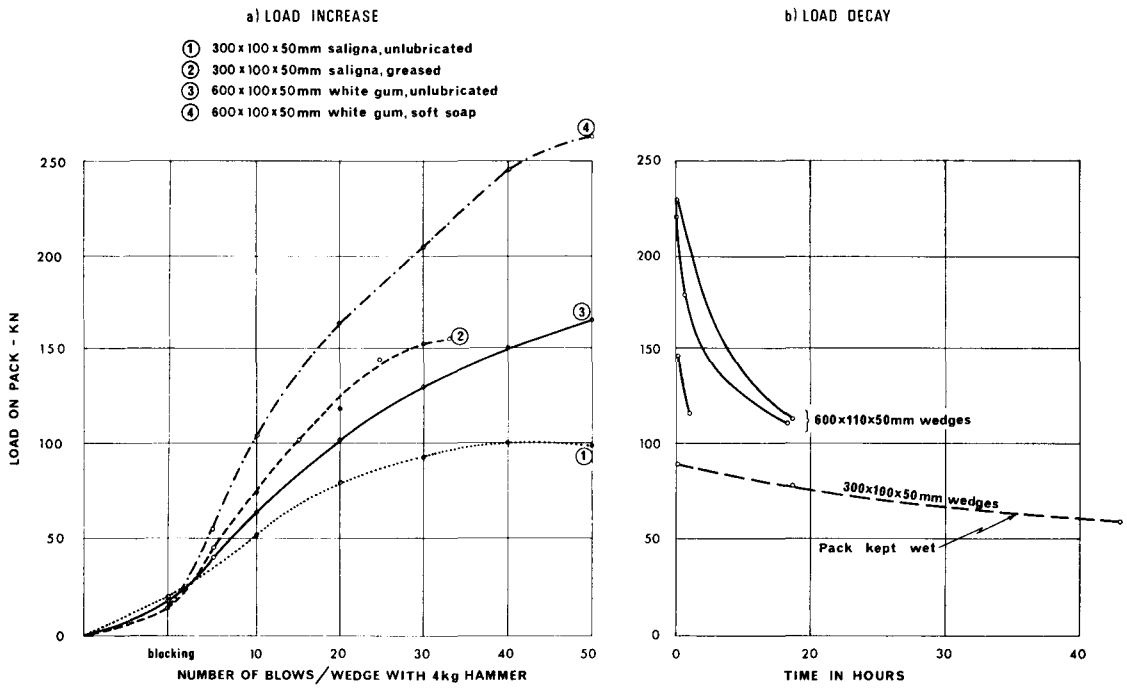

Fig. 13—(a) The effectiveness of pack wedging and (b) load loss due to creep

The cost in money and effort of a proper wedging layer such as the one described is nevertheless completely justified because the ineffectiveness and creep losses of casual wedging methods are even more pronounced[7]. Moreover, what could be a major weakness in the pack is largely avoided.

Conclusion

Stated simply, the main object in pack design is to rapidly generate an adequate load in the support and to maintain it at more or less constant value during subsequent compression.

Two things make it difficult to achieve this object. Firstly, concrete has negligible tensile strength with which to resist bursting apart as the inevitable stope convergence causes internal stresses to build up rapidly in the rigid concrete. Secondly, the timber, which is necessary for cushioning and to provide the required transverse reinforcing, has an inherent tendency to shed load by creep.

Fortunately the design features that contribute to increasing the rate of load generation also tend to reduce creep. However, a compromise is necessary if the resulting high load is not to prematurely destroy the structure. It is unlikely that it will ever be economically possible to use exotic materials or even steel to provide the transverse reinforcing necessary to prevent the pack from destroying itself. This means that sufficient timber must be provided for that purpose, with the inevitable consequence that the pack will be softer and will suffer increased creep. The final compromise is, of course, imposed by the overriding considerations of economics. With the existing rail-tariff structure, the savings possible as a result of reduced cement content do not match the cost increase resulting from the use of processed timber (Table IV). Nevertheless, further improvements in stope support can and should be made.

An understanding of the effects of, and interactions between, the principal factors of vertical stiffness, cushioning, creep, and transverse reinforcing as outlined in this paper should show that improvements are possible. That improvement is necessary and desirable is perhaps best appreciated by considering the performance of various packs, not in terms of load versus compression, but in terms of height of hangingwall supported at various distances from the stope face (Fig. 12).

Consider that the packs are installed to a pattern of 2,6 m centre spacing, 1,7 m behind the face of an extensively mined longwall of 1 m stoping width at a depth of 3000 m. According to its laboratory characteristic (Curve 1), the E.R.P.M. sandwich pack is capable of supporting 2,0 m of hangingwall after two or three blasts, at which stage it is 2,5 m from the face. This support capability would seem to be quite adequate if the closest major bedding weakness was 2 m in the hangingwall, say. Because of creep, however, the actual underground pack (Curve 3) would acquire the capability of preventing bed-separation at this weakness when only 6 m from the face! To attain its desired final capability of 5 m would require another 10 m of face advance. Note that support of equal competence could be achieved with an appreciable saving in cement by the use of weaker bricks (Curve 2).

On the same basis, a 4-pointer pack would support less than 1 m of roof until it was 10 m from the face, by which time support would no longer be required and the back area would be virtually inaccessible anyway.

Use of the same basic components but splitting the chocks and using them as criss-cross layers would improve the theoretical capability of the support over that shown in Curve 5 of Fig. 12. Allowing for creep, such support would actually be capable of supporting the 2 m weakness by the time it was 3,5 m from the face, and it would have reached full design performance about 8 m back.

The use of similar-sized gum-planks instead of split chocks would improve the theoretical performance as indicated by Curve 4. Because the contact area and the aspect ratio are much greater for planks than for chocks, the creep rate should be very much less. In operation, such a pack should thus acquire the capability to support 2 m of hangingwall after a face advance of 0,4 m, and 5 m of hangingwall within 2,5 m of the face.

The relative costs and performance capabilities of these packs are summarized in Table IV.

Recent observations suggest that the height to which a collapse might extend in a deep-level stope is fairly limited. Thus, the value of 5 m as a design requirement for the support is quite realistic. The area supported by a pack of type 4 could thus be doubled before onset of failure of the bricks. The limiting factor would be the ability of the immediate hanging to support itself over larger spans.

The proper remedy for such conditions is a high density of lower-capacity supports. This requirement could be satisfied by hydraulic or timber props used together with a much smaller number of stiff packs. On several mines, stope-support methods based on this argument are at present undergoing trial or have even been put into practice on a wider scale.

TABLE IV

COMPARISON OF COST AND PERFORMANCE OF VARIOUS 0,6 M BY 0,6 M PACKS AT A STOPE WIDTH OF 1 M

Type of pack, (spaced at 2,6 m centres)	Peak strength at % compression kN	Distance from face, m, for support capability of		Approximate relative cost
		2 m of hangingwall	5 m of hangingwall	
4-pointer, 125 mm rise	—	15	—	78
(1) E.R.P.M. standard (31 MPa brick)	3700 at 37%	6	16	100
(2) E.R.P.M. standard (15 MPa brick)	2800 at 36%	6	16	96
(4) Criss-crossed split chocks (30 MPa brick)	6500 at 27%	3,5	8	108
(5) Gum planks with 20 MPa brick	5000 at 22%	2,1	2,5	150

Addendum A — Tensile Strength Determinations by the National Timber Research Institute

Material	Specimen no.	Failure load kN	Failure stress MPa	Mod. of elasticity MPa	Density kg/m³
Softboard 13 mm thick	A1	0,240	0,92	232,8	240
	A2	0,270	1,04	247,3	237
	A3	0,210	0,81	233,5	228
	A4	0,245	0,94	216,3	242
	A5	0,248	0,95	244,8	237
Plywood 3 Plies Inner: 9 mm thick Outer: 6 mm thick Face grain parallel to loading direction	B1	14,625	33,24	12000,0	605
	B2	19,250	43,75	7347,0	614
	B3	20,000	45,45	7968,0	653
	B4	11,625	26,42	10146,0	590
Particleboard Resoshield 12 mm thick	C1	2,610	10,88	4379,7	750
	C2	4,050	16,88	3881,7	758
	C3	3,500	14,58	3320,3	712
	C4	3,600	15,00	3580,7	744
	C5	4,250	17,71	4734,8	774
Chipboard 16 mm thick	D1	2,775	8,67	2467,1	660
	D2	2,980	9,31	2394,1	684
	D3	2,750	8,59	3495,0	641
	D4	2,910	9,09	2197,3	661
	D5	3,225	10,08	2547,6	687
S.A. Pine 12 mm thick	E1	13,250	55,17	8333,3	373
	E2	10,750	44,79	16666,7	354
Eucalyptus 12 mm thick	F1	23,350	97,29	25720,2	956
	F2	19,250	80,21	23148,2	1114
	F3	19,250	80,21	17361,0	876
	F4	27,000	112,50	30637,3	981
	F5	23,000	95,83	21701,4	907
Saligna 12 mm thick	G1	16,250	67,70	12400,8	519
	G2	15,850	66,04	14076,6	597
Black Wattle 12 mm thick	H1	22,000	91,67	10850,7	795

Addendum B — Wedging

Soon after the introduction of concrete sandwich packs on E.R.P.M. Limited, it became apparent that the wedging of the packs warranted special attention. Friction made the use of conventional 300 mm long wedges between concrete and timber ineffective, and the disarrangement of the bricks promoted early failure at the wedging layer.

A series of tests involving the use of various sizes, shapes, and arrangements of wedges was carried out. A steel test-frame was designed to accommodate a full-sized 0,6 by 0,6 m sandwich pack between the top and bottom plates, which were filled with roughened, undulating concrete to simulate the uneven hangingwall and footwall underground. Wire-resistance strain-gauged load cells between the top plate and the vertical posts of the test-frame measured the total load in the pack with a sensitivity of about 2 kN.

The use of a specially designed hydraulic wedge-driver enabled the thrust applied to the wedge to be determined. From these measurements, the efficiency of the wedge as a function of the wedge angle and the coefficient of friction was established. Although the hydraulic wedger was shown to be reasonably effective in prestressing a pack, it was considered too cumbersome to be a practicable technique underground. Moreover, a considerable amount of the wedging effort was soon lost in creep of the timber at the points of high stress (Fig. 13b).

Despite the realization that creep was unavoidable, it was considered worth while to use good-quality 600 mm long wedges and provide specially shaped hammers for driving the wedges.

The method then adopted as standard by E.R.P.M. Ltd required that 600 by 110 by 50 mm wedges be enclosed longitudinally between pairs of half-chocks previously sawn through in the surface timber yard. The points of the wedges were overlapped during construction to leave about 200 mm of wedge protruding on each side of the pack. The wedging layer was placed on strike immediately above the first layer of bricks. Saw-split chocks were also used to block the pack firmly against the hangingwall before the wedges were driven in.

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Discussion of the previous paper

H. K. R. CAHNBLEY*

I congratulate Mr Ortlepp on his excellent paper, which not only covers all the relevant aspects of the sandwich pack but also supplies some important information on the use of concrete for stope support in general. The author deserves particular commendation for his successful endeavour to present and explain some long-known, but sometimes not fully understood or appreciated, facts in the light of recent findings, and to provide at the same time some very useful figures for the design of an effective stope support.

Every observant mining man must often have wondered about the complexity of the interaction between stope support and hangingwall strata in general, and between the timber and the concrete blocks of a sandwich pack in particular. It is very frustrating for the rock mechanics practitioner who has designed a support to find that the support is not performing in the expected manner in some areas whilst it is giving perfectly satisfactory results in others. I should like to draw attention to the influence that time has on the quality of the timber used in such packs. The author has shown that the type, age, and water content of the wood are parameters not to be neglected, and he has given evidence of the detrimental effect of time on the resistance of the pack by demonstrating the occurrence of timber creep. But it was probably beyond the scope of his paper also to discuss the imponderables involved in the decay of untreated timber. This parameter may not have such a great significance in the case of rapidly advancing longwall faces with a low stoping width, but it is only second in importance to the initial pack stiffness where the stoping width is high, the face advance is rather low, and the mined-out area has to be used for a relatively long distance behind the face. In fact, for a mine like Western Areas Gold Mine that practises multi-reef mining, the longevity of the stope support is of vital importance.

The situation here is particularly complicated by block- and scatter-mining, often with limited stope spans and frequent geological discontinuities. Therefore, the loading rate of the packs is seldom uniform for given pack positions, and considerable changes of the loading rate may occur throughout the useful lifespan of a pack. A rather paradoxical behaviour of the sandwich pack support can often be observed after a sudden settlemene of a hangingwall area: the younger packs near the fact containing the sounder and stronger timber are disintegrating (in the fashion described) as a consequence of the failing concrete blocks, whilst the older packs, the timber of which is already much decayed, are squashed in a stable fashion so that the concrete blocks become safely embedded in the compacted cushioning layers of rotten timber. Although there is then hardly any transverse reinforcing, these packs remain remarkably stable for long times.

As the degree of timber decay is mainly dependent on the ambient temperature and, particularly, the humidity of the air, it is extremely difficult to make a reasonable assessment with respect to the remaining strength. Unfortunately, this fact makes it virtually impossible, as much as all the other parameters may have become assessable, to calculate 'adequate' support for such conditions. One is therefore forced to revert to the trial-and-error method in order to arrive at an acceptable compromise, but this often leads to a considerable degree of oversupporting.

The grout-base pack has now, in general practice, superseded the sandwich pack on the gold mines of J.C.I. Apart from its greater initial stiffness, its longtime behaviour is somewhat superior to that of the sandwich pack. It would be inappropriate to go into great detail here, and suffice it to say that again it is timber decay that determines the longtime performance of this pack. As the timber cage rots, the grout core loses its confinement and begins to disintegrate under very little additional load. However, the strength of the concrete grout plays an important role, possibly a greater role than that of concrete blocks as stated by Mr Ortlepp. Initially, great emphasis was put on the highest attainable grout strength, but experience showed that very strong grout cores resembling a mild sandstone tended to brittle failure in spite of the cushioning topping with a minimum of three layers of timber. It is, therefore, surprising that Mr Spengler[1] has been able to produce such curves of almost ideal performance for his modified type of grout-base pack, although he has not been using any timber topping at all. Weaker grout mixes are now giving better longtime results since the failure is more ductile. However, the need for holding the crumbling grout together arises at an earlier stage, and imposes a

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very considerable strength requirement on the constraining timber skeleton. The wider the chocks, the more satisfactory are the results.

In spite of many years' experience with the solid timber pack, the sandwich pack, and the grout-base pack, no generally valid judgement as to quality can be given. When all three types of support were observed in close proximity to one another, it was noted that the success or failure of the units was determined entirely by local conditions, especially by the degree of compatibility of their differing characteristics with the mode and time of loading.

Mr Ortlepp quite rightly emphasizes the well-known fact that concrete has negligible tensile strength with which to resist bursting apart, and that it is vitally important for transverse reinforcing to be applied through the width and depth of a pack. In the light of this, it is surprising to hear of the success, as reported by Mr Stone[2], of the unreinforced, narrow 'sausage' pack developed and used at Rustenburg Platinum Mines.

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